Final Report

Horsham and Wartook Valley Flood Investigation

Wimmera CMA

16 August 2019

Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
01	Draft	Ben Hughes	Ben Hughes	10/05/2019
02	Final	Ben Tate	Ben Tate	16/08/2019

Project Details

Project Name	Horsham and Wartook Valley Flood Investigation
Client	Wimmera CMA
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Document Number	4149-01_R06V02F_Final_Report_HorshamWartook

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16 August 2019

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Dear Paul

Horsham and Wartook Valley Flood Investigation

This report is the Final Report for the Horsham and Wartook Valley Flood Investigation. This report supersedes all other reports during the progress of the flood investigation.

We would like to thank Wimmera CMA for engaging us to complete this project, and Horsham Rural City Council, GWMWater, VICSES and DELWP for their technical input into the project. Water Technology would specifically like to thank the community members who gave their time to attend meetings, provide their personal observations of flooding, and provide feedback on the flood modelling. Strong contributions from key stakeholders and community members has resulted in improved outcomes from this study, which will assist with flood related land use planning, floodplain risk management, flood emergency response and raising community awareness of individual flood risk.

Yours sincerely

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Principal Engineer

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WATER TECHNOLOGY PTY LTD

EXECUTIVE SUMMARY

Wimmera CMA commissioned Water Technology to undertake the Horsham and Wartook Valley Flood Investigation. The study included detailed hydrologic and hydraulic modelling of the Wimmera River, Mackenzie River, Burnt Creek, Bungalally Creek, Darragan Creek and Sandy Creek, covering a large rural area and the township of Horsham. (see Figure 1-1). The major objective of the study was to produce design flood mapping over a range of events of different magnitude, describe the flood behaviour and extract valuable flood intelligence to assist in flood risk management and emergency flood response.

Several communities were actively involved in the investigation through community consultation sessions. The community consultation sessions were largely managed by Wimmera CMA and Horsham Rural City Council. The aims of the community consultation were to raise awareness of the investigation, to identify key community concerns, to provide information to the community and seek their feedback/input regarding the existing flood behaviour and proposed mitigation options for the Horsham township.

Community meetings were held in Riverside, Horsham and Wonwondah over three stages. The purpose of the three meetings are described below:

- Stage 1 – Introduction to the project, work completed to date, what we hope to achieve, how the community will be engaged and what information we are hoping to receive from them, and discussion of mitigation options. At this meeting, community flood observations were recorded and used during the modelling process.
- Stage 2 – Modelling progress, discussion around historical events, discussion of model calibration and draft 1% AEP flood extents and behaviour. Asked community for suggested mitigation options.
- Stage 3 – Presentation of final mapping, mitigation option assessments, project outcomes and the progression of the technical information to mitigation and planning scheme implementation. This was undertaken by sending letters to all properties impacted by the 1% AEP event, encouraging recipients to review the results and contact the Wimmera CMA for an individual appointment to discuss the results.

The Wimmera River at Horsham (Walmer) streamflow gauge provides an indication of flow and flood impacts along the Wimmera River through Horsham. The water level at this gauge has been linked to the developed flood maps and the resulting flood impacts. Early predictions to what flow and level can be expected at this gauge can be determined by the observed flows at the upstream Wimmera River at Glenorchy gauge. These gauges can be used as the basis of a predictive flood warning network for the Wimmera River. However, the location of the Burnt Creek at Wonwondah gauge makes flow very difficult to gauge on Burnt Creek.

The hydraulic model was calibrated using the January 2011 and September 2016 flood events. The calibration used surveyed flood heights, stream level information, aerial imagery and community observations. The calibrated model was then used to produce design flood mapping across a wide range of events 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, PMF and climate change scenarios. The design flood mapping showed there were 182 buildings flooded above floor across the study area during a 1% AEP flood event.

During the process of the investigation, several structural mitigation options were suggested to reduce the impact of floods in Horsham, and across the broader study area. Water Technology considered all proposed mitigation options, and using a prefeasibility assessment approach, identified the following options to be investigated further:

- Horsham Levee – a series of levee options were modelled protecting the area north of the Wimmera River. Modelling was undertaken for the 1% AEP and 2% AEP events. A lesser AEP was modelled to confirm the potential to provide protection for events smaller than a 1% AEP.
- Western Highway Bridge capacity increase – The potential to double the capacity of flows underneath the Western Highway bridge was assessed as it is a major restriction to flow.

- Horsham – Combined Horsham levee and Western Highway Bridge capacity increase.
- Restricting flow in the Wimmera River downstream of Dooen Swamp – The potential to use Dooen Swamp as a retardation basin.
- Wimmera River channel deepening – A section of the Wimmera River was deepened to increase capacity.
- Wimmera River channel deepening and Western Highway Bridge capacity increase.
- Restricting capacity in Burnt Creek upstream between Reynolds Road and Millers Road to retard flow.
- Reducing the starting level of Lake Wartook to increasing available storage volume.

The investigation made the following recommendations:

1. The outputs from the Horsham Wartook Valley Flood Investigation should be used to provide flood advice for any flood related planning matter (Section 5.4.2).
2. The Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO) and associated planning scheme amendment documentation produced as part of this investigation be adopted in the Horsham Rural City Council Planning Scheme (Section 5.4.2)
3. The Victoria Flood Database (VFD) should be updated using the outputs of the Horsham and Wartook Valley Flood Investigation, which have been formatted into the standard VFD format (Section 4.5).
4. The Horsham and Wartook Valley Flood Investigation VFD deliverables be uploaded to FloodZoom (Section 4.5).
5. The Horsham Rural City Council Municipal Flood Emergency Plans be updated with the information provided in the Horsham and Wartook Valley Flood Investigation Flood Intelligence Report (Section 6).
6. The local CFA brigades (particularly along the Mackenzie River) should be actively engaged in community preparedness education for flooding (Section 5.4.3).
7. Levee options were investigated as part of this project, with levees providing a 1% AEP standard of protection in some areas causing increases in water level in other areas. The Horsham community should be consulted regarding the difficulty of levee-based flood mitigation options in Horsham, investigating their perspective on what level of protection they would require. This could reduce the level of protection a potential levee offers, with the levee having less of an impact on other areas of the floodplain (Section 5).
8. The potential for stormwater mitigation in Horsham and Haven should be further considered with the incorporation of the stormwater capacity mapping. Detailed feature survey may be required of some parts of the existing stormwater system (Section 4.5.4).
9. VicRoads, Horsham Rural City Council and Wimmera CMA discuss the potential to use the proposed B2 option of the Horsham Bypass as a flood mitigation measure for the town. Previous modelling of Rokeskys Road has shown the potential for a floodplain restriction to reduce flood levels. Infrastructure projects of this size do not occur often in the Wimmera and their potential should be considered in full (Section 5).
10. Ensure that any strategic flood-prone infrastructure has its own emergency plan that includes protective actions related to triggers. These plans should be updated based on the flood intelligence contained in the Horsham and Wartook Flood Intelligence Report (Section 6).
11. Update the Horsham Local Flood Guide based on the Horsham and Wartook Flood Intelligence Report (Section 6).

12. Conduct future community flood education activities across the investigation area based on findings of this report. Activities should focus on Horsham and East Horsham with specific information targeting how residents find out about their flood risk, where gauge and mapped information can be found, how they will receive warnings and how to evacuate if required. (Section 5.4.3).
13. Ensure that flood communication (e.g. Flood Bulletins) is constructed in simple language talking about impacts of potential flooding on the local communities in the investigation area and required actions including possible evacuation. It should consistently advise people of either stream heights or volumes (Section 5.4.3).
14. Effectively communicate the likely flood behaviour to the Horsham community and the need to plan and act early. With long lead times to the peak of flooding, the risk is that people become complacent and do not act early. With access sometimes cut well prior to the peak of flooding, leaving mitigation and evacuation actions to the last minute can expose people to unnecessary risk (Section 5.4.3).
15. Consider moving the Burnt Creek at Wonwondah streamflow gauge to a location further downstream to improve the ability to measure streamflow gauging (Section 5.4.3).
16. Emergency response agencies to acknowledge that local residents in parts of the Wartook Valley use alternative communication methods such as CFA pagers and telephone trees (a network of phone calls) to warn and communicate with others in their communities (Section 5.4.3).
17. Ensure that all people in the community (including newcomers and renters) have the opportunity to be included in community flood education and engagement before, during and after flood events (Section 5.4.3).
18. Check that the Vulnerable Persons Register is updated and used during a flood emergency (Section 5.4.3).
19. Any community flood education should reiterate the message from VicSES regarding the risks of attempting to drive through flood waters. This is the most common cause of flood related fatalities (Section 5.4.3).
20. Tourists in relevant areas of the Grampians National Park should be made aware of flood risks through interpretive signage and programs conducted by the Parks staff (Section 5.4.3).

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1 INTRODUCTION

1.1 Investigation Area

The Wimmera River originates in the Pyrenees Ranges on the northern slopes of the Great Dividing Range and flows north west, intersecting Horsham. At this point the upstream catchment is over 4,000 km^2.

Approximately 25 km upstream of Horsham the Wimmera River splits to Yarriambiack Creek, a portion of which returns to the Wimmera River via Two Mile Creek further downstream. An overland flow path south of the Wimmera River also carries flood water breaking out from downstream of Drung to Riverside.

Several tributaries feed the Wimmera River between Horsham and Quantong with runoff from the northern Grampians Mountain Ranges. These include: Burnt Creek, Bungalally Creek, Mackenzie River, Norton Creek, Darragan Creek, and Sandy Creek.

The Mackenzie River is fed by the Wartook Reservoir, and intricately linked to Burnt Creek and Bungalally Creek. Burnt Creek receives flood waters distributed from the Mackenzie River. Further along Burnt Creek a similar distribution occurs to Bungalally Creek, which then flows back into the Mackenzie River.

The investigation area, including waterways to be mapped is shown in Figure 1-1.

1.2 Project Purpose

Wimmera CMA engaged Water Technology to undertake the Horsham and Wartook Valley Flood Investigation. The objective of the study was to produce flood mapping over a range of different flood event magnitudes, describe the flood behaviour and extract valuable flood intelligence information form the flood modelling and mapping. A review of the flood warning system was included along with an investigation into possible flood mitigation options. The impact of stormwater flooding in Horsham and Haven was also investigated.

The information produced from this investigation must improve the availability of flood mapping and flood intelligence for floodplain risk management, land use planning, emergency response and raising community awareness of individual flood risk.

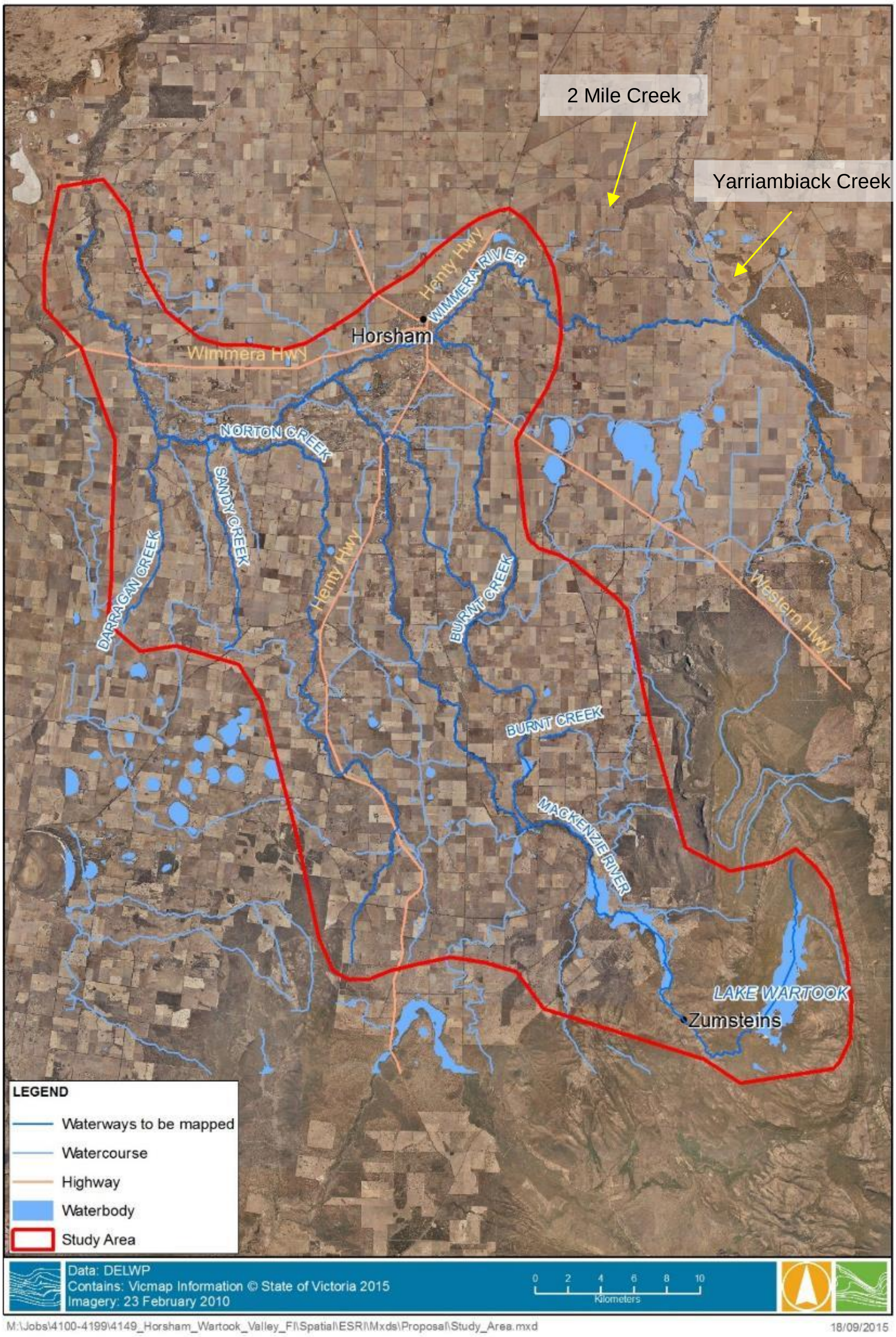


FIGURE 1-1 STUDY AREA

2 DATA COLLATION AND REVIEW

2.1 Site Visits

There were numerous site visits during the Horsham Wartook Flood Investigation, these were as follows:

- An initial site visit covering the entire study area undertaken at the beginning of the project visiting key hydraulic structures along the tributaries and Wimmera River. A number of photos were taken during the site visit, as well as approximate dimensions of culverts. Key features can be seen in Figure 2-1.
- A secondary site visit though Horsham and Haven reviewing stormwater infrastructure.
- Several specific site visits to review key areas along the Mackenzie River and Wimmera River.


a) Burnt Creek / McKenzie River confluence


b) Grahams Bridge, McKenzie River


c) Bungalally Creek Crossing with Laharum Rd


d) Rocklands channel near Bungalally Creek


e) Bungalally Creek near confluence with Mackenzie River


f) Burnt Creek / Mackenzie River confluence

FIGURE 2-1 SELECTED PHOTOS FROM SITE VISIT, 24 NOVEMBER 2015

2.2 Previous Studies

Several flood studies have been completed within the investigation area, however there is no study that considers the interaction between the Horsham River and the tributaries that flow from the Wartook Valley.

The following studies are specifically relevant to the current investigation and will be used to inform the current study:

- Horsham Flood Study (Water Technology, 2002)
- Lower Wimmera River Regional Flood Mapping (Water Technology, 2016)
- Wartook to Zumsteins Walking Track Flood Investigation (Water Technology, 2015)
- East Horsham Channel Decommissioning (Water Technology, 2014)
- Horsham Bypass Hydrology and Hydraulics Impact Study (Water Technology, 2012)
- East Horsham Flood Plan (Water Technology, 2011)
- Wimmera CMA Flood Report – January 2011 (Water Technology, 2011)
- Wimmera River and Yarriambiack Creek Flow Modelling Study (Water Technology, 2009)

2.2.1 Horsham Flood Study (2002)

2.2.1.1 Overview

The study modelled 20%, 10%, 5%, 2%, 1% and 0.5% AEP design flood events. Model results were used as the basis for extent, depth and water level mapping. They were also used for planning purposes and the basis of a series of recommendations.

Calibration flows determined for the study were based on gauge records at the Wimmera River at Horsham (Walmer) and Burnt Creek at Wonwondah gauges, Flood Frequency Analysis (FFA) was then used to determine peak design flows. The study also documented the existing levee systems within Horsham and historic flood events occurring along the Wimmera River at Horsham.

2.2.1.2 Relevant Findings

The calibration and design flow estimates used in the Horsham Flood Study will be reviewed and compared to estimates produced in this study. The FFA completed at each gauge determined the peak flows shown in Table 2-1.

Existing levees and flood mitigation infrastructure was incorporated into the flood modelling. The main levee identified was the Menadue St/Peppertree Lane levee, this was surveyed by Findlay Irrigation Services and BM Consulting Engineers for the then Department of Natural Resources and Environment in 1996. A long section from that survey is shown in Figure 2-2. This levee has not been maintained and it is likely that with the levee deteriorating, that the current levee crest levels may be different to those surveyed in 1996.

TABLE 2-1 PEAK FLOWS DETERMINED BY FFA AT THE WIMMERA RIVER AT HORSHAM (WALMER) AND BURNT CREEK AT WONWONDAH EAST

AEP (%)	Wimmera River at Horsham (Walmer)		Burnt Creek at Wonwondah East	
	Peak flow (ML/d)	Peak flow (m^3/s)	Peak flow (ML/d)	Peak flow (m^3/s)
20	12,900	149	1,200	14
10	18,100	209	1,800	21

AEP (%)	Wimmera River at Horsham (Walmer)		Burnt Creek at Wonwondah East	
	Peak flow (ML/d)	Peak flow (m^3/s)	Peak flow (ML/d)	Peak flow (m^3/s)
5	23,700	274	2,500	29
2	31,200	361	3,400	39
1	37,000	428	4,200	49
0.5	43,000	498	5,100	59

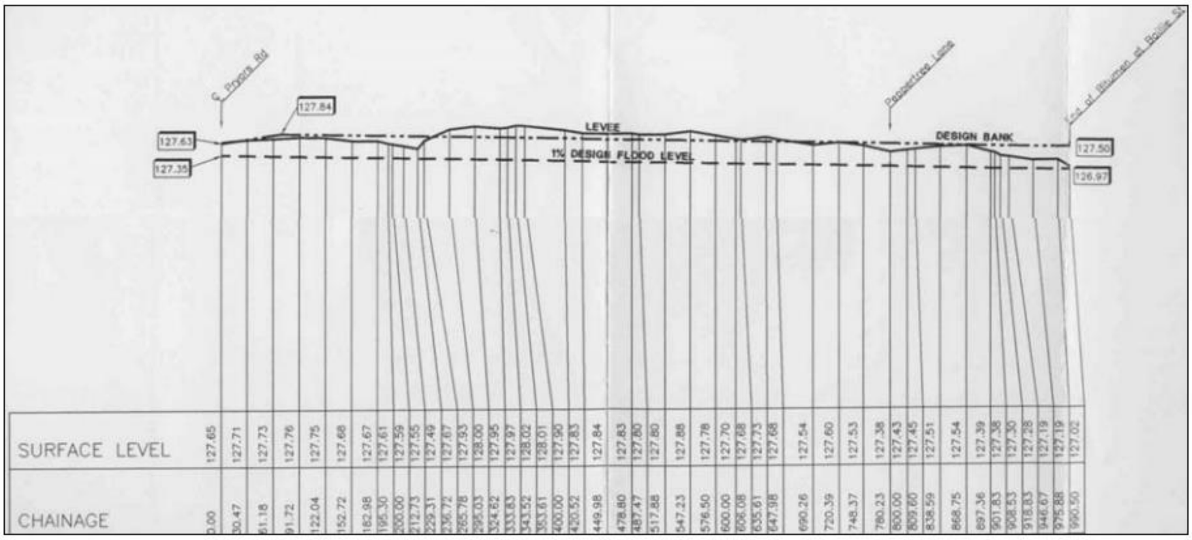


FIGURE 2-2 MENADUE STREET/PEPPERTREE LANE LEVEE LONGSECTION SURVEY

2.2.2 Lower Wimmera River Regional Flood Mapping (2016)

2.2.2.1 Overview

Water Technology undertook the Lower Wimmera River Regional Flood Mapping project in 2016. The objective of the project was to develop regional scale flood mapping for the Lower Wimmera River between Quantong and Lake Hindmarsh. To provide meaningful flood information, the flood mapping was tied back to the Horsham (Walmer) gauge, which is of relevance to this study.

2.2.2.2 Relevant Findings

In developing the hydrology for the project, several discussions were had between Wimmera CMA, DELWP employed hydrography contractors and Water Technology regarding the significant changes to the gauge rating curve after the January 2011 flood event. This change was due to a high flow gauging during the January 2011 flood event. It was determined the measured flow was accurate and that the current rating curve was reliable. This resolution was critical to the current project as it meant that Flood Frequency Analysis (FFA) at the Horsham (Walmer) gauge was impacted by the revised rating curves. In addition, historical research was completed to improve the period of record. This resulted in improved design flood flows for the Wimmera River at Horsham (Walmer) gauge as compared to previous investigations. Further details regarding the streamflow gauge at Horsham can be found in Section 2.5.1.1. The hydrological analysis undertaken for the Horsham (Walmer) gauge was adopted in this project.

The Lower Wimmera River Flood Mapping project also considered the influence of concurrent flows in the Mackenzie River, and it was found that the Mackenzie River peak at Horsham generally arrives well before the Wimmera River peak. An analysis of streamflow data revealed that the Mackenzie River peaked between 2.5 and 3.5 days earlier than the Wimmera River at Horsham on all significant flood events where concurrent records were available (September 1988, October 1992, October 1996, September 2010 and January 2011). It was also found that the Mackenzie River flows had receded by the time the Wimmera River peak arrived. This is due to the Wimmera River having a much larger catchment than the smaller Wartook Valley tributaries. This indicates that the interaction between the Wartook Valley tributaries and the Wimmera River is likely to have negligible impact on flood extents and levels.

2.2.3 Wartook to Zumsteins Walking Track (2015)

2.2.3.1 Overview

Horsham Rural City Council received funding for a proposed walking/cycling trail to link Wartook to Zumsteins car park in the north-west Grampians. A preferred alignment was selected for the design of the trail, following the 'Historic Back Track', approximately 9.5 km in length.

Water Technology undertook a flood analysis of the proposed alignment, modelling the 1% AEP flood event in 2015.

2.2.3.2 Relevant Findings

As part of the hydrological assessment for this project, a flood frequency analysis was undertaken for the Mackenzie River @ Wartook Reservoir gauge. This analysis is detailed further in Section 2.5.1.3, and will be adopted for the current study as an upstream boundary to the hydraulic model.

2.2.4 East Horsham Flood Plan (2011)

2.2.4.1 Overview

The East Horsham Flood Plan 2011 modelled the area from Riverside in the west to Yarriambiack Creek offtake in the east. The project focused on Wimmera River flooding and the 20%, 10%, 5%, 2% and 0.5% AEP events were added to the already modelled 1% AEP event. The project resulted in a Flood Intelligence Report, to allow for an update of the Horsham Rural City Council Flood Response Plan to include the area of East Horsham, and a Drainage Recommendations Report. Recommendations identified were predominately related to channel infrastructure and the potential impact of channel decommissioning. Some of these recommendations were addressed during the East Horsham Channel Decommissioning Project commissioned by GWMWater and completed by Water Technology. This project is detailed further in Section 2.2.8.

2.2.4.2 Relevant Findings

As many of the channels have now been decommissioned, flood mapping from this study will no longer represent the on-ground conditions, however the general discussion around areas of concern will highlight where specific detail is required in the development of the hydraulic model. The report also details significant details regarding the January 2011 event which may be used in the model calibration process.

The East Horsham Flood Plan determined flows and peak flood heights for the Wimmera River @ Horsham (Walmer) gauge for each of the modelled AEP flood events, as shown in Table 2-2. These were considered in the hydrological analysis of the Lower Wimmera River Regional Flood Mapping project, with hydrology for the Wimmera River at Horsham updated.

TABLE 2-2 MODELLED PEAK FLOWS AND WATER LEVELS AT THE WIMMERA RIVER AT HORSHAM GAUGE DETERMINED DURING THE EAST HORSHAM FLOOD PLAN

Event AEP (%)	Peak Level (m AHD)	Peak Flow (ML/d)	Peak Flow (m^3/s)
20	123.41	10,109	117
10	123.43	10,454	121
5	123.80	22,291	258
2	124.10	30,326	351
1	124.11	34,646	401
0.5	124.46	42,854	496

Floor level survey data was captured as part of the East Horsham Flood Plan, complimenting data captured during the Horsham Flood Study (2002) (as discussed in Section 2.2.1). The extent of the captured floor level survey is shown in Figure 2-3, purple points indicate data captured during the Horsham Flood Study (2002) and yellow the East Horsham Flood Plan (2015).

Available floor level survey

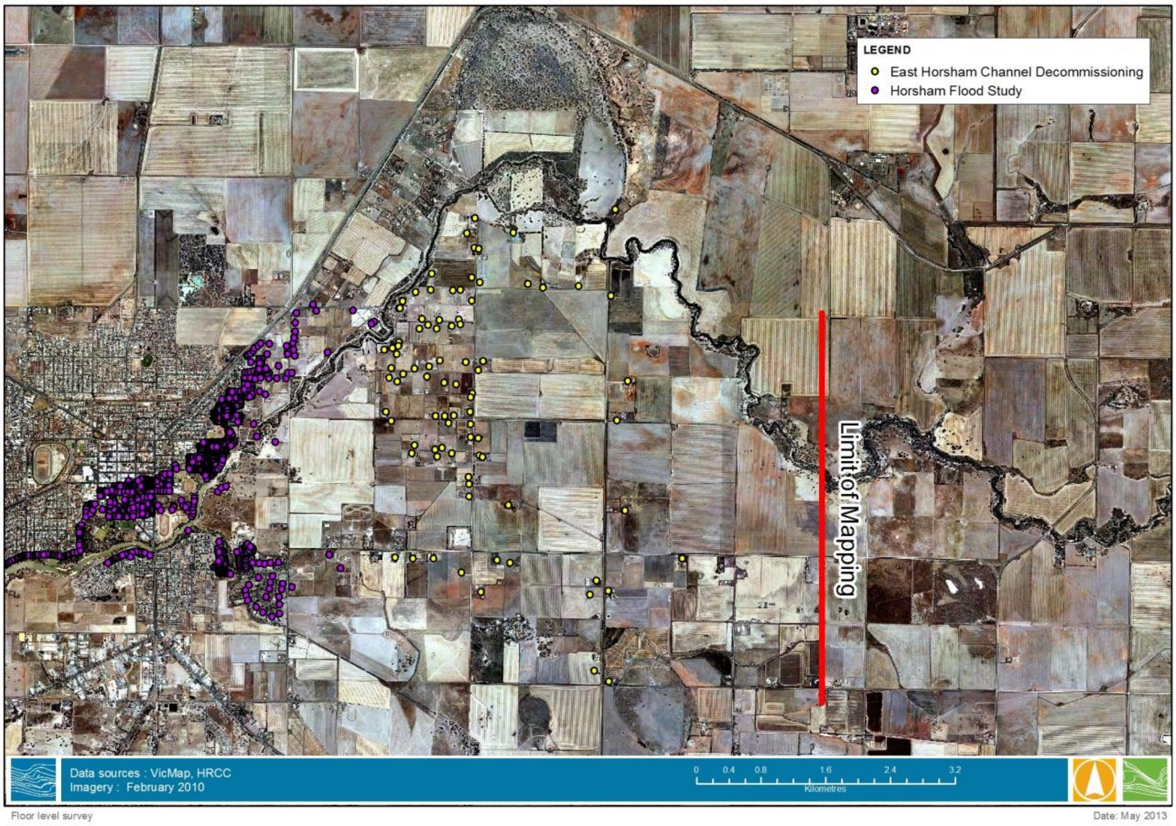


FIGURE 2-3 FLOOR LEVEL SURVEY CAPTURED AS PART OF THE EAST HORSHAM FLOOD PLAN

2.2.5 Wimmera CMA Flood Report – January 2011 (2011)

2.2.5.1 Overview

The Wimmera Region Flood Report – January 2011 provides a summary of the flood event, reviews the actions that occurred, and provided recommendations to improve the approach to dealing with future floods. Several of the recommendations from the Wimmera CMA Flood Report have since been actioned, including the commissioning of the following studies:

- Natimuk Flood Investigation.
- Horsham and Wartook Valley Flood Investigation.
- Dunmunkle Creek Flood Investigation.
- Mt William Creek Flood Investigation.

2.2.5.2 Relevant Findings

The report provides a detailed account of flooding during the January 2011 flood event, including temporary mitigation measures and properties impacted. These were used in the calibration phase to verify the hydraulic model.

This study addressed the recommendation to undertake flood studies for Mackenzie River and Norton Creek, and the area south of Horsham including Burnt Creek.

2.2.6 Wimmera River and Yarriambiack Creek Flow Modelling Study (2009)

2.2.6.1 Overview

The Wimmera River and Yarriambiack Creek Flow Modelling Study undertook hydrologic and hydraulic modelling of the Wimmera River and Yarriambiack Creek between Glenorchy, Horsham and Warracknabeal. Design flows into the hydraulic model were determined by an URBS model built by the Bureau of Meteorology for flood warning purposes (BoM, 2004).

The complex nature of flow distribution of Wimmera River flows to Yarriambiack Creek resulted in the development and use of several hydraulic models. The project modelled 'current day' and 'pre-European settlement' scenarios.

2.2.6.2 Relevant Findings

An overland flow path where flow splits from the Wimmera River upstream of the Drung Drung gauge, towards the south west (East Horsham) was identified. This resulted in two Wimmera River inflows to the study area, these were:

- The main Wimmera River flow path along the Wimmera River Channel
- The overland flow path south of the Wimmera River. This flows in a westerly direction crossing East Road between Horsham-Lubeck Road (to the north) and North Road (to the south).

The relationship for the proportional split of flows was established from hydraulic modelling for a range of events and will be utilised for hydrology input to this study.

The study also analysed the distribution of flow from Mackenzie River to Burnt Creek at Distribution Heads. Distribution Heads regulates low-medium flows from Mackenzie River and Moora Channel into Burnt Creek. The split was analysed for the 1983, 1988 and 1996 calibration events (observed data was available at Wonwondah East for these events). The result was highly variable, and as such an estimated ratio of 2:1 (Mackenzie River: Burnt Creek) was applied for the design modelling. During this project the flow split was modelled hydraulically and was shown to vary with event magnitude and a set flow split was not an accurate assumption. However, it was the best available information at the time.

2.2.7 Horsham Bypass Hydrology and Hydraulic Investigation (2012)

2.2.7.1 Overview

The Horsham Bypass Hydrology and Hydraulic Investigation was commissioned by VicRoads to review a series of bypass options for the Horsham Township. The study extended modelling completed during the Wimmera River and Yarriambiack Creek Flow Modelling Study to the south and west to ensure each of the potential bypass alignments were covered. The model covered from east of this investigation area, at around School Road, to downstream of the Mackenzie River and Wimmera River confluence. Each option was assessed for potential impact to floodplain inundation and the number/size of crossings required for the 10% and 1% AEP events were determined.

2.2.7.2 Relevant Findings

The hydraulic model extent for the Horsham Bypass Hydrology and Hydraulics Investigation covers a large portion of the area that is of interest to this study. This includes almost all the Wimmera River floodplain and some of the Burnt Creek floodplain. It did not include an accurate representation the flow distribution among the Mackenzie River, Burnt Creek and Bungalally Creek.

2.2.8 East Horsham Channel Decommissioning Modelling (2014)

2.2.8.1 Overview

Due to completion of the Wimmera Mallee Pipeline Project, GWMWater no longer had the need for their irrigation channel network across East Horsham, and as a result were decommissioning large portions of the channel network. A large number were in the Wimmera River floodplain and interacted with overland flood flows from the Wimmera River. To better understand this potential impact GWMWater commissioned Water Technology to model the impact of the channel decommissioning across East Horsham. Modelling was completed using the model developed during the Horsham Bypass Hydrology and Hydraulics Assessment.

The initial modelling was followed by a range of mitigation scenarios to ensure that the channel could be removed without impacting flood levels in East Horsham. An upgrade to Rokeskys Road and a new private levee protecting one landholder was designed and constructed to allow Channel No. 3 to be decommissioned without impacting flood levels in East Horsham.

During the study there was significant road and channel crest height survey undertaken.

2.2.8.2 Relevant Findings

The road crest and channel embankment survey undertaken as part of the East Horsham Channel Decommissioning Modelling falls within the study area of this project and will be incorporated into the model for design flood modelling. The areas surveyed are shown in Figure 2-4.

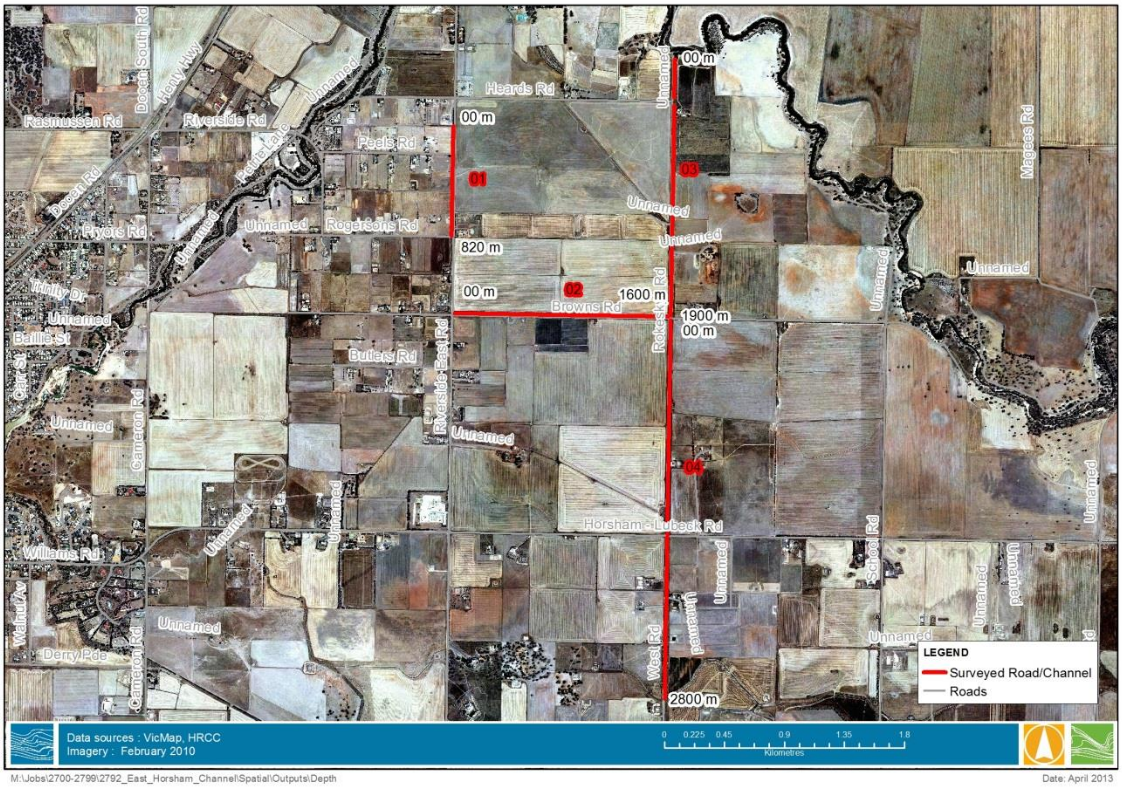


FIGURE 2-4 ROAD AND CHANNEL CREST SURVEY

2.3 LiDAR Data

2.3.1 LiDAR Data Availability

Three LiDAR datasets were available within the study area, these datasets are as follows:

- 2016 Horsham LiDAR - Data was captured specifically for this project. Provided as a 1 m resolution grid, 0.2 m vertical accuracy, 0.3 m horizontal accuracy.
- 2004 WCMA LiDAR – Coverage of the Wimmera CMA management area, excluding Warracknabeal. Provided as a 2 m resolution grid, 0.5 m vertical accuracy, 1.5 m horizontal accuracy.
- 2010 ISC LiDAR – Coverage of major waterways within WCMA management area. Provided as a 1 m resolution grid, 0.2 m vertical accuracy, 0.3 m horizontal accuracy.

The 2004 WCMA LiDAR has been verified across numerous projects including:

- East Horsham Channel Decommissioning Modelling (Water Technology, 2013) (Commissioned by HRCC)
- Warracknabeal and Brim Flood Investigation (Water Technology, 2016) (Commissioned by Wimmera CMA)[1]

[1] Water Technology (2014), Warracknabeal and Brim Flood Investigation, Wimmera CMA

- Dunmunkle Creek Flood Investigation (Water Technology, 2016) (Commissioned by Wimmera CMA)[2]
- Natimuk Flood Investigation (Water Technology, 2012) (Commissioned by Wimmera CMA)[3]

The 2010 ISC LiDAR data has not been used as the base topography in the above projects due to inconsistencies in the data, these have included datum shifts and water in the channel in several waterways. This is explained in detail in the Warracknabeal and Brim Flood Investigation[1] and Dunmunkle Creek Flood Investigation[2] data verification reports.

2.3.2 Methodology

The new 2016 LiDAR data was verified in a two-step process:

- Verification against feature survey.
  - Two surveyed road crests within Horsham
  - One surveyed road crest in East Horsham
- Comparison with the 2004 and 2010 datasets.

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

Feature survey is the most accurate representation of the ground surface and road crest feature survey was used for verification in this project. Transects along a road crest enable a visual comparison as well as a statistical analysis on a point by point basis such as mean, max and minimum difference.

Comparing the LiDAR to previous LiDAR datasets allows a topographic comparison across the entire overlapping area. This highlights any spatial topographic inconsistences such as large earth works, changes to agricultural management (removal of irrigation channels, drainage improvements) 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 can also highlight misrepresentations within a LiDAR dataset including "banding" where inconsistent elevations are present at the edge of LiDAR flight runs.

2.3.3 Feature Survey Comparison

2.3.3.1 Overview

Road crest feature survey was captured in three locations in Horsham, this data was provided to Water Technology by Horsham Rural City Council[4]. Road crest survey was also available for five road crests in East Horsham, this data was captured as part of the East Horsham Channel Decommissioning Project[5]. The road crests surveyed in Horsham were Kenny Road, Tucker Street and Lewis Street. Road crests surveyed in East Horsham were Riverside East Road, Browns Road, West Road and Rokeskys Road which was separated in to northern and southern section's either side of Browns Road.

Surveyed road crest locations are shown in Figure 2-5.

[2] Water Technology (2016). Dunmunkle Creek Flood Investigation, Wimmera CMA
[3] Water Technology (2012), Natimuk Flood Investigation, Wimmera CMA
[4] Survey was captured as part of HRCC road upgrades, data was provided by Lyndon White.
[5] Water Technology (2013), East Horsham Channel Decommissioning, HRCC

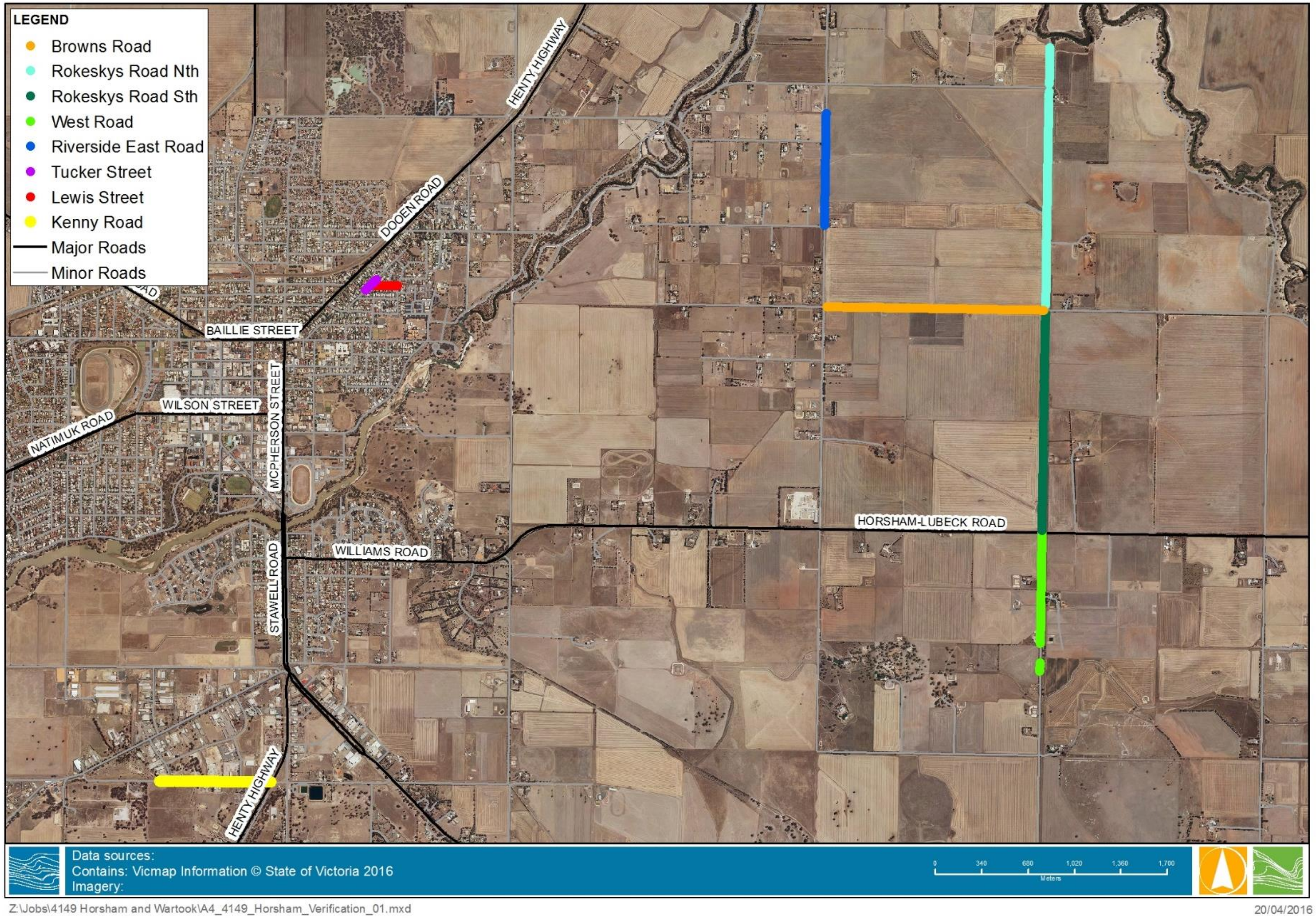


FIGURE 2-5 VERIFICATION SURVEY LOCATIONS

2.3.3.2 Horsham – Road crest survey

Comparison between the Horsham surveyed road crest levels was made against the 2016 LiDAR data at each location. A map of the survey locations along Lewis Street and Tucker Street is shown in Figure 2-6, with longsection comparisons shown in Figure 2-7 and Figure 2-8 respectively.

A map of the surveyed heights along Kenny Road is shown in Figure 2-9, with a long-section comparison between the survey and LiDAR data shown in Figure 2-10.

FIGURE 2-6 TUCKER STREET AND LEWIS STREET SURVEYED POINTS

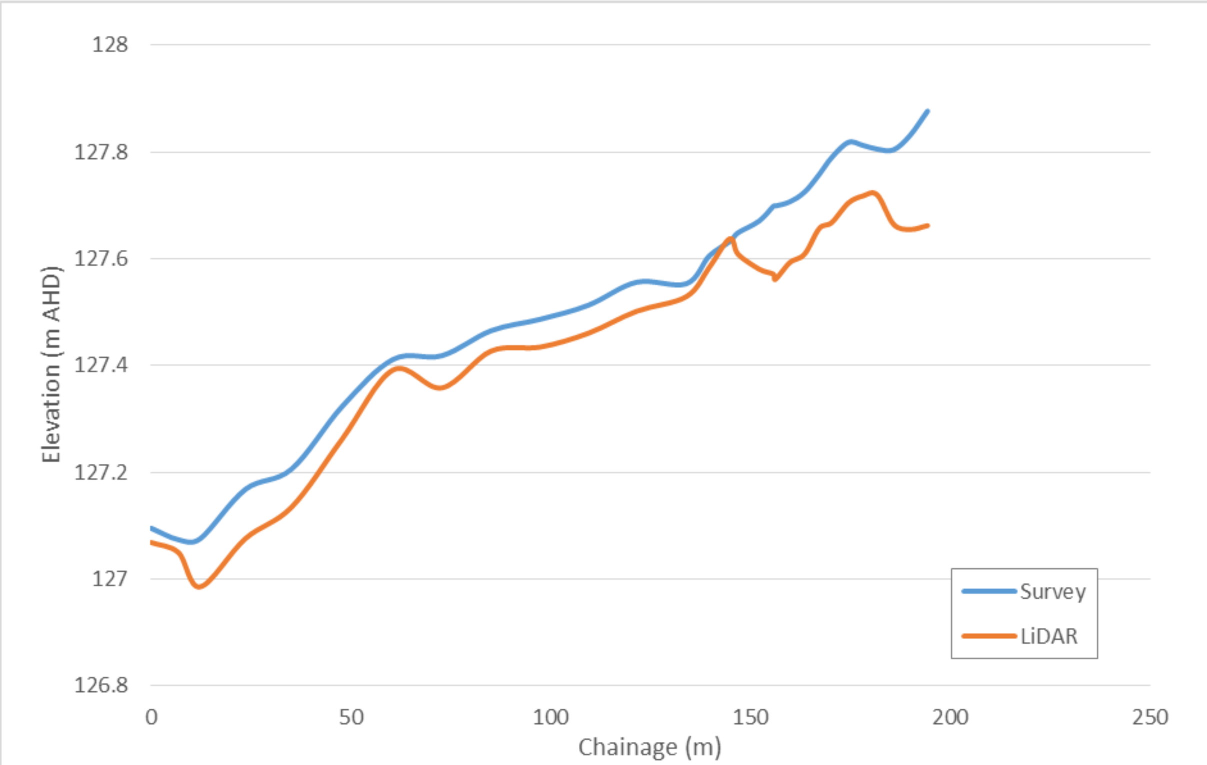


FIGURE 2-7 LEWIS STREET - SURVEY AND 2016 LIDAR DATA COMPARISON

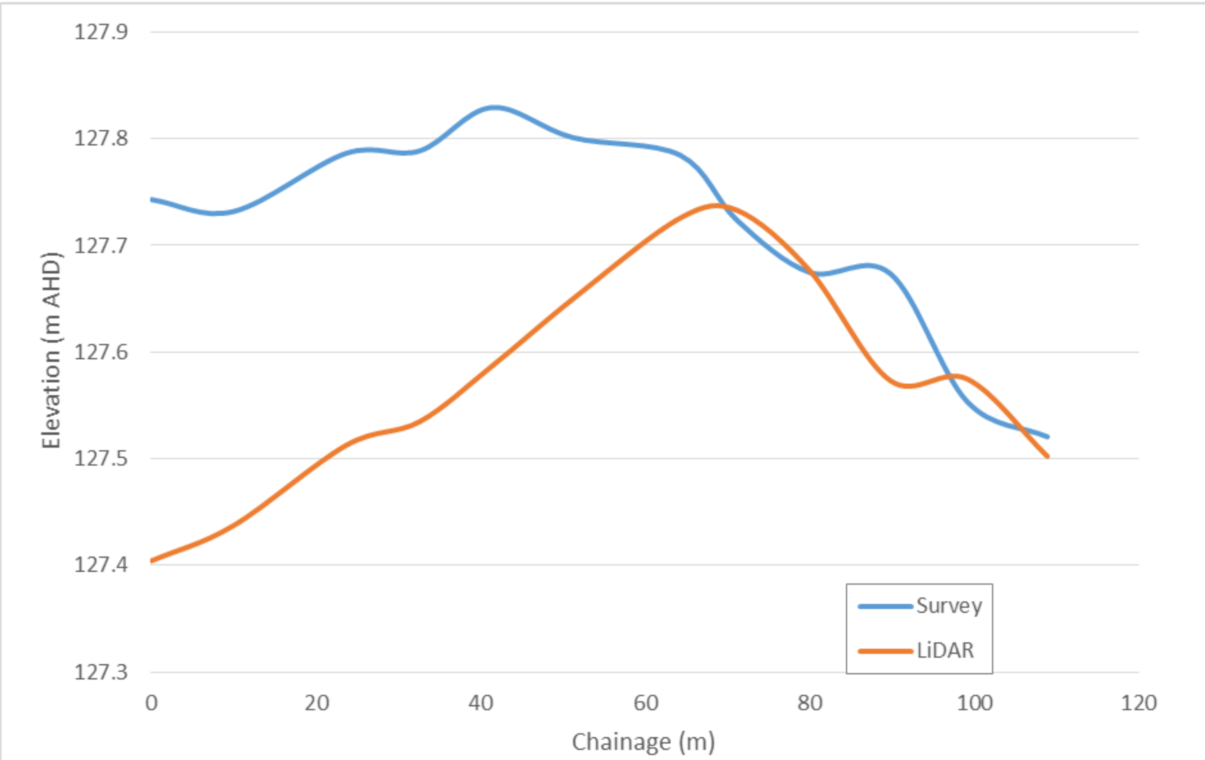


FIGURE 2-8 TUCKER STREET - SURVEY AND 2016 LIDAR DATA COMPARISON

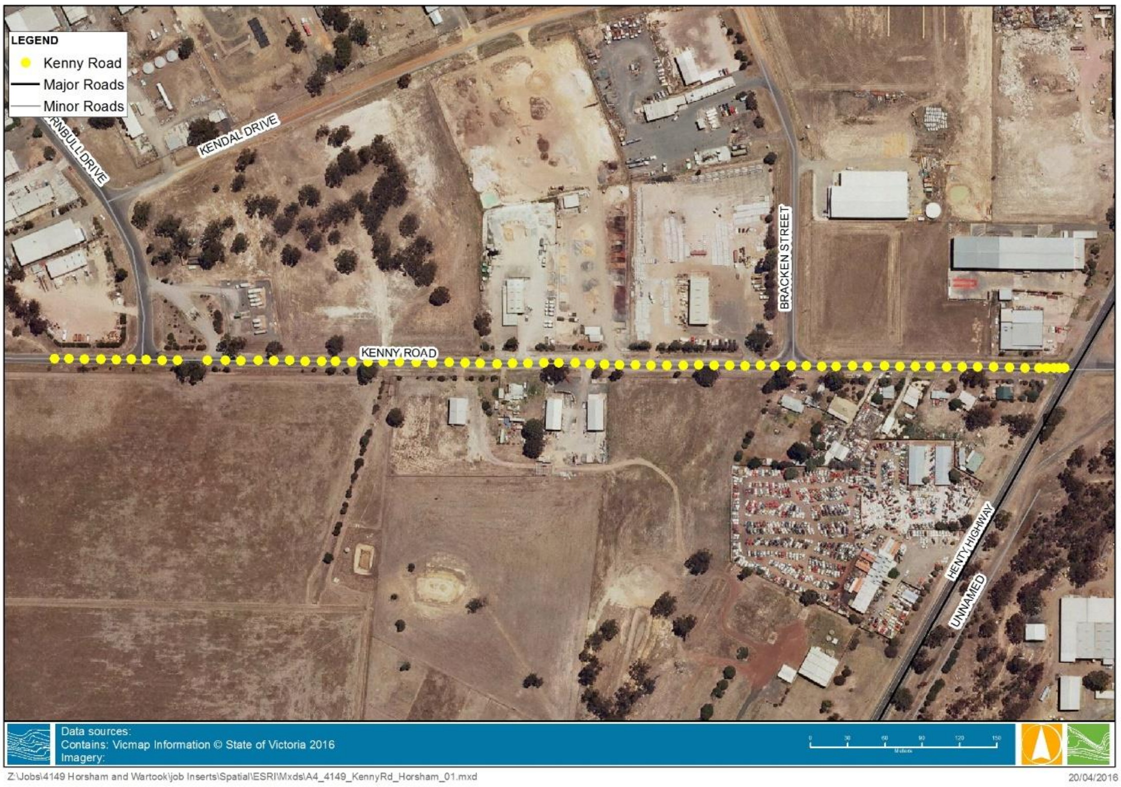


FIGURE 2-9 KENNY ROAD – SURVEYED POINTS

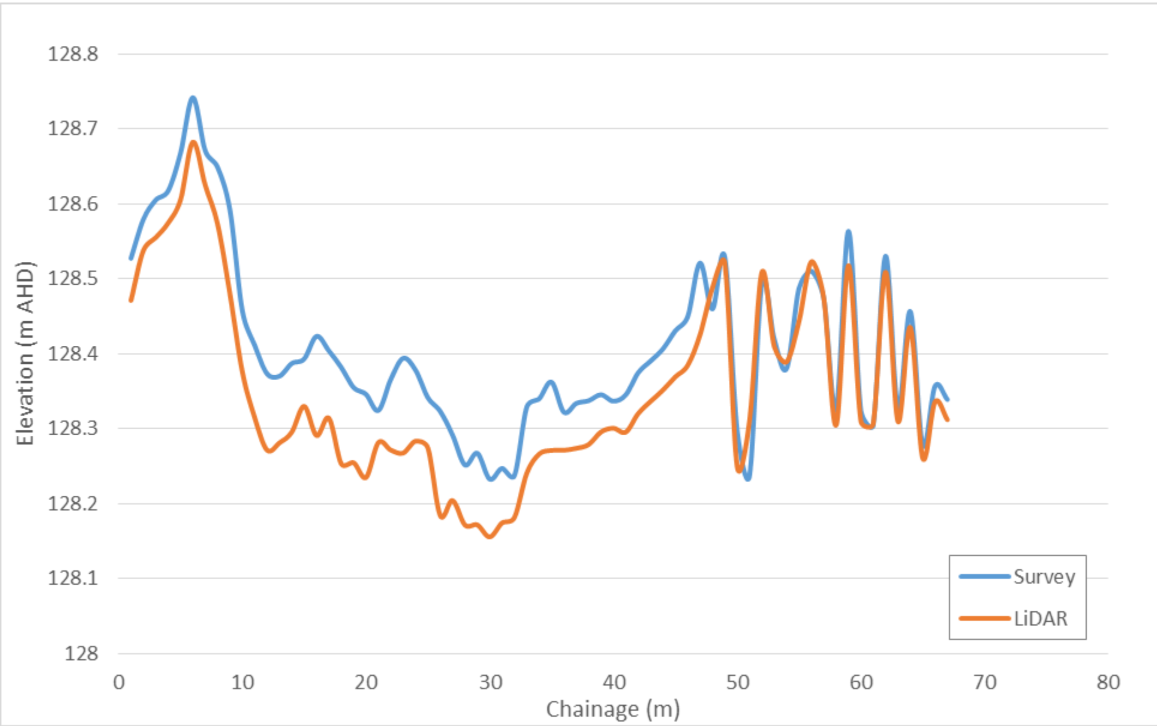


FIGURE 2-10 KENNY ROAD - SURVEY AND 2016 LIDAR DATA COMPARISON

The difference between the survey and 2016 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 2-3.

TABLE 2-3 MEAN, MAXIMUM, MINIMUM AND STANDARD DEVIATION DIFFERENCES BETWEEN SURVEYED AND 2016 LIDAR TOPOGRAPHY LEVELS

Statistic	Elevation difference (LiDAR – Survey)		
	Lewis Street	Tucker Street	Kenny Road
Average (m)	-0.08	-0.14	-0.06
Max. (m)	0.01	0.02	0.07
Min. (m)	-0.21	-0.34	-0.14
Standard Deviation (m)	0.05	0.13	0.04

Comparison of the 2016 LiDAR and road crest elevations in Horsham showed the 2016 LiDAR to be reasonably accurate. The longsections showed the LiDAR to be consistently lower across all locations. This was also represented in the average difference between the datasets. The Lewis Street and Kenny Road longsections showed the LiDAR matched the survey data well, this was particularly the case for Kenny Road at points 45-67 where there was considerable undulation in the road level represented in both datasets.

The Tucker Road longsection showed a disparity between the survey and LiDAR data levels for points 1-7, this difference is not considered to be an issue with the LiDAR data given its consistent nature across the remainder of the points. Horsham Rural City Council were contacted to determine whether road works had occurred along Tucker Street and it was confirmed the road was lowered by around 0.3 m in late 2015[6].

The average difference between the LiDAR and surveyed levels for Lewis Street and Kenny Road is less than 0.08 m, well within the stated vertical accuracy of the data at 0.20 m.

2.3.3.3 East Horsham - Road crest survey

The surveyed road crest levels captured during the East Horsham Channel Decommissioning Project[5] were compared to the 2016 LiDAR. The survey locations are shown in Figure 2-5 with a comparison of the survey and LiDAR data levels for Riverside East Road, Browns Road, Rokeskys Road and West Road shown in Figure 2-11, Figure 2-12, Figure 2-13 and Figure 2-14 respectively.

[6] Pers. Comm. Lyndon White, Horsham Rural City Council.

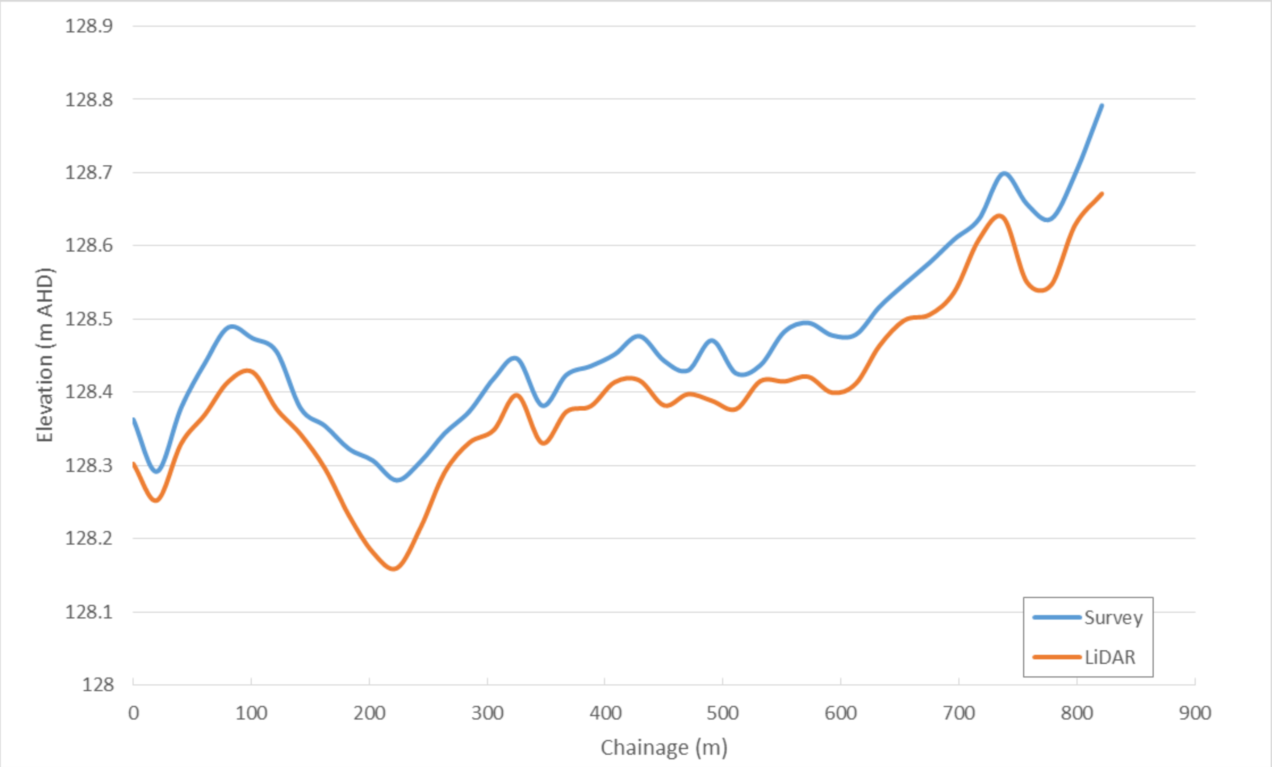


FIGURE 2-11 RIVERSIDE EAST ROAD - SURVEY AND 2016 LIDAR DATA COMPARISON

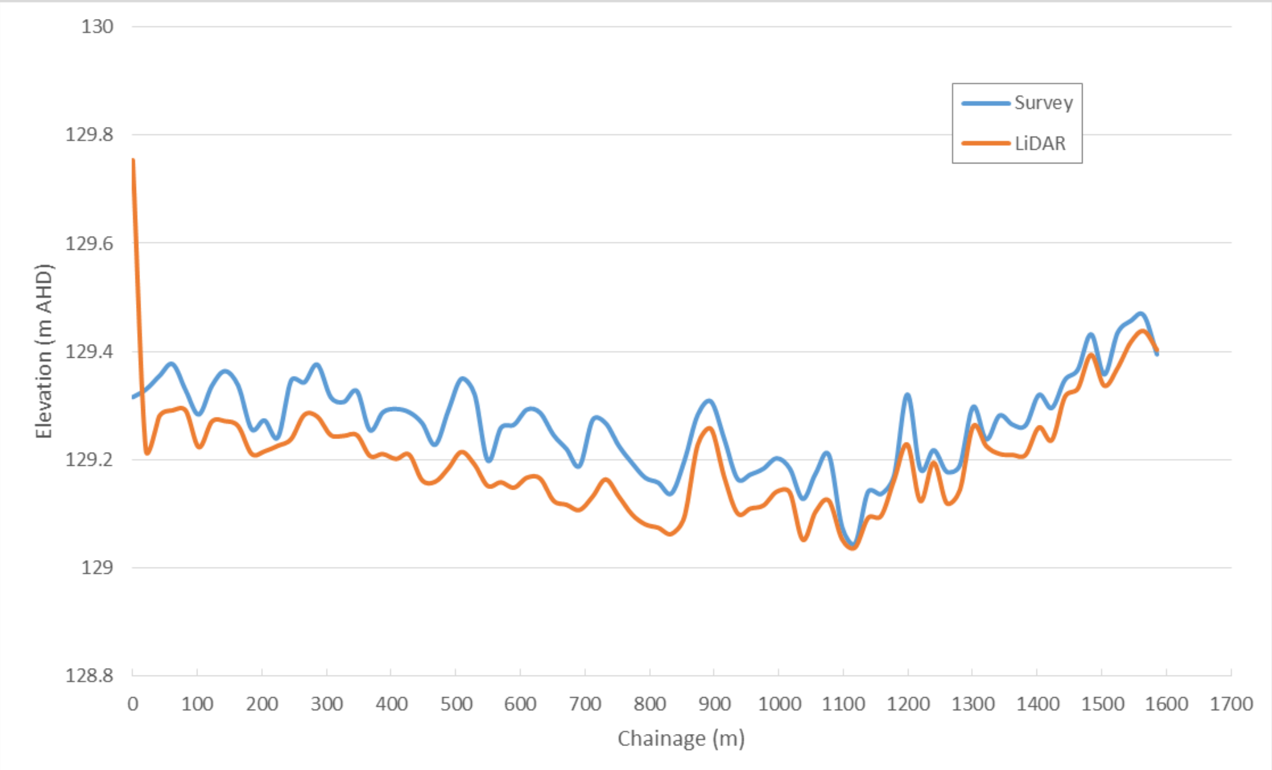


FIGURE 2-12 BROWNS ROAD - SURVEY AND 2016 LIDAR DATA COMPARISON

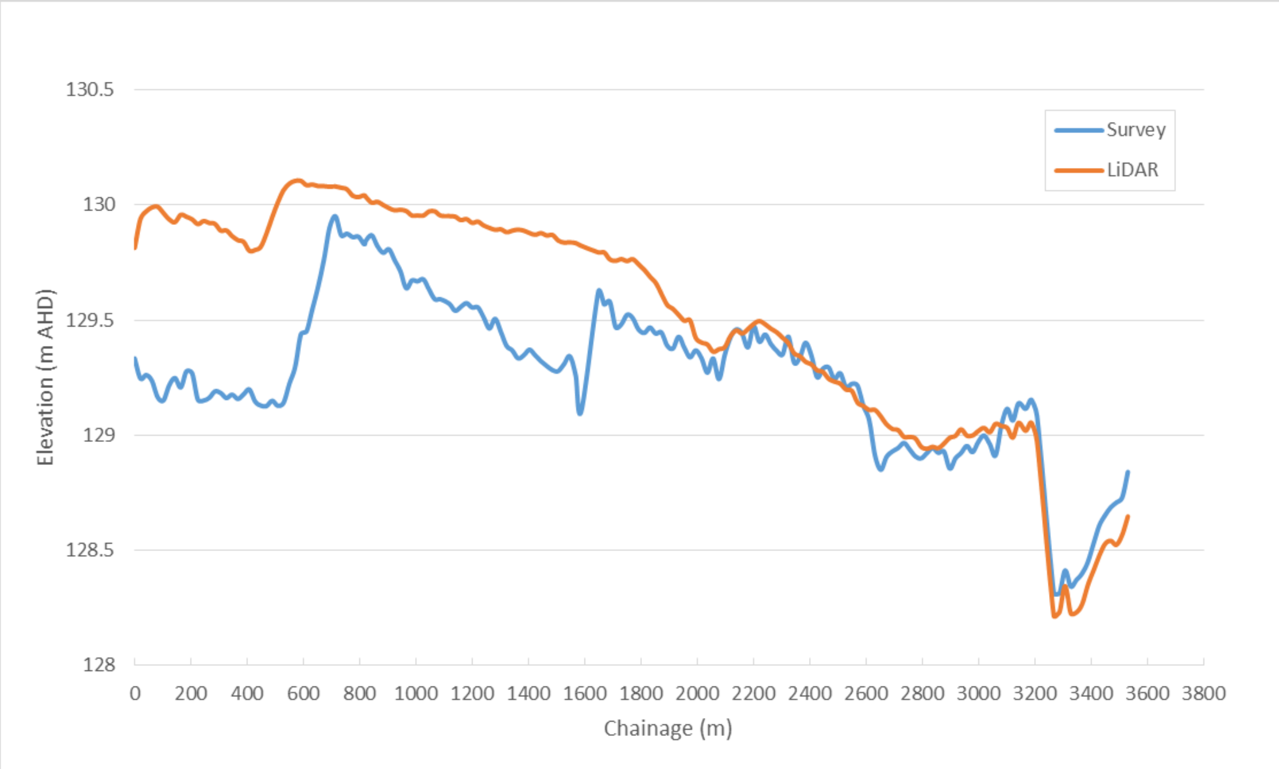


FIGURE 2-13 ROKESKYS ROAD - SURVEY AND 2016 LIDAR DATA COMPARISON

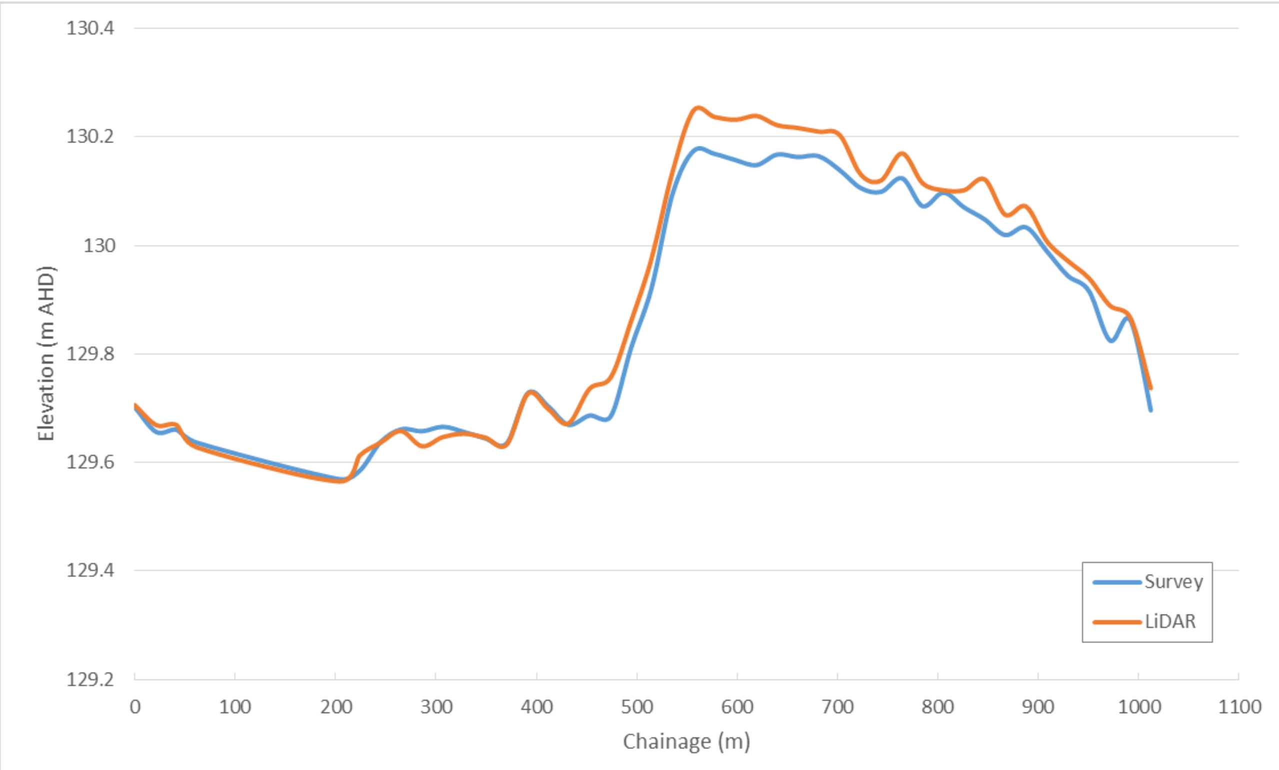


FIGURE 2-14 WEST ROAD - SURVEY AND 2016 LIDAR DATA COMPARISON

The difference between the survey and the 2016 LiDAR was calculated at each survey point and the maximum, minimum and average difference for each location was calculated. The statistics are shown in Table 2-4.

TABLE 2-4 MEAN, MAXIMUM, MINIMUM AND STANDARD DEVIATION DIFFERENCES BETWEEN SURVEYED AND 2016 LIDAR TOPOGRAPHY LEVELS

Statistic	Elevation difference (LiDAR – Survey)			
	Riverside East Road	Browns Road	Rokeskys Road	West Road
Average (m)	-0.06	-0.03	0.16	-0.06
Max. (m)	-0.02	0.03	0.92	0.44
Min. (m)	-0.13	-0.09	-0.19	-0.14
Standard Deviation (m)	0.02	0.03	0.29	0.07

The 2016 LiDAR and survey data comparison for Rokeskys Road was highly inconsistent, this is due to works undertaken by HRCC and GWMWater raising the road crest to replace Channel No. 3, which was decommissioned during the GWMWater Channel Decommissioning Program. The replacement was required to ensure no change in flood flow distribution was caused by the removal of the channel. The design of the increase in Rokeskys Road was designed by Water Technology and Driscoll Engineering. While the road upgrade means this survey can not be used for verification purposes, it does confirm that the LiDAR represents this important change within the floodplain.

The remaining road crest comparisons show similar trends to that observed in Horsham, with the LiDAR generally slightly lower than surveyed road crest levels.

The general shape of the longsections is matched very closely for each dataset with a slight uniform shift. The uniform shift at each comparison location is reflected in the average differences. A maximum average difference of -0.06 m was observed at the Riverside East Road and West Road transects; this was within the stated vertical accuracy of the LiDAR data at 0.2 m.

2.3.4 LiDAR Data Comparison

2.3.4.1 Overview

Comparison of available LiDAR datasets is used to identify any potential issues with survey datums, large scale changes to topography over time, or the presence of water in lakes/waterways etc. It can also highlight “banding” where the processing and merging of LiDAR flight paths can influence the final topography data produced.

The 2016 LiDAR dataset was compared to the 2010 ISC and 2004 WCMA region LiDAR datasets. The comparison was made by subtracting each of the 2010 and 2004 data sets from the 2016 data, calculated as follows:

Difference = 2016 LiDAR - 2010 ISC (or 2004) LiDAR

This calculation results in a positive value when the 2016 data is higher, and a negative value when the 2016 data is lower. Figure 2-15 and Figure 2-16 show the difference between the 2016 LiDAR data and 2010 ISC and 2004 WCMA region LiDAR datasets respectively.

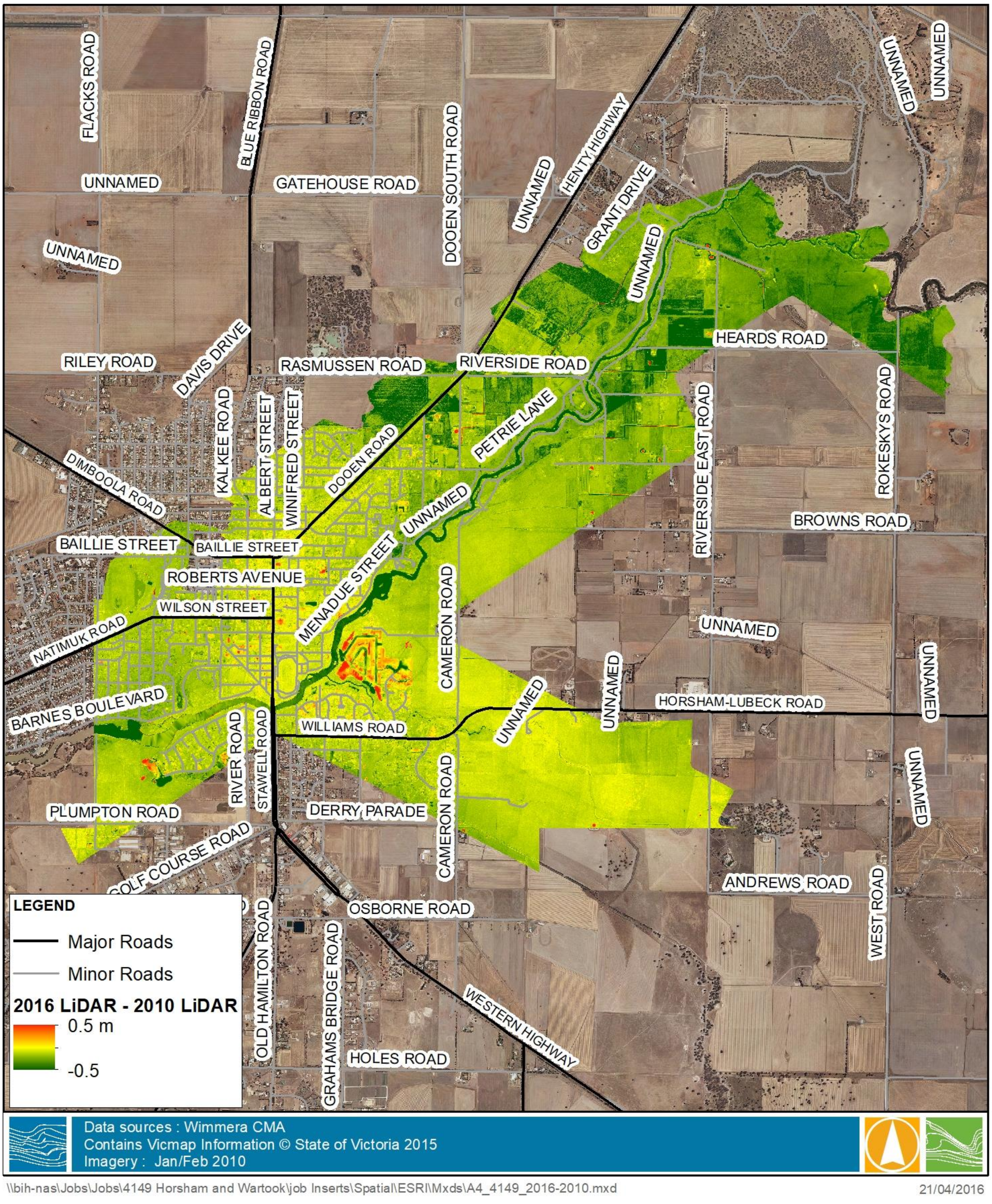


FIGURE 2-15 DIFFERENCES BETWEEN THE 2016 AND 2010 ISC DATASETS (2016-2010)

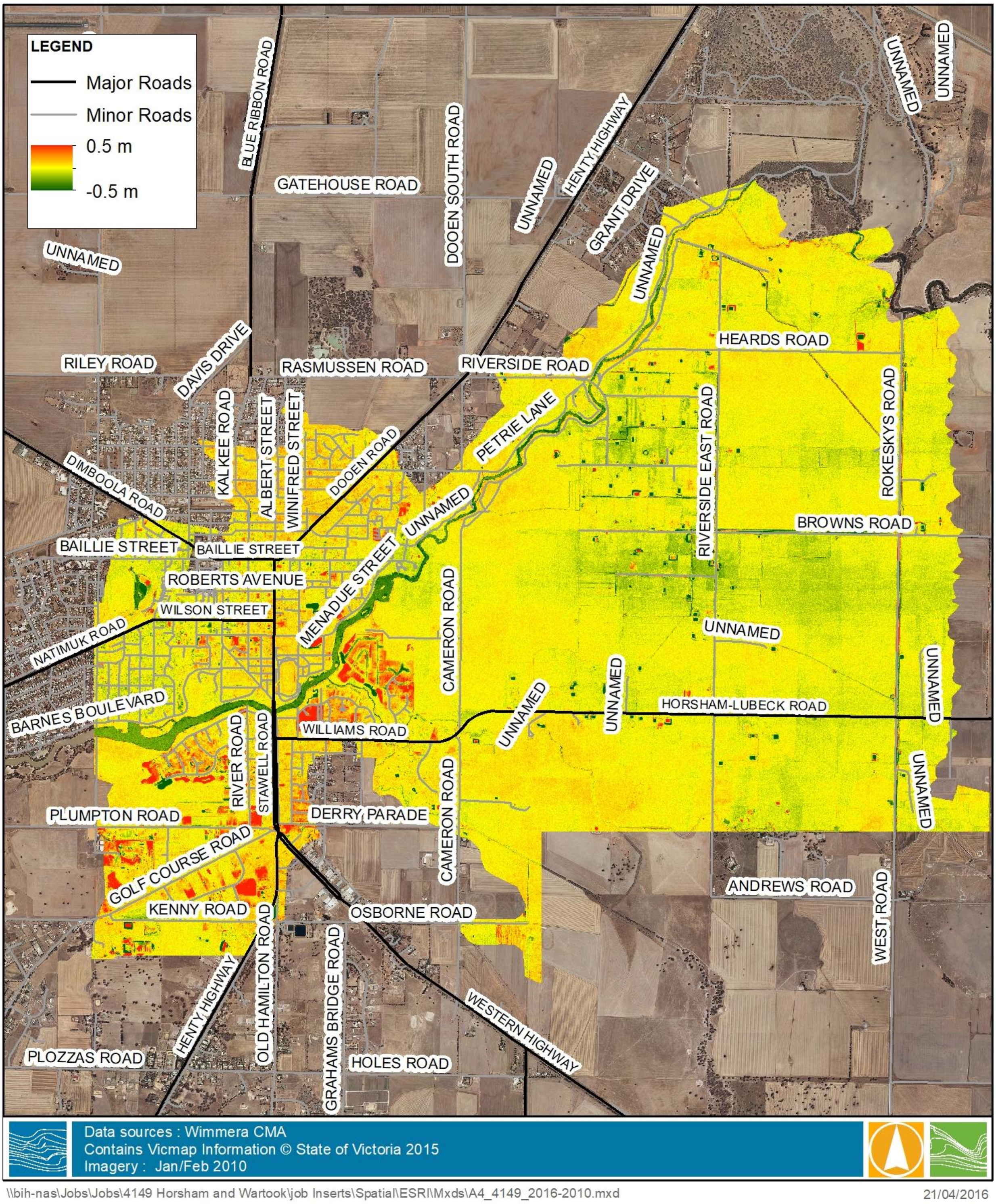


FIGURE 2-16 DIFFERENCES BETWEEN THE 2016 AND 2004 WCMA REGION LIDAR (2016-2004)

2.3.4.2 Discussion

The LiDAR comparison between the 2016 and 2010 datasets showed several differences and are discussed further below. Areas showing particularly high or low differences were north of Heards Road and Water Links Estate north of Williams Road. These areas are shown in more detail in Appendix A.

Differences at the Water Links Estate are due to the cut and fill placed in the development area as part of raising several lots and lowering of the internal road network. Differences north of Heards Road are due to thick vegetation, most likely pasture, the height of which changed between LiDAR captures. This is most likely in the older 2010 ISC dataset which was not present when the 2016 data was captured. The Wimmera River channel is also lower in the 2016 dataset with less water in the channel at the time it was flown. Across the broader comparison area, the 2016 LiDAR is generally higher than the 2010 data, this can be observed by the orange areas in the colour pallet indicating a difference of 0.1 to 0.2 m.

It was also noted there was a localised difference at Heards Road which wasn't continuous, with the 2016 LiDAR lower than the 2010 data in the green areas shown in Figure 2-17.

Some of these differences are due to pasture or crops present in the 2010 data but not the 2016; however, the area highlighted in Figure 2-17 indicates an area that is not consistent. Half of two paddock appear to have had a crop or this pasture in them with a diagonal cut through them. It is thought the paddocks must have been harvested or cut between LiDAR flight swaths.

Comparison between the 2016 and 2004 datasets showed a much closer general match across the comparison area than the 2010 data. Like the 2010 comparison there were several specific areas where changes in topography between 2004 and 2016 show differences. The majority of these are due to GWMWater or private channels and dam decommissioning in East Horsham. There are also several increases in the industrial area of Horsham along Golf Course Road. On the western side of the comparison area the 2016 data is a reasonable amount higher than the 2010 data, as highlighted in Figure 2-17, the cause of this is unknown, however it may be due to thick grass being present at the time the 2016 data was flown, and bare earth during 2010.

Statistics were extracted for each LiDAR data comparison, calculated across the overlapping topography extent, these statistics are shown in Table 2-5 Differences between 2016 and 2010/2004 LiDAR topography levels

TABLE 2-5 DIFFERENCES BETWEEN 2016 AND 2010/2004 LIDAR TOPOGRAPHY LEVELS

Road transect	Elevation difference (m) (2016 LiDAR – 2010 or 2004 LiDAR)	
	2010 ISC LiDAR	2004 WCMA LiDAR
Mean (m)	-0.20	0.01
Max. (m)	4.76	6.13
Min. (m)	-4.39	-5.99
Standard Deviation (m)	0.19	0.19

Statistics on each LiDAR comparison confirm the visual assessment with large minimum and maximum differences as explained above. The mean differences also indicate the 2010 ISC data is consistently lower than the 2016 data, whereas the 2004 data is generally very similar. The difference observed in the 2010 ISC LiDAR is similar to differences observed in 2004 and 2010 LiDAR described in past projects[1, 2].

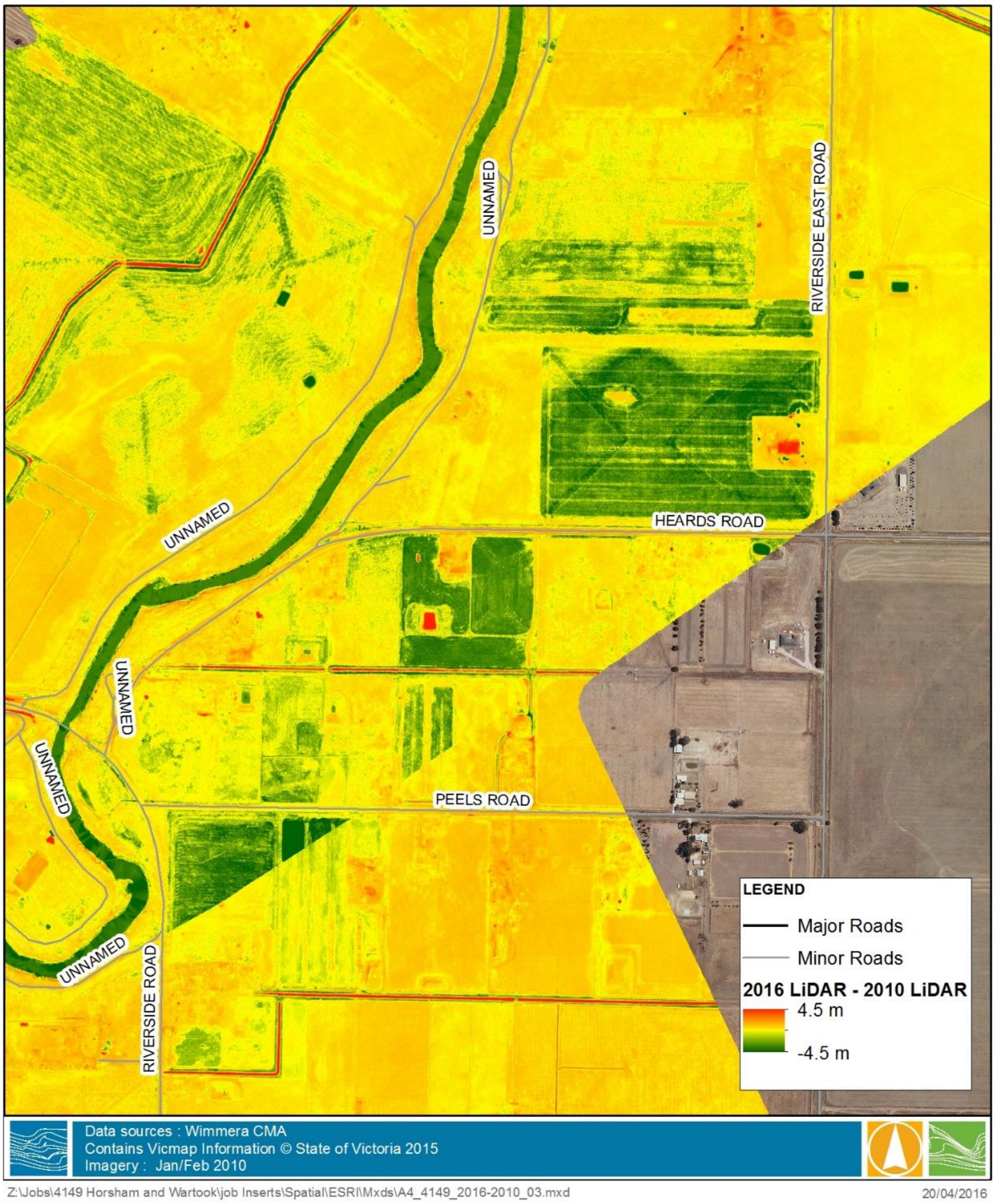


FIGURE 2-17 DIFFERENCES BETWEEN THE 2016 AND 2004 WCMA REGION LIDAR (2016-2010) AT HEARDS ROAD

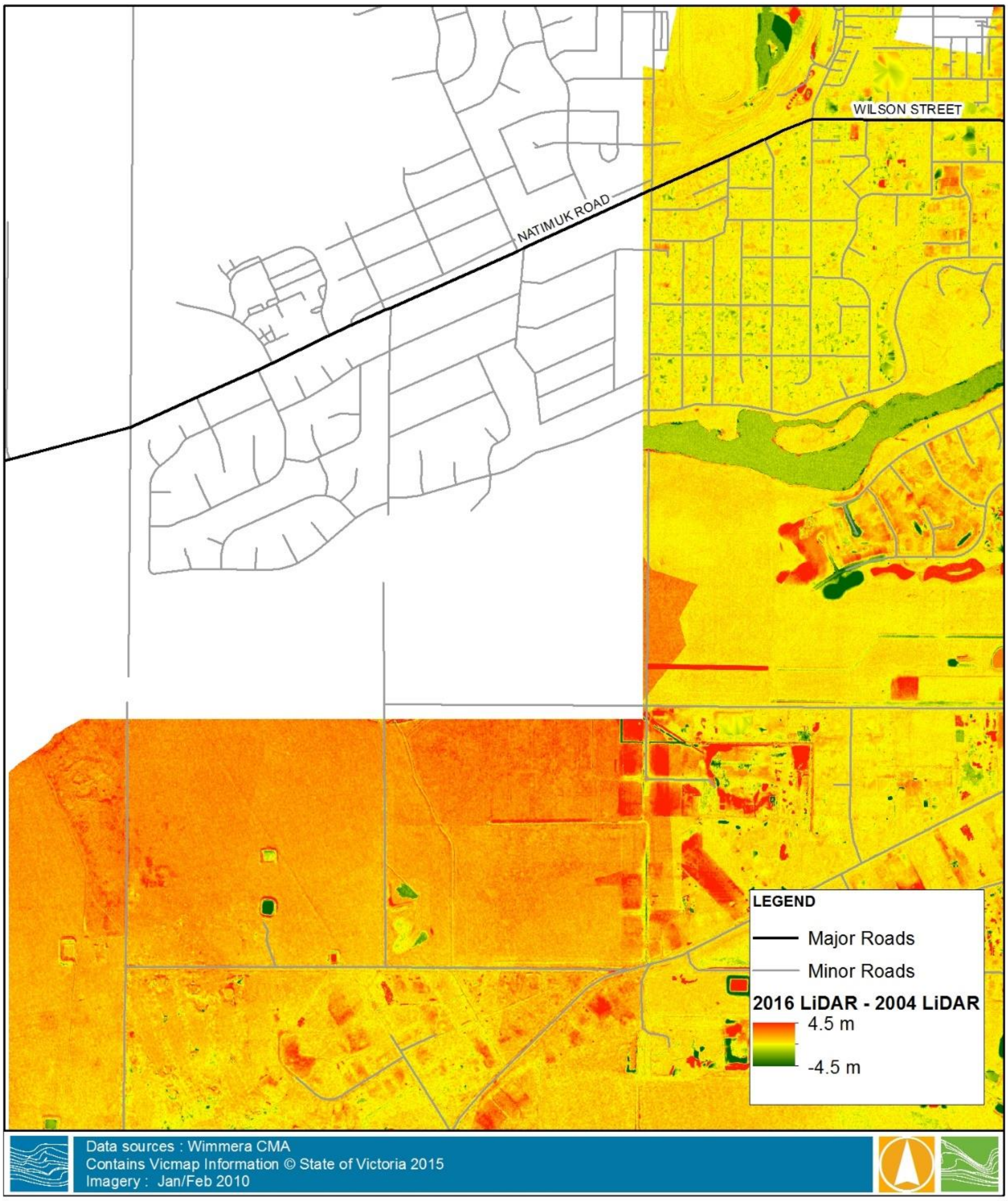


FIGURE 2-18 DIFFERENCES BETWEEN THE 2016 AND 2004 WCMA REGION LIDAR (2016-2004) AT WEST OF HORSHAM

2.3.5 LiDAR Data Discussion and Recommendation

Comparison of the 2016 LiDAR data to surveyed levels has shown the LiDAR to be within the stated error bounds. The extracted longsections showed the LiDAR data is representing varying topography well. The LiDAR comparison also showed that recent work which has raised Rokeskys Road, cut and fill from various developments, and channel decommissioning across the study area is well represented in the data.

The close match between the 2016 LiDAR data and feature survey, and general match between the 2016 and 2004 datasets, has determined that the 2016 data is fit for use in this project.

The 2004 data has been verified to feature survey across several projects and will be used in areas not covered by the 2016 data. The 2010 ISC LiDAR was not used in this study.

2.4 Feature Survey

2.4.1 Floor Level Survey

A previous floor level survey was undertaken as part of the Horsham Flood Study and East Horsham Flood Plan (2002 and 2014 respectively). A total of 909 floor levels (residential and commercial) have been captured, as seen in Figure 2-19.

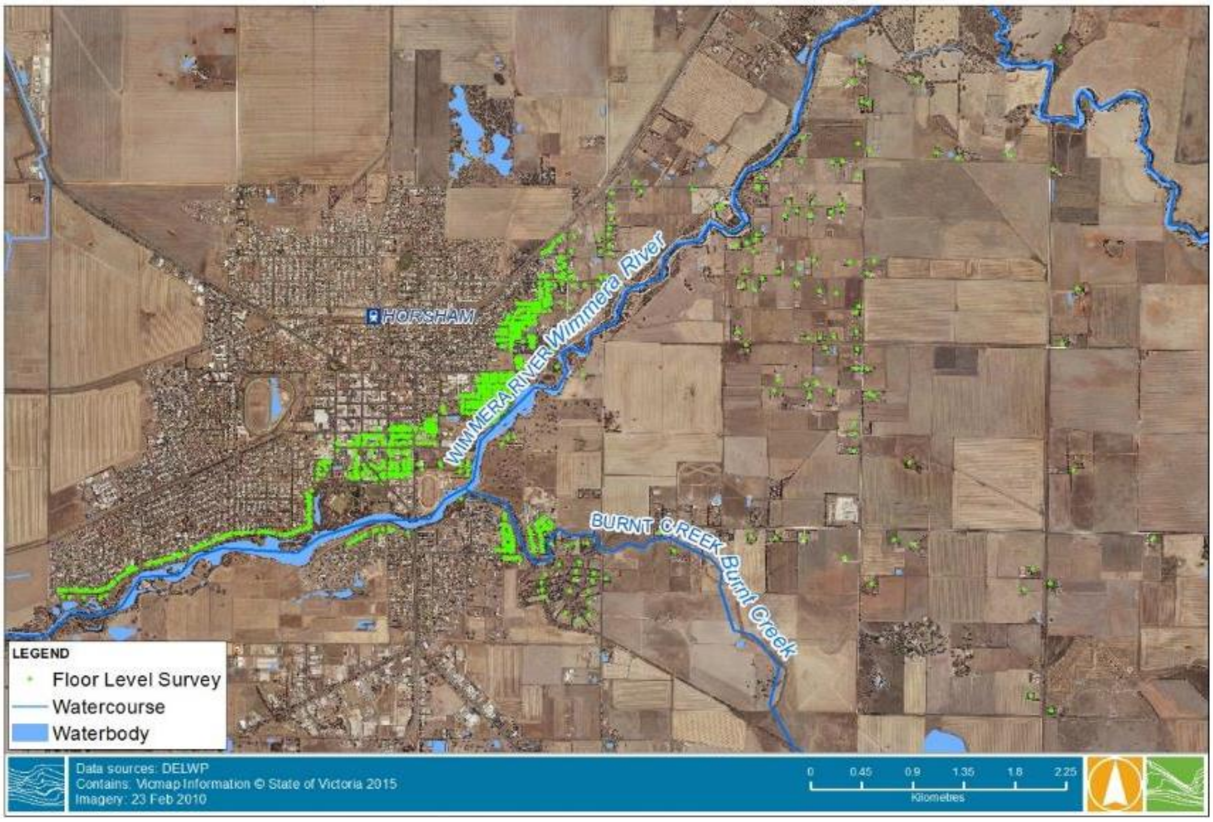


FIGURE 2-19 LOCATION OF AVAILABLE FLOOR LEVEL SURVEY DATA

On completion of the preliminary 0.5% AEP design hydraulic modelling, additional floor level survey was captured during this project, Figure 2-20.

Details of five culverts in East Horsham were acquired as part of the East Horsham Culvert Assessment; however, the recommendation was for replacement of some of these existing structures and past details were considered no longer accurate. The culverts were relatively minor channel structures and not included in the model.

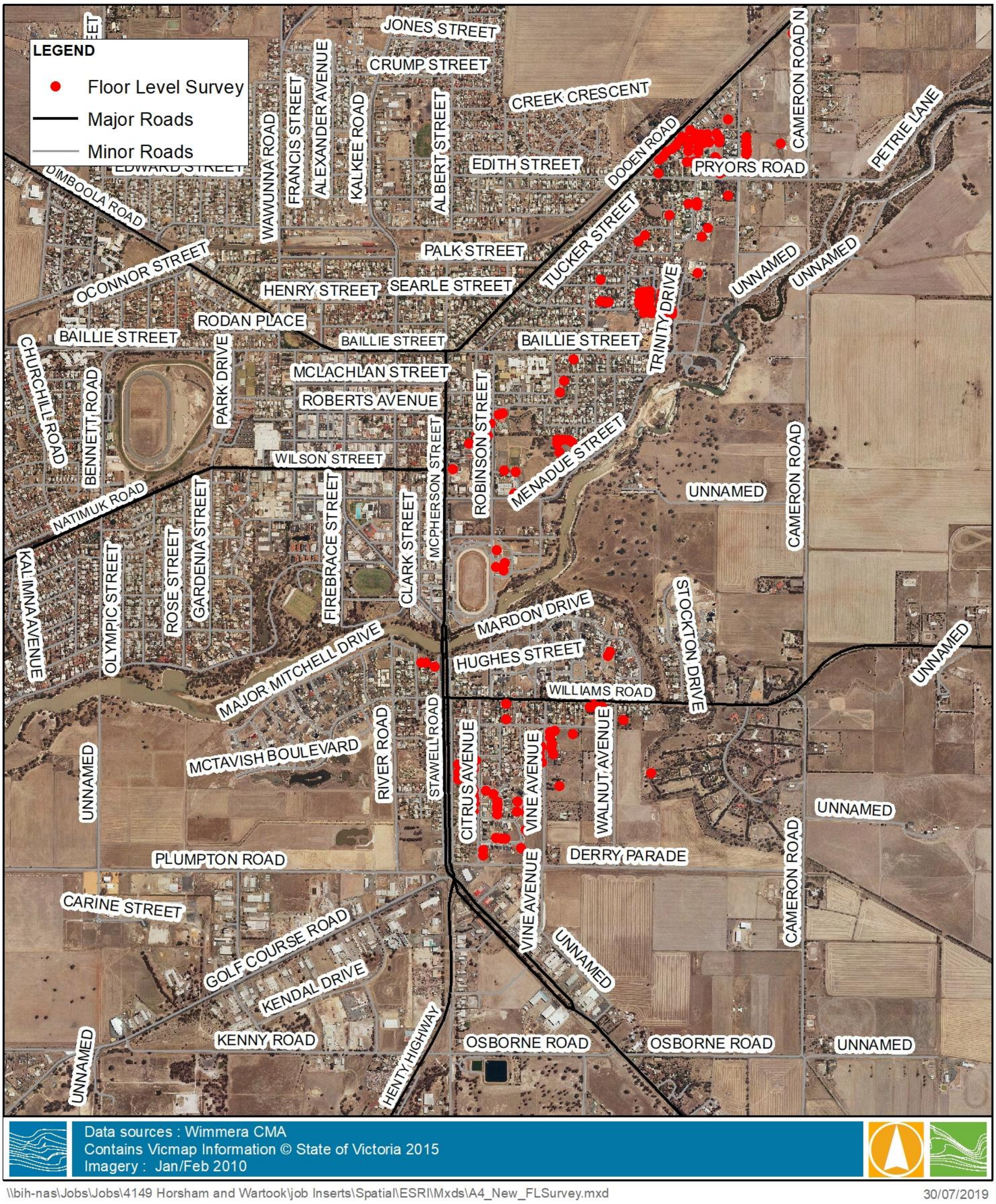


FIGURE 2-20 ADDITONAL FLOOR LEVEL SURVEY

2.4.2 Wimmera River cross sections

A series of Wimmera River cross sections were captured as part of the Horsham Flood Study (2002), the survey completed was replicated in this project to determine if there had been any change to the cross sections post the high flow events in September 2010, January 2011 and September 2016. The resurveyed cross sections were used to form the Wimmera River bathymetry in the Horsham Weir pool. This area was not captured as part of the LiDAR data given it was under water.

The available survey data is shown below in Figure 2-21 with comparisons of the 2006 and 2018 cross sections shown in Figure 2-22 to Figure 2-27.

FIGURE 2-21 WIMMERA RIVER CROSS SECTION LOCATIONS

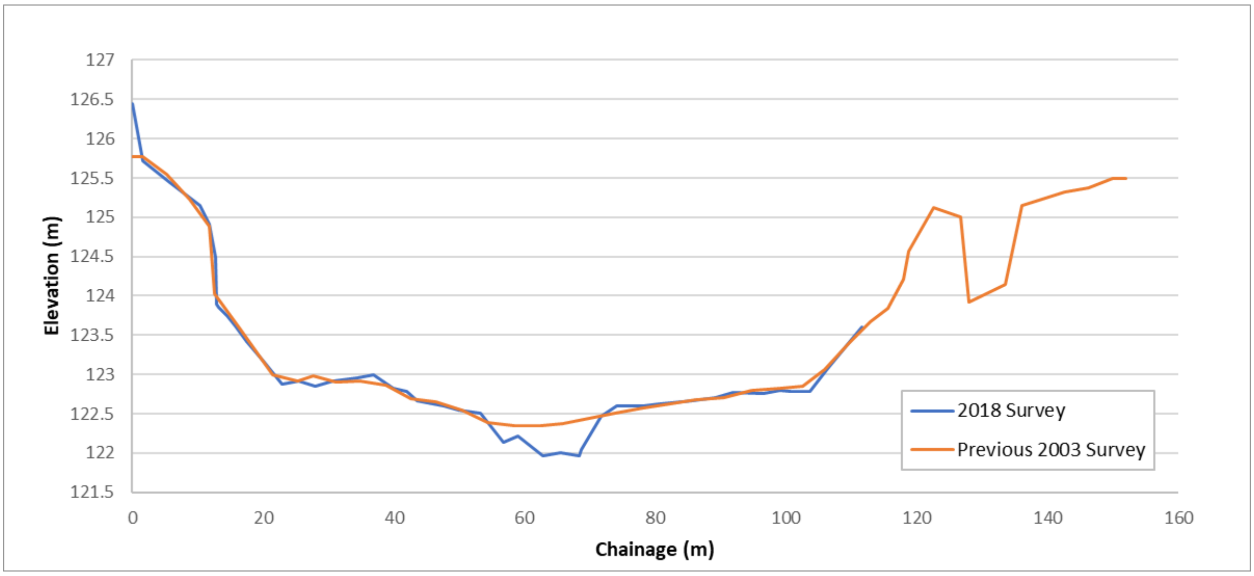


FIGURE 2-22 WIMMERA RIVER CROSS SECTION 1

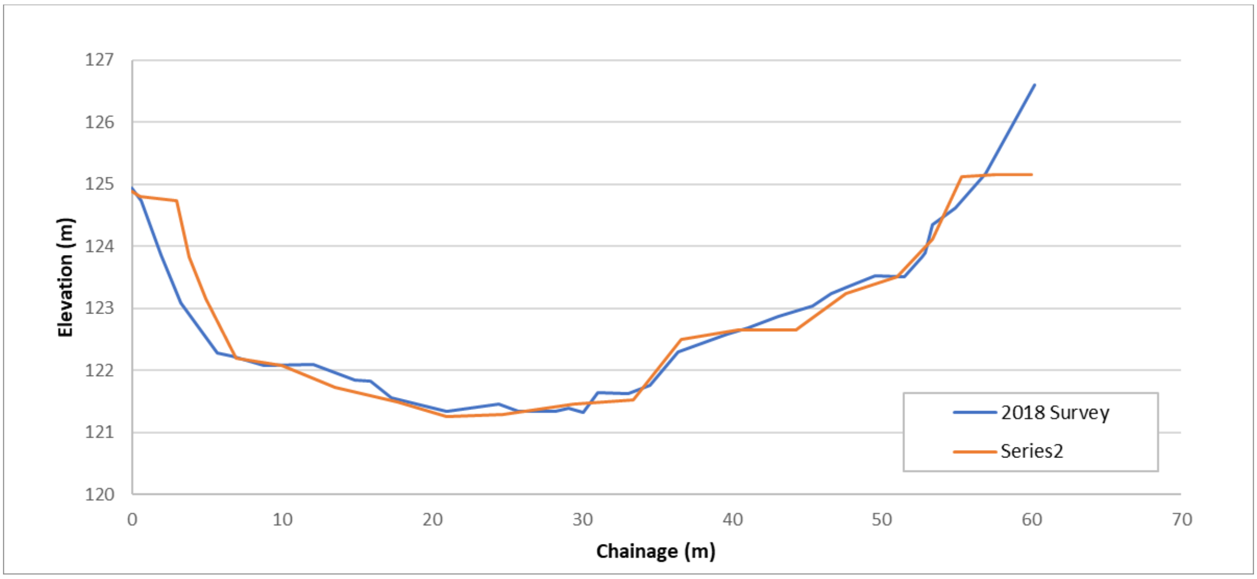


FIGURE 2-23 WIMMERA RIVER CROSS SECTION 2

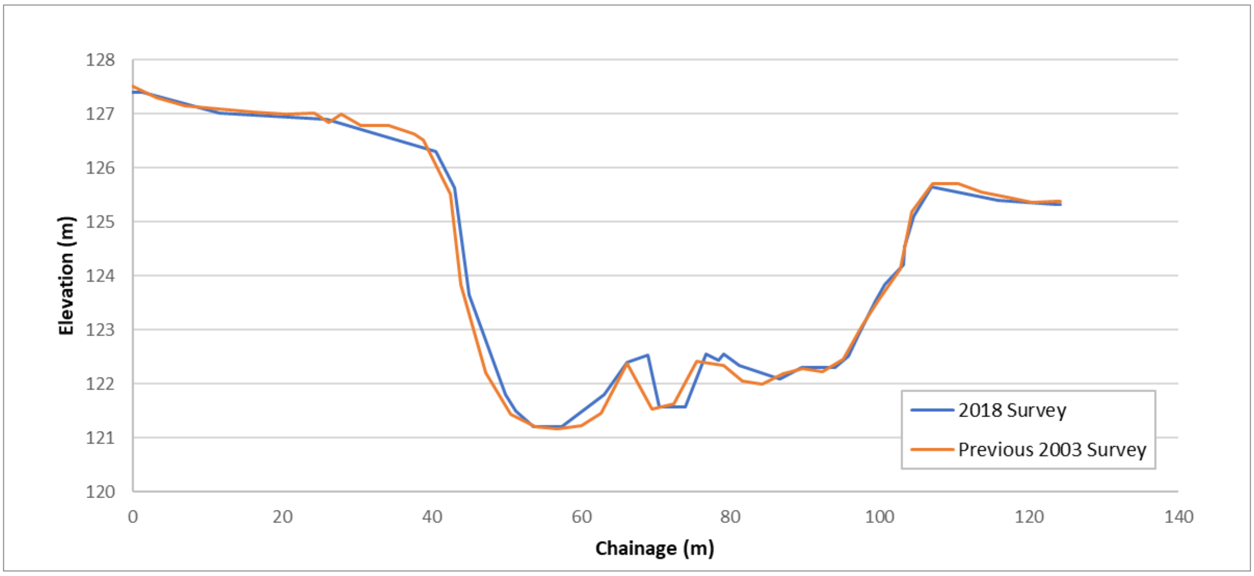


FIGURE 2-24 WIMMERA RIVER CROSS SECTION 3

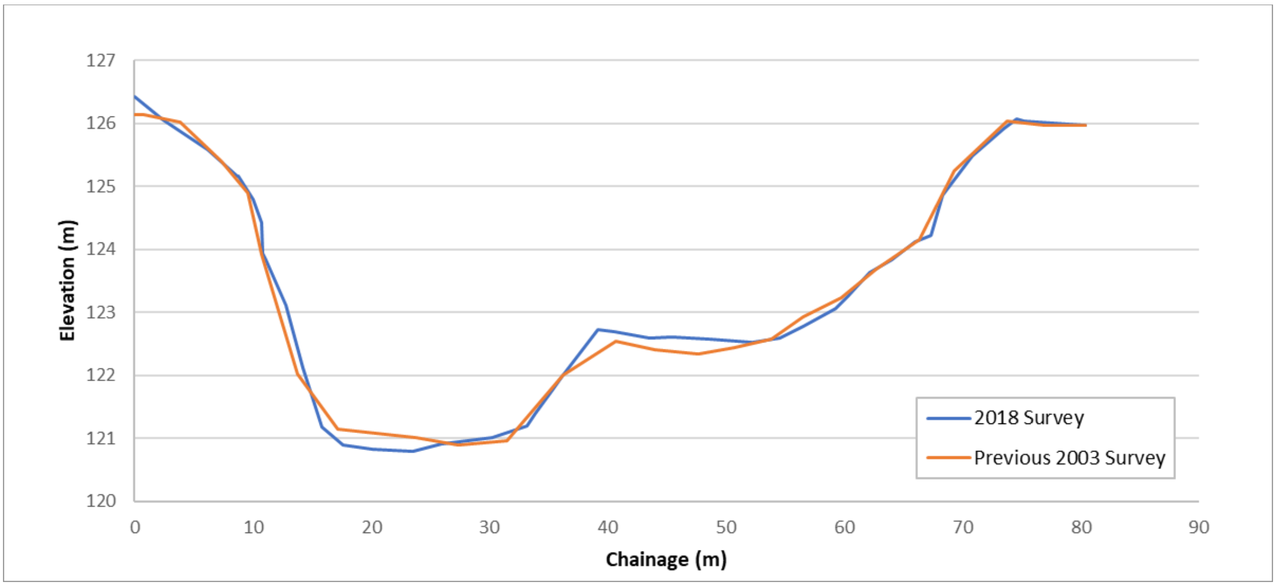


FIGURE 2-25 WIMMERA RIVER CROSS SECTION 4

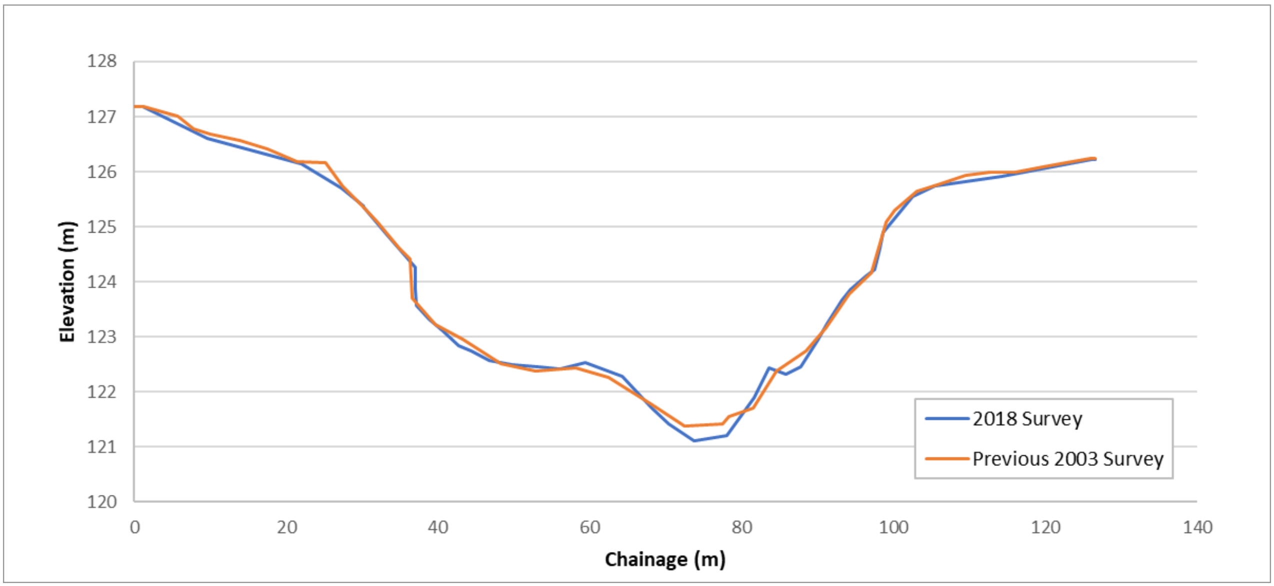


FIGURE 2-26 WIMMERA RIVER CROSS SECTION 5

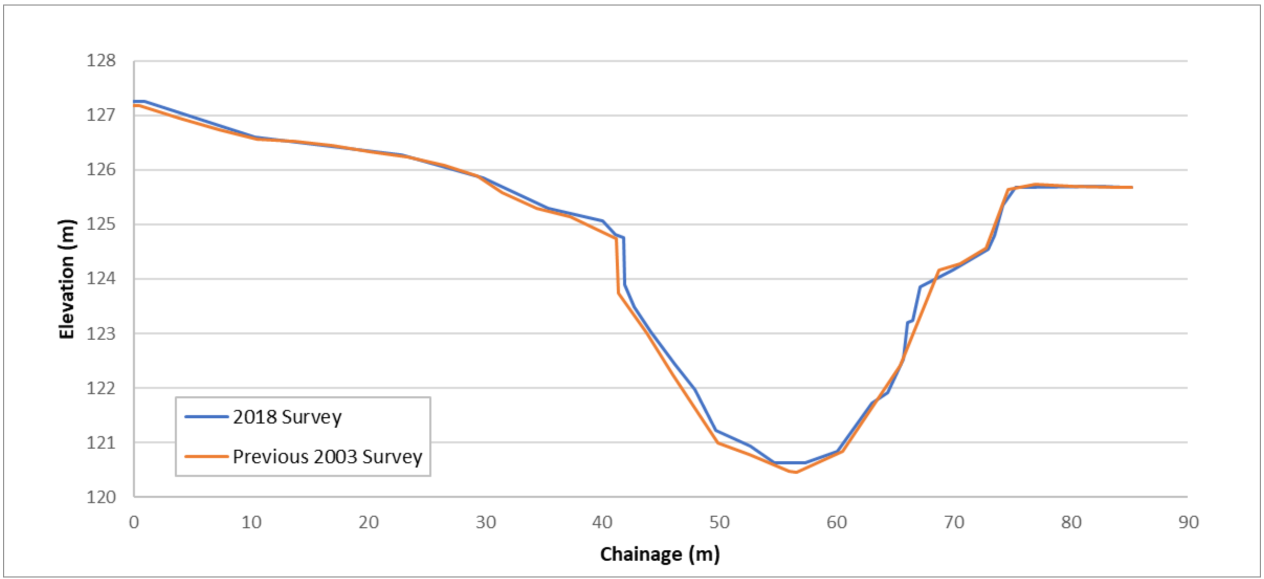


FIGURE 2-27 WIMMERA RIVER CROSS SECTION 6

The cross section comparison showed very similar results across all locations. There was some change in the bed levels of Cross section 1 with a slightly deeper invert in the newer survey. Cross section 2 at the Western Highway Bridge showed some changes to the left bank. Works were previously undertaken putting a pedestrian walkway in place at this location, which is likely to be the cause of this change.

2.5 Hydrological Data

2.5.1 Streamflow

There are numerous streamflow gauges within the study area, as seen in Figure 2-28 and summarised in Table 2-6. These played a vital role in the development and calibration of hydrology and hydraulic modelling in this investigation.

Several gauges have a limited period of record, leading to less confidence in the rating curve. In particular, Norton Creek at Lower Norton only estimates flow up to 160 ML/d, at a height of 0.6 m. Based on past events, this is often exceeded and is based on only 6 complete years of record.

In contrast, there are several gauges that have records spanning up to 104 years, providing large amounts of data on which to base the rating curve.

There was considerable investigation into the Wimmera River gauge at Horsham (Walmer) during the Lower Wimmera River Regional Flood Mapping project. The calibration and design flow estimates determined from this previous study were used for the Horsham and Wartook Valley Flood Investigation modelling.

The Wimmera River at Drung Drung gauge misses a portion of flow that branches from the Wimmera River upstream of the gauge and returns via Two Mile Creek

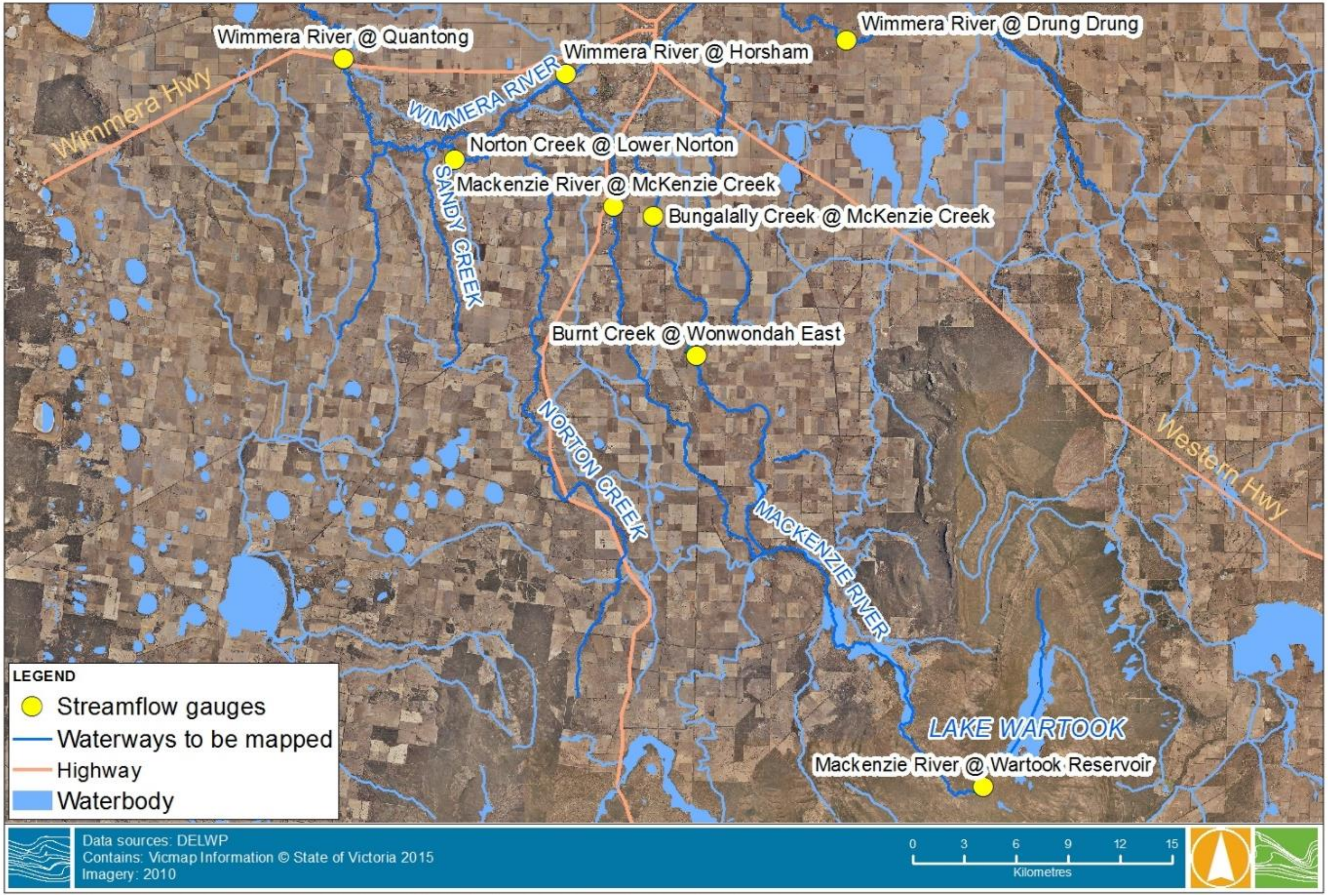


FIGURE 2-28 STREAMFLOW GAUGES WITHIN THE STUDY AREA

TABLE 2-6 RELEVANT STREAMFLOW GAUGES

ID	Gauge	Period of Record	Notes
415202	Mackenzie River @ Wartook Reservoir	1975 - current	Heavily influenced by Wartook outflows, FFA completed as part of the Wartook to Zumsteins Flood Assessment (HRCC).
415223	Burnt Creek @ Wonwondah East	1983 - current	Immediately downstream of the Burnt Creek distribution to Bungalally Creek
415249	Bungalally Creek @ McKenzie Creek	1988 - 1993	Very limited period of record. Water level information only.
415251	Mackenzie River @ McKenzie Creek	1988 - current	Upstream of the point where the Bungalally Creek enters the Mackenzie River
415239	Wimmera River @ Drung Drung	1978 - current	Misses a portion of the Wimmera River flow returning via Two Mile Creek. Water Level data only.
415200	Wimmera River @ Horsham	1910 - current	Known as the Walmer gauge. Was rigorously investigated as part of the Lower Wimmera Regional Flood Mapping project.
415273	Norton Creek @ Lower Norton	2008 - current	Limited rating curve exceeded very often, only 6 years of complete record, influenced by backwater of the Wimmera River. Water level information only.
415261	Wimmera River @ Quantong	2009 - current	Water level information only. No rating curve.

2.5.1.1 Wimmera River at Horsham (Walmer)

Wimmera River inflows to the study area are based on historic and design flows at the Walmer gauge. There have been numerous historic events recorded at the gauge, with daily flow recorded from 1889 to 1910 and daily gauge heights from 1920 to 1963, and instantaneous recordings from 1963 onwards. There is some concern regarding the quality of the data prior to 1910; however, several large floods have occurred more recently. The annual peak flows and their source for the Horsham gauge are summarised in Table 2-7. The January 2011 hydrograph is the highest recorded event in recent record and the most representative of flows in modern catchment condition, however it is smaller than records of the 1909 event. A hydrograph of the January 2011 event is shown in Figure 2-29, along with the recorded hydrography quality codes.

TABLE 2-7 WIMMERA RIVER AT HORSHAM - MAXIMUM RECORDED ANNUAL FLOWS

Year	Source and comments	Peak Flow	
		ML/d	m^3/s
1889	Horsham Flood Study (1979)	21,168	245
1893	Horsham Flood Study (1979)	13,306	154
1894	Significant uncertainty, the DELWP gauge records 44,249 ML/d but is most likely incorrect, adopted flow from Horsham Flood Study (1979) and written gauge book records (sourced by Abdul Aziz of Wimmera CMA).	24,792	287
1903	Historical society document showing 1903 having similar level on Firebrace Street as 1956, 1960 and 1964, adopted average of the three other flows.	16,848	195
1906	Historical society document showing 1906 having similar level on Firebrace Street as 1942	14,342	166
1909	Significant uncertainty, the DELWP gauge records 43,860 ML/d but is most likely incorrect, adopted flow from Horsham Flood Study (1979).	38,880	450
1910	Horsham Flood Study (1979)	14,515	168
1911	Horsham Flood Study (1979)	20,650	239
1912	Horsham Flood Study (1979)	15,293	177
1915	Horsham Flood Study (1979)	27,648	320
1916	Horsham Flood Study (1979)	23,242	269
1918	Horsham Flood Study (1979)	13,478	156
1920	Horsham Flood Study (1979)	13,306	154
1923	Horsham Flood Study (1979)	25,056	290
1924	Horsham Flood Study (1979)	21,254	246
1936	Horsham Flood Study (1979)	12,355	143
1942	Horsham Flood Study (1979)	14,342	166
1955	Horsham Flood Study (1979)	17,107	198
1956	Horsham Flood Study (1979)	16,416	190
1960	DELWP gauge	17,802	206
1964	DELWP gauge	16,325	189
1973	DELWP gauge	15,266	177
1974	DELWP gauge	20,466	237
1975	DELWP gauge	15,951	185
1981	DELWP gauge	23,879	276
1983	DELWP gauge	25,312	293
1988	DELWP gauge	21,005	243
1992	DELWP gauge	13,480	156
1996	DELWP gauge	19,198	222
2010	DELWP gauge	11,723	136
2011	Gauging was undertaken at Western Highway at the peak of the event	33,000	382

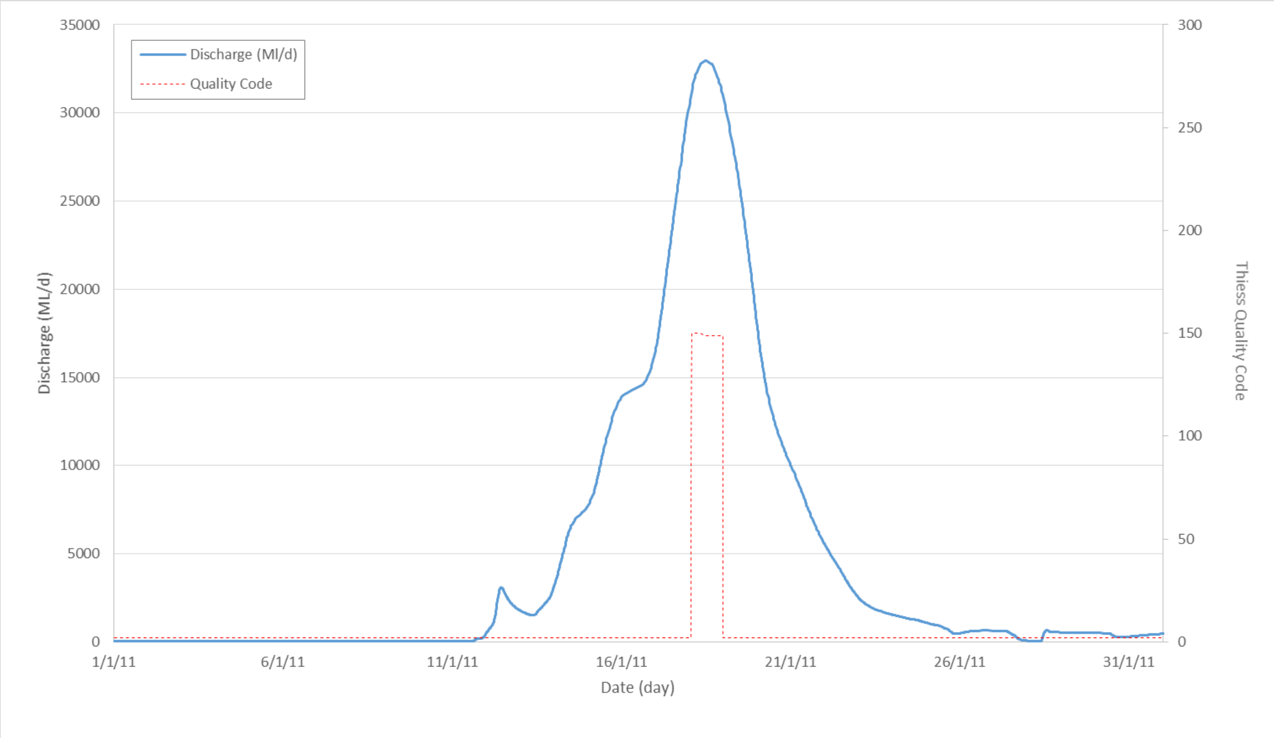


FIGURE 2-29 JANUARY 2011 HYDROGRAPH RECORDED AT THE WIMMERA RIVER AT HORSHAM (WALMER) STREAMFLOW GAUGE

During January 2011, the Wimmera River flow rate was measured at the Western Highway Bridge 5.5 km upstream by DELWP hydrographers (Ventia - Formerly Thiess Environmental[7]), the gauging was completed at this location due to the Horsham gauge being too dangerous for Thiess staff to access. The location of the Horsham gauge (Walmer) and the Western Highway Bridge are shown in Figure 2-30.

Using the gauged water levels at the Horsham gauge and the recorded flow at the Western Highway Bridge, the Wimmera River at Horsham (Walmer) gauge rating curve was revised by Thiess Environmental, with significant changes at high flows.

The current (revised) Wimmera River at Horsham (Walmer) gauge streamflow rating curve and historic measurements are shown in Figure 2-31, with the previous and current rating curves shown in Figure 2-32.

The change between the current rating curve and the rating curve in use prior to the January 2011 gauging was significant, especially at high flows. At the maximum level reached during the January 2011 event (4.277 m), the current rating table estimates a flow of 382 m^3/s (33,000 ML/d), whereas the previous rating was exceeded at 3.65 m and with the shape of the rating curve, if extrapolated would estimate a flow of well in excess of 50,000 ML/d (clearly incorrect).

The January 2011 flow was measured at a very confined location (Western Highway Bridge) with the use of an acoustic doppler which produced velocity distributions across the river profile. In consideration of the velocity profiles and site conditions, the hydrographers attributed these gaugings with a level of accuracy of 3.4% and as a result there is a high level of confidence in the 33,000 ML/d flow measurement.

The Quantong gauge is located 18 km downstream of the Horsham gauge, and the time from peak to peak during the January 2011 event was roughly 12 hours. This indicates that the peak of the flood was moving

[7] Pers. Comm. - Thiess Environmental (Rebekah Webb)

down the system at approximately 1.5 km/hr (0.42 m/s). The distance between the Western Highway and the Horsham gauge is approximately 6 km. By applying the same travel speed for the flood peak, this would suggest that the flood peak took 4 hrs to travel between the Western Highway and the Horsham gauge. This indicates that the flood may have peaked at the Western Highway around 8 am, almost exactly when the flow gauging was completed at the Western Highway.

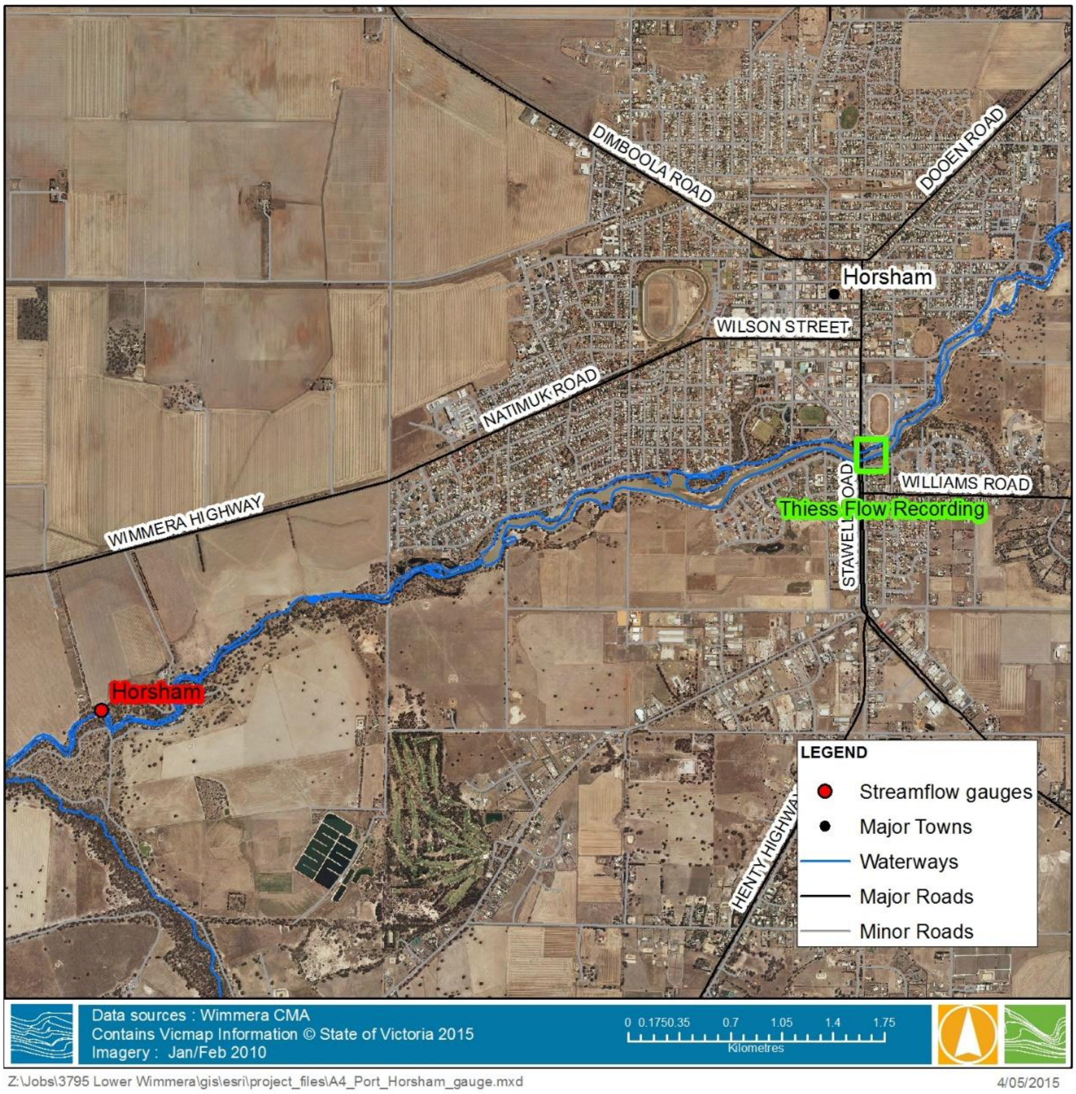


FIGURE 2-30 WIMMERA RIVER AT HORSHAM (WALMER) GAUGE AND WESTERN HIGHWAY JANUARY 2011 MEASUREMENT LOCATIONS

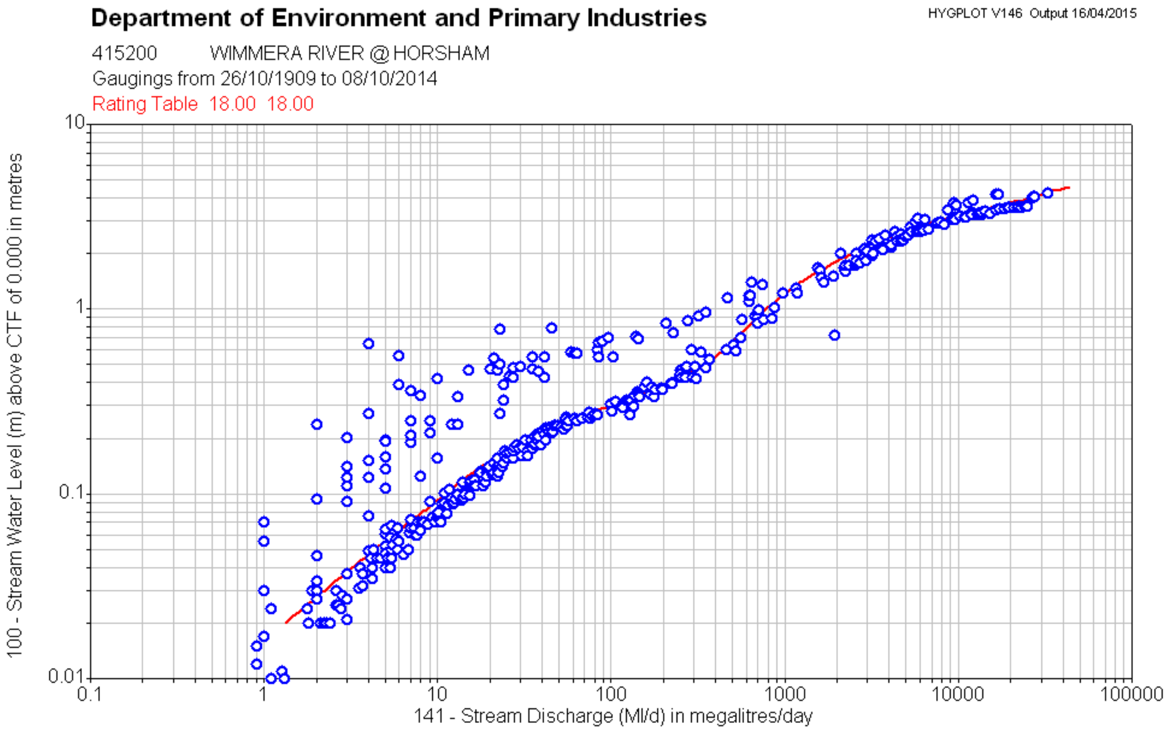


FIGURE 2-31 WIMMERA RIVER AT HORSHAM STREAMFLOW GAUGE RATING CURVE AND MEASUREMENTS[8]

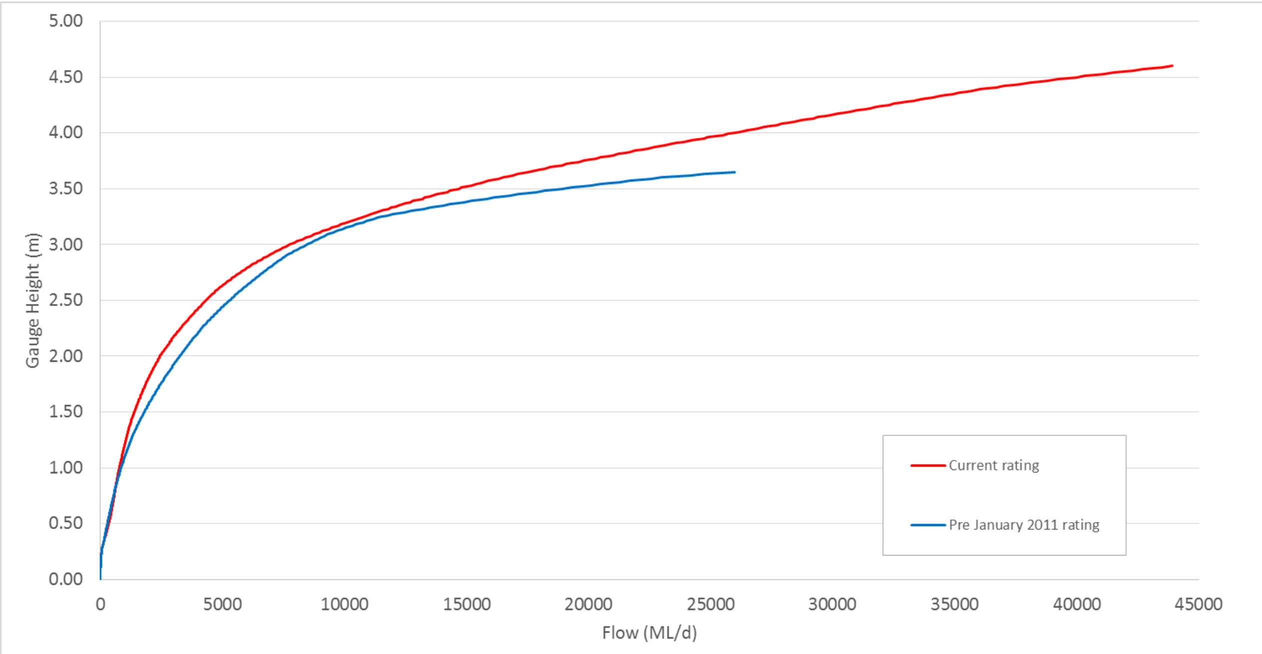


FIGURE 2-32 WIMMERA RIVER AT HORSHAM CURRENT AND PREVIOUS RATING CURVES

[8] DEL - Water Measurement Information System (Accessed 27/10/2014)

Previous modelling of Horsham and aerial imagery of the January 2011 event shows that some flow bypasses the highway, breaking out of the river between Bailie and McBryde Streets, travelling west along Hamilton Street, across Firebrace St, then heading south back to the river. Previous modelling shows this flow rate was likely to be between 100 to 1,000 ML/d based on the previous 2% and 1% AEP modelling results respectively.

Assuming the flow bypassing the highway may be somewhere between the two above estimates, it was concluded that the peak January 2011 flow was approximately 33,000 ML/d (382 m^3/s).

The Mackenzie River flows into the Wimmera River approximately 1 km downstream of the Horsham (Walmer) gauge. There has long been speculation as to the impact of Mackenzie River on the Horsham (Walmer) gauge. A series of hydraulic model scenarios were run to test the potential impact of Mackenzie River on Wimmera River flow gauging.

During the Lower Wimmera River Regional Flood Mapping Study, modelling showed that with a low Wimmera River flow of 10 m^3/s (864 ML/d), the Mackenzie River can have a significant impact on the Wimmera River gauge with water levels increasing at the gauge by 0.37 m with the Mackenzie River flow increasing from 25 to 50 m^3/s (2,160 to 4,320 ML/d). This demonstrates that at low Wimmera River flows Mackenzie River can have a significant impact on the water level in the Wimmera River at the Horsham (Walmer) gauge. At these low Wimmera River flows, an increase in water level at the Horsham (Walmer) gauge of this magnitude translates to an increase in the flow estimate of approximately 400-500 ML/d from the existing rating curve.

At higher flows, with the Wimmera River at 200 m^3/s (17,280 ML/d), an increase in Mackenzie River flows from 10 to 100 m^3/s (864 to 8,640 ML/d) results in a water level increase at the Horsham (Walmer) gauge of 0.19 m. This is a significant increase with respect to the sensitivity of the rating curve on estimated flow. At high Wimmera River flows an increase in water level of this magnitude translates to an increase in the estimated flow of approximately 4,000-5,000 ML/d from the existing rating curve.

The Mackenzie River generally peaks 2.5 to 3.5 days prior to the peak of the Wimmera River. At the time of the Wimmera River peak flow at Horsham (Walmer), the Mackenzie River at McKenzie Creek gauge has measured between 200-630 ML/d of flow over several historic flood events where concurrent gauging was available. These low Mackenzie River flows that generally occur at the same time as the Wimmera River peak flows are unlikely to have any real impact on the water level at the Horsham (Walmer) gauge and no impact on flood levels upstream in Horsham.

Based on the best available annual series for the Horsham (Walmer) gauge (Table 2-7), the Lower Wimmera Regional Flood Mapping Study used a FFA approach to derive peak design flows estimates shown in Table 2-8.

TABLE 2-8 WIMMERA RIVER AT HORSHAM (WALMER) – FFA DETERMINED DESIGN FLOW PEAKS

AEP (%)	Peak Flow (ML/d)	Peak Flow (m3/s)
20	13,100	152
10	19,200	222
5	25,000	289
2	31,900	369
1	36,500	423
0.5	40,700	471
0.2	45,400	525

2.5.1.2 Norton Creek at Lower Norton

This gauge has known rating curve limitations, with records spanning only from May 2008 to present day. The 6 years of complete annual records is insufficient for any high flow statistical analysis. Water levels above 0.4 m are extrapolated, and the top of the rating curve is at 0.6 m. For comparison, the largest event on record was in January 2011, where the gauge recorded a peak height of 2.56 m on the 18th January. The top of the rating curve has been exceeded six times since 2009.

Figure 2-33 shows the stream height gauge record and the rating curve limit. Given the rating table is exceeded very frequently, the gauge flow record was not used for this study.

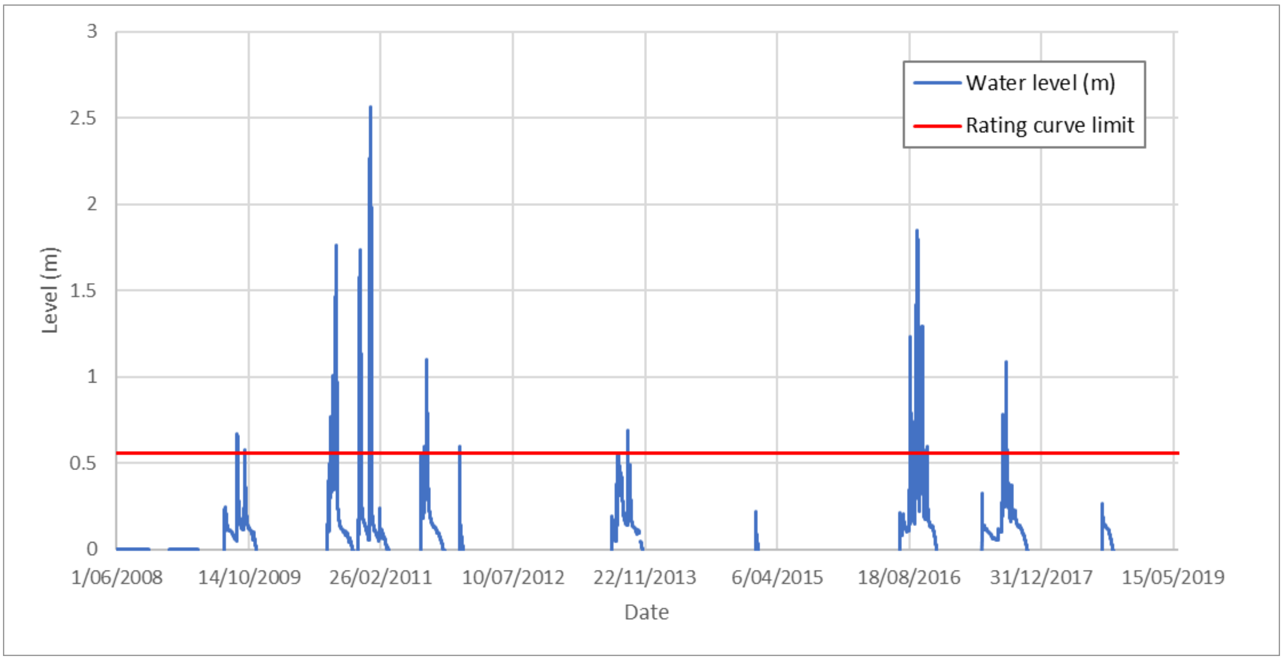


FIGURE 2-33 GAUGE RECORD AT NORTON CREEK AT LOWER NORTON SHOWING WATER LEVEL AND LIMIT OF EXTRAPOLATED SECTION OF THE RATING CURVE

2.5.1.3 Mackenzie River at Wartook Reservoir

The streamflow gauge for Mackenzie River at Wartook Reservoir is located immediately downstream of Lake Wartook. The gauge had instantaneous flow records spanning from May 1975 to present day, with average daily flows back to 1887 when the lake was constructed. The gauge is missing data for the January 2011 flood peak but has been estimated by GWMWater as 3,780 ML/d[9] based on a peak level of 1.992 m recorded on the 13th January at approximately 6pm.

The rating curve for the Mackenzie River at Wartook gauge is based on 206 ratings and is considered of sufficient accuracy for completion of flood frequency analysis (FFA), with the addition of the estimated January 2011 flow estimate. A flood frequency analysis was undertaken as part of the Wartook to Zumsteins Walking Track Flood Investigation (Water Technology, 2015).

For the period of record, no outliers (low flows) were detected, however the analysis clearly indicated a change in distribution for flows greater than 500 ML/d, which is the maximum regulated outflow from Lake Wartook.

The Log Normal distribution was found to be the best representing distribution for the annual peak flow data set, determined by a FFA completed during the Wartook to Zumsteins Walking Track project, and can be seen

[9] Water Technology, 2011 – Wimmera Region Flood Report – January 2011

in Figure 2-34. The distribution estimates a 1% AEP flow of 3,570 ML/d which is in line with anecdotal evidence of the January 2011 event in the Wimmera region being between a 2% and 0.5% flood event[3].

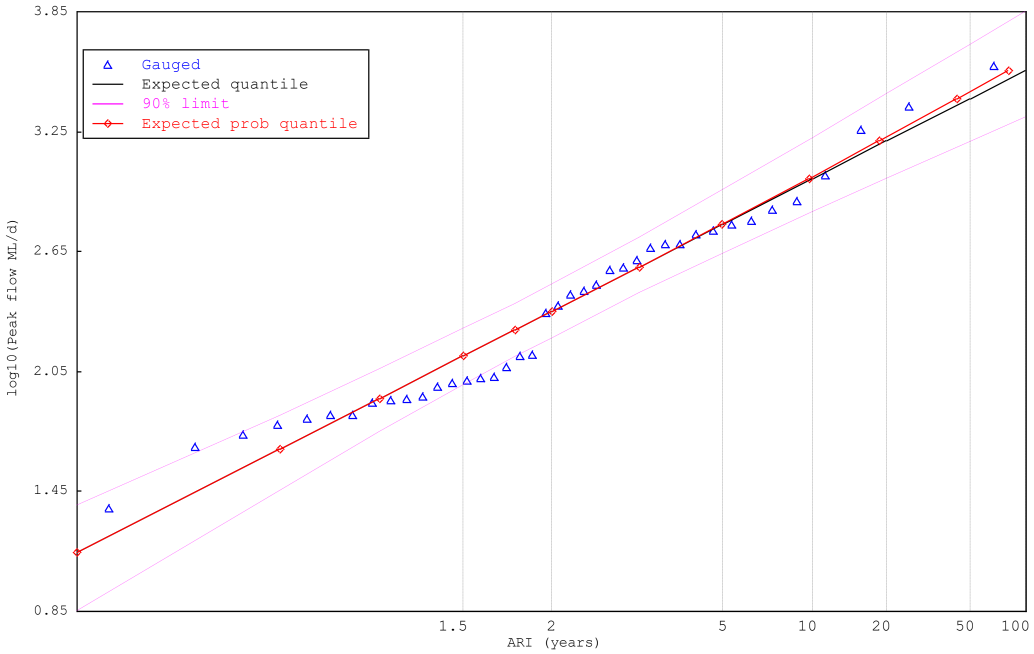


FIGURE 2-34 MACKENZIE RIVER MAXIMUM DISCHARGE FLOOD FREQUENCY DISTRIBUTION (LOG NORMAL)

Historical records for the gauge indicate for floods greater than 10% AEP a typical flood duration of 8 days can be expected. This is summarised in Table 2-9. Given this relatively consistent event duration, during the Wartook to Zumsteins Walking Track study, a FFA was completed on 8 day volume with a 1% AEP flood volume of 18,200 ML determined.

TABLE 2-9 MACKENZIE RIVER AT WARTOOK RESERVOIR HISTORICAL FLOOD EVENTS

Start	End	Peak Flow, ML/d	Flood duration, days
8/10/1975	18/10/1975	1805	10
23/10/1975	4/11/1975	1627	12
31/8/1983	30/9/1983	1027	30
30/8/1992	07/09/1992	1345	8
11/9/1992	17/9/1992	1173	6
21/9/1992	26/9/1992	1429	5
28/9/1992	1/10/1992	1156	3
7/10/1992	16/10/1992	1660	9
21/11/1992	24/11/1992	1218	3
18/12/1992	25/12/1992	2373	7
Mean flood duration			**9.3**
Median flood duration			**7.5**

2.5.1.4 Burnt Creek at Wonwondah East

The Burnt Creek gauge at Wonwondah East is located approximately 16 km downstream of the confluence with the Mackenzie River, and immediately downstream (~ 400 m) of the confluence with Bungalally Creek. The rating table is based on 200 gaugings and is valid for flows up to 1,950 ML/d. Flows up to 4,000 ML/d are extrapolated. For the period of record, the rating curve has not been exceeded, and flows have been extrapolated on only a handful of occasions.

Over the gauge record spanning from 1983 to present day the largest flood recorded at the gauge is the January 2011 flood, during which the water level peaked at 1.07 m, equivalent to a flow of 1,596 ML/d on the 14th January at 5:45am.

The water levels produced at this gauge were considered reliable, but flow was not. Water levels were used to verify modelling of the flow split into Bungalally Creek.

2.5.1.5 Mackenzie River at McKenzie Creek

The Mackenzie River gauge is located approximately 3.5 km upstream of the confluence with Bungalally Creek, and 8.5 km upstream of the Wimmera River.

In January 2011, the recorded water level exceeded the rating curve, with a water level of 2.357 m, with an equivalent (extrapolated) flow of 4,269 ML/d on the 15th at approximately 8:30am.

The gauge record spans from 1983 to present day. The gauge is considered to be an accurate representation of flows and will be used in the verification of hydrology and hydraulic modelling.

2.5.1.6 Summary

The five gauges discussed above all have different periods of record and vary considerably in their reliability. A summary of how each gauge was used in this study is given below:

- Wimmera River at Horsham (Walmer) – Detailed investigation was conducted in the Lower Wimmera Regional Flood Mapping Study. Discussions with State hydrographers, Wimmera CMA and Water Technology staff has resulted in consensus regarding a revised rating curve and estimates of historic flows. The hydrological analysis from the Lower Wimmera Regional Flood Mapping Study were adopted for this study.
- Norton Creek at Lower Norton – The gauge only has a short period of record and has not been rated to estimate high flows. Gauge flows were not used in this study, however timing of peak levels were used.
- Mackenzie River at Wartook Reservoir – Assessed as part of the Wartook to Zumsteins Walking Trail Flood Study. The flood frequency analysis developed during that study was adopted as an upstream boundary to the hydraulic model for this study.
- Burnt Creek at Wonwondah East – Reasonably reliable level gauge, the location of the gauge means flow is very hard to measure. Historic level records were used to verify the hydraulic model and validate flow split relationships.
- Mackenzie River at McKenzie Creek – Reasonably reliable gauge. Flow and level records were used to verify the hydraulic model.

2.5.2 Rainfall

There are numerous daily rainfall gauges within or nearby the study area, as well as three pluviograph stations. Rainfall gauges that are of relevance to this study are shown in Figure 2-35, with details of available data summarised in

Table 2-10 and Table 2-11.

The average annual rainfall varies throughout the study catchment, reaching 600 mm at the headwaters of Mt William Creek and as low as 330 mm near north of Horsham. Daily rainfall gauges were used to develop a spatial pattern across the study area, for input to the hydrology model, while the pluviograph rainfall stations were used to derive temporal patterns for the calibration rainfall events.

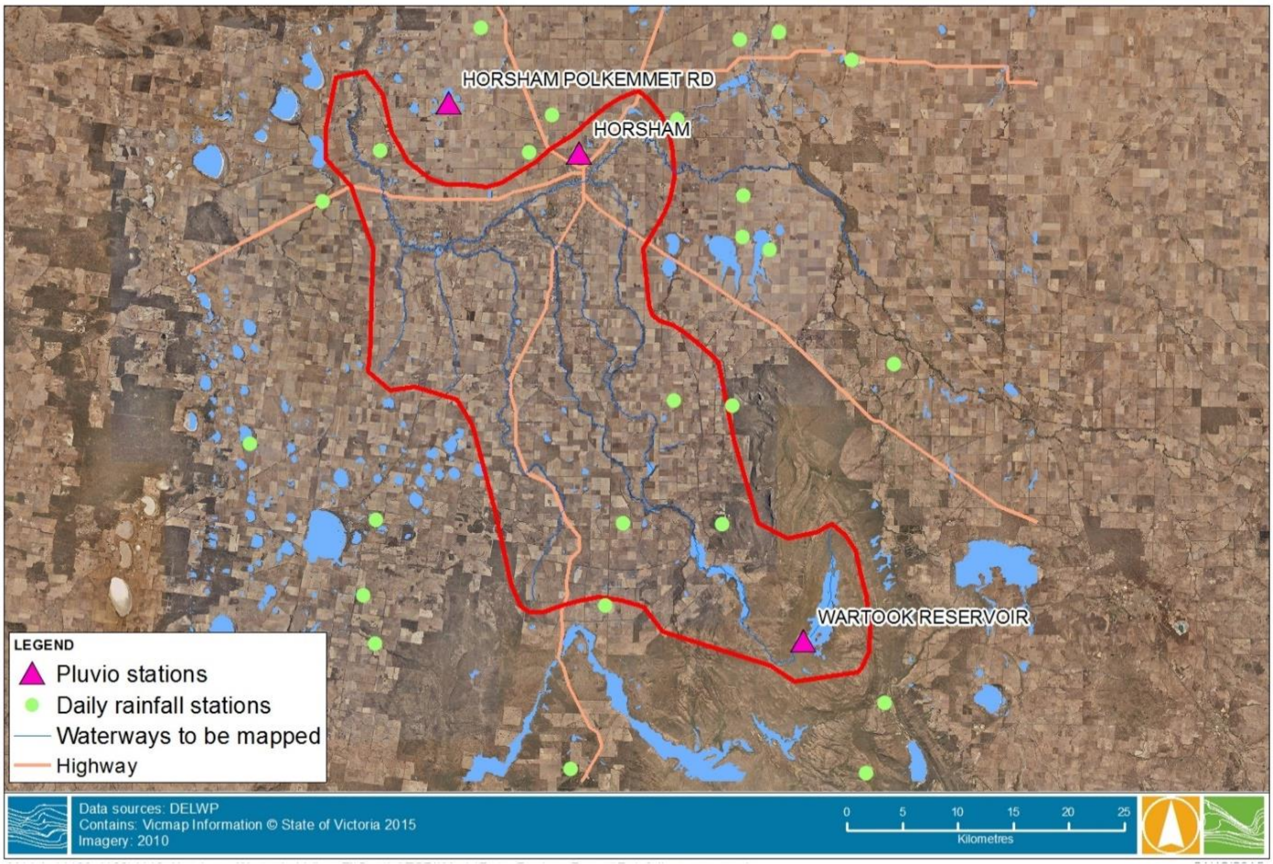


FIGURE 2-35 RAINFALL GAUGE LOCATIONS WITH RESPECT TO THE STUDY AREA

TABLE 2-10 RAINFALL GAUGES WITHIN THE HORSHAM AND NORTHERN GRAMPIANS CATCHMENTS

Gauge No.	Location	Period	Years
78016	JUNG	1935 - 2009	74
78017	JUNG JUNG	1886 - 1952	66
78057	JUNG JUNG NORTH	1897 - 1924	27
78063	PIMPINIO	1913 - 1922	9
79008	CLEAR LAKE	1903 - 2013	110
79010	DRUNG DRUNG	1905 - 2013	108
79020	HALLS GAP	1876 - 1963	87
79023	HORSHAM POLKEMMET RD	1873 - 2012	139
79028	LONGERENONG	1863 - 2013	150
79035	MURTOA	1883 - 2013	130
79036	NATIMUK	1889 - 2013	124
79044	TELANGATUK (SCHOLFIELD)	1901 - 1951	50
79045	TOOLONDO	1934 - 1946	12
79046	WARTOOK RESERVOIR	1890 - 2013	123
79047	WARTOOK POST OFFICE	1888 - 1966	78
79049	WONWONDAH (MOUNT ZERO)	1900 - 1961	61
79055	JUNG (DOOEN NORTH)	1928 - 1934	6
79063	NATIMUK (JILPANGER)	1938 - 1949	11
79064	HORSHAM (LAURISTON DOLLAN)	1920 - 1941	21
79067	STAWELL (NATTA WALLA)	1905 - 1911	6
79070	WALMER	1901 - 1921	20
79074	HALLS GAP	1958 - 2013	55
79077	DADSWELLS BRIDGE	1968 - 2013	45
79078	TELANGATUK EAST (MILINGIMBI)	1968 - 2013	45
79082	HORSHAM	1958 - 2013	55
79098	PINE LAKE	1983 - 1987	4
79100	HORSHAM AERODROME	1997 - 2013	16
79106	LAH-ARUM (MT STAPYLTON)	1997 - 2004	7
89057	GLENISLA	1905 - 1918	13

TABLE 2-11 RELEVANT PLUVIOGRAPHY STATIONS

Gauge No.	Location	Period
79023	Horsham Polkemmet Rd	1873 – Present day
79046	Wartook Reservoir	1890 - Present day
79052	Rocklands Reservoir	1948 - Present day
79082	Horsham	1958 - Present day

2.5.3 Storages

Lake Wartook, constructed in 1887, is the only managed storage within the study catchment. It is located within the Grampians National Park and is the most southern edge of the study area.

The lake has a full supply volume of 29,300 ML and receives average annual inflows of 26,000 ML/y from the 75 km^2 contributing catchment. The catchment is extremely efficient as a result of the rock formations that make up most of its catchment.

Flow releases are currently managed up to 500 ML/d, though historically (prior to 1992) releases were up to 800 ML/d. The reservoir has two spillways. The primary spillway has been designed to handle spills up to a 1% AEP event; once this is exceeded the secondary spillway comes into operation. This did occur during the January event indicating that outflows from Lake Wartook were in excess of a 1% AEP event.

At the beginning of January 2011, the lake contained 27,980 ML (95.5%). During the January event, Lake Wartook is thought to have peaked at a storage volume of approximately 32,120 ML (109.6%). Due to the flood height, gauge readings were unable to be taken during the peak of the event on Friday 14th January. Gauge readings continued on Saturday the 15th.

GWMWater have supplied inflow, outflow and water level hydrographs of the January event for Lake Wartook as shown in Figure 2-36. The hydrograph shows the maximum inflow at 15,780 ML/d with a maximum outflow of 3,780 ML/d. This indicates the peak flow through Lake Wartook was attenuated by approximately 12,000 ML/d. A reduction in the maximum flow of 12,000 ML/d substantially reduces the potential flood impacts downstream of Lake Wartook.

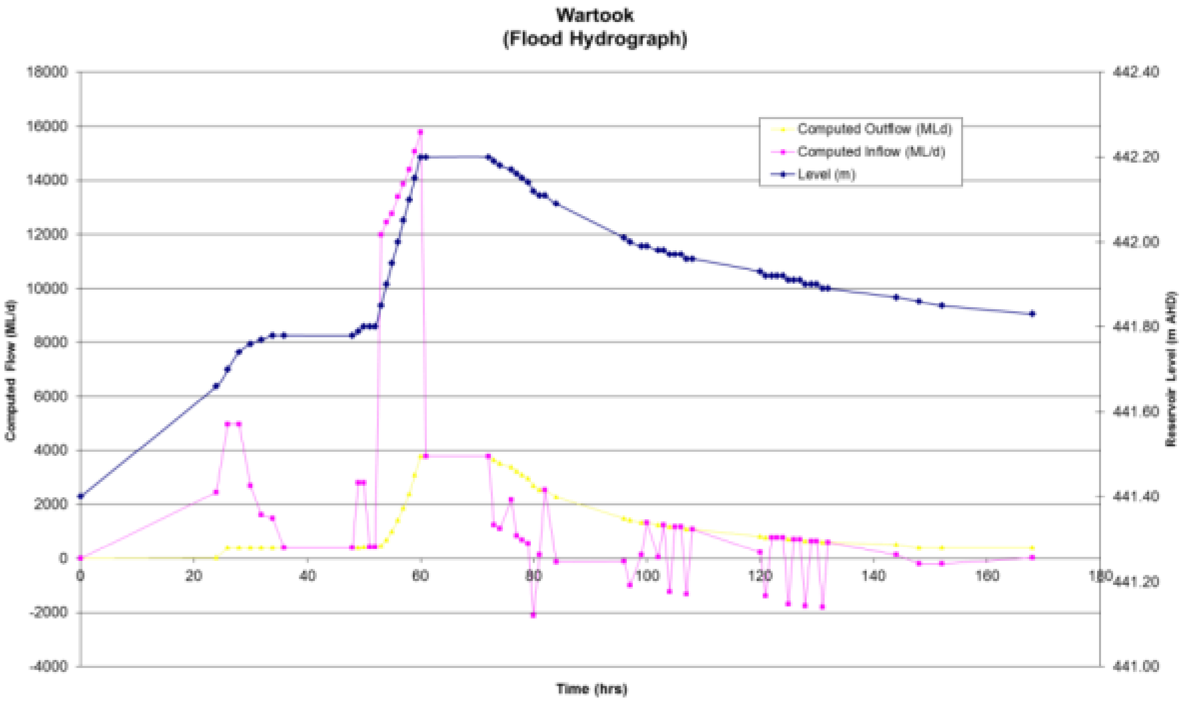


FIGURE 2-36 INFLOW, OUTFLOW AND LEVEL OF LAKE WARTOOK IN JANUARY 2011

2.6 Flood Records

2.6.1 Overview

Flooding of Horsham from the Wimmera River has been a regular feature, with around 22 large floods occurring between 1889 and 2016. The largest of these was the 1909 event, followed by January 2011. The most recent flood event on record was the September 2016 event.

Detailed contour and flood information has been captured for several of the historical events. January 2011 was the most extensively captured flood on record, with 95 flood heights surveyed within the study area. However, there are also numerous peak flood heights available for the September 2016, September 2010, October 1996 and October 1983 events.

Figure 2-37 shows the distribution of historic flood information captured within the study area.

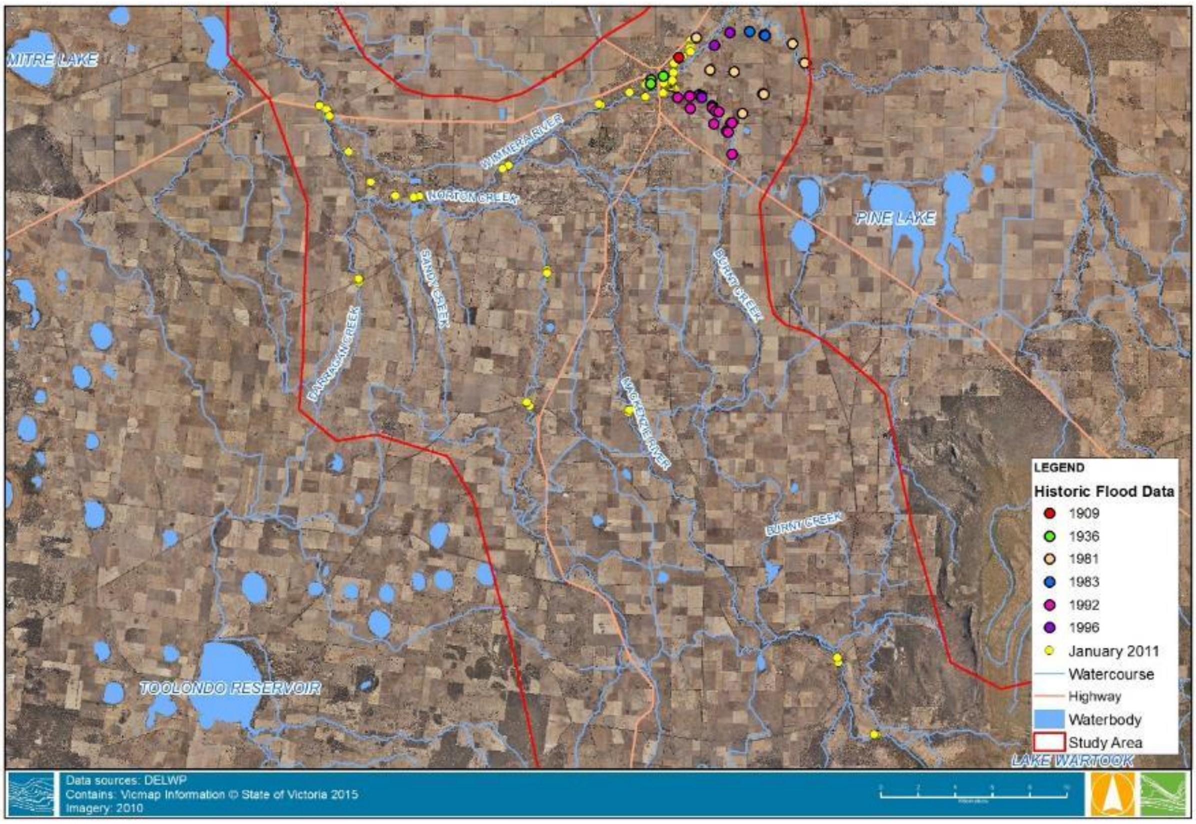


FIGURE 2-37 HISTORIC FLOOD DATA CAPTURE

As mentioned in Section 2.5.1, there are several stream height and flow gauges within the study area. These gauges have recorded accurate flood levels of past events that can be used to compare to modelled flood levels.

The January 2011 event was used as the primary calibration event within this study as it gives the best representation of large flooding with today's catchment conditions and it also has a large amount of calibration data available. The September 2016 event was used as a model verification event. This event also has a large amount of calibration data available and was a lower flood magnitude. Using both large and small floods in the model calibration ensures the model can reproduce flood levels across a range of flows.

2.6.2 January 2011

The January 2011 flood is the largest recent flood on record for the Wimmera River. It is estimated to have been between a 1% and 0.5% AEP event in areas upstream of Horsham and between a 2% and 1% AEP event downstream of Horsham.

High rainfall totals were recorded across the Wimmera River catchment on Wednesday the 12th and Friday the 14th of January. Both the Horsham Aerodrome and Polkemmet Road rainfall gauges recorded around 100 mm in the 24 hours prior to 9 am on Friday the 14th. Prior to the heavy rainfall in January and in response to forecasts, the boards were fully removed from the Horsham weir on Monday 10th January.

Flooding observed within the study area prior to the 16th can be attributed to direct rainfall and local runoff or flooding from the local tributaries (Burnt Creek, Mackenzie River etc.), while flooding after the 16th is predominately attributed to riverine flooding from the Wimmera River.

Flooding from Burnt Creek on Friday the 14th closed Williams Road. Properties along much of the creek were sandbagged. The Burnt Creek at Wonwondah East gauge peaked on the afternoon of Saturday the 15th. At the same time the Wimmera River was rising and recorded a gauge level of 3.32 m at Walmer, approximately 1 m below its eventual flood peak level. In the days preceding the maximum water level in the Wimmera River there was a substantial amount of inundation through suburban streets and riverine areas. Some suburban areas were inundated by water backing up through urban stormwater drains and into the street.

Media outlets reported that Horsham was completely cut by floodwaters on Tuesday the 18th with no access to the town from the east (Melbourne side) due to floodwater inundating Hamilton Street from the river to Firebrace Street. The Wimmera River also started breaking out upstream of Peppertree Lane. Septic systems associated with homes on the outskirts of Horsham were affected on Wednesday 19th January with reports of raw sewerage entering floodwaters.

It is estimated that there were approximately 141 properties affected in Horsham, 260 properties without power and 500 properties isolated. Within Horsham there were 15 houses inundated above floor. This compares to the predicted 35 during a 1% AEP event and 111 in a 0.5% AEP event, as estimated in the Horsham Flood Study[10]. The Horsham North Kindergarten incurred structural damage, and 31 shops were affected by floodwaters. Within Horsham there were two aged care facilities evacuated, along with other Municipal facilities and one Caravan Park. Horsham Rural City Council pushed up a levee on the Western Highway and in the Burnt Creek drain to keep water in the creek corridor and flowing towards the Wimmera River. Riverside, located to the east of the main Horsham township, was also affected by flooding from the Wimmera River and Burnt Creek.

The Western Highway was fully re-opened on Wednesday 19th January.

There were many calibration datasets available for the January 2011 event, these included:

- Water level and flow information at the streamflow gauges discussed in Section 2.5.1.
- Peak flood height information captured after the event by Wimmera CMA.
- Aerial photography – fixed wing and helicopter.
- Linescan data from VICSES.
- Instantaneous streamflow information recorded by State hydrographers at the Western Highway bridge over the Wimmera River.
- News media, photographs and stories provided by local community and government agencies.

After the January 2011 event Wimmera CMA had a series of peak flood height levels surveyed to use as the basis for hydraulic model calibration. Within the study area there were 95 flood heights surveyed, as shown in Figure 2-38. There are 46 in the direct vicinity of Horsham, 7 on the Mackenzie River upstream of the Burnt Creek offtake and 4 downstream, 8 on Norton Creek, 4 on Darragan Creek and 14 on the Wimmera River between Walmer and Quantong. Linescans were also flown over the Horsham area capturing the extent of inundation. This comprehensive spread of calibration data made the January 2011 event an excellent choice for use in the model calibration.

[10] Water Technology (2004), Horsham Flood Study, commissioned by Wimmera CMA.

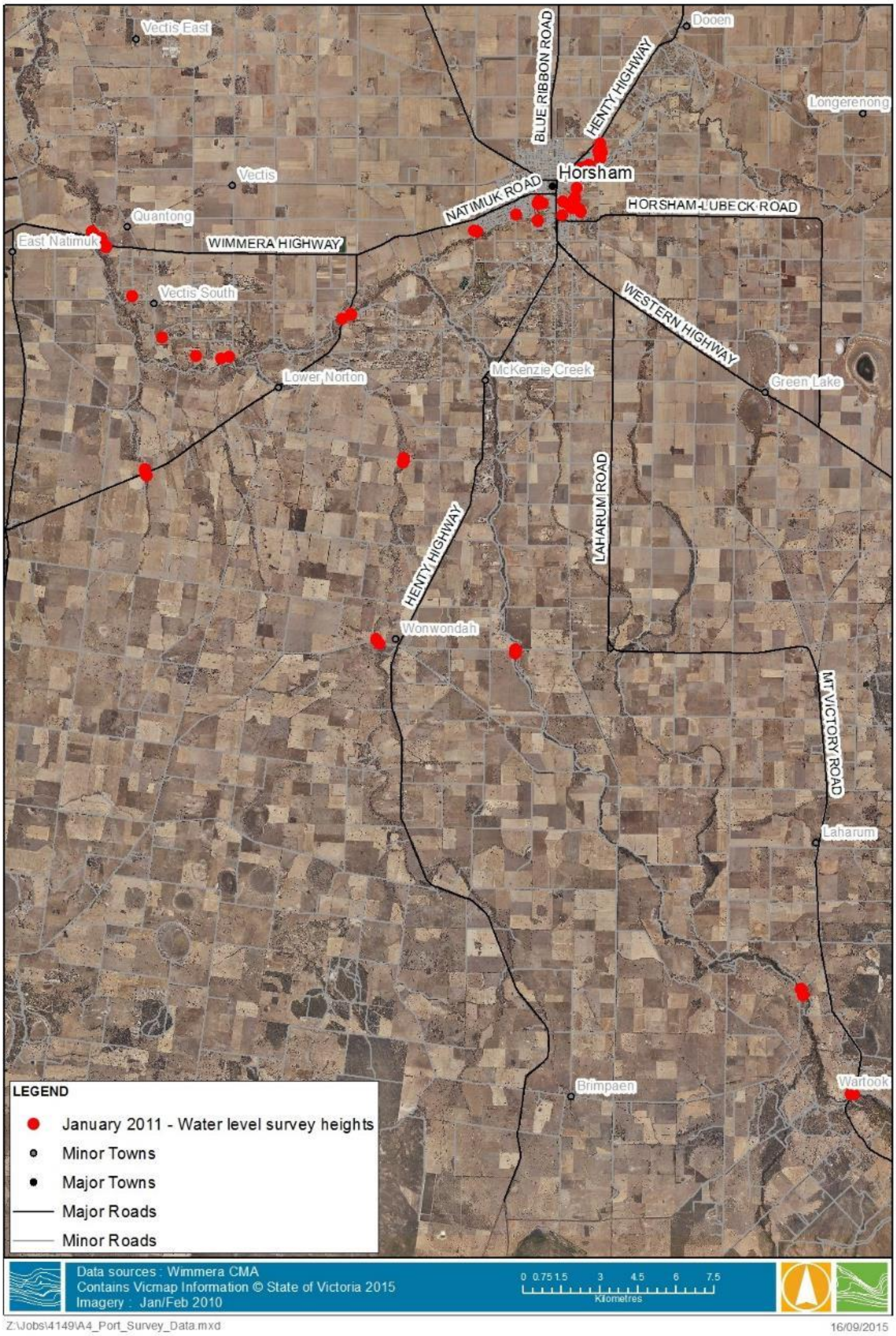


FIGURE 2-38 JANUARY 2011 - PEAK FLOOD HEIGHTS SURVEYED BY WIMMERA CMA WITHIN THE STUDY AREA

2.6.3 September 2016

The September 2016 event was relatively minor in the Wimmera River around Horsham, with some reasonable flow along Burnt Creek inundating areas of East Horsham.

Reasonable rainfall totals were recorded across the Wimmera River catchment on Thursday 8th September with a second front causing further rainfall on Tuesday 13th, Wednesday 14th and Thursday 15th of September.

Flooding from the Mackenzie River and Burnt Creek largely impacted agricultural areas with some flooding near houses along Burnt Creek in the East Horsham area. The Burnt Creek at Wonwondah East gauge peaked on the evening of Wednesday the 14th at 156.01 m AHD. At the same time the Wimmera River was rising and recorded a maximum gauge level of 123.75 m AHD at Walmer, in the early morning of Monday 19th. In the days preceding the maximum water level in the Wimmera River there was a substantial amount of inundation through the East Horsham area from Burnt Creek flooding.

No dwellings of businesses were reported as inundated above floor.

Like January 2011, there were several calibration datasets available for the September 2016 event, these included:

- Water level and flow information at the streamflow gauges discussed in Section 2.5.1.
- Peak flood height information captured after the event by Wimmera CMA.
- News media, photographs and stories provided by local community and government agencies.

After the September 2016 event Wimmera CMA had a series of peak flood height levels surveyed to use as the basis for hydraulic model calibration. Within the study area there are 41 surveyed flood heights from the September 2016 event, as shown in Figure 2-38. There are 25 in the direct vicinity of Horsham, 1 on the Mackenzie River upstream of the Burnt Creek offtake and 3 downstream, 4 on Bungalally Creek, and 4 on the Mackenzie River downstream of the Bungalally Creek confluence.

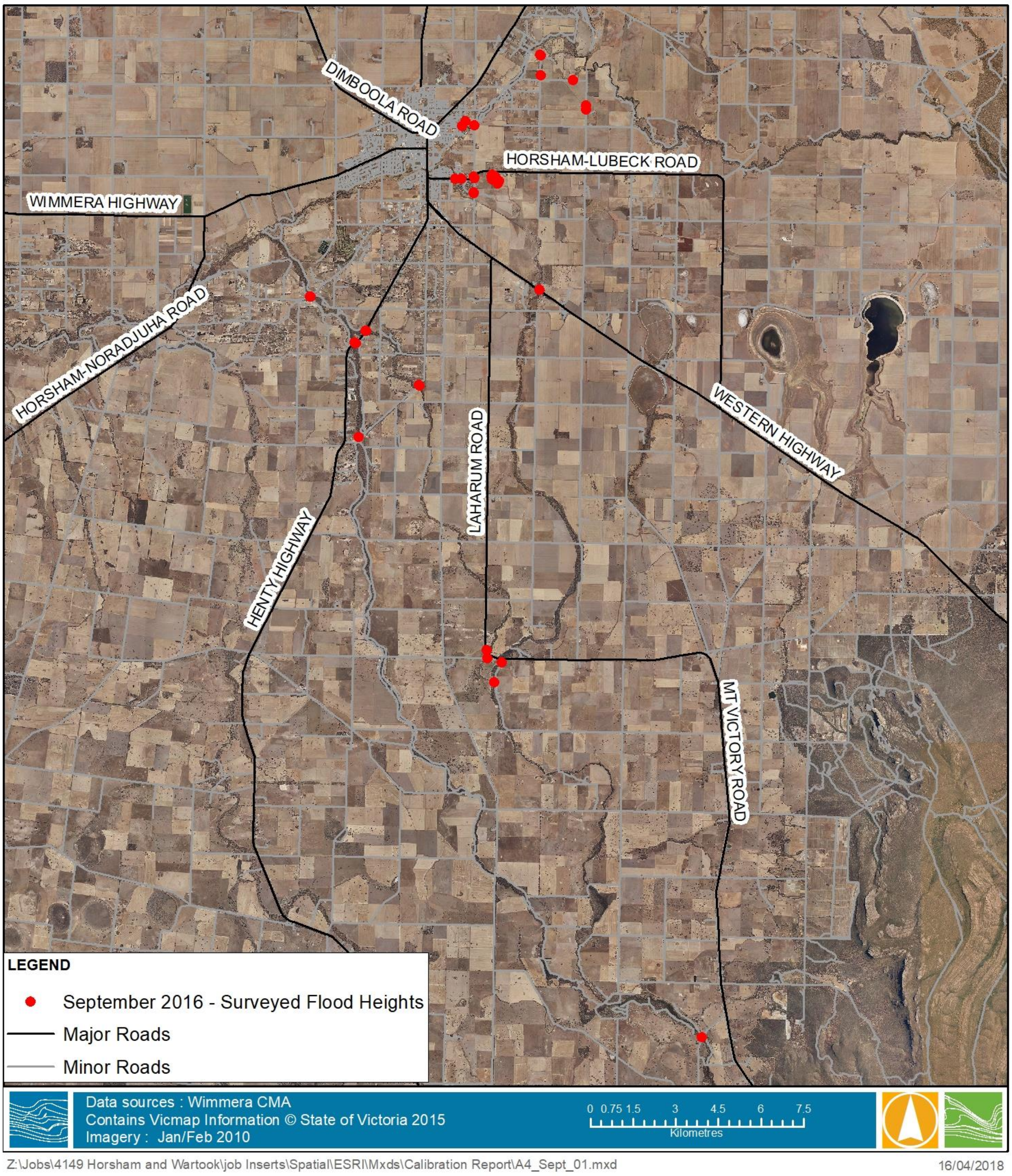


FIGURE 2-39 SEPTEMBER 2016 - PEAK FLOOD HEIGHTS SURVEYED BY WIMMERA CMA WITHIN THE STUDY AREA

3 PROJECT CONSULTATION

Community meetings were held in Riverside, Horsham and Wonwondah over three stages. The purpose of the three meetings is described below:

- Stage 1 – Introduction to the project, work completed to date, what we hope to achieve, how the community will be engaged and what information we are hoping to receive from them, and discussion of mitigation options. At this meeting, community flood observations were recorded and used during the modelling process.
  - This meeting was especially well received in the upper and mid Mackenzie River area with residents appreciating the investment made by Wimmera CMA and Horsham Rural City Council. The community had a demonstrated knowledge of flooding and how it impacted them.

    Across Horsham and East Horsham there was some specific local knowledge held by individuals, but a lack of general community understanding was evident.
- Stage 2 – Modelling progress, discussion around historical events, discussion of model calibration and draft 1% AEP flood extents and behaviour. Asked community for suggested mitigation options.
  - Feedback from the community led to several small changes to the model in order to match their observations but in general the community were happy with how the maps replicated these events.
- Stage 3 – Presentation of final mapping, mitigation option assessments, project outcomes and the progression of the technical information to mitigation and planning scheme implementation.
  - This was undertaken by sending letters to all properties impacted by the 1% AEP event, encouraging recipients to review the results and contact the Wimmera CMA for an individual appointment to discuss the results.

4 MODELLING

4.1 Methodology

The scope of the Horsham and Wartook Valley Flood Investigation was to consider riverine flooding from the Wimmera and Mackenzie Rivers and their major tributaries and anabranches, and also local overland stormwater flooding in the Horsham and Haven area. An overview of the riverine and stormwater modelling methodologies is discussed below:

- Riverine Inundation
  - Flow in the Wimmera River was determined using the Horsham (Walmer) streamflow gauge, with flows transposed to the upstream Wimmera River model boundary. During calibration, the gauged flows were factored up and lagged in time iteratively until they reproduced the gauge record at Horsham (Walmer) gauge. The Wimmera River flow at the model boundary is separated into flow in the Wimmera River and on the floodplain south of the river. Modelling completed in the Warracknabeal and Brim Flood Investigation[1] was used to determine the flow split between the river and floodplain. Design flows used a flood frequency analysis of the Horsham (Walmer) gauge transposed to the model boundary.
  - Flow in the Mackenzie River downstream of Mackenzie Falls was determined by directly applying the Lake Wartook outflow. A flood frequency analysis was used for design flows.
  - Flow entering the study area from the Wimmera River tributaries, Burnt Creek, Bungalally Creek, Norton Creek, Darragan Creek and Sandy Creek was determined using a RORB rainfall runoff model for both historic and design flood events.
  - The gauged and modelled flows were input into a Mike Flexible Mesh (MIKEFM) model which modelled the flow behaviour of historic and design floods, producing flood level, depth, velocity and hazard outputs.
  - Model calibration was completed using the January 2011 and September 2016 events.
  - Design modelling for the Mackenzie River, Burnt Creek and other tributaries to the Wimmera River was completed using ARR2016 methodologies and 2016 BoM IFD parameters. The 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events were modelled.
- Stormwater Inundation
  - Stormwater inundation in Horsham and Haven was modelled by directly applying historic and design rainfall to a TUFLOW hydraulic model topography. An extensive pipe network was added to the model based on the Horsham Rural City Council infrastructure data. Rain accumulates within model cells and flows to the lowest adjacent cell, flow from multiple cells combine to form flow paths before pooling in low areas or flowing into a waterway. Pipes transfer water from between areas within the model topography. This type of modelling represents overland stormwater runoff during localised storm events.
  - Model calibration was completed using the January 2011 event.
  - Design modelling was completed using ARR2016 methodologies and 2016 BoM IFD parameters.

A detailed description of each modelling methodology and how it was applied in the Horsham and Wartook Valley Flood Investigation is included in the following sections.

4.2 Riverine Inundation

4.2.1 Gauge flows

Modelling of the two major rivers within the study area used inflows extracted from gauge records at the Wimmera River at Horsham (Walmer) gauge and the Mackenzie River at Lake Wartook gauge. To apply flows from these gauges to the hydraulic model boundaries at the upstream extent of the model, the gauge flows were lagged, scaled and split between multiple model boundary locations. The streamflow gauge locations and their model input locations are show in Figure 4-1.

FIGURE 4-1 GAUGED MODEL INFLOWS

Gauge flows for the Wimmera River at Horsham (Walmer) gauge were translated to the hydraulic model boundary which required an increase in the peak flow and lagging the hydrograph backward in time. This was completed across several iterations in order to match the timing and attenuation between the model boundary and the Horsham (Walmer) gauge. At the model boundary the Wimmera River flow separates into flow along the main channel, and floodplain flow along an overland flow path through East Horsham. Modelling of the January 2011 event completed during the Warracknabeal and Brim Flood Investigation[1] was used to determine this flow split, the September 2016 event did not engage this area of floodplain. The combined Wimmera River inflows and gauged flows for the January 2011 and September 2016 events are shown in Figure 4-2 and Figure 4-3 respectively.

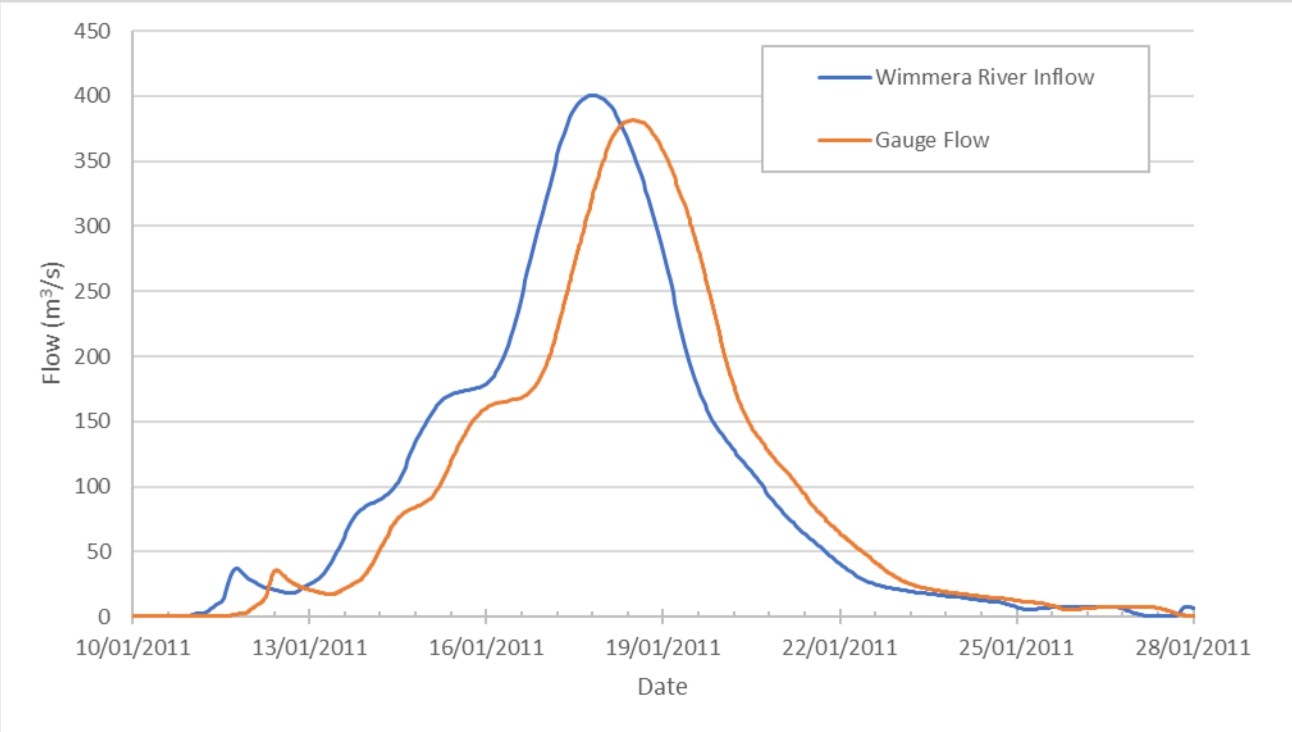


FIGURE 4-2 JANUARY 2011 – WIMMERA RIVER MODEL INFLOWS AND WIMMERA RIVER AT HORSHAM (WALMER) GAUGE RECORD

4149-01_R06V02F_Final_Report_HorshamWartook

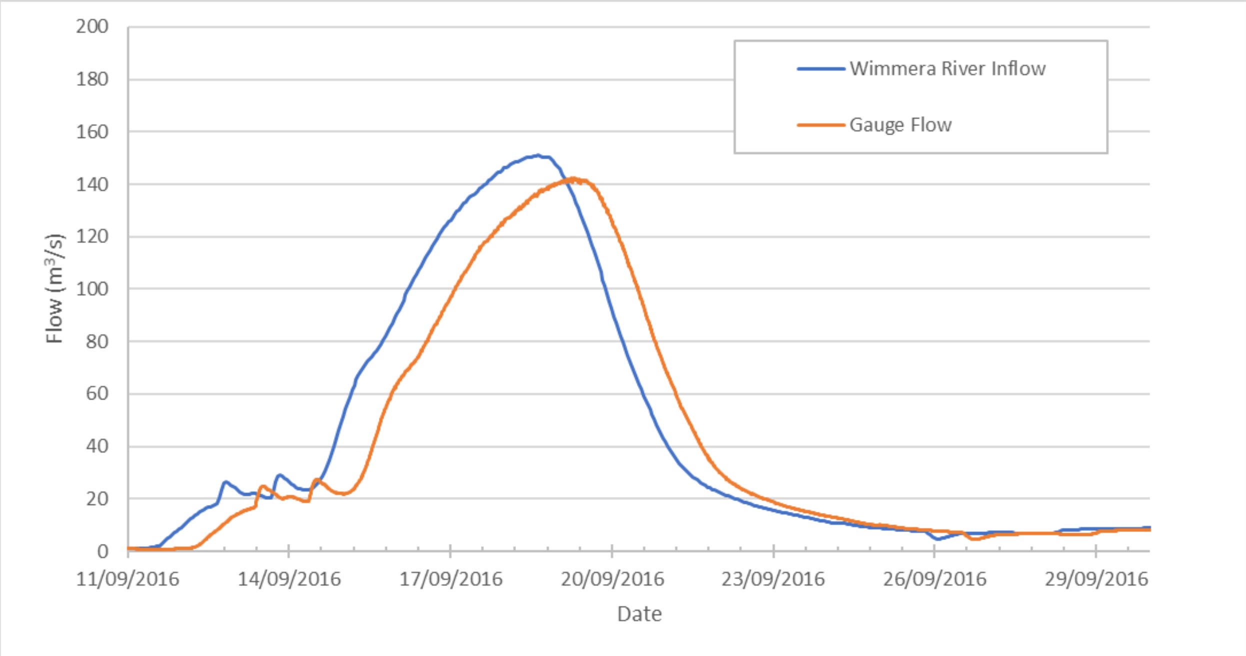


FIGURE 4-3 SEPTEMBER 2016 – WIMMERA RIVER MODEL INFLOWS AND GAUGE RECORD AND WIMMERA RIVER AT HORSHAM (WALMER) GAUGE RECORD

Gauge flows from the Mackenzie River at Wartook gauge were input directly into the model, translated downstream of Mackenzie Falls. Given the steepness of this reach, the time lag is insignificant between the gauge location and the model boundary location and did not warrant any adjustments to the inflow hydrograph.

The modelled January 2011 and September 2016 inflows are shown in Figure 4-4 and Figure 4-5 respectively.

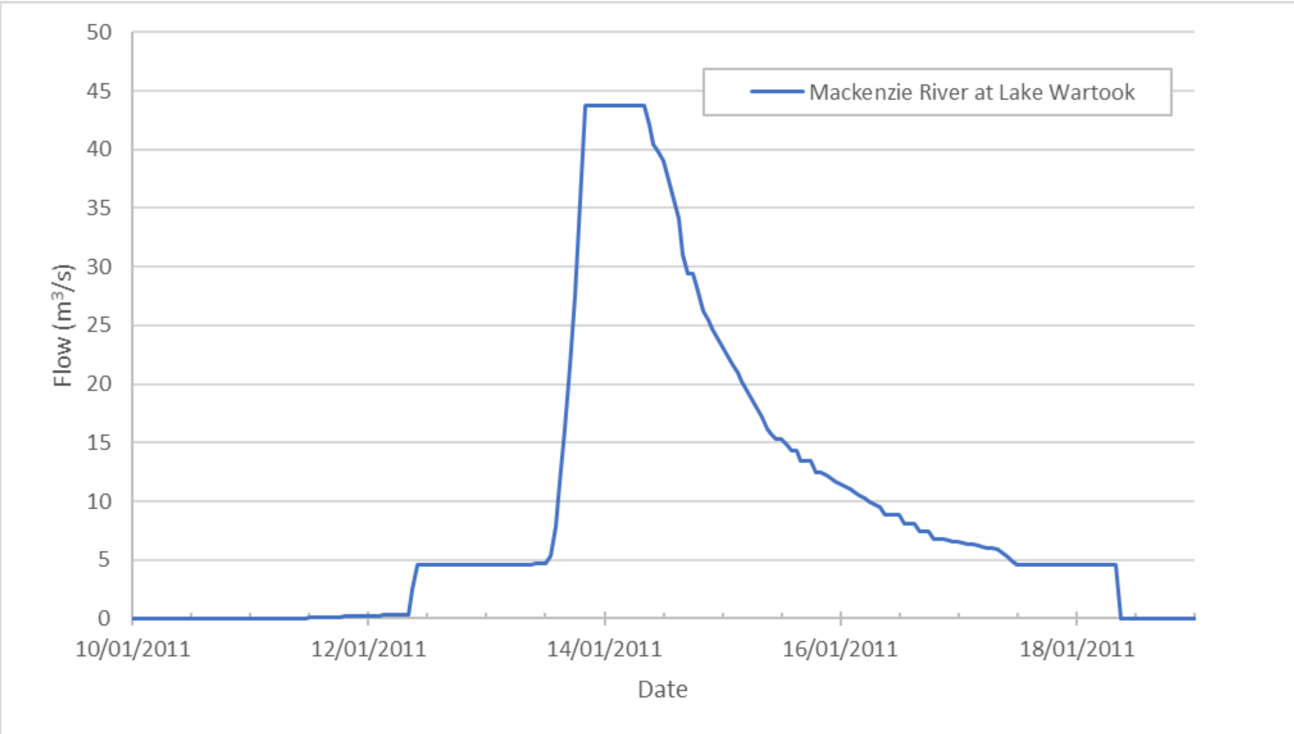


FIGURE 4-4 JANUARY 2011 – MACKENZIE RIVER MODEL INFLOWS

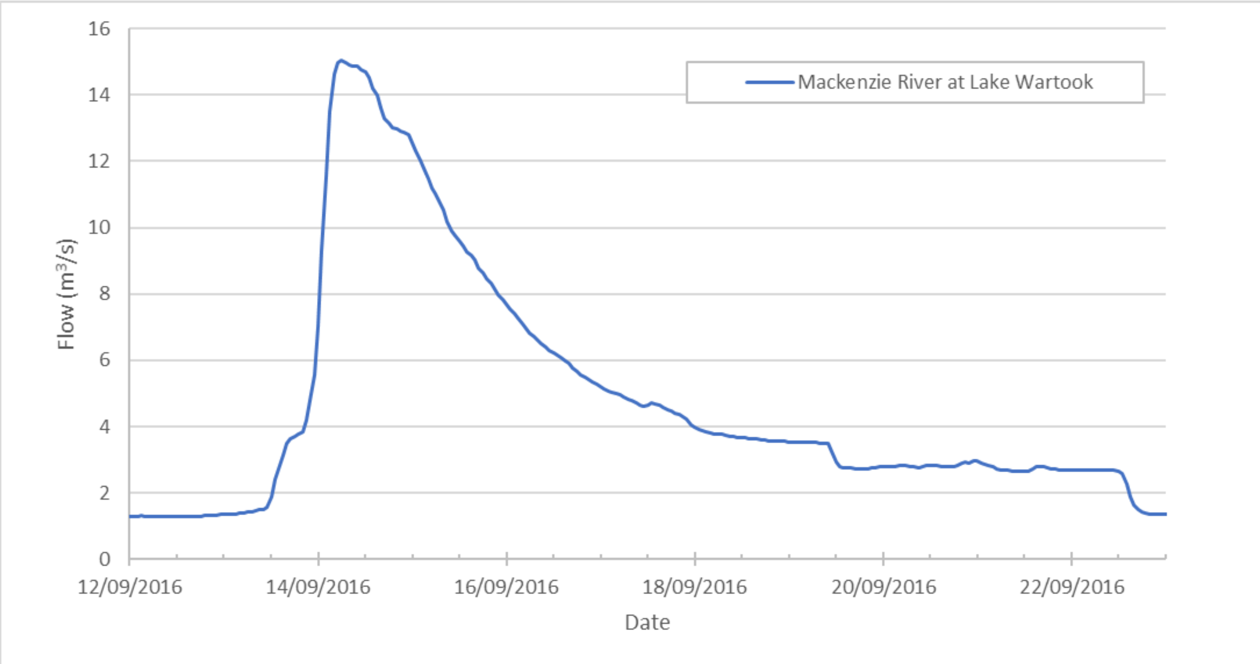


FIGURE 4-5 SEPTEMBER 2016 – MACKENZIE RIVER MODEL INFLOWS

4.2.2 RORB

A RORB model of the Wimmera River, Mackenzie River, Burnt Creek, Bungalally Creek, Darragan Creek, Norton Creek and Sandy Creek was constructed to develop inflows along each waterway. The RORB model was constructed using MiRORB (MapInfo RORB tools), RORB GUI and RORBWIN V6.15.

4.2.2.1 Sub-areas and Reaches

Sub-area boundaries and reaches were delineated using ArcHydro and revised as necessary to allow flows to be extracted at the points of interest. The sub areas and reaches were delineated from the 2004-2005 Wimmera CMA LiDAR, covering their entire management area. Nodes were placed at areas of interest, the centroid of each sub-area and the junction of any two reaches. Nodes were then connected by RORB reaches, each representing the length, slope and reach type.

Reach types in the model were set to be consistent with the land use across the catchment. All reaches were set to natural reach types in RORB, representative of the open grassed areas and natural waterways in the catchment. The RORB subarea and reach delineation is shown in Figure 4-6.

4.2.2.2 Fraction Impervious

Fraction Impervious (FI) values were calculated using MiRORB. Default sub-area FI values were calculated based on the current Planning Scheme Zones, the fraction impervious values used for each zoning is shown in Table 4-1, with the zones mapped in Figure 4-7.

The area weighted average FI of the catchment was calculated to be 0.03, reflecting the predominantly rural nature of the catchment. The spatial distribution of the weighted average FI for each sub-area is shown in Figure 4-8.

TABLE 4-1 RORB MODEL FRACTION IMPERVIOUS VALUES AND ZONES[11]

Zone	Description	Typical Fraction Impervious
FZ	Farming Zone	0
PCRZ	Protection of natural environment or resources.	0
PPRZ	Main zone for public open space, incl. golf courses.	0.1
PUZ1	Power lines, Pipe tracks and retarding basins	0.05
PUZ2	Schools and Universities	0.7
PUZ3	Hospitals	0.7
PUZ7	Museums	0.6
RDZ1	Major roads and freeways.	0.7
RLZ	Predominantly residential use in rural environment.	0.2
TZ	Small township with little zoning structure	0.55

[11] Melbourne Water, 2010 – Music Guidelines, Recommended input parameters and modelling approaches for MUSIC users

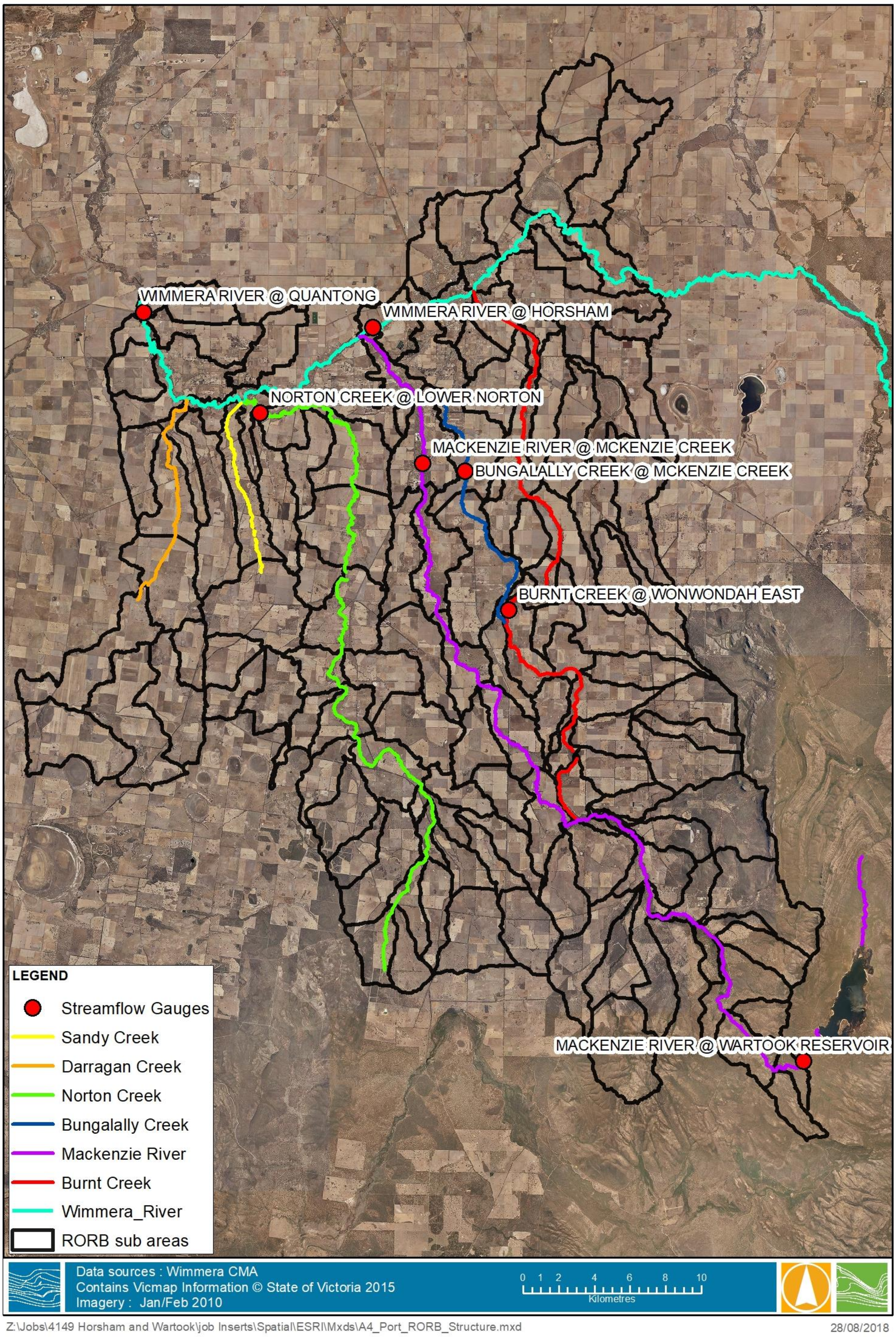


FIGURE 4-6 RORB SUBAREA AND REACH DELINEATION

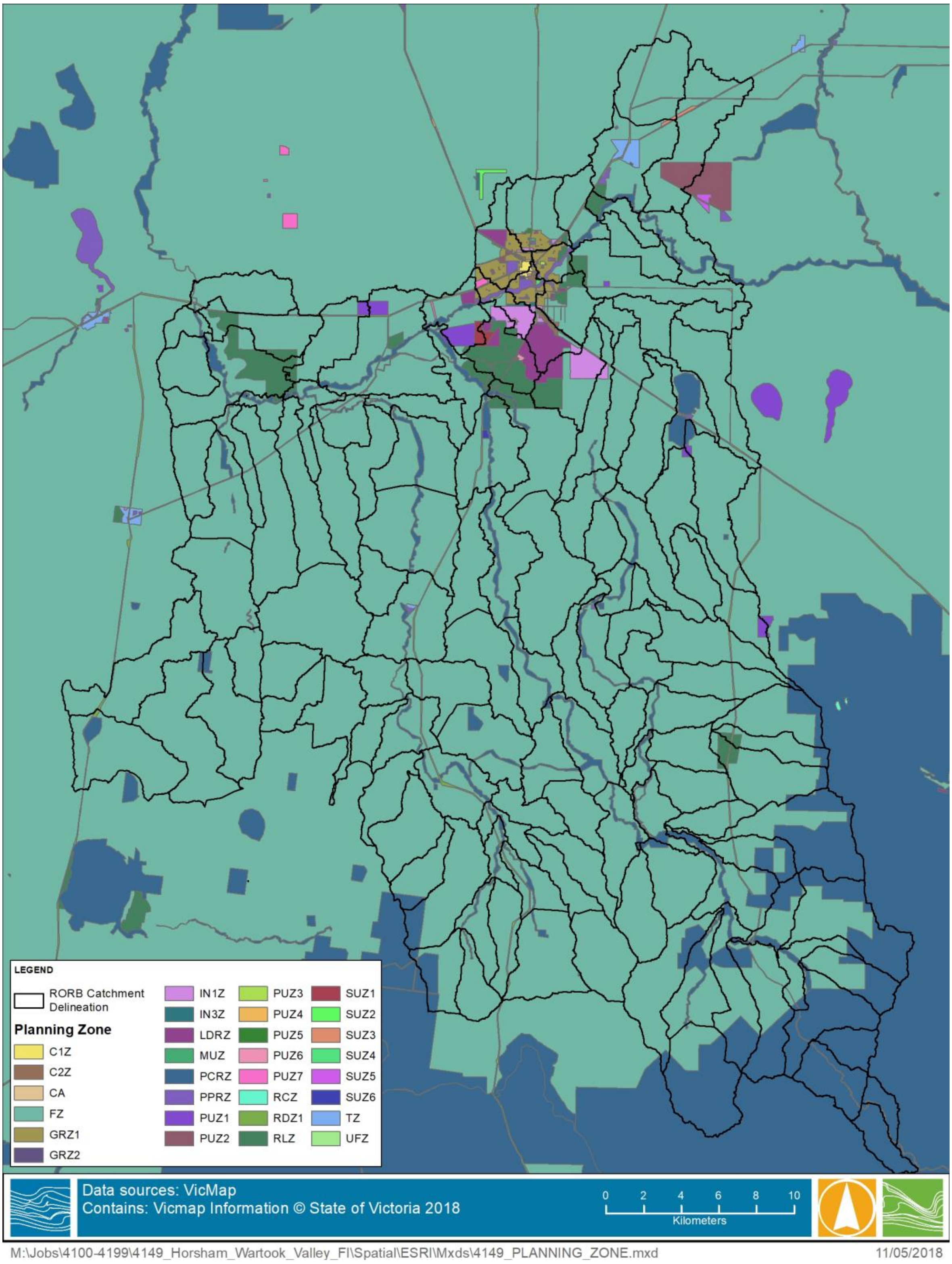


FIGURE 4-7 RORB MODEL PLANNING ZONES

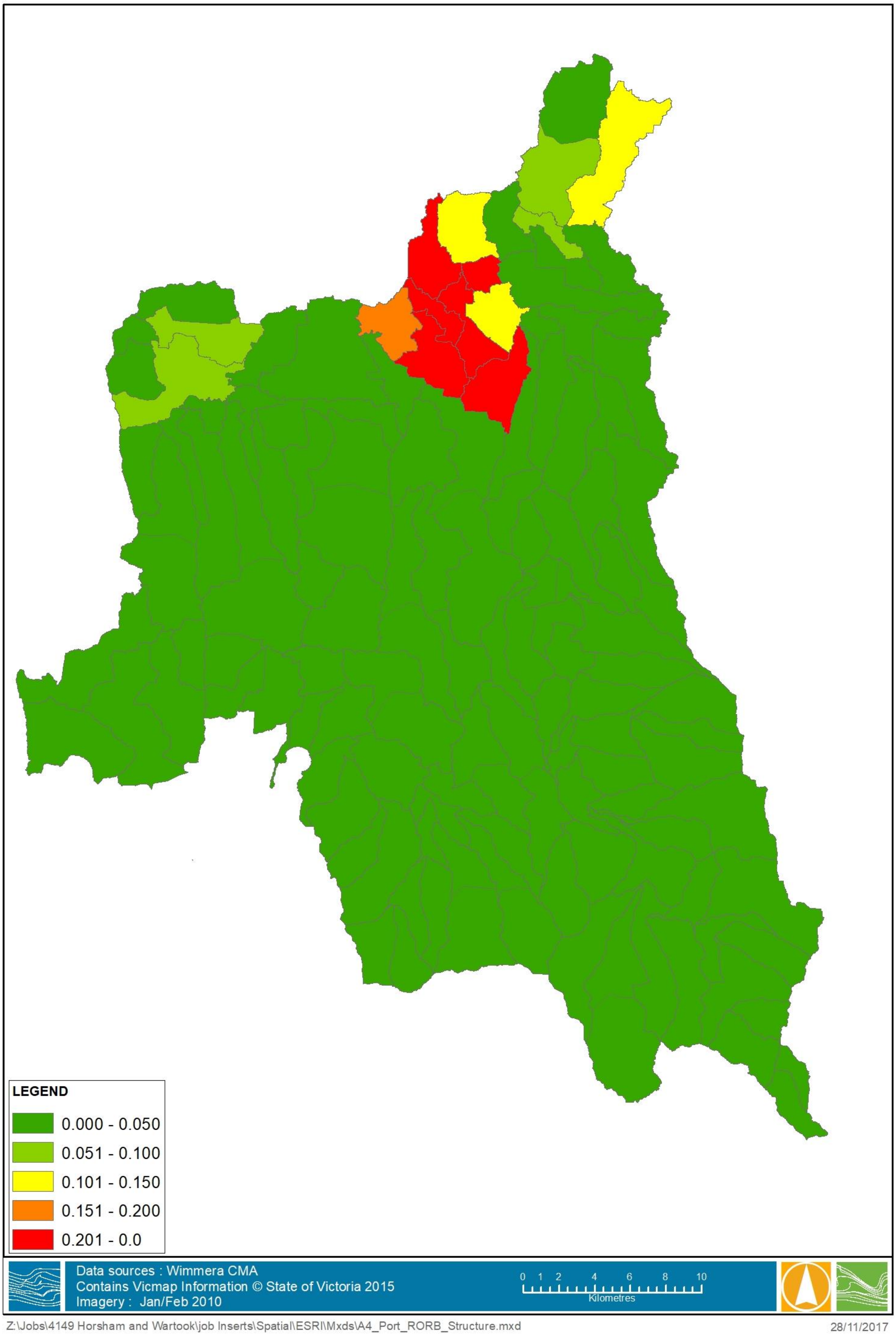


FIGURE 4-8 RORB MODEL FRACTION IMPERVIOUS CALCULATED DISTRIBUTION

4.2.2.3 Model Parameters

The RORB model was broken up into a series of interstation areas; which each interstation area assigned kc, m, initial loss and continuing loss model parameters. The model parameters were firstly estimated using industry standard values and values from nearby models and were iteratively adjusted to achieve the best possible model calibration.

The kc for each interstation area was determined using the Victorian data estimate available in RORB (Pearse et al, 2002[12]) - $kc=1.25*D_{av.}$ Water Technology has found this kc approximation equation to perform well for rural Victorian catchments.

Losses were initially determined using the ARR data hub, these were then modified to get the best match between the hydrology and hydraulics for each calibration event.

The RORB m value was left at 0.8, as per the RORB Manual recommendations.

4.2.3 Mike Flexible Mesh Hydraulic Model

The Mike Flexible Mesh (MIKEFM) model is comprised of several key components:

- Topography – represented as a mesh
- Boundaries – model inflows and outflows
- Roughness – a representation of resistance to flow due to vegetation/permeable structures etc.

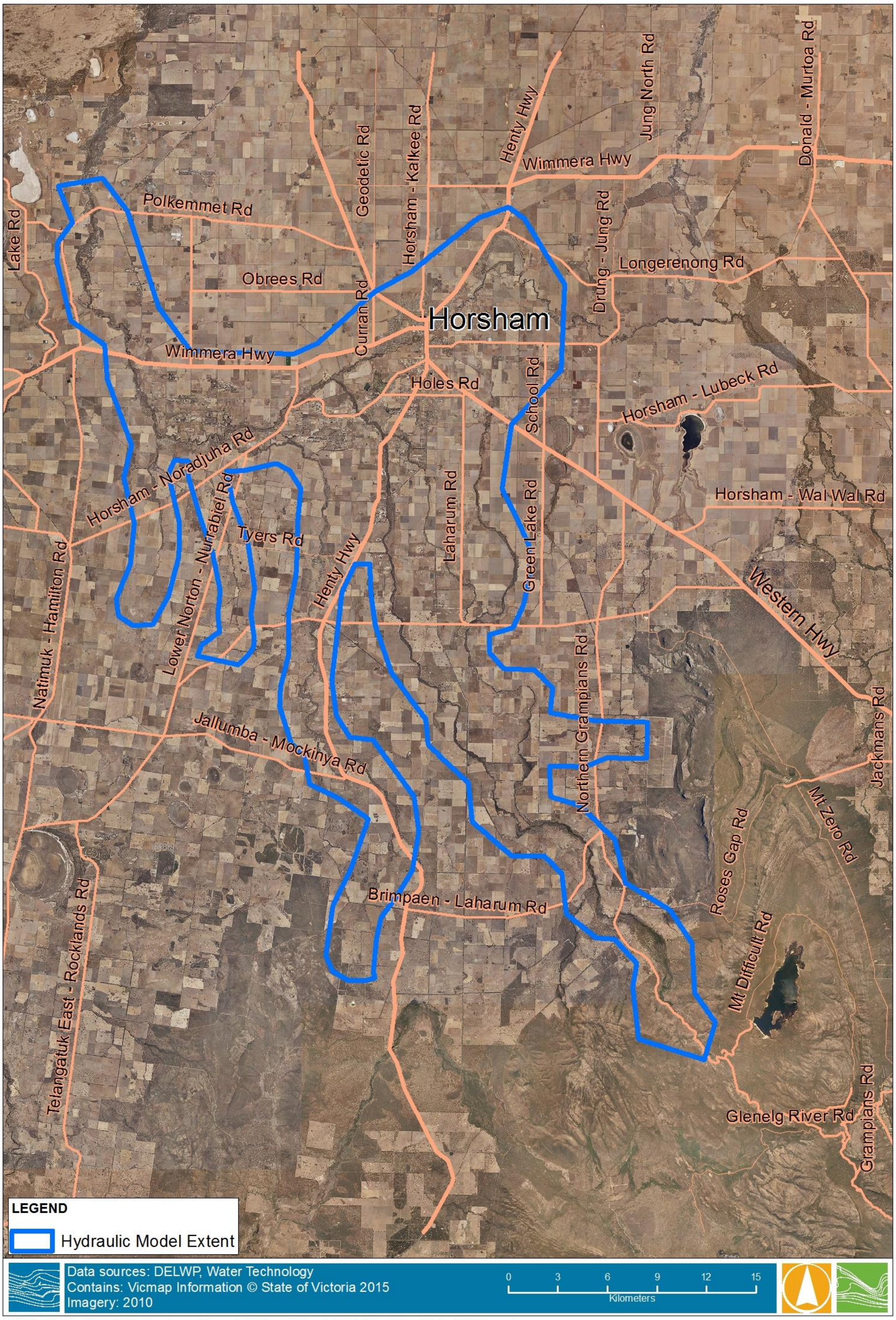
Each of these components are discussed in the following sections.

4.2.3.1 Model Mesh

The MIKEFM model was comprised of triangular and quadrilateral elements. Generally, the waterways were modelled using quadrilateral elements with the surrounding floodplains modelled using triangular elements. The mesh was developed ensuring structures and each waterway channel was represented in enough detail to allow a good representation of the flow capacity, but not in too much detail to make the model simulation times impractical.

The MIKEFM model extent is shown below in Figure 4-9 with an example of the model mesh shown in Figure 4-10.

[12] Pearse et al, 2002 – A Simple Method for Estimating RORB Model Parameters for Ungauged Rural Catchments, Water Challenge: Balancing the Risks: Hydrology and Water Resources Symposium, 2002



M:\Jobs\4100-4199\4149_Horsham_Wartook_Valley_FI\Spatial\ESRI\Mxds\Available_LiDAR.mxd 12/22/2015

FIGURE 4-9 MIKEFM MODEL EXTENT

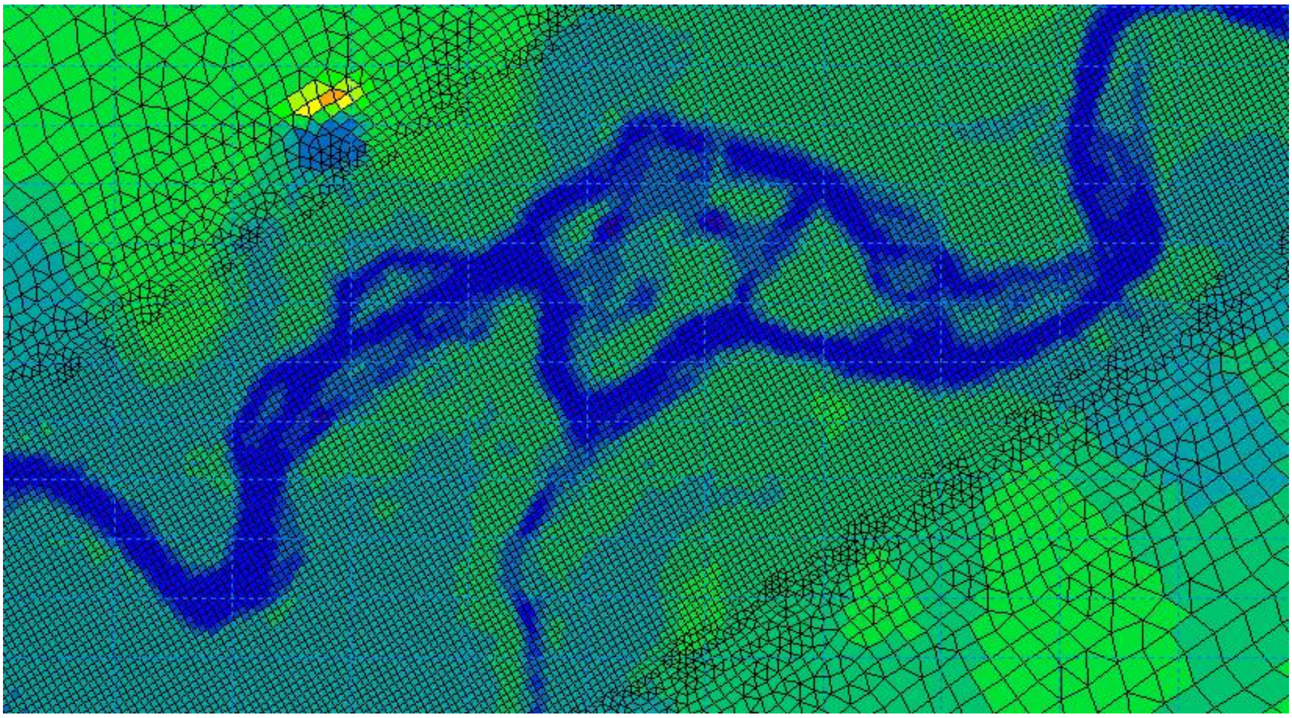


FIGURE 4-10 MIKEFM EXAMPLE PORTION OF MESH

As discussed in the Data Verification component of this project[13], there are three LiDAR datasets available to be used as the basis of the model topography:

- 2016 Horsham LiDAR
- 2004 WCMA LiDAR
- 2010 ISC LiDAR

The 2004 Wimmera CMA LiDAR has been verified across numerous projects including:

- East Horsham Channel Decommissioning Modelling (Water Technology, 2013) (Commissioned by HRCC)
- Warracknabeal and Brim Flood Investigation (Water Technology, 2016) (Commissioned by Wimmera CMA)[1]
- Dunmunkle Creek Flood Investigation (Water Technology, 2016) (Commissioned by Wimmera CMA)[14]
- Natimuk Flood Investigation (Water Technology, 2012) (Commissioned by Wimmera CMA)[3]

The 2010 ISC LiDAR data was not used as the base topography in the above projects due to inconsistencies in the data, these have included datum shifts and water in the channel in several waterways. This is explained in detail in the Warracknabeal and Brim Flood Investigation[1] and Dunmunkle Creek Flood Investigation[2] data verification reports, while the 2016 Horsham LiDAR was verified as part of this project.

During the January 2011 calibration the 2004 LiDAR was used as the basis for the model topography while the September 2016 calibration was completed with the inclusion of the 2016 LiDAR data taking precedence

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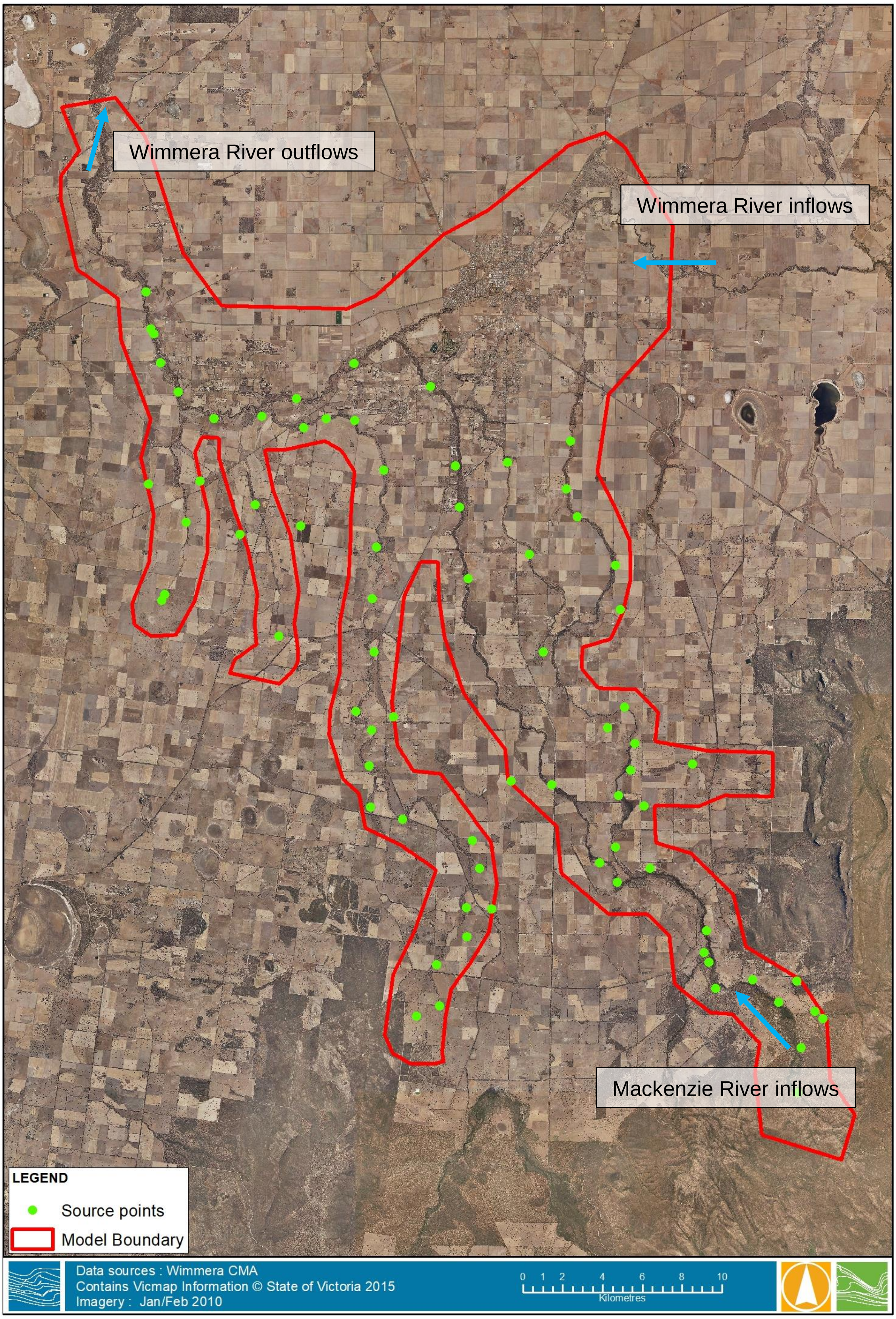
[13] Water Technology (2016), Horsham and Wartook Valley Flood Investigation, Data Verification Memo
[14] Water Technology (2016), Dunmunkle Creek Flood Investigation, Wimmera CMA

over that captured in 2004. Design modelling will be completed with the same topography as the September 2016 model calibration.

There were numerous dike lines included in the hydraulic model these were located along road centrelines, remaining channels and levees. Dikes were used to ensure the top of each bank was adequately represented. Initially all significant roads and channel were included with additions made during the model calibration as part of calibration process.

4.2.3.2 Model Boundaries

The hydraulic model boundaries used both streamflow gauge records, flood frequency analysis and hydrographs from a RORB model. The boundary locations are highlighted in Figure 4-11, outlining the two gauge boundaries, with the remainder based on RORB model inflows.



Z:\Jobs\4149 Horsham and Wartook\job Inserts\Spatial\ESRI\Mxds\A4_Port_RORB_Structure.mxd 28/08/2018

FIGURE 4-11 HYDRAULIC MODEL BOUNDARIES

4.2.3.3 Hydraulic Roughness

The hydraulic model roughness was represented by Manning's 'n' based on land use and aerial photography. A 2D grid of the estimated hydraulic roughness was developed based on those recommended in Open Channel Hydraulics (Chow, 1959)[15]. The adopted roughness values for each land use are outlined in Table 4-2 and shown graphically in Figure 4-12.

TABLE 4-2 ADOPTED MANNING'S 'N' VALUES FOR RIVERINE FLOOD MODEL

Description	Manning's 'm'	Manning's 'n'
Residential areas	12.5	0.08
Floodplain areas	25	0.04
Treed or forested areas	20	0.05
Thick riverine vegetation	20	0.05
Sparse riverine vegetation	33	0.03
Open Water	50	0.02

[15] Chow (1959), Open Channel Hydraulics

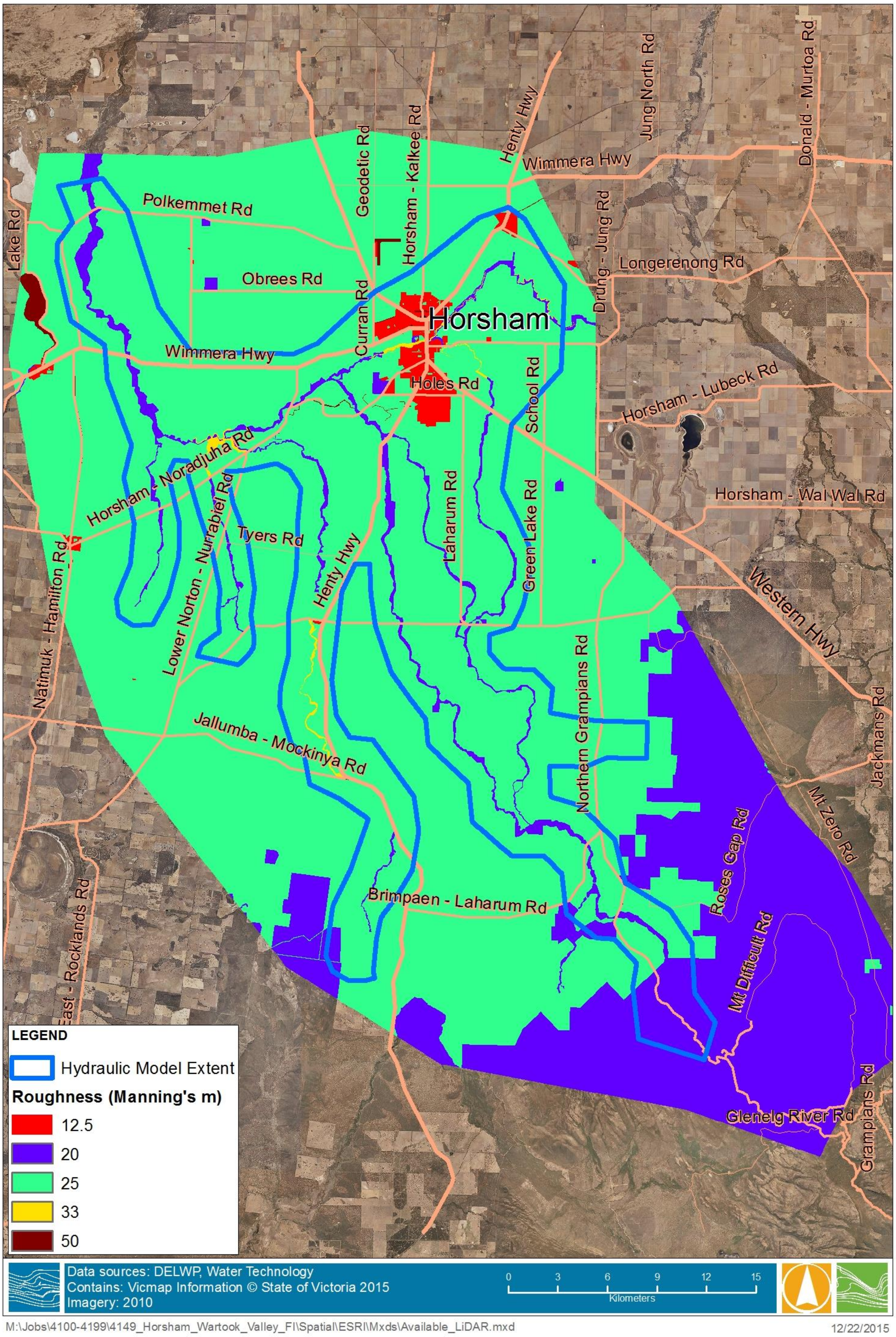


FIGURE 4-12 ADOPTED MANNING'S 'M' VALUES FOR RIVERINE FLOOD MODELLING

4.3 Stormwater Inundation – TUFLOW

A *'Rain on Grid'* (RoG) hydraulic model of Horsham and Haven was developed across two TUFLOW models, north and south of the Wimmera River. Each model had rainfall directly applied to the topography, allowing water to flow overland, pool in low areas and flow to the Wimmera River via the Horsham stormwater drainage system. The model extent for each of the northern and southern models along with the drainage system included in the model is shown Figure 4-13. The drainage system details were reasonable, but some assumptions had to be made in order to connect pipes where no invert data was known.

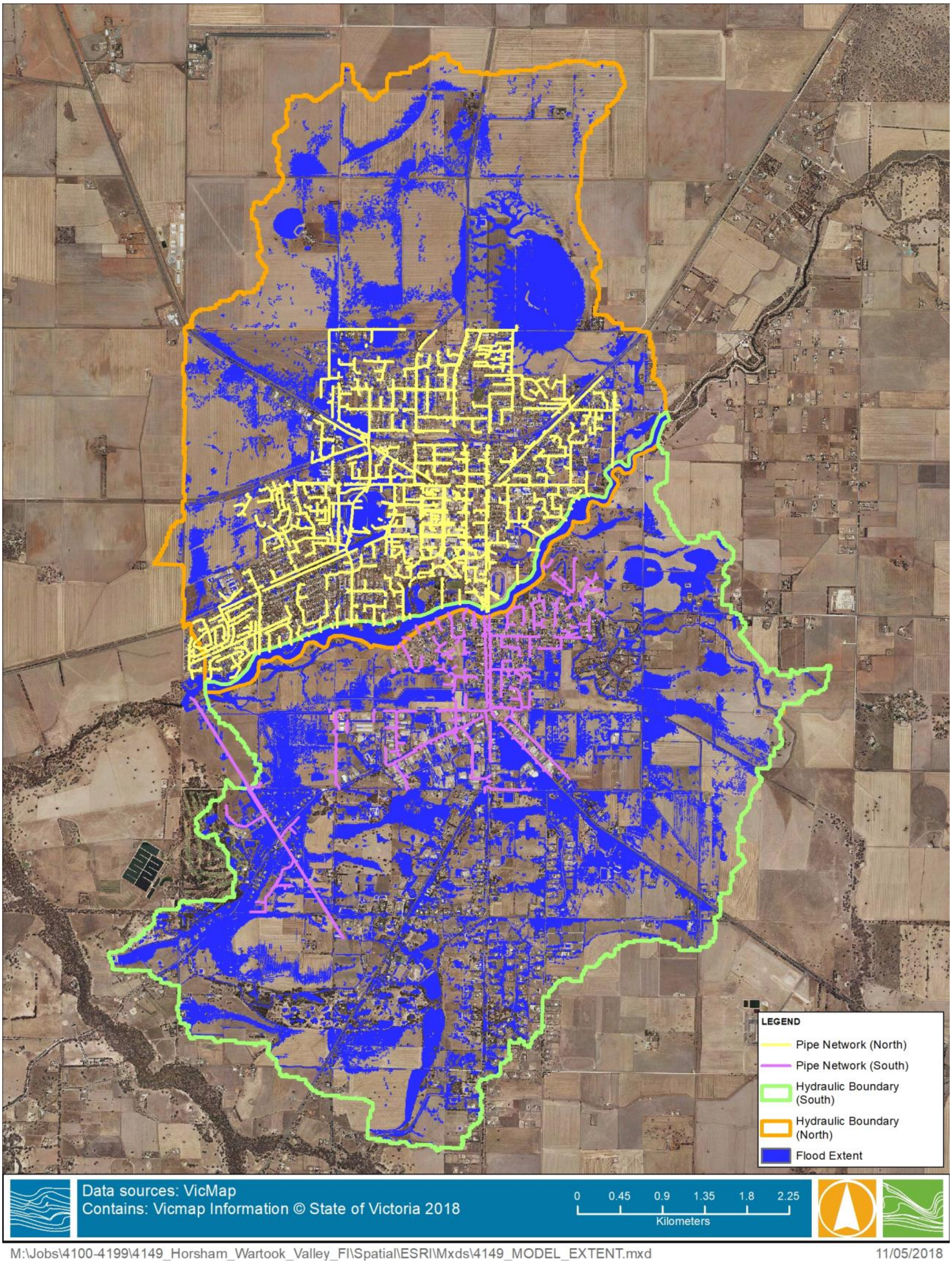


FIGURE 4-13 RAIN ON GRID – MODEL EXTENTS

4.3.1 Model Topography

The model topography was based on a combination of the 2004 and 2016 LiDAR datasets with the 2016 data taking precedence in areas of overlap. The 1x1 m resolution LiDAR was resampled at a 3x3 m grid resolution. This resolution was chosen as it gives an accurate representation of council roads and drainage paths and reasonable model run times given both model areas are reasonably large. As discussed in Section 2.4.2, the Wimmera River bathymetry was created by interpolating between cross sections surveyed as part of this project.

4.3.2 Rainfall

Rainfall was directly applied to the model topography for each storm scenario with a uniform spatial pattern, and a temporal pattern based on historic record or a chosen design temporal pattern. The chosen temporal pattern for each event is outlined below in Section 4.4 when presenting results for each storm scenario.

4.3.3 Hydraulic Roughness

The RoG hydraulic roughness was delineated based on land use and aerial photography. The estimated hydraulic roughness values were developed based on those recommended in Open Channel Hydraulics (Chow, 1959) . The adopted roughness values for each land use are outlined in Table 4-3 and shown graphically in Figure 4-14. The adopted roughness values were different to that used in the Flexible Mesh model due to their very different model type and extent.

Table 4-3 RoG - Adopted Manning's 'n' values

Description	Manning's 'n'
Residential - Urban (higher density) - when building footprints and remainder of parcel are modelled together (with one roughness value)	0.35
Residential - Rural (lower density) - when building footprints and remainder of parcel are modelled together (with one roughness value)	0.15
Residential Footprint - Urban (higher density) - when building footprints are modelled separately to remainder of parcel	0.4
Residential - Urban (higher density) - when building footprints are modelled separately to remainder of parcel	0.1
Residential Footprint - Rural (lower density) - when building footprints are modelled separately to remainder of parcel	0.4
Residential - Rural (lower density) - when building footprints are modelled separately to remainder of parcel	0.05
Industrial/Commercial or large buildings on site	0.3
Significant Drainage Easement (regardless of zone type)	0.05
Open Space or Waterway - minimal vegetation	0.04
Open Space or Waterway - moderate vegetation	0.06
Open Space or Waterway - heavy vegetation	0.09
Open water (with reedy vegetation)	0.065
Open water (with submerged vegetation)	0.02
Car park/pavement/wide driveways/roads	0.02

Railway line	0.125
Concrete lined channels	0.016

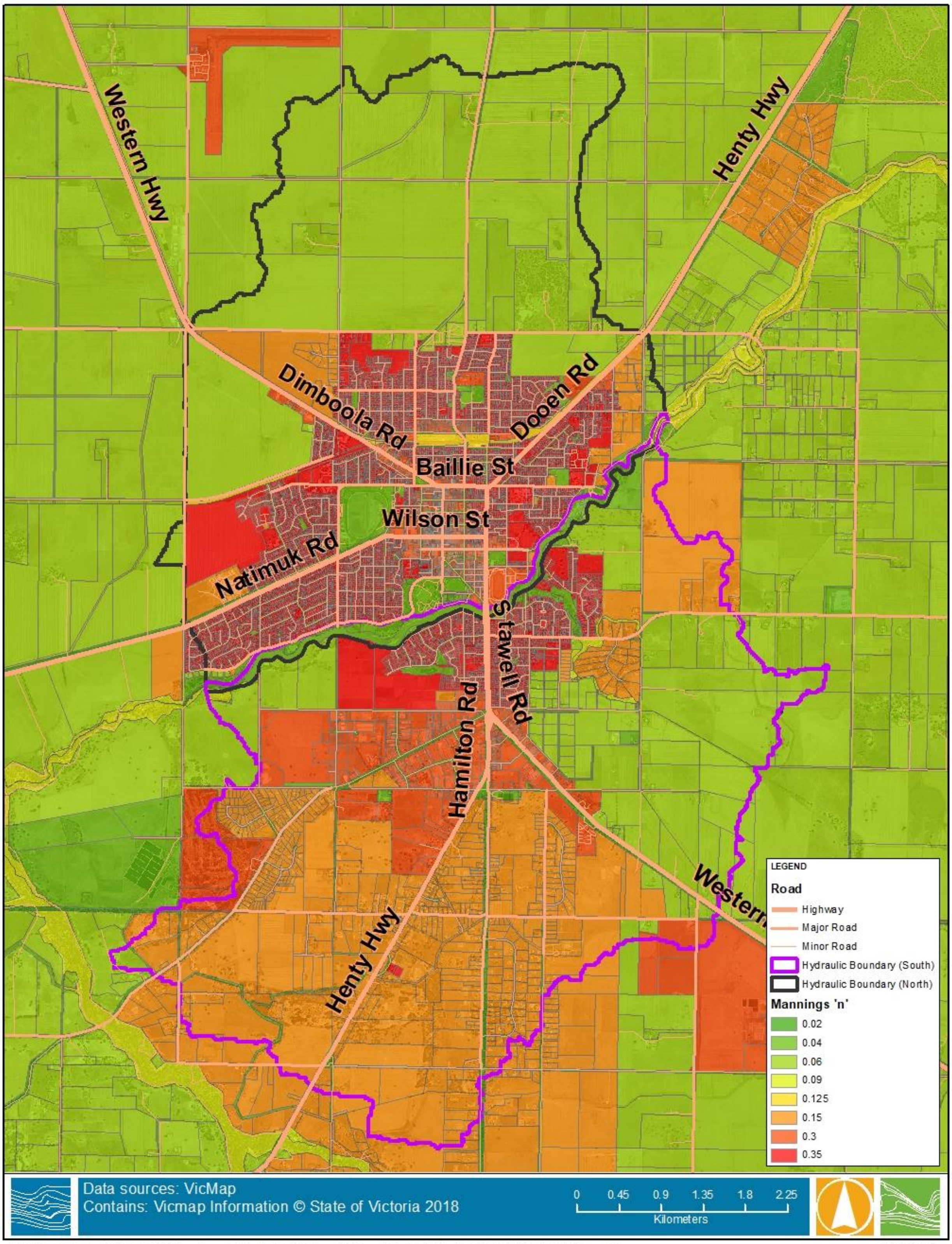


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FIGURE 4-14 RAIN ON GRID - ADOPTED MANNING'S 'N' VALUES

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4.3.4 Rainfall Losses

Rainfall losses were adopted in the RoG model representing the rainfall which does not become runoff. A continuing loss model was adopted, the adopted values are discussed within the calibration and design modelling sections, Section 4.4 and 4.5 respectively.

4.4 Model Calibration

4.4.1 Riverine Inundation

4.4.1.1 January 2011

As discussed in Section 2.6.2, there were numerous calibration data sources available from the January 2011 event.

The January 2011 event was modelled numerous times using the MIKEFM model, changing the model topography, inserting roads and levees, and adjusting the roughness values to achieve a suitable model calibration. Some iteration of the RORB hydrology and the lagging and scaling of the Wimmera River inflow boundary was also completed to achieve a suitable calibration.

The following sections compare the model results to observed data, assessing the model calibration. The January 2011 modelled flood extent is shown in Figure 4-15.

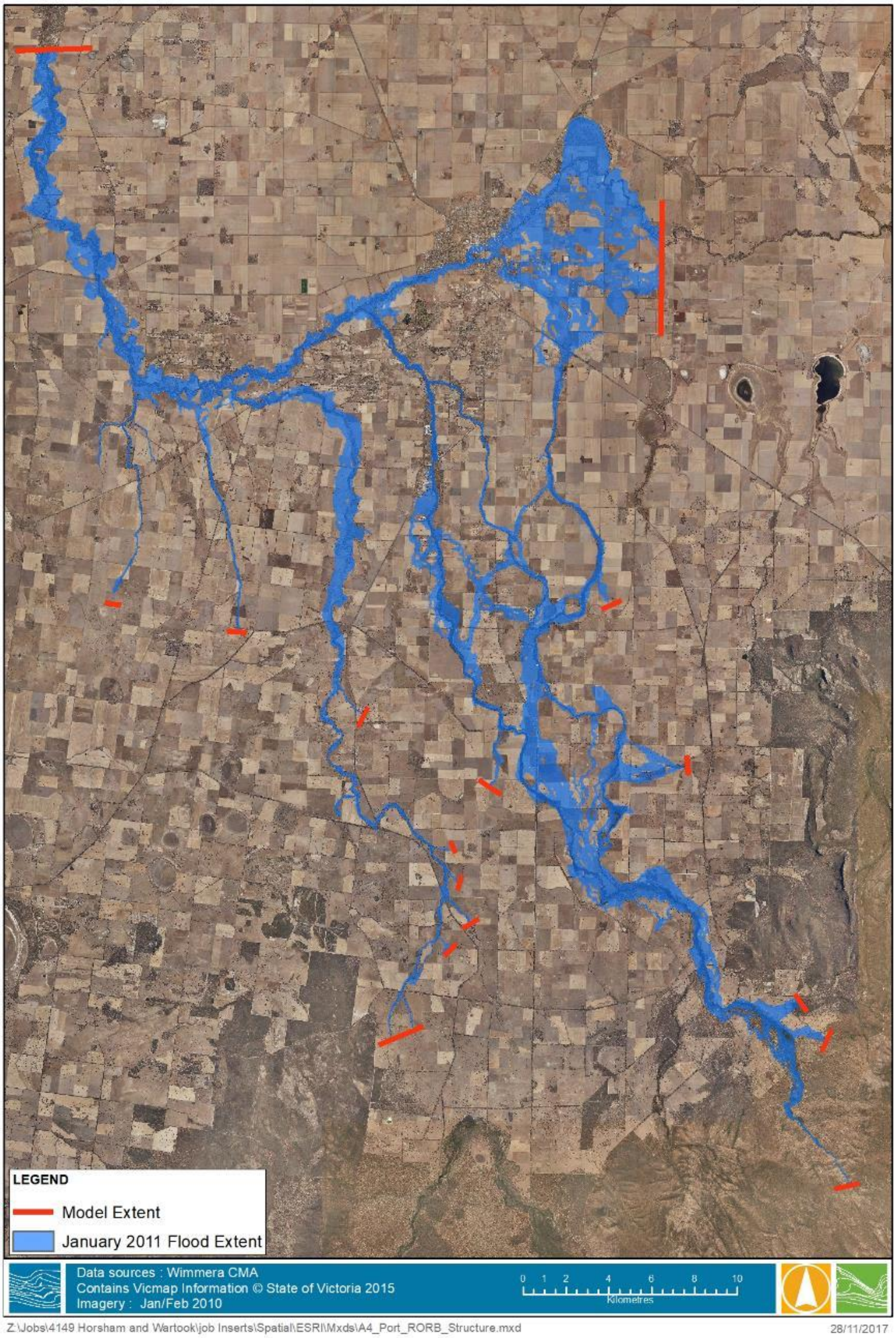

FIGURE 4-15 JANUARY 2011 – MODELLED INUNDATION EXTENT

4.4.1.1.1 SURVEYED FLOOD HEIGHTS

As discussed in Section 2.6.2, there were 95 peak flood heights surveyed during and after the January 2011 event, marking the estimated highest level flood water reached at each specific location. These peak flood heights were compared to the peak modelled water level to give an indication of how well the model was performing. Of the surveyed heights, 47 matched the model results within 100 mm of that surveyed, 81 points within 200 mm of that surveyed, leaving 14 points with a difference of greater than 200 mm. This is an excellent calibration result.

The difference between the surveyed and modelled peak flood heights was thematically mapped to give a spatial understanding of the model results. The mapping was completed using the differences between surveyed and modelled levels. The difference between surveyed and modelled levels was calculated as follows:

Difference = Modelled peak level – surveyed peak level

This gives a positive value where the model results are higher than that observed and a negative value when the model results are lower than that observed. The mapping categories are outlined in Figure 4-16, and mapped for the entire model area in Figure 4-17. The same difference classification has been used for all calibration events.

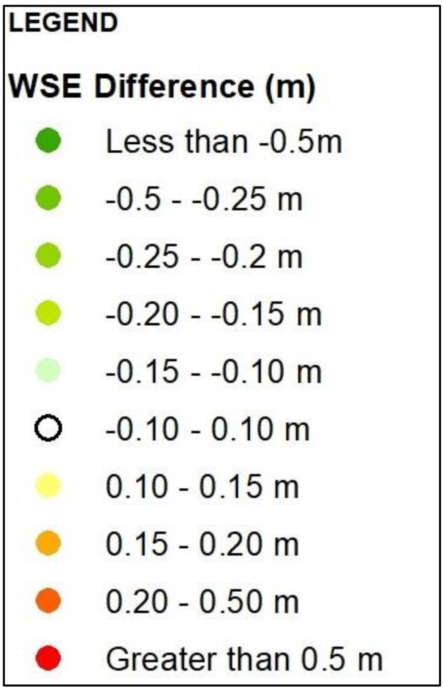

FIGURE 4-16 THEMATIC MAPPING CATEGORIES

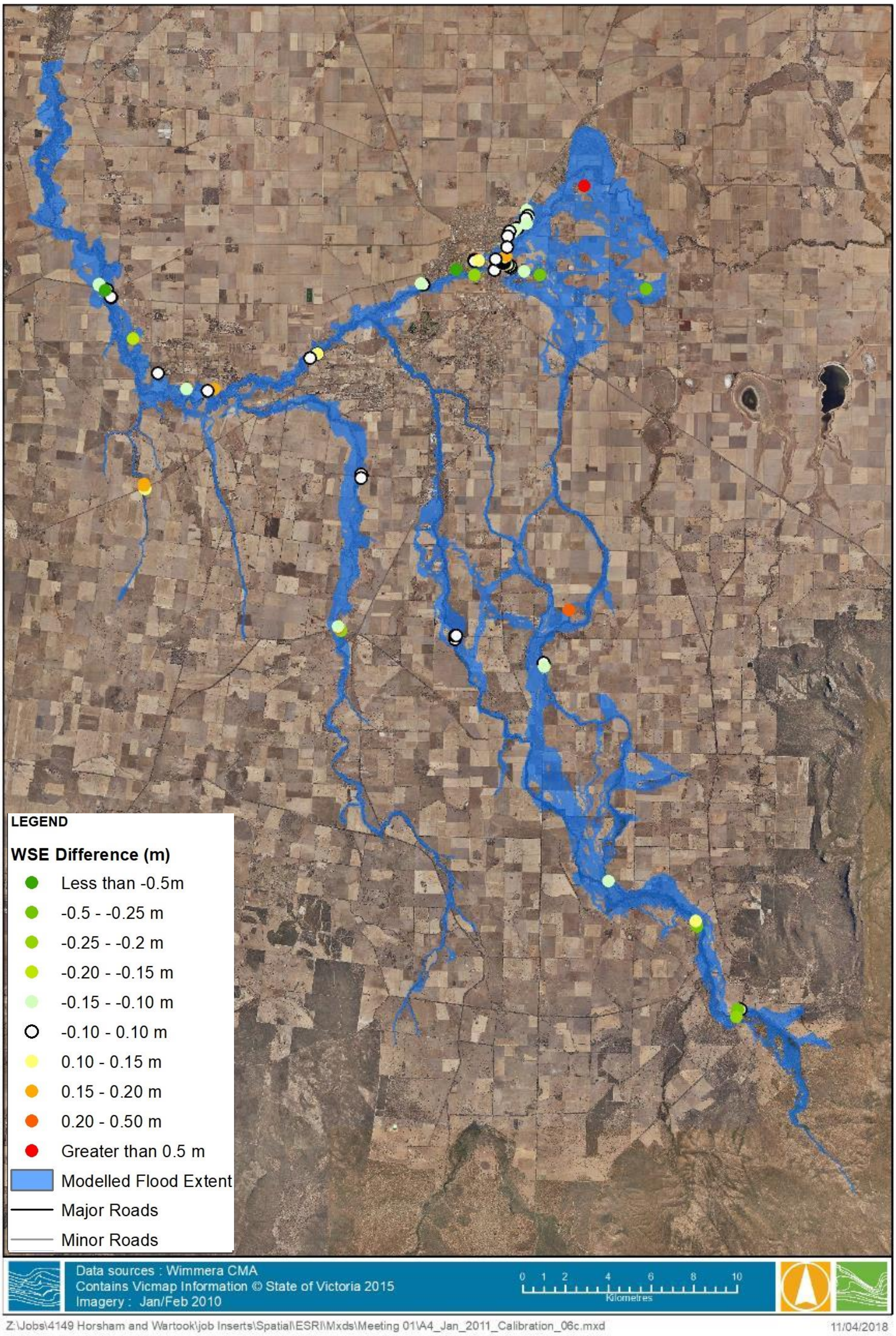

FIGURE 4-17 THEMATIC MAPPING – 2011 SURVEYED VS. MODELLED PEAK FLOOD HEIGHTS

The 14 points with a difference between surveyed and modelled levels greater than 200 mm were interrogated more rigorously. There are nine points showing the model results are too low, and six too high. The remaining 81 points all matched within 200mm showing an excellent model calibration in general and provided a solid foundation for design modelling.

The nine points that are showing the model results too low are discussed further below:

- Mackenzie River (2)
  - Mt Victory Road – the modelled level was 0.26 m below that surveyed and downstream of another point where the modelled level is 0.2 m lower than observed. Immediately upstream of the point the modelled and surveyed levels match within 0.1 m. The points are all on the edge of the flood extent. See Figure 4-18.
  - Brimpaen Laharum Road – the modelled level was 0.34 m below that surveyed and immediately upstream of a point with a modelled level 0.16 m lower than that observed. Downstream of the point two surveyed heights are showing the modelled levels to be 0.38 m and 0.14 m above that surveyed. See Figure 4-19.
- Norton Creek (1) – the modelled level was 0.23 m below that surveyed and is immediately upstream of a point with a modelled level 0.2 m below that surveyed. However, downstream of the point there are two surveyed points where the modelled level was 0.36 m higher than that observed and within 0.1 m of that observed. See Figure 4-20.
- East Horsham (3)
  - School Road – the modelled level was 0.28 m lower than that surveyed. No other points were in the vicinity. See Figure 4-21.
  - East of Riverside East Road – the modelled level was 0.43 m below that surveyed. There is a point 25 m north of the point 0.59 m above that observed. See Figure 4-22.
  - Horsham Lubeck Road – the modelled level is 0.26 m below that surveyed, there is a point immediately west with a modelled level 0.16 m below that observed. Downstream of the point there are numerous points matching within 0.1 m. See Figure 4-23.
- Horsham (2)
  - Major Mitchell Drive – the modelled level was 0.22 m lower than that surveyed, there is a point immediately east with a modelled level 0.2 m below that surveyed. See Figure 4-24.
  - Bennett Road – the point is north of the Wimmera River; the model results do not show water reaching this point. See Figure 4-24.
- Quantong (1) – the modelled level was 2.1 m below that surveyed. There are points immediately upstream and downstream with modelled levels within 0.1 m of that surveyed. See Figure 4-25.

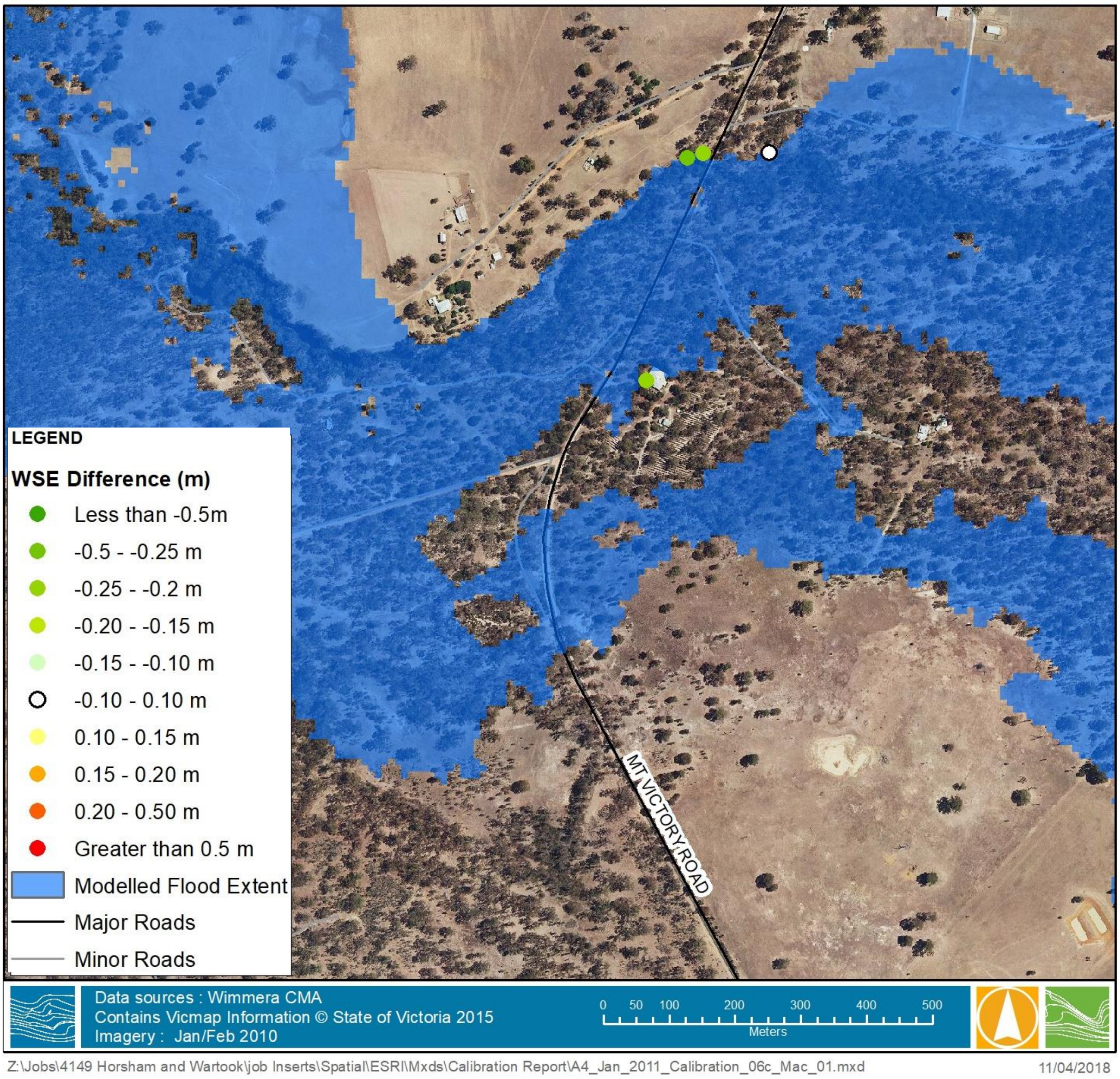

FIGURE 4-18 LOW POINTS – MACKENZIE RIVER AT MT VICTORY ROAD

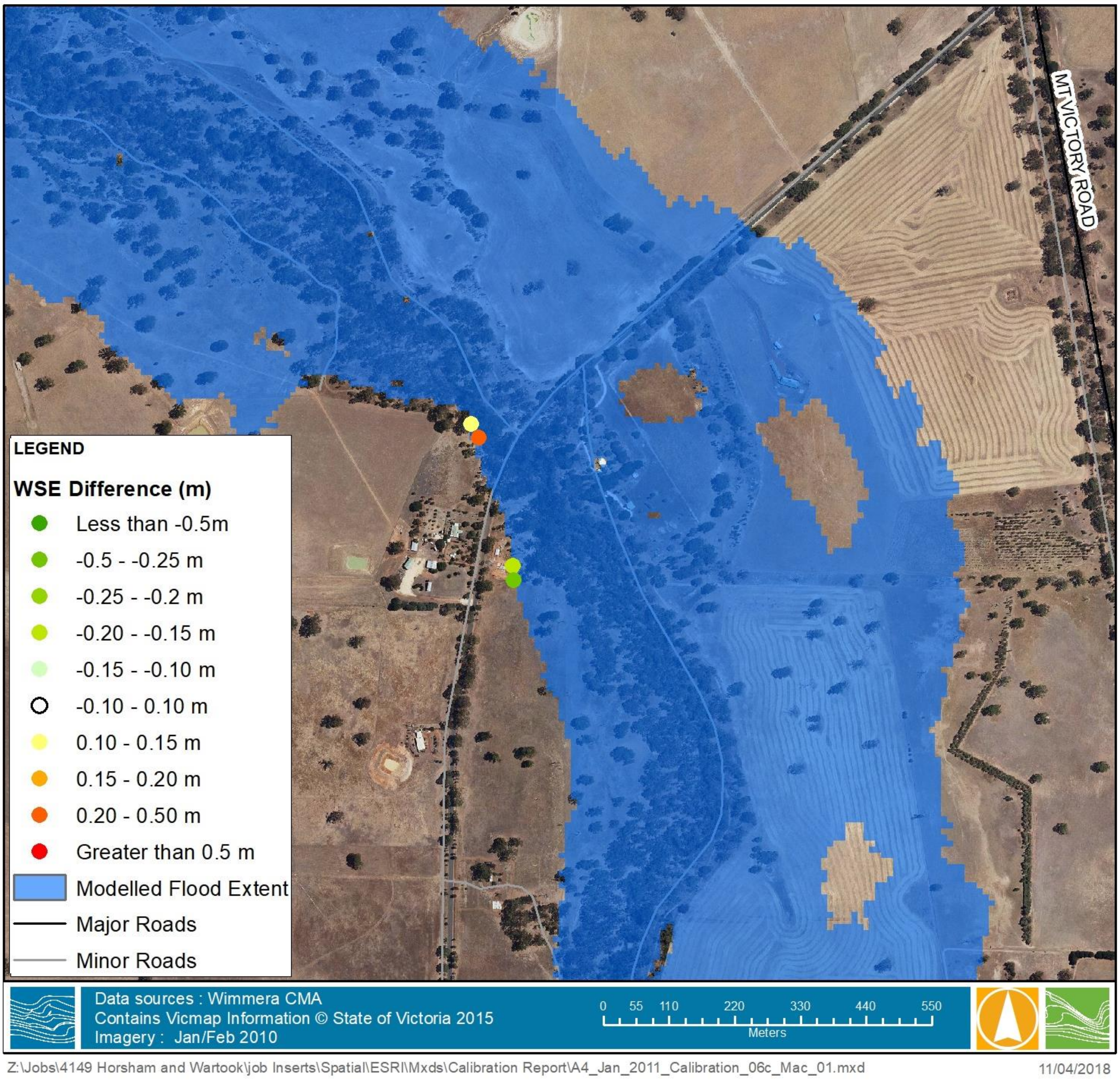

FIGURE 4-19 LOW POINTS – MACKENZIE RIVER AT BRIMPAEN LAHARUM ROAD

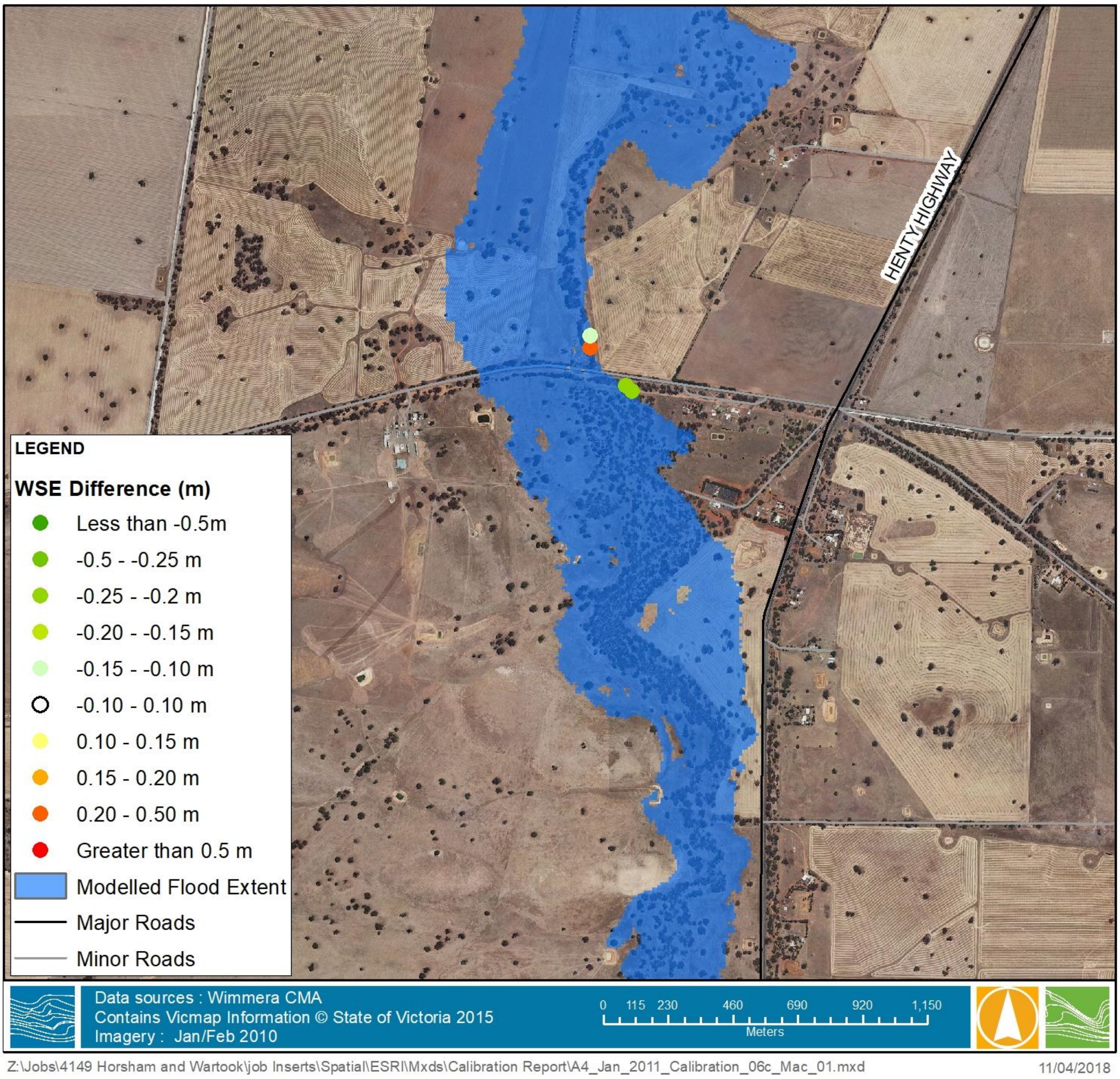

FIGURE 4-20 LOW POINTS – NORTON CREEK AT HENTY HIGHWAY

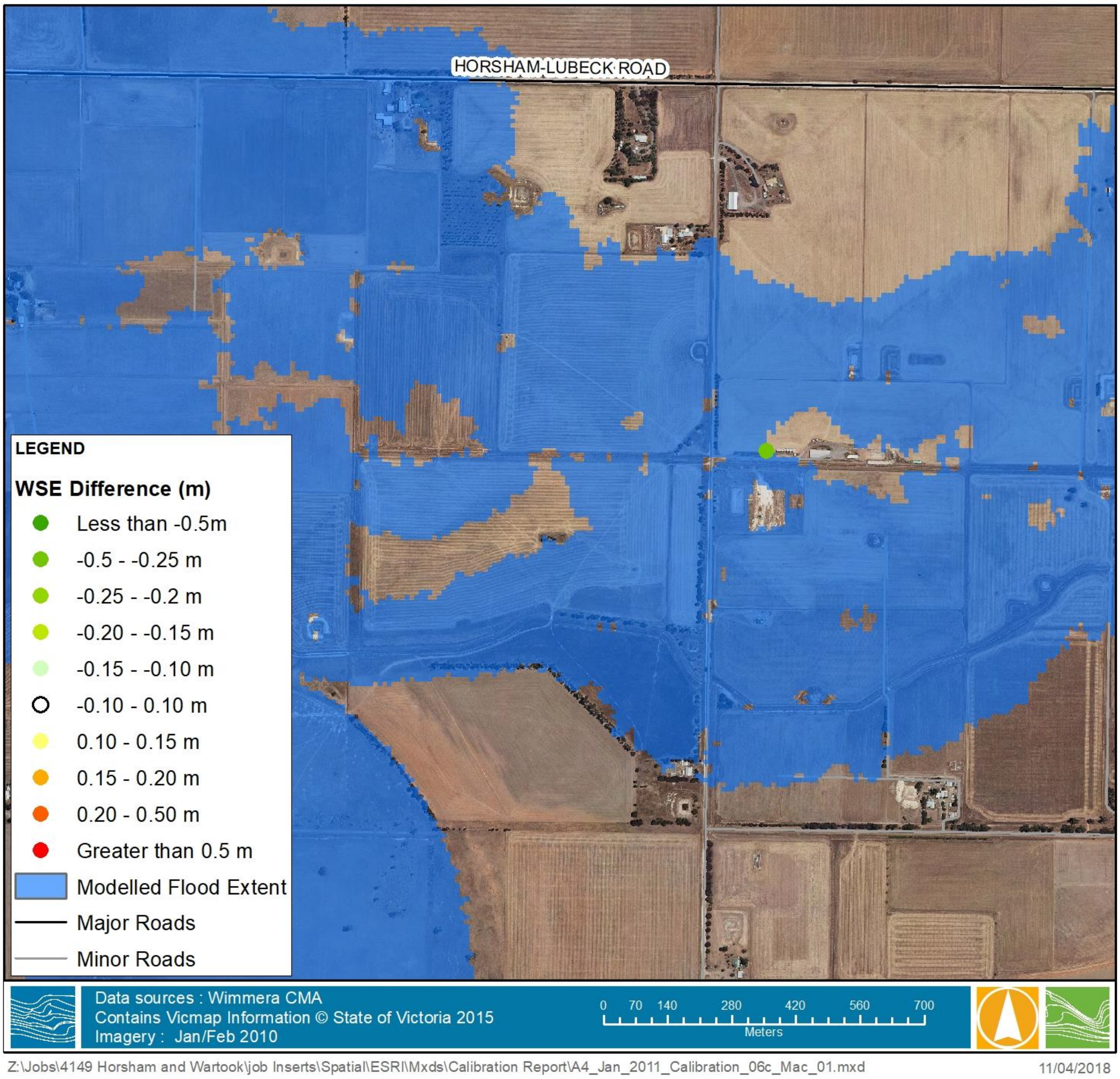

FIGURE 4-21 LOW POINTS - WIMMERA RIVER OVERLAND FLOW PATH AT SCHOOL ROAD

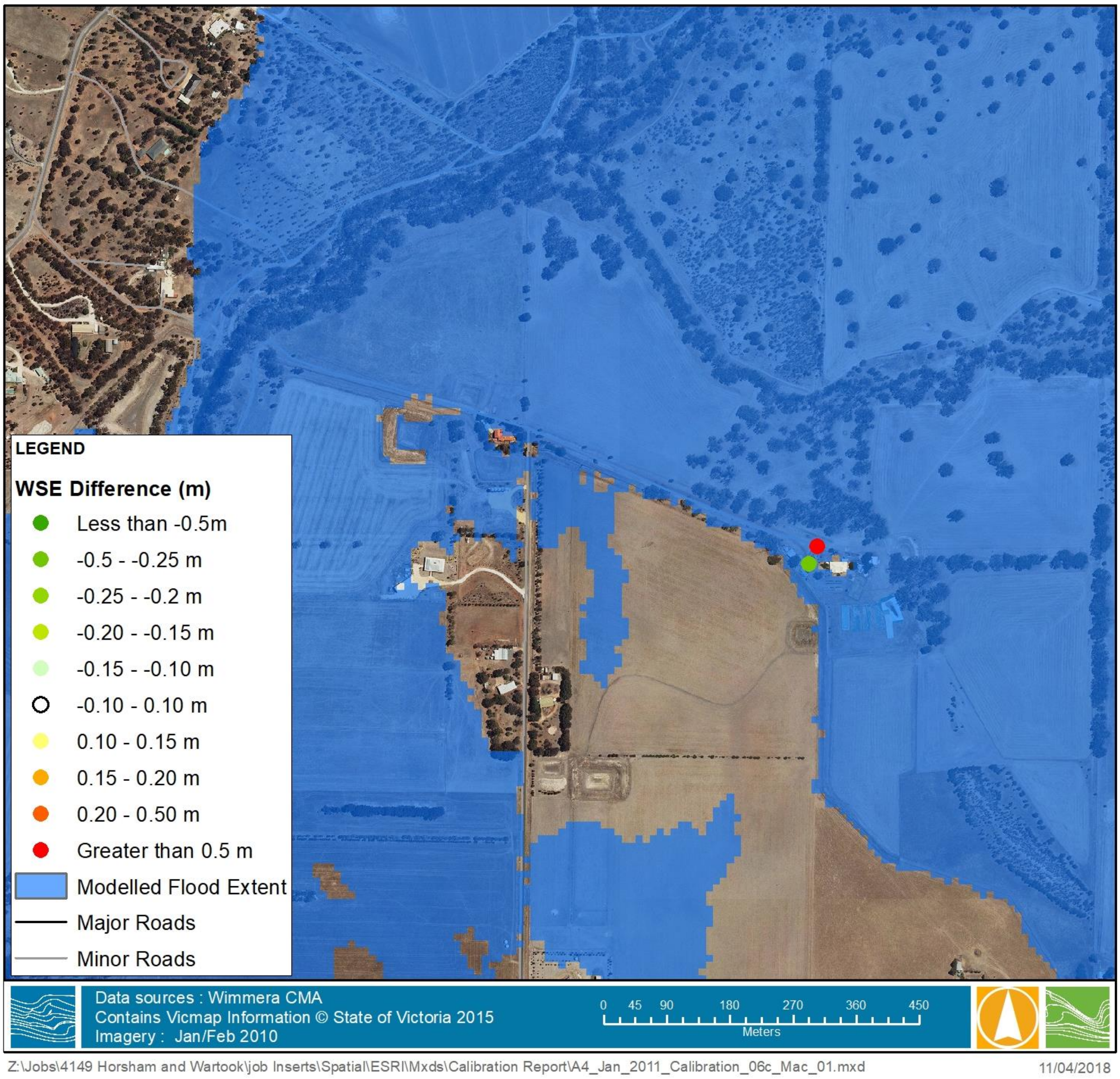

FIGURE 4-22 LOW POINTS - WIMMERA RIVER EAST OF RIVERSIDE EAST ROAD

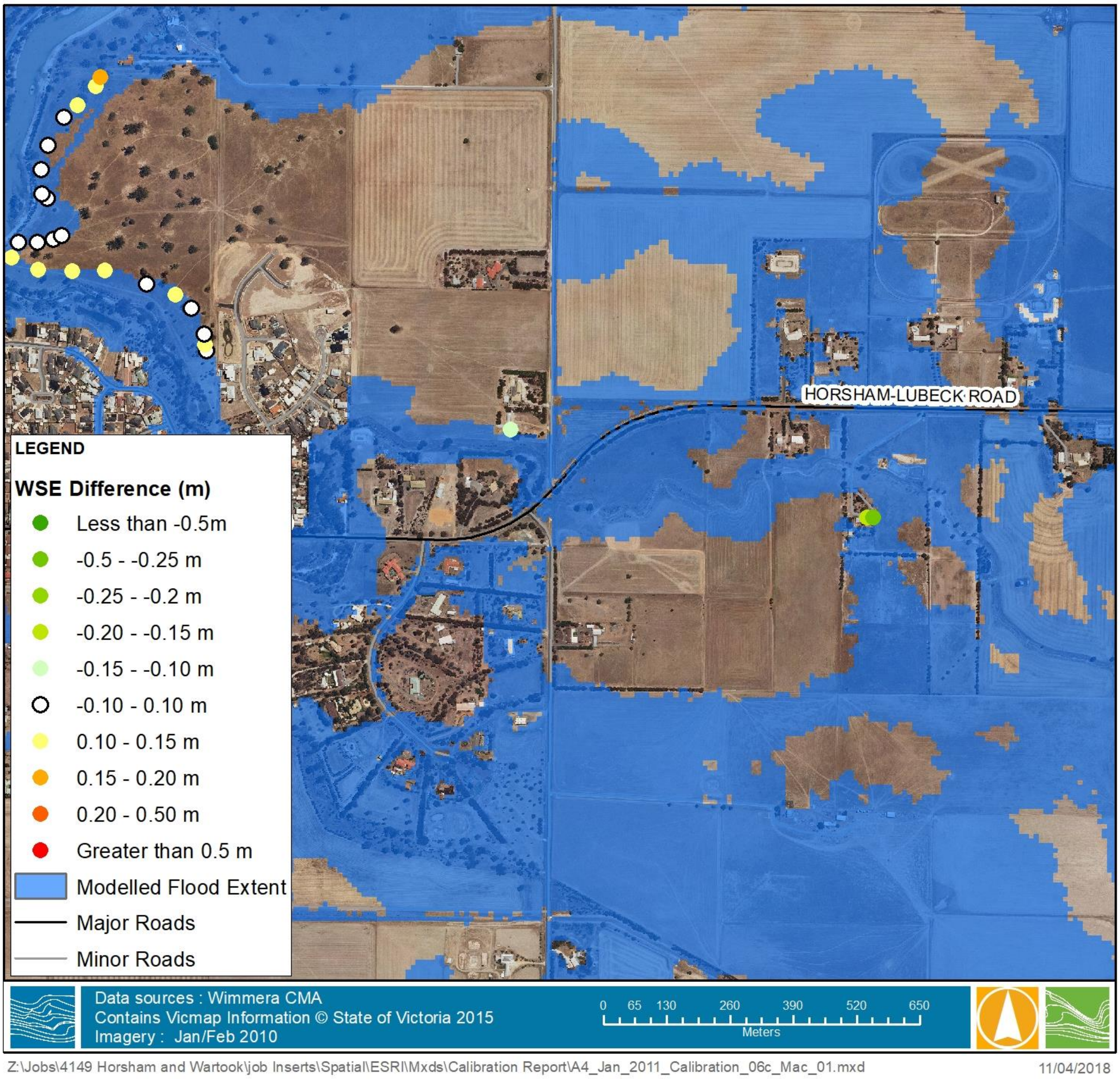

FIGURE 4-23 LOW POINTS - WIMMERA RIVER AT HORSHAM LUBECK ROAD

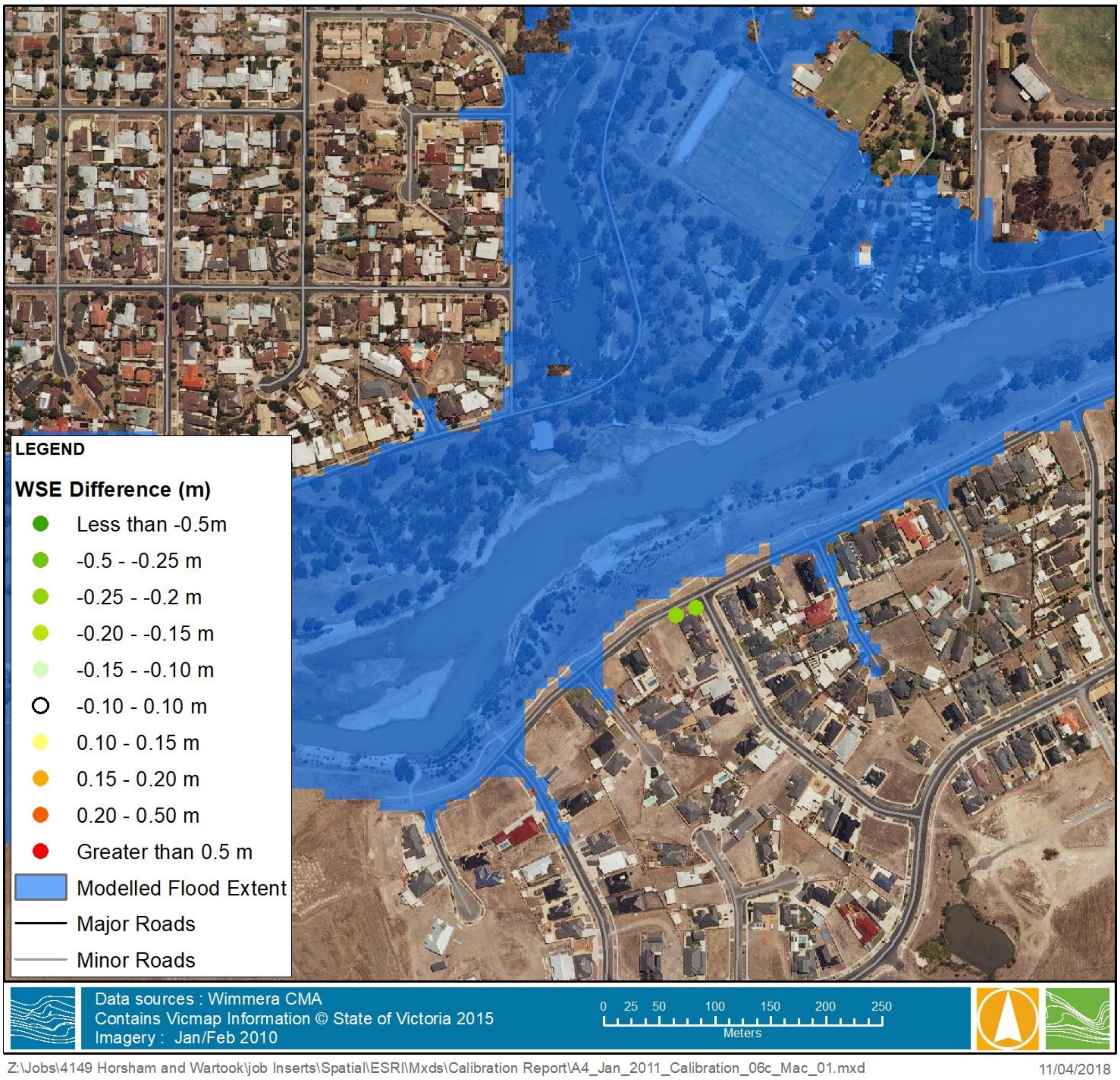

FIGURE 4-24 LOW POINTS - WIMMERA RIVER AT MAJOR MITCHELL DRIVE AND BENNETT ROAD

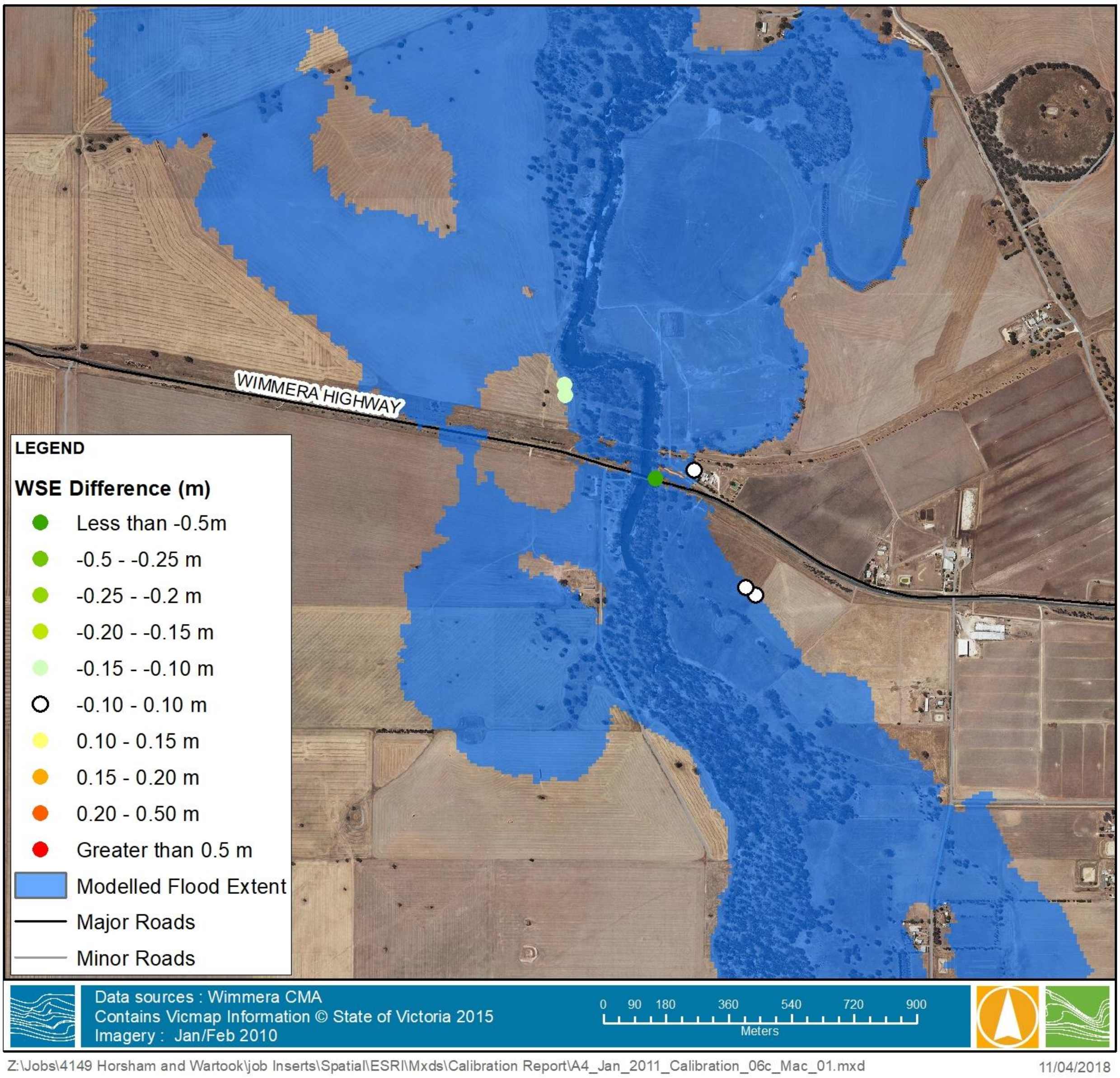

FIGURE 4-25 LOW POINTS - WIMMERA RIVER AT QUANTONG

The six points that are showing modelled water levels greater than 0.2 m above that surveyed are located as follows:

- Mackenzie River (1) – the point is downstream of Brimpaen Laharum Road, the modelled level was 0.38 m higher than that surveyed. The point is in direct proximity to another point with a modelled level 0.14 m above that surveyed and downstream of two points showing modelled water levels lower than that surveyed. See Figure 4-19.
- Burnt Creek (1) – the point is on the Burnt Creek floodplain, the modelled level was 0.36 m higher than that surveyed, there are no other flood heights in the vicinity. See Figure 4-26.
- Norton Creek (2)
  - Toolondo Road – there is a cluster of surveyed heights around the Norton Creek structure on Toolondo Road. On the downstream side one survey point showed the model results were 0.36 m

above that surveyed. Immediately north of the point another survey mark shows the model results are within 0.1 m of that surveyed. Upstream of the Toolondo Road two surveyed flood heights are both showing the modelled levels are lower than that surveyed. See Figure 4-20.

  - Plush Hannans Road – there is a cluster of four survey points around Plush Hannans Road on Norton Creek, one of the points shows the modelled level to be 0.38 m above that observed. The remaining three are within 0.1 m. See Figure 4-27.

- East Horsham Floodplain (1) – there is a surveyed flood height east of Riverside East Road showing the modelled flood level is 0.59 m above that observed. There is a surveyed point directly south of this showing the modelled level is 0.43 m above that observed. See Figure 4-22.

- Horsham (1) – within Horsham a surveyed flood height on Market Lane had a modelled flood height of 0.21 m above that surveyed. There are two survey points directly downstream of the point both within 0.1 m of that surveyed. See Figure 4-28.

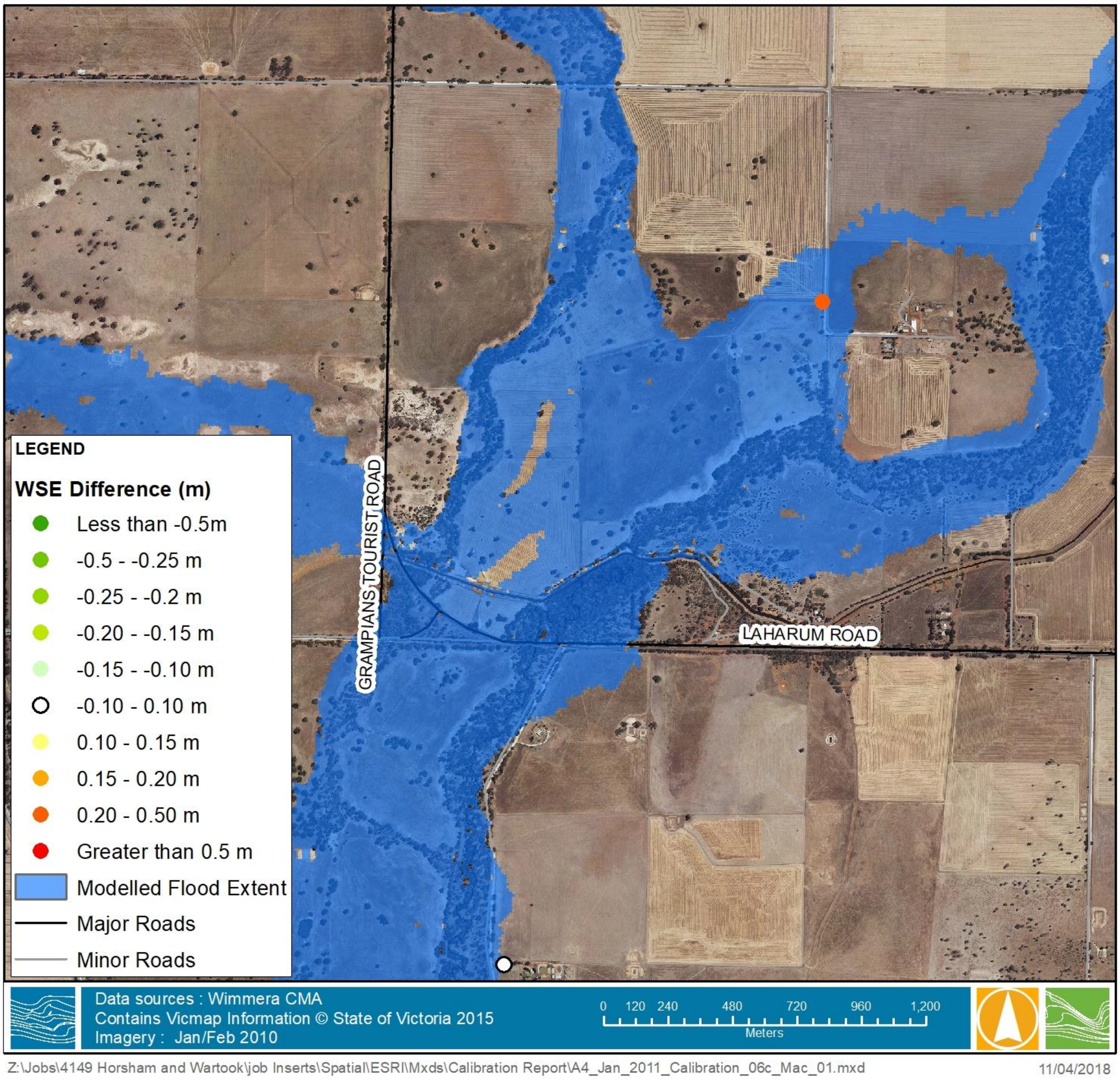

FIGURE 4-26 HIGH POINTS – BURNT CREEK FLOODPLAIN

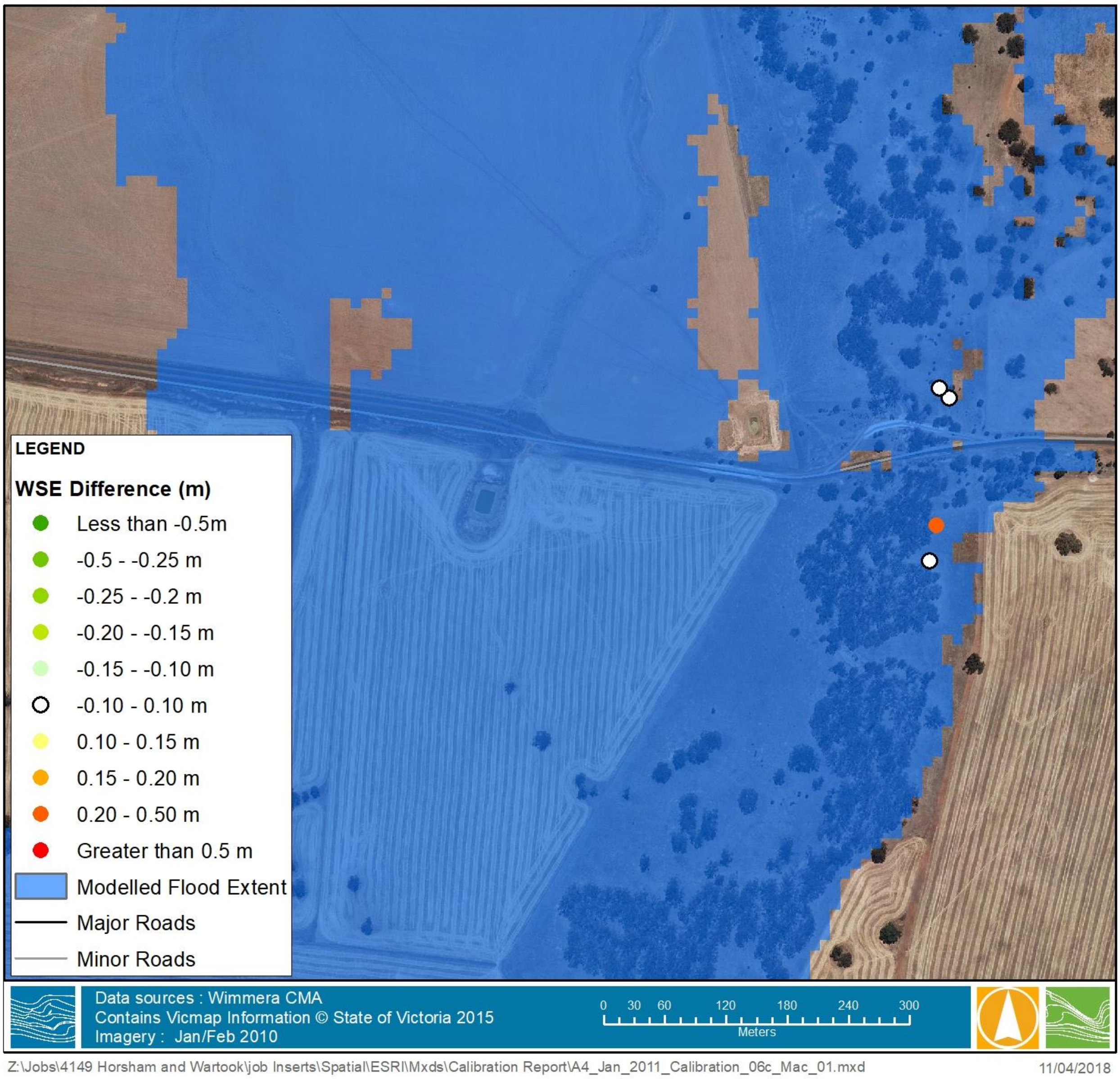

FIGURE 4-27 HIGH POINTS – NORTON CREEK AT PLUSH HANNANS ROAD

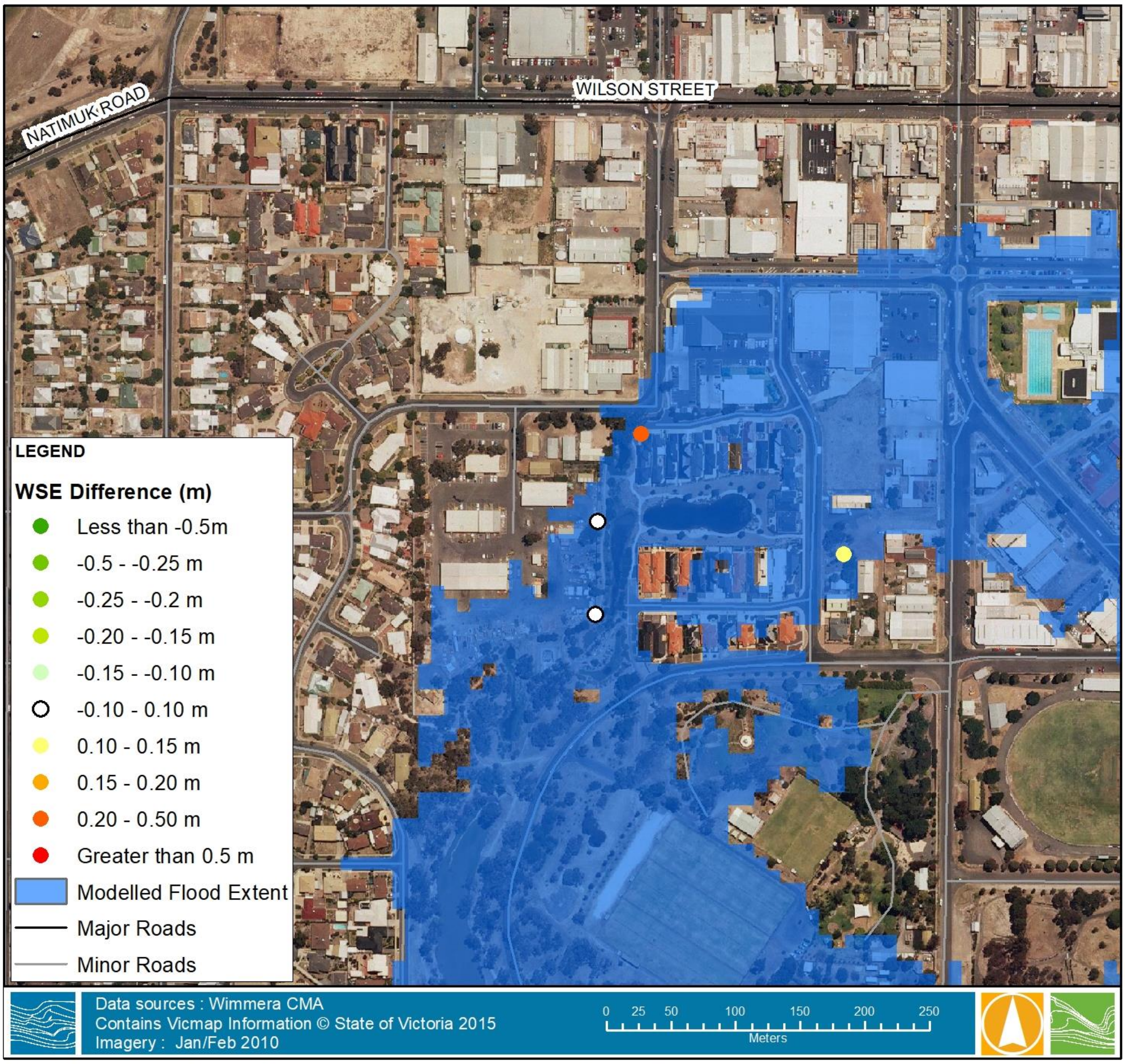

FIGURE 4-28 HIGH POINTS – WIMMERA RIVER AT MARKET LANE

4.4.1.1.2 STREAMFLOW RECORD – CALIBRATION SUMMARY

As discussed in Section 2.5.1 there are several streamflow gauges within the study area. The calibration of modelled levels at these gauges is summarised in Table 4-4.

The recorded and modelled peak levels at each gauge were shown to match within 0.2 m at all gauges. Timing was shown to be close at the Wimmera River gauges but with some discrepancy at the tributary gauges. See Table 4-5 a summary.

TABLE 4-4 RELEVANT STREAMFLOW GAUGES

ID	Gauge	Calibration Notes
415202	Mackenzie River @ Wartook Reservoir	Gauge is outside hydraulic model area and used as an inflow for historic events. Not used for model calibration.
415223	Burnt Creek @ Wonwondah East	Immediately downstream of the Burnt Creek distribution to Bungalally Creek. Used in the model calibration.
415249	Bungalally Creek @ McKenzie Creek	Very limited period of record. Water level information only, no gauge zero. Not used for model calibration.
415251	Mackenzie River @ McKenzie Creek	Upstream of the point where the Bungalally Creek enters the Mackenzie River. Used in the model calibration.
415200	Wimmera River @ Horsham (Walmer)	Was rigorously investigated as part of the Lower Wimmera River Regional Flood Mapping Study. Flow and water level information. Used in the model calibration.
415273	Norton Creek @ Lower Norton	Water level information only, no gauge zero. Not used in model calibration.
415261	Wimmera River @ Quantong	Water level information only, no rating curve. Used in model calibration.

TABLE 4-5 JANUARY 2011 - GAUGE HEIGHT AND TIMING COMPARISON

ID	Gauge	Gauged		Modelled		Difference	
		Level (m AHD)	Time of peak	Level (m AHD)	Time of peak	Height (m)	Timing (hrs)
415223	Burnt Creek @ Wonwondah East	156.01	14/01/2011 5:00	155.84	12/01/2011 17:55	-0.17	+35
415251	Mackenzie River @ McKenzie Creek	136.89	15/01/2011 8:00	137.02	13/01/2011 0:10	+0.13	-7.5
415200	Wimmera River @ Horsham	124.66	18/01/2011 11:00	124.62	18/01/2011 11:00	-0.04	0
415261	Wimmera River @ Quantong	117.37	18/01/2011 22:00	117.36	18/01/2011 18:15	-0.01	-3.75

4.4.1.1.3 AERIAL IMAGES

There were three types of aerial images captured during January 2011:

- Linescan images (thermal imaging which can identify water bodies effectively).
- Orthorectified photos captured from a fixed wing aircraft (18th January 2011).
- Photos captured from a helicopter with GPS points associated.

The orthorectified photos provide the best representation of the flooding due to the detail captured. Two photos were captured covering the Riverside and Horsham areas. The images are shown in Figure 4-29 with the maximum flood extent overlayed.

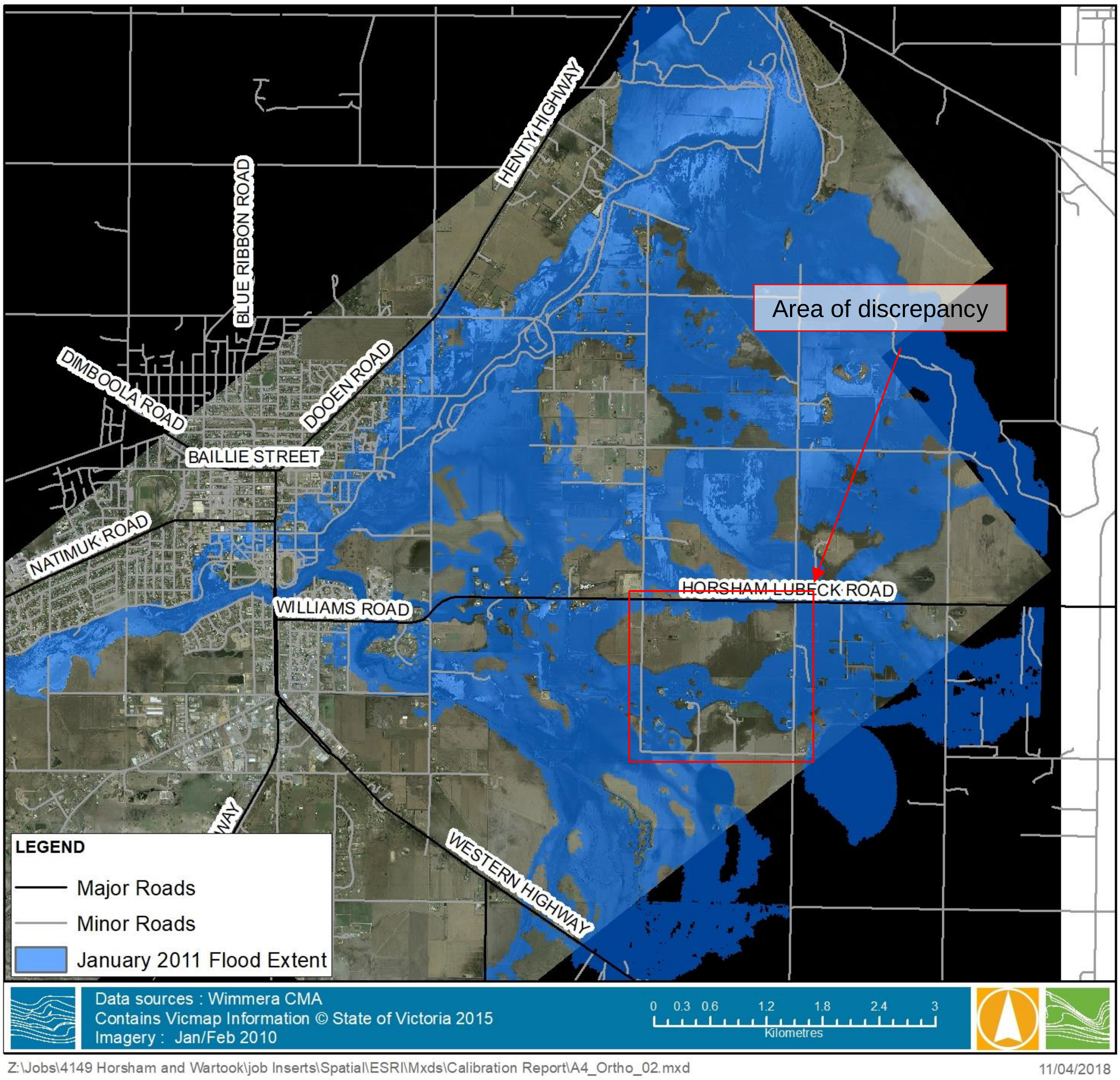

FIGURE 4-29 ORTHORECTIFIED AERIAL IMAGES WITH THE MODELLED FLOOD EXTENT OVERLAYED

The comparison highlighted the main areas of discrepancy in East Horsham, south of Horsham Lubeck Road, this area is highlighted in Figure 4-30.

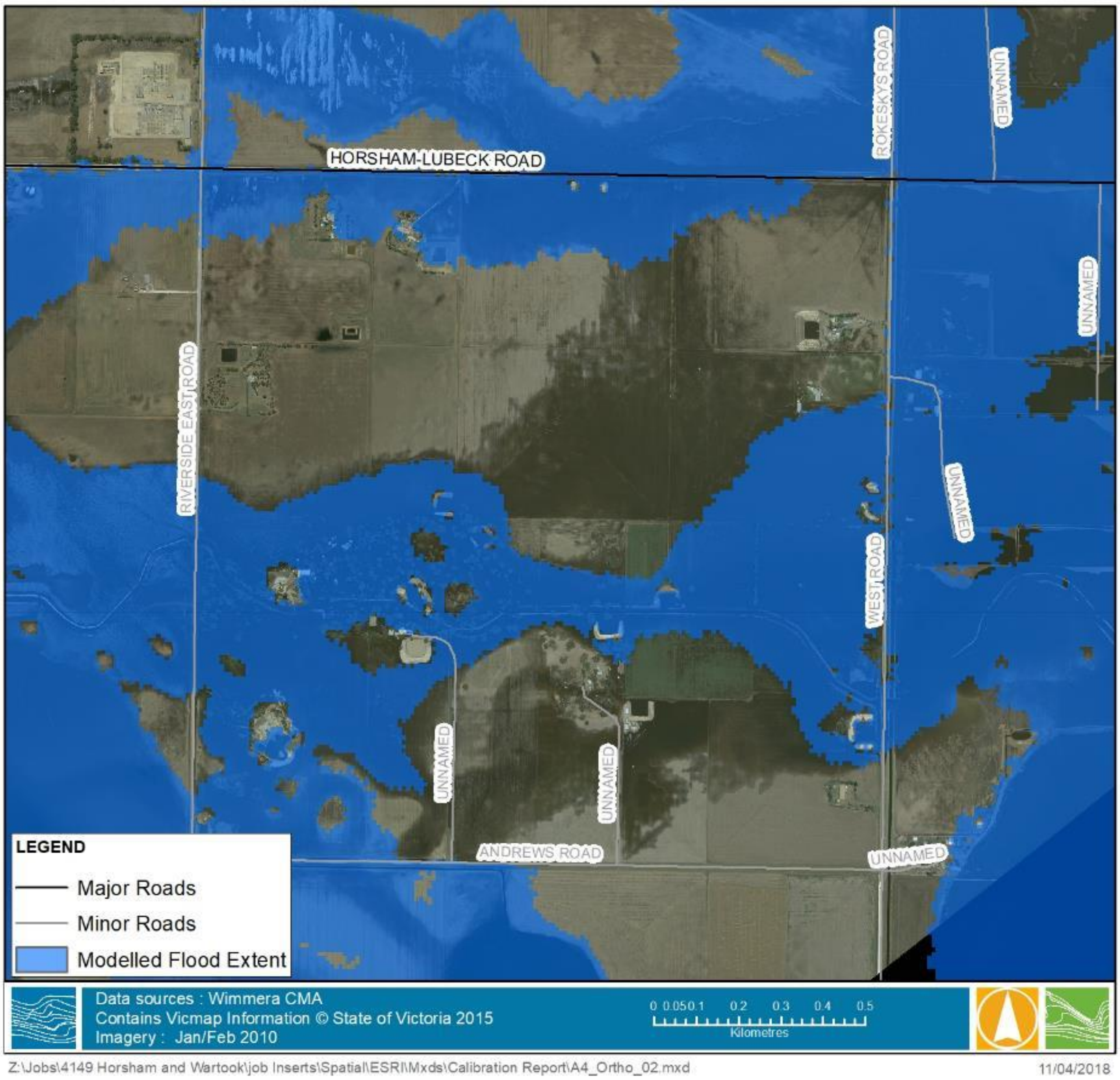

FIGURE 4-30 ORTHORECTIFIED AERIAL IMAGES WITH THE MODELLED FLOOD EXTENT OVERLAYED – SOUTH OF HORSHAM LUBECK ROAD

The modelled flood extent matches in reasonably well except for the area immediately west of West Road, where there is a greater flood extent in the observed image. Further downstream at Riverside East Road the match is close again. The difference is believed to be due to changes made to channel infrastructure prior to or during the January 2011 event; however, further investigation would be required to determine this.

4.4.1.1.4 DISCUSSION

Modelling of the January 2011 event has shown a good match to surveyed flood heights and gauge records. There were several areas in the East Horsham area where infrastructure has influenced flood levels. Channels and roads have been stamped into the model topography; however, it is highly likely breaches, excavations or water carried along the channels are not fully represented in the model as no data is available regarding any breaches that occurred. The channels in East Horsham have been decommissioned since 2011 and how well they are represented in the calibration becomes somewhat irrelevant given they will be removed as part of the design modelling.

4.4.1.2 September 2016

The September 2016 event occurred at the beginning of this project, it was a smaller event and therefore the same quantity of data wasn't collected as January 2011. The data available for the model calibration included:

- Water level and flow information at the following streamflow gauges:
  - Wimmera River at Horsham (Walmer)
  - Wimmera River at Quantong
  - Burnt Creek at Wonwondah East
  - Mackenzie River at McKenzie Creek
- Peak flood height information captured after the event by Wimmera CMA.

4.4.1.2.1 SURVEYED FLOOD HEIGHTS

There were 41 surveyed peak flood heights captured by Wimmera CMA during and after the September 2016 event. Like January 2011, the surveyed flood heights were compared to the modelled levels and mapped thematically (see Figure 4-16).

A comparison of modelled and surveyed levels across the entire model area is shown in Figure 4-31.

The 41 points are distributed across the study area floodplain as follows:

- Mackenzie River – 7
- Bungalally Creek – 4
- Wimmera River - 11
- Burnt Creek – 19

Of the 41 points there are 19 modelled levels within 200 mm of that surveyed, and 10 within 100 mm of that surveyed.

Along the Mackenzie River the upstream most point matches within 0.1 m at Brimpaen Laharum Road, the remaining points are at the lower end of the Mackenzie River and are all showing the modelled levels higher than that surveyed. A closer perspective of this area is shown in Figure 4-32.

At Old Hamilton Road (the Mackenzie River at McKenzie Creek gauge) the modelled level is 0.89 m above that observed. While at the Henty Highway there are three points at the bridge structure and at Three Bridges Road there are two. A closer perspective of these three locations is shown in Figure 4-33, Figure 4-34 and Figure 4-35.

At the Mackenzie River at McKenzie Creek gauge the surveyed level was 135.69 m AHD, this compared to a modelled height of 136.58 m AHD. The gauge recorded a height of 136.19 m AHD. Comparing to the surveyed heights the model produced a water level 0.89 m high, however comparing to the gauge record the modelled water levels were 0.39 m higher. Given the surveyed flood height is 0.5 m lower than the recorded stream flow gauge at this location, the accuracy of the survey is considered questionable.

There were two surveyed heights upstream of the Henty Highway, both levels were showing the modelled heights to be higher than that surveyed, one by 0.79 m the other 0.3 m. These levels are directly beside one another, casting doubt over the accuracy of the survey. The point on the downstream side of the Henty Highway is showing a modelled level 0.12 m above that surveyed.

At three Bridges Road there are levels upstream and downstream of the bridge structure, upstream of the bridge the modelled level is 0.24 m above that surveyed while the downstream level is within 0.1 m.

Along Bungalally Creek there are six surveyed levels, four in the lower reach, two at each the Henty Highway and Old Hamilton Road, and two in the upper reach, immediately after the distribution from Burnt Creek. The lower Bungalally Creek points are shown in Figure 4-31 with the upper points shown in Figure 4-36.

At the Henty Highway, the upstream point has a modelled water level 0.16 m lower than observed, while the downstream modelled water level is within 0.1 m of that observed. At Old Hamilton Road the two points show the modelled water level 0.2 and 0.18 m lower than that observed. In the upper Bungalally Creek the two points are 0.27 m too low, and within 0.1 m.

In East Horsham there are seven points scattered across the floodplain, as shown in Figure 4-37. Four of these points are located outside the modelled flood extent, however, there is some thought the levels may have been generated by direct rainfall accumulation. Three of the points are clustered at the end of Riverside East Road, the modelled levels at these points are within 25 m of each other and the modelled levels match that observed by 0.0 m, 0.12 m and 1.16 m. There is clearly an issue with one of the surveyed marks.

On the Wimmera River directly upstream of Horsham there are five surveyed flood heights, of these points two match within 0.1 m, one 0.12 m and the other 0.25 m. These points are highlighted in Figure 4-38.

Along the lower end of Burnt Creek there are 14 survey points, five of these points are located along Horsham Lubeck Road, while the remaining nine are in a cluster south of Horsham Lubeck Road. Of the points on Horsham Lubeck Road one point shows a modelled level within 0.1 m of that surveyed, two are approximately 0.15 m lower than that surveyed and the remaining two are greater than 0.4 m above that surveyed. In the cluster of nine surveyed points the modelled levels are generally 0.3 m lower than that surveyed.

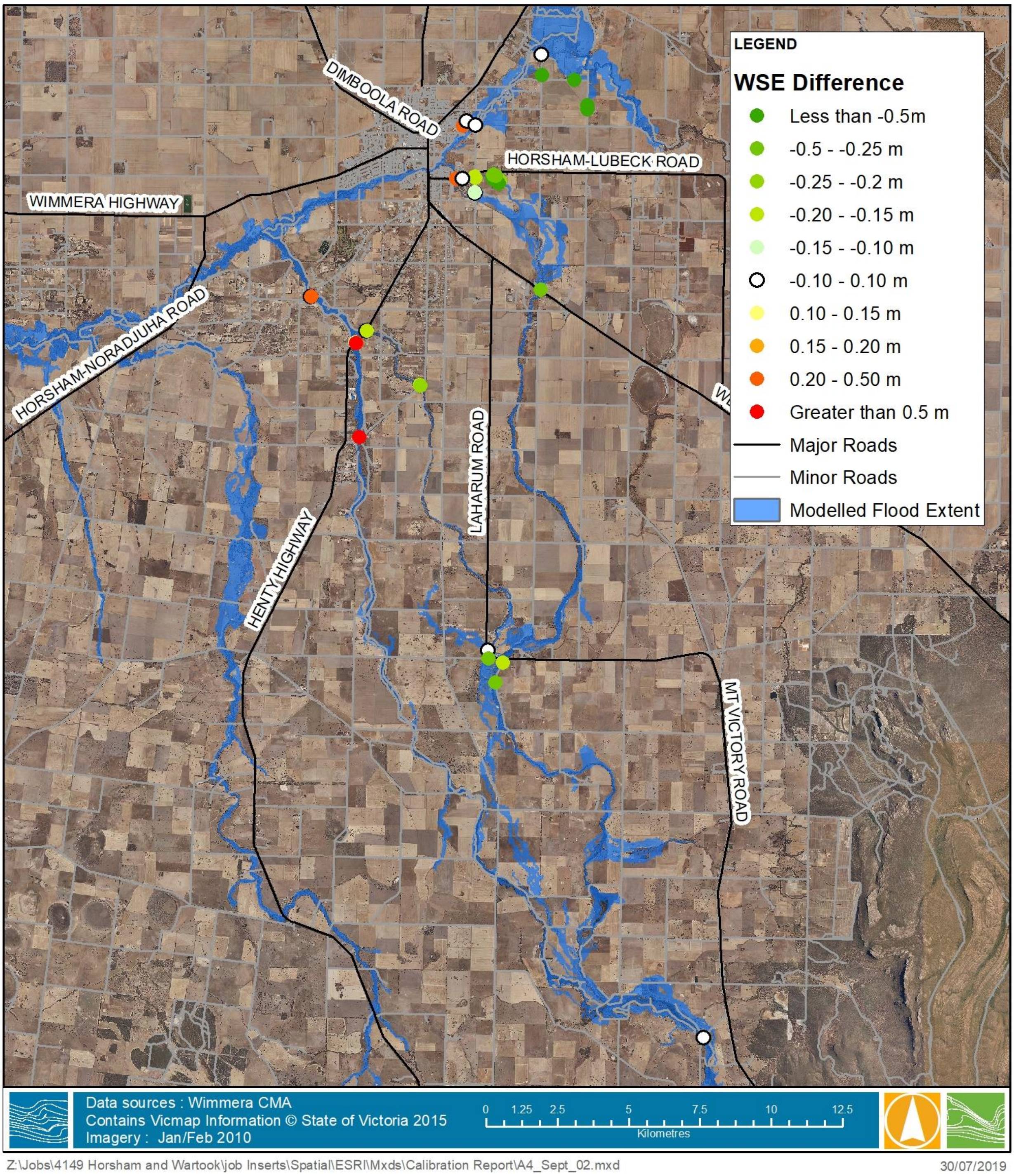

FIGURE 4-31 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON

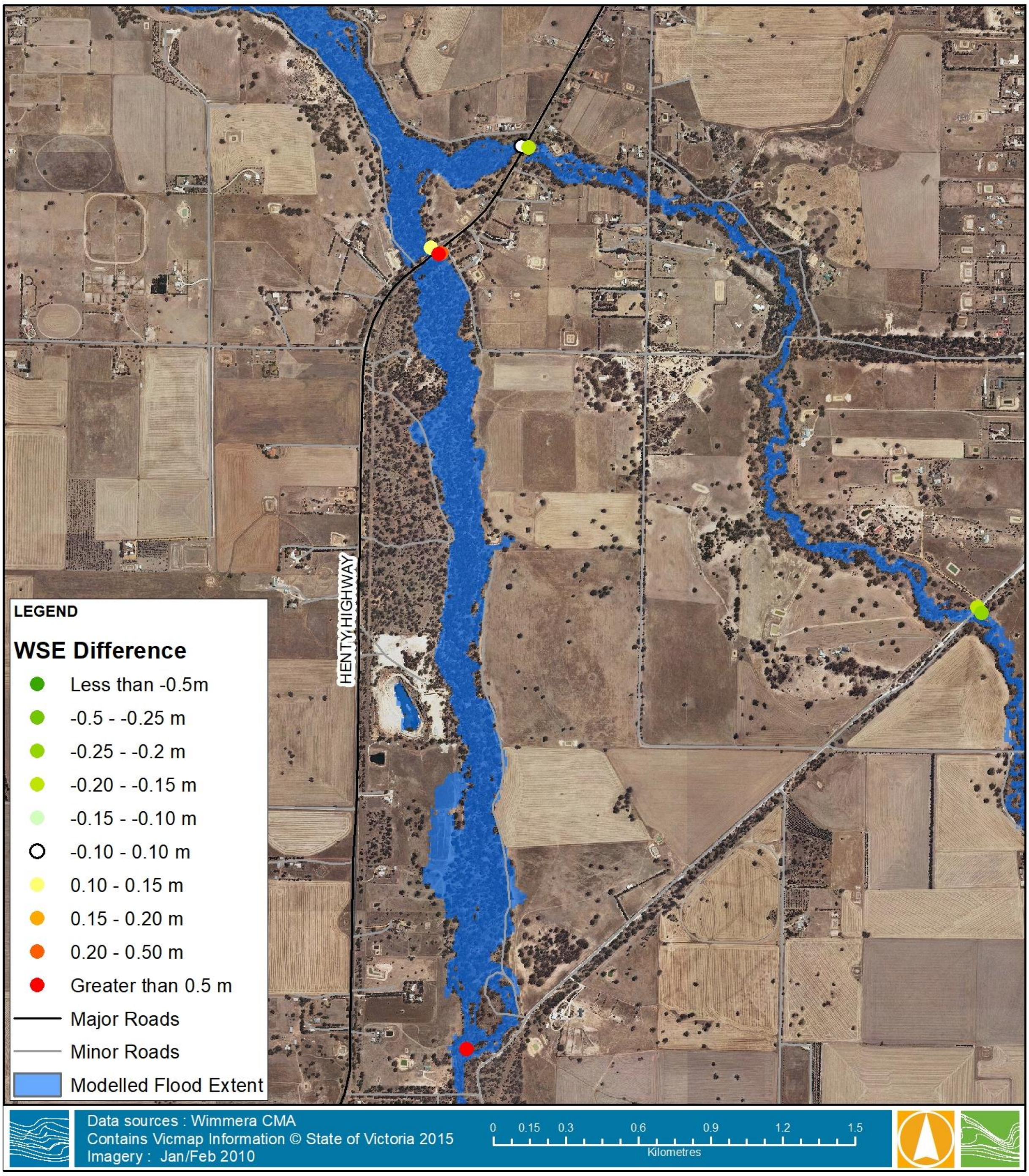

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FIGURE 4-32 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON – LOWER MACKENZIE RIVER/BUNGALALLY CREEK

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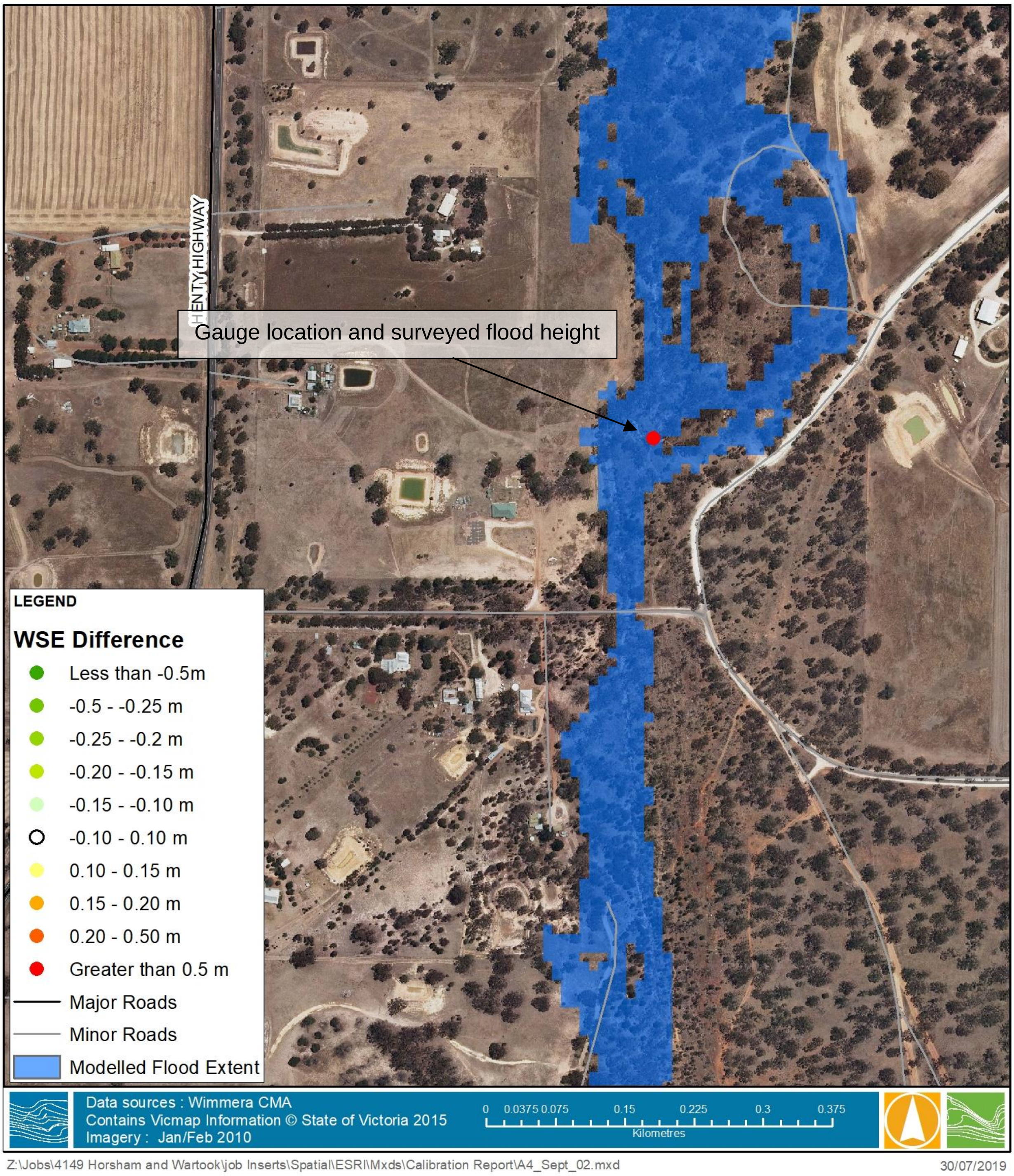

FIGURE 4-33 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON – MACKENZIE GAUGE

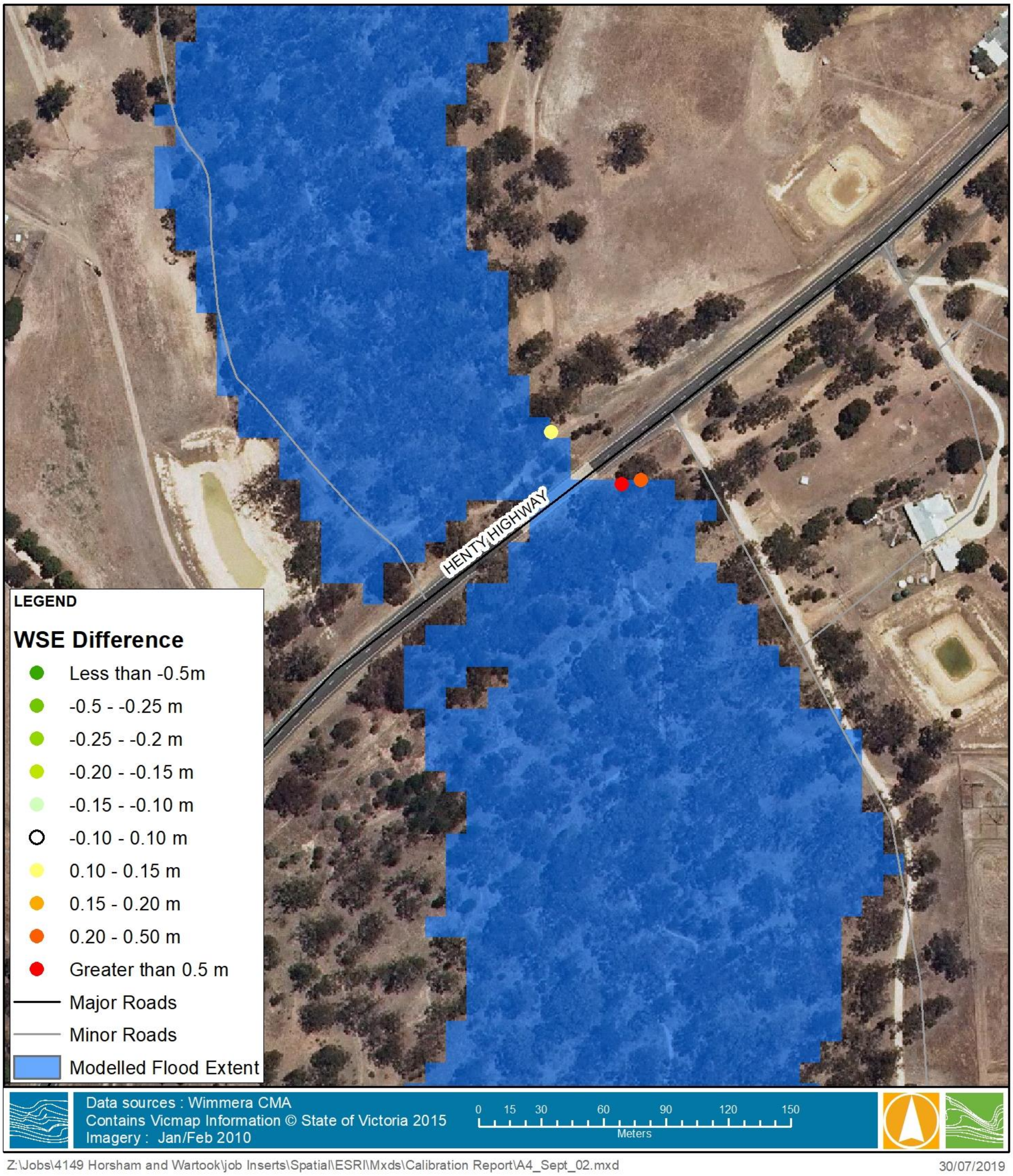

FIGURE 4-34 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON – HENTY HIGHWAY

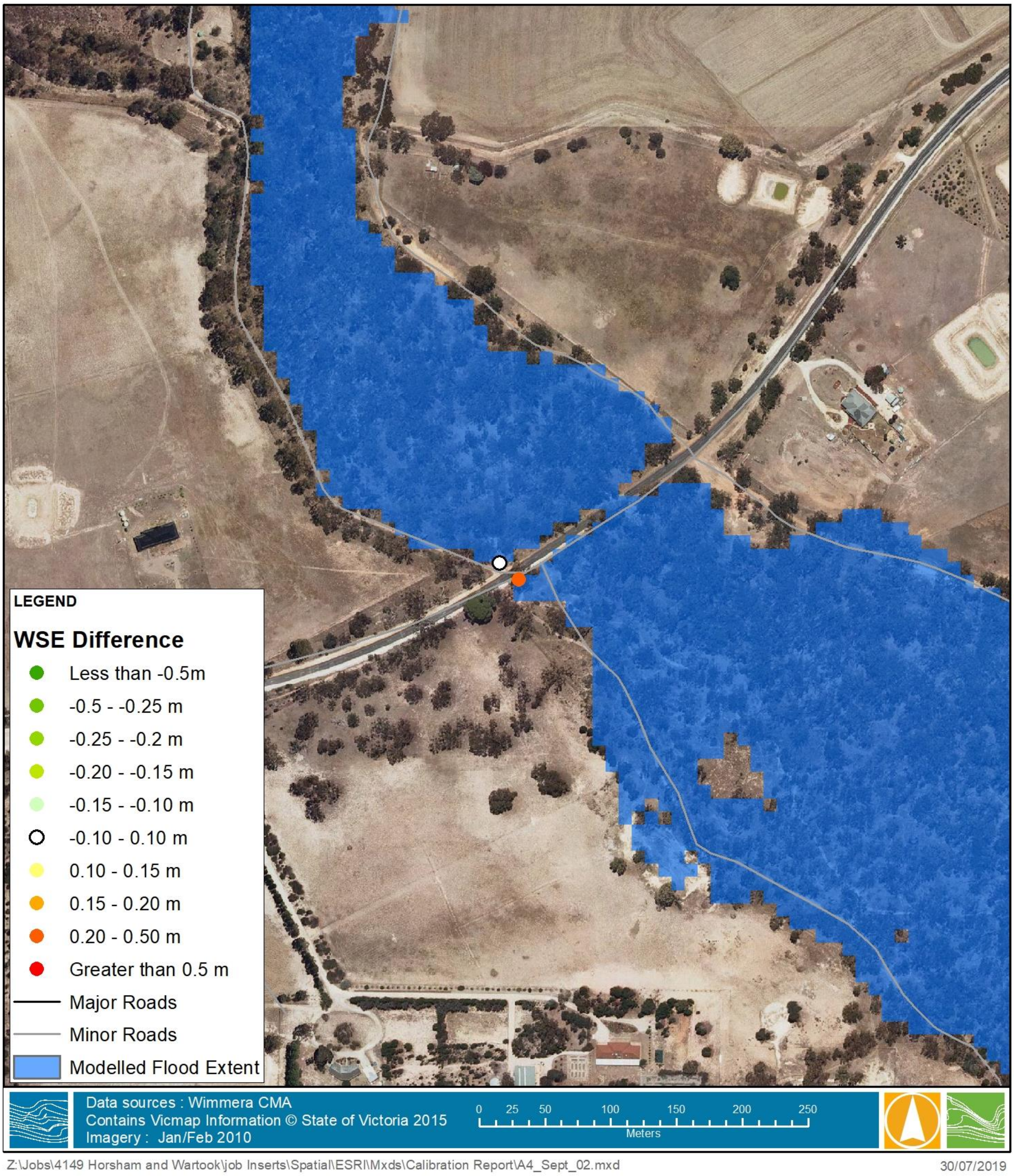

FIGURE 4-35 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON – THREE BRIDGES ROAD

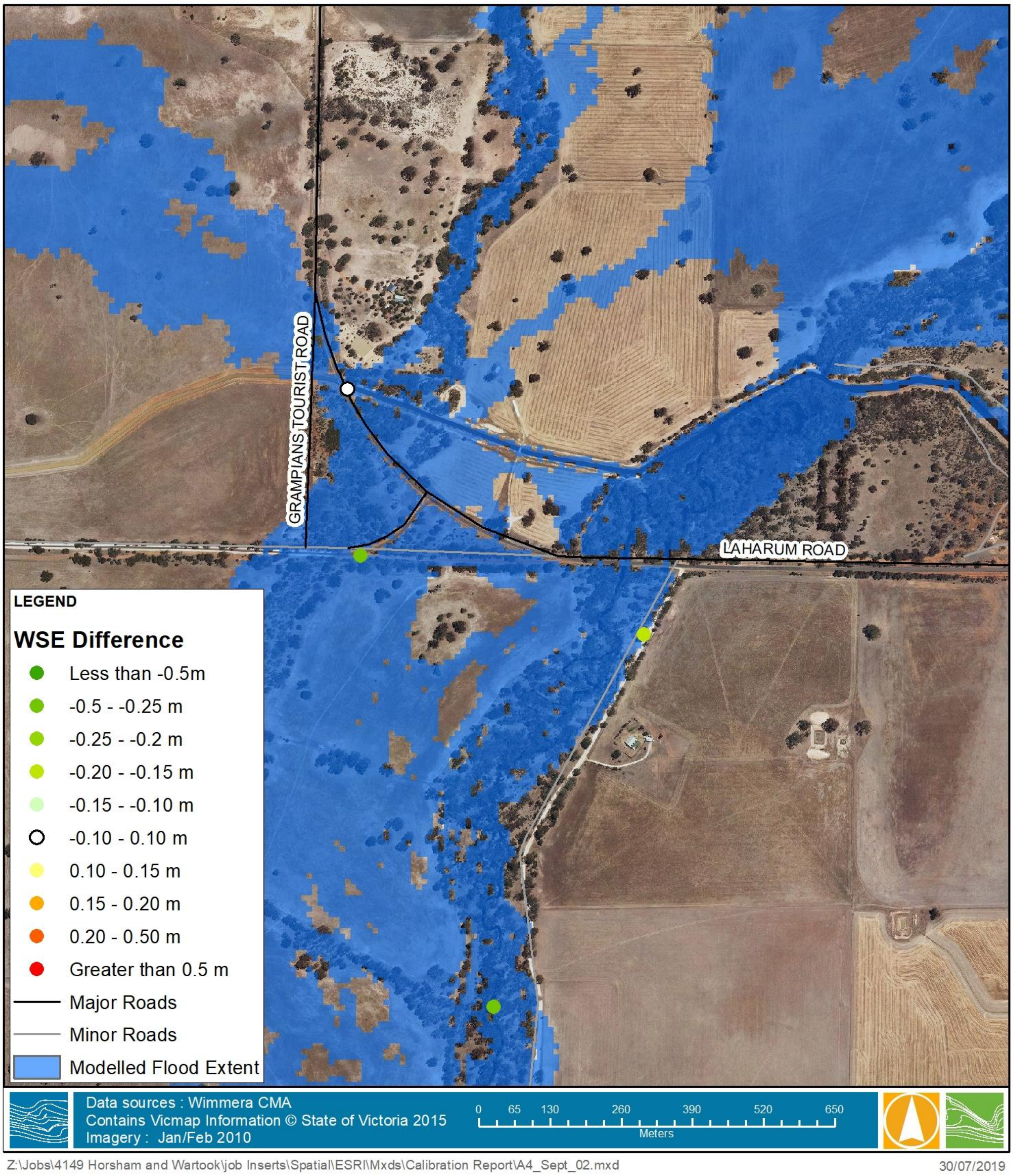

FIGURE 4-36 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON – UPPER BUNGALALLY CREEK

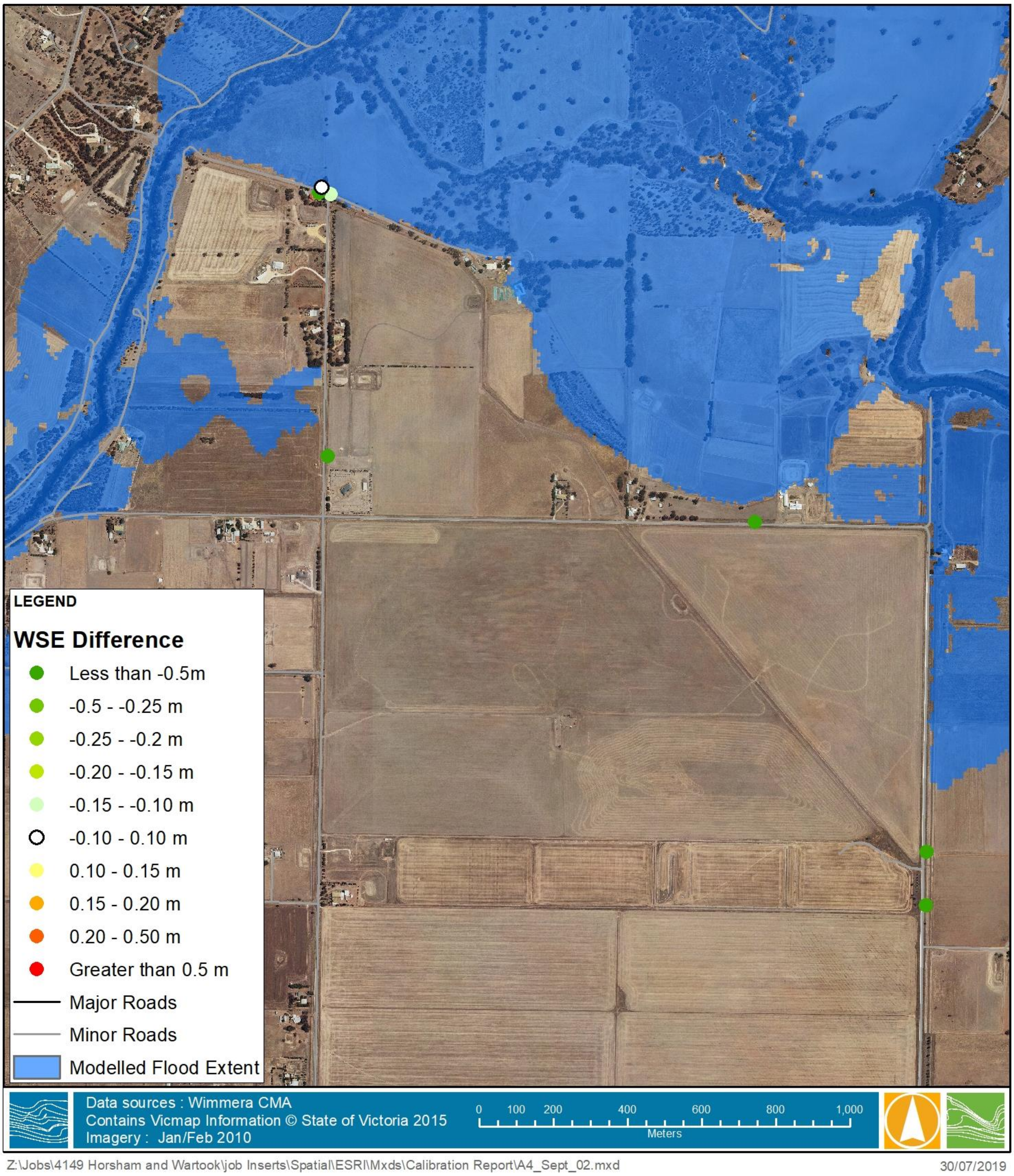

FIGURE 4-37 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON – WIMMERA RIVER EAST HORSHAM

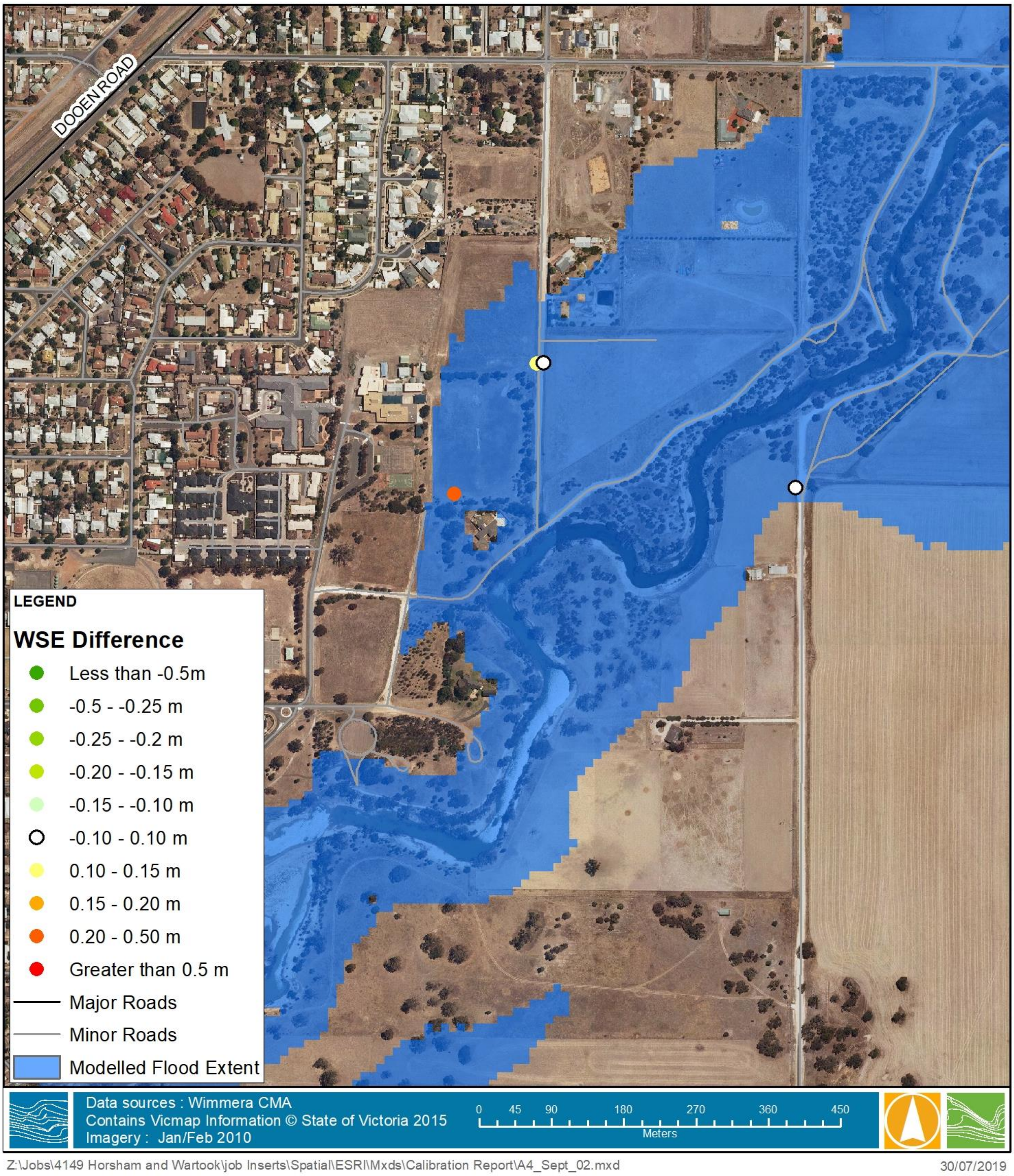

FIGURE 4-38 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON – WIMMERA RIVER US HORSHAM

FIGURE 4-39 SEPTEMBER 2016 MODELLED AND SURVEYED LEVEL COMPARISON – LOWER BURNT CREEK

4.4.1.2.2 STREAMFLOW RECORDS

As discussed in Section 4.4.1.2.2 there are four streamflow gauges within the study area able to be used for calibration. A summary of the comparison between modelled and observed levels is shown in Table 4-4. The recorded and modelled peak levels at each gauge were shown to match within 0.3 m at all gauges. Timing was shown to be close at the Wimmera River gauges but with some discrepancy at the tributary gauges. See Table 4-6 for details.

TABLE 4-6 SEPTEMBER 2016 - GAUGE HEIGHT AND TIMING COMPARISON

ID	Gauge	Gauged		Modelled		Difference	
		Level (m AHD)	Time of peak	Level (m AHD)	Timing	Height (m)	Timing (hours)
415223	Burnt Creek @ Wonwondah East	156.01	14/09/2016 19:15	155.74	14/09/2016 14:30	-0.27	+4
415251	Mackenzie River @ McKenzie Creek	136.89	12/09/2016 2:00	136.59	15/09/2016 13:45	-0.30	+17
415200	Wimmera River @ Horsham	123.75	19/09/2016 5:45	123.63	19/09/2016 3:44	-0.12	+2
415261	Wimmera River @ Quantong	116.59	19/09/2016 21:30	116.83	19/09/2016 14:09	0.24	+7

4.4.1.2.3 DISCUSSION

The September 2016 calibration is not as strong as January 2011, with several areas of discrepancy. However, there are some obvious concerns around the accuracy of the 2016 calibration data with points in direct proximity to one another showing large differences in elevation and surveyed points not matching known recorded gauge heights. This was also observed in the Lower Wimmera Regional Flood Mapping Study[16] in the September 2010 flood height survey. The approach to pegging of flood heights can sometimes be questionable with pegs placed before the peak level is reached.

In general, the location of the points and the modelled extent indicates the model is producing the observed flood extent quite well.

4.4.2 Stormwater Inundation

The stormwater inundation model verification was undertaken using the January 2011 event only. There was no surveyed calibration information available, however a reasonable amount of anecdotal information was available through several community meetings. These meetings were both open to the public and with targeted community members who had been actively involved in responding to inundation or had specifically contacted Wimmera CMA.

January 2011 modelling was completed using the Horsham AWS temporal pattern and rainfall depths, applied with a uniform spatial pattern.

The model was run with standard loss values of 4 mm initial loss and 1.5 mm/hr continuing loss, the Manning's 'n' values are detailed in Section 4.2.3.3.

Horsham was modelled with two separate models, north and south of the Wimmera River. Anecdotally, the model results matched observations from Council employees and a selected group of the community who were involved in the stormwater response.

The January 2011 modelled inundation depths for the north and south modelled areas are provided in Figure 4-40 and Figure 4-41 respectively.

[16] Water Technology (2016), Lower Wimmera Regional Flood Mapping Study, Wimmera CMA

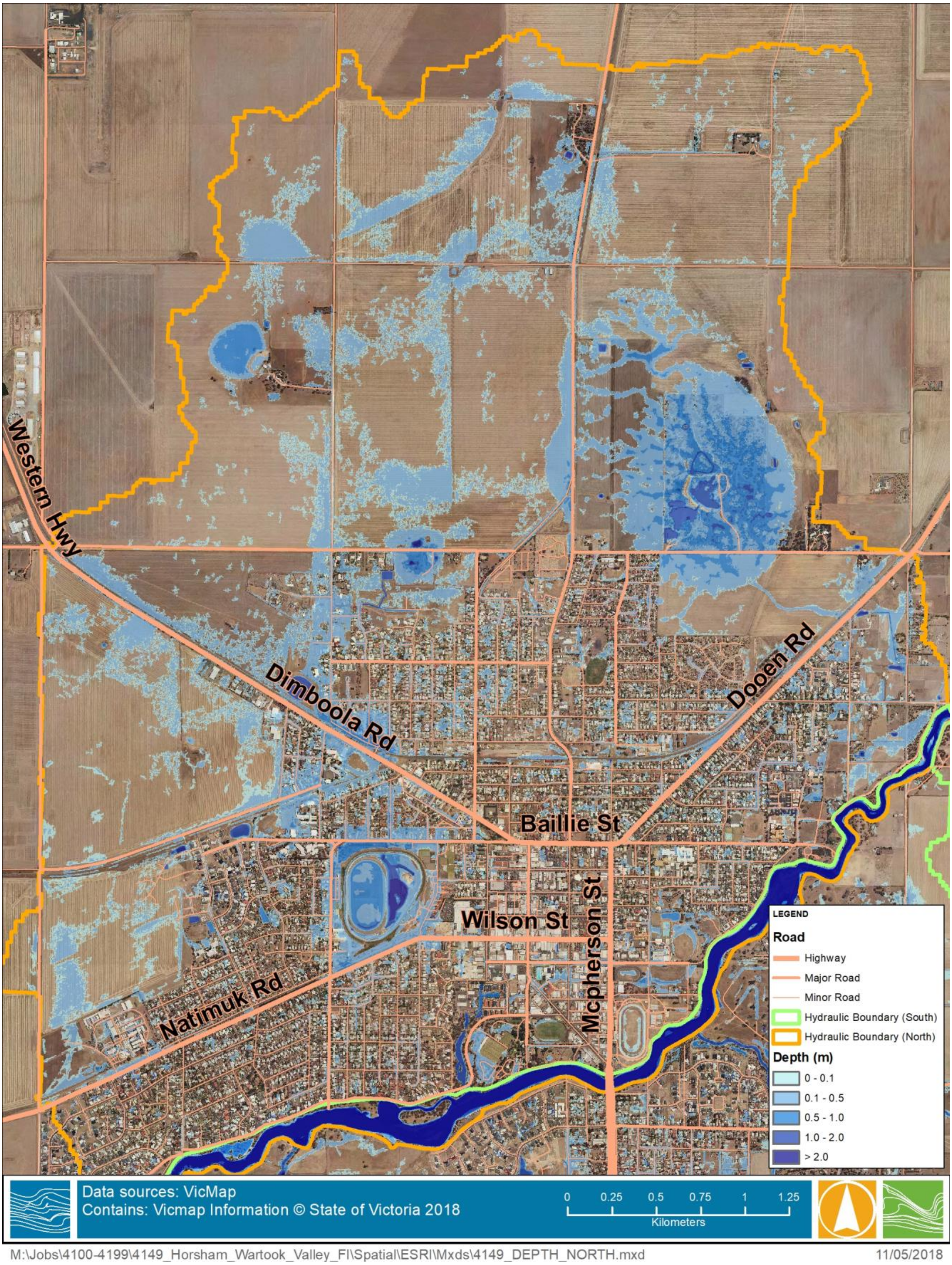

FIGURE 4-40 NORTH HORSHAM STORMWATER MODELLING – JANUARY 2011

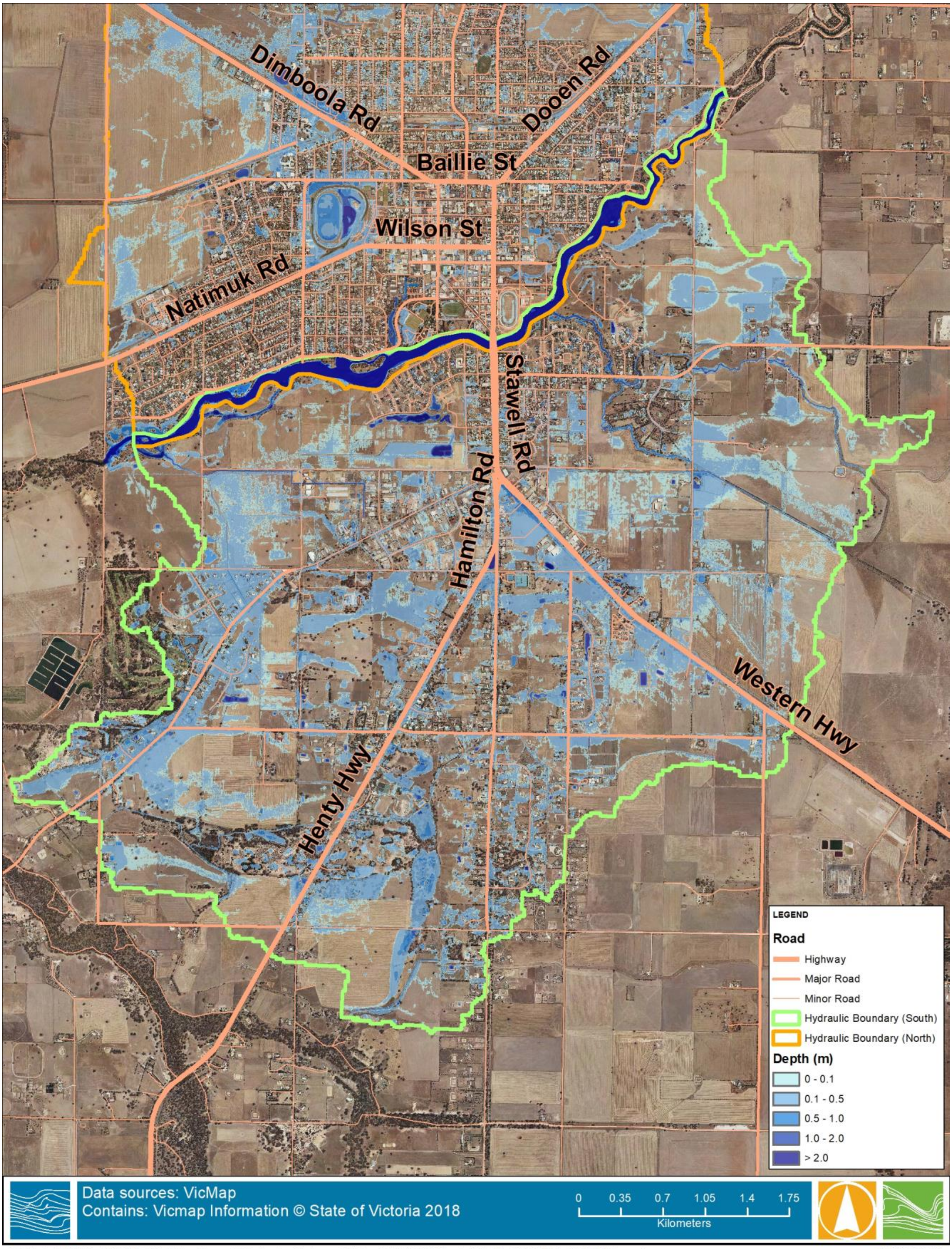

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FIGURE 4-41 SOUTH HORSHAM STORMWATER MODELLING – JANUARY 2011

4149-01_R06V02F_Final_Report_HorshamWartook

4.5 Design Modelling

4.5.1 Summary

Wimmera River and upper Mackenzie River inflows were based around Flood Frequency Analysis undertaken at Wimmera River at Horsham and Mackenzie River at Wartook gauges, while tributary flows and catchment contributions within the model area were determined by the RORB model detailed in Section 4.2.2.

RORB modelling was undertaken using Monte Carlo and Ensemble approaches recommended in Australian Rainfall and Runoff 2016 (ARR2016)[17]. The methodology for developing inflows to the hydraulic model was as follows.

RORB input parameters are determined using ARR 2016 methods

RORB Monte Carlo modelling used to determine peak flows and event critical durations at various locations throughout the model area

RORB Ensemble modelling used to determine which temporal patterns best matched the Monte Carlo peak flows

The most appropriate temporal pattern for each AEP was chosen. This results in a range of AEPs and event durations to be modelled and the event critical durations determined

The determined design flows were modelled in the calibrated hydraulic model to produce design depth, flood levels, velocities and extents.

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[17] Australian Rainfall and Runoff (2016) - Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2016, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia

4.5.2 Hydrology

4.5.2.1 Wimmera River – Flood Frequency Analysis

4.5.2.1.1 PEAK FLOW

This study adopted the Wimmera River design flows developed during the Lower Wimmera River Regional Flood Mapping Study. During this project a Flood Frequency Analysis (FFA) was used to determine peak design flows for the range of modelled design events. An annual series was constructed from the available instantaneous flow record, and historic information sourced by Wimmera CMA. The larger historic peak flows used to construct the annual series were displayed earlier in Table 2-7, this was supplemented with smaller flows from other years. A complete annual series was constructed from 1889 to 2015. The low flows were filtered using the Grubbs Beck test, censoring 58 of the 127 years of annual series.

It should be noted that the annual series used the Wimmera River at Horsham (Walmer) flow data without any adjustment due to the impact of Mackenzie River backwater. For Wimmera River flood flows it has been demonstrated that the impact of Mackenzie River on peak water levels at the gauge is generally quite low.

A range of statistical distributions were trialled in Flike (software used to carry out FFA), including LP3, Log-Normal, Gumbel, GEV, and Generalised Pareto. The LP3 distribution plotted the best against the historic series.

TABLE 4-7 WIMMERA RIVER AT HORSHAM FFA RESULTS (LP3 WITH LOW FLOW CENSORING)

AEP (%)	Peak Flow (ML/d)	Peak Flow (m^3/s)
20	13,100	152
10	19,200	222
5	25,000	289
2	31,900	369
1	36,500	423
0.5	40,700	471
0.2	45,400	525

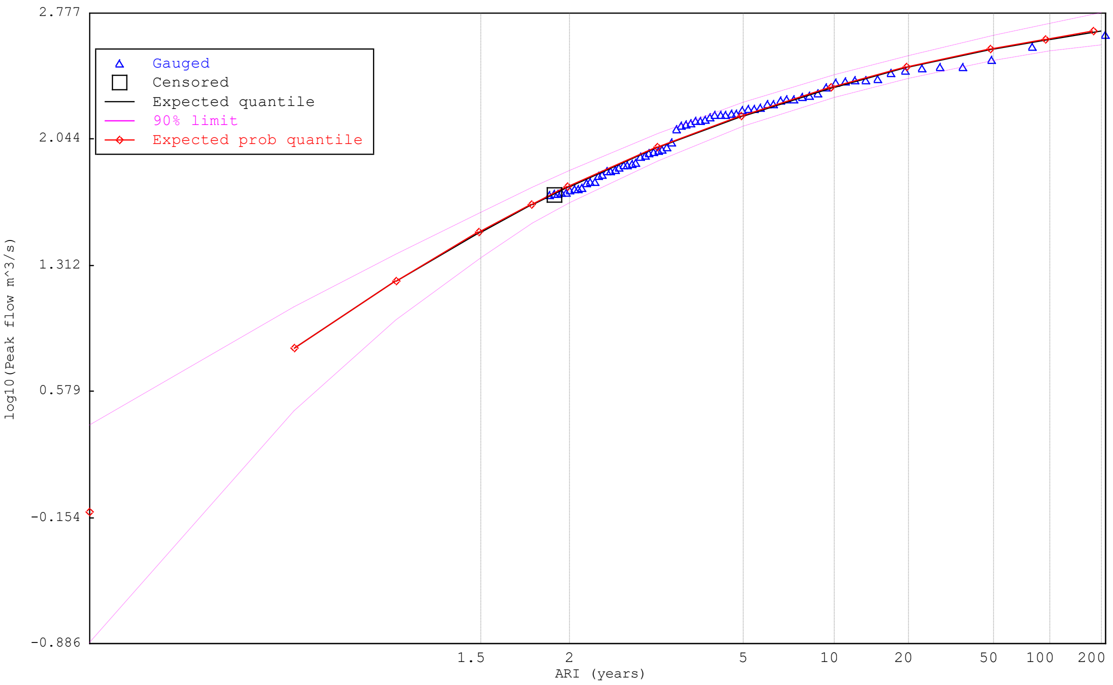

FIGURE 4-42 WIMMERA RIVER AT HORSHAM FFA (LP3 WITH LOW FLOW CENSORING)

4.5.2.1.2 EVENT VOLUME

A flood frequency analysis was completed following a similar procedure as described above for peak flow. A number of historic events were analysed, and it was found that large flood events on the Wimmera River at Horsham can last between 6 to 8 days. A 7-day volume flood frequency analysis was carried out, using an annual series from 1910 to current and censoring 54 years with low 7 day event volumes. The 1909 and 1895 events could not be included in the volume analysis due to a lack of detail around the rising and falling water levels i.e. only the peak level was known.

TABLE 4-8 WIMMERA RIVER AT HORSHAM FFA RESULTS OF SEVEN DAY VOLUME

AEP (%)	Seven day event volume (ML)
20	53,800
10	85,800
5	110,600
2	132,400
1	142,600
0.5	149,100
0.2	154,200

4.5.2.1.3 DESIGN FLOW HYDROGRAPHS

The January 2011 event was adopted for the design hydrograph shape. The design hydrographs were adjusted to match the peak design flow estimates and event volume from the FFA.

The design inflow hydrographs for the Wimmera River are shown in Figure 4-43.

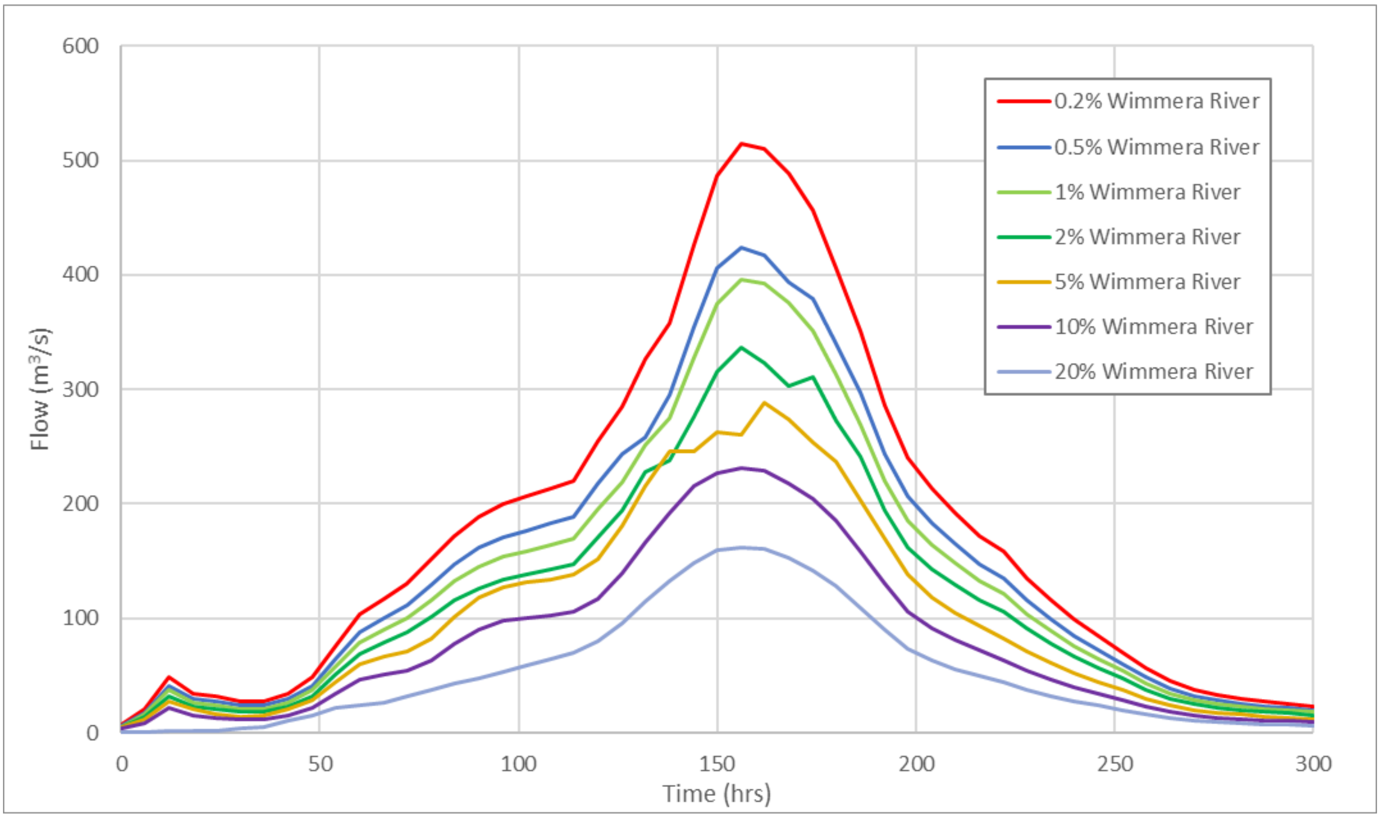

FIGURE 4-43 WIMMERA RIVER DESIGN INFLOWS

4.5.2.1.4 APPLICATION OF DESIGN HYDROGRAPHS WITHIN HYDRAULIC MODEL

As discussed in Section 4.1, Wimmera River inflows were applied to the hydraulic model at the eastern extent of the model, east of School Road. The design hydrology was determined for the Wimmera River at Horsham (Walmer) gauge, which is to the west of Horsham, a considerable distance from the hydraulic model upstream boundary. The design flow hydrographs were factored up for each AEP so that when they were run through the hydraulic model, they reproduced the design flows determined for the Wimmera River at Horsham (Walmer) streamflow gauge. Table 4-9 shows the design peak flows calculated at the Horsham (Walmer) gauge location, the factored up inflows applied to the models upstream inflow boundary, and the resulting modelled flows at the Horsham (Walmer) gauge. The modelled flows after being routed through the model match the calculated flows at the gauge within 1-2% for each AEP event.

Tributary and Wimmera River peak flows were modelled targeting at having a difference of 4 days between the peak flow at the Wimmera River at Horsham (Walmer) and Burnt Creek at Wonwondah gauges. This was shown to be the regularly observed difference among historic events, as shown in Table 4-10.

TABLE 4-9 PEAK FLOWS DETERMINED BY FFA, MODEL RESILTS AND MODEL INFLOWS

AEP (%)	Peak flow (m^3/s)			
	Hydraulic Model Inflow	Hydraulic Model at the Gauge	Horsham (Walmer) Gauge FFA	% difference
20	162	151	152	-1%
10	235	222	222	0%
5	333	285	289	-1%

AEP (%)	Peak flow (m^3/s)			
	Hydraulic Model Inflow	Hydraulic Model at the Gauge	Horsham (Walmer) Gauge FFA	% difference
2	392	361	369	-2%
1	449	417	423	-1%
0.5	498	460	471	-2%
0.2	560.9	523	525	0.04%

TABLE 4-10 HISTORIC TIMING BETWEEN BURNT CREEKA AND WIMMERA RIVER FLOWS

Event	Burnt Creek @ Wonwondah	Wimmera River @ Walmer	Time between peaks
October 1996	01/10/1996 0:38	05/10/1996 4:00	4 days, 3:22 hrs
September 2010	05/09/2010 4:30	09/09/2010 12:00	4 days, 7:30 hrs
January 2011	14/01/2011 5:45	18/01/2011 11:30	4 days, 5:45 hrs

4.5.2.2 Tributaries

4.5.2.2.1 OVERVIEW

As discussed in Section 4.2.2 the Wimmera River tributaries between upstream of Horsham to Quantong were modelled in RORB to determine both calibration and design flow estimates.

The design flow methodology adopted during the study was in line with ARR2016 recommendations[17]. The following sections outline how each of the key RORB design inputs were determined.

4.5.2.2.2 RAINFALL DEPTHS

The Intensity Frequency Duration (IFD) rainfall depths were sourced from the Bureau of Meteorology (BoM) online IFD tool[18]. Areal reduction factors and temporal patterns were sourced from the ARR Data Hub[19]. Both data sets were based on the coordinates of the catchment centroid (-36.88527778, 142.2022222).

Rainfall depths for rare events (less than 0.5% AEP) are only supplied for storm durations greater than 24 hours. Therefore, the required points were extrapolated for shorter durations using the growth factors from the 24 hour duration.

Rainfall was spatially distributed across the RORB subareas for each AEP based on the ARR (1987)[20] IFD distribution using the 12 hour, 2% AEP rainfall depth grid. Water Technology has digitised the 1987 ARR IFD datasets. There were no ARR2016 rainfall grids available at the time the hydrology was being completed, but point comparisons were made across the catchment. There was a reasonable change in rainfall depths across the RORB model area with a maximum difference of 25%, north to south. Most of the spatial variation was close to the Grampians National Park. It was concluded that the spatial pattern of the design rainfall from ARR1987 was appropriate to use, with the actual rainfall depths adopted from the ARR2016 IFD.

[18] http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016
[19] http://data.arr-software.org/
[20] Institution of Engineers, Australia (1987) Australian Rainfall and Runoff: A Guide to Flood Estimation, Vol. 1, Editor-in-chief D.H. Pilgrim, Revised Edition 1987 (Reprinted edition 1998), Barton, ACT

4.5.2.2.3 LOSSES

Losses for the RORB model were initially determined using the ARR online datahub, suggesting the use of 34 mm initial loss and 3 mm/hr continuing loss.

The hydraulic model calibration process determined an initial loss of 35 mm and a continuing loss of 4 mm/hr for January 2011 and an initial loss of 35 mm and a continuing loss of 2.5 mm/hr for September 2016.

Given the similarities between the calibration and ARR Data Hub losses it was determined the Datahub recommended losses would be adopted as shown in Table 4-11 for design purposes. The initial loss was adopted as the initial loss applied in all the RORB Ensemble runs and was used as the median initial loss for the Monte Carlo runs.

TABLE 4-11 ADOPTED LOSSES

Loss Type	Loss
Initial Loss	34 mm
Continuing Loss	3 mm/hr

4.5.2.2.4 KC

The initial kc value for each interstation area was determined using the Victorian data estimate available in RORB (Pearse et al, 2002[21]) where kc=1.25*$D_{av.}$ This resulted in the kc values outlined in Table 4-12.

TABLE 4-12 CALIBRATION AND DESIGN KC VALUES

Catchments	Kc
Norton Creek, Sandy Creek, Darragan Creek	64.9
Burnt Creek and Mackenzie River	43.2

4.5.2.2.5 M

As modelled in both the January 2011 and September 2010 calibration events the RORB model 'm' value was maintained at 0.8. This is generally accepted as an industry standard value unless observed information indicates it should be changed to achieve a better calibration.

4.5.2.2.6 MODEL RESULTS

Monte Carlo

As discussed in Section 4.5.1, RORB modelling was completed running the Monte Carlo methodology initially to determine statistical peak flows. This was then followed by the Ensemble methodology. 1,000 Monte Carlo runs were completed sampling randomly from the potential temporal patterns and initial loss distribution. The Monte Carlo peak flows were determined for 10 locations within the RORB model. The determined peak flows for each AEP are shown in Table 4-13. Table 4-14 shows the critical duration highlighted for each location and event. The 12 hour event is clearly the most prevalent critical duration, particularly in the more frequent events, while at rarer AEPs the 24hr and 48hr events are the most common critical duration. In locations where the 72hr event was critical it was only marginally higher than the next highest duration peak flow, typically the 12 hour event for the upper reaches of the tributaries. For example, at the Mid Mackenzie River location during a

[21] Pearse et al, 2002 – A Simple Method for Estimating RORB Model Parameters for Ungauged Rural Catchments, Water Challenge: Balancing the Risks: Hydrology and Water Resources Symposium, 2002

5% AEP event, the critical duration was 72hrs with a peak flow of 21.5 m³/s, only marginally higher than the 12hr event at 21.1 m³/s.

TABLE 4-13 MONTE CARLO DETERMINED PEAK FLOWS

Location	Peak flow (m³/s)					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
Mackenzie Upper	10.1	37.9	74.0	124.8	168.6	220.6
Mackenzie Mid	2.0	10.4	21.5	38.5	54.3	72.2
Mackenzie Lower	2.8	15.7	34.4	64.2	94.6	127.3
Burnt Mid	8.4	38.1	74.5	139.6	199.1	269.7
Norton Mid	1.7	8.4	18.1	33.0	47.5	64.3
Norton Lower	2.2	9.2	20.1	38.1	61.6	87.9
Sandy Mid	2.1	4.4	7.7	12.9	18.9	24.7
Sandy Lower	0.7	1.9	3.7	7.1	10.4	14.5
Darragan Mid	0.4	2.6	6.0	11.4	17.8	25.6
Darragan Lower	0.7	3.1	7.1	13.9	19.1	28.1

TABLE 4-14 MONTE CARLO DETERMINED PEAK FLOW CRITICAL DURATIONS

<table>
<tr><th rowspan="2">Location</th><th colspan="6">Peak flow (m³/s)</th></tr>
<tr><th>20% AEP</th><th>10% AEP</th><th>5% AEP</th><th>2% AEP</th><th>1% AEP</th><th>0.5% AEP</th></tr>
<tr><td>Mackenzie Upper</td><td colspan="6">12hr</td></tr>
<tr><td>Mackenzie Mid</td><td colspan="2">12hr</td><td>72hr</td><td colspan="3">12hr</td></tr>
<tr><td>Mackenzie Lower</td><td colspan="2">12hr</td><td>72hr</td><td>12hr</td><td colspan="2">72hr</td></tr>
<tr><td>Burnt Mid</td><td colspan="4">12hr</td><td colspan="2">24hr</td></tr>
<tr><td>Norton Mid</td><td colspan="2">12hr</td><td>72hr</td><td colspan="2">12hr</td><td>48hr</td></tr>
<tr><td>Norton Lower</td><td colspan="4">12hr</td><td colspan="2">24hr</td></tr>
<tr><td>Sandy Mid</td><td colspan="3">12hr</td><td colspan="3">24hr</td></tr>
<tr><td>Sandy Lower</td><td>24hr</td><td>12hr</td><td>72hr</td><td>48hr</td><td>24hr</td><td>48hr</td></tr>
<tr><td>Darragan Mid</td><td colspan="2">12hr</td><td colspan="2">72hr</td><td>24hr</td><td>48hr</td></tr>
<tr><td>Darragan Lower</td><td colspan="2">12hr</td><td colspan="2">72hr</td><td>24hr</td><td>48hr</td></tr>
</table>

Ensemble

The RORB model was run using an Ensemble Analysis, using the determined kc values and recommended ARR2016 losses. The RORB Ensemble Analysis was run for all ten ARR2016 recommended temporal patterns for each event duration. For this case, six design events were modelled, resulting in 60 design event simulations for each of the four durations (12hr, 24hr, 48hr and 72hr), totalling 240 model simulations. The peak flows determined in the Monte Carlo analysis were used to find a temporal pattern from the Ensemble Analysis producing a hydrograph with a similar peak flow. This comparison of peak flows between the Monte Carlo and Ensemble Analysis was completed at each of the ten output locations along the Wimmera River tributaries. This is summarised in Table 4-15, showing which temporal pattern generated the closest match, opting for the temporal pattern which produced a peak slightly higher than the Monte Carlo analysis.

TABLE 4-15 TEMPORAL PATTERN NUMBER WHICH IS CLOSEST TO THE MONTE CARLO ANALYSIS PEAK FLOW

<table>
<tr><th colspan="11">Temporal Pattern</th></tr>
<tr><th>AEP (%)</th><th>Mackenzie Upper</th><th>Mackenzie Mid</th><th>Mackenzie out</th><th>Burnt Mid</th><th>Norton Mid</th><th>Norton Lower</th><th>Sandy Mid</th><th>Sandy Lower</th><th>Darragan Mid</th><th>Darragan Lower</th></tr>
<tr><td>20</td><td>10</td><td colspan="3">2</td><td>10</td><td colspan="2">2</td><td>7</td><td colspan="2">10</td></tr>
<tr><td>10</td><td>2</td><td colspan="2">10</td><td colspan="2">2</td><td>10</td><td colspan="2">8</td><td colspan="2">10</td></tr>
<tr><td>5</td><td>2</td><td colspan="2">3</td><td>8</td><td>3</td><td>2</td><td>8</td><td>10</td><td colspan="2">3</td></tr>
<tr><td>2</td><td>2</td><td colspan="6">8</td><td colspan="2">3</td><td>10</td></tr>
<tr><td>1</td><td>3</td><td>8</td><td colspan="2">3</td><td>8</td><td colspan="5">3</td></tr>
<tr><td>0.5</td><td colspan="2">1</td><td colspan="8">3</td></tr>
<tr><th colspan="11">Ensemble Peak Flow Matching the Monte Carlo Peak Flow Closest</th></tr>
<tr><th>AEP (%)</th><th>Mackenzie Upper</th><th>Mackenzie Mid</th><th>Mackenzie out</th><th>Burnt Mid</th><th>Norton Mid</th><th>Norton Lower</th><th>Sandy Mid</th><th>Sandy Lower</th><th>Darragan Mid</th><th>Darragan Lower</th></tr>
<tr><td>20</td><td>10.2</td><td>2.1</td><td>2.4</td><td>8.7</td><td>1.6</td><td>1.9</td><td>2.1</td><td>0.7</td><td>0.4</td><td>0.7</td></tr>
<tr><td>10</td><td>39.7</td><td>9.6</td><td>14.7</td><td>34.1</td><td>7.6</td><td>8.8</td><td>4.5</td><td>1.7</td><td>2.5</td><td>2.8</td></tr>
<tr><td>5</td><td>75.1</td><td>38.2</td><td>64.4</td><td>67.0</td><td>33.3</td><td>16.2</td><td>7.9</td><td>7.8</td><td>14.4</td><td>18.3</td></tr>
<tr><td>2</td><td>130.3</td><td>40.4</td><td>63.5</td><td>143.1</td><td>33.6</td><td>35.8</td><td>14.2</td><td>7.3</td><td>23.4</td><td>26.1</td></tr>
<tr><td>1</td><td>173.5</td><td>63.5</td><td>151.7</td><td>218.1</td><td>52.5</td><td>63.4</td><td>20.0</td><td>10.7</td><td>18.2</td><td>20.1</td></tr>
<tr><td>0.5</td><td>225.9</td><td>72.8</td><td>183.3</td><td>302.3</td><td>77.9</td><td>93.7</td><td>26.8</td><td>14.8</td><td>27.0</td><td>29.8</td></tr>
</table>

During review of the most common temporal patterns it became apparent there were large discrepancies between the Monte Carlo and Ensemble peak flows for events with a critical duration of 72 hours. For example, at the Lower Mackenzie River location the RORB 1% AEP Monte Carlo peak flow was 94.6 m^3/s, with the 1% AEP, 72hr duration, with the ensemble of temporal patterns resulted in peak flows ranging from 5 to 191 m^3/s as shown in Table 4-16.

TABLE 4-16 1% AEP, 72 HOUR DURATION – PEAK FLOWS IN THE LOWER MACKENZIE

Temporal Pattern	Peak Flow (m^3/s)
1	25.1
2	4.7
3	151.7
4	74.4
5	25.2
6	6.2
7	57.4
8	39.3
9	25.0
10	191.0

The scenarios producing flows on either side of the Monte Carlo peak flow were significantly different and too far apart for adoption without adjustment. The peak flows clearly show temporal pattern 3 and 10 are significantly higher than the remaining patterns. These temporal patterns for the 1% AEP, 72hr event are plotted in Figure 4-44. In both instances between 35 to 40% of the total rainfall depth fell in a single 3 hour time increment. These patterns are clearly very different to the rest of the temporal patterns for the 72 hour, 1% AEP ensemble. Further analysis showed that these temporal patterns were sampled from gauges high on the Great Dividing Range (High Camp, north of Kilmore, and Jerangle, north of Cooma). Given the inability of the temporal pattern ensembles for the 72 hour duration to be able to reproduce a peak flow close to that of the Monte Carlo analysis, and the fact that the 72 hour peak flow was very similar to other durations anyway, the 72 hour duration was removed from the analysis.

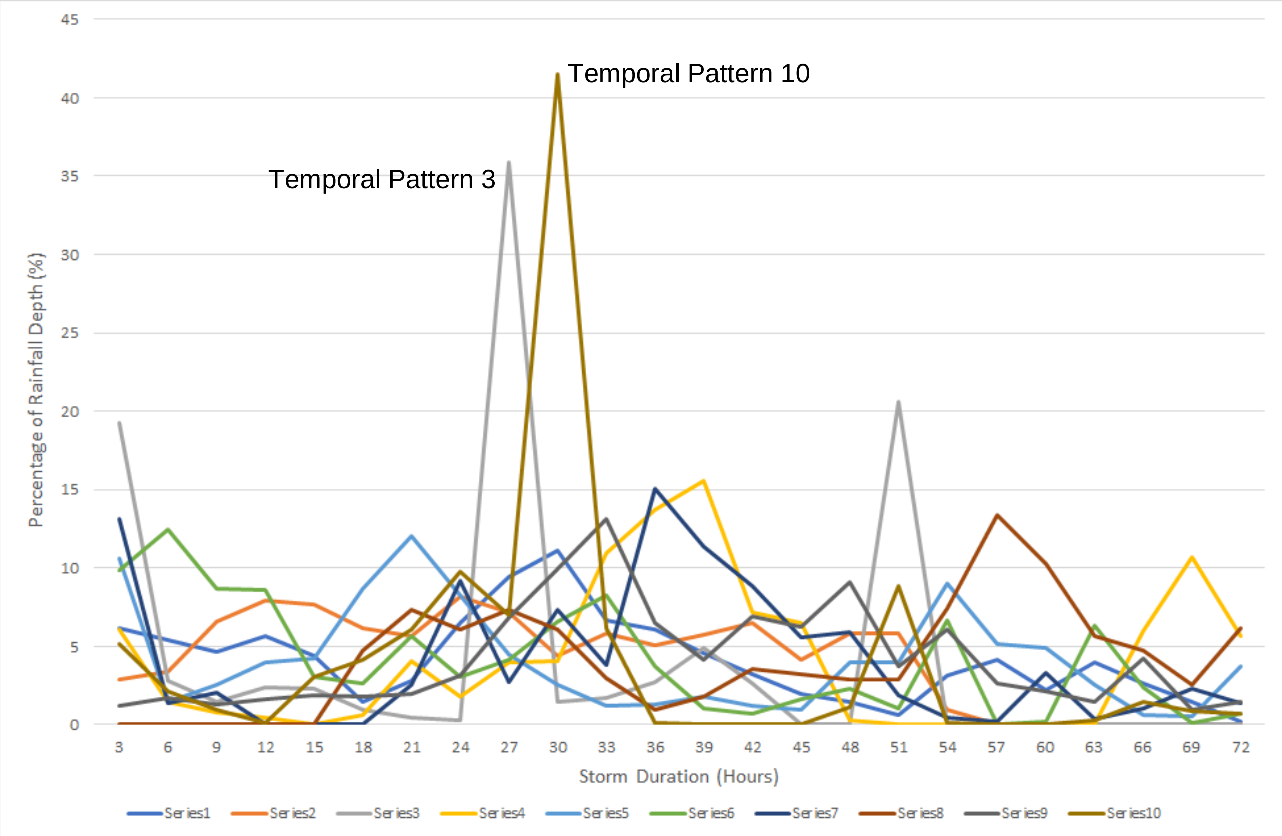

FIGURE 4-44 72 HOUR, 1% AEP TEMPORAL PATTERNS

To reduce the potential number of hydraulic model runs a single temporal pattern for each AEP was chosen. For instance, temporal pattern 3 was shown to produce peak flows most similar to those produced in the Monte Carlo analysis at eight of the ten locations within the tributary catchments for the 1% AEP event, and it was therefore chosen as the temporal pattern to be used to produce inflows to the hydraulic model across the six event durations for the 1% AEP. The chosen temporal patterns for each of the AEP events are shown in Table 4-17.

TABLE 4-17 CHOSEN REPRESENTITIVE TEMPORAL PATTERNS FOR EACH AEP

AEP (%)	Chosen Temporal Pattern
20	2
10	10
5	3
2	8
1	3
0.5	3

4.5.3 Hydraulics

4.5.3.1 Riverine Inundation

Design hydraulic modelling was completed by introducing the tributary design flow hydrographs into the hydraulic model, followed by the Wimmera River design flow hydrographs. A timing difference between the tributaries and the Wimmera River was based around historic observations at the Burnt Creek streamflow gauge at Wonwondah and the Wimmera River streamflow gauge at Horsham (Walmer). Historically, the timing difference at this gauge has been slightly more than 4 days. This also lines up with URBS runoff routing modelling completed during the Horsham Bypass Hydrology and Hydraulics Assessment[22]. This is demonstrated in Table 4-18.

TABLE 4-18 TIMING DEFERENCE BETWEEN THE HORSHAM AND WONWONDAH STREAMFLOW GAUGES

Event	Burnt Creek @ Wonwondah	Wimmera River @ Walmer	Time between peaks
October 1996	01/10/1996 0:38	05/10/1996 4:00	4 days, 3 hours
September 2010	05/09/2010 4:30	09/09/2010 12:00	4 days, 7 hours,
January 2011	14/01/2011 5:45	18/01/2011 11:30	4 days, 6 hours
December 2016	14/09/2016 14:45	19/09/2016 5:45	4 days, 15 hours
Previous Model predictions	-	-	4 days, 6 hours

Model inflows were placed directly into the hydraulic model at the specified model boundaries as shown in Section 4.1.

The hydraulic model setup, roughness and other modelling parameters for design modelling was the same as that of the calibrated model.

The design flood extents for the entire study area and Horsham are shown in Figure 4-45 and

[22] Water Technology (2013) – Horsham Bypass Hydrology and Hydraulics Assessment

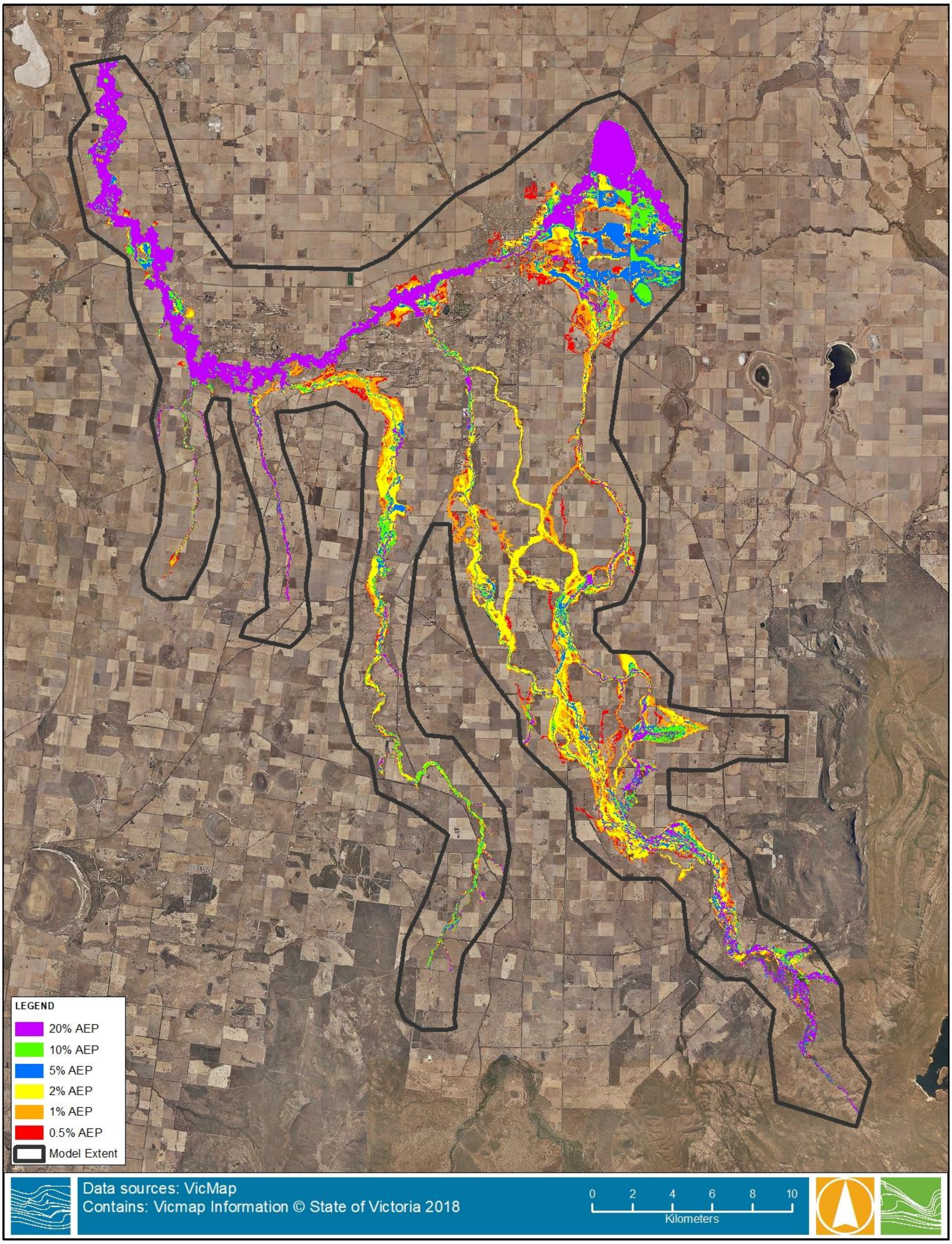

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FIGURE 4-45 1% AEP DESIGN MODEL EXTENT – STUDY AREA

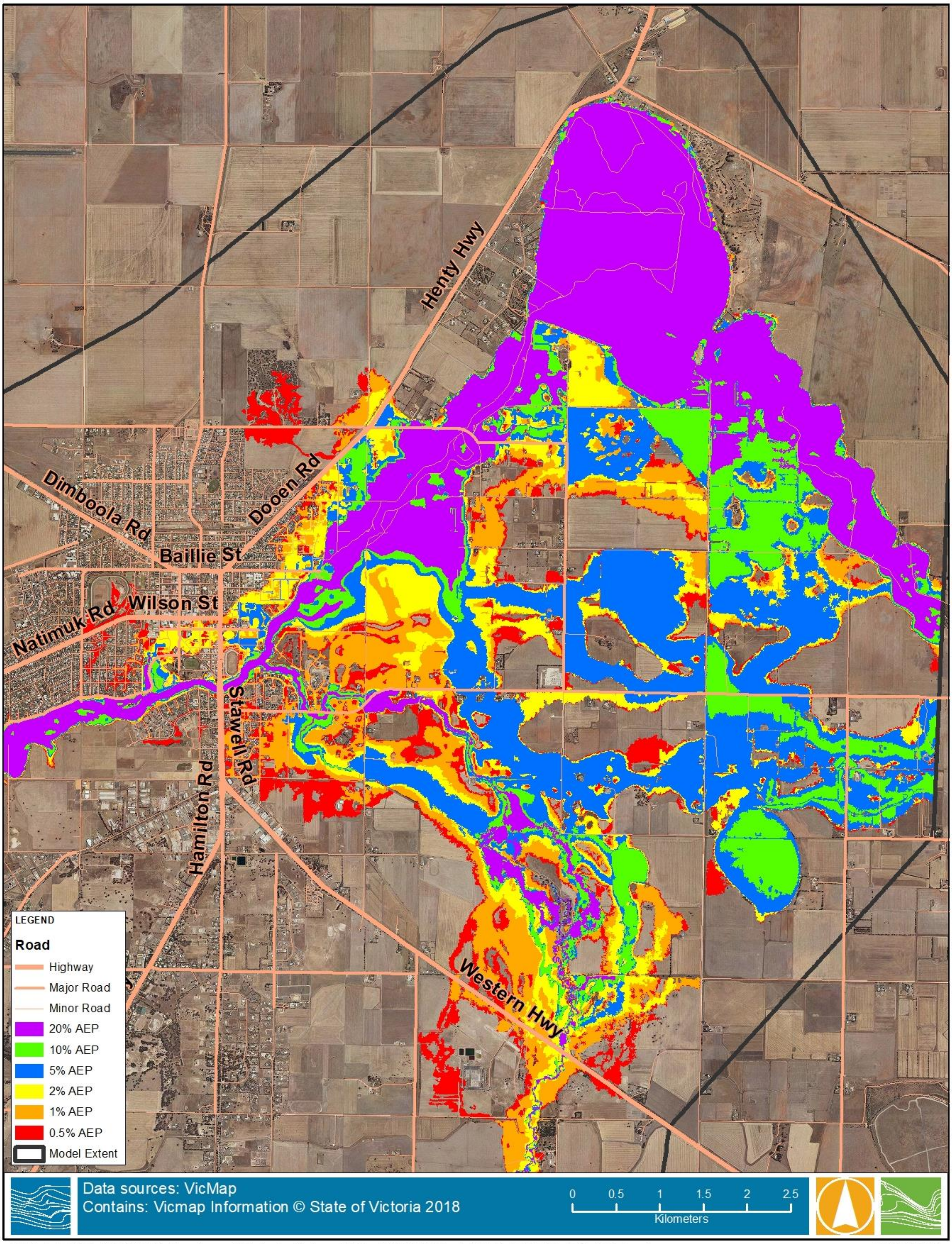

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FIGURE 4-46 1% AEP DESIGN MODEL EXTENT – HORSHAM AND EAST HORSHAM

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4.5.4 Stormwater Inundation

Similar to the design RORB modelling, the rain on grid stormwater model was run using the ARR2016 design rainfall and recommended temporal patterns. The rainfall losses determined during model verification were adopted, as outlined in Section 4.1.

Modelling of the 1% AEP event was completed for all ten of the recommended temporal patterns, the water levels produced were compared to determine which temporal pattern produced the most 'average' set of results. This was done by creating an average water level grid, then mapping the temporal patterns which most closely matched the average value. This is shown in Figure 4-47 for the northern model extent and Figure 4-48 for the southern model extent.

Temporal Pattern 2 produced the most average water surface elevation and was adopted for modelling of the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events.

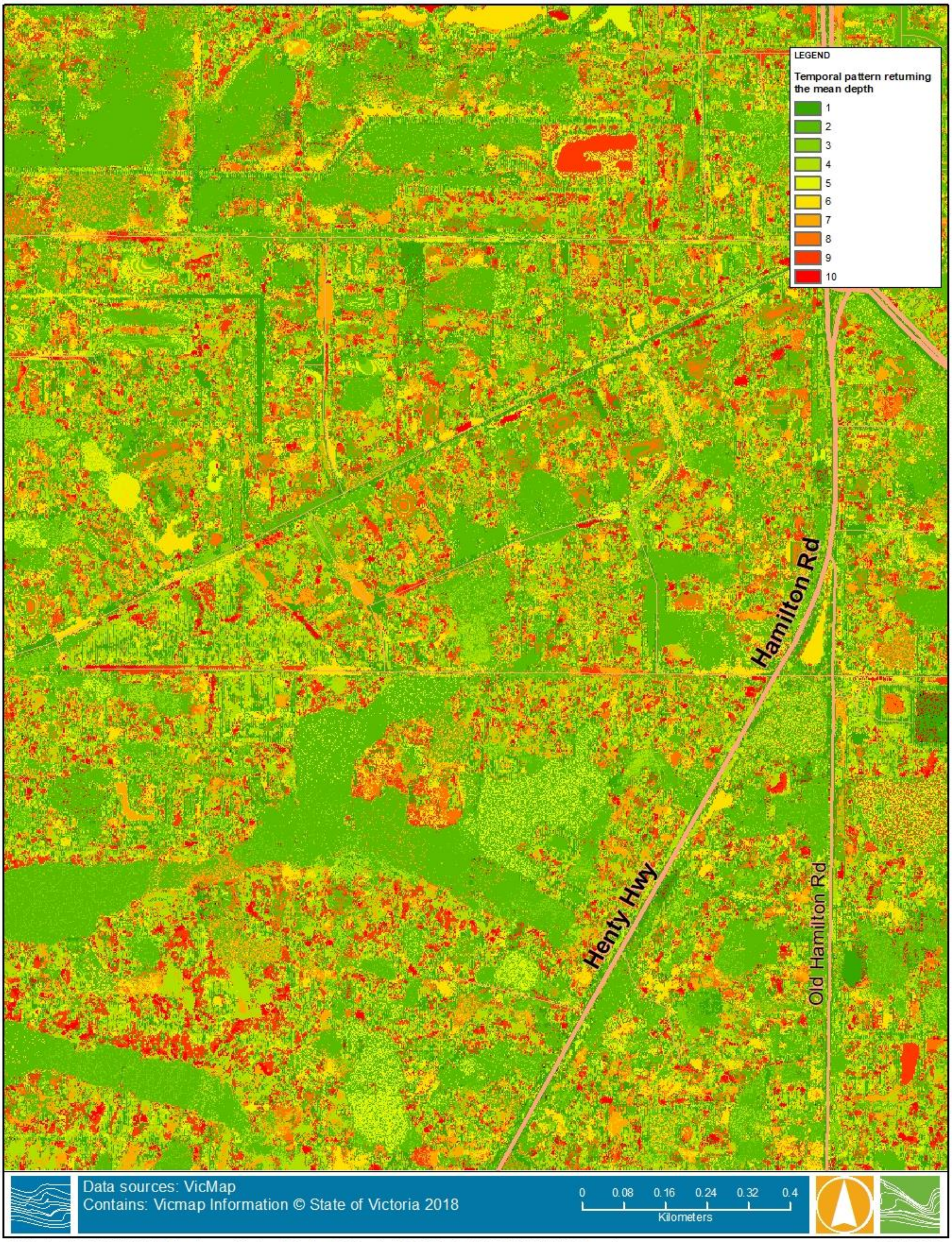

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FIGURE 4-47 TEMPORAL PATTERNS MOST CLOSELY MATCHING THE AVERAGE WATER LEVELS – NORTHERN MODEL

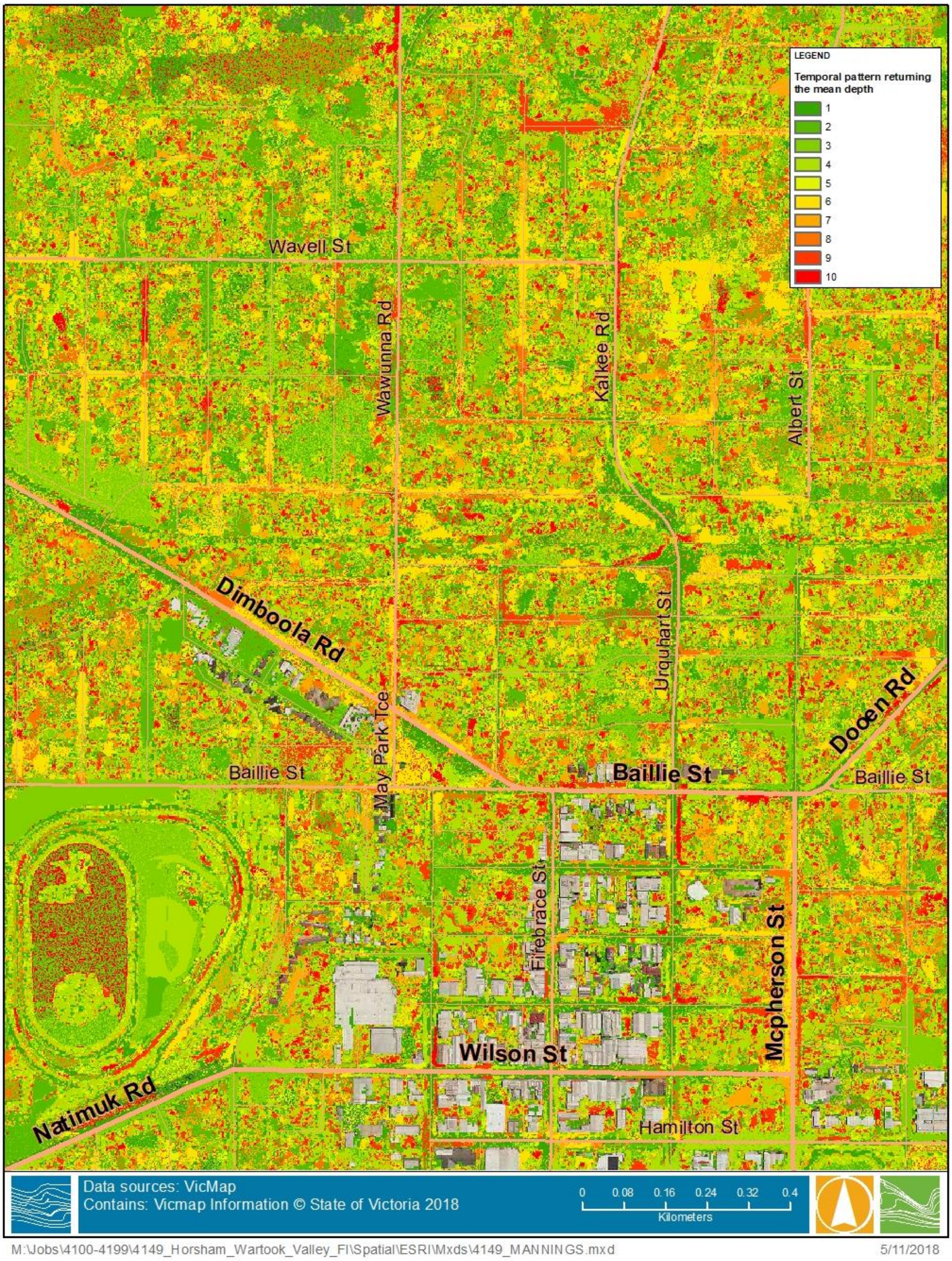

FIGURE 4-48 TEMPORAL PATTERNS MOST CLOSELY MATCHING THE AVERAGE WATER LEVELS – SOUTHERN MODEL

The 1% AEP inundation depths are shown in Figure 4-49.

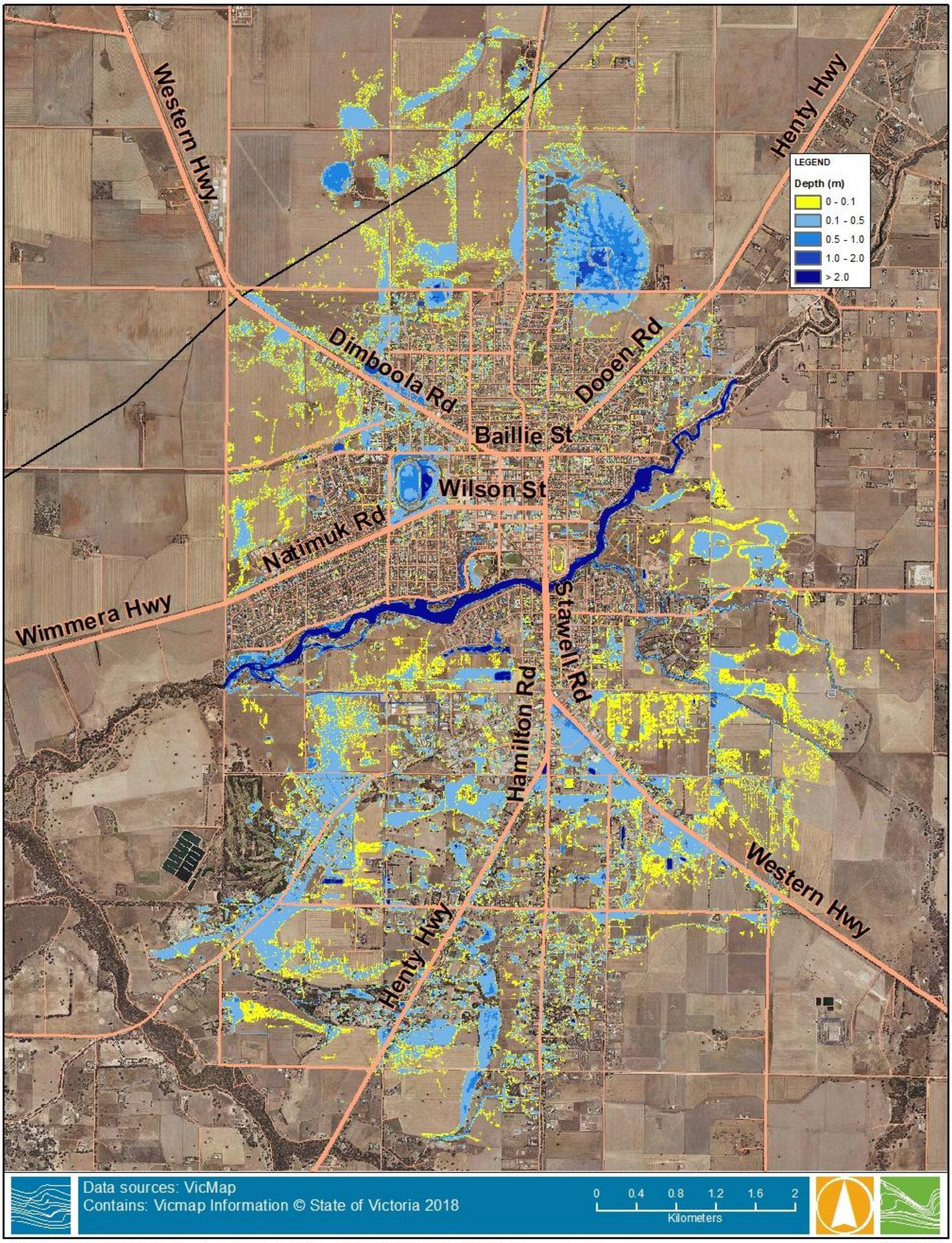

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FIGURE 4-49 1% AEP STORMWATER INUNDATION IN HORSHAM

5 MITIGATION

5.1 Overview

Flood risk and flood damages within the study area can be reduced with structural and non-structural mitigation. Non-structural mitigation measures focus on ensuring that new development doesn't occur in high flood risk areas, it aims to raise community awareness of the risk and improves the emergency response during a flood event. Structural mitigation options are engineering solutions focused on reducing flood extent, depth and damage.

5.2 Buildings at Risk

5.2.1 Overview

The January 2011 flood event was close to the largest flood recorded within the study area. Hydrologic analysis of the Wimmera River at Horsham (Walmer) streamflow gauge (415200) indicated the January 2011 flood event was between a 1% and 2% AEP event.

During community consultation, the January 2011 event was often talked about and was the focus of discussion regarding reducing the impact that flood had on the community. For this reason, the January 2011 event was used to highlight the potential buildings impacted during the mitigation prefeasibility assessment.

The mitigation prefeasibility assessment was separated into areas, these included the Wimmera River at Horsham and lower Burnt Creek, upper Burnt Creek, upper Mackenzie River, Bungalally Creek, Norton Creek, Darragan Creek and Sandy Creek.

5.2.2 Wimmera River

Within the study area, the Wimmera River is the main driver for property inundation, the majority of this is within the Horsham and East Horsham area.

There are three major flood mechanisms impacting the Wimmera River and lower Burnt Creek floodplain at Horsham:

- Wimmera River breaking out into Horsham from the south and east.
- An overland flow path beginning around Drung, flowing through east Horsham.
- Burnt Creek exceeding its capacity and flowing overland.

Each flood mechanism and the areas they impact are listed below and highlighted in Figure 5-1. Each area also has an individual figure showing a closer perspective of the properties impacted:

1. Burnt Creek south of Williams Road – Lower Burnt Creek and Wimmera River overland flow path (Figure 5-2).
2. Burnt Creek north of Williams Road – Wimmera River breakouts upstream of Dooen Swamp (Figure 5-2).
3. East Horsham properties south of Horsham Lubeck Road - Lower Burnt Creek and Wimmera River overland flow path (Figure 5-3).
4. East Horsham properties north of Horsham Lubeck Road - Wimmera River breakouts upstream of Dooen Swamp (Figure 5-4).

5. Properties north of the Wimmera River – Wimmera River flooding (Figure 5-5). This area has the most properties impacted, with numerous houses within the January 2011 flood extent. Protection of this area could be achieved be preventing breakout flows from the Wimmera River.

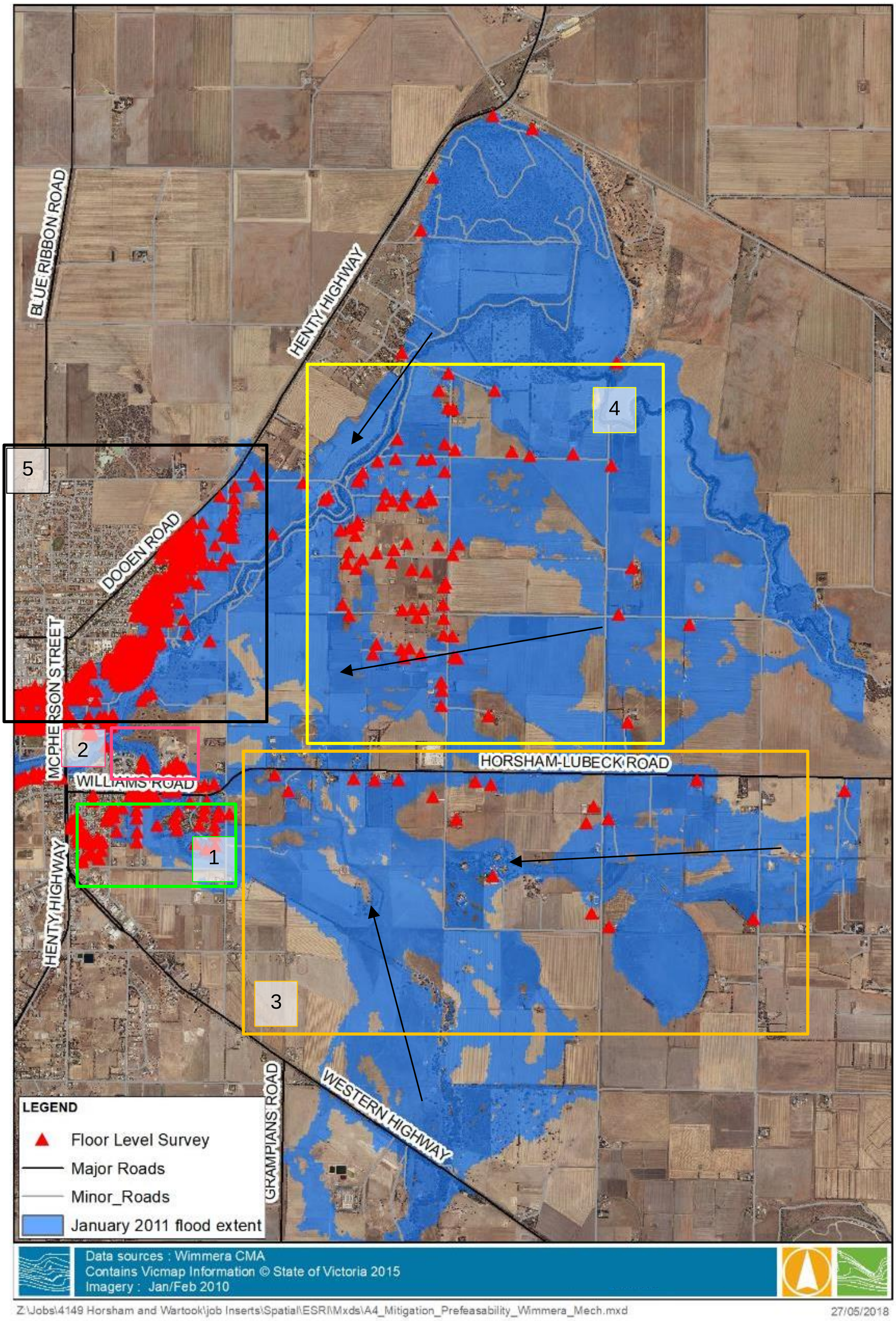

FIGURE 5-1 WIMMERA RIVER FLOOD MECHANISMS

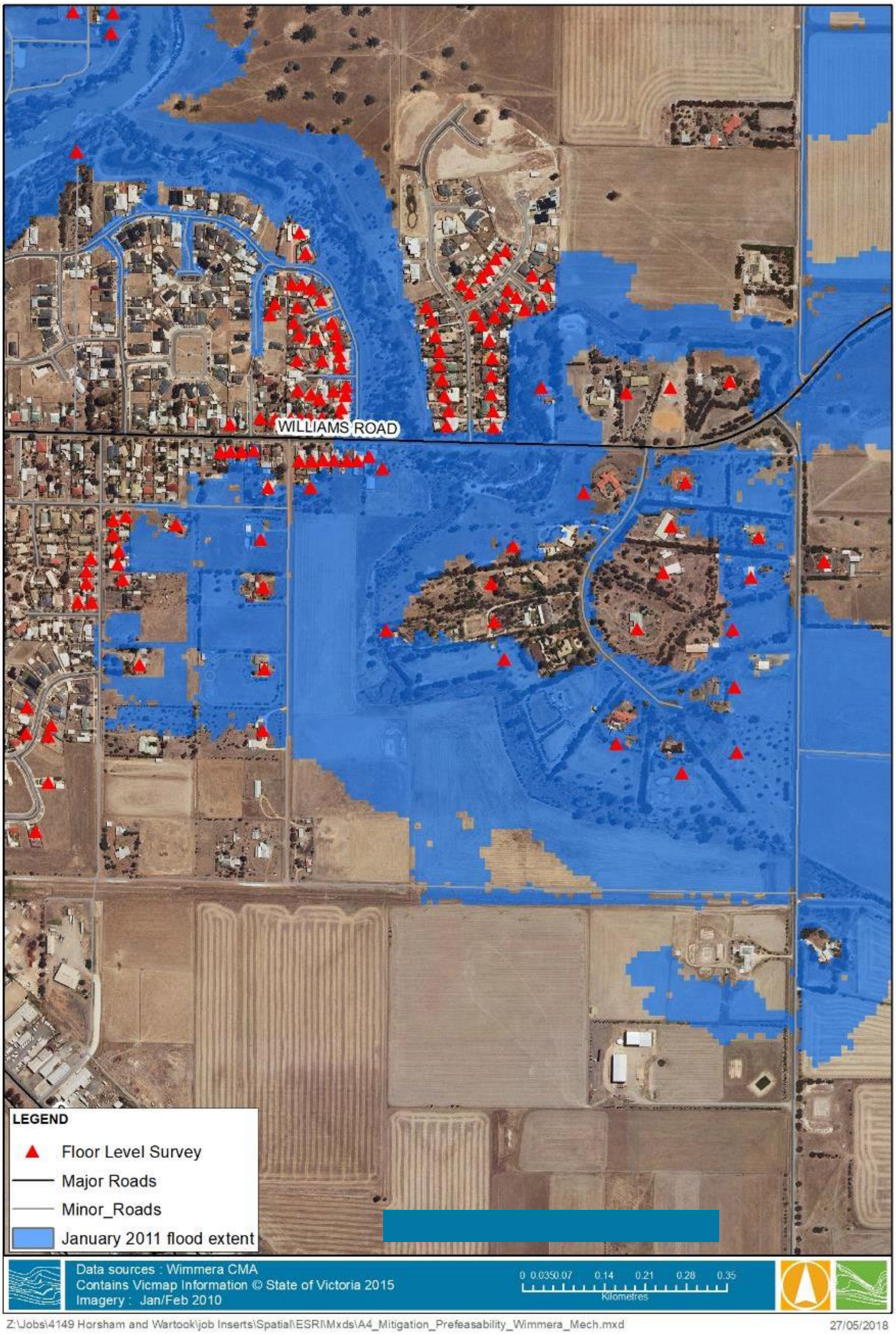

FIGURE 5-2 BURNT CREEK SOUTH AND NORTH OF WILLIAMS ROAD (1 AND 2)

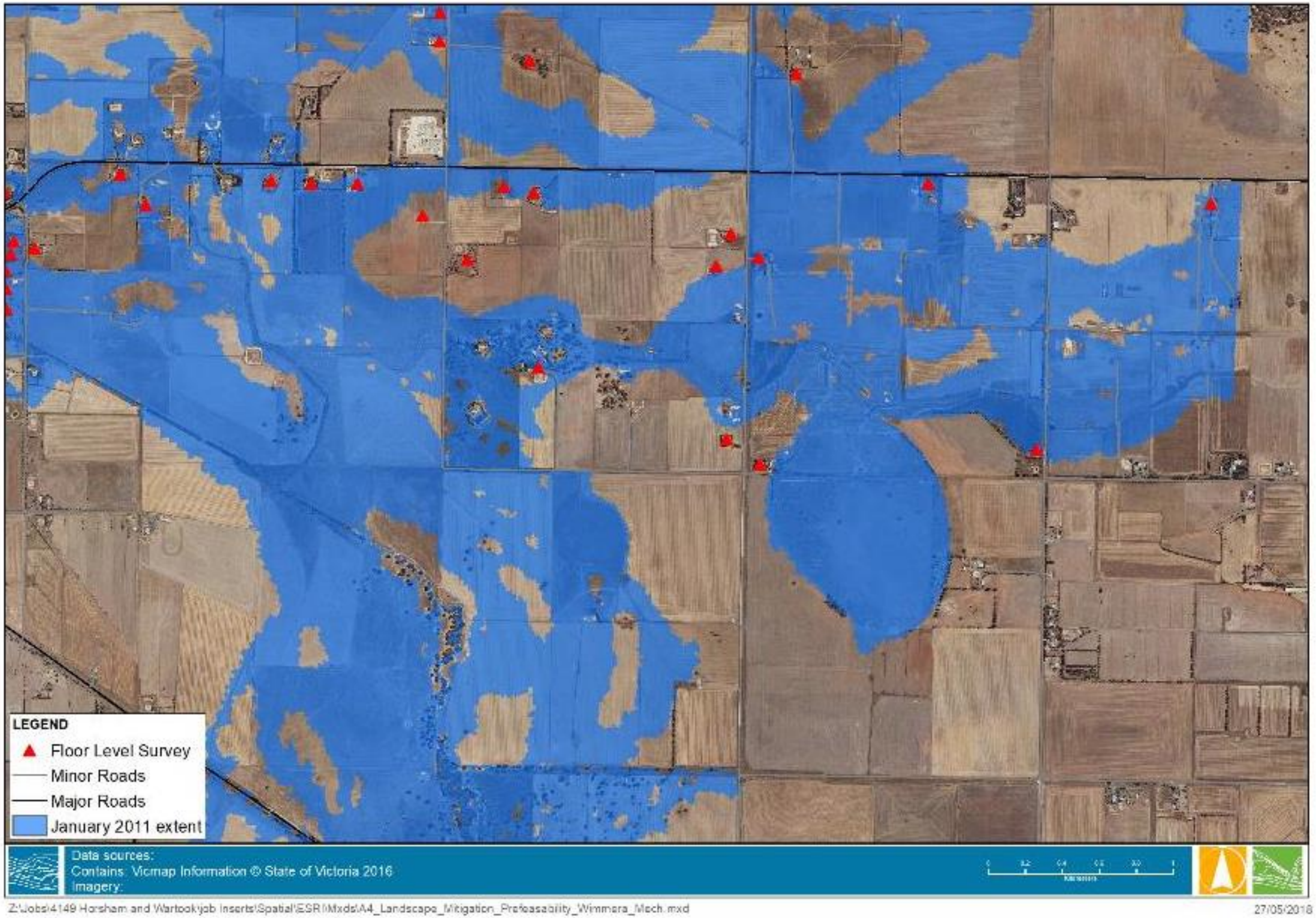

FIGURE 5-3 EAST HORSHAM PROPERTIES SOUTH OF HORSHAM LUBECK ROAD (3)

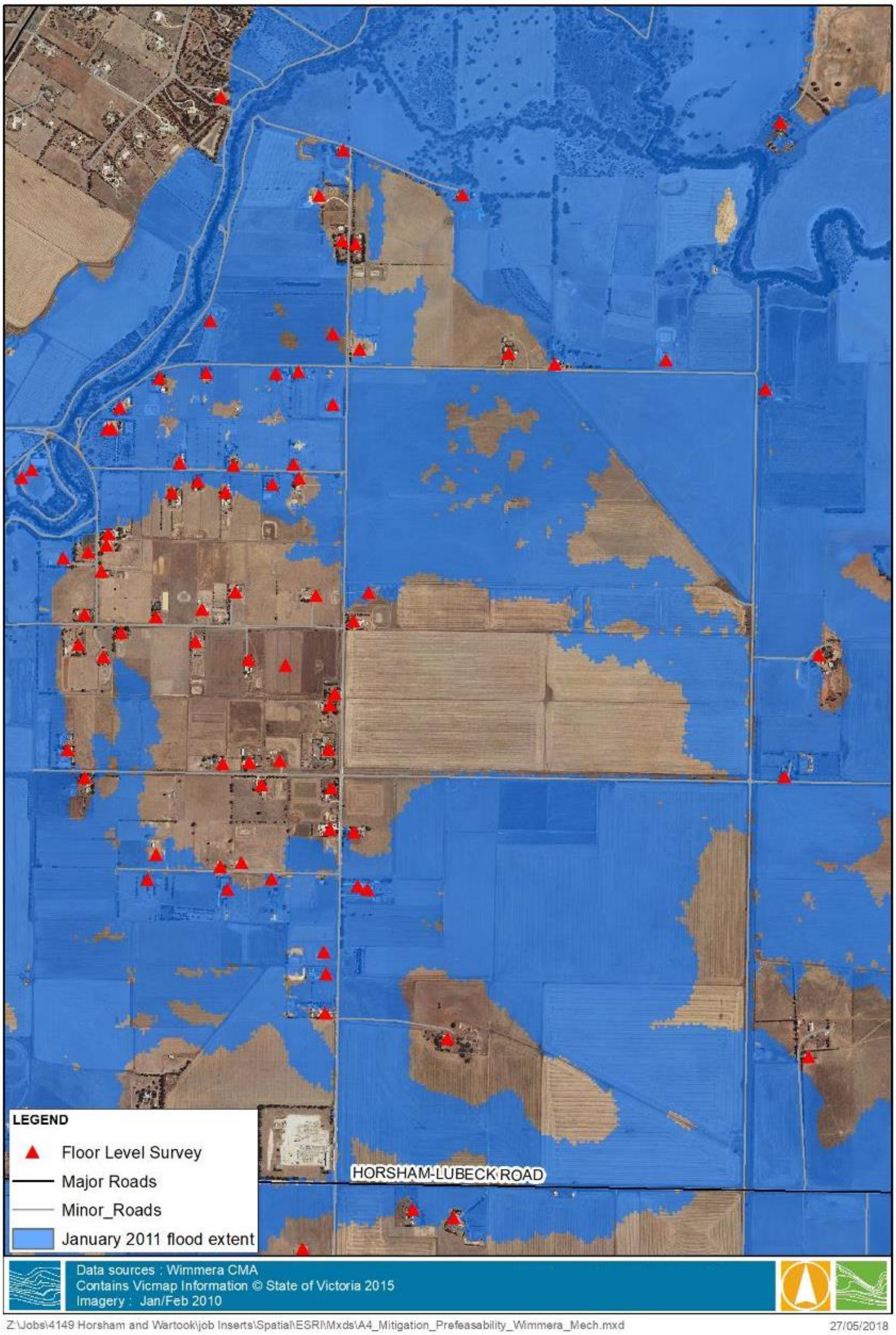

FIGURE 5-4 EAST HORSHAM PROPERTIES NORTH OF HORSHAM LUBECK ROAD (4)

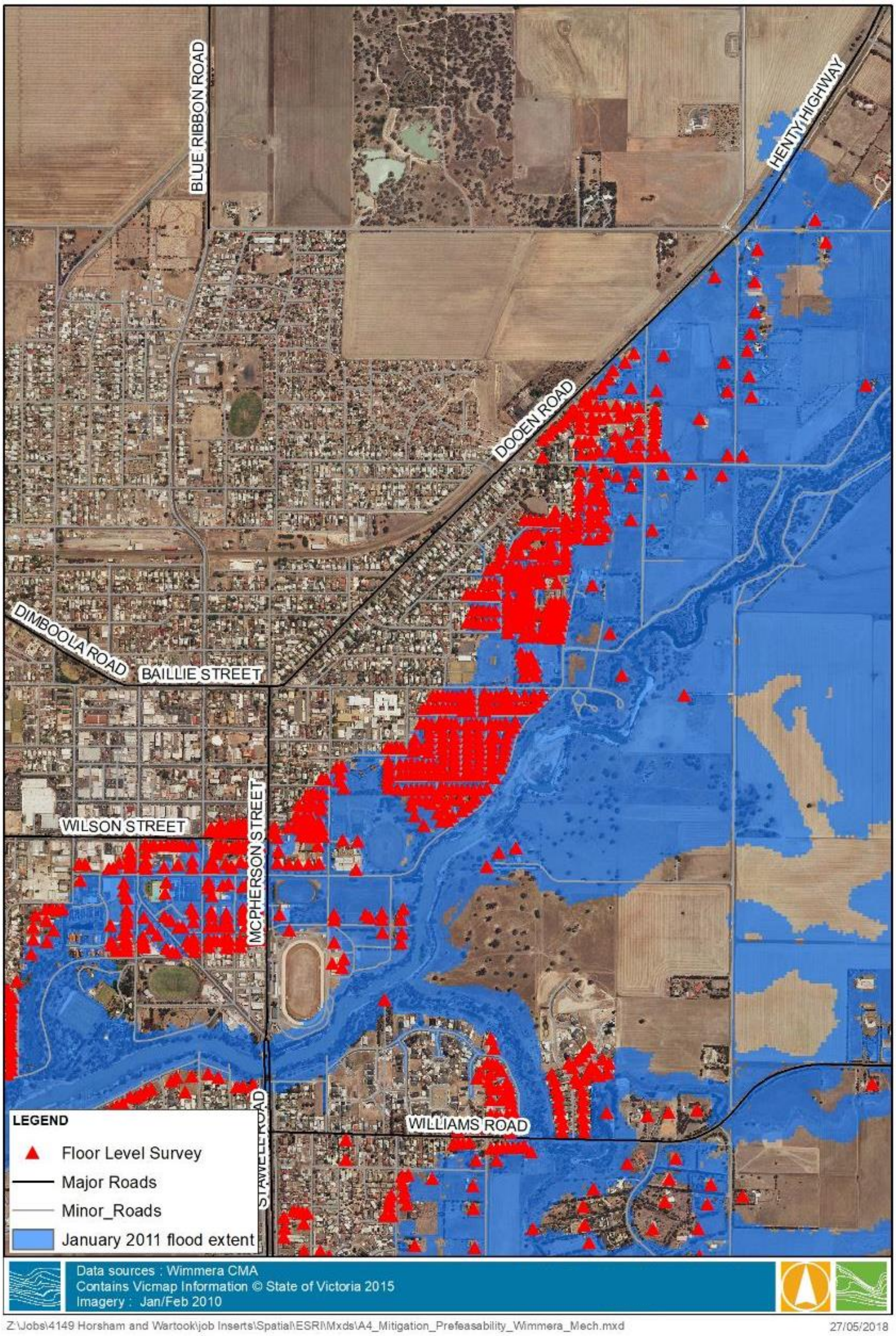

FIGURE 5-5 PROPERTIES NORTH OF THE WIMMERA RIVER (5)

5.2.3 Upper Mackenzie River and Upper Burnt Creek

The upper sections of the Mackenzie River and Burnt Creek have relatively sparse populations with no concentration of dwellings or businesses, the sparse population also leads to landowners constructing buildings in areas of lower flood risk. The widespread population also leads to two main possibilities for mitigation; reducing flows along each section of waterway or individual property mitigation i.e. private levees. Given the distance between properties levees to protect individual buildings are unlikely to have negative consequences for neighbouring buildings.

During January 2011 there was one business flooded above floor in the upper Mackenzie River, located on Northern Grampians Road, Wartook.

The five buildings located within or close to the January 2011 flood extent are shown in Figure 5-6.

5.2.4 Mid Burnt Creek, Mid Mackenzie River and Bungalally Creek

The mid sections of Burnt Creek, the Mackenzie River and Bungalally Creek are of similar nature to the upper reaches, with relatively isolated properties and individual property mitigation the most practical solution. There are only three properties within or close to the January 2011 extent, Figure 5-7.

5.2.5 Lower Mackenzie River, Norton Creek, Darragan Creek and Sandy Creek

There are more at-risk properties in the lower reaches of the Mackenzie River, Norton Creek, Darragan Creek and Sandy Creek than the mid reaches. There is a group of four properties on Norton Creek upstream of Horsham Noradjuha Road, and individual properties on the Mackenzie River, Darragan Creek and the Wimmera River. The cluster of four properties are located on either side of Norton Creek, this means that individual levees may impact on the neighbouring properties and further consideration of protecting these properties would be required.

The properties close to or within the January 2011 flood extent are shown in Figure 5-8.

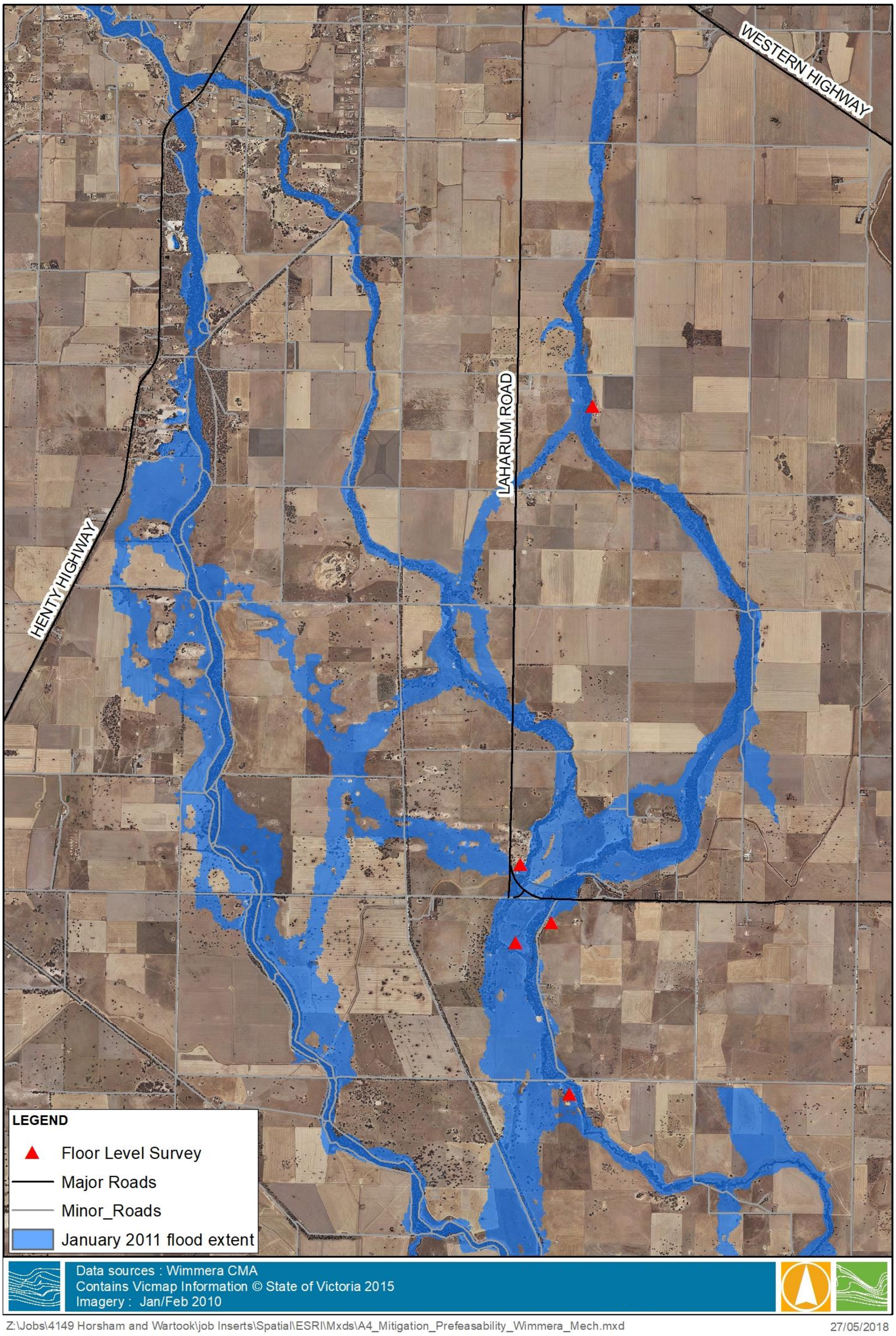

FIGURE 5-6 UPPER MACKENZIE RIVER AND UPPER BURNT CREEK

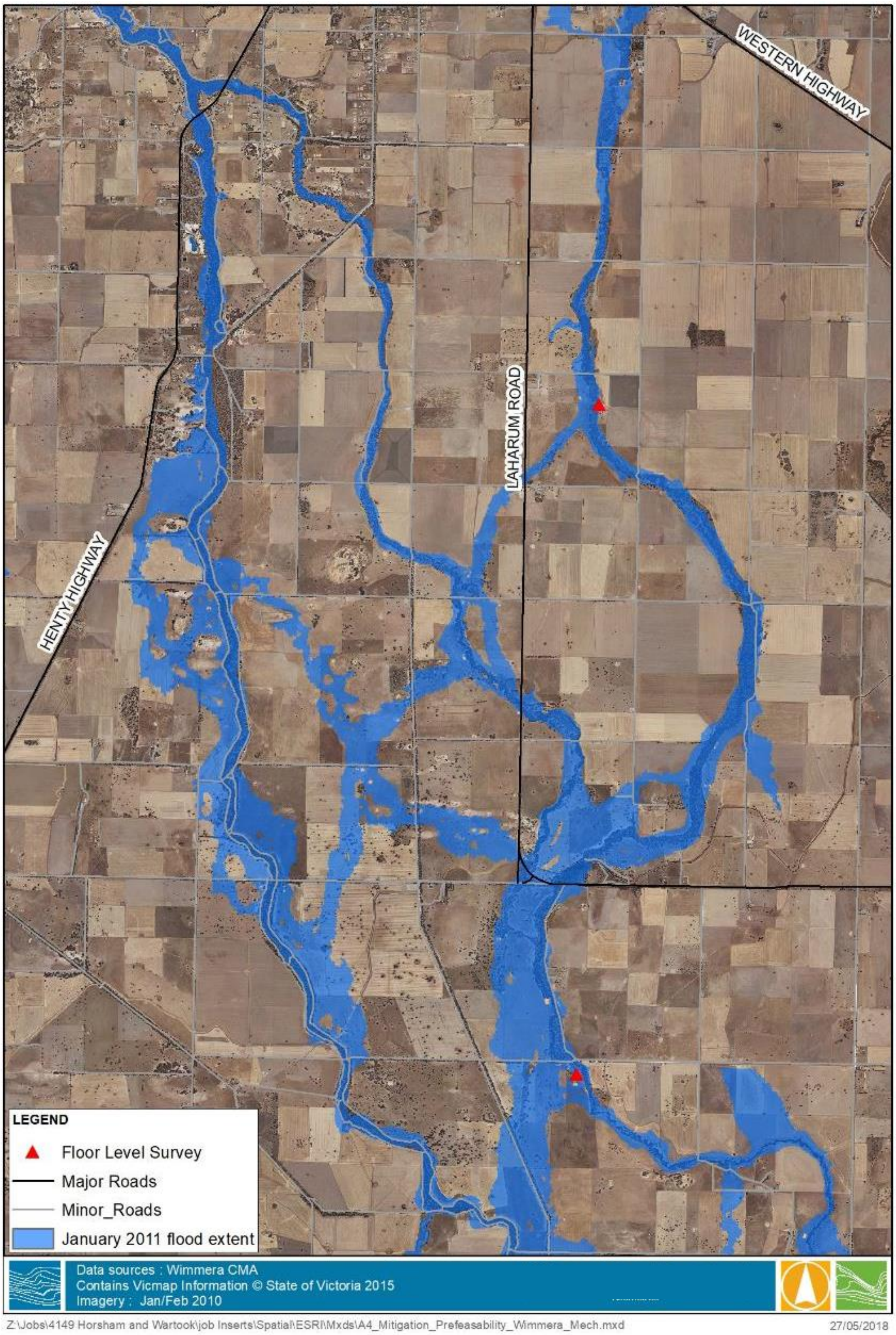

FIGURE 5-7 MID BURNT CREEK, MID MACKENZIE RIVER AND BUNGALALLY CREEK

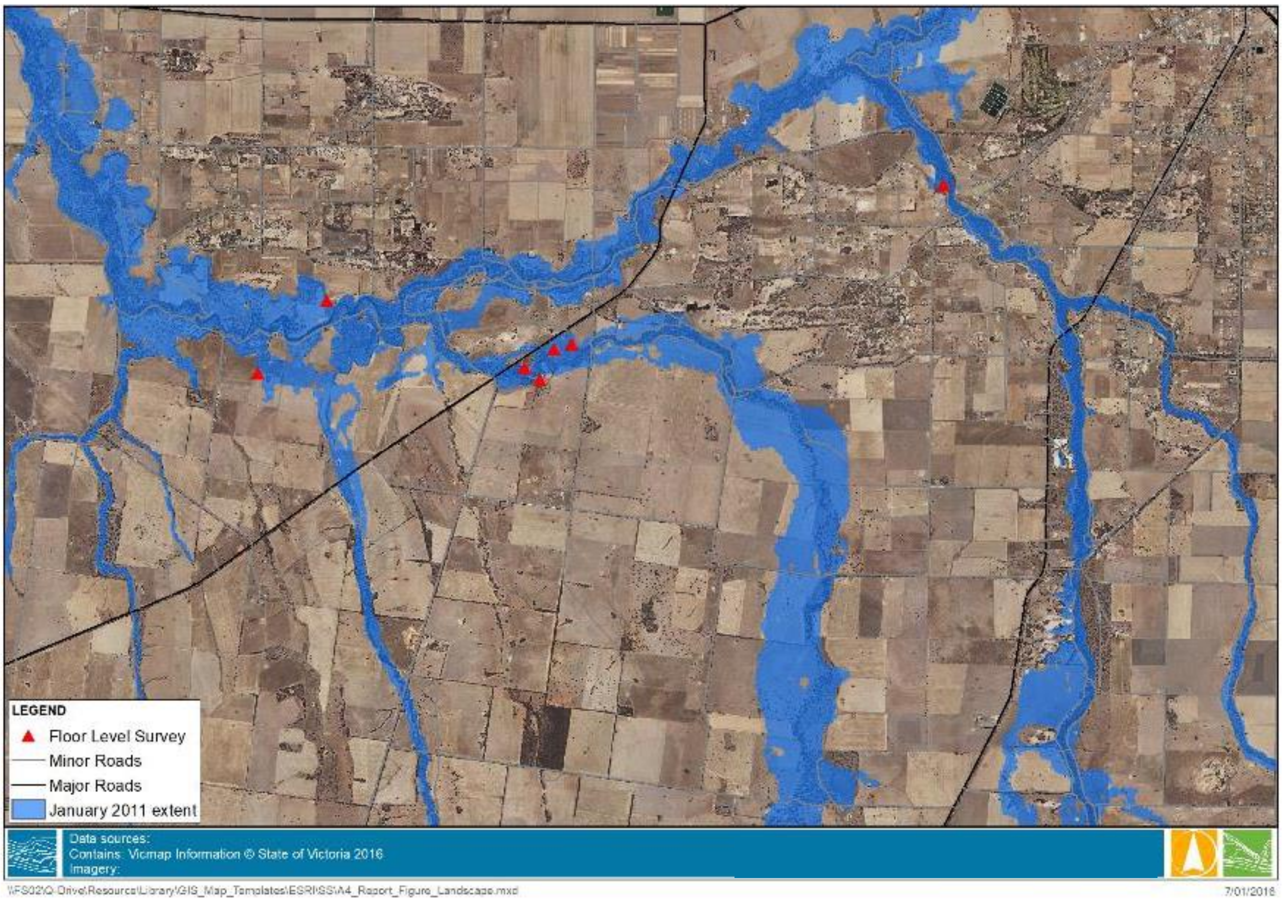

FIGURE 5-8 LOWER MACKENZIE RIVER, NORTON CREEK, DARRAGAN CREEK AND SANDY CREEK

5.3 Structural Mitigation

5.3.1 Prefeasibility Assessment

5.3.1.1 Overview

Over the course of the project several flood mitigation options were suggested by the community and project steering group. Each option was assessed to determine its feasibility and to highlight any property which may be negatively impacted by the construction of the option. Mitigation solutions using changes to existing infrastructure were listed and described separately to the construction of new infrastructure, however all options are rated together. The full list of suggested mitigation measures is summarised below in Table 5-1, each option has a figure associated with it, as listed in the table.

Table 5-1 Suggested mitigation options

Option No.	Detail	Source
Changes to Existing Infrastructure		
1	Operating Lake Wartook at a lower level to allow for some flood storage (Figure 5-9).	Community
2	Increase the height and length of the Menadue Street Levee in Horsham (increase height of Menadue St (southern end) and Baillie Street to Peppertree Lane, create new section from Lutheran School to Peppertree Lane (Figure 5-14).	Project Steering Committee
New Infrastructure		
3	Change split at Dunns Corner through levees/road (Figure 5-10)	Wimmera CMA
4	Construct a retarding basin on Burnt Creek upstream of the Western Highway using a levee (Figure 5-11)	Wimmera CMA
5	Install a new gauge downstream of Dunns Corner – (Burnt Creek @ Wonwondah East – on the BoM site) (Figure 5-10)	Wimmera CMA
6	Resolve issue around decommissioned channel and resultant undersized culvert at Camerons Rd (Figure 5-12)	Project Steering Committee
7	Use Dooen Swamp as a formal retardation storage (Figure 5-13)	Wimmera CMA
8	Create a levee from the Lutheran School to Peppertree Lane through to Pryors Road and east of Camerons Road north to the Henty Highway and Riverside Rd intersection (Figure 5-14)	Project Steering Committee
9	Create a levee from Menadue Street to Horsham Showgrounds, south eastern corner of the Horsham Greyhound Track (Figure 5-15)	Project Steering Committee
10	Create a levee to prevent backflow at Watonga Basin (Figure 5-15)	Project Steering Committee

FIGURE 5-9 OPTION 1 – LOWER LAKE WARTOOK OPERATING LEVEL

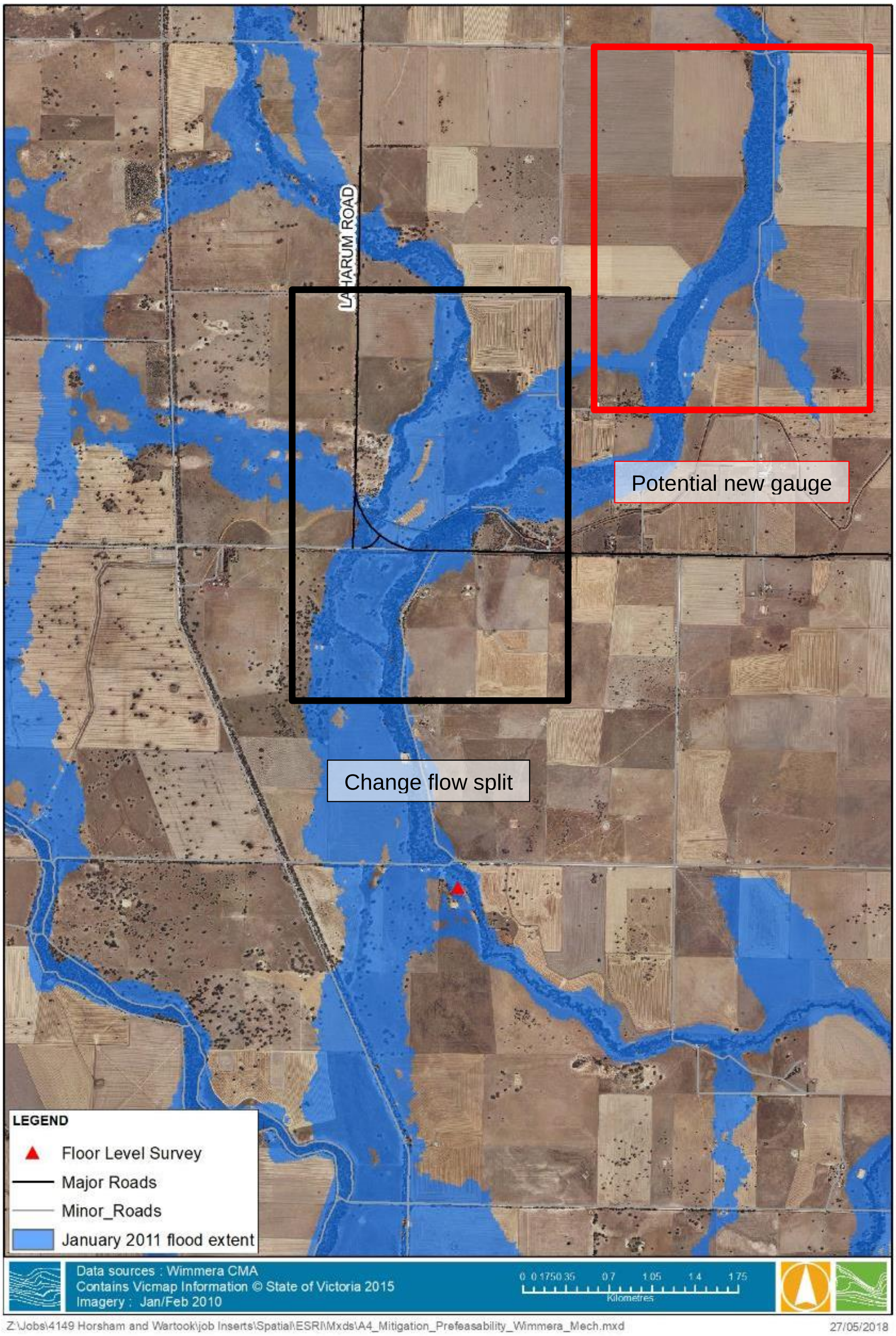

FIGURE 5-10 OPTION 3 AND 5- CHANGE SPLIT AT DUNNS CORNER/INSTALL A NEW GAUGE ON BURNT CREEK

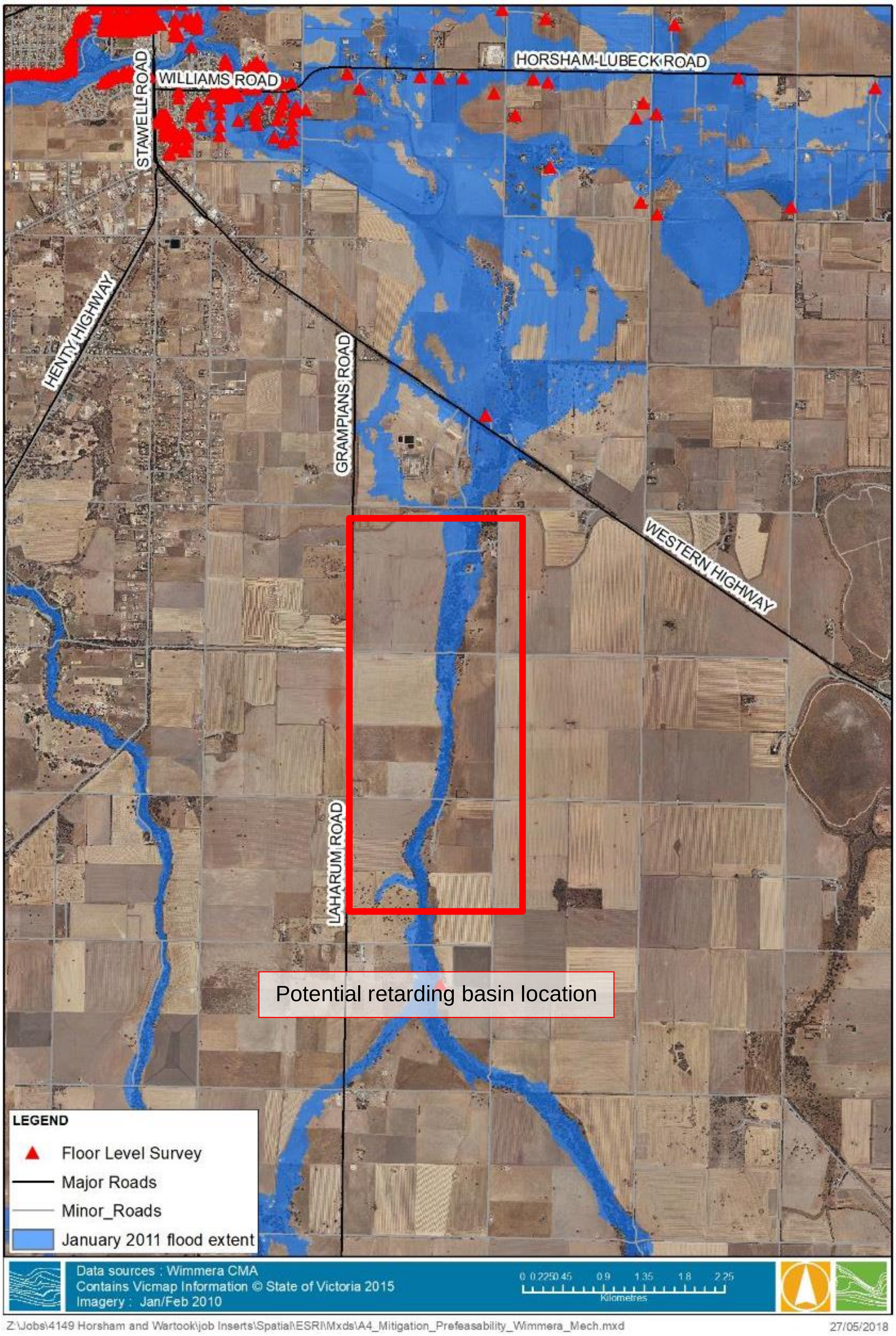

FIGURE 5-11 OPTION 4 - CONSTRUCT A RETARDING BASIN ON BURNT CREEK

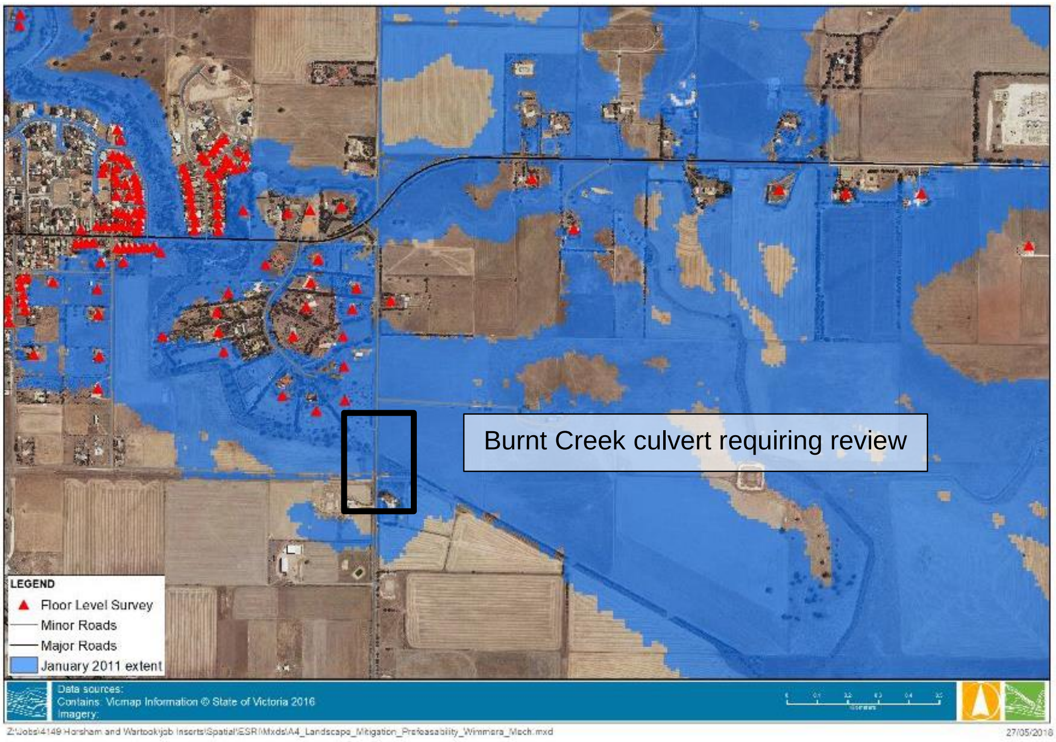

FIGURE 5-12 OPTION 6 – RESOLVE ISSUE AROUND DECOMMISSIONED CHANNEL AND UNDERSIZED CULVERT AT CAMERONS RD

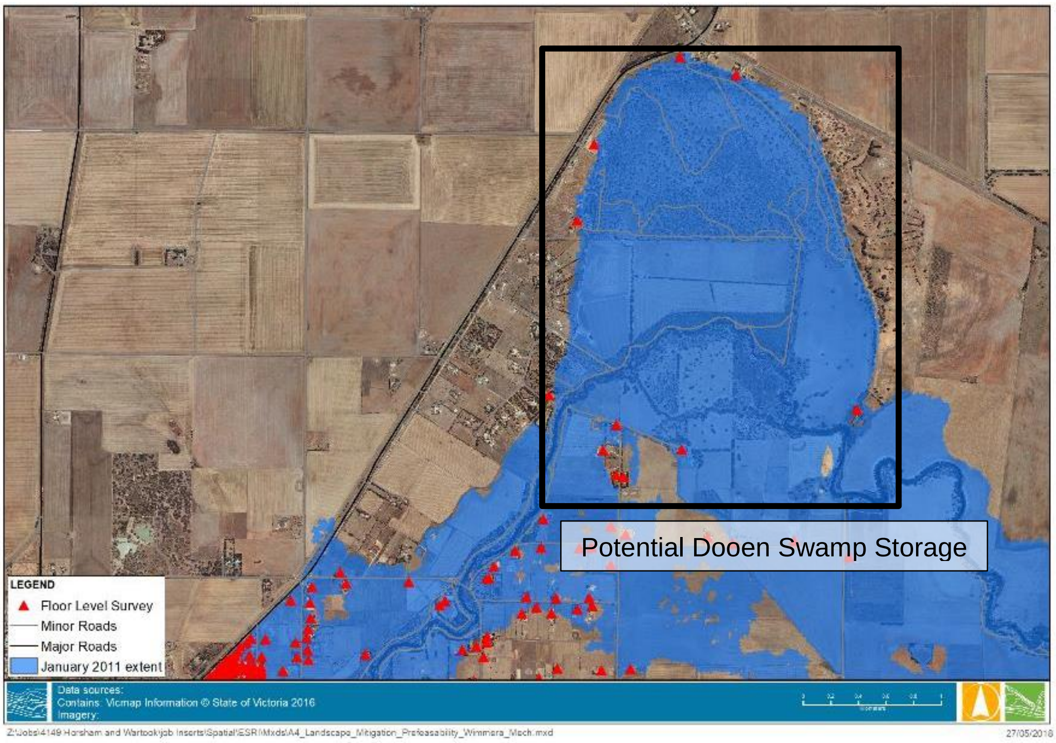

FIGURE 5-13 OPTION 7 – USE DOOEN SWAMP AS A FORMAL RETARDATION STORAGE

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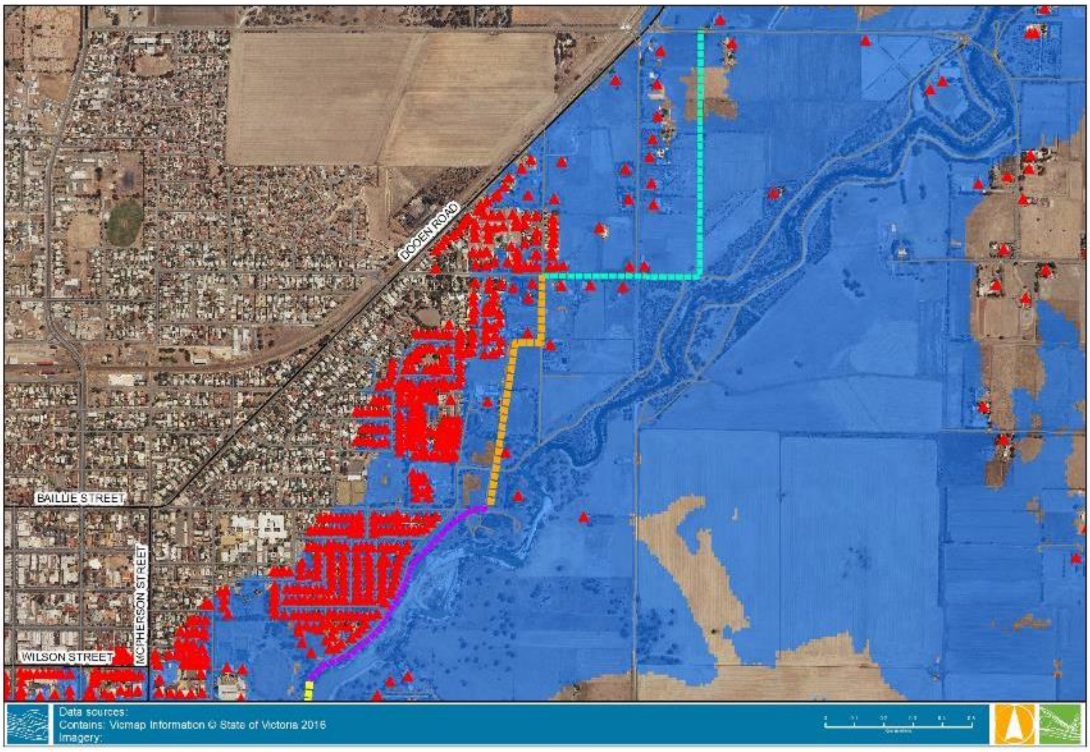

FIGURE 5-14 OPTION 2, 8 – CREATE A LEVEE FROM THE LUTHERAN SCHOOL TO PEPPERTREE LANE THROUGH TO PRYORS ROAD AND EAST OF CAMERONS RD NORTH TO THE HENTY HIGHWAY AND RIVERSIDE RD INTERSECTION

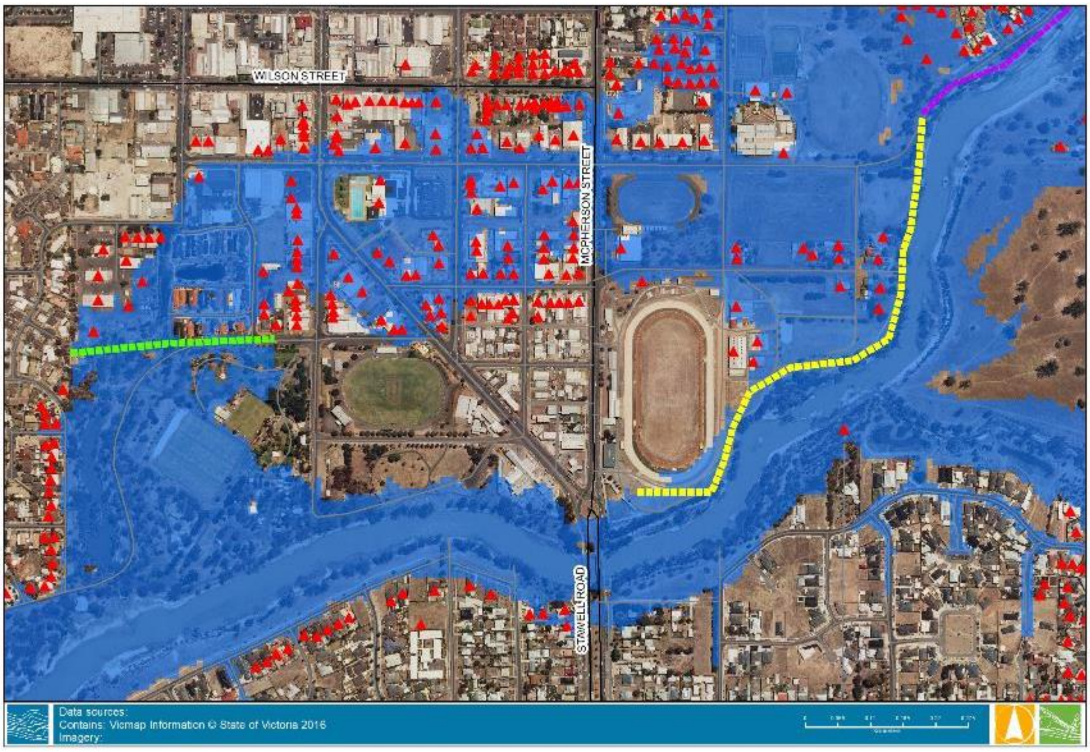

FIGURE 5-15 OPTION 9 AND 10 – A LEVEE FROM MENADUE ST TO HORSHAM SHOWGROUNDS AND CREATE A LEVEE TO PREVENT BACKFLOW AT WATONGA BASIN

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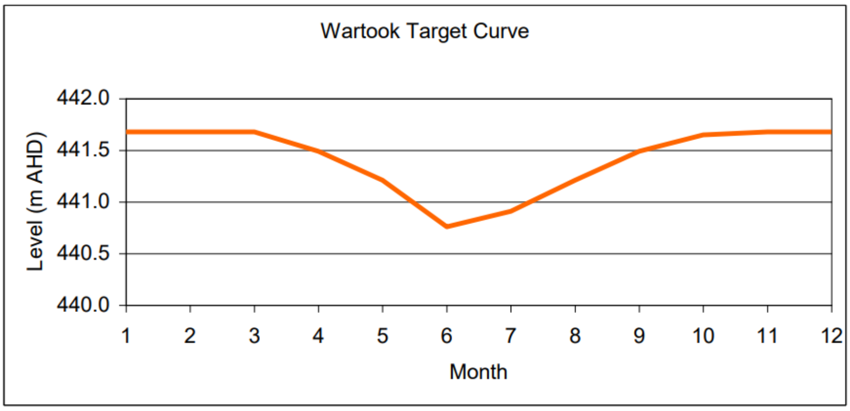
5.3.1.2 Options Discussion

5.3.1.2.1 OPTION 1 - OPERATING LAKE WARTOOK AT A LOWER LEVEL TO ALLOW FOR SOME FLOOD STORAGE

Lowering the operating height of Lake Wartook was suggested by the community to attenuate the Mackenzie River hydrograph. Lake Wartook has a capacity of 29,300 ML at Full Supply Level (FSL) which is 0.15 m below the spillway crest of 441.83 m AHD. When Lake Wartook is at its FSL, an additional 1,400 ML is required before it will spill. The Lake Wartook target level curve is shown in Figure 5-16. This target curve shows the water level that GWMWater aim to operate the storage at, drawing it down in the lead up to winter-spring for it to then refill ready for summer.



Month	Level (m AHD)
January	441.68
February	441.68
March	441.68
April	441.49
May	441.21
June	440.76
July	440.91
August	441.21
September	441.49
October	441.65
November	441.68
December	441.68

FIGURE 5-16 LAKE WARTOOK TARGET LEVEL CURVE[23]

The lake is used for drinking water supply and delivery of environmental flows along the Mackenzie River and Burnt Creek. Lowering the operating level of the lake would be a decision made by GWMWater, the reservoir manager, whose primary concern is the supply and delivery of water. Lowering the operating level would put the water supply resource at increased risk.

The cost of this option determined in the prefeasibility assessment has been determined on a lost opportunity cost, because there is less water available in the storage to use for water supply, that asset no longer exists and the cost of losing that water is likely to be quite high.

There is also an environmental cost with less ability to store environmental water for release through the Mackenzie River, Burnt Creek and Wimmera River.

Assessing the impact of lowering the Lake Wartook operating level could be assessed using an extended RORB model, including the reservoir. Currently the RORB model used in this project only extends to the Mackenzie River at Lake Wartook streamflow gauge, with a Flood Frequency Analysis used to determine inflows.

[23] GWMWater, 2016 - Storage Management Rules for the Wimmera-Mallee System Headworks Version: 2.02 Last amendment: August 2016

5.3.1.2.2 OPTION 2 - MENADUE STREET LEVEE UPGRADE (INCREASE - MENADUE ST (SOUTHERN END), RAISE- BAILLIE STREET TO PEPPERTREE LANE, CREATE- LUTHERAN SCHOOL TO PEPPERTREE LANE

The Menadue Street levee is currently considered to be at around a 2% AEP height, with floodwater able to flow around the levee to the north, close to the Wimmera Highway. The Menadue Street section of the levee is also of relatively inconsistent height and it is not maintained, so appears to be of poor condition. Increasing the height and extending this levee to the Wimmera Highway would give greater protection to numerous properties north of the Wimmera River within Horsham. However, increases and extensions to this levee may increase flood levels on the southern side of the river.

5.3.1.2.3 OPTION 3 - CHANGE SPLIT AT DUNNS CORNER THROUGH LEVEES/ROAD

Burnt Creek distributes water to Bungalally Creek at Dunns Corner at Wonwondah East. Bungalally Creek then returns to the Mackenzie River. There are numerous roads and channel embankments in this area which influence the flow split between the two waterways, this infrastructure could be used to change the flow split directing more water to Bungalally Creek rather than Burnt Creek where there is a much larger population at risk. The change in flow split would also increase flood levels in Bungalally Creek and lower Mackenzie River. Given the amount of existing infrastructure in place at Dunns Corner there are numerous constraints in making changes.

5.3.1.2.4 OPTION 4 - CONSTRUCT A RETARDING BASIN ON BURNT CREEK UPSTREAM OF THE WESTERN HIGHWAY USING A LEVEE

A rural retarding basin could be used to attenuate Burnt Creek flood flows. The retarding basin would be designed to allow low flows through the embankment to a rate which did not cause residential inundation. Resulting upstream inundation would be on agricultural land, avoiding buildings and road infrastructure, however landholders impacted would need to be consulted and most likely compensated.

5.3.1.2.5 OPTION 5 - INSTALL A NEW GAUGE DOWNSTREAM OF DUNNS CORNER – (BURNT CREEK @ WONWONDAH EAST – ON THE BOM SITE)

A new gauge downstream of Dunns Corner would provide a more reliable estimate of flow in Burnt Creek. The current gauge is not located in the best possible location which can lead to very minor increases in height corresponding with large increases in flow.

This suggested option will be reviewed as part of the Flood Warning Recommendations.

5.3.1.2.6 OPTION 6 - RESOLVE ISSUE AROUND DECOMMISSIONED CHANNEL AND RESULTANT UNDERSIZED CULVERT AT CAMERONS ROAD

The Burnt Creek culvert and channel arrangement at Camerons Road was modified as part of the GWMWater channel decommissioning. Community members have raised concerns that the replacement culvert is too small, which has resulted in an increase in inundation along Horsham Lubeck Road. To fully understand the impact of this option, modelling of the culvert capacity is required; however, given the widespread inundation in this area during large events the culvert capacity may only influence flood inundation during smaller floods.

5.3.1.2.7 OPTION 7 – USE DOOEN SWAMP AS A FORMAL RETARDATION STORAGE

Dooen Swamp provides a lot of natural storage during a flood event, with a natural choke in the channel capacity on the downstream end. Artificially restricting the flow at the outlet could be used to attenuate the flow further and reduce the Wimmera River peak flow through Horsham. It is likely that increased water levels in Dooen Swamp may cause more water to flood through East Horsham and there are several buildings around Dooen Swamp which may be impacted by increased inundation.

5.3.1.2.8 OPTION 8 - CREATE A LEVEE FROM THE LUTHERAN SCHOOL TO PEPPERTREE LANE THROUGH TO PRYORS ROAD AND EAST OF CAMERONS ROAD NORTH TO THE HENTY HIGHWAY AND RIVERSIDE RD INTERSECTION

A levee north of Camerons Road through to the Henty Highway would prevent inundation of around 13 properties, the suggested alignment does cutoff three properties south of Camerons Road North and some adjustment and assessment of the topography would be required to determine if including these properties is viable. Construction of the series of levees will prevent inundation of a large portion of floodplain and this is likely to result in increased flood levels in other areas. A final alignment would require further discussion with Horsham Rural City Council, and modelling completed to determine the impacts on the remaining floodplain.

5.3.1.2.9 OPTION 9 - CREATE A LEVEE FROM MENADUE STREET TO HORSHAM SHOWGROUNDS, SOUTH EASTERN CORNER OF THE HORSHAM GREYHOUND TRACK

Extending the Menadue Street levee to the south along the northern side of the Wimmera River would assist in preventing the overland flow path through Robinson Road/Macpherson Street which re-enters the Wimmera River through Watonga Basin. This option could only be considered if the Menadue Street levee was increased in height as some overland flow does return to the Wimmera River via this flow path.

5.3.1.2.10 OPTION 10 - CREATE A LEVEE TO PREVENT BACKFLOW AT WATONGA BASIN

A levee preventing backflow through Watonga Basin would be required in conjunction with the Menadue Street levee and the southern extension.

5.3.1.3 Assessment Criteria

Each mitigation option was assessed against several 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 5-2 below. The reduction in flood damage to built infrastructure (dwellings, commercial buildings etc.) was the most heavily weighted criteria as this is really the main objective for all flood mitigation (i.e. not pasture or crop damage which can have a higher financial value). Table 5-3 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 5-2 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

5.3.1.4 Assessment

Each of the suggested mitigation options was assessed using the outlined assessment criteria and is discussed in Table 5-3.

TABLE 5-3 PREFEASIBILITY ASSESSMENT CRITERIA

No.	Mitigation Option	Criteria					Score
		Damages Reduction	Cost ($)	Feasibility	Enviro. Impact	Comments	
Existing Infrastructure							
1	Operating Lake Wartook at a lower level to allow for some flood storage	3	1	2	2	Option is unlikely to cause any major reduction in buildings flooded, may cause a reduction in agricultural land flooded. May impact on the reservoirs primary function. Relatively easy to assess preliminarily by extending the hydrologic model to cover the Lake Wartook catchment. Likely to impact on environmental and domestic water availability.	9
2	Increase the height and length of the Menadue Street Levee in Horsham	4	3	4	5	Will reduce the impact of large floods, relatively easy and cost effective to achieve but may impact on the view of the Wimmera River for some houses and may increase flood levels south of the river.	15.5
New infrastructure							
3	Change split at Dunns Corner through levees/road	3	3	2	4	Could be difficult to achieve given the amount of infrastructure already in the area. Increasing flow towards Bungalally Creek may cause some additional inundation in that area.	12
4	Construct a retarding basin on Burnt Creek upstream of the Western Highway using a levee	3	3	3	5	May reduce the peak flow along Burnt Creek, is also likely to cause a significant area of agricultural land to be inundated. The volume in the Burnt Creek hydrograph may just fill the storage before the peak flow arrives.	13
5	Install a new gauge downstream of Dunns Corner – (Burnt Creek @ Wonwondah East – on the BoM site)	3	5	5	5	Relatively easy to achieve, probably not a big decrease in flood damages. Option will be assessed during the Flood Warning Assessment.	16
6	Resolve issue around decommissioned channel and resultant undersized culvert at Camerons Rd	3	5	5	5	Easy to assess and cheap to resolve. Unlikely to cause any big reductions in flood impacts but is important for some residents.	16

No.	Mitigation Option	Criteria					Score
		Damages Reduction	Cost ($)	Feasibility	Enviro. Impact	Comments	
7	Use Dooen Swamp as a formal retardation storage	3	3	3	3	May be hard to achieve given the water spilling through east Horsham. Dooen Swamp may fill before the Wimmera River peak flow arrives. Relatively easy to assess.	12
8	Create a levee from the Lutheran School to Peppertree Lane through to Pryors Road and east of Camerons Rd north to the Henty Highway and Riverside Rd intersection	5	2	4	5	Relatively easy to achieve, would significantly reduce flood damages in Horsham but may also cause some increases in flood level south of the Wimmera River.	16.5
9	Create a levee from Menadue St to Horsham Showgrounds, south eastern corner of the Horsham Greyhound Track	4	3	5	5	Easy to construct and would need to be assessed in combination with other levee options.	16
10	Create a levee to prevent backflow at Watonga Basin	4	4	5	5	Easy to construct and would need to be assessed in combination with other levee options.	17

Using the prefeasibility assessment above, the 10 mitigation options were ranked by weighted score. Their ranking is shown below in Table 5-4.

TABLE 5-4 WEIGHTED PREFEASIBILITY MITIGATION SCORES

Rank	Option No.	Mitigation Option	Weighted Score
1	10	Create a levee to prevent backflow at Watonga Basin	17
2	8	Create a levee from the Lutheran School to Peppertree Lane through to Pryors Road and east of Camerons Rd north to the Henty Highway and Riverside Rd intersection	16.5
3	5	Install a new gauge downstream of Dunns Corner – (Burnt Creek @ Wonwondah East – on the BoM site)	16
4	6	Resolve issue around decommissioned channel and resultant undersized culvert at Camerons Rd	16
5	9	Create a levee from Menadue St to Horsham Showgrounds, south eastern corner of the Horsham Greyhound Track	16
6	2	Increase the height and length of the Menadue Street Levee in Horsham	15.5
7	4	Construct a retarding basin on Burnt Creek upstream of the Western Highway using a levee	13
8	3	Change split at Dunns Corner through levees/road	12
9	7	Use Dooen Swamp as a formal retardation storage	12
10	1	Operating Lake Wartook at a lower level to allow for some flood storage	9

5.3.1.5 Discussion

In the list of suggested mitigation options there are several options that are highly likely to provide a reduction in flood damages. These options were recommended for modelling to test their potential impact. The options suggested for detailed modelling and reason for inclusion are as follows:

- Model all proposed levees north of the Wimmera River in a single simulation
- Changing the operating level of Lake Wartook
- Use Dooen Swamp as a formal retardation storage

Using the proposed bypass of Horsham to mitigate flooding in Horsham was not included in the options assessed due to the lack of ministerial approval and the timeframe it is likely to be constructed in. This project is looking at potentially adopting a mitigation option in the short to medium term (2-5 years) rather than long term (20-50 years). When a bypass of Horsham is further considered in the future, the opportunity of using it to reduce flows into Horsham should be assessed.

Modelling of the Camerons Road culvert wasn't completed due to its limited ability to impact on widespread damages. The culvert is clearly located in a flood flow path and conveyance through the culvert will impact local flood levels. The design criteria for structure should be discussed between Wimmera CMA and Horsham Rural City Council.

5.3.2 Modelling

5.3.2.1 Overview

The testing of mitigation ideas was completed in tandem with the design modelling. During this process the significance of the Western Highway Bridge on the Wimmera River and the Wimmera River channel shape and invert became apparent. Due to the importance of these structures additional survey of the Wimmera River was sourced. This survey replicated that captured during the Horsham

Flood Study[24] for comparison. The Western Highway Bridge was also surveyed to ensure changes made to the walking tracks underneath the bridge were adequately represented (as discussed in Section 2.4.2). Testing the feasibility of several mitigation options was completed before this survey was available; however, given the comparison of model results is relative they still provided an accurate representation of their potential to reduce flood damages.

As the modelling of mitigation options discussed in the prefeasibility assessment progressed, several modifications and additions to options were made. The final mitigation options modelled included:

- Horsham Levee
  - 1% AEP design level
  - 2% AEP design level
- Western Highway Bridge capacity increase
- Combined Horsham levee and Western Highway Bridge capacity increase
- Restricting flow in the Wimmera River downstream of Dooen Swamp
- Wimmera River channel deepening
- Wimmera River channel deepening and Western Highway Bridge capacity increase
- Restricting capacity in Burnt Creek upstream between Reynolds Road and Millers Road
- Increasing available storage within Lake Wartook

The model results are discussed in the following sections along with the existing conditions flood damages for context. It is important to note that the testing of each mitigation option was completed using either flows on the Wimmera River **or** Burnt Creek/Mackenzie Creek (not both waterways flooding simultaneously). This was completed to enable the true impact of the mitigation option to be assessed e.g. if a levee increased flood levels in a Wimmera River dominant event but not in a Burnt Creek dominant event this would be understood.

All flood levels across east Horsham and in Horsham north of the Wimmera River are dominated by Wimmera River flooding. Along Burnt Creek downstream of the Western Highway the cause of peak water levels for each AEP varies. For example, the peak water level along the lower end of Burnt Creek for the 20%, 10% and 5% AEP events are the Wimmera River. For the 2% AEP event Burnt Creek and the Wimmera River peak flows are relatively similar and for the 1% and 0.5% AEP events flood levels along the lower portions of Burnt Creek area generated by Burnt Creek.

Each mitigation option was discussed comparing the mitigated results to those in existing conditions. Comparison was made by subtracting the existing results from those in the mitigated scenario. This calculation is shown as follows:

Mitigated Scenario – Existing Conditions

The calculation results in positive values when the mitigation scenario results in an increase to flood levels and depths, and negative values when the flood level is decreased. The change in water levels and depths were then thematically mapped. Decreases in water level and depth were represented as shades of green (light to dark), while increases were shades of orange. Areas that were wet in existing condition but became dry as a result of the mitigation option were shown in magenta and areas that were dry and became wet are shown in blue. An example of the thematic mapping is shown in Figure 5-17.

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[24] Water Technology (2006), Horsham Flood Study

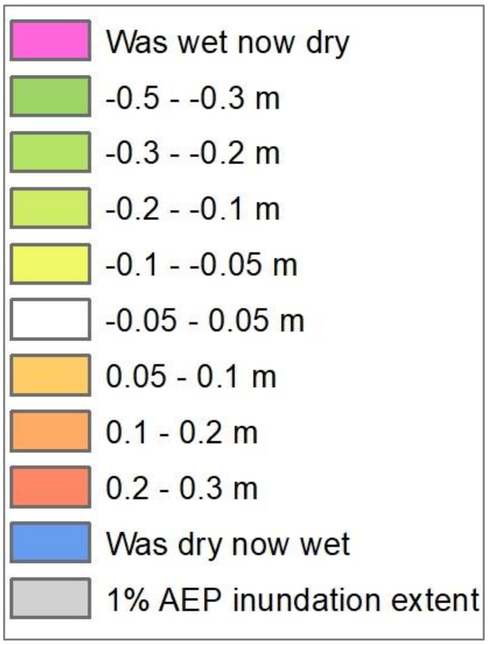

FIGURE 5-17 THEMATIC MAPPING OF CHANGES TO WATER LEVEL AND DEPTH DUE TO MITIGATION

5.3.2.2 Existing conditions flood damages

Under current conditions there are numerous buildings flooded above and below floor, with an estimated 182 buildings flooded above floor in a 1% AEP flood event. There is only one residential building flooded above floor in a 5% AEP event, this increases to 58 in a 2% AEP event indicating around the 2% AEP is the threshold for providing widescale flood mitigation.

Table 5-5 outlines a summary of the buildings flooded above and below floor for each of the modelled AEP events.

Appendix A shows the location of the buildings flooded above and below floor in a 1% AEP event. The mapping shows clear areas where the impact of the 1% AEP event is greatest. This includes the area north of the Wimmera River (east of Robinson Street and south of Bailie Street, and between Culliver Street and Peppertree Lane) and along Burnt Creek at Williams Road. These areas are an obvious focus for mitigation.

TABLE 5-5 SUMMARY OF FLOOD AFFECTED PROPERTIES WITHIN THE STUDY AREA

	Design Flood (AEP)					
	0.5%	1%	2%	5%	10%	20%
Residential Buildings Flooded Above Floor	242	140	37	1	-	-
Commercial Buildings Flooded Above Floor	60	42	21	-	-	-
Properties Flooded Below Floor*	588	591	520	171	111	74
Total Properties Flooded	890	773	578	172	111	74

* Properties flooded below floor include parcels with buildings on them.

5.3.2.3 Horsham Levee

5.3.2.3.1 OVERVIEW

Option 8 and 9 assessed in the prefeasibility assessment suggested levees to protect areas of northern Horsham. Preliminary mitigation modelling showed individual portions of levee would be susceptible to outflanking, so the options were combined into a single levee protecting the maximum area possible. The location of the modelled levee is shown in Figure 5-18. Given the threshold for significant flood damage in Horsham was shown to be the 2% AEP event, both the 1% and 2% AEP events were modelled. The results of the 2% AEP event show the potential for a levee with lower level of protection.

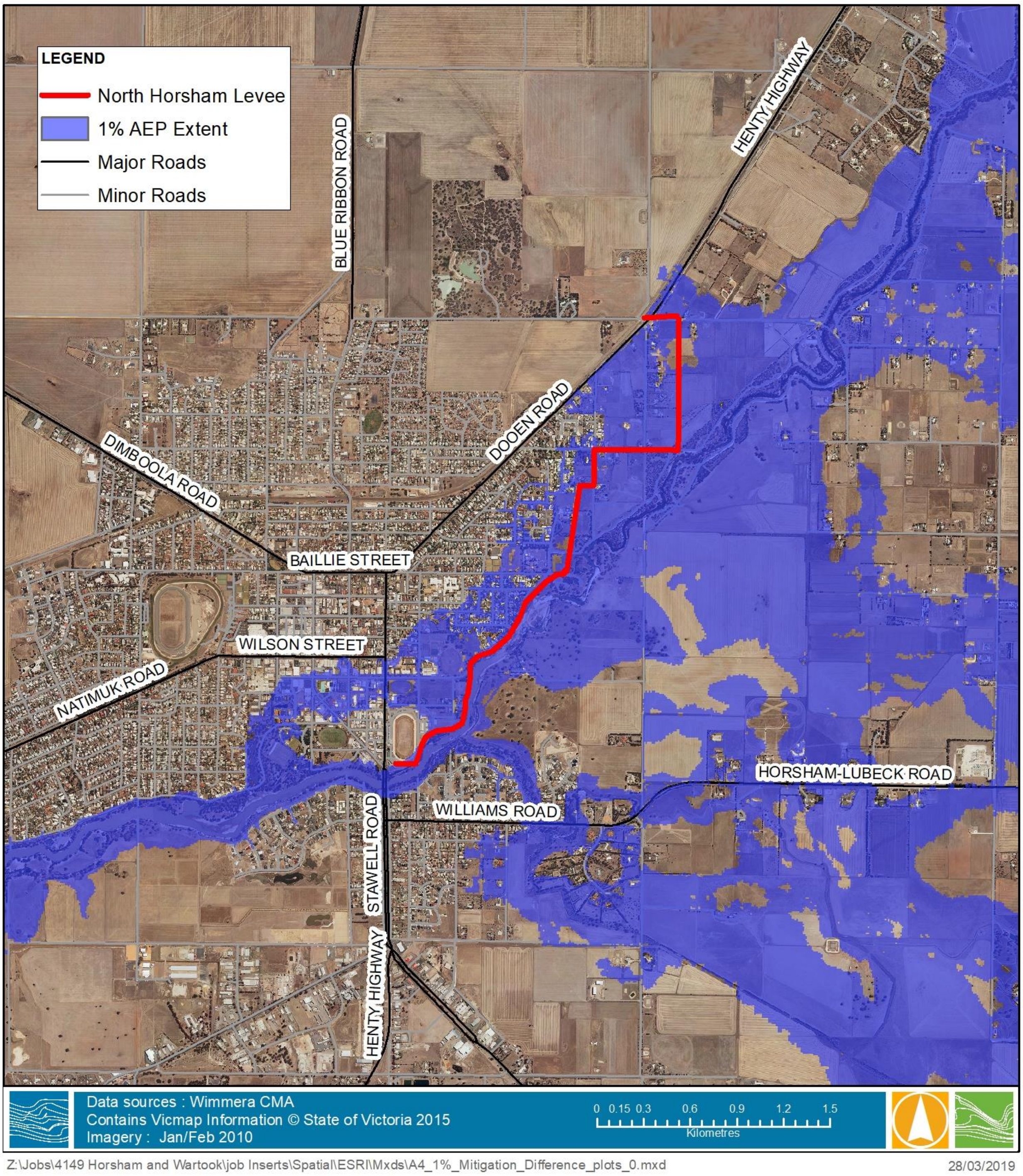

FIGURE 5-18 HORSHAM – NORTHERN LEVEE LOCALITY MAP

5.3.2.3.2 1% AEP

Modelling of the of the northern Horsham levee in a 1% AEP flood event showed the levee increased flood levels on the southern side of the Wimmera River and along Burnt Creek as well as Cameron Road. The tested levee alignment did not quite extend far enough to the north and increases in water level resulted in water outflanking the levee.

The resulting change in flood depths and extents during a 1% AEP event due to the levee is shown in Figure 5-19. Due to water flowing around the northern end of the levee there isn't a removal of flood water through the area north of the Wimmera River, just decreased in flood levels.

The increase in flood levels has caused inundation of the police paddock with water overtopping the Henty Highway. There are also significant increases in flood extent along Burnt Creek east of the Western Highway on the southern side of Williams Road. There are numerous buildings flooded above floor in the areas of water level increase.

So although the levee is effective in reducing flooding to the east of the levee, it results in an increase in flood levels that will increase the depth of inundation on several homes already flooded above floor in East Horsham.

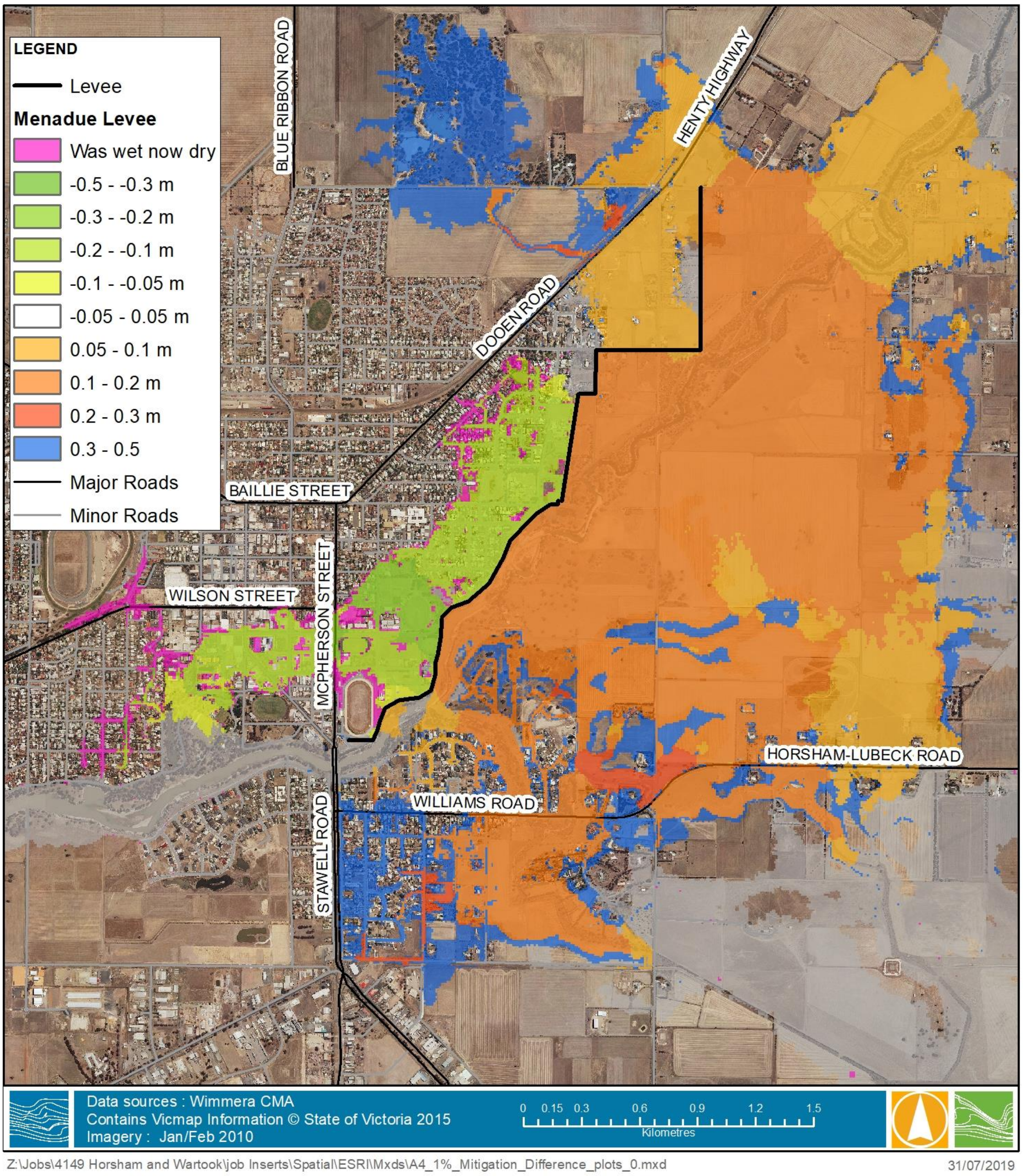

FIGURE 5-19 NORTH HORSHAM LEVEE – 1% AEP EVENT, CHANGE IN FLOOD LEVEL AND EXTENT

5.3.2.3.3 2% AEP

Modelling of the northern Horsham levee in a 2% AEP flood event showed similar results to that of the 1% AEP event, with widespread increases in depth and extent along Burnt Creek and the Wimmera

River through East Horsham, Figure 5-20. Depths along Burnt Creek have increased by around 0.09 m, while depths in the Wimmera River have increased by around 0.13 m (to a maximum of 0.22 m). The inundation extent has increased the most north of Horsham Lubeck Road, around Cameron Road.

There are buildings in this area flooded above and below floor in a 2% AEP event, the levee would increase this inundation and damage to these properties.

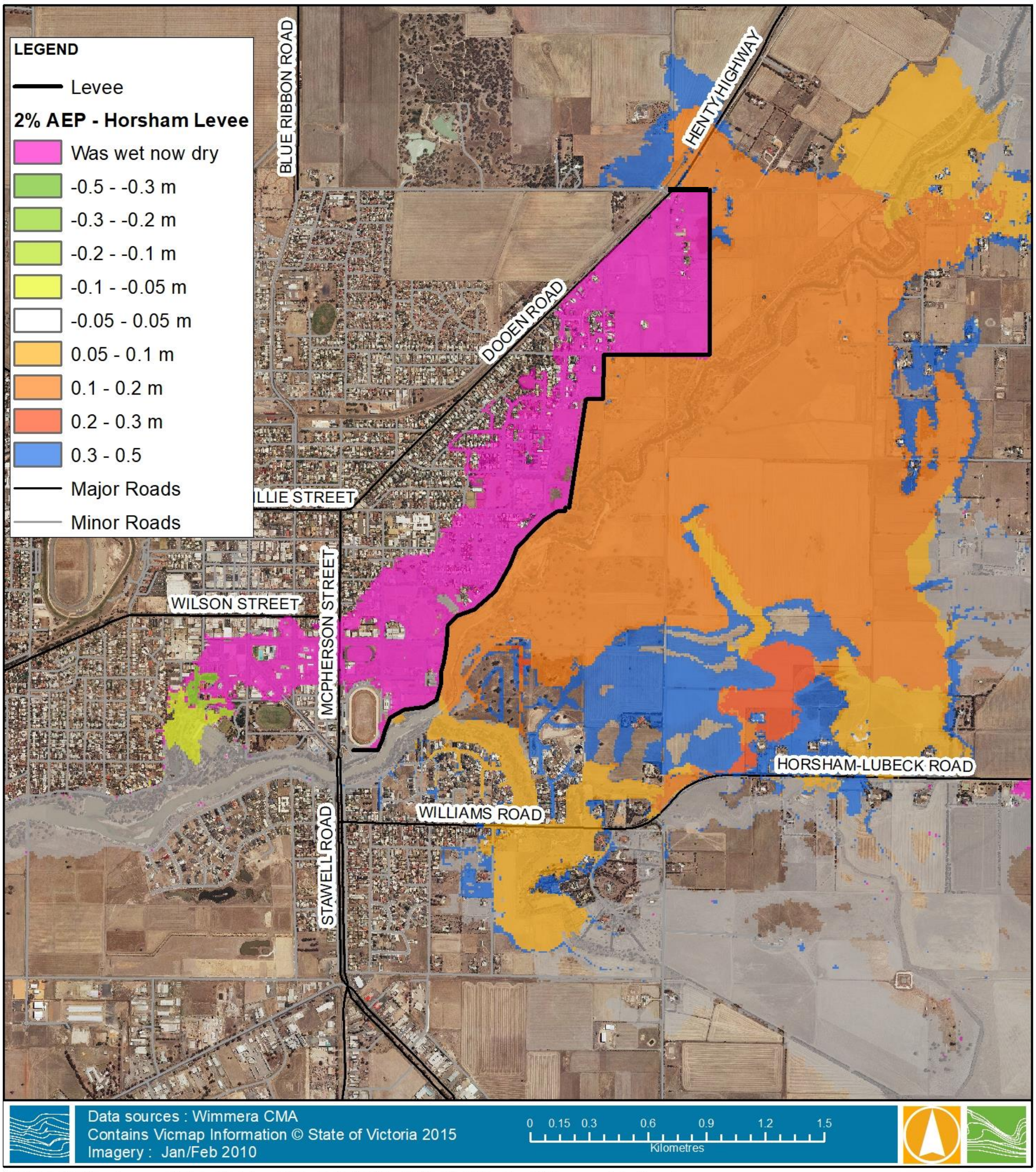

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FIGURE 5-20 NORTH HORSHAM LEVEE – 2% AEP EVENT, CHANGE IN FLOOD LEVEL AND EXTENT

5.3.2.4 Wimmera River Channel Deepening

As discussed in Section 5.3.2.1, the Wimmera River channel invert and cross-sectional area has been shown to be an influencing factor in the design modelling process. To determine the potential impact of channel deepening on flood levels, lowering of the Wimmera River bed was tested. A uniform lowering of 1.0 m from downstream of the Western Highway Bridge to Peppertree Lane was incorporated into the flood model. Lowering was made to the area that would typically be wet when the Horsham Weir Pool was full. The model approximated what might be possible to show the potential reduction in flood levels. Any physical lowering of the bed of the Wimmera River would be much less uniform and would involve considerable investigations into the impact on the waterway stability, ecology, and would require planning approvals from the Wimmera CMA.

Uniformly lowering the bed of the Wimmera River caused a decrease in flood level and extent along the Wimmera River and Burnt Creek. Decreases in flood level in Burnt Creek were around 0.06 m, while decreases on the Wimmera River were around 0.07 m. Decreases in extent were most pronounced along and to the east of Stockton Drive.

Noticeably there was virtually no change in water levels upstream of the Western Highway Bridge, this indicated the bridge itself is likely to be a hydraulic control given its significant narrowing of the Wimmera River and associated floodplain.

The change in depth and extent due to the Wimmera River bed lowering in a 1% AEP event is shown in Figure 5-21.

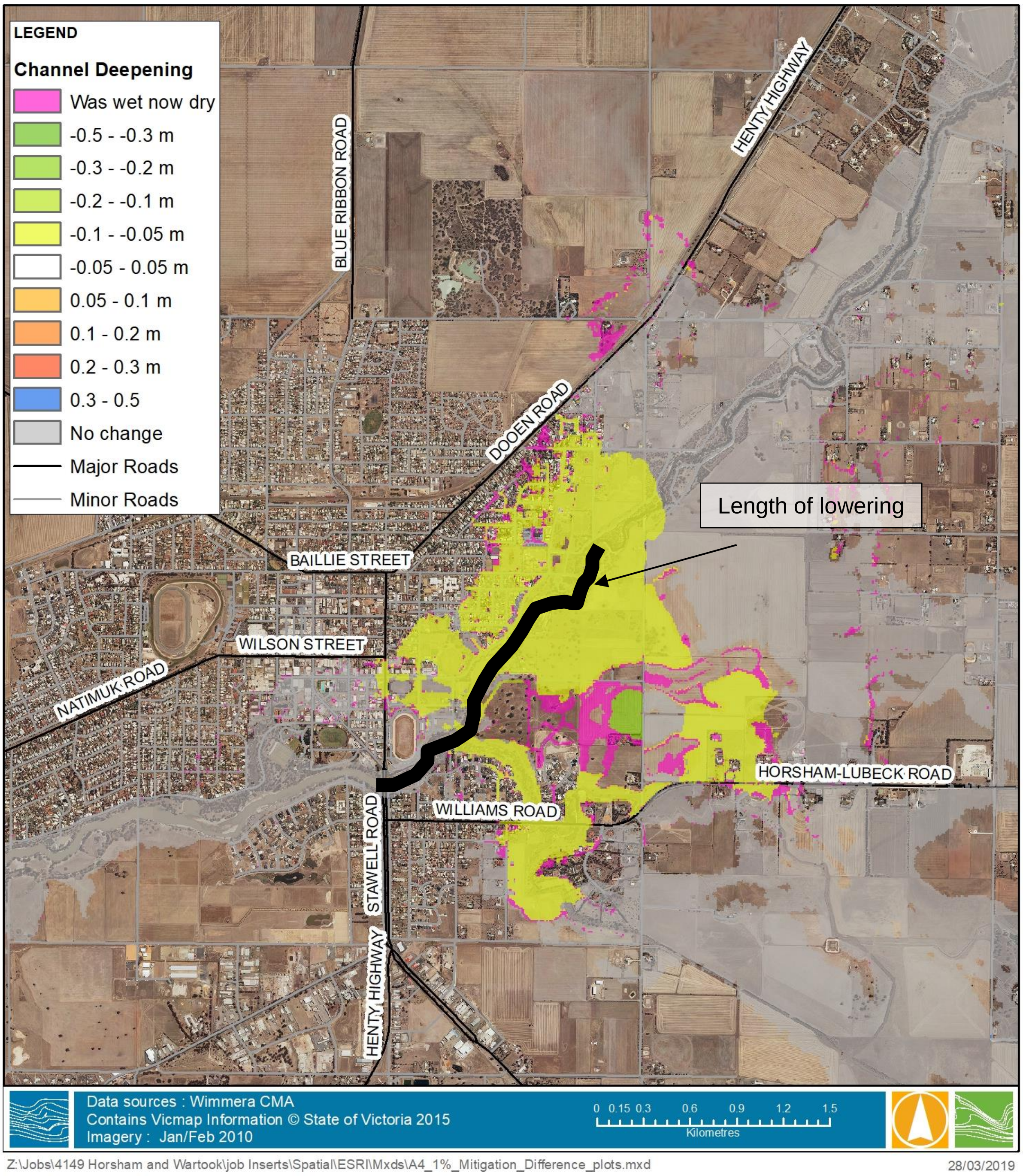

FIGURE 5-21 WIMMERA RIVER CHANNEL LOWERING – 1% AEP EVENT, CHANGE IN FLOOD LEVEL AND EXTENT

5.3.2.5 Western Highway Bridge Capacity Increase

Design and mitigation modelling highlighted the Western Highway was a significant hydraulic control on the Wimmera River. The impact of a large-scale increase to the bridge size to around double its current span to the north was tested, Figure 5-22. This increase was completed to test a 'maximum impact' scenario, with no consideration given to the practicalities of the engineering of the bridge widening. The scenario was modelled to determine what could be achieved in terms of lowering flood levels.

FIGURE 5-22 WESTERN HIGHWAY – CAPACITY INCREASE

Model results showed a maximum reduction in flood levels of around 0.27 m, directly upstream of the Western Highway Bridge. The decrease reduced with distance from the bridge until no change was observed at around Cameron Road. There were reductions in water level in the most impacted areas of Horsham with depths south of Baillie Street reducing by 0.07 m and depths along Burnt Creek reducing by 0.16 m.

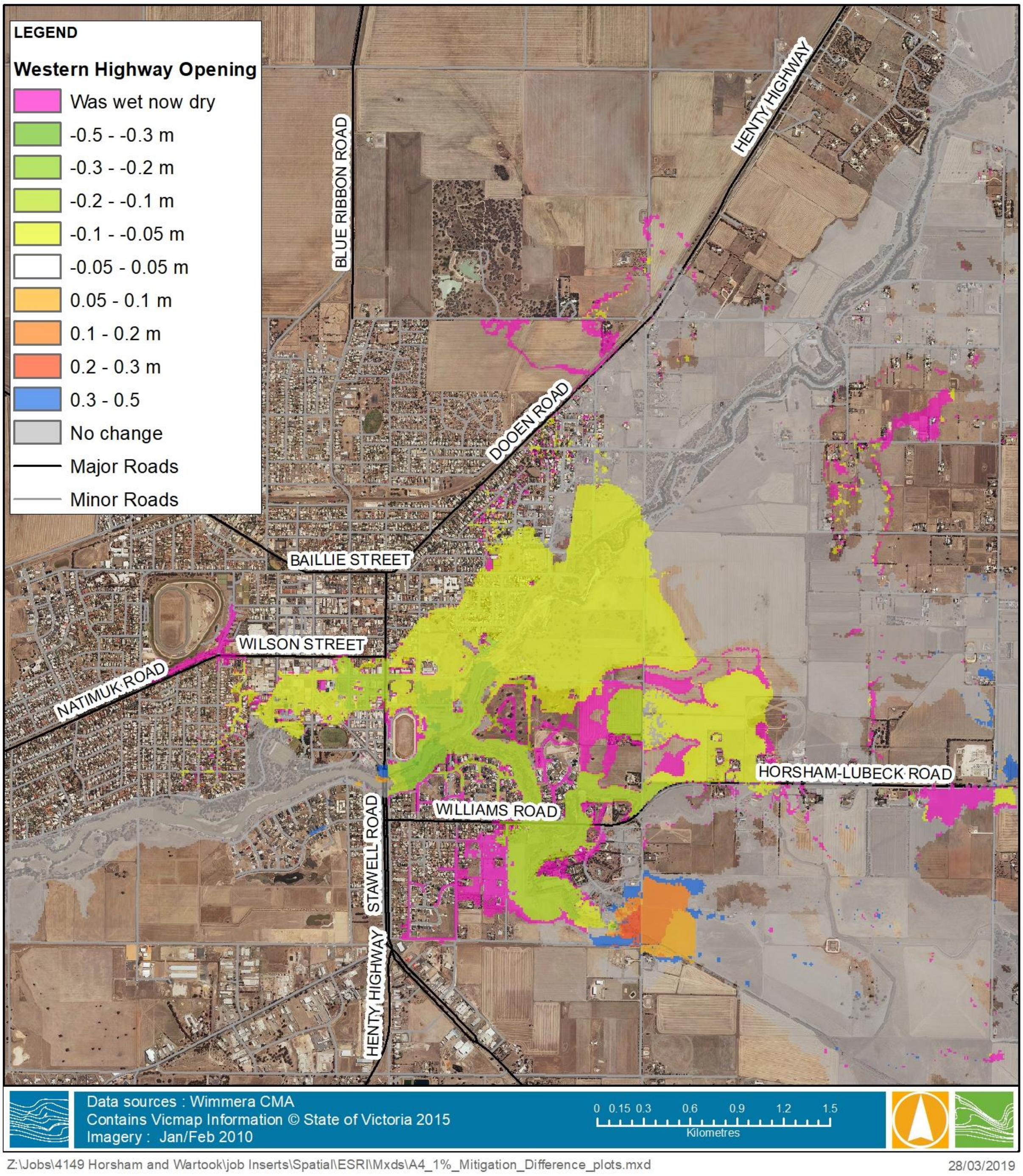

FIGURE 5-23 WESTERN HIGHWAY BRIDGE CAPACITY INCREASE – 1% AEP EVENT, CHANGE IN DEPTHS AND EXTENT

5.3.2.6 Western Highway Opening and Horsham Levee

While the North Horsham Levee prevented inundation at many properties on the northern side of the Wimmera River there were significant increases in depth and extent to the south. To try and negate these increases, the combination of an increased Western Highway Bridge capacity and the Northern Horsham Levee were tested together. Opening of the Western Highway was completed as outlined in Section 5.3.2.5 and the levee was included as outlined in Section 0.

The model results showed opening the Western Highway prevented the widespread increases along Burnt Creek and south of the Wimmera River west of Burnt Creek. However, it was not enough to offset the increases in flood level caused by the northern levee. There are several dwellings in this area, particularly along Horsham Lubeck Road which would be impacted by the increased flood levels in this option. The change in water levels and extents as a result of opening the Western Highway Bridge and the Horsham Levee is shown in Figure 5-24.

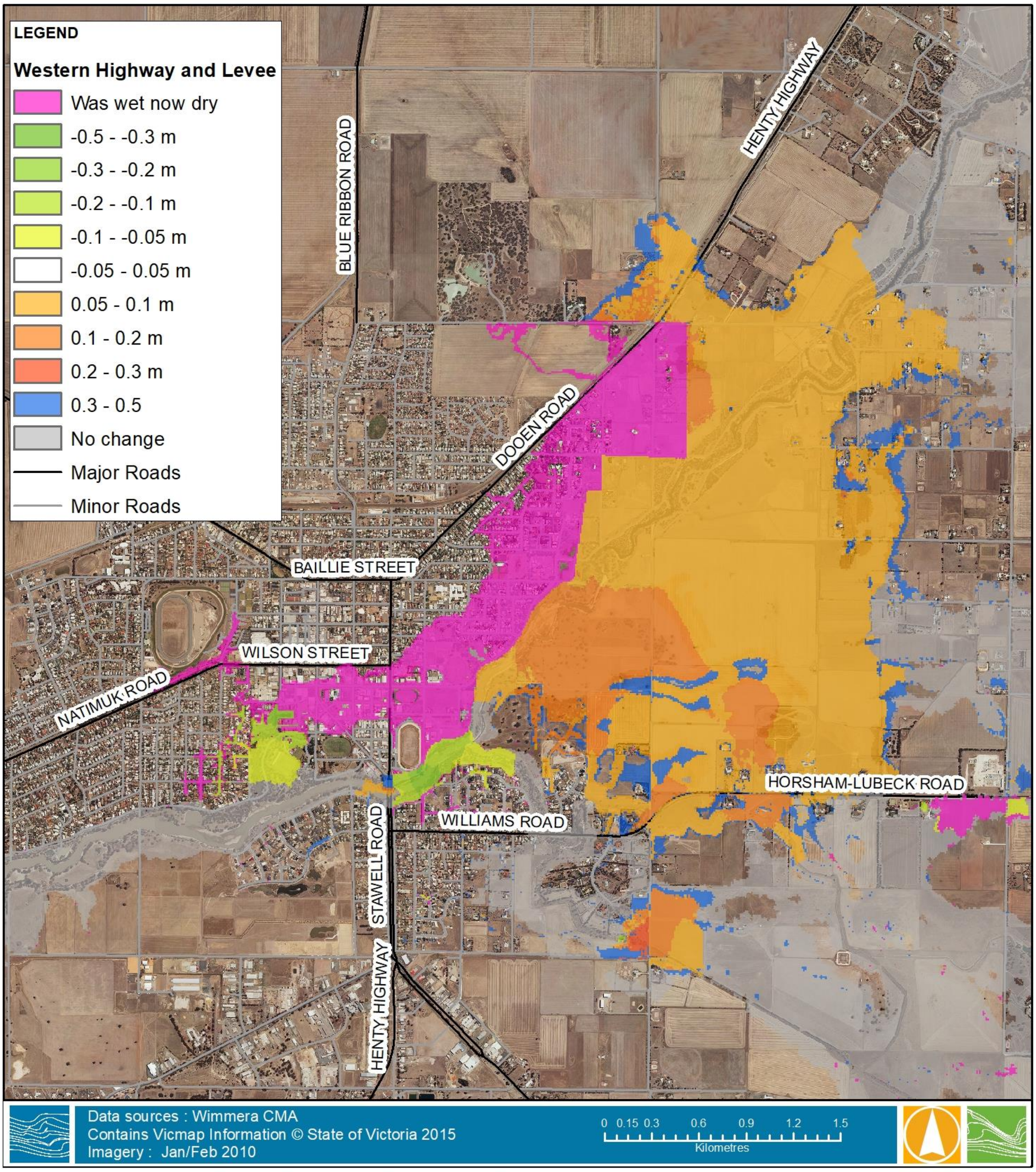

FIGURE 5-24 WESTERN HIGHWAY BRIDGE CAPACITY INCREASE AND NORTHERN HORSHAM LEVEE – 1% AEP EVENT, CHANGE IN FLOOD LEVELS AND EXTENT

5.3.2.7 Channel Deepening and Bridge Opening

Modelling showed deepening the Wimmera River channel by 1 m was able to reduce flood levels upstream of the Western Highway Bridge, but the capacity of this opening became a limiting factor to the improvements which could be made. To improve on this option the Wimmera River channel deepening (discussed in Section 5.3.2.4) was combined with opening the Wimmera River Bridge to around double its current span to the north (discussed in Section 5.3.2.5).

The change in water levels and extents due opening the Western Highway Bridge and deepening the Wimmera River is shown in Figure 5-25.

Immediately upstream of the bridge there are decreases in depth of around 0.26 m, north of the Wimmera River residential areas decrease by between 0.22 and 0.16 m, along Burnt Creek water levels decrease by around 0.22 m and the general Wimmera River floodplain decreases by 0.2 m.

The inundation extent decreases by a significant amount along Burnt Creek north of Horsham Lubeck Road.

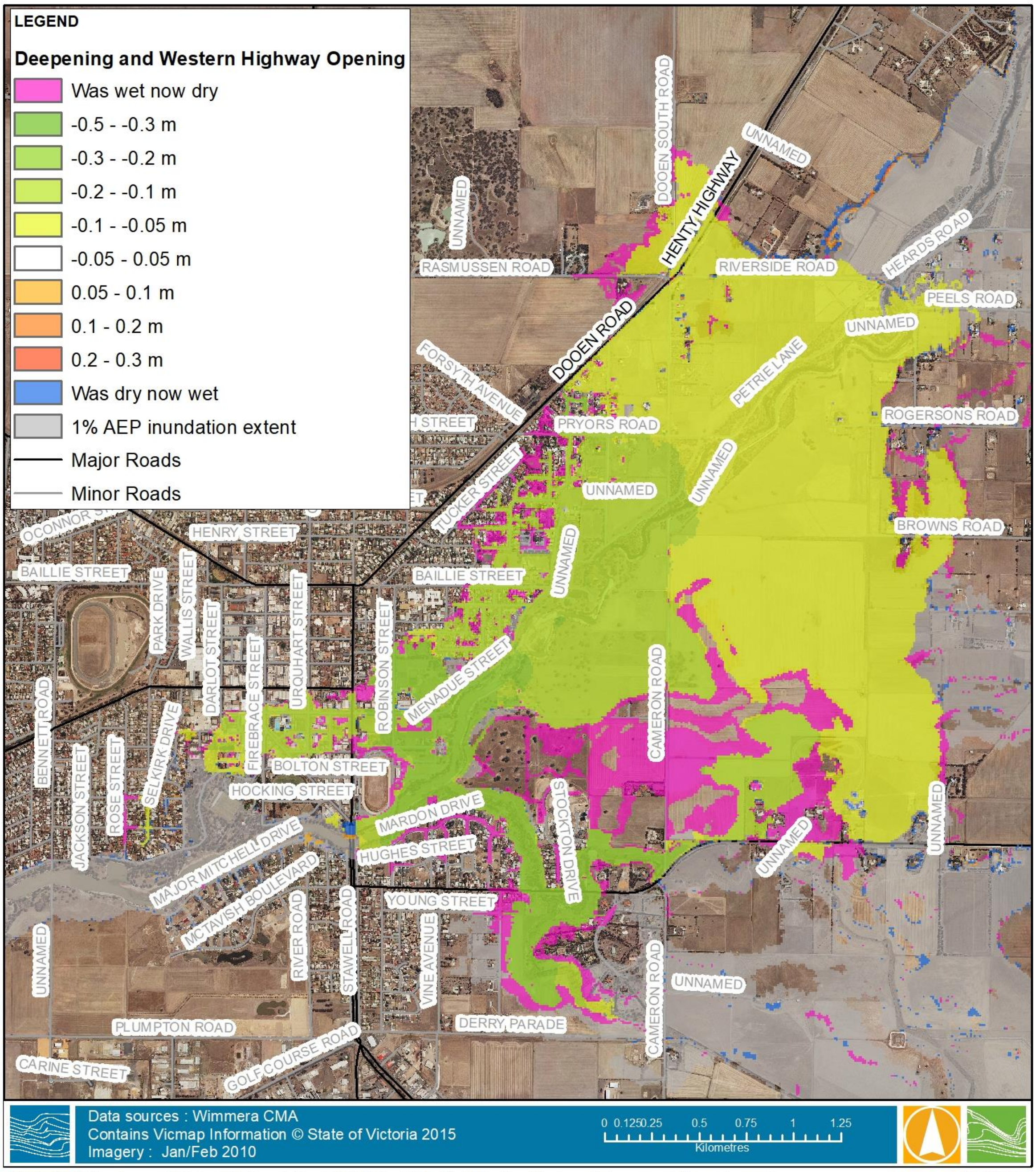

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FIGURE 5-25 INCREASEING THE WESTERN HIGHWAY BRIDGE CAPACITY AND DEEPENING THE WIMMERA RIVER – 1% AEP EVENT, CHANGE IN FLOOD LEVELS AND EXTENT

5.3.2.8 Increasing the storage in Dooen Swamp by creating a ‘choke’ at the Wimmera River Outlet

The potential to reduce flood levels along the Wimmera River by creating additional storage in Dooen Swamp was tested by creating a choke on the Wimmera River outlet point. The intent of this choke was to allow low flows to occur as they currently do but restrict out of bank flows.

Embankments were included in the model restricting the cross section of the Wimmera River, as shown in Figure 5-26

FIGURE 5-26 DOOEN SWAMP CAPACITY RESTRICTION EMBANKMENTS

The impact on 1% AEP water levels is shown in Figure 5-27. The results show increases to water levels and extents within and immediately south of Dooen Swamp. There are small reductions immediately downstream of the outlet where the banks were included but the reduction did not reach Horsham and the impact on flood damages is negligible.

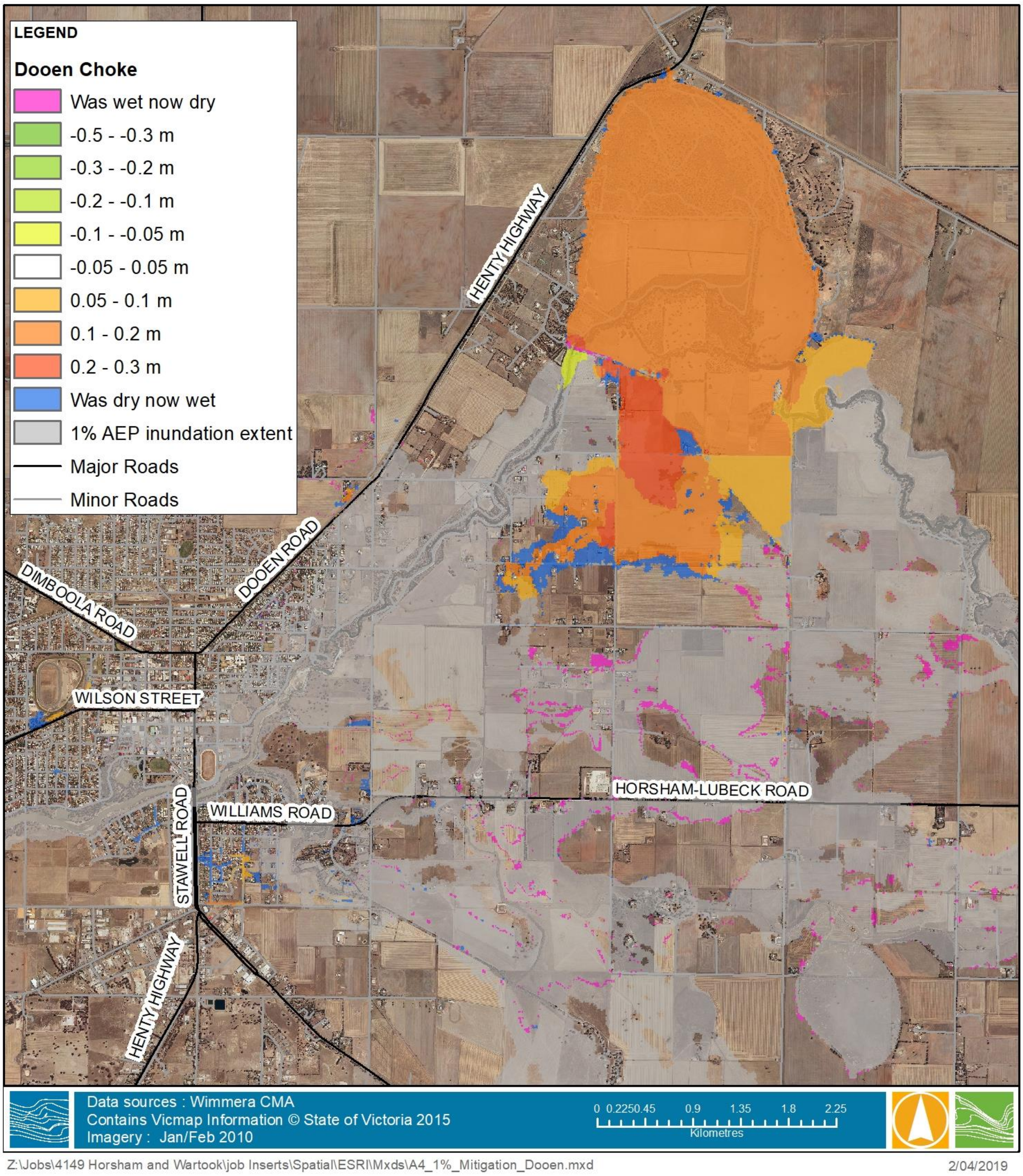

FIGURE 5-27 CHANGE IN WATER LEVELS AND EXTENT DUE TO RESTRICTING THE DOOEN SWAMP OUTFLOW

5.3.2.9 Increasing available storage within Lake Wartook

As discussed in Section 5.3.1.2.1, Lake Wartook has a target curve for volume stored which varies throughout the year and depending on when an event occurs the target volume can differ. This has influenced the potential for historic events to overtop the spillway, as shown in Figure 5-28. Spills are shown to occur in 2011 and 2016.

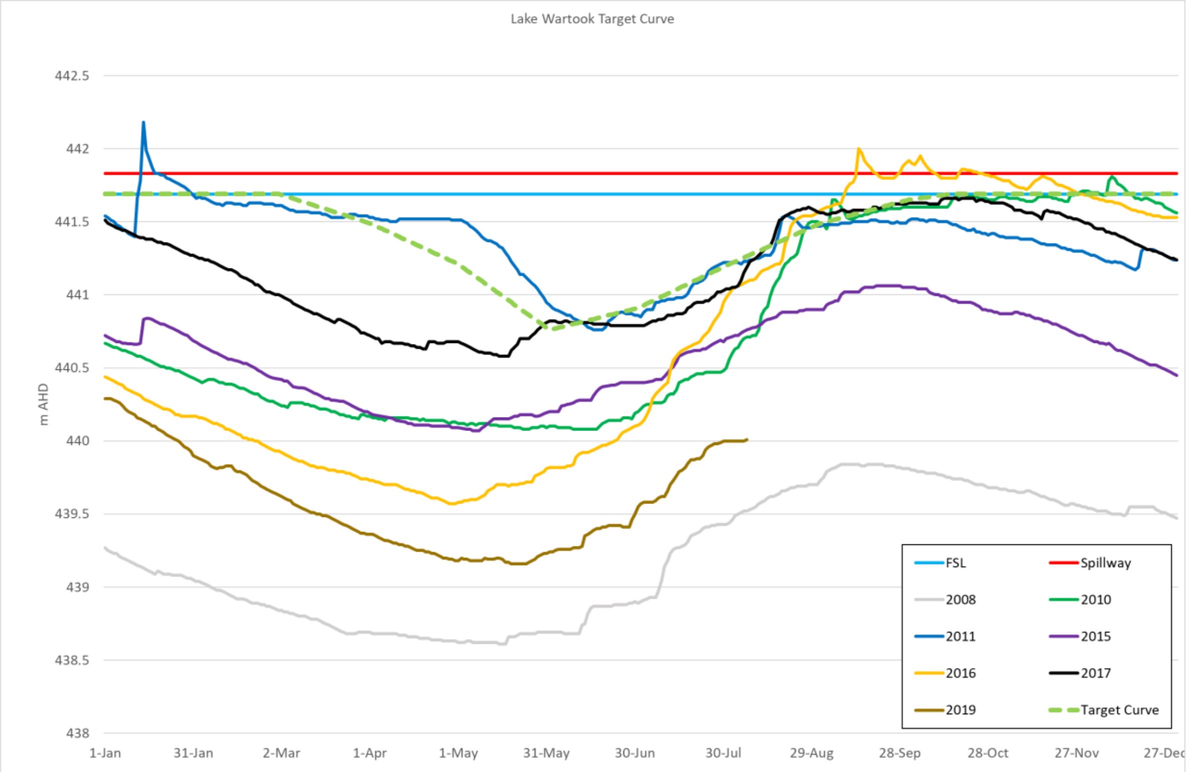

FIGURE 5-28 HISTORIC LEVELS IN LAKE WARTOOK FOR PREVIOUS HIGH INFLOW EVENTS

A separate RORB model of Lake Wartook and its associated catchment was built to assess the impact of modelling various starting levels in the reservoir. Design flows were determined using the 1% AEP, 12hr event using Temporal Pattern 3, and the 1% AEP, 72hr event using Temporal Pattern 2, these temporal patterns were shown to be the most often adopted in the RORB modelling discussed in Section 4.5.2. All recommended ARR2016 losses (an initial loss of 34mm and continuing loss of 3 mm/hr – these are the same as those adopted across the RORB model used for areas downstream of Lake Wartook) and rainfall IFD values were adopted. Kc was determined using the Pearce Equation. The Pearce Equation was adopted due to its basis being Victoria Data. The Pearce Equation was also shown to be the most accurate Kc prediction equation within the neighbouring Natimuk Creek catchment during the Natimuk Flood Investigation[3].

Modelling was completed with Lake Wartook at spillway height (Wartook Spillway level: 441.83 m AHD, Vol: 30,741 ML) and 95%, 90% and 85% capacity from spillway height.

The impact on flows from Lake Wartook for the 12hr and 72hr events is shown in Figure 5-29 and Figure 5-30 respectively.

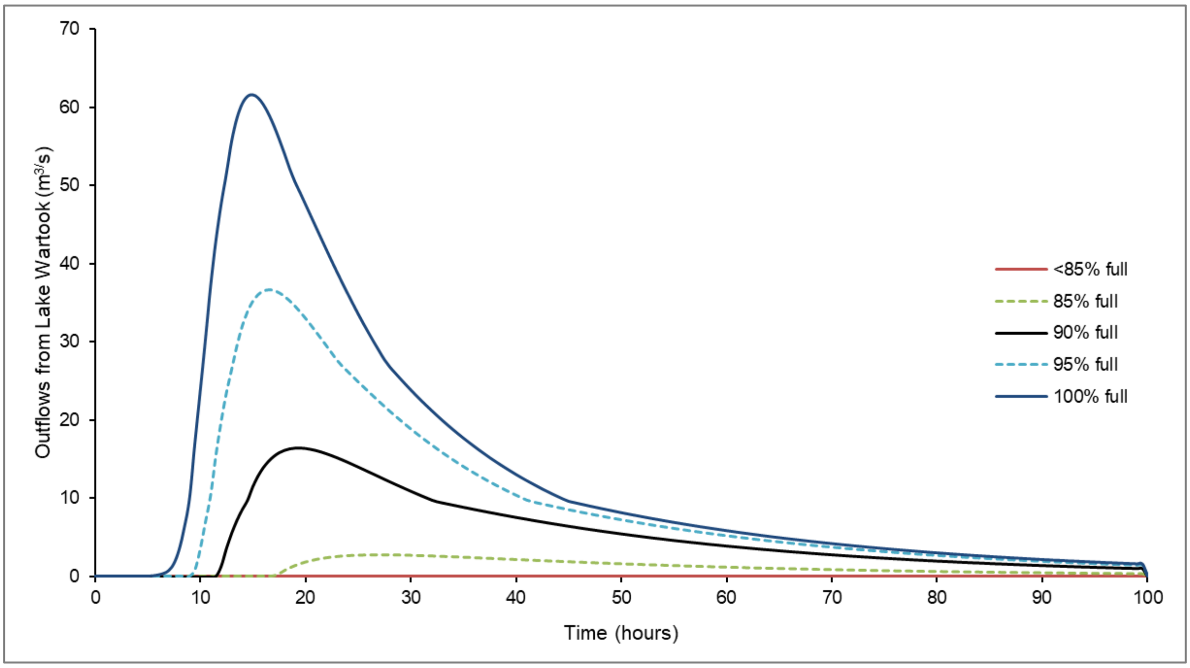

FIGURE 5-29 THE IMPACT OF INCREASING THE AVAILABLE STORAGE IN LAKE WARTOOK – 12HR EVENT

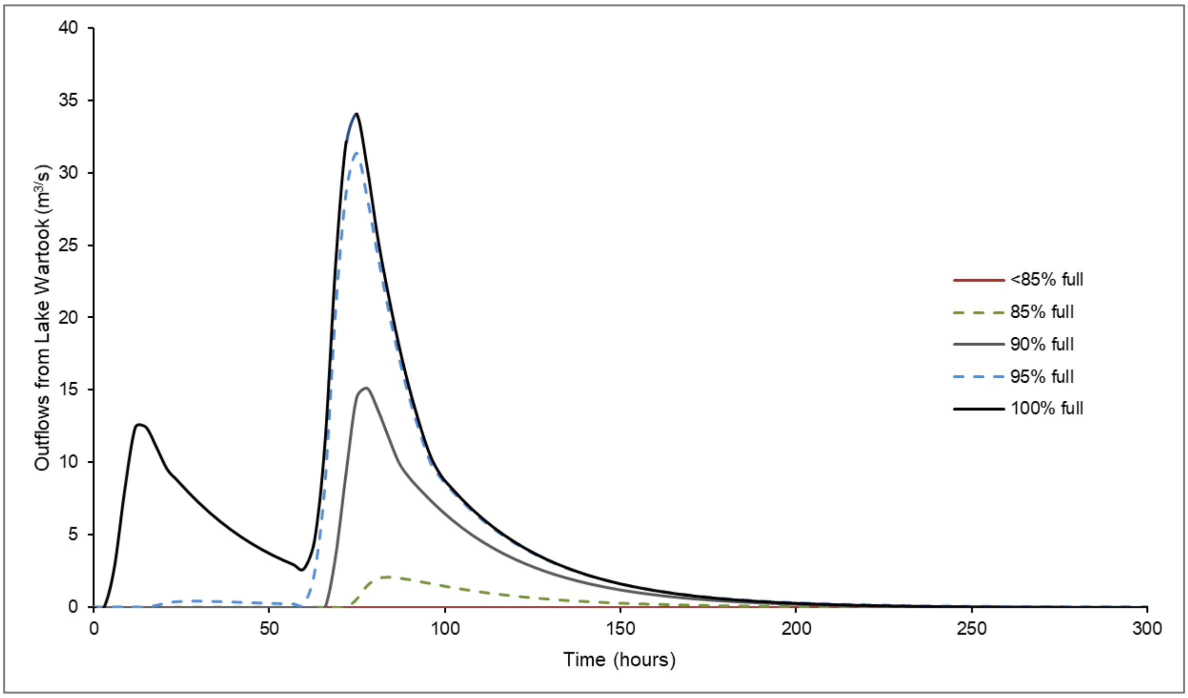

FIGURE 5-30 THE IMPACT OF INCREASING THE AVAILABLE STORAGE IN LAKE WARTOOK – 72 HR EVENT

The change to outflows from Lake Wartook was significant with the lake able to fully absorb the 1% AEP event volume at 85% full for both the 12hr and 72 hour events for Temporal Pattern 3 and 2 respectively meaning that no water would pass over the lake wall. How this impacts flood levels and extents could be assessed using the hydraulic model, this was not completed due to the limited number of hydraulic model runs allowed for within the project and the relatively low number of buildings impacted along the upper reaches of the Mackenzie River and changes in flow are not expected to result in significant decrease in flood damages.

Lake Wartook is managed at an Full Supply Level of 441.69 m AHD (Vol: 29,395 ML), this is around 95% of the lake volume at spillway height in the scenarios shown in Figure 5-29 and Figure 5-30.

The reality of a significant change in the operating height of Lake Wartook is very complex with numerous other factors to consider including domestic, recreation and environmental water supply and further investigation into the possibility of this option is required. The cost or impacts of managing and maintaining a lower lake operating level has not been completed in this flood investigation.

5.3.2.10 Restricting capacity along Burnt Creek

Creating a capacity restriction along Burnt Creek in its most confined section between Rodda Road and Reynolds Road was tested. The channel was restricted to 5-10m wide with levees 2m high either side. Modelling of the 12hr, 1% AEP event showed the restriction increased flood levels by more than 0.5 m on the upstream side of the embankment but only a limited decrease downstream was observed at around 0.03 m. No perceivable decrease was observed in Horsham.

A comparison of the existing and mitigation scenario water levels is shown in Figure 5-31.

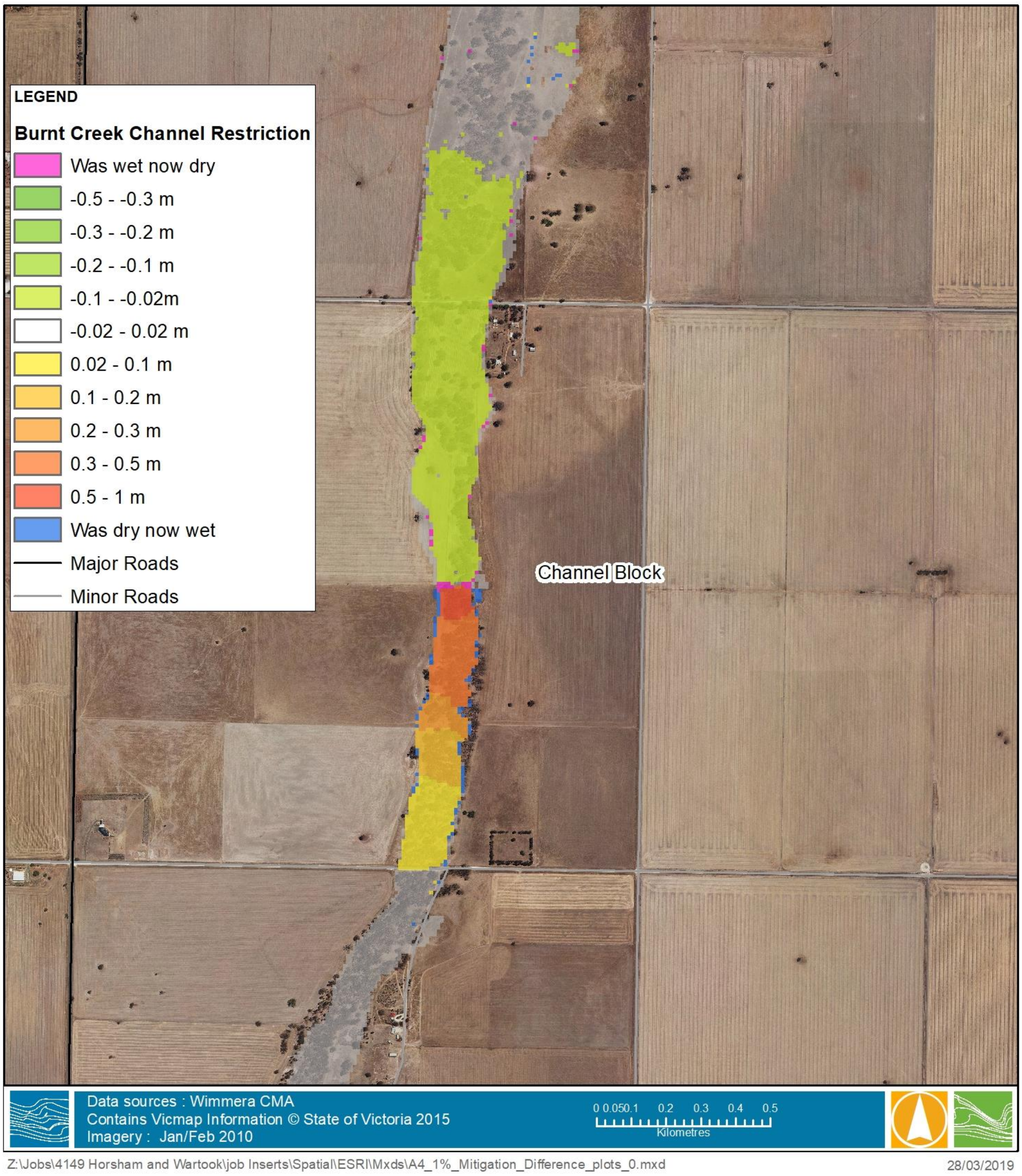

FIGURE 5-31 CHANGE IN WATER LEVELS AND EXTENT DUE TO RESTRICTING BURNT CREEK

5.3.3 Discussion and Summary

Modelling of the various mitigation options has shown there is no easy solution to reduce flood damages within Horsham, as protecting the area to the north of Horsham can result in flood waters increasing in other areas.

Modifying the outlet of Dooen Swamp to restrict its outflow was shown to be unsuccessful with flood water breaking out east of the proposed works and increasing flood levels through areas of East Horsham and not significantly reducing water levels closer to Horsham. Similarly, a retarding basin on Burnt Creek was unsuccessful because of the lake of temporary storage created by the retarding basin tested.

A levee protecting the areas north of the Wimmera River shows the greatest potential reduction in flood damages, purely because of the number of impacted buildings in that area. However, this option results in increased flood levels along Burnt Creek and through East Horsham, in areas with buildings already flooded above floor.

Increasing the Wimmera River capacity by channel lowering and increasing the capacity of the Western Highway Bridge did not significantly reduce the extent of inundation but the reduction in flood levels would cause a large decrease in properties flooded above floor. In existing conditions there are 64 residential buildings and 10 commercial buildings flooded above floor by less than 100mm and reductions in flood level greater than that amount could cause a significant reduction in flood damages. In existing conditions the number of residential properties flooded above floor is decreased from 140 to 47 and commercial properties is decreased from 42 to 19. Increasing the capacity of the Wimmera River could offset the increased flood level along Burnt Creek caused by the northern levees, but increased flood levels in the less densely populated areas north of Horsham Lubeck Road are likely to remain.

Lowering the operating level of Lake Wartook was shown to reduce peak flows immediately downstream of the reservoir and there may be some potential flood benefit to doing this. However, operating the storage at a lower level is likely to place the security of drinking water for Horsham and water for environmental flows at higher risk. Discussion with GWMWater is required to better understand the potential and the likely costs of this option.

5.3.4 Recommendations

In considering future structural flood mitigation measures, it is recommended that Council consider the options presented and in discussion with Wimmera CMA and the impacted community, decide what level of risk is appropriate, and what standard of protection is warranted from any structural mitigation options.

The structural options that have been shown to reduce flood risk are large costly options that will impact many stakeholders. The viability of widening the bridge and increasing the capacity of the Wimmera River should be discussed with Council, VicRoads and Wimmera CMA.

It is recommended that when the bypass of Horsham is further considered in the future, that the opportunity to use it for flood mitigation be assessed. This bypass project will provide an opportunity for large scale flood mitigation that could potentially provide benefits for many stakeholders.

5.4 Non-structural Mitigation

5.4.1 Overview

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

- Land use planning;
- Flood warning and response; and,

- Flood awareness.

During this project, sub-consultant Molino Stewart was engaged to assist with reviewing the current non-structural flood mitigation arrangements, specifically around flood warning, response and awareness in *Horsham and Wartook Valley Flood Investigation - Flood Warning Assessment and Recommendations Report* (Molino Stewart, 2019).

The below section summarises the Molino Stewart report, if further detail is required, please refer to the standalone report.

5.4.2 Land Use Planning

The Victoria Planning Provisions (VPPs) contain several 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 62(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 controls to Planning Schemes is available from the Department of Environment, Land, Water and Planning's Practice Note 12 on Applying the Flood Provisions in Planning Schemes (DELWP, 2015).

Planning Schemes can be viewed online at http://services.land.vic.gov.au/maps/pmo.jsp. It is recommended that the planning scheme for this project's study area is amended to reflect the flood risk identified by this project.

This study has produced the outputs for generation of LSIO and FO layers for inclusion in the Horsham Rural City Council Planning Schemes. The LSIO is representative of the 1% AEP extent of inundation, while FO represents a higher flood risk, combining 1% AEP flood depths and velocities. Wimmera CMA specify FO be defined by depths greater than 0.5 m and a velocity depth product greater than 0.4 m^2/s. The Wimmera CMA plan to introduce revised FO and LSIO layers into the Horsham Rural City Council Planning Scheme as part of a greater planning scheme amendment, considering multiple flood mapping products within Horsham Rural City Council.

5.4.3 Flood Warning Recommendations

5.4.3.1 Overview

An objective of the Horsham and Wartook Valley Flood Investigation was to identify options for improved flood warning arrangements. Below is a summary of the full Horsham and Wartook Valley Flood Investigation – Total Flood Warning System (TFWS) Assessment[25]. The objectives of the flood warning system assessment were:

- To assess the existing flood warning system for the investigation area; and,
- To recommend improvements to form a TFWS based on the assessment.

5.4.3.2 Total Flood Warning Systems

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.

[25] Molino Stewart (2019), Horsham and Wartook Valley Flood Investigation – Total Flood Warning System Assessment

As part of best practice in flood risk management in Australia, flood prediction and warning is viewed as an important treatment option for residual flood risk for existing and future development in the floodplain (Australian Emergency Management Institute, 2013, page 82).

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 (Attorney-General's Department, 2009).

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.

Manual 21 (page 7) stresses that for the TFWS to "work effectively, these components must all be present, and they must be integrated rather than operating in isolation from each other."

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 the community requires and what 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.

Some researchers such as Molino et al (2011) believe that there are additional preliminary components required for an effective TFWS, including understanding the flood risk that the TFWS operates under, the impact of prior community flood education and the guidance provided by emergency management action plans (e.g. Municipal Flood Emergency Plans). This more holistic TFWS framework is shown in Figure 5-32 and is adopted for analysis in this project.

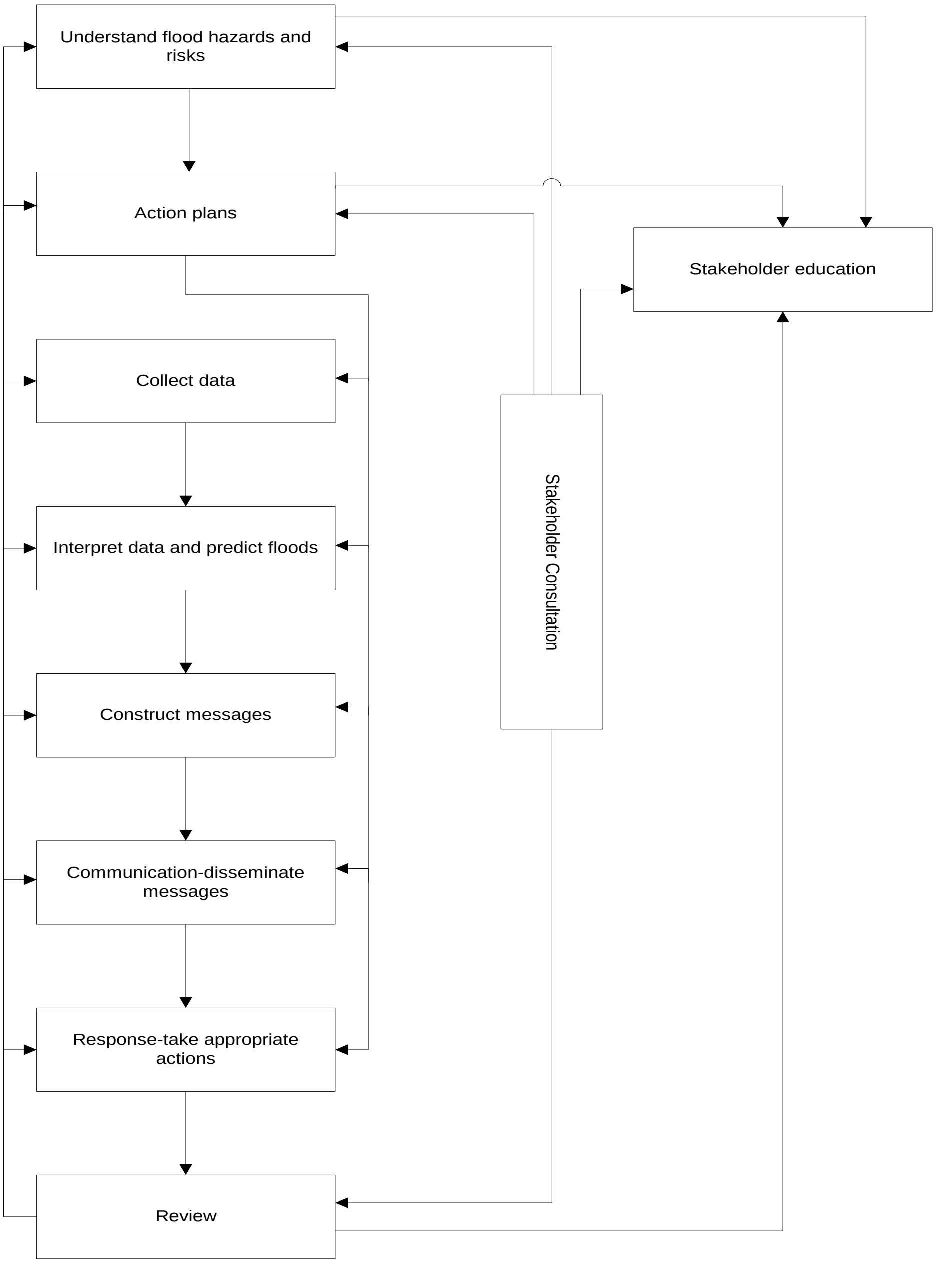

FIGURE 5-32 THE TOTAL FLOOD WARNING SYSTEM (SOURCE: MOLINO ET AL, 2011)

5.4.3.3 Development of a TFWS

There is good agency and Council understanding of flood risk in Riverside, Horsham and the tributary floodplains along the Mackenzie River, Burnt Creek, Bungalally Creek, Darragan Creek, Norton Creek and Sandy Creek due to previous flood events, and several investigations including this one.

The existing flood warning system has the hallmarks of a TFWS with robust activity across all 12 components. The Horsham and Wartook Flood Intelligence Report and its associated flood intelligence cards provide improved flood data and interpretation for a local TFWS. However, there are several suggested actions that will improve the existing flood warning system to help develop a TFWS in the study area, these are as follows:

1. Update the Horsham Rural City Council planning scheme.
2. Incorporate flood intelligence cards from the Horsham and Wartook Flood Intelligence Report into the Horsham Rural City Council Flood Emergency Plan.

3. Ensure that any critical infrastructure that is flood prone has its own emergency plan that includes protective actions related to triggers. These plans should be updated based on the flood intelligence cards from the Horsham and Wartook Flood Intelligence Report.
4. Update the Horsham Local Flood Guide based on the Horsham and Wartook Flood Intelligence Report.
5. Conduct other future community flood education activities across the study area based on findings of the Report. Activities should focus on Horsham and East Horsham with specific information targeting how residents find out about their flood risk, where gauge and mapped information can be found, how they will receive warnings and how to evacuate if required
6. Ensure that flood communication (e.g. Flood Bulletins) are presented in simple language talking about impacts of potential flooding on the local communities in the study area and required actions including possible evacuation. It should consistently advise people of either stream heights or flow volumes.
7. Communicate the long time for floodwaters to arrive and then recede to people in the study area, meaning that they need to take relevant precautions, particularly if evacuation is possible.
8. Acknowledge in the MFEP and ICC that in emergency response that local residents in parts of the Wartook Valley use alternative communication methods such as CFA pagers and telephone trees to warn and communicate with others in their communities.
9. Ensure that all people in the community (including newcomers and renters) have the opportunity to be included in community flood education and engagement before, during and after flood events.
10. Check that the Vulnerable Persons Register is updated and used during a flood emergency.
11. Any community flood education should reiterate the message from VicSES regarding the risks of attempting to drive through flood waters. This is the most common cause of flood related fatalities.
12. Make tourists in the Grampians National Park aware of flood risks through interpretive programs conducted by the park staff.
13. Consider other ways in which the community can participate in the design, implementation and review of the TFWS.
14. Amend the MFEP to describe the practical integration of the local flood warning system.

6 FLOOD INTELLIGENCE

6.1 Project Scope and Objectives

The flood mapping information produced over the course of this project was translated into meaningful flood intelligence that can be used by emergency managers and community members to plan for and respond to a flood event.

The Flood Intelligence Report was written to allow easy update of the Horsham Rural City Council (HRCC) Municipal Flood Emergency Plan (MFEP). The report contains flood intelligence information for the following communities:

- Drung (The Wimmera River)
- Horsham (The Wimmera River and Burnt Creek)
- Quantong (The Wimmera River)
- Wartook (The Mackenzie River)
- Laharum (The Mackenzie River and Burnt Creek)
- McKenzie Creek (The Mackenzie River)
- Wonwondah (Burnt Creek)
- Bungalally (Bungalally Creek)
- Lower Norton (Norton Creek, Sandy Creek, Darragan Creek)

Reporting was written in the structure of Sections A to F of the VICSES Municipal Flood Emergency Plan template revised October 2011. This allows for sections to be 'cut and paste' into the HRCC MFEP without the need for major formatting, but additional detail may be required. The report was written with both non-operational and operational components; providing a background to historic floods, potential flood impacts and flood sources along the above-mentioned waterways for Wimmera Catchment Management Authority, VICSES, Victoria Police, Horsham Rural City Council and other authorities to read and understand prior to a flood event, it should also be used as a reference document during flood events to confirm flood response actions required.

In this Final Report the key flood intelligence information is summarised.

6.2 Key Flood Intelligence Information

6.2.1 Overview

The most densely populated area within the study area is Horsham, followed by Riverside. The remaining properties impacted are less densely populated agricultural properties.

Inundation from overland runoff and stormwater inundation can cause flooding of properties throughout Horsham and Haven, this was observed during January 2011. Overland flood modelling of these areas was completed as part of the Horsham and Wartook Valley Flood Investigation.

High flows in the Wimmera River have the potential to cause widespread flooding well upstream of Horsham, through Greens Creek and Glenorchy.

The number of properties impacted for a range of design flood events is shown below in Table 6-1.

The warning area associated with each gauge is shown in Figure 6-1.

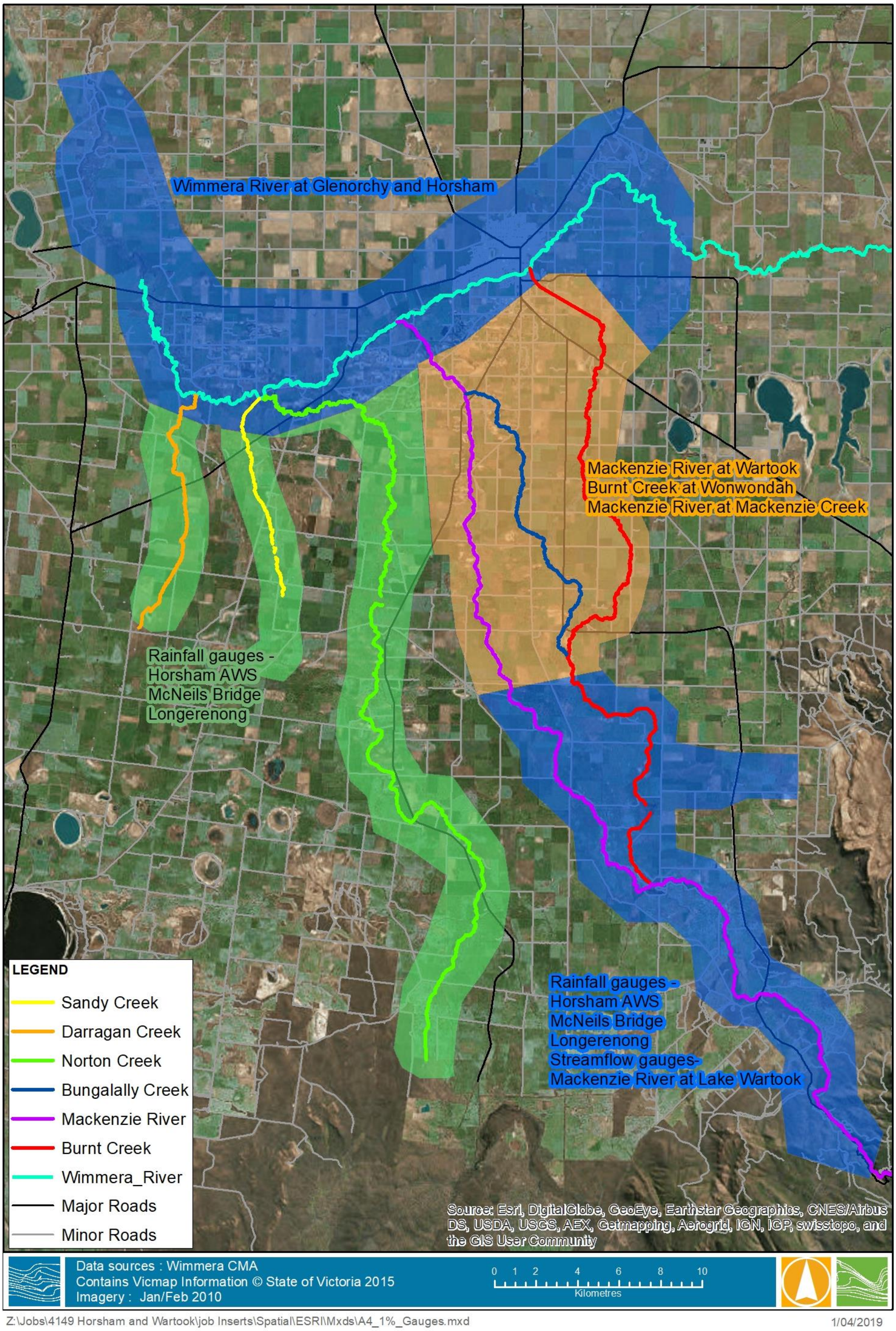

FIGURE 6-1 GAUGES WARNING AREAS

TABLE 6-1 SUMMARY OF FLOOD AFFECTED PROPERTIES WITHIN THE STUDY AREA

Summary of flood affected properties along the Wimmera River (East Horsham, Horsham and Quantong), Mackenzie River, Burnt Creek, Norton Creek Sandy Creek and Darragan Creek						
	Design Flood AEP (%)					
	20	10	5	2	1	0.5
Gauge height at Wimmera River @ Horsham (m)	3.44	3.70	3.92	4.15	4.29	4.40
Gauge height at Wimmera River @ Horsham (m AHD)	123.82	124.08	124.30	124.53	124.67	124.78
Gauge height at Burnt Creek @ Wonwondah (m)	-0.09	-0.02	-0.01	0.05	0.11	0.22
Gauge height at Burnt Creek @ Wonwondah (m AHD)	154.86	154.93	154.94	155	155.06	155.17
Gauge height at Mackenzie River @ Mackenzie Creek (m)	1.12	1.5	1.64	2.26	2.42	2.49
Gauge height at Mackenzie River @ Mackenzie Creek (m AHD)	135.66	136.04	136.18	136.8	136.96	137.03
Residential Buildings Flooded Above Floor	-	-	1	37	140	242
Commercial Buildings Flooded Above Floor	-	-	0	21	42	60
Properties Flooded Below Floor	74	111	171	520	591	588
Total Properties Flooded	74	111	172	578	773	890

A summary of public assets and infrastructure which may be inundated by flood events up to a 0.5% AEP includes:

- Horsham Equestrian Centre and Pony Club
- Power Substation (East Horsham – corner of Riverside East Road and Horsham Lubeck Road), not inundated but isolated
- Horsham Riverside Caravan Park
- St. Brigid's College
- Wimmera Base Hospital
- Horsham CFA Station
- Horsham SES Station
- Horsham Ambulance Station
- Horsham Medical Centre
- Horsham Basketball Stadium
- Horsham YMCA
- Horsham Primary School
- Holy Trinity Lutheran College
- Sunnyside Lutheran Retirement Village

There is significant isolation risk for residents along the Wimmera River, Mackenzie River and Burnt Creek. Given the large area covered by the Horsham and Wartook Valley Flood Investigation, reporting the risk of isolation was separated into each of the waterways, separating the Wimmera River floodplain into three segments (Riverside, Horsham and Quantong), and the Mackenzie River/Burnt Creek and Bungalally Creek reported together.

Due to the long warning time available, evacuation of community members from high risk areas is possible prior to flooding at Horsham. If there is an unexpected rainfall event causing localised stormwater inundation, evacuation via private property may be possible, however consent and advice from the landholder should be sought prior to accessing private land.

6.2.2 Wimmera River

6.2.2.1 Riverside

Riverside is directly impacted by flooding of the Wimmera River and gauge levels at the Wimmera River at Glenorchy and Drung Drung should be used to gain an understanding of timing and magnitude. Bureau of Meteorology predictions for the Wimmera River at Horsham are directly applicable for Riverside but inundation can be expected to occur earlier prior to the peak.

All roads across Riverside have the potential to be inundated with numerous buildings potentially flooded below floor during events as low as 2% AEP (1 in 50 year ARI). Sandbagging is expected to be required in a 5% AEP event (1 in 20 year ARI).

The Horsham Equestrian Centre/Pony Club is particularly susceptible to inundation and must be warned early.

There are numerous channels across the East Horsham region that have the potential to impact on the depth and extent of inundation. The mapping relates to the channels in their current state and no changes to infrastructure should be made immediately prior to or during a flood event without proper consideration and approvals from the appropriate authority.

6.2.2.2 Horsham – Wimmera River

Significant portions of Horsham are at risk of inundation in events greater than a 10% AEP (1 in 10 year ARI). Buildings in Peppertree Lane, Pryors Road and Bailie Street are flooded below floor in the 5% AEP event.

Inundation has the potential to breakout of the Wimmera River over the Wimmera Highway toward the Police Paddocks. The largest area at risk is north of the Wimmera River with a significant number of buildings susceptible to above and below floor inundation. In the 0.5% AEP event there is potential for a breakout at Barnes Blvd into residential streets toward the Wimmera Highway. This can inundate numerous residential streets and flows northward, overtopping Natimuk Road and Park Drive.

Modelling undertaken during this project assumed a culvert under the Henty Highway and Horsham to Dooen railway which connects Wimmera River flood flows to the Horsham Police Paddock. The closure of this culvert is recommended in the current Horsham Rural City Municipal Flood Emergency Plan and the advice updating it as part of this project. 1% AEP water levels in the Wimmera River floodplain are around 127.63 m AHD at the point it can enter the Police paddock while topographic levels on the edge of the residential development around Rasmussen Road are around 126.08 m AHD. While water levels in the Wimmera River are unlikely to be high enough to allow flow into the Police Paddock for long enough to result in sufficient volume to fill the police paddock there is a chance subsequent rainfall events could fill low areas. Closing the culvert is not anticipated to cause significant increases to flood levels in the Wimmera River floodplain south of the Henty Highway due to the limited flowrate capable of flowing through the culverts. At the railway line around 3.5 m^3/s is capable of flowing through the culverts, this is less than 1% of the 1% AEP Wimmera River flow of 427 m^3/s.

6.2.2.3 Burnt Creek

Inundation along Burnt Creek can be caused by the Wimmera River overland flow and/or flooding of Burnt Creek itself. Inundation due to high flows on Burnt Creek is the dominant cause of flooding in most of the modelled design flood events.

Inundation has the potential to inundate several residential streets and inundate residential properties above and below floor.

6.2.2.4 Quantong

Quantong experiences mostly inundation of agricultural land with some roads inundated. Struthers Avenue and Overall Avenue have the potential to be inundated and inundation gets close to properties along Blocks Road.

Several properties are isolated, but none flooded above or below floor.

6.2.3 Mackenzie River, Burnt Creek, Bungalally Creek, Norton Creek, Sandy Creek and Darragan Creek

6.2.3.1 Mackenzie River

The Mackenzie River distributes a significant portion of its overland flow to Burnt Creek, with some returning via Bungalally Creek in high flow events. There are large areas of agricultural inundation with several buildings at risk, with the Wander Inn at 2637 Northern Grampians Road being most susceptible to inundation.

All roads that intersect with the Mackenzie River have the potential to be inundated and all residents isolated.

6.2.3.2 Burnt Creek

Inundation along Burnt Creek is distributed from the Mackenzie River with a significant catchment contributing upstream of Horsham. Upstream of Horsham inundation can get close to to 478 Laharum Grahams Bridge Road and 100 Millers Road but no buildings are flooded below or above floor.

Floodwater is pretty well confined to the Burnt Creek floodplain between Laharum Road and the Western Highway with all roads running east west between these points likely to be flooded.

During January 2011 some Burnt Creek flow was diverted along the Western Highway to the north west. This may occur in the 1% AEP and 0.5% AEP events and should be monitored. If it becomes apparent minor flows are occurring on the southern side of the Western Highway there is potential to block this flow to prevent slow overland flow coming into town. However, this should be reviewed and approved by the Incident Control Centre.

Many streets within Horsham can be inundated and many buildings flooded above and below floor.

6.2.3.3 Bungalally Creek

Floodwater generally remains within a confined floodplain inundating rural areas with no buildings at risk.

6.2.3.4 Norton Creek

Norton Creek remains within a confined floodplain upstream of Toolondo Road. Downstream of Toolondo Road the floodplain inundation expands.

There are four buildings at risk of inundation immediately upstream of Horsham Noradjuha Road.

6.2.3.5 Sandy and Darragan Creek

Both Sandy and Darragan Creek inundate agricultural areas with no risk to buildings. A shed on Barrs Road gets close to inundation but is not inundated.

6.3 Typical Flood Peak Travel Times

The time it takes rainfall associated with severe weather or thunderstorm activity to develop into runoff and streamflow is highly dependent on catchment antecedent conditions (dryness). The lack of geographical spread of pluviographs within the catchment increase the difficulty in estimating rainfall-runoff response times.

The timing of flood flows in the Wimmera River can be based on upstream gauging at Eversley, Glynwylln, Glenorchy and Drung Drung. Timing of flooding along the Mackenzie River, Burnt Creek and Bungalally Creek can be based on upstream gauging at the Mackenzie River at Lake Wartook and Burnt Creek at Wonwondah. Timing of flooding on Norton Creek, Sandy Creek and Darragan Creek can be based on rainfall gauges and informed by the rainfall-runoff modelling completed during this study and the water level gauge on Norton Creek at Lower Norton.

The speed a flood hydrograph travels along a waterway is dependent on antecedent conditions and the magnitude of the flood, (i.e. is it travelling within the channel, or out on the floodplain). A flood on a ‘dry’ watercourse will generally travel more slowly than a flood on a ‘wet’ watercourse (e.g. the first flood after a dry period will travel more slowly than the second flood in a series of floods), and big floods tend to travel faster than small floods. In large floods, often the front of the peak may come through reasonably quickly as it travels through the channel, then the peak will come later as the floodplain flow travels a little slower. Hence, the size of the flood, recent flood history, soil moisture and forecast weather conditions all need to be considered when using the following information to direct flood response activities.

The reality that a community at risk can be inundated before the peak of the flood should not be overlooked. In the past, efforts have concentrated on estimating and forecasting the time of the peak, however this can sometimes be detrimental. Messaging should focus on the expected extent and timing of inundation with respect to upstream areas and the broader floodplain, warning can focus on the progression of floodwater along the Wimmera River and eastern tributaries ensuring monitoring of the progress of a flood. The below table shows the expected peak inundation in Horsham will occur approximately 70-80 hrs after the peak is observed at the Wimmera River gauge at Glenorchy.

Figure 6-2, to Figure 6-4**Error! Reference source not found.** below show the flood timing for the September 2016, January 2011 and September 2010 flood events at gauges along the Wimmera River.

Table 6-2 below documents travel times observed during the most recent events on the Wimmera River with time zero the peak timing at Eversley, while travel times were calculated as the time that the **peak** of the event takes to move from one gauge to the next. Note that the onset of flooding can occur before the peak water level occurs. CMA/local knowledge should be used for additional travel time information

TABLE 6-2 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	September 2016
Wimmera River at Eversley	0	0	0
Wimmera River at Glynwylln	9.5 hrs	19 hrs	22 hrs
Wimmera River at Glenorchy	22.5 hrs	40 hrs	36 hrs
Wimmera River at Drung Drung	52.5 hrs	91 hrs	86 hrs

Wimmera River at Horsham	99 hrs	112 hrs	117 hrs
Wimmera River at Quantong	109 hrs	127 hrs	133 hrs

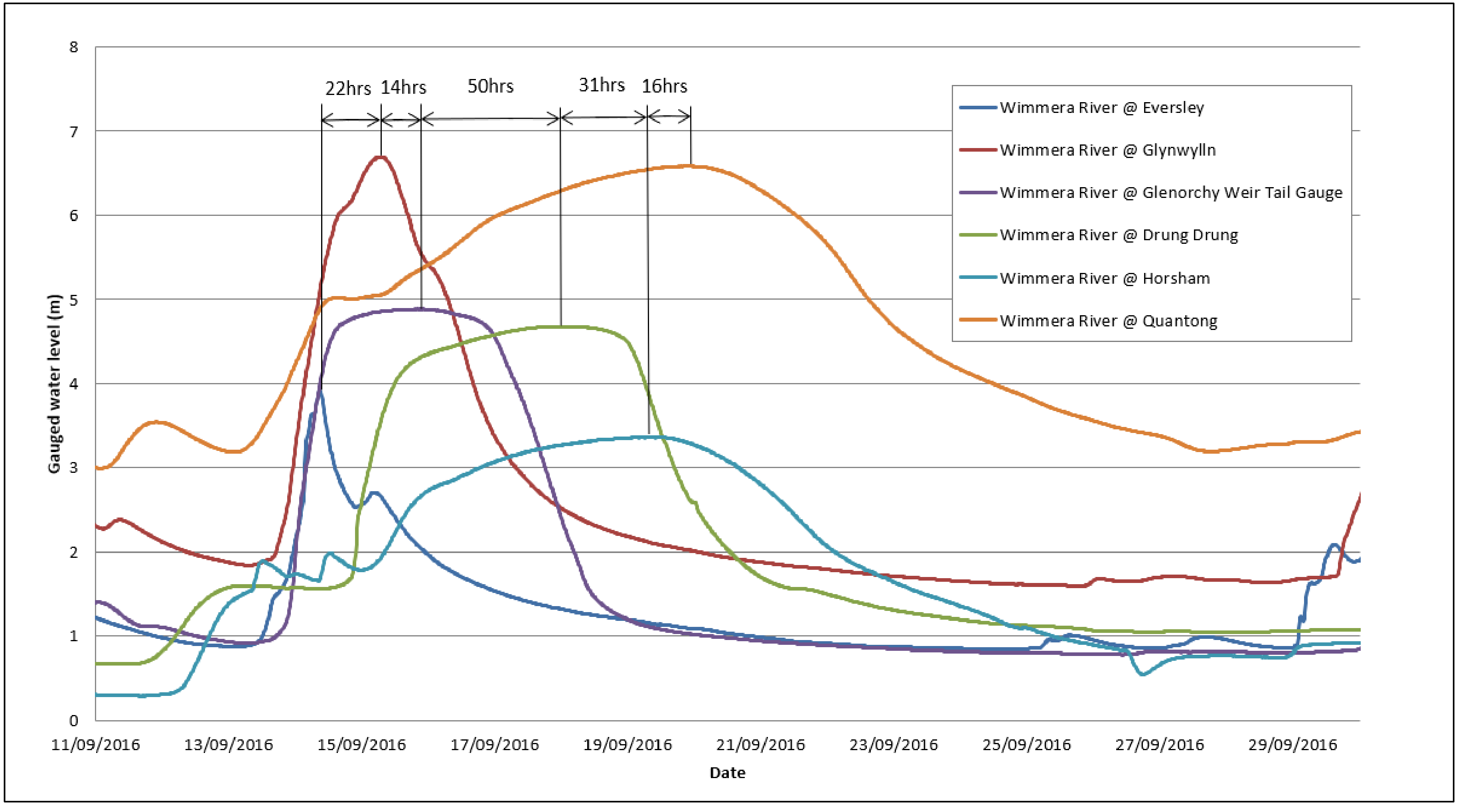

FIGURE 6-2 SEPTEMBER 2016 - GAUGED WATER LEVELS AND TRAVEL TIMES

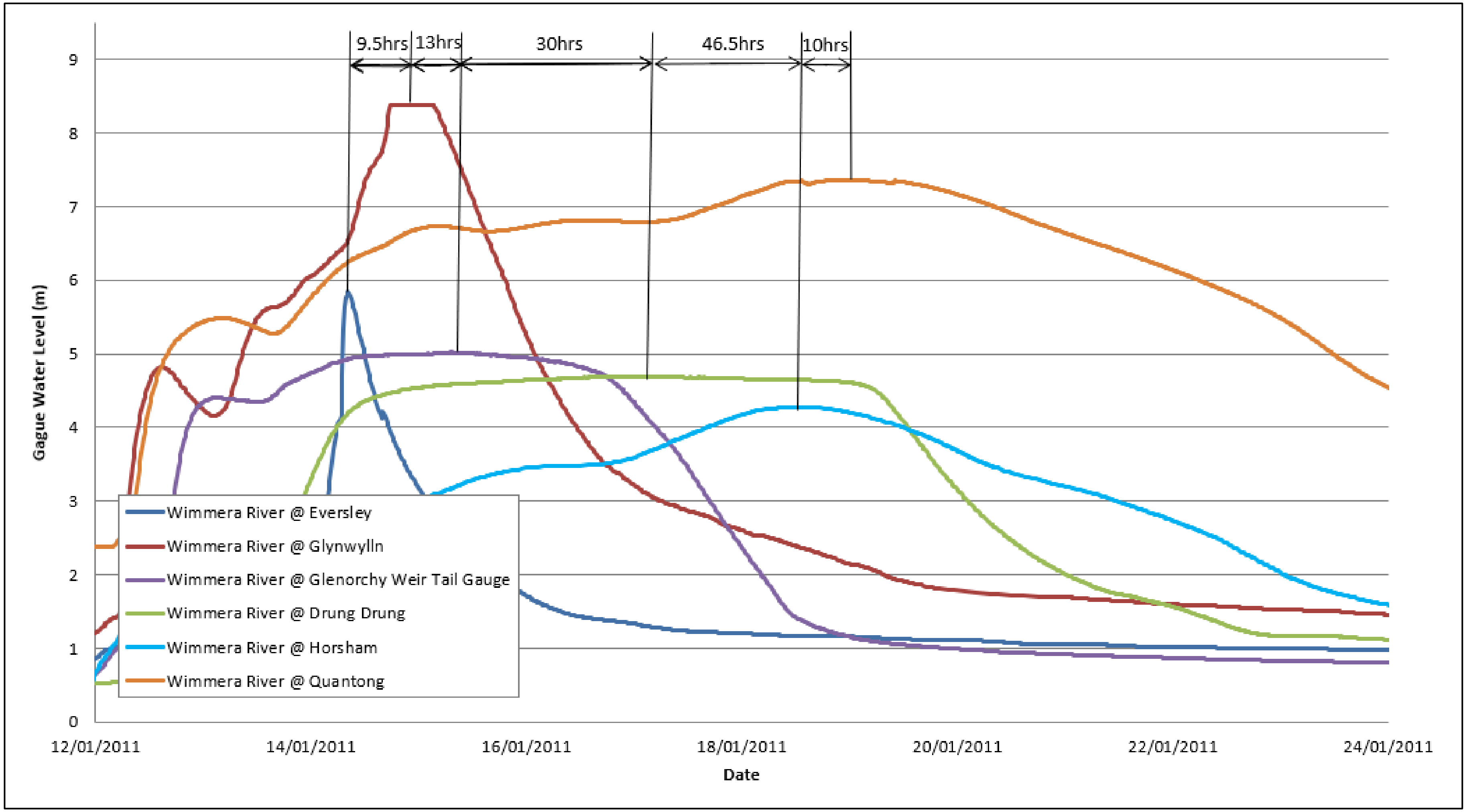

FIGURE 6-3 JANUARY 2011 - GAUGED WATER LEVELS AND TRAVEL TIMES

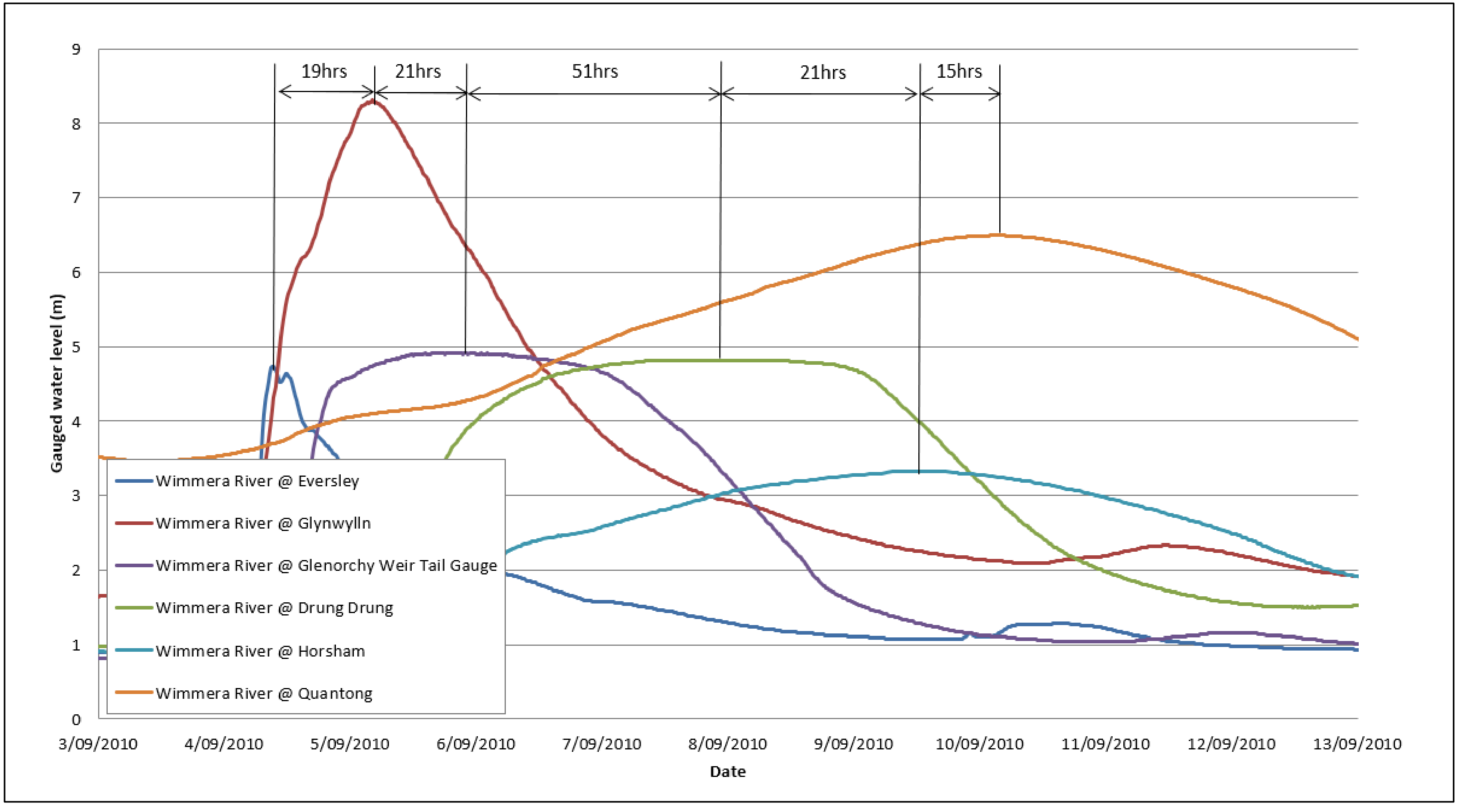

FIGURE 6-4 SEPTEMBER 2010 - GAUGED WATER LEVELS AND TRAVEL TIMES

Location From	Location To	Typical Travel Time	Comments
RIVERINE FLOODING – Wimmera River			
Floods are characterised by long flat peaks and slow recessions although the rise can be quite sharp, particularly at Glenorchy and upstream. The further down the catchment the longer the peak and the slower the recession. A second flood on the river will travel faster than a flood on a dry river and a big flood will in general travel faster than a small flood.			
Start of rainfall (upper catchment)	-	0	
Eversley	Glynwylln	9 – 22 hours	
Glynwylln	Glenorchy	18 – 30 hours	
Glenorchy	Drung Drung	45 – 60 hours	.
Glenorchy	Horsham	3 - 4 days	
Horsham	Quantong	10 - 16 hours	
RIVERINE FLOODING – Mount William Creek			
Start of rainfall (upper catchment)	Mokepilly	24-36 hrs	Travel time can vary due to the spatial distribution of rainfall to the east. Rainfall distribution can vary due to the topography.
Mokepilly	Lake Lonsdale (DS)	12-36 hrs	Travel time can vary due to the contribution of Fyans Creek and storage volume available in Lake Bellfield as well as the storage volume available in Lake Lonsdale.
Lake Lonsdale (DS)	Dadswells Bridge	12-24 hrs	Travel time of Mount William Creek depends on the storage volume available in Lake Lonsdale. Flood peaks can coincide, causing floodwaters to join across the Wimmera floodplain and the lower reaches of the Mount William floodplain
RIVERINE FLOODING – Mackenzie River, Burnt Creek, Bungalally Creek, Sandy Creek, Darragan Creek and Norton Creek			
Start of rainfall (upper catchment)	Wartook	2-6 hrs	Travel time can vary due to the spatial distribution of rainfall to the east. Rainfall distribution can vary due to the Grampians.

Location From	Location To	Typical Travel Time	Comments
Start of rainfall (upper catchment)	Laharum	12-36 hrs	Travel time can vary due to the spatial pattern of rainfall and spilling of Lake Wartook. The level in Lake Wartook plays a large part in the attenuation of flow from the reservoir.
	McKenzie Creek		
	Wonwondah		
	Bungalally		
	Lower Norton		

7 RECOMMENDATIONS

The Horsham and Wartook Valley Flood Investigation has implemented a very rigorous approach to understanding the flood risk and has engaged with the local community to ensure their knowledge of the floodplain informed the study.

The below recommendations are made following the completion of this study:

1. The outputs from the Horsham Wartook Valley Flood Investigation should be used to provide flood advice for any flood related planning matter.
2. The Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO) and associated planning scheme amendment documentation produced as part of this investigation be adopted in the Horsham Rural City Council Planning Scheme.
3. The Victoria Flood Database (VFD) should be updated using the outputs of the Horsham and Wartook Valley Flood Investigation, which have been formatted into the standard VFD format.
4. The Horsham and Wartook Valley Flood Investigation VFD deliverables be uploaded to FloodZoom.
5. The Horsham Rural City Council Municipal Flood Emergency Plans be updated with the information provided in the Horsham and Wartook Valley Flood Investigation Flood Intelligence Report.
6. The local CFA brigades (particularly along the Mackenzie River) should be actively engaged in community preparedness education for flooding.
7. Levee options were investigated as part of this project, with levees providing a 1% AEP standard of protection in some areas causing increases in water level in other areas. The Horsham community should be consulted regarding the difficulty of levee-based flood mitigation options in Horsham, investigating their perspective on what level of protection they would require. This could reduce the level of protection a potential levee offers, with the levee having less of an impact on other areas of the floodplain.
8. The potential for stormwater mitigation in Horsham and Haven should be further considered with the incorporation of the stormwater capacity mapping. Detailed feature survey may be required of some parts of the existing stormwater system.
9. VicRoads, Horsham Rural City Council and Wimmera CMA discuss the potential to use the proposed B2 option of the Horsham Bypass as a flood mitigation measure for the town. Previous modelling of Rokeskys Road has shown the potential for a floodplain restriction to reduce flood levels. Infrastructure projects of this size do not occur often in the Wimmera and their potential should be considered in full.
10. Ensure any strategic flood-prone infrastructure has its own emergency plan that includes protective actions related to triggers. These plans should be updated based on the flood intelligence contained in the Horsham and Wartook Flood Intelligence Report.
11. Update the Horsham Local Flood Guide based on the Horsham and Wartook Flood Intelligence Report.
12. Conduct future community flood education activities across the investigation area based on findings of this report. Activities should focus on Horsham and East Horsham with specific information targeting how residents find out about their flood risk, where gauge and mapped information can be found, how they will receive warnings and how to evacuate if required.

13. Ensure that flood communication (e.g. Flood Bulletins) is constructed in simple language talking about impacts of potential flooding on the local communities in the investigation area and required actions including possible evacuation. It should consistently advise people of either stream heights or volumes.
14. Effectively communicate the likely flood behaviour to the Horsham community and the need to plan and act early. With long lead times to the peak of flooding, the risk is that people become complacent and do not act early. With access sometimes cut well prior to the peak of flooding, leaving mitigation and evacuation actions to the last minute can expose people to unnecessary risk.
15. Consider moving the Burnt Creek at Wonwondah streamflow gauge to a location further downstream to improve the ability to measure streamflow gauging.
16. Emergency response agencies to acknowledge that local residents in parts of the Wartook Valley use alternative communication methods such as CFA pagers and telephone trees (a network of phone calls) to warn and communicate with others in their communities.
17. Ensure that all people in the community (including newcomers and renters) have the opportunity to be included in community flood education and engagement before, during and after flood events.
18. Check that the Vulnerable Persons Register is updated and used during a flood emergency.
19. Any community flood education should reiterate the message from VicSES regarding the risks of attempting to drive through flood waters. This is the most common cause of flood related fatalities.
20. Tourists in relevant areas of the Grampians National Park should be made aware of flood risks through interpretive signage and programs conducted by the Parks staff.

2004, BoM - URBS Model Developed by the BoM for flood forecasting purposes
Water Technology, 2013 - East Horsham Culvert Assessment Modelling

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