Calibration Report

Horsham and Wartook Valley Flood Investigation

Wimmera CMA

September 2018

Document Status

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18 September 2018

Paul Fennell
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Dear Paul

Horsham and Wartook Valley Flood Investigation

Please see the attached Calibration Report for the Horsham and Wartook Valley Flood Investigation.

If you have any queries, please don't hesitate to contact me.

Yours sincerely

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WATER TECHNOLOGY PTY LTD

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1 INTRODUCTION

Wimmera CMA has engaged Water Technology to undertake the Horsham and Wartook Valley Flood Investigation. The objective of the study was to update and extend the flood mapping across the study area, update the flood intelligence for emergency planning, and investigate flood mitigation measures along the Wimmera River at Horsham. Stormwater flooding in Horsham and Haven was also investigated.

RORB hydrology models were developed for the Mackenzie River and minor tributaries that drain the study area and the flood frequency analysis completed in the Lower Wimmera Regional Flood Mapping Study was used for Wimmera River hydrology. Hydraulic models were constructed for both riverine and stormwater inundation. Riverine inundation was modelled using the Mike by DHI Flexible Mesh software, while the stormwater inundation was modelled using TUFLOW.

1.1 Reporting Stages

The project was delivered in stages, with milestone reports produced at each stage as follows:

- Data Collation and Review Report (Complete)
- Model Calibration Report (This report)
- Design Modelling Report
- Flood Mitigation Report
- Flood Intelligence Report
- Flood Warning and Assessment Report
- Planning Scheme Amendment Reporting
- Final Report

This report is the Model Calibration Report, discussing the model build and hydrology and hydraulic calibration. This report forms the basis for the design modelling report and provides a summary of the design modelling methodology.

1.2 Study 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, which is fed by the Wartook Reservoir, is intricately linked to Burnt Creek and Bungalally Creek. Burnt Creek receives an effluent distribution from the MacKenzie River. Further along Burnt Creek similar distribution occurs to Bungalally Creek, which then flows back into the MacKenzie River.

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

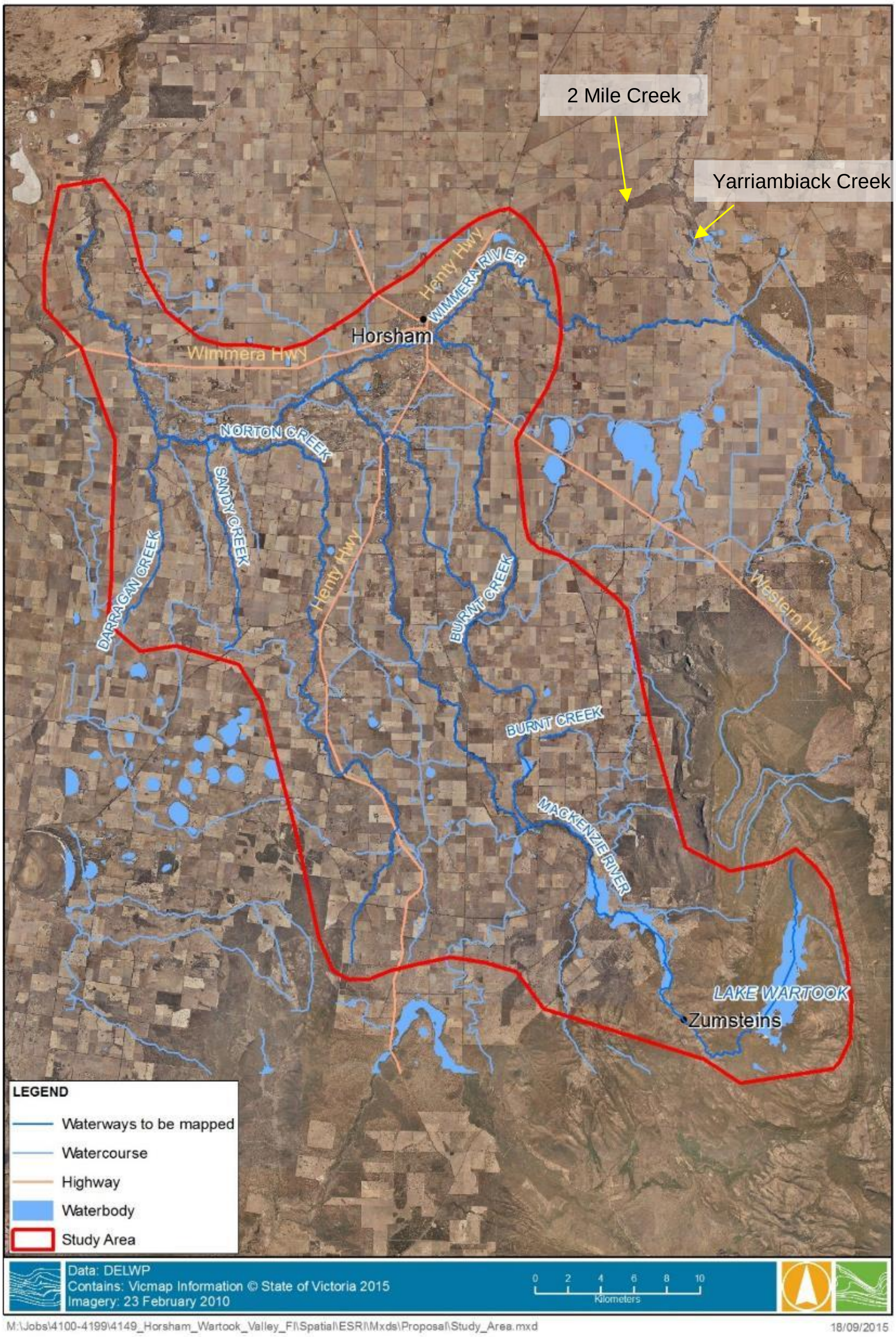

Figure 1-1 Study area

2 FLOOD RELATED STUDIES

Several relevant flood related studies have been completed within the study area, however there is no study that considers the interaction between the Wimmera River and the Grampians northern tributaries, and the subsequent implications on flood levels.

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

- Lower Wimmera River Regional Flood Mapping Study (Water Technology, 2017)
- Wartook to Zumsteins Walking Track Flood Investigation (Water Technology, 2015)
- East Horsham Flood Plan (Water Technology, 2011)
- Wimmera CMA Flood Report – January 2011 (Water Technology, 2011)
- Yarriambiack Creek and Wimmera River Flows (Water Technology, 2009)
- Horsham Bypass Hydrology and Hydraulics Impact Study (Water Technology, 2012)
- East Horsham Channel Decommissioning (Water Technology, 2014)

Relevant findings from each of the above studies are summarised below.

2.1 Lower Wimmera River Regional Flood Mapping Study

Water Technology is currently undertaking the Lower Wimmera River Regional Flood Mapping Study, the objective of which is to develop regional scale flood mapping for the Lower Wimmera River between Quantong and Jeparit. To provide meaningful flood information, the flood mapping is tied back to the Horsham (Walmer) gauge, which is of relevance to this study.

After the January 2011 flood the rating curve of the Wimmera River at Horsham (Walmer) gauge was changed significantly at the upper end of the curve. The study demonstrated that the revised rating curve was accurate and should be used to estimate flood flows. Further details regarding the streamflow gauge at Horsham can be found in Section 3.1.1. The hydrological analysis undertaken for the Wimmera River at Horsham (Walmer) gauge was adopted for the Horsham and Wartook Valley Flood Investigation.

The Lower Wimmera River Regional Flood Mapping Study 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 indicates that the interaction between Northern Grampians tributaries and the Wimmera River is likely to have negligible impact on flood extents and levels, however this will still be tested in the hydraulic model. The analysis did show that as the Mackenzie River peaks, the backwater caused in the Wimmera River upstream is likely to raise water levels and impact the accuracy of the rating curve at the Wimmera River at Horsham (Walmer) gauge. This is not a major issue however as the two rivers generally peak 2.5 to 3 days apart and the flow in the Wimmera River is significantly larger than that in the Mackenzie River.

Based on the best available annual series for the Horsham gauge the Lower Wimmera River Regional Flood Mapping Study determined the peak design flow estimates using a flood frequency analysis shown in Table 2-1.

Table 2-1 Wimmera River at Horsham – FFA determined design flow peaks

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

2.2 Wartook to Zumsteins Walking Track

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.

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 3.1.3, and will be adopted for the current study as an upstream boundary to the hydraulic model.

2.3 East Horsham Flood Plan

The East Horsham Flood Plan modelled the area from Riverside to west of the Yarriambiack Creek offtake from the Wimmera River. 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.

As many of the channels have now been decommissioned, and some mitigation works constructed, flood mapping from this study no longer represents the on-ground conditions, however the general discussion around areas of concern highlights where specific detail is required in the development of the new hydraulic model. The report also includes 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 Study, 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

There was significant floor level survey captured as part of the East Horsham Flood Plan, adding to that captured during the Horsham Flood Investigation (as discussed in Section 2.7). The extent of the captured floor level survey is shown in Figure 2-1.

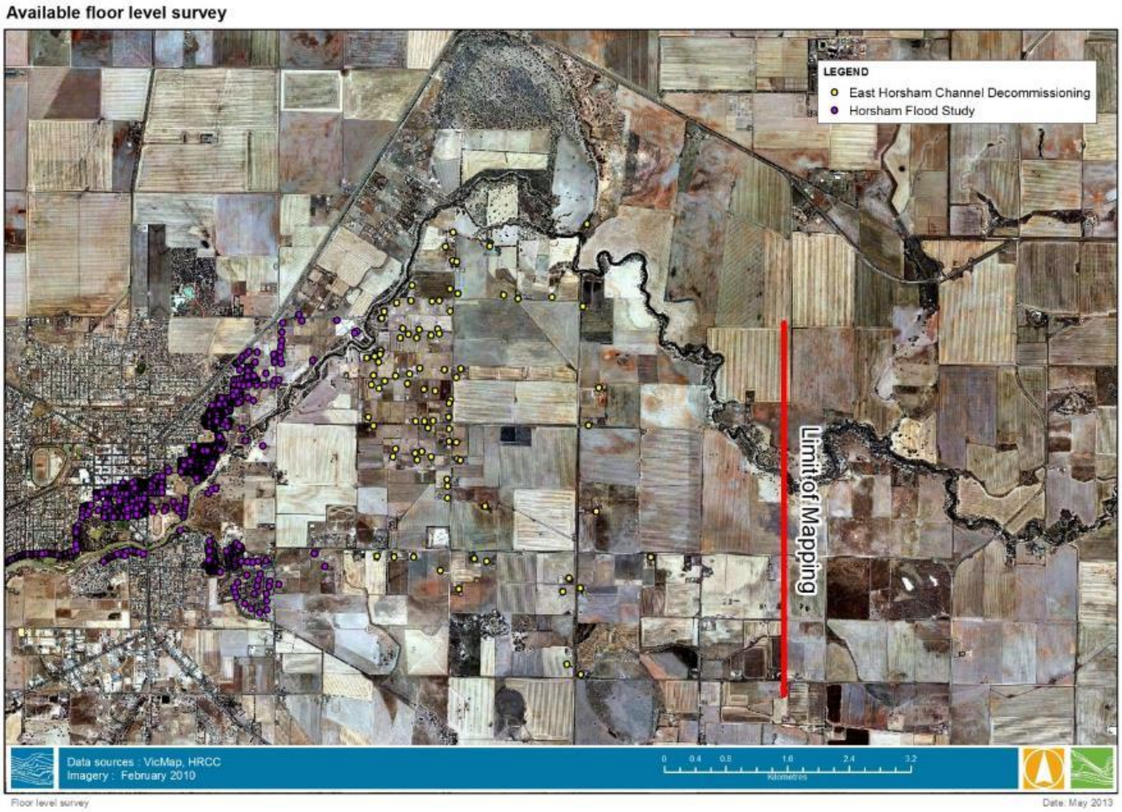

Figure 2-1 Floor level survey captured as part of the East Horsham Flood Plan

2.4 Wimmera CMA Flood Report – January 2011

This report provides a summary of the January 2011 flood event, reviews the emergency response actions, and provided recommendations to improve the approach to dealing with future floods.

Many of the recommendations from the Wimmera CMA Flood Report have since been actioned, including the commissioning of the following studies:

- Natimuk Flood Study
- Horsham and Wartook Valley Flood Investigation (including Norton Creek)
- Dunmunkle Creek Flood Investigation
- Mt William Creek Flood Investigation

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

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

2.5 Yarriambiack Creek Flows Study

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 using an URBS model built by the Bureau of Meteorology for flood warning purposes[1].

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.

An overland flow path where flow splits from the Wimmera River upstream of the Drung Drung gauge towards the south west was identified. This resulted in two Wimmera River inflows to the study area. The overland flow path intersects the Horsham-Drung South Road at approximately level with Domarchenz Road. The relationship for the proportional split of flows was established from hydraulic modelling for a range of incremental flows, 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 the distribution heads. Distribution Heads regulates low-medium flows from MacKenzie River and Moora Channel into Burnt Creek, the MacKenzie River and Old Natimuk Channel. 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 flows: Burnt Creek contribution) was applied for the design modelling.

2.6 Horsham Bypass Hydrology and Hydraulic Investigation

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 Flows Study to the south and west to ensure each of the potential bypass alignments were covered. The model covered an area from around School Road at Drung, 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.

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 of the Wimmera River floodplain.

[1] 2004, BoM - URBS Model Developed by the BoM for flood forecasting purposes

Model results produced in the Horsham Bypass Hydrology and Hydraulics Investigation will be compared to those produced in this study.

2.7 Horsham Flood Study

The objective of the Horsham Flood Study was to better understand the impact of flooding post implementation of several flood mitigation works including a levee system and river widening. The study modelled 20%, 10%, 5%, 2%, 1% and 0.5% AEP events. Model results were used as the basis for extent, depth and 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 recordings 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.

The calibration and design flow estimated 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 2-3. Note that the Lower Wimmera River Regional Flood Mapping Study has updated the design flows for the Wimmera River at Horsham (Walmer) gauge.

Table 2-3 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
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

The levee systems and flood mitigation infrastructure highlighted will also be incorporated into the modelling undertaken in this project if appropriate. The main levee identified in the Horsham Flood Study 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. The location and condition of this levee will be assessed during a site inspection.

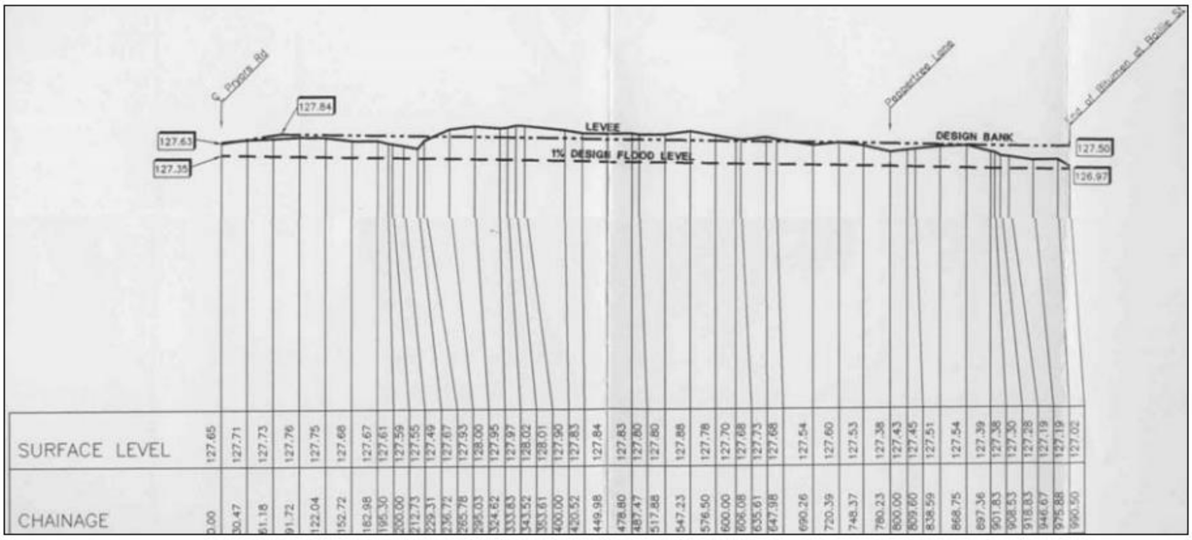

Figure 2-2 Menadue Street/Peppertree Lane levee longsection survey

2.8 East Horsham Channel Decommissioning Modelling

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 of channels were located 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 negate impact of the channel decommissioning and designs completed for the replacement of Channel No. 3 with a raised height of Rokeskys Road and a private levee protecting one landholder.

During the study there was significant road and channel crest height survey undertaken. 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. The areas surveyed are shown in Figure 2-3.

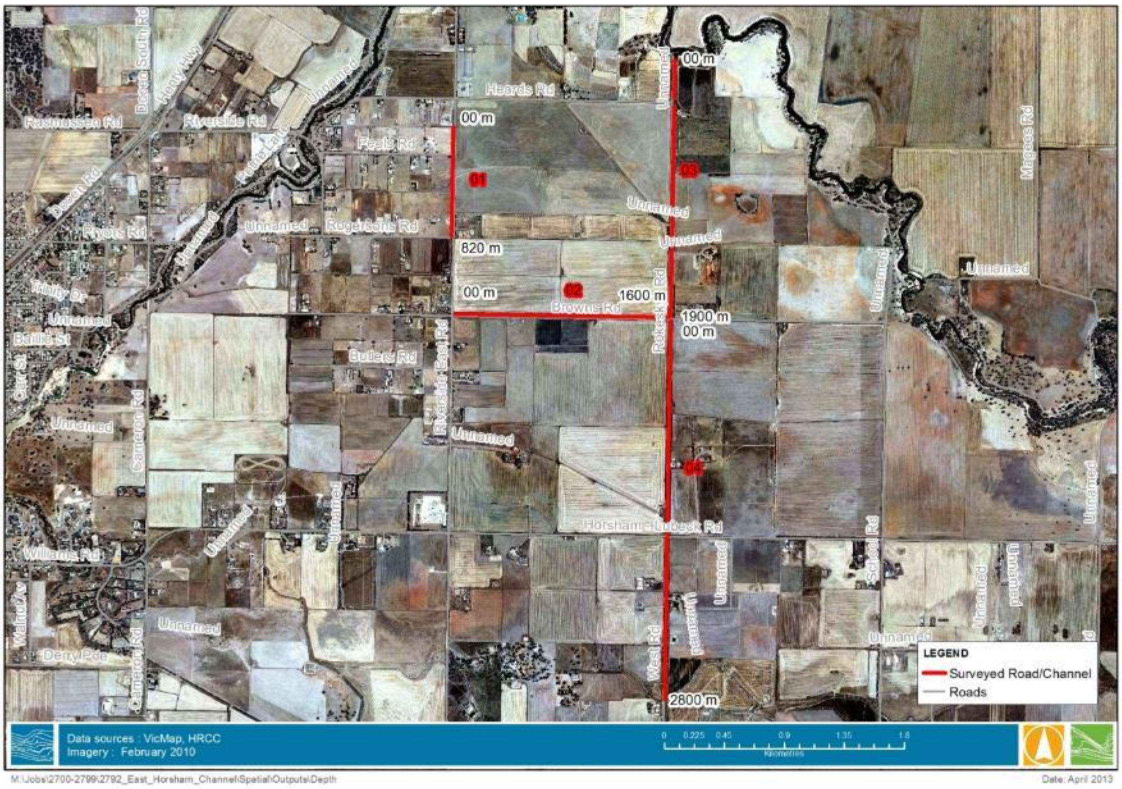

Figure 2-3 Road and channel crest survey

The study clearly outlined which channels were to be decommissioned across East Horsham, this understanding will be used in the Horsham and Wartook Valley Flood Investigation.

3 HYDROLOGICAL DATA

3.1 Streamflow

There are numerous streamflow gauges within the study area, as seen in Figure 3-1 and summarised in Table 3-1. These play a vital role in the development and calibration of hydrology and hydraulic model components to flood studies.

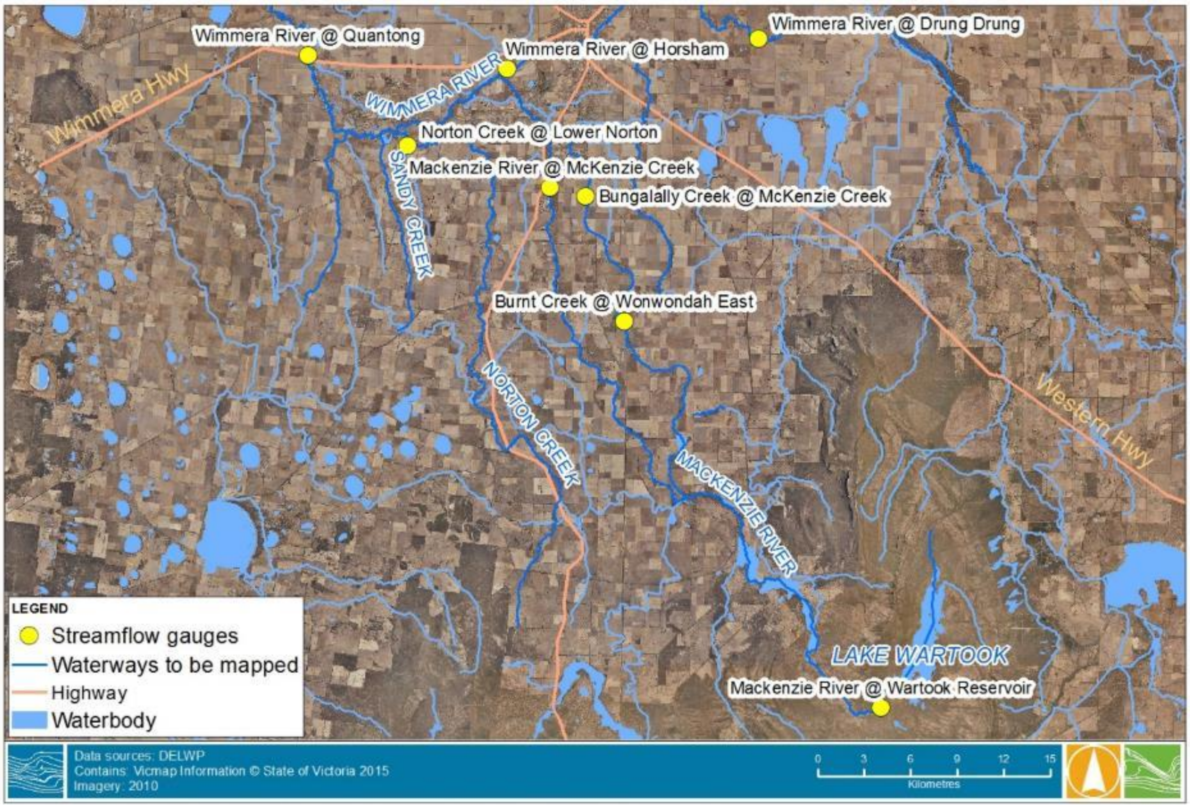

Figure 3-1 Streamflow gauges within the study area

Several gauges have a limited period of record, leading to less confidence in the rating curve as many have not had a sufficient period to establish an accurate rating curve over a range of flows. In particular, Norton Creek at Lower Norton only estimates flows 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 and many opportunities for hydrographers to undertake gauging events to base a rating curve on.

There was considerable investigation into the Wimmera River gauge at Horsham (Walmer) during the Lower Wimmera River Regional Flood Mapping Study, with design hydrology from that investigation used directly within this study.

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.

All gauges within the study area will be useful for calibration of the hydrology and hydraulic models. It was necessary to undertake calibration in tandem with the hydraulic model to ensure the MacKenzie River to Burnt

Creek and Burnt Creek to Bungalally Creek flow distributions were accurately represented. These distributions are best modelled within the hydraulic model not the hydrology model.

Table 3-1 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.
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 River Regional Flood Mapping Study.
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.

3.1.1 Wimmera River at Horsham (Walmer)

Wimmera River inflows to the study area were based on historic and design flows at the Horsham (Walmer) gauge. There have been numerous historic events recorded at the gauge, with daily flow recorded from 1889 to 1910, daily gauge heights/flow from 1920 to 1963, and instantaneous height/flow recordings from 1963 onwards. There is some concern regarding the quality of the data prior to 1910. The annual series of peak flows was constructed during the Lower Wimmera River Regional Flood Mapping Study, using the best available data. It is noted that the current gauge record is different to records of peak flows documented in previous publications. The annual peak flow series and the source of the data for the Horsham (Walmer) gauge are summarised in Table 3-2. 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 the 1909 event. A hydrograph of the January 2011 event is shown in Figure 3-2, along with the recorded Thiess Quality Code.

Table 3-2 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

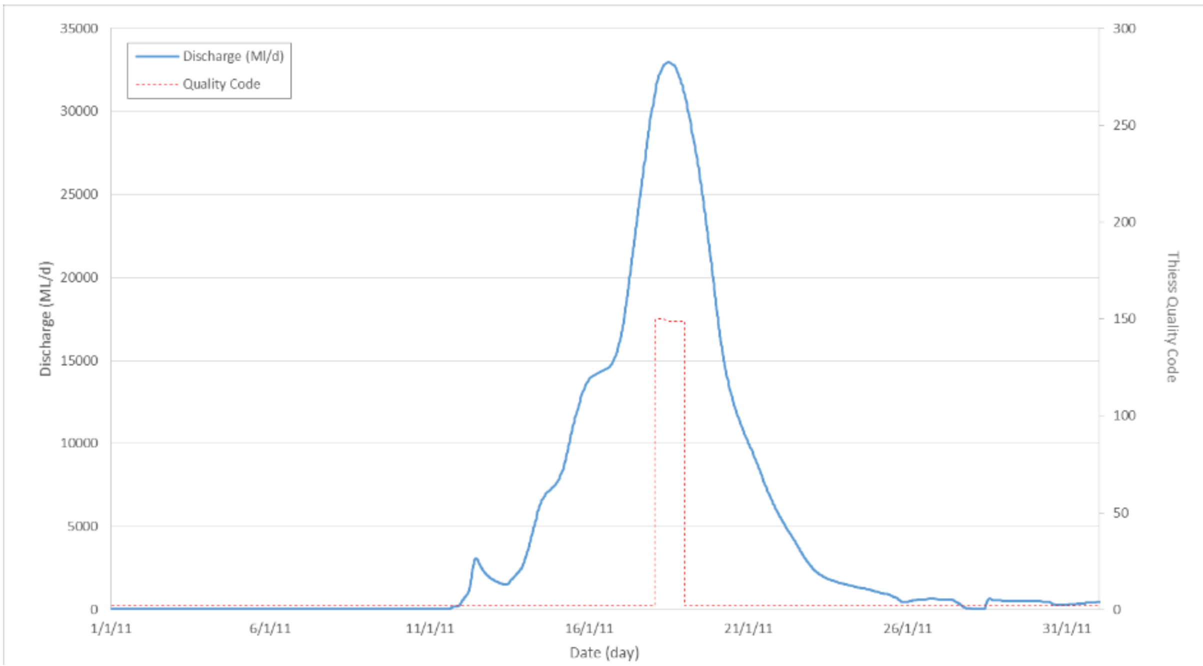

Figure 3-2 January 2011 hydrograph recorded at the Wimmera River at Horsham (Walmer) streamflow gauge

During January 2011, the Wimmera River flow rate was measured at the Western Highway Bridge 5.5 km upstream of the gauge, by Ventia (Formerly Thiess Environmental[2]). The gauging was completed at this location due to the Horsham gauge being too dangerous for hydrographers to access. The location of the Horsham gauge (Walmer) and the Western Highway Bridge are shown in Figure 3-3.

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 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 3-4, with the previous and current rating curves shown in Figure 3-5.

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 if extrapolated out would estimate a flow much larger. The current rating curve produces lower flow estimates than the previous rating curve for large floods.

Ventia measured the January 2011 flow 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

[2] Pers. Comm. Jessica Littlejohn of Ventia

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.

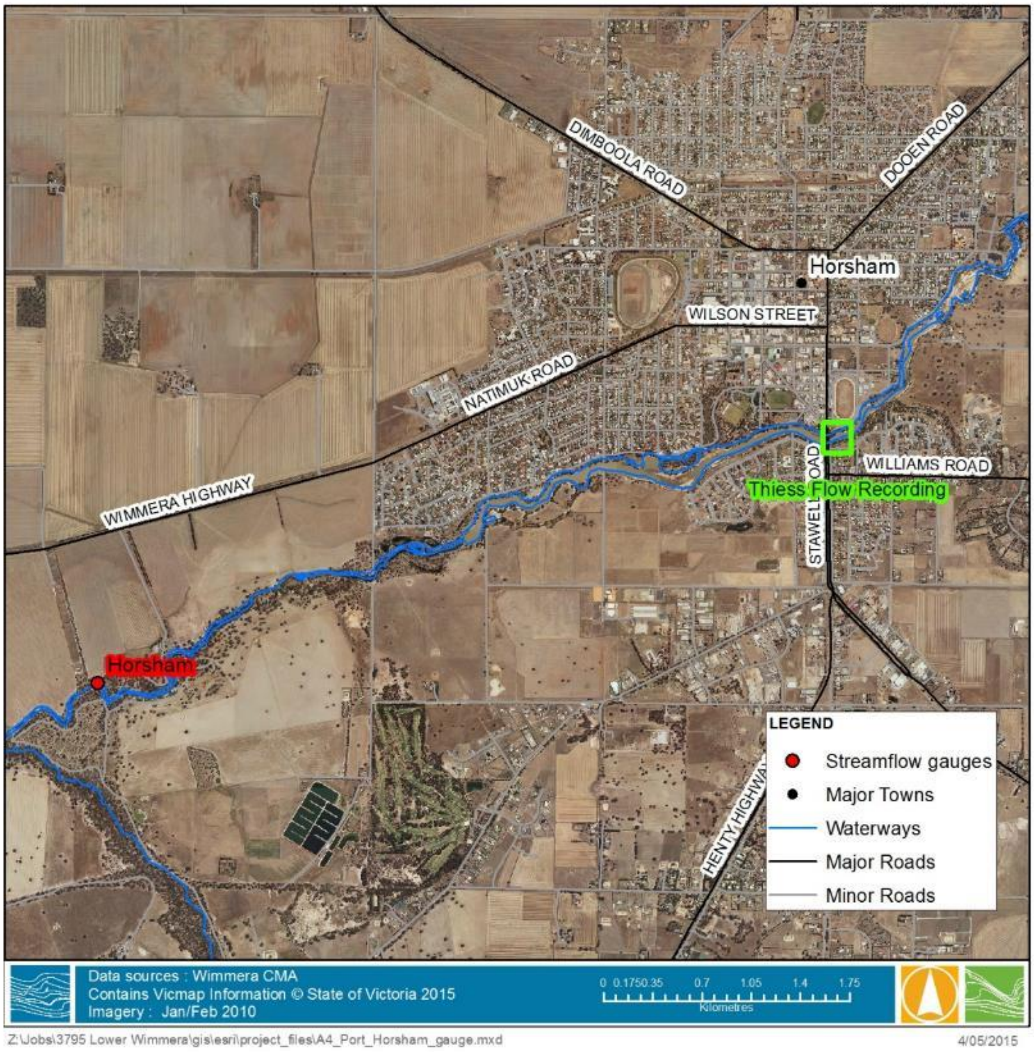

Figure 3-3 Wimmera River at Horsham (Walmer) gauge and Western Highway January 2011 measurement locations

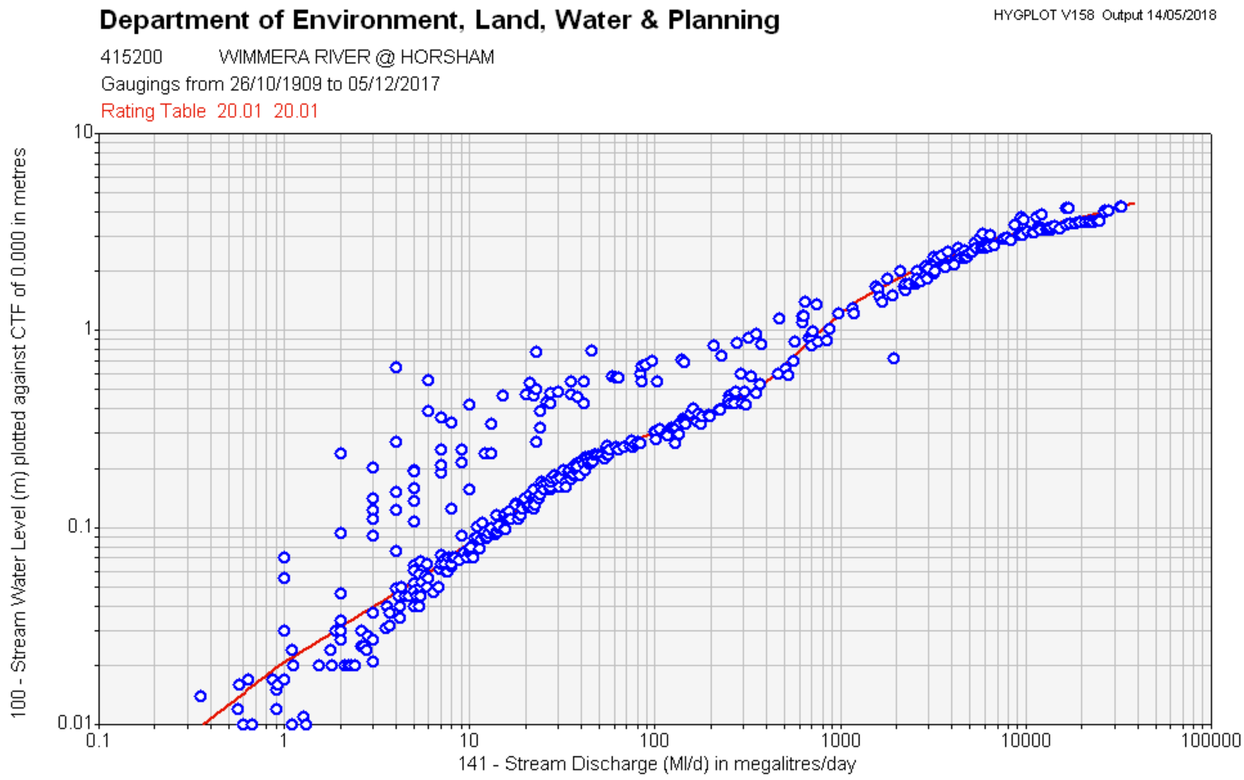

Figure 3-4 Wimmera River at Horsham streamflow gauge rating curve and measurements[3]

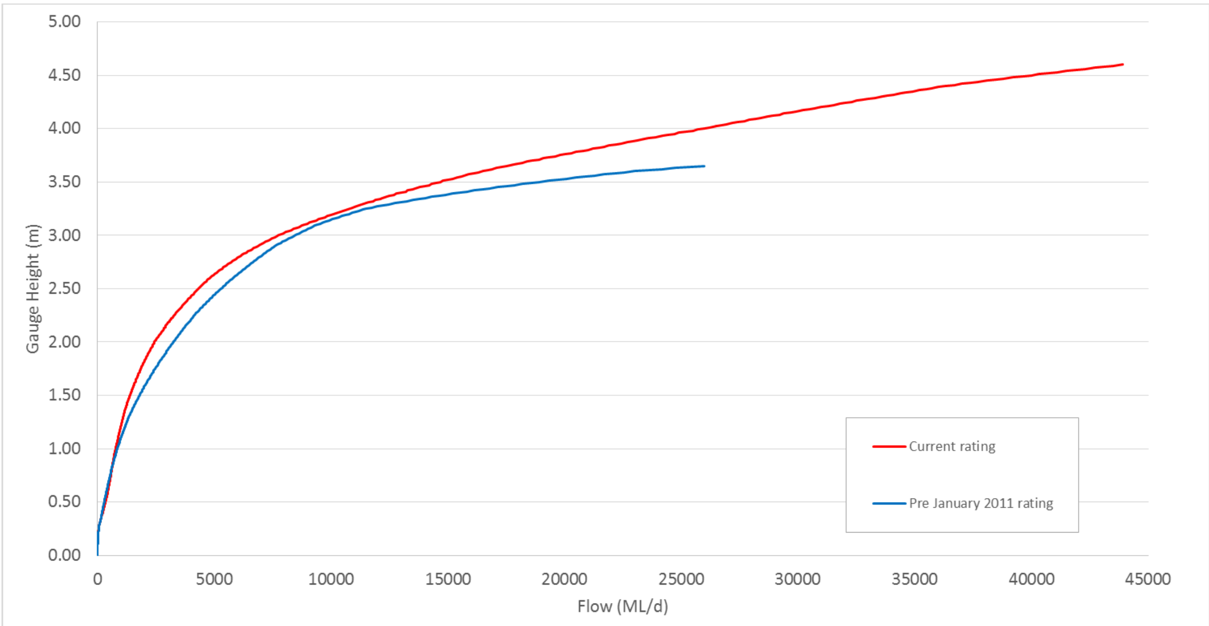

Figure 3-5 Wimmera River at Horsham current and previous rating curves

[3] DELWP - Water Measurement Information System (Accessed 16/04/2015)

3.1.2 Norton Creek at Lower Norton

This stream 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 extent of the rating curve is only to 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. This is over six times the extent of the rating curve.

Figure 3-6 shows the stream height gauge record and the rating curve limit. Given the rating table is exceeded very frequently it is unlikely the gauge flow record will be useful for determining design flows. However, the gauge height record will give an indication of timing comparative to Wimmera River gauges.

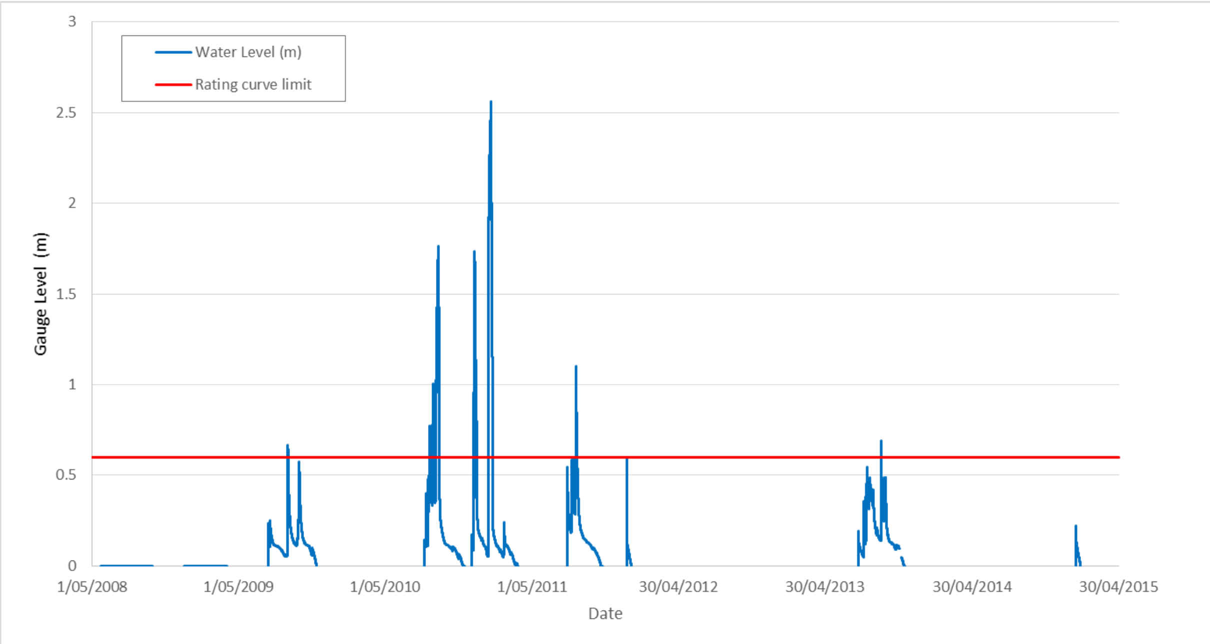

Figure 3-6 Gauge record at Norton Creek at Lower Norton showing water level and limit of extrapolated section of the rating curve

3.1.3 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. The gauge is missing data for the January 2011 flood peak but it was estimated by GWM Water at 3,780 ML/d[4] based on a peak level of 1.992 m recorded on the 13th January at approximately 6pm.

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

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.

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

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 in Figure 3-7. 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[5].

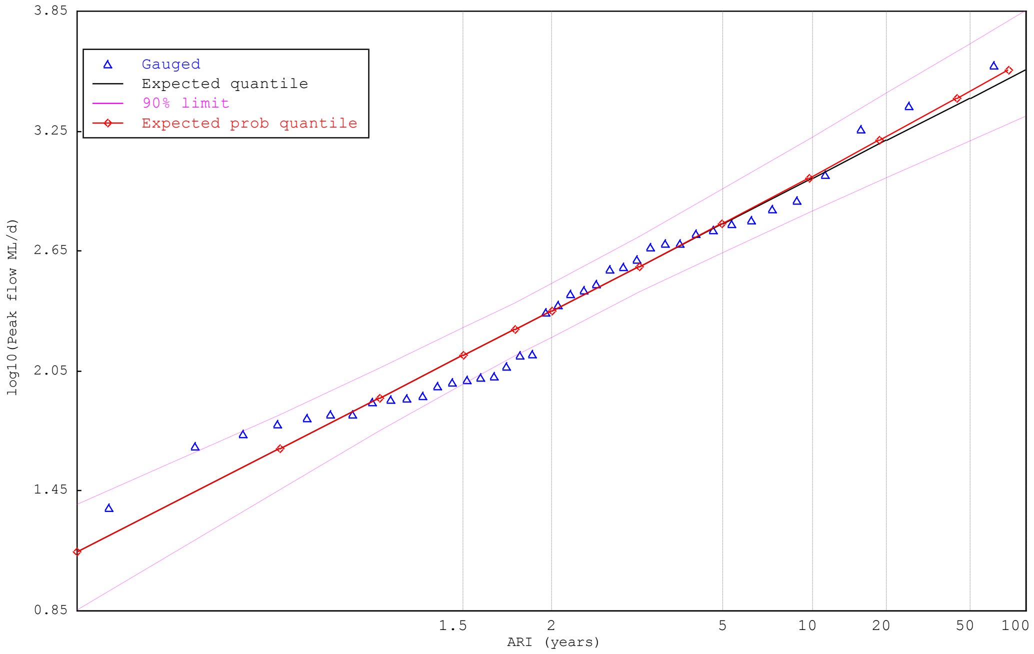

Figure 3-7 MacKenzie River maximum discharge flood frequency distribution (Log Normal)

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 3-3. 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 3-3 MacKenzie River at Wartook Reservoir Historical Flood Events

Start	End	Peak Flow, ML/d	Flood length, 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

[5] Water Technology – Natimuk Flood Investigation (2012), Horsham Bypass Hydrology and Hydraulics Study (2013), Warracknabeal and Brim Flood Investigation Hydrology and Hydraulics Report (2015)

Start	End	Peak Flow, ML/d	Flood length, days
18/12/1992	25/12/1992	2373	7
MEAN FLOOD LENGTH			**9.3**
MEDIAN FLOOD LENGTH			**7.5**

3.1.4 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 curve 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 gauge record is considered reliable.

3.1.5 Mackenzie River at McKenzie Creek

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

The rating curve is made up of 88 gaugings and is valid for flows up to 957 ML/d, at a height of 1.60 m. The rating curve is extrapolated through to 2.40 m or a flow of 4,670 ML/d. In January 2011, the recorded water level exceeded the reliable part of 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 provide a reasonable representation of flows, however the accuracy of the highest flood flow estimates is somewhat uncertain.

3.1.6 Summary

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

- Wimmera River at Horsham (Walmer) – The gauge data along with hydrological analysis from the Lower Wimmera River Regional Flood Mapping Study will be adopted for this study.
- Norton Creek at Lower Norton – Gauge flows are unlikely to be used in this study, however timing of peak levels will be used to determine the timing of any Norton Creek contribution to the Wimmera River.
- Mackenzie River at Wartook Reservoir – The gauged flow and the flood frequency analysis developed during the Wartook to Zumsteins Walking Trail Flood Study was adopted as an upstream boundary to the hydraulic model.
- Burnt Creek at Wonwondah East – Historic level records were used to verify the hydraulic model and validate flow split relationships.
- Mackenzie River at McKenzie Creek – Flow and level records were used to verify the hydrology and hydraulic models.

3.2 Rainfall

The average annual rainfall varies throughout the study catchment, reaching 600 mm at the headwaters of the Mackenzie River and as low as 330 mm north of Horsham.

There are several daily rainfall gauges and pluviograph stations within or nearby the study area, as shown in Figure 3-8. Details of available rainfall data is summarised in Table 3-4 and Table 3-5.

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 will be used to derive temporal patterns for the calibration rainfall events.

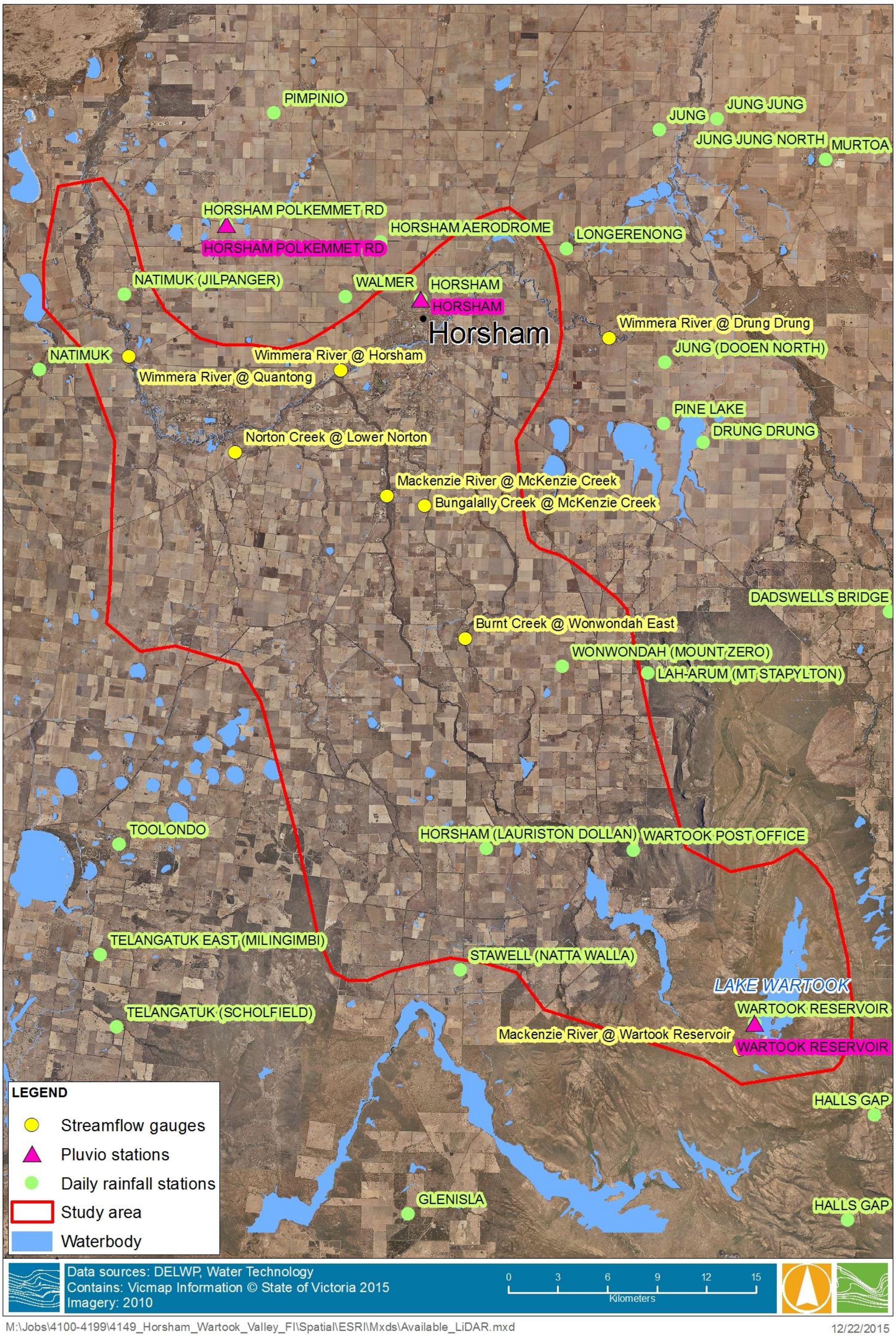

Figure 3-8 Rainfall gauge locations with respect to the study area

Table 3-4 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 3-5 Relevant pluviograph stations

Gauge No.	Location	Period
79023	Horsham Polkemmet Rd	1873 - 2015
79046	Wartook Reservoir	1890 - 2015
79082	Horsham	1958 - 2015

3.3 Storages

Lake Wartook, constructed in 1887, is the only managed storage within the study catchment. It is located within the Grampians National Park.

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).

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

GWMWater have supplied inflow, outflow and water level hydrographs of the January 2011 event for Lake Wartook as shown in Figure 3-9.

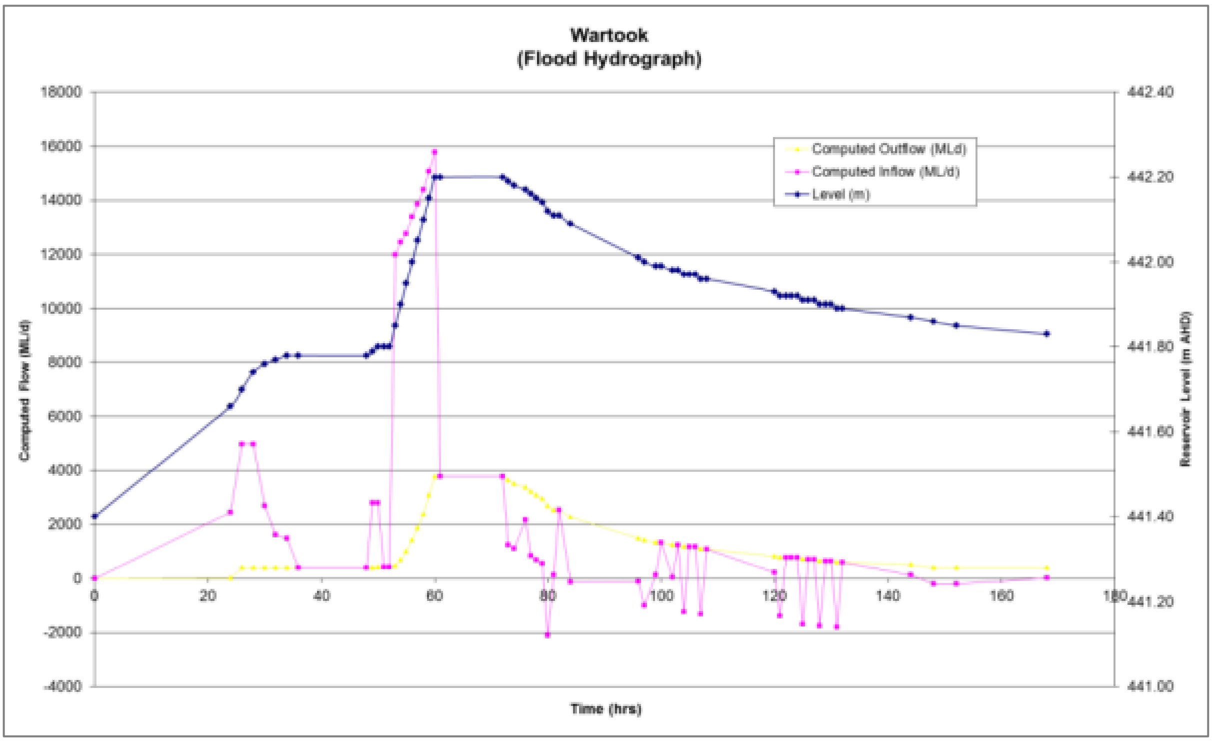

Figure 3-9 Inflow, outflow and level of Lake Wartook in January 2011

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 has substantially reduced the potential flood impacts downstream of Lake Wartook.

An aerial image of the Wartook Reservoir embankment and spillway is shown in Figure 3-10.

Figure 3-10 Wartook Reservoir – Embankment and spillway (Source: https://www.film.vic.gov.au/choose-victoria/locations/lake-wartook)

4 FLOOD RECORDS

4.1 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 4-1 shows the distribution of historic flood information captured within the study area.

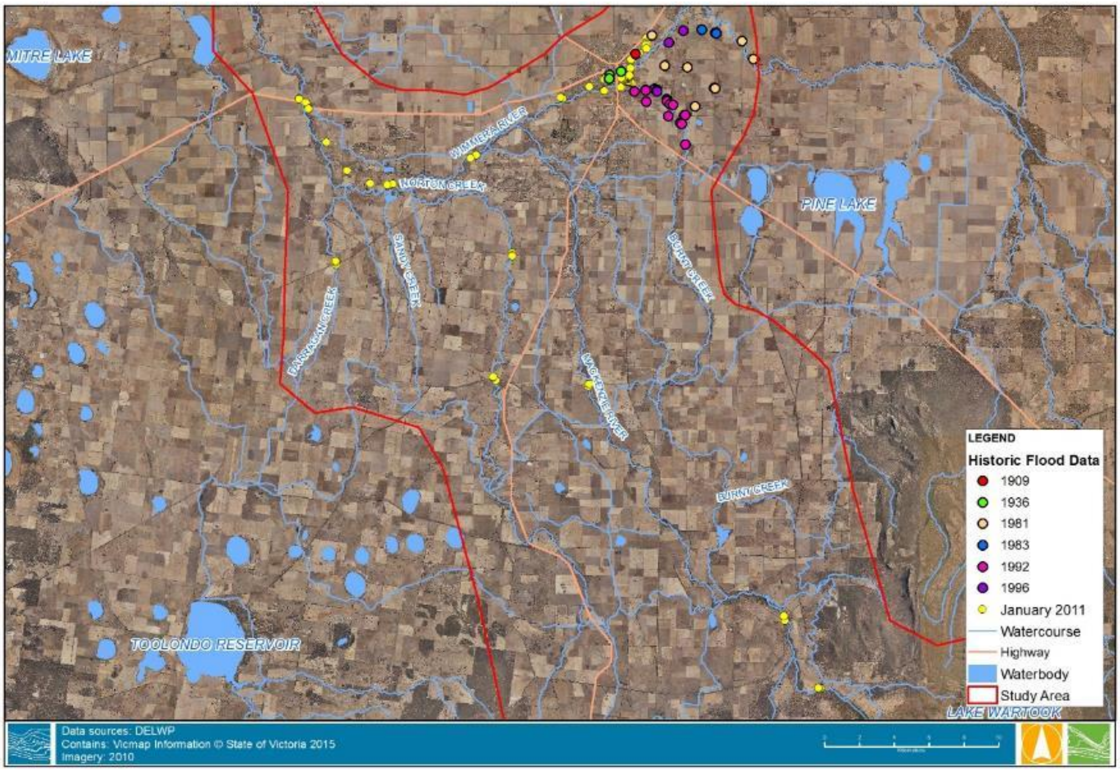

Figure 4-1 Historic flood data capture

As mentioned in Section 3.1, 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 is able to reproduce flood levels across a range of flows.

4.2 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. It was estimated in Horsham there were approximately 15 houses inundated above floor level and that 31 shops were affected by floodwaters[4].

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 runoff or rainfall in the Wimmera River tributaries (Burnt Creek, Mackenzie River etc.), while flooding after the 16th is predominately attributed to rainfall in the upper and mid Wimmera River catchment.

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[6]. 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.

4.2.1 Calibration Data

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 3.1.
- Peak flood height information captured after the event by Wimmera CMA.
- Aerial photography – fixed wing and helicopter.
- Linescan data from VICSES.

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

- Instantaneous streamflow information recorded by Ventia Pty Ltd at the Western Highway bridge over the Wimmera River.
- News media, photographs and stories provided by local community and government agencies.

Post January 2011 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 83 flood heights surveyed, as shown in Figure 4-2. 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.

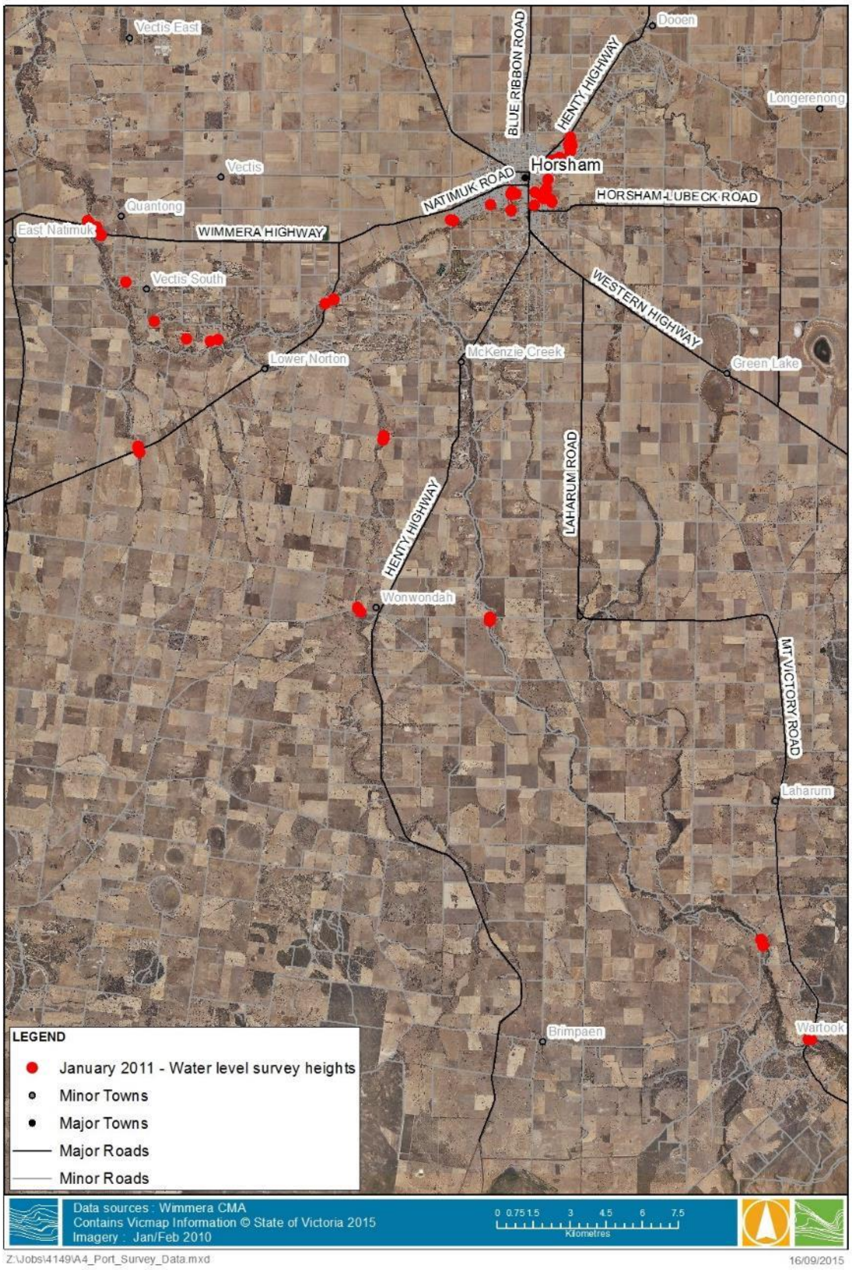

Figure 4-2 January 2011 - Peak flood heights surveyed by Wimmera CMA within the study area

4.3 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 the 8th, September with a second front causing further rainfall on Tuesday the 13th, Wednesday the 14th and Thursday the 15th of September.

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

No dwellings of businesses were reported as inundated above floor.

4.3.1 Calibration Data

Similar to 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 3.1.
- Peak flood height information captured after the event by Wimmera CMA.
- News media, photographs and stories provided by local community and government agencies.

Post January 2011 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 41 flood heights surveyed, as shown in Figure 4-2. 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.

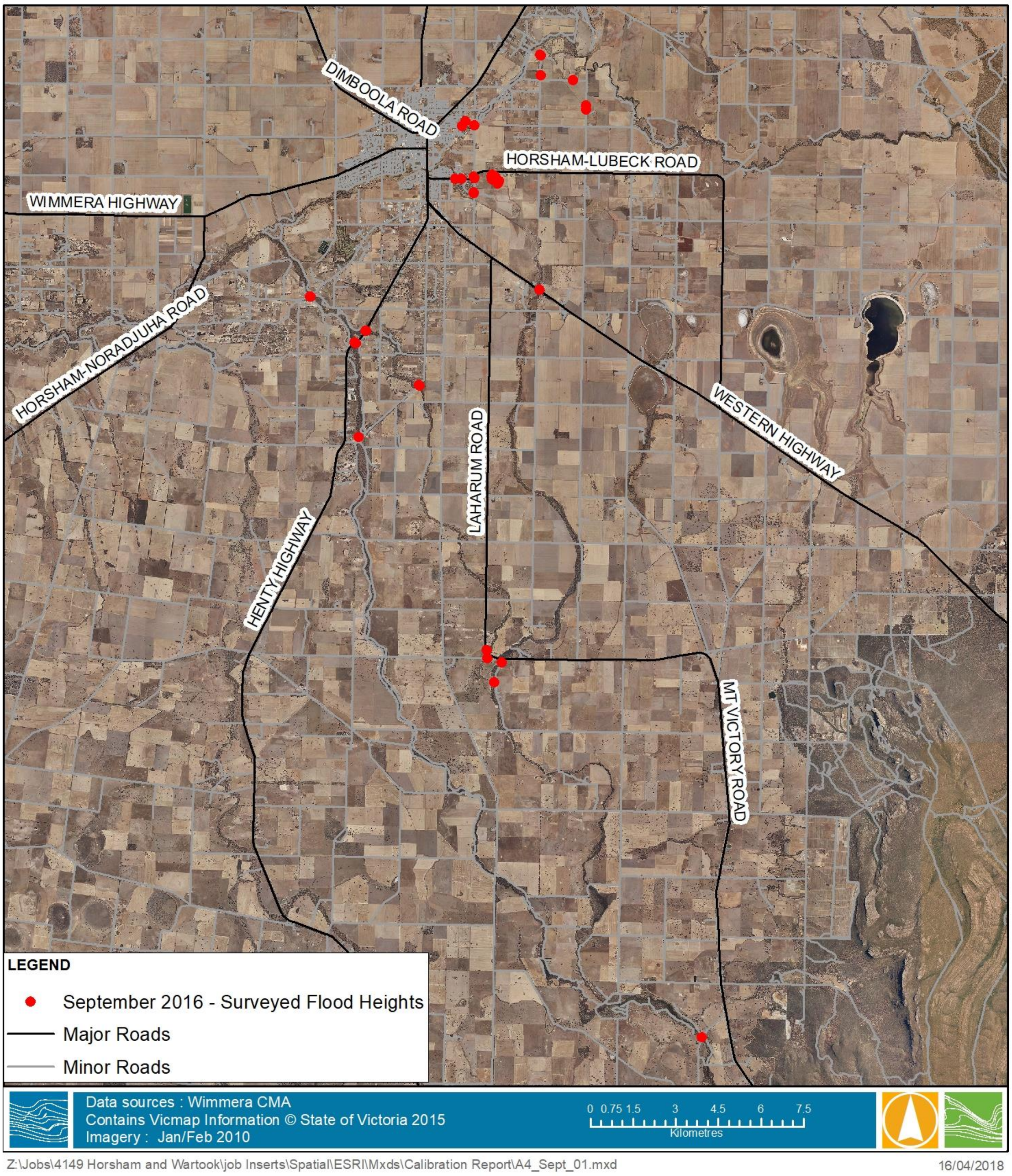

Figure 4-3 September 2016 - Peak flood heights surveyed by Wimmera CMA within the study area

5 REQUIRED SURVEY

To construct a flood model, accurate survey is required of the land surface, the waterways and the hydraulic structures, and physical features of the floodplain that control the behaviour of flooding.

5.1 Topographic survey

Five LiDAR datasets were available for the study area and are summarised in Table 5-1. The extents of the five datasets across the study area are shown in Figure 5-1. LiDAR is an aerial laser survey technique used to capture detailed survey of the ground surface from a fixed wing aircraft. The survey is then processed to remove trees, buildings, etc, providing a bare earth digital elevation model (DEM).

Table 5-1 Key metadata for LiDAR datasets

Dataset	Source	Date of Capture	Vertical accuracy (1 sigma)	DTM resolution
2005 Wimmera CMA Zone 1 (WCMA LL)	LiDAR	Jan 2005	0.15 m	2 m
2005 Wimmera CMA Zone 2 (WCMA HL)	LiDAR	Jan 2005	0.50 m	2 m
2009-10 ISC Rivers LiDAR	LiDAR	Dec 2009 to Oct 2010	0.20 m	1 m
2010-11 Floodplains Stage 2 LiDAR	LiDAR	Jul-Aug 2011	0.10 m	1m
2016 Horsham LiDAR	LiDAR	December 2016	0.10 m	1 n

The 2016 Horsham LiDAR was captured because as par to this study and a recommendation to commission updated LiDAR due to the significant development and channel decommissioning works undertaken since 2005.

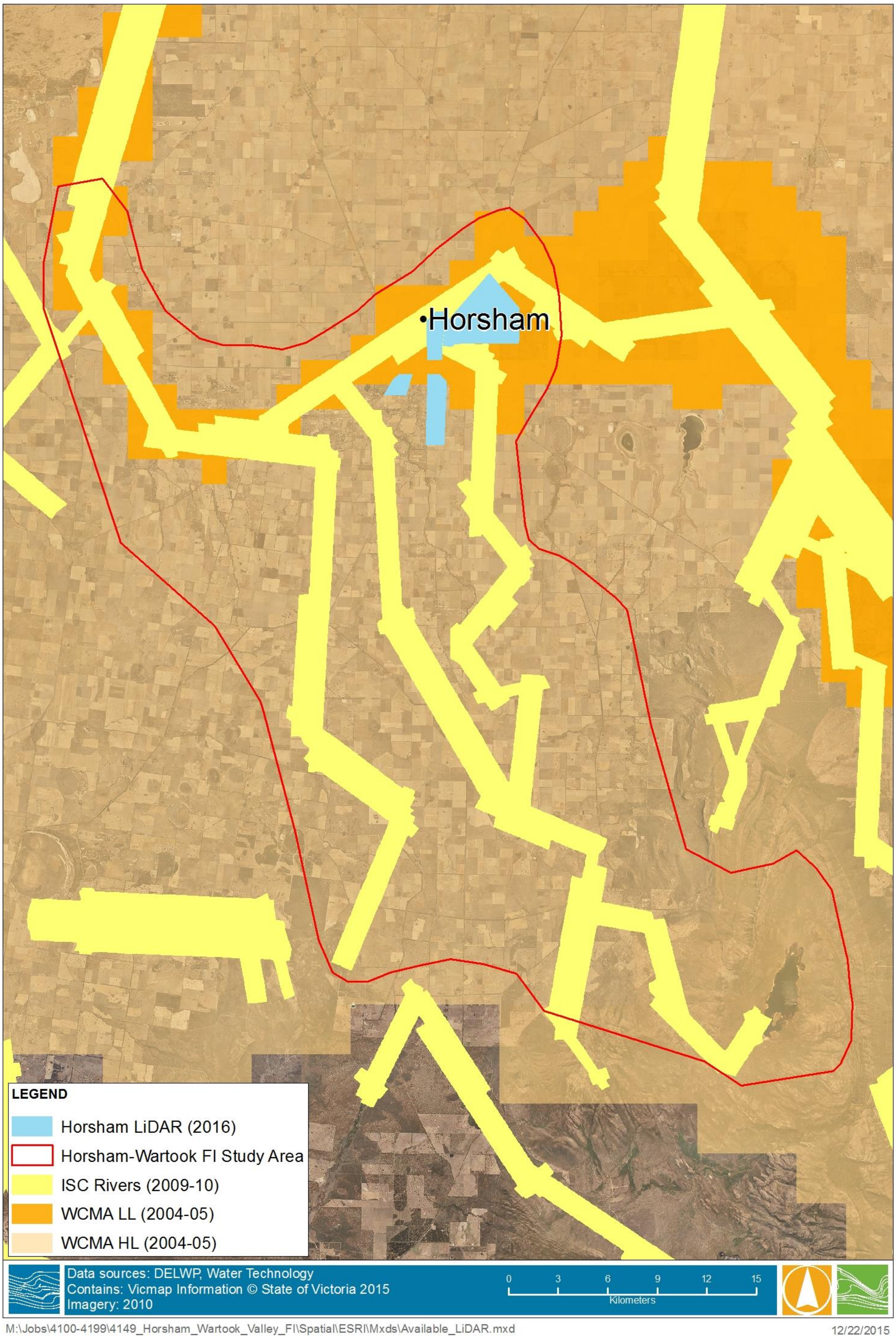

Figure 5-1 Available LiDAR

5.2 Floor level and feature survey

5.2.1 Floor level survey

Previous floor level survey was undertaken in Horsham, as part of the Horsham Flood Study. A total of 909 levels (residential and commercial) have been captured, as seen in Figure 5-2.

On completion of the preliminary 0.5% AEP design hydraulic modelling, floor level survey was commissioned and was underway at the time of this reports production. Wimmera CMA also commissioned high resolution drone based survey of the central Horsham area, this survey is intended to be used as part of this project.

Details of 5 culverts in East Horsham were acquired as part of the East Horsham Culvert Assessment[7], however the recommendation was for replacement of some of these existing structures and hence details may no longer be accurate.

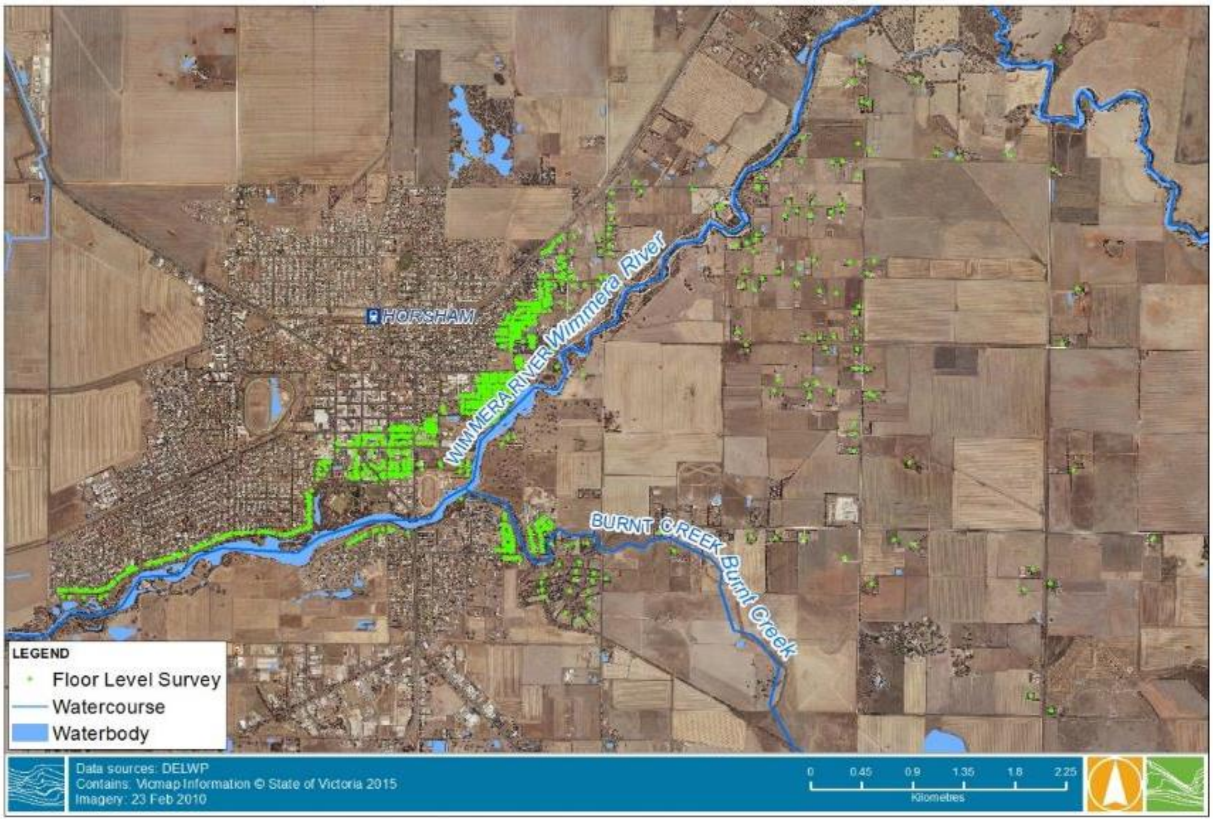

Figure 5-2 Location of available floor level survey data

5.2.2 Wimmera River cross sections

A series of Wimmera River cross sections were captured as part of the original Horsham Flood Study[6]. These 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 5-3.

[7] Water Technology, 2013 - East Horsham Culvert Assessment Modelling

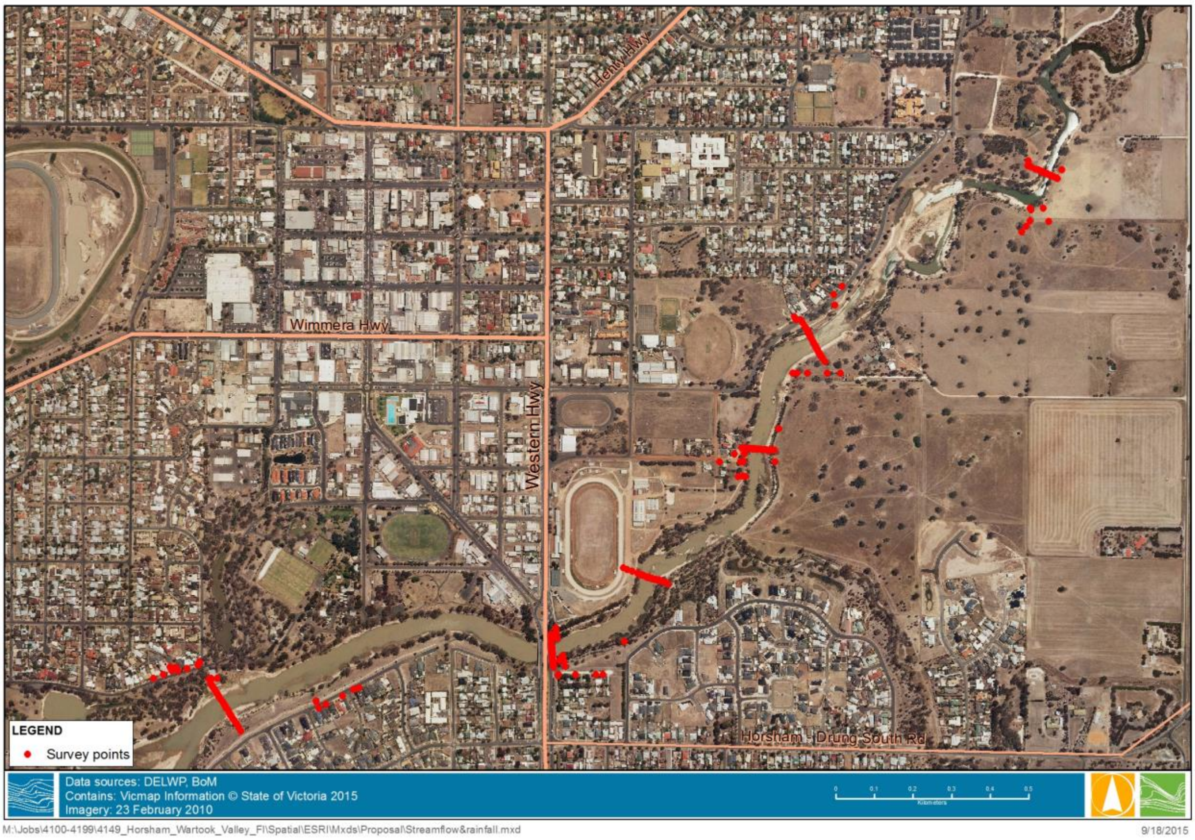

Figure 5-3 Wimmera River cross section survey

6 MODELLING METHODOLOGY

The study area is very large, requiring riverine flood modelling of the Wimmera and Mackenzie River floodplains, and numerous tributaries and anabranches. The study also requires flood mapping local storm events over Horsham itself.

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, transposed to the 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[8] 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 runoff routing 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.
- Stormwater Inundation
  - Stormwater inundation in Horsham and Haven was modelled by directly applying historic and design rainfall to a TUFLOW hydraulic model topography. 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. This type of modelling represents overland stormwater runoff during localised storm events.
  - Model calibration was completed using the January 2011 event.

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.

6.1 Riverine Inundation

6.1.1 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 they were translocated, and in the case of the Wimmera River, were lagged, scaled and split between multiple model boundary locations. The streamflow gauge locations and their model input locations are show in Figure 6-1.

[8] Water Technology (2014), Warracknabeal and Brim Flood Investigation (Commissioned by Wimmera CMA)

Figure 6-1 Gauged model inflows

Gauge flows for the Wimmera River at Horsham (Walmer) gauge were translocated 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 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 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 6-2 and Figure 6-3 respectively.

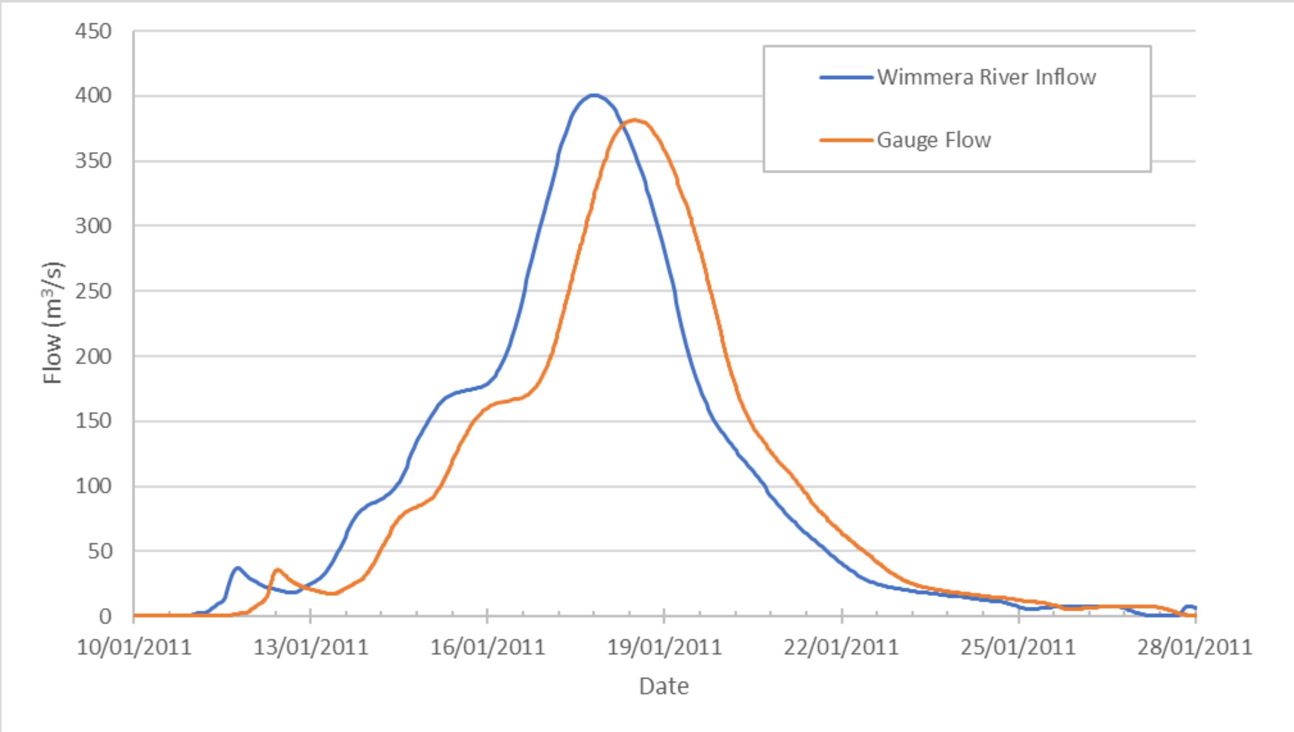

Figure 6-2 January 2011 – Wimmera River model inflows and Wimmera River at Horsham (Walmer) gauge record

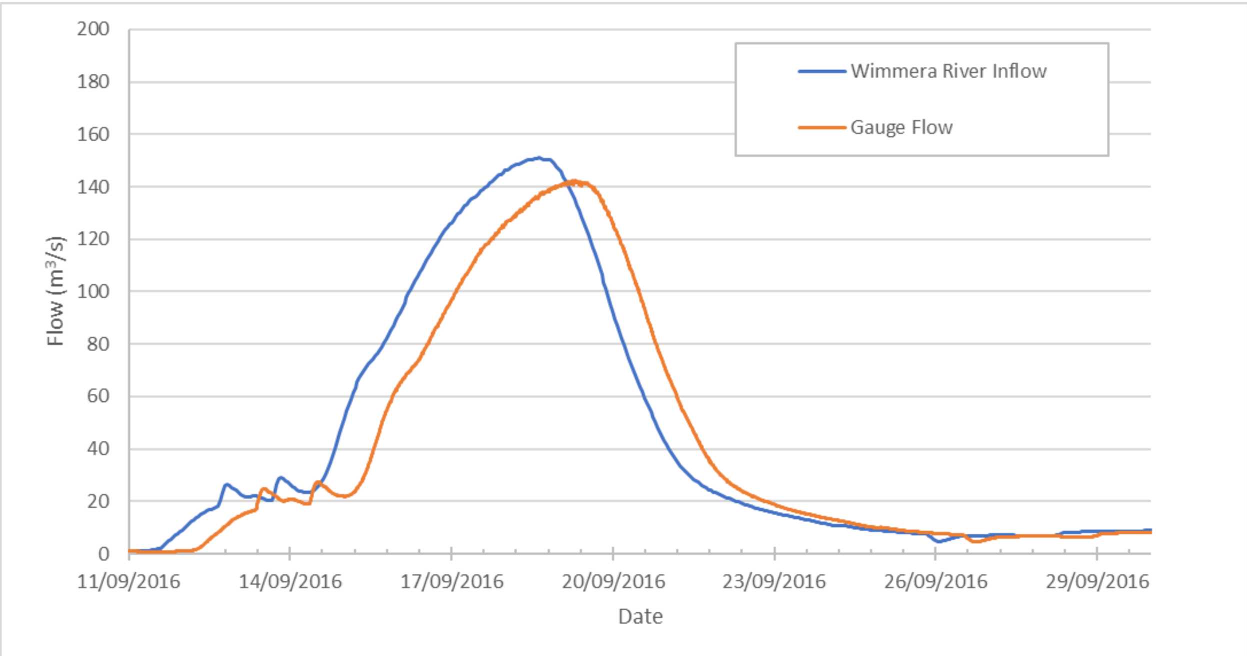

Figure 6-3 September 2016 – Wimmera River model inflows and gauge record and Wimmera River at Horsham (Walmer) gauge record

Gauge flows from the Mackenzie River at Wartook gauge were input directly into the model, translocated 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 6-4 and Figure 6-5 respectively.

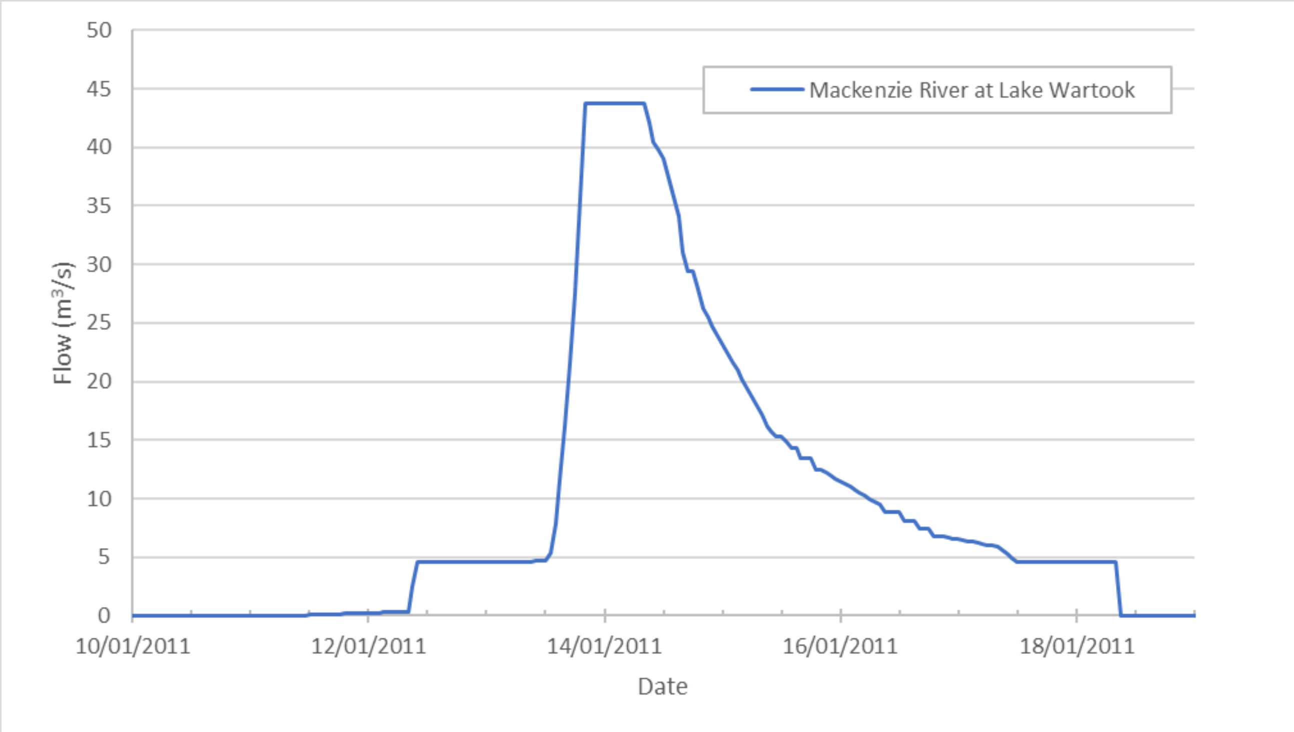

Figure 6-4 January 2011 – Mackenzie River model inflows

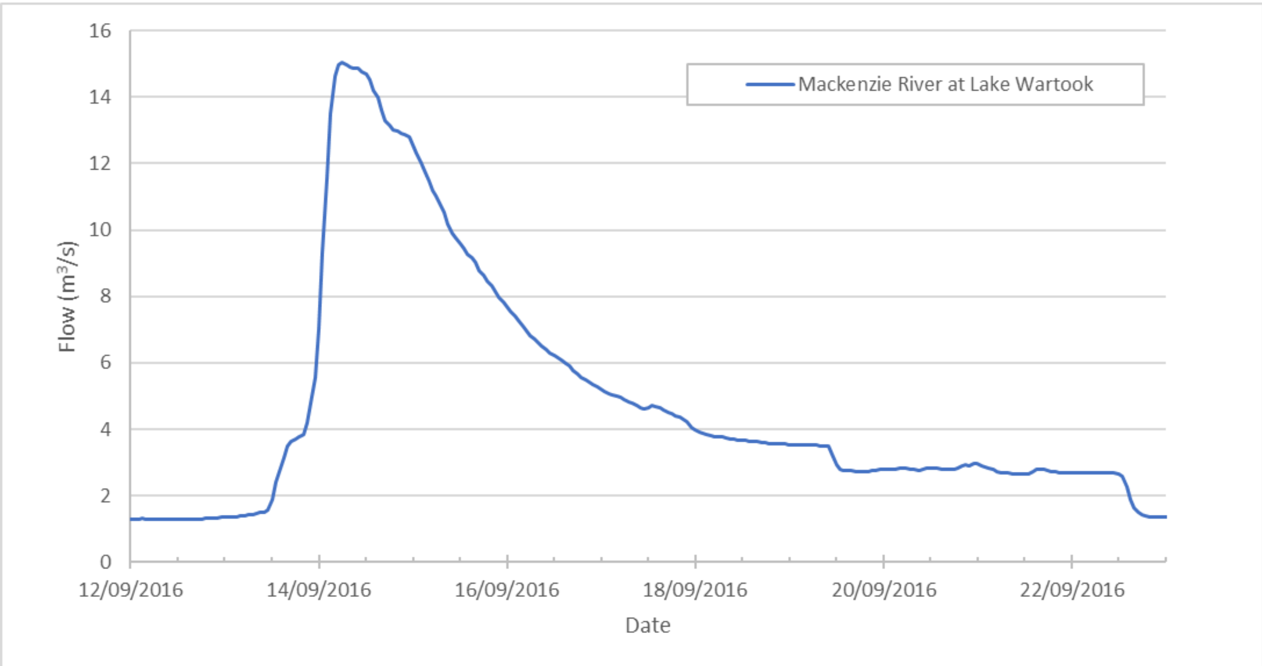

Figure 6-5 September 2016 – Mackenzie River model inflows

6.1.2 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.

6.1.2.1 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 6-6.

6.1.2.2 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 6-1, with the zones mapped in Figure 6-7.

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 6-8.

Table 6-1 RORB Model fraction impervious values and zones[9]

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

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

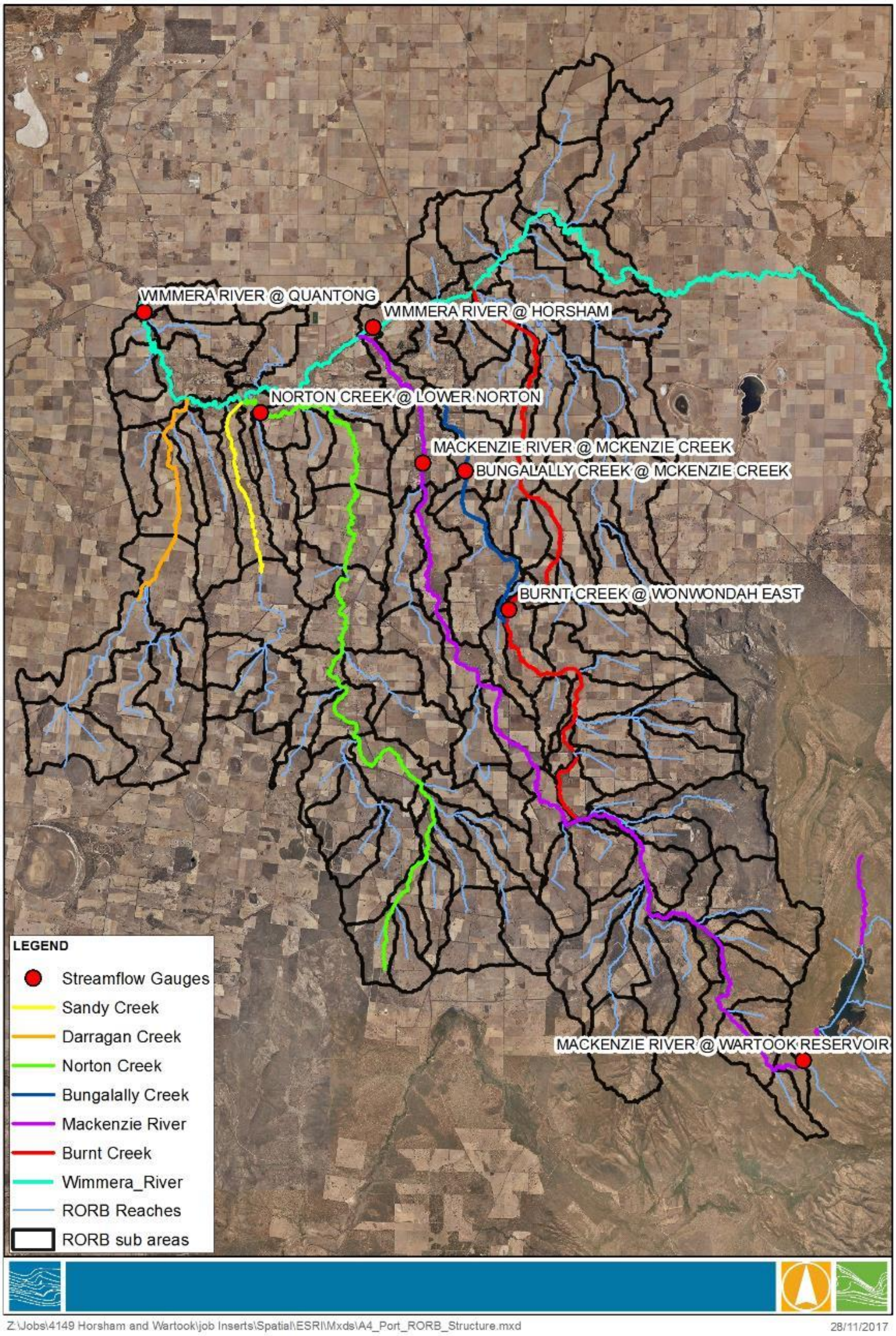

Figure 6-6 RORB subarea and reach delineation

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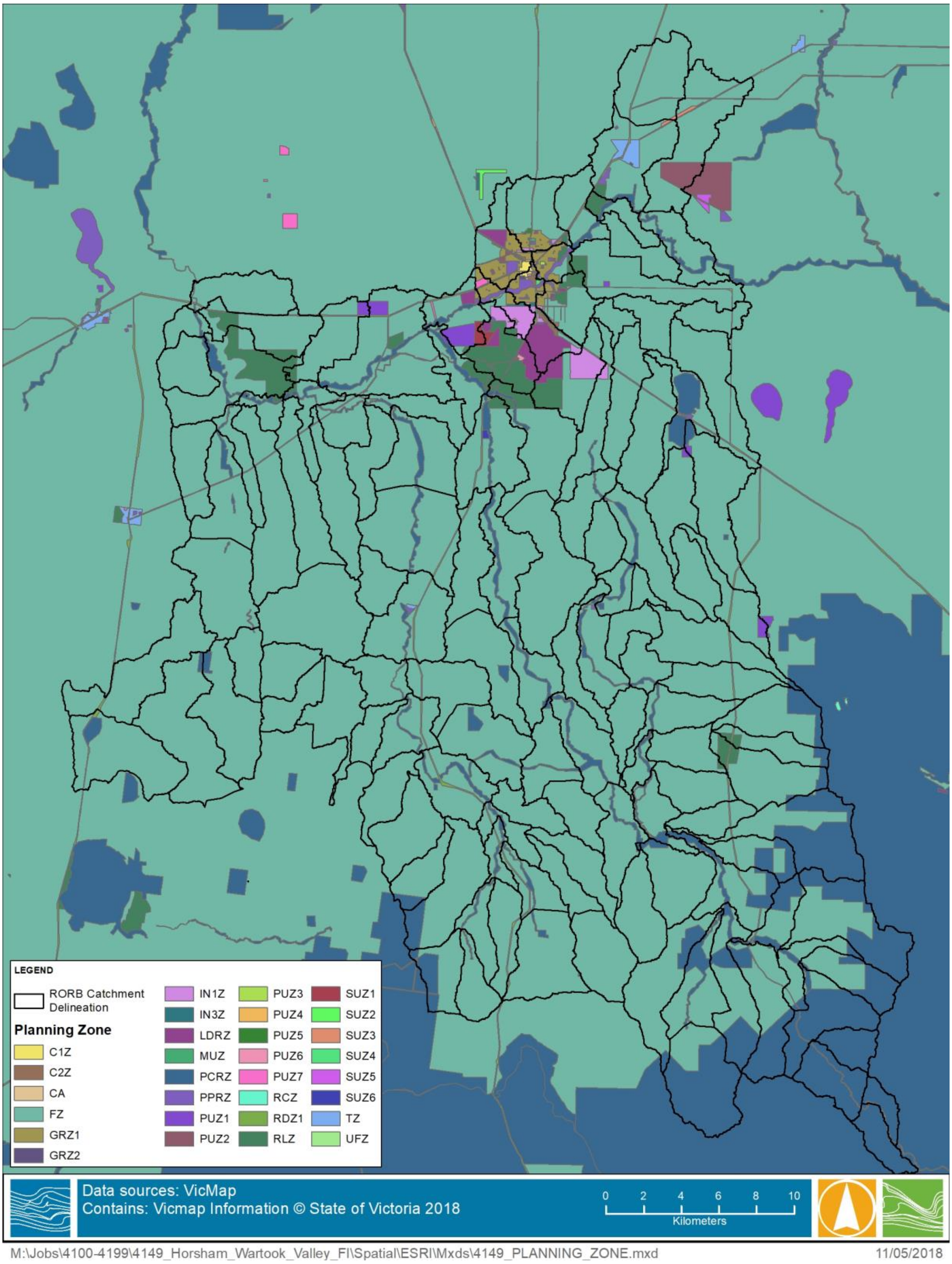


Figure 6-7 RORB model planning zones

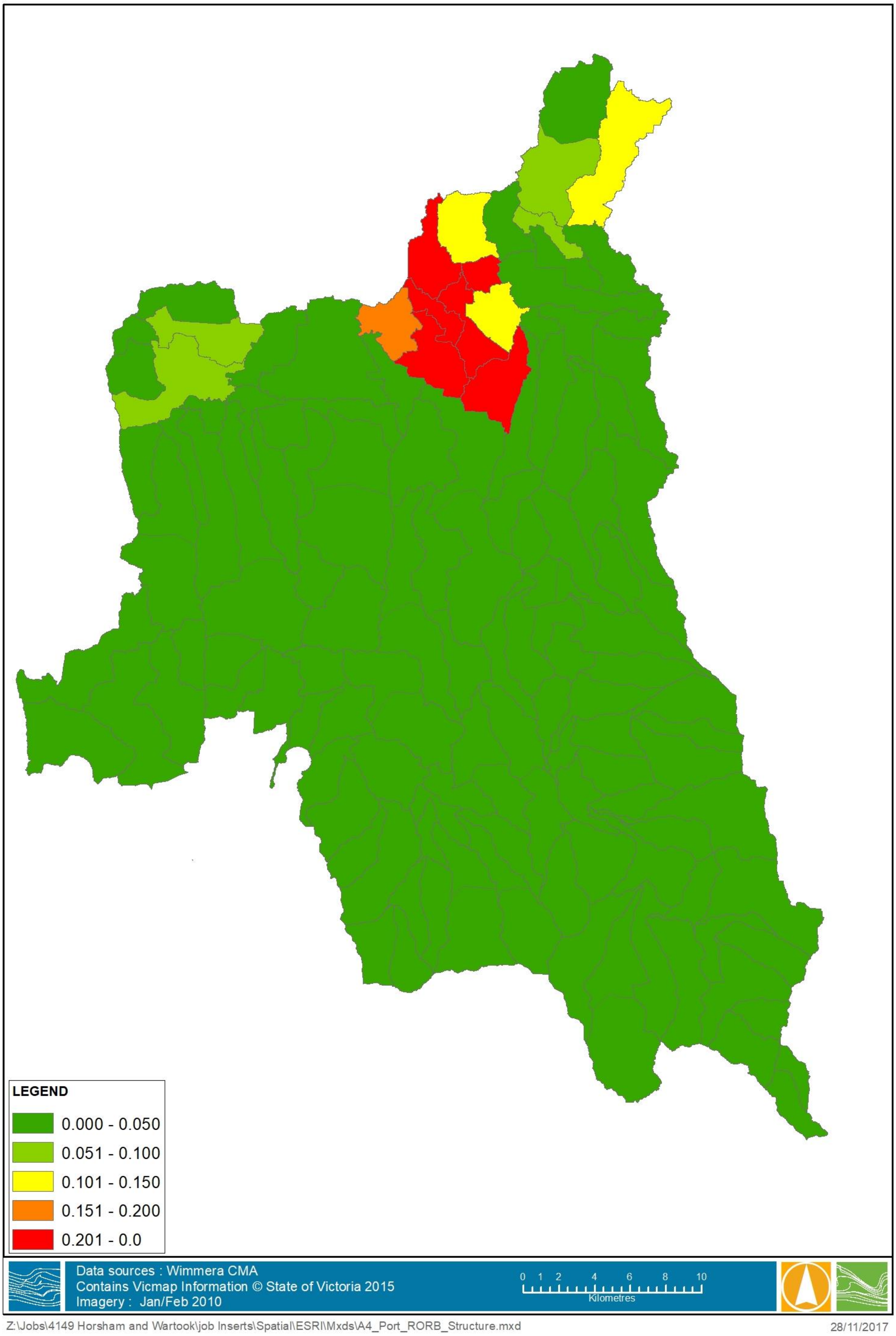


Figure 6-8 RORB model fraction impervious calculated distribution

6.1.2.3 Model Parameters

The RORB model was broken up into a series of interstation areas; these areas had a kc, m, initial loss and continuing loss applied to them. Several model iterations were run, determining inflows to the hydraulic model, which was then compared to observed flood heights.

The kc for each interstation area was determined using the Victorian data estimate available in RORB (Pearse et al, 2002[10]) - kc=1.25*$D_{av.}$

We have found this to be the best match 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.

6.1.3 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.

6.1.3.1 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 6-9 with an example of the model mesh shown in Figure 6-10.

[10] 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

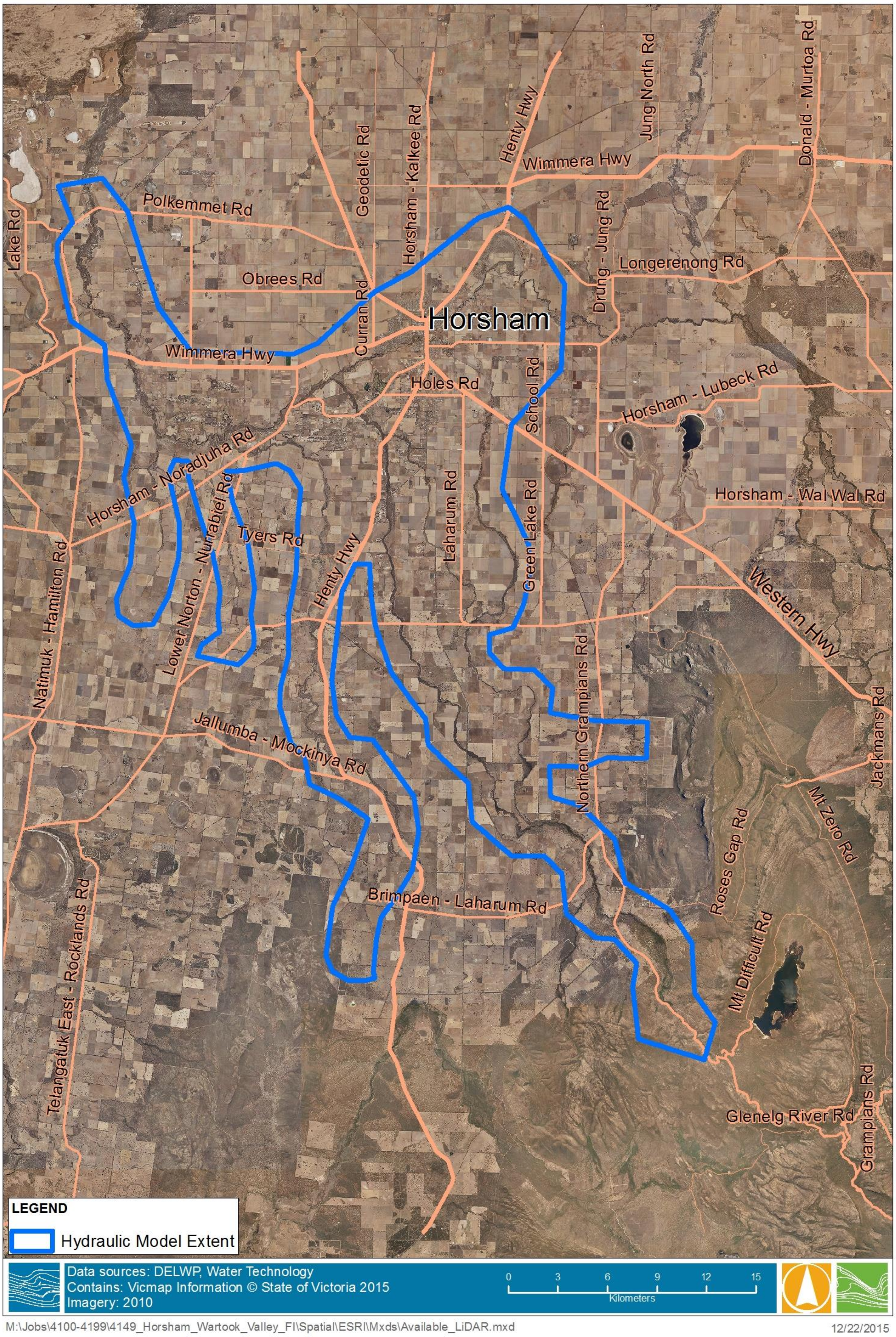


Figure 6-9 MIKEFM model extent

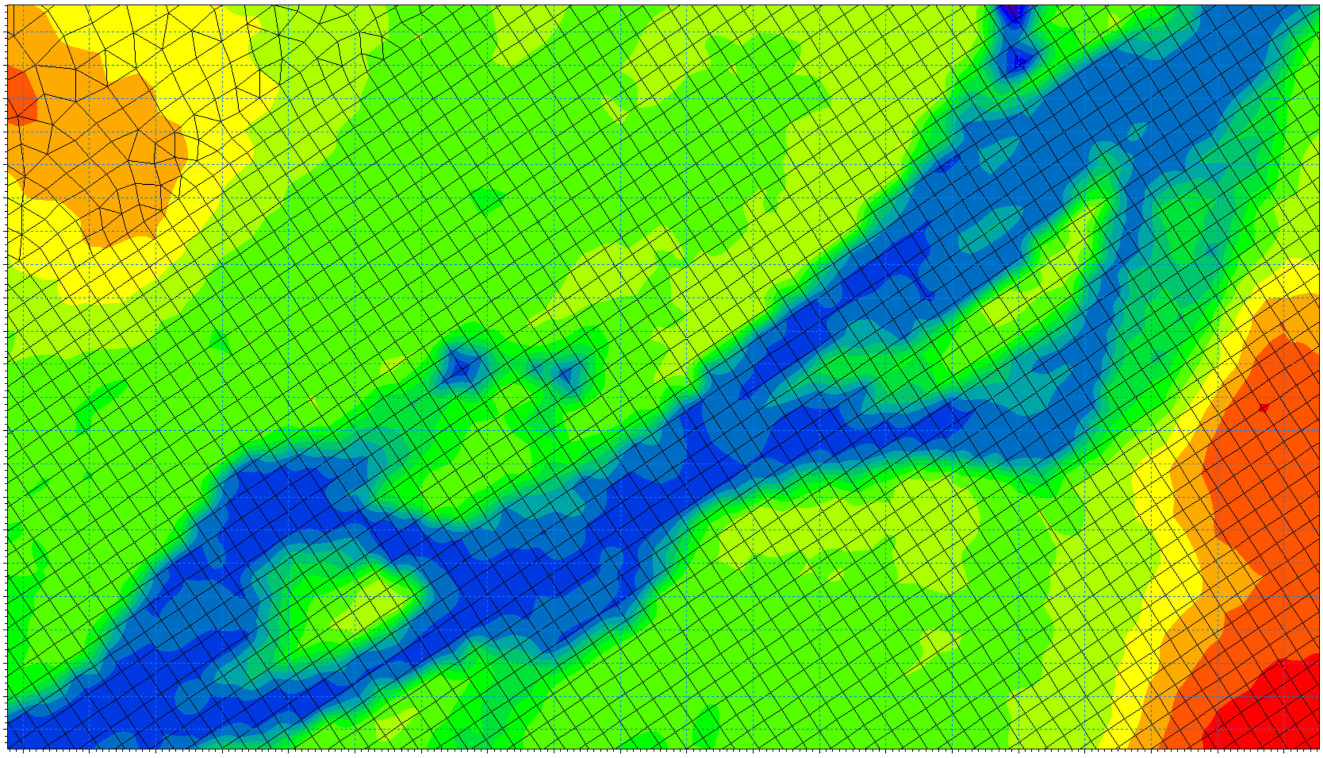


Figure 6-10 MIKEFM example portion of mesh

As discussed in the Data Verification component of this project[11], 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)[12]
- Dunmunkle Creek Flood Investigation (Water Technology, 2016) (Commissioned by Wimmera CMA)[13]
- Natimuk Flood Investigation (Water Technology, 2012) (Commissioned by Wimmera CMA)[14]

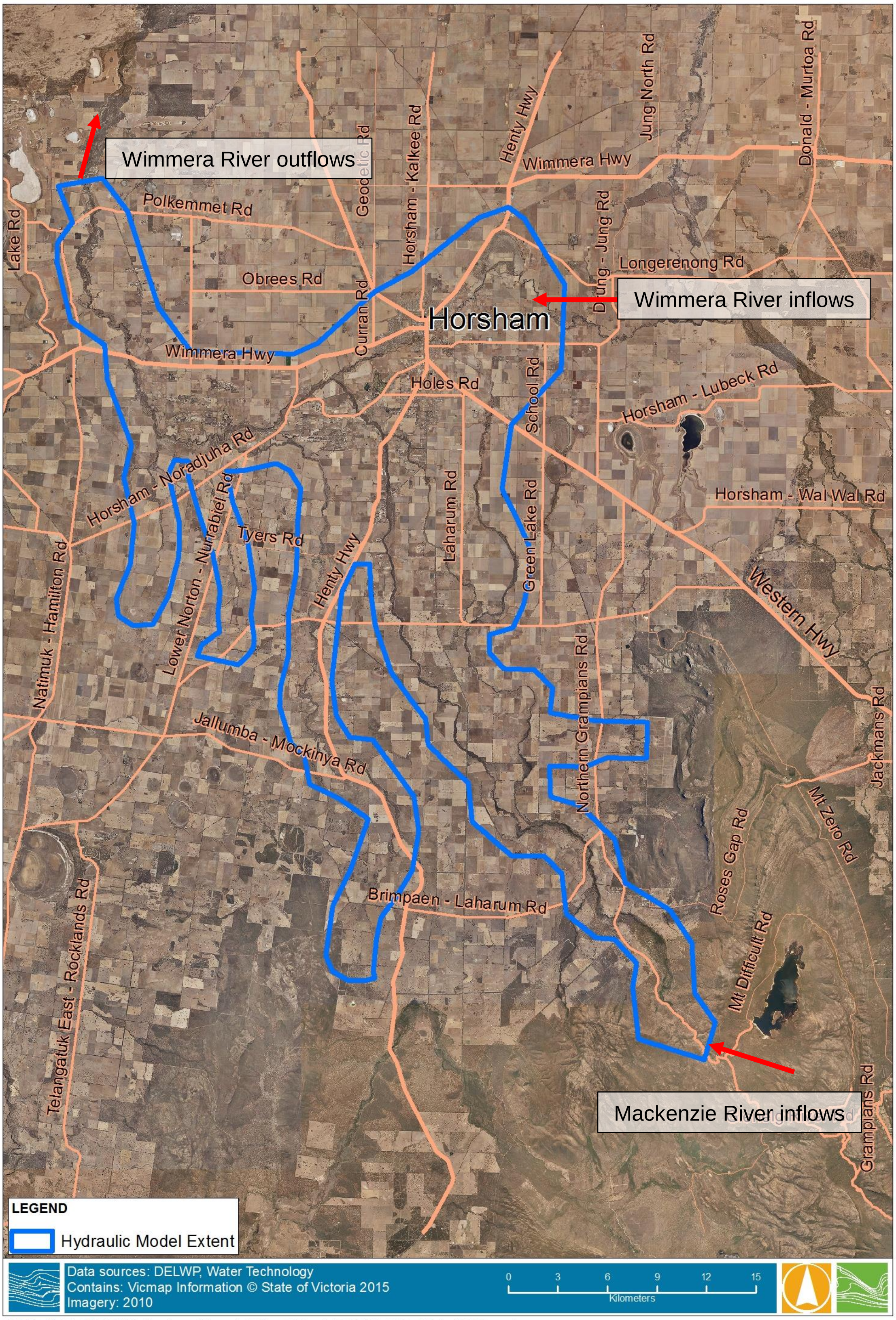
The 2010 ISC LiDAR data was not used as the base topography in the above projects due to inconsistencies in the data, these have included datum shifts and water in the channel in several waterways. This is explained in detail in the Warracknabeal and Brim Flood Investigation[12] and Dunmunkle Creek Flood Investigation[2] data verification reports, while the 2016 Horsham LiDAR was verified as part of this project.

[11] Water Technology (2016), Horsham and Wartook Valley Flood Investigation, Data Verification Memo
[12] Water Technology (2016), Warracknabeal and Brim Flood Investigation, Wimmera CMA
[13] Water Technology (2016). Dunmunkle Creek Flood Investigation, Wimmera CMA
[14] Water Technology (2012), Natimuk Flood Investigation, Wimmera CMA

During the January 2011 calibration the 2004 LiDAR was used as the basis for the model topography while the September 2016 calibration was complete with the inclusion of the 2016 data taking precedence over that captured in 2004. Design modelling will be completed with the same topography as the September 2016 model calibration.

6.1.3.2 Model Boundaries

The hydraulic model boundaries used both streamflow gauge records and hydrographs from a RORB model. The boundary locations are highlighted in Figure 6-11, outlining the two gauge boundaries, with the remainder based on RORB model inflows.



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

Figure 6-11 Hydraulic model boundaries

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6.1.3.3 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[15]. The adopted roughness values for each land use are outlined in Table 6-2 and shown graphically in Figure 6-12.

Table 6-2 Adopted Manning's 'n' values for riverine flood model

Description	Manning's 'm'
Residential areas	12.5
Floodplain areas	25
Treed or forested areas	20
Thick riverine vegetation	20
Sparse riverine vegetation	33
Open Water	50

[15] Chow (1959), Open Channel Hydraulics

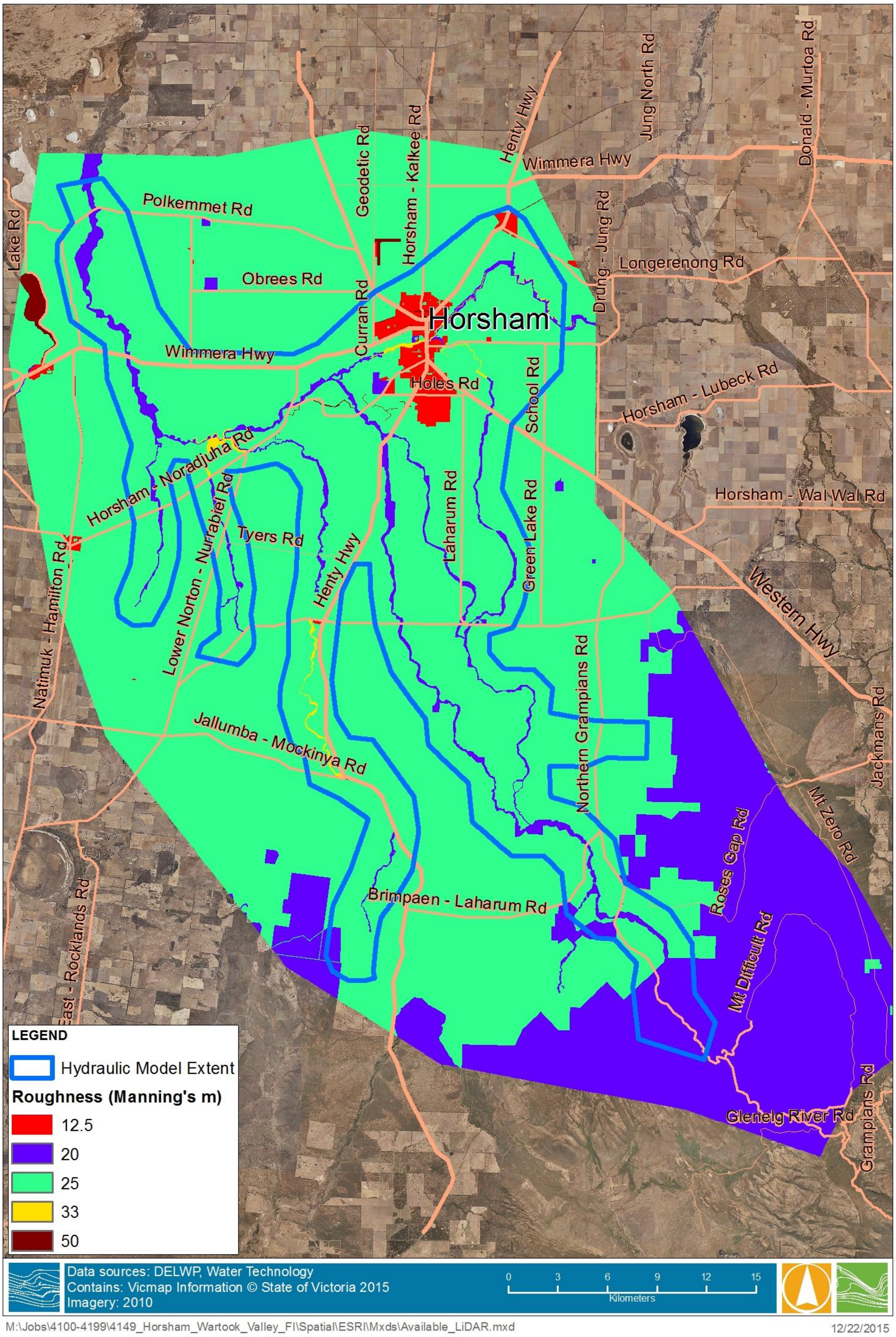

Figure 6-12 Adopted Manning's 'n' values for riverine flood modelling

6.2 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 6-13. The drainage system details were reasonable but some assumptions had to be made in order to connect pipes where no invert data was known.

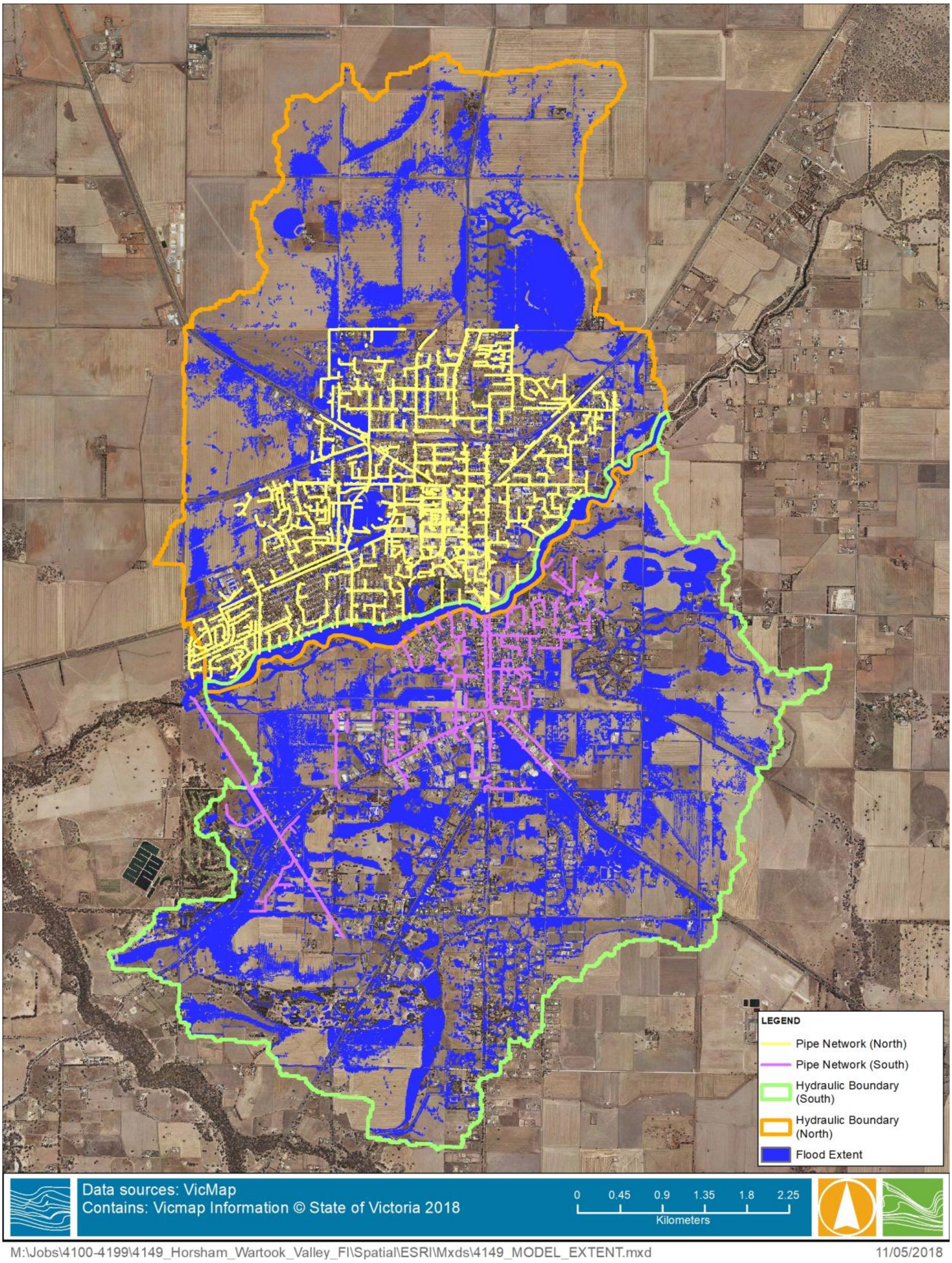

Figure 6-13 Rain on Grid – Model Extents

6.2.1 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.

6.2.2 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 7 when presenting results for each storm scenario.

6.2.3 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[16]. The adopted roughness values for each land use are outlined in Table 6-3 and shown graphically in Figure 6-14. The adopted roughness values were different to that used in the Flexible Mesh model due to their very different model type and extent

Table 6-3 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

[16] Chow (1959), Open Channel Hydraulics

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

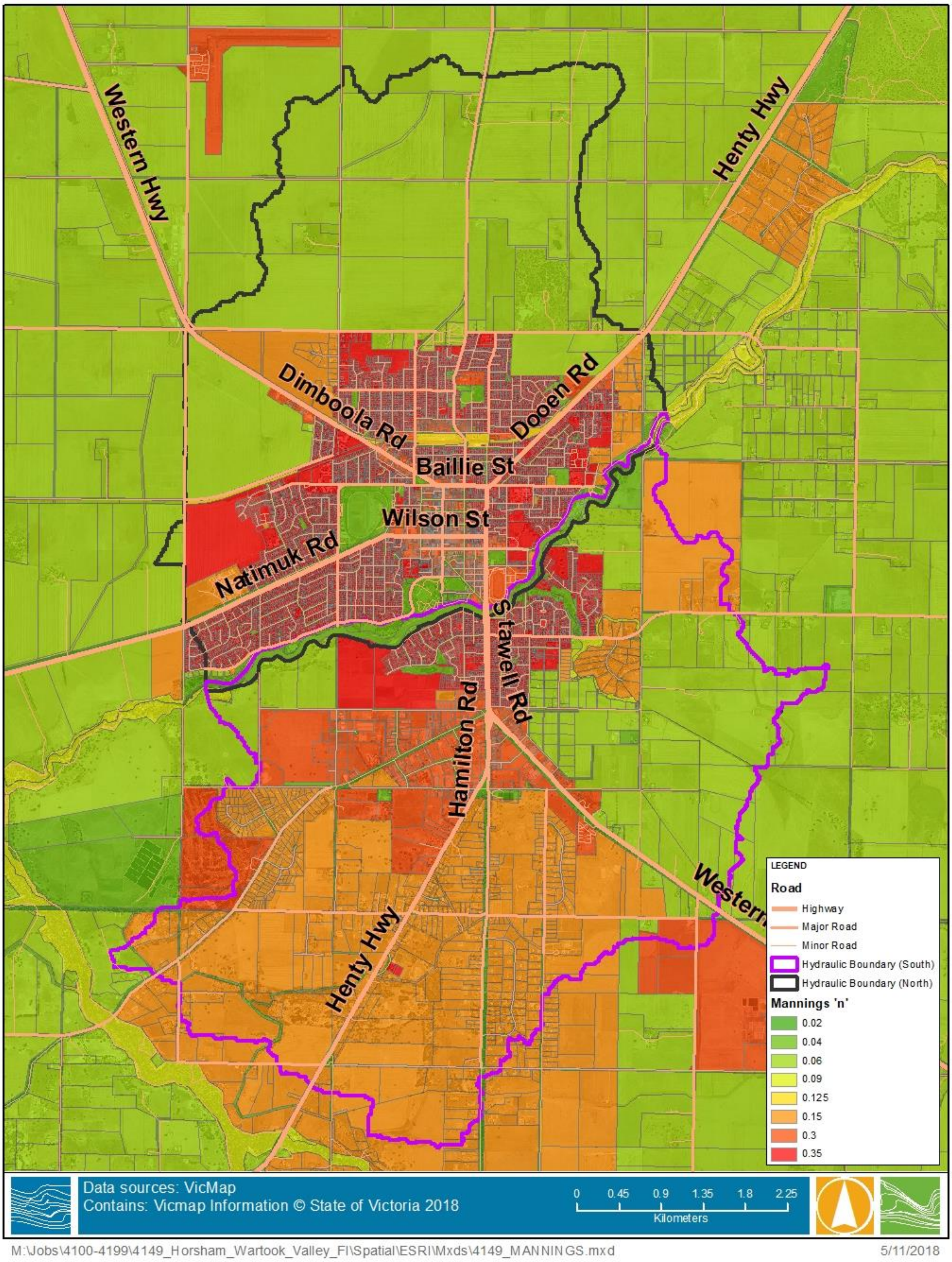

Figure 6-14 RoG - Adopted Manning's 'n' values

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6.2.4 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 7 and 8.1 respectively.

7 MODEL CALIBRATION

7.1 Riverine Inundation

7.1.1 January 2011

As discussed in Section 4.2, there were numerous calibration data sources available from the January 2011 event. These 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 survey captured after the event by Wimmera CMA.
- Aerial flood photography.
- Streamflow information recorded by Ventia Pty Ltd at the Western Highway bridge over the Wimmera River.

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 final area of inundation for January 2011 is shown in Figure 7-1.

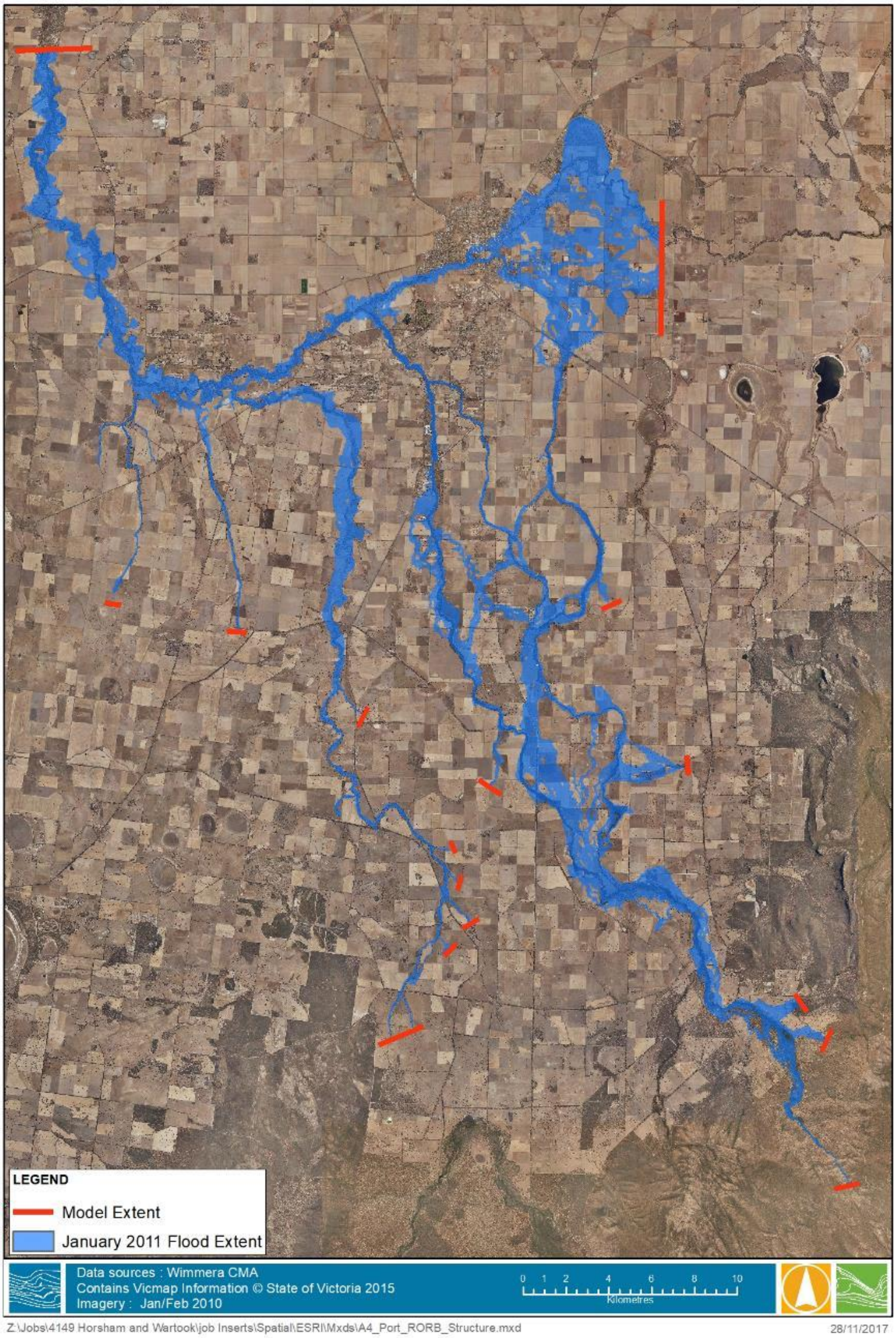

Figure 7-1 January 2011 – Modelled inundation extent

7.1.1.1 Surveyed Flood Heights

As discussed in Section 4, 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 7-2, and mapped for the entire model area in Figure 7-3. The same difference classification has been used for all calibration events.

Figure 7-2 Thematic mapping categories

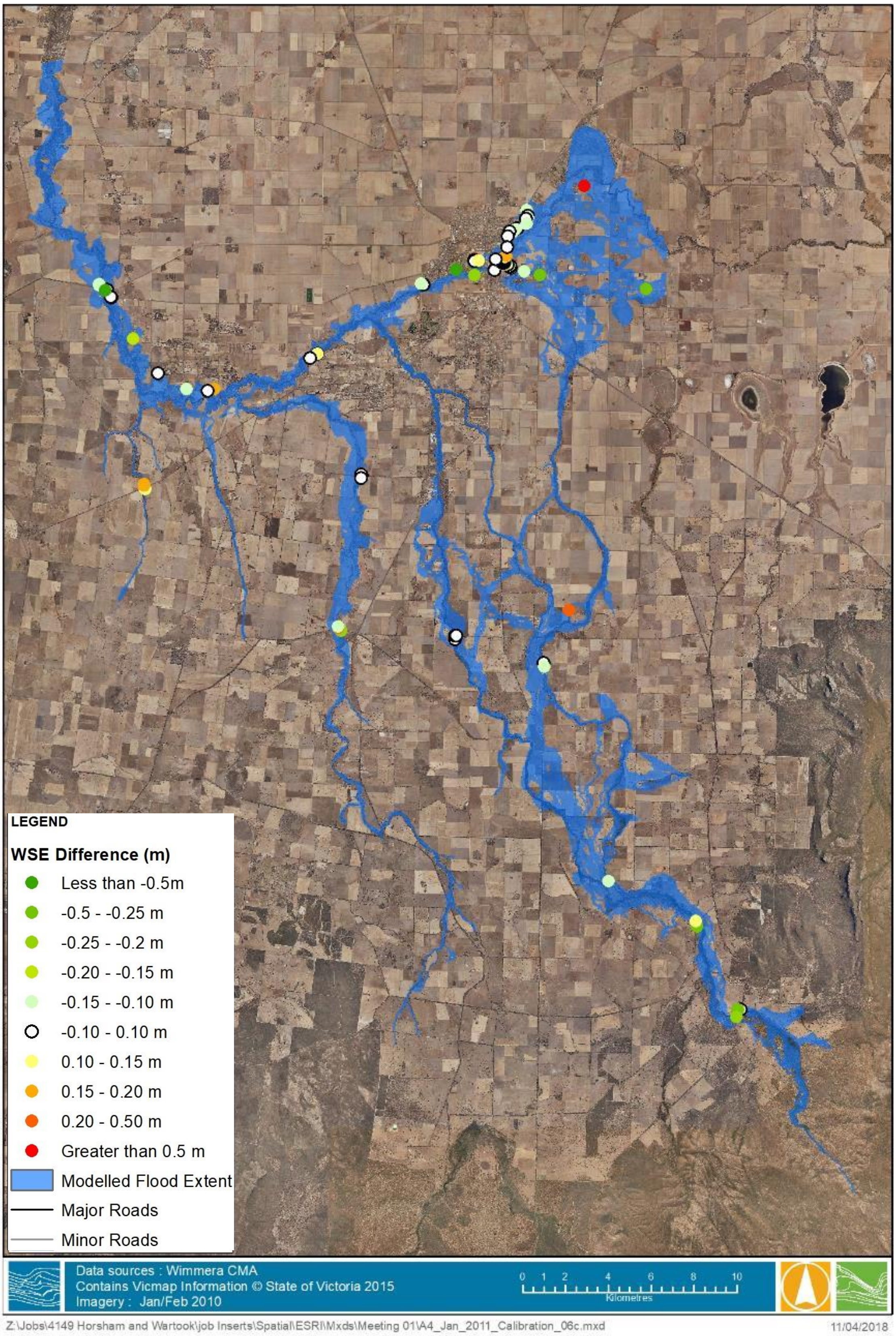

Figure 7-3 Thematic mapping – 2011 Surveyed vs. Modelled peak flood heights

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 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 7-4.
  - 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 7-5.
- 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 7-6.
- 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 7-7.
  - 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 7-8.
  - 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 7-9.
- 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 7-10.
  - Bennett Road – the point is north of the Wimmera River, the model results do not show water reaching this point. See Figure 7-10.
- 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 7-11.

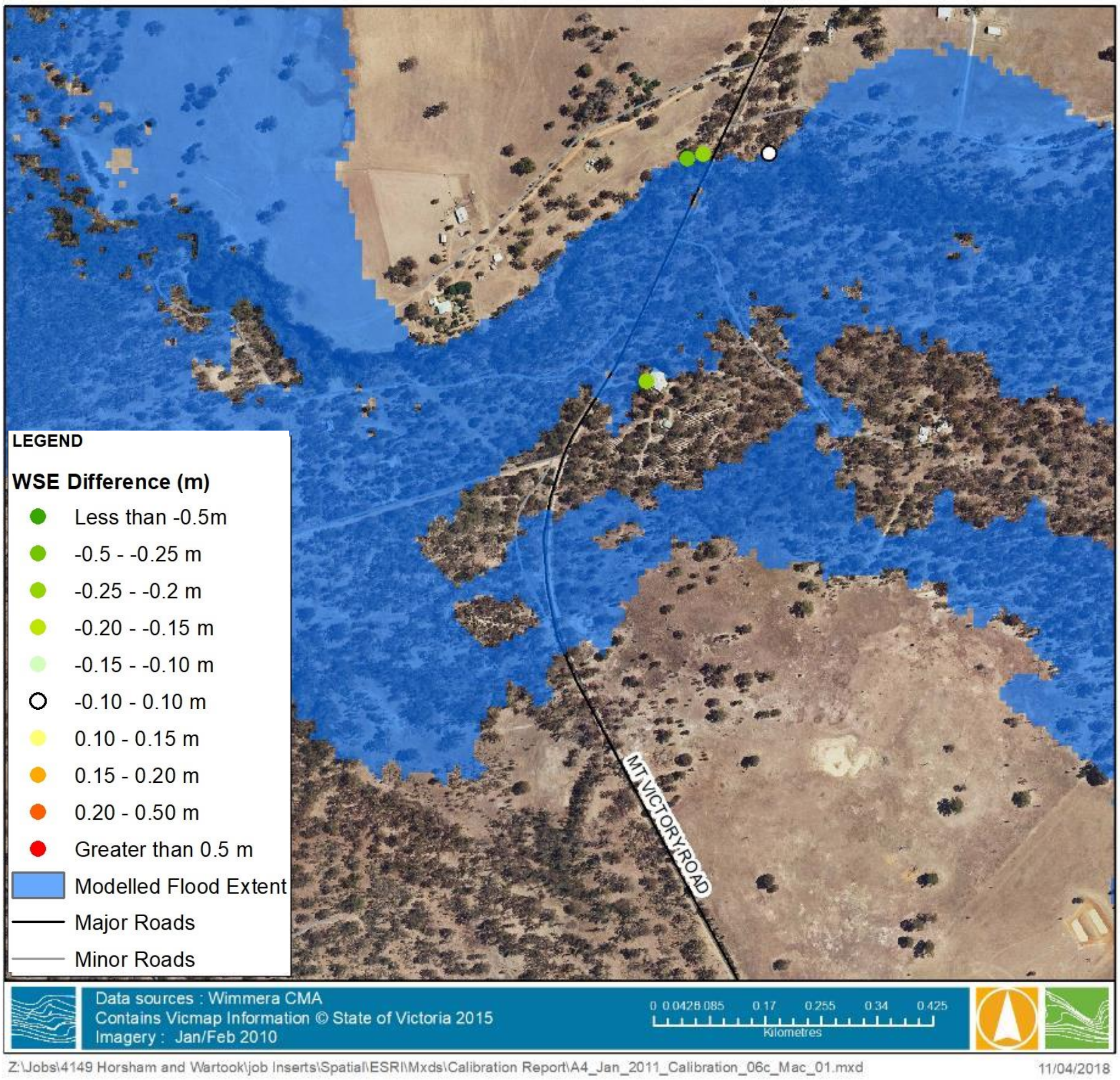

Figure 7-4 Low points – Mackenzie River at Mt Victory Road

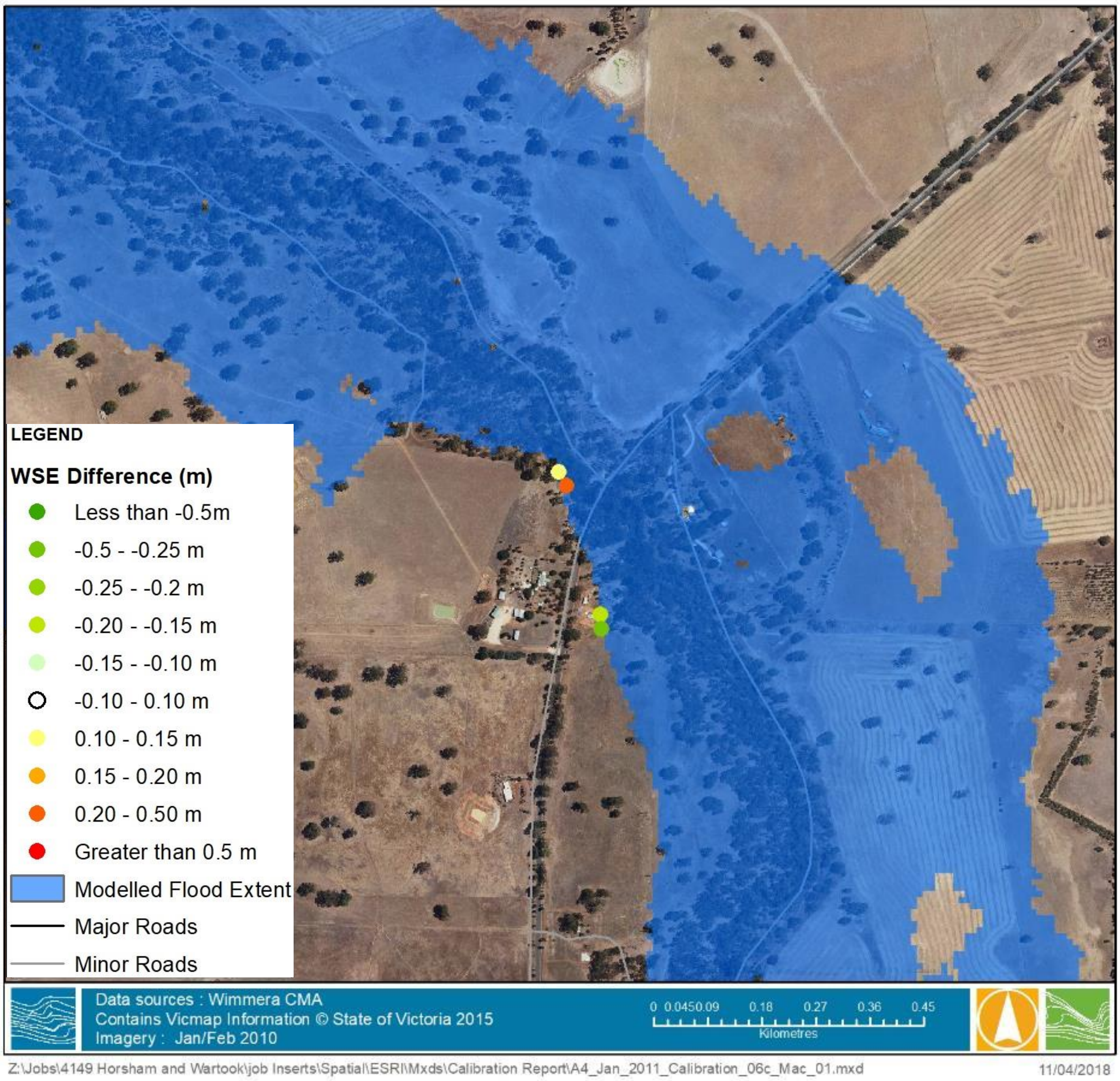

Figure 7-5 Low points – Mackenzie River at Brimpaen Laharum Road

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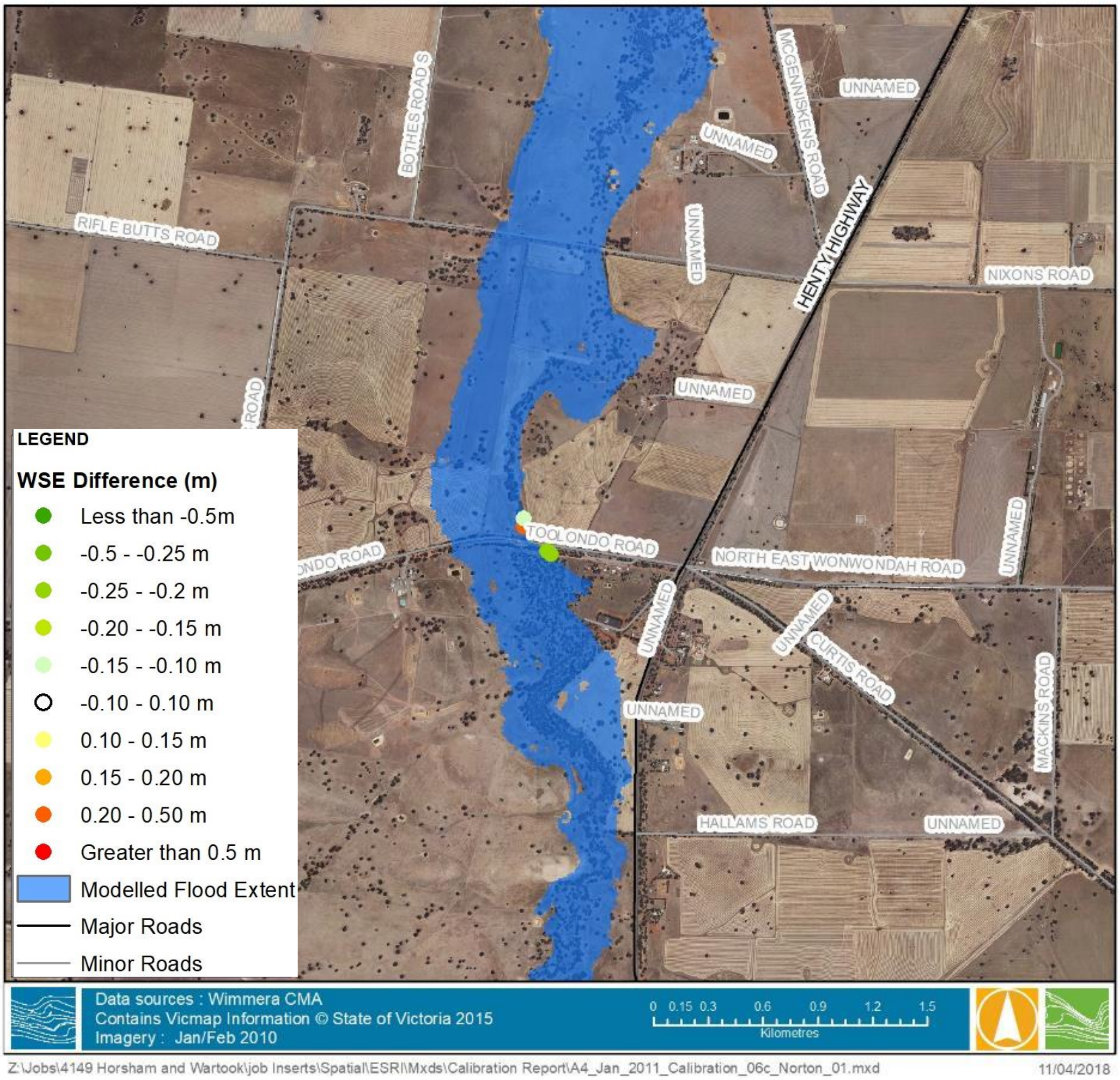

Figure 7-6 Low points – Norton Creek at Henty Highway

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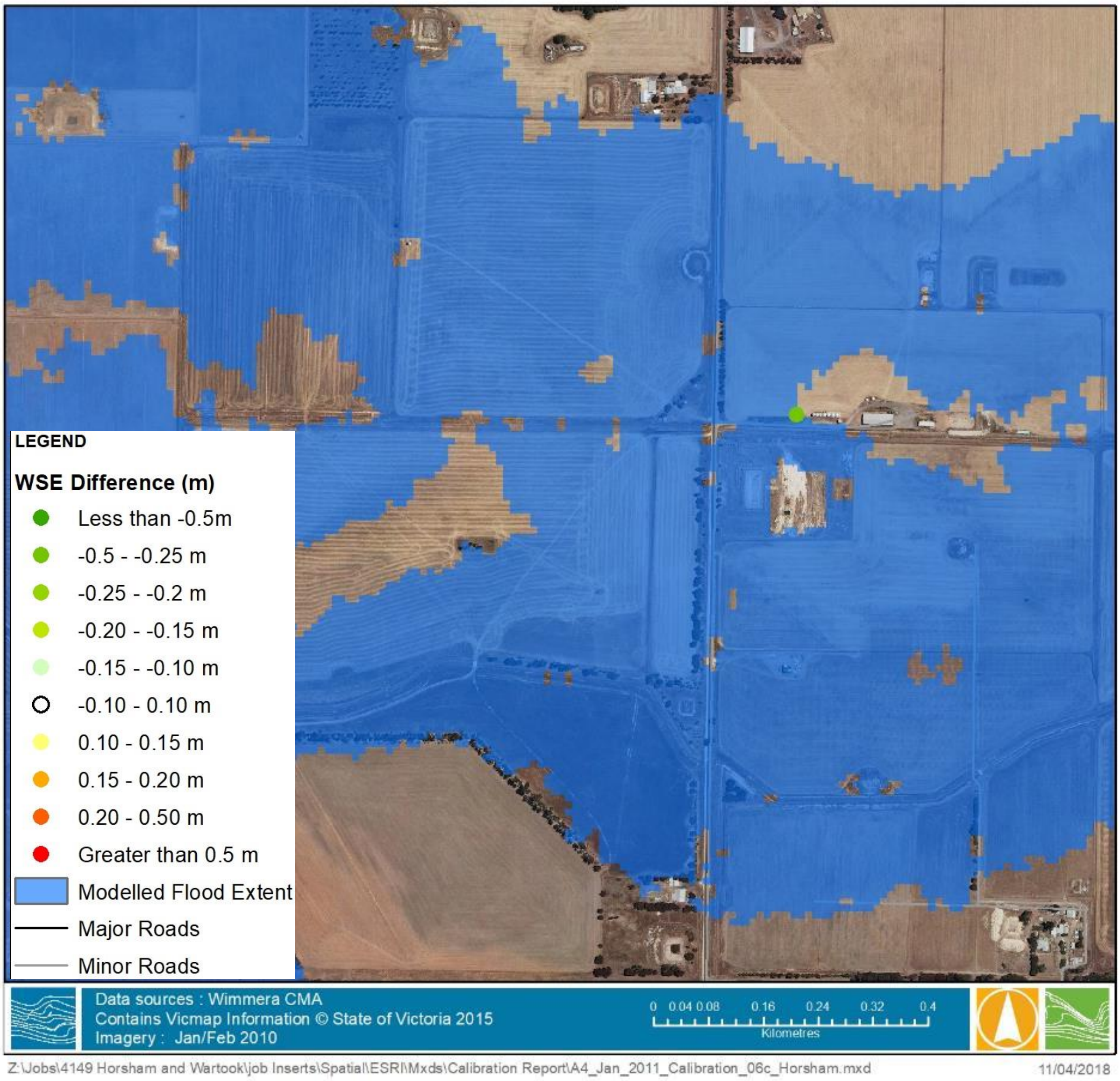

Figure 7-7 Low Points - Wimmera River overland flow path at School Road

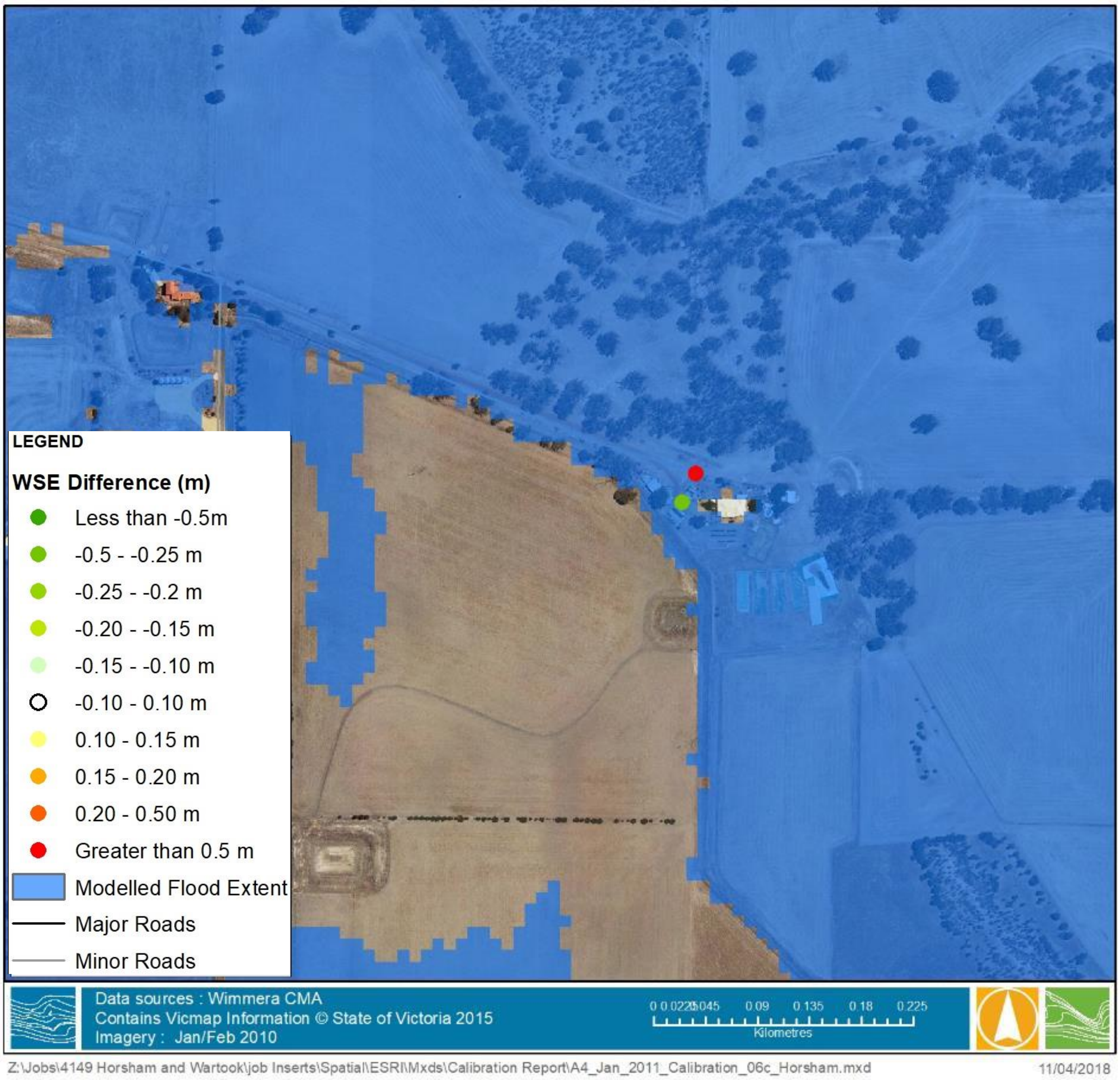

Figure 7-8 Low Points - Wimmera River east of Riverside East Road

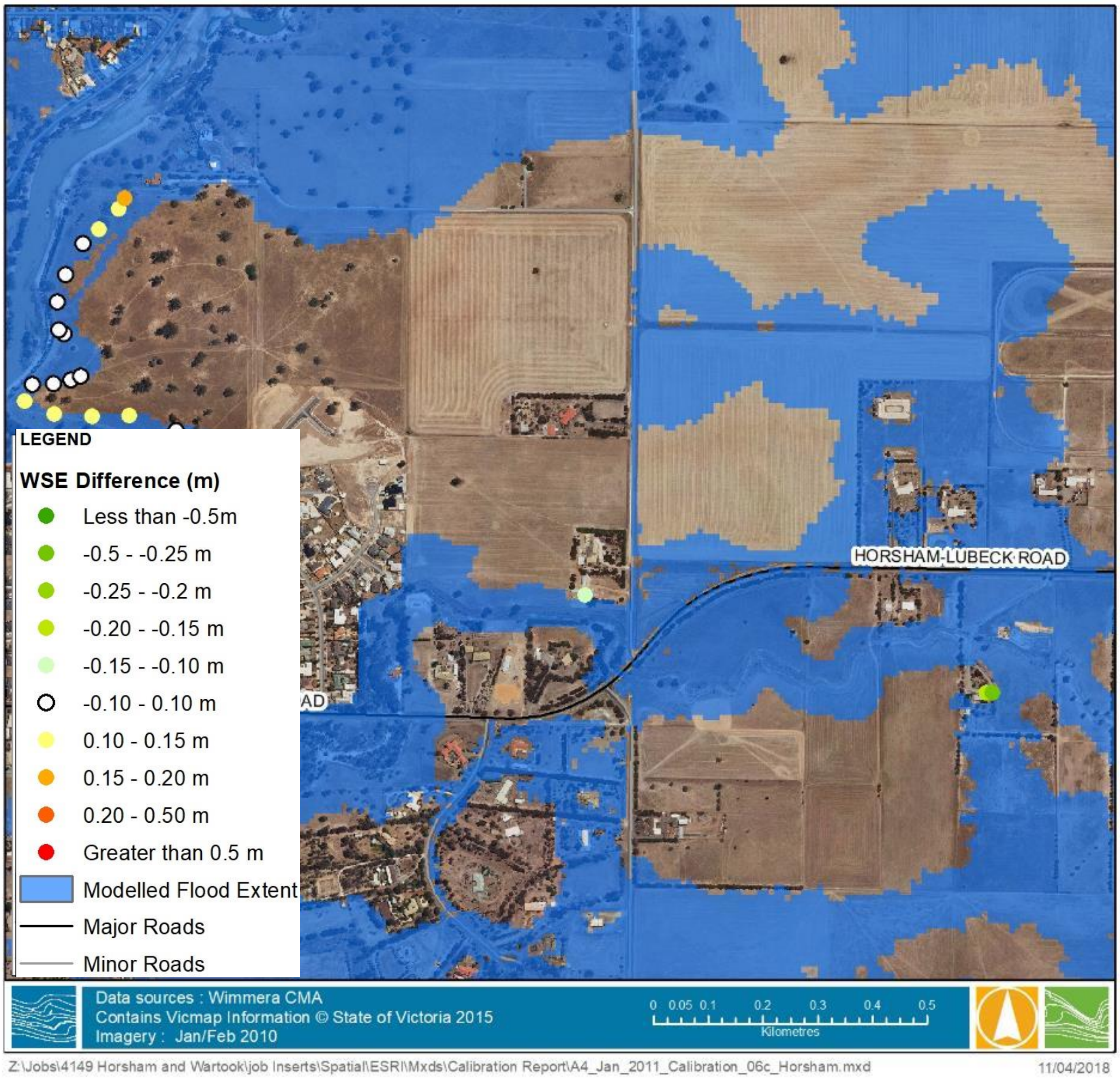

Figure 7-9 Low Points - Wimmera River at Horsham Lubeck Road

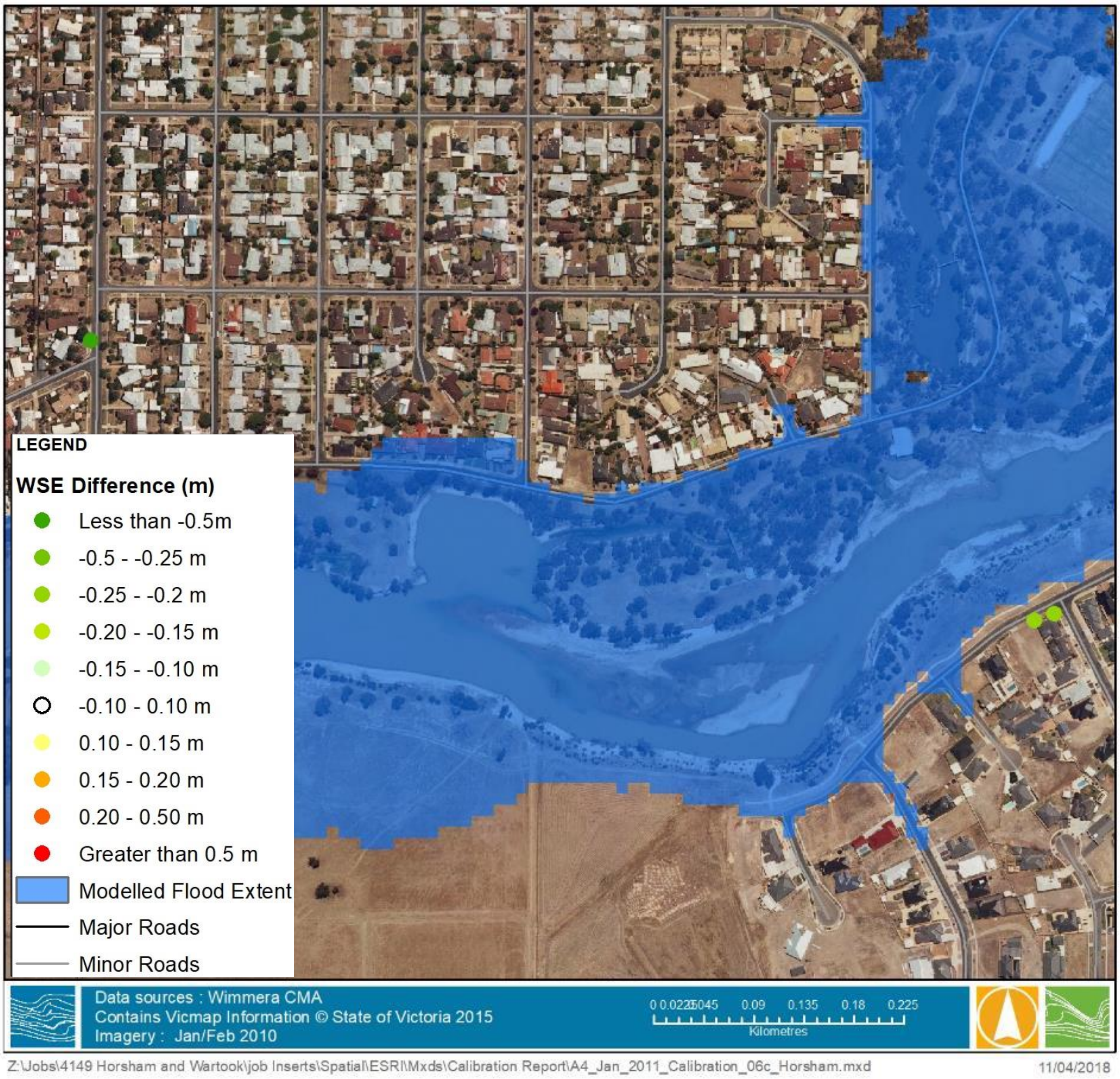

Figure 7-10 Low Points - Wimmera River at Major Mitchell Drive and Bennett Road

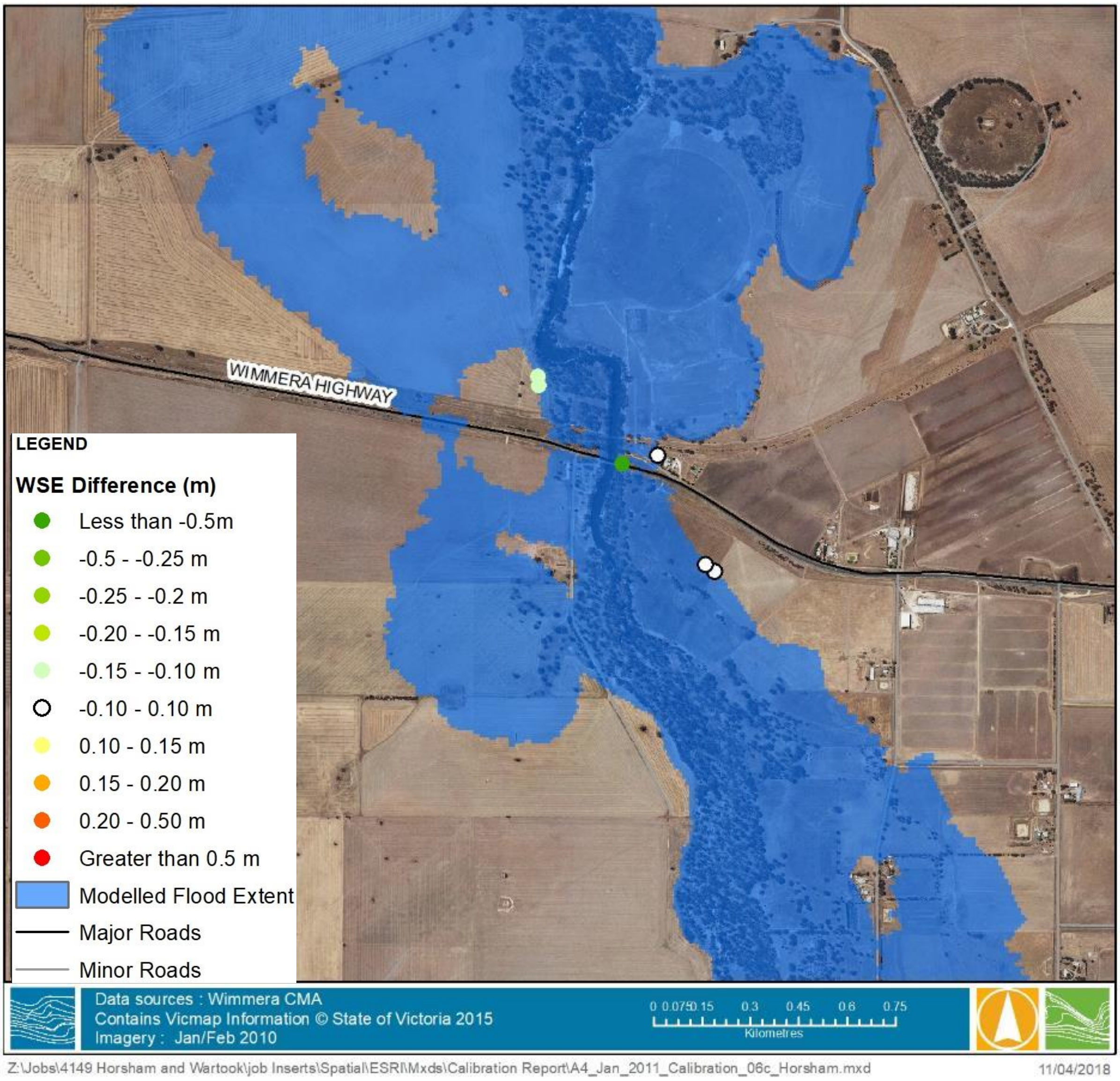

Figure 7-11 Low Points - Wimmera River at Quantong

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 7-5.
- 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 7-12.
- Norton Creek (2)
  - Toolondo Road – there is a cluster of surveyed heights around the Norton Creek structure on Toolondo Road. On the downstream site one survey point showed the model results are 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 7-6.

- 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 7-13.

- 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 7-8.
- 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 7-14.

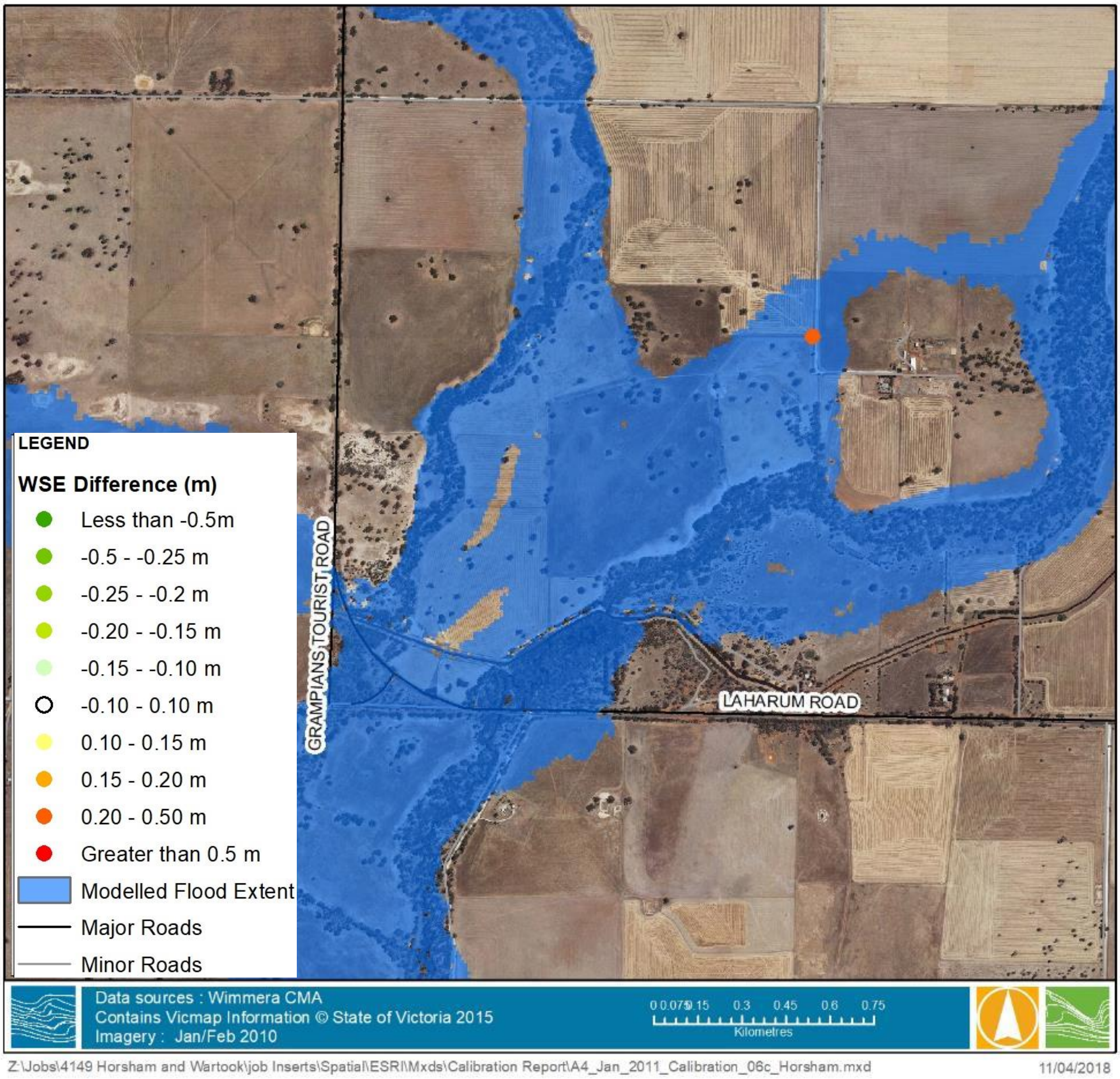

Figure 7-12 High Points – Burnt Creek floodplain

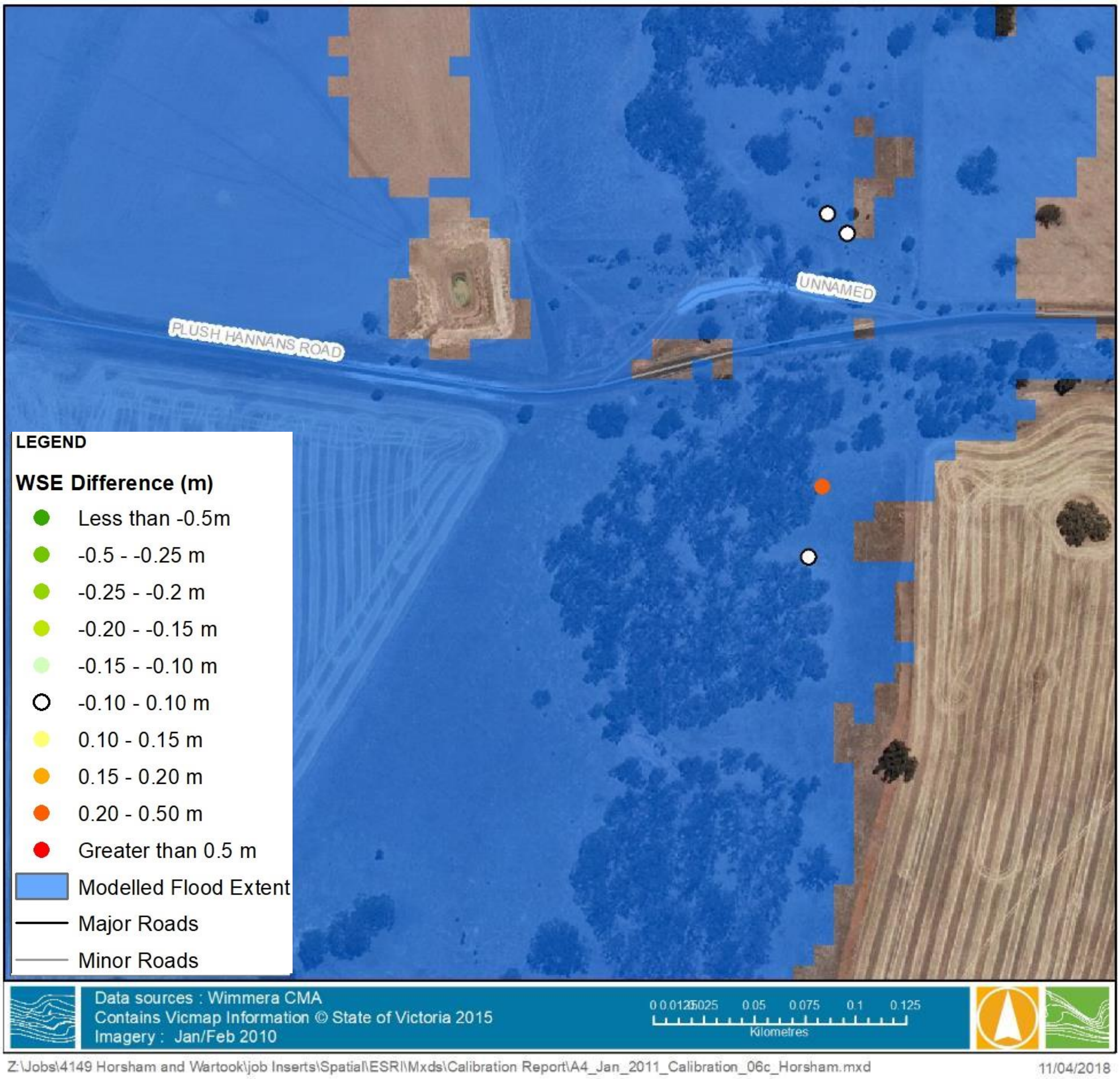

Figure 7-13 High Points – Norton Creek at Plush Hannans Road

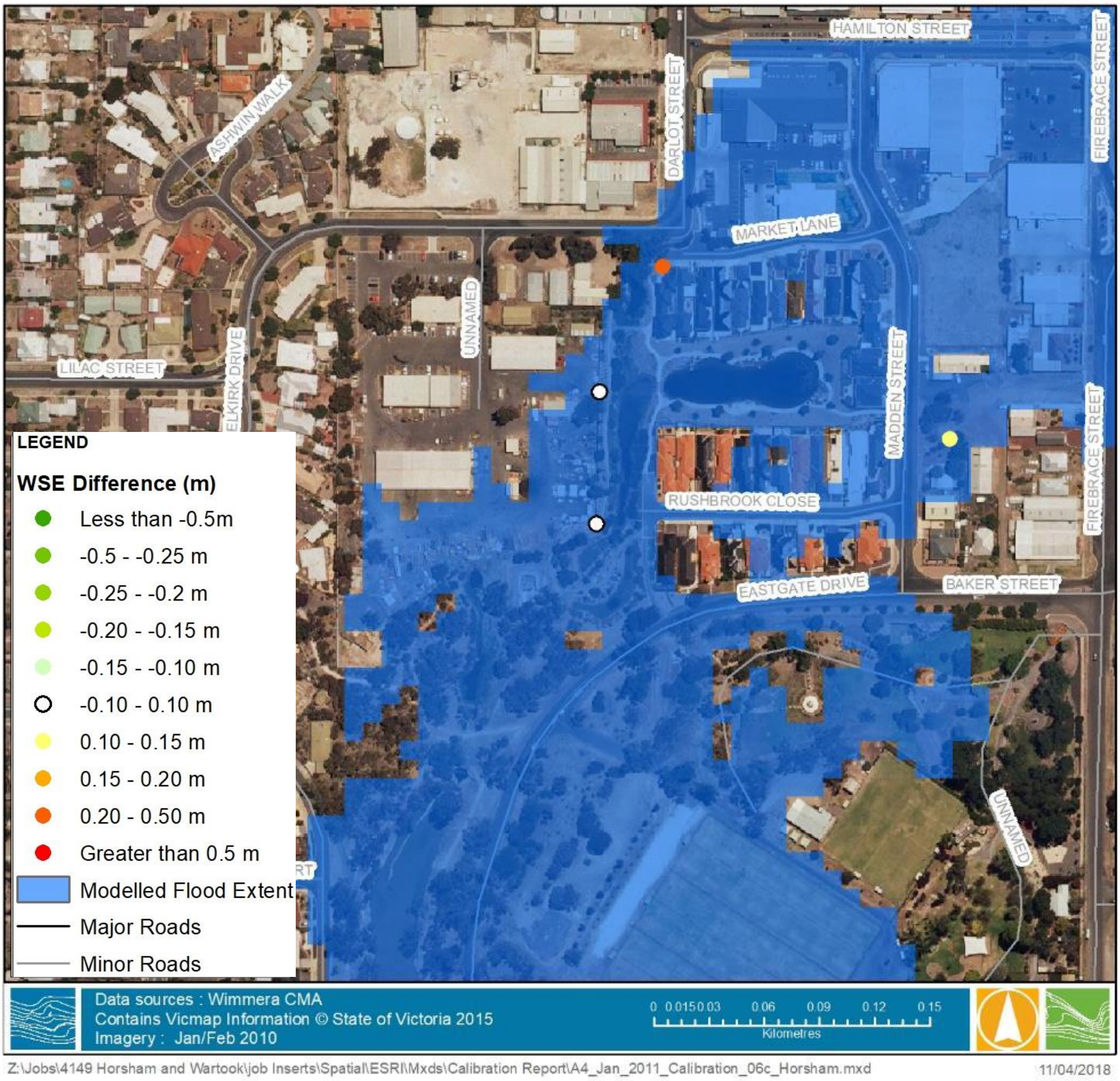

Figure 7-14 High Points – Wimmera River at Market Lane

7.1.1.2 Streamflow Records

As discussed in Section 3.1 there are several streamflow gauges within the study area. The calibration of modelled levels at these gauges is summarised in Table 7-1.

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 7-2 for details.

Table 7-1 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 7-2 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

7.1.1.3 Aerial Images

There were three types of aerial image flown 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 7-15 with the maximum flood extent overlayed.

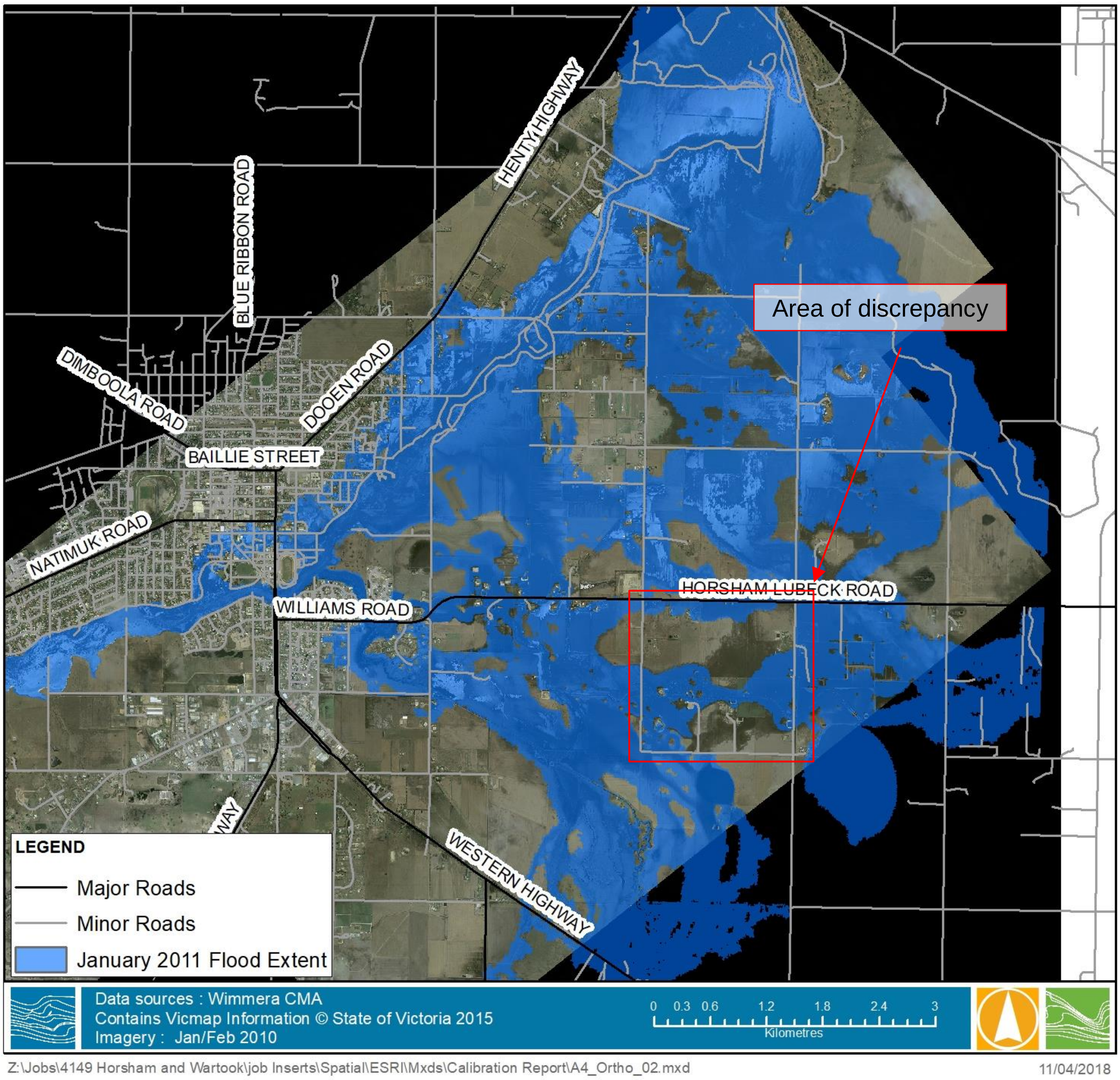

Figure 7-15 Orthorectified aerial images with the modelled flood extent overlayed

The comparison highlighted to main areas of discrepancy in East Horsham, south of Horsham Lubeck Road, this area is highlighted in Figure 7-16.

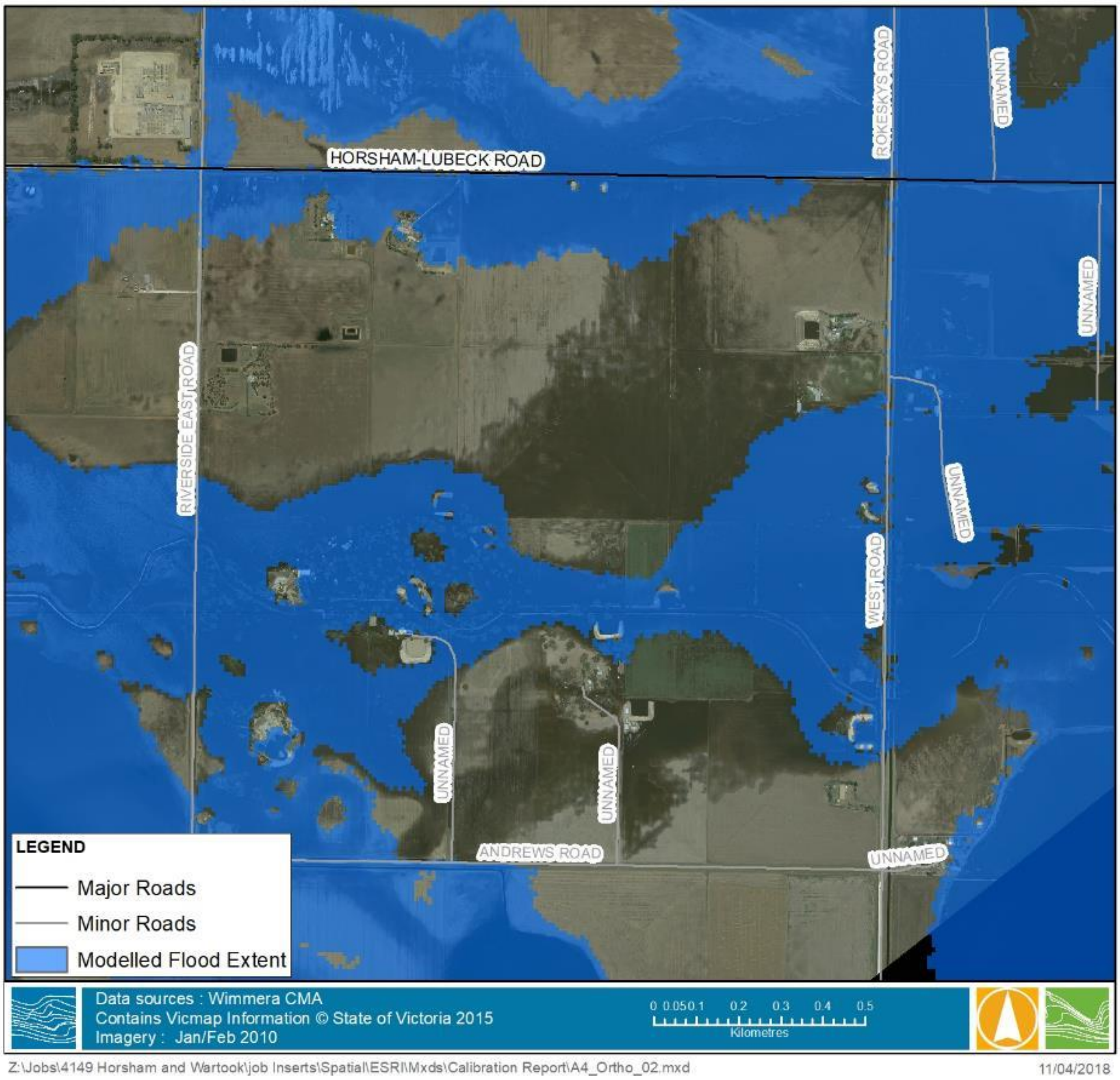

Figure 7-16 Orthorectified aerial images with the modelled flood extent overlayed – South of Horsham Lubeck Road

The modelled flood extent matches in reasonably well except from 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.

7.1.1.4 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 as to if a breach occurred and if so, to what extent. 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.

7.1.2 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.

7.1.2.1 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 7-2).

A comparison of modelled and surveyed levels across the entire model area is shown in Figure 7-17.

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 7-18.

At Old Hamilton Road (the Mackenzie River at Mackenzie 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 7-19, Figure 7-20 and Figure 7-21.

At the Mackenzie River at Mackenzie 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 high. 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. The point on the downstream side of the Henty Highway is showing a modelled level 0.12 m above that surveyed.

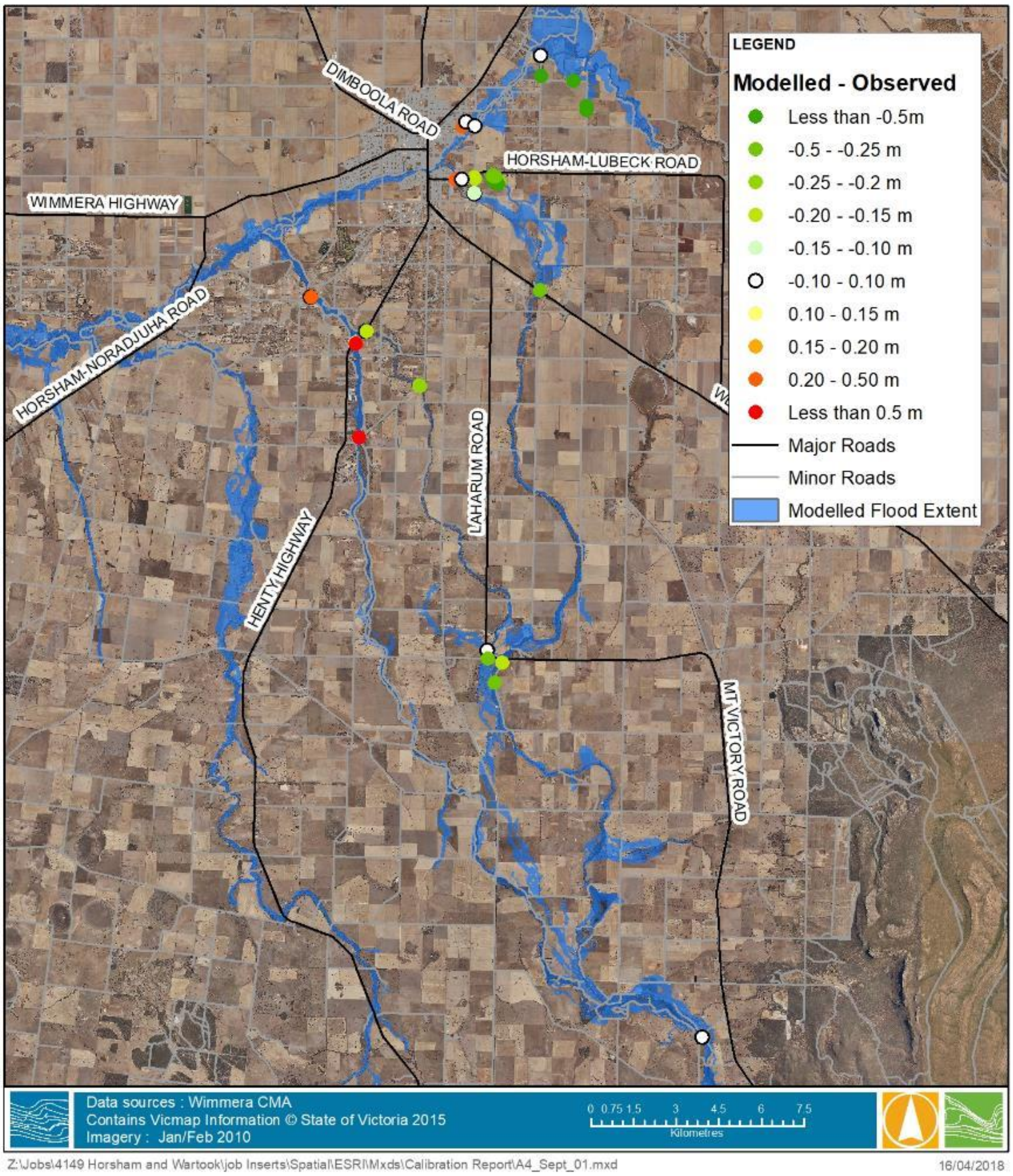

Figure 7-17 September 2016 modelled and surveyed level comparison

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 7-17 with the upper points shown in Figure 7-22.

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 7-23. 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 7-24.

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.

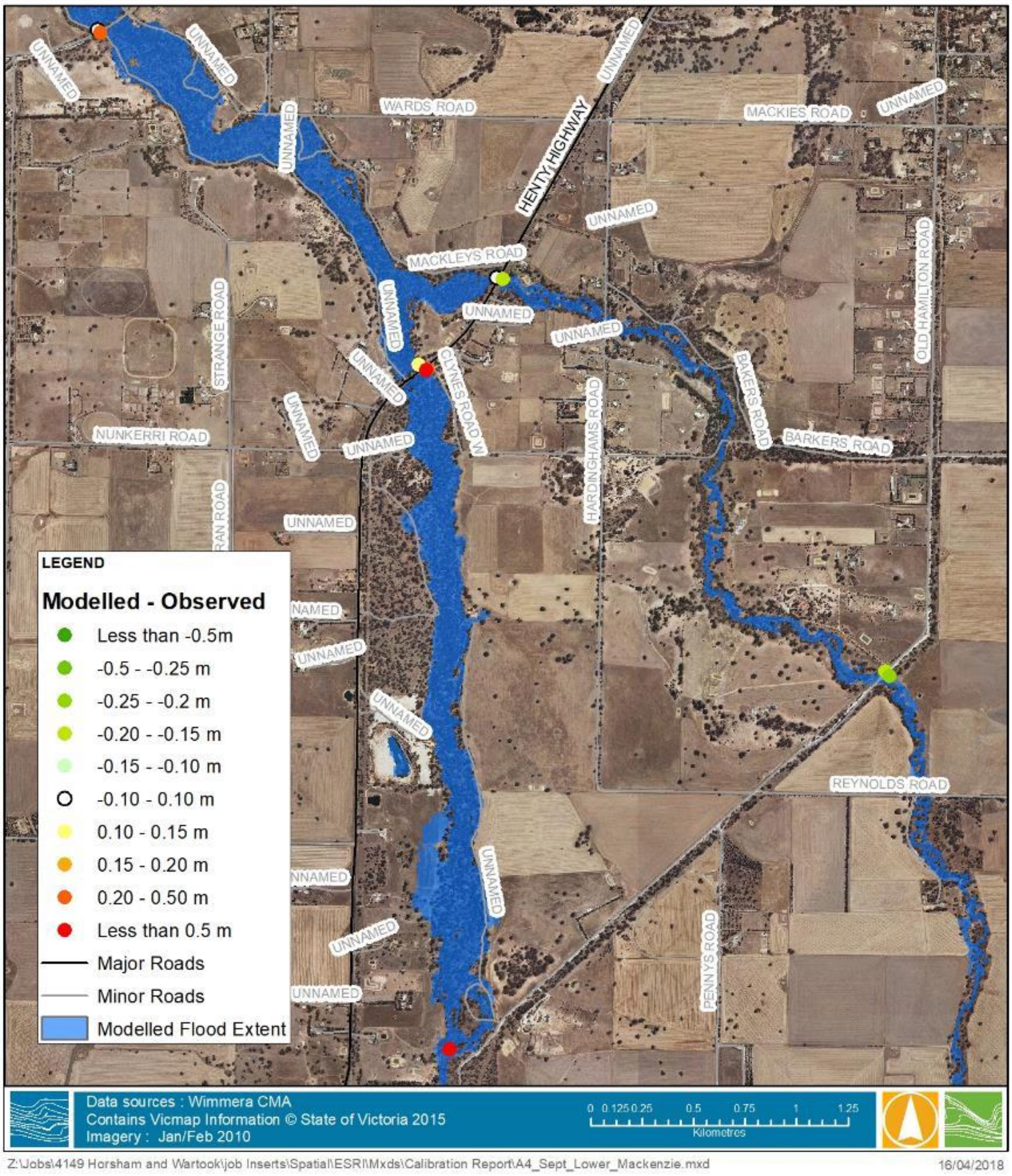

Figure 7-18 September 2016 modelled and surveyed level comparison – Lower Mackenzie River/Bungalally Creek

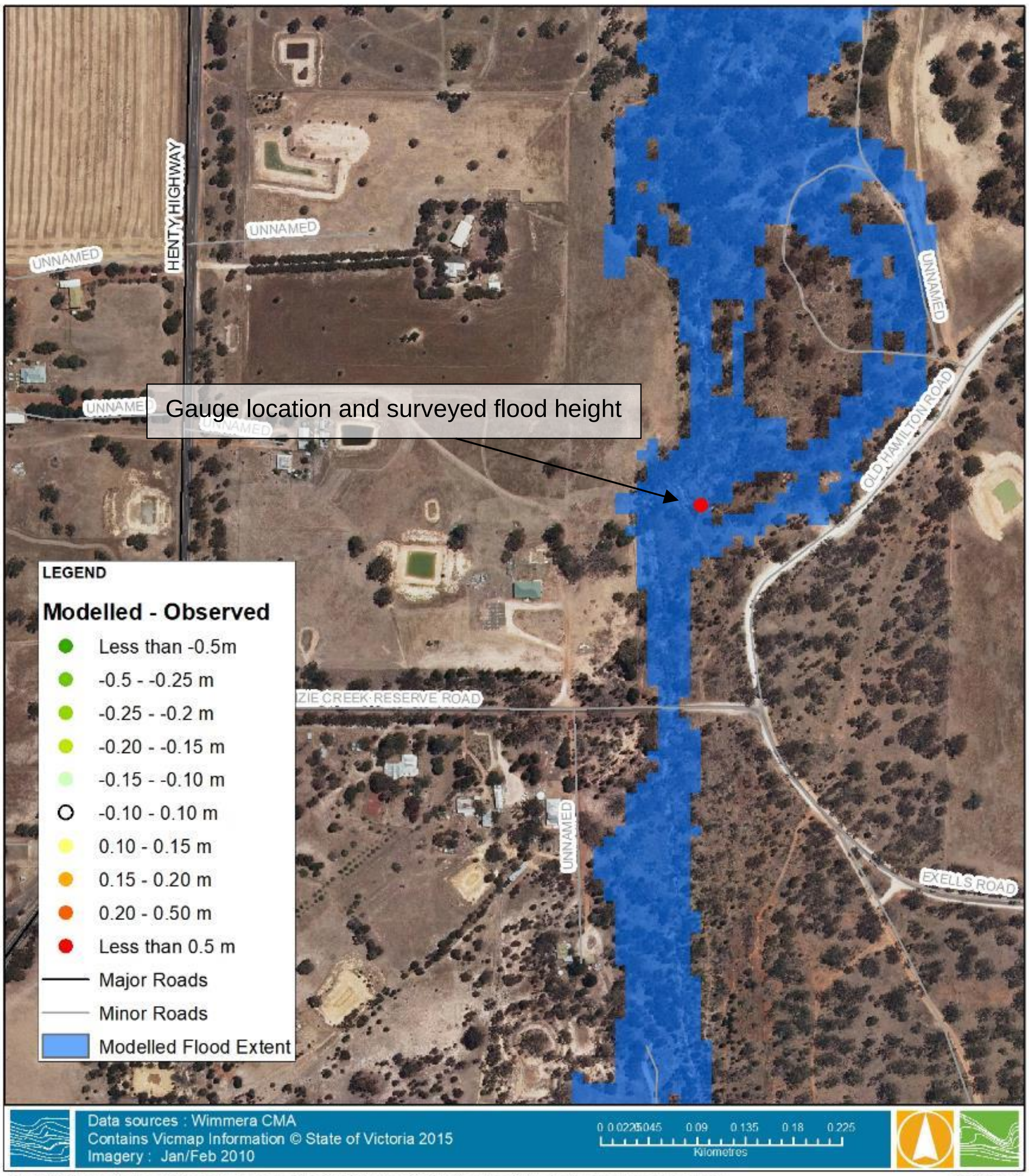

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Figure 7-19 September 2016 modelled and surveyed level comparison – Mackenzie Gauge

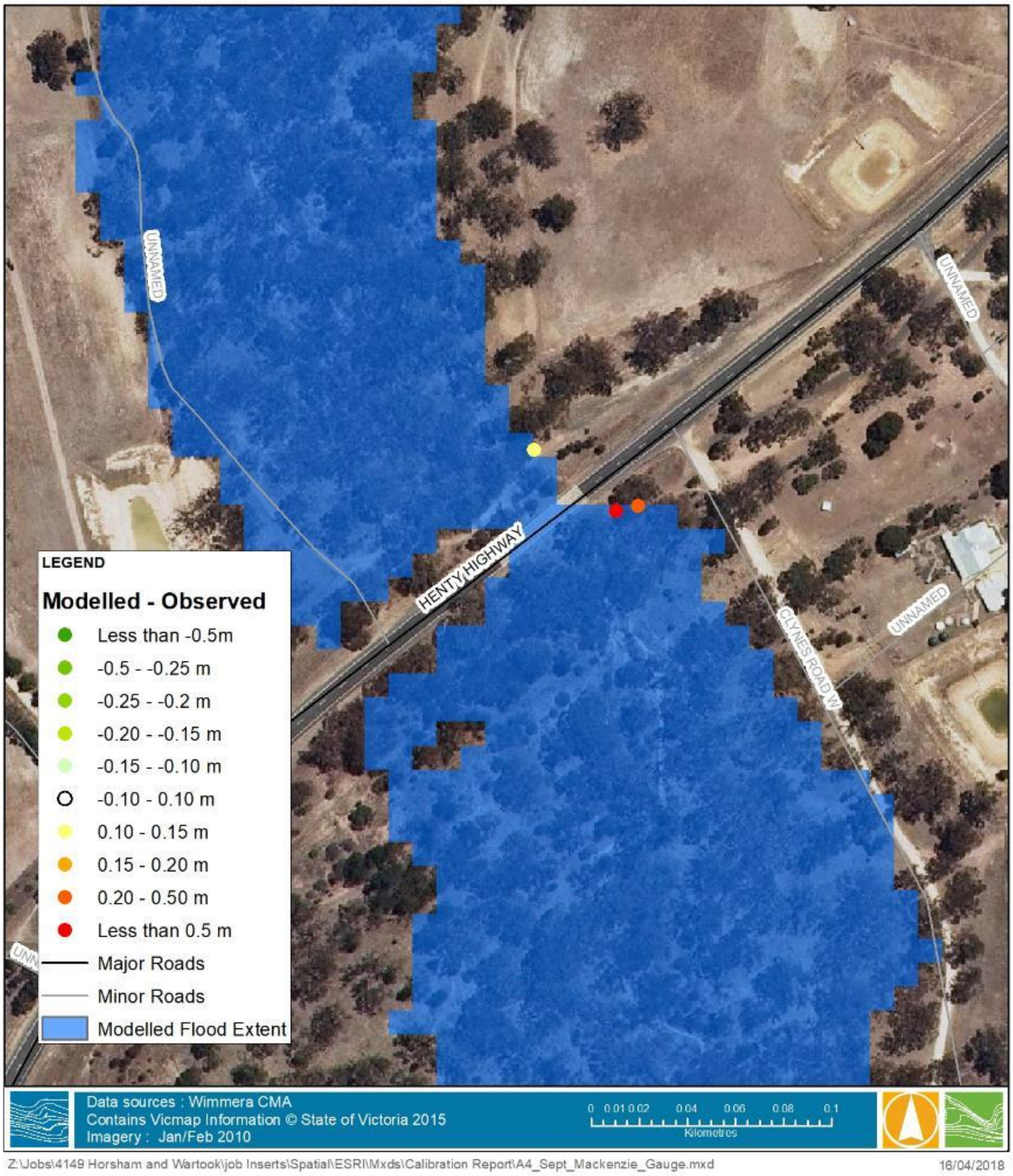


Figure 7-20 September 2016 modelled and surveyed level comparison – Henty Highway

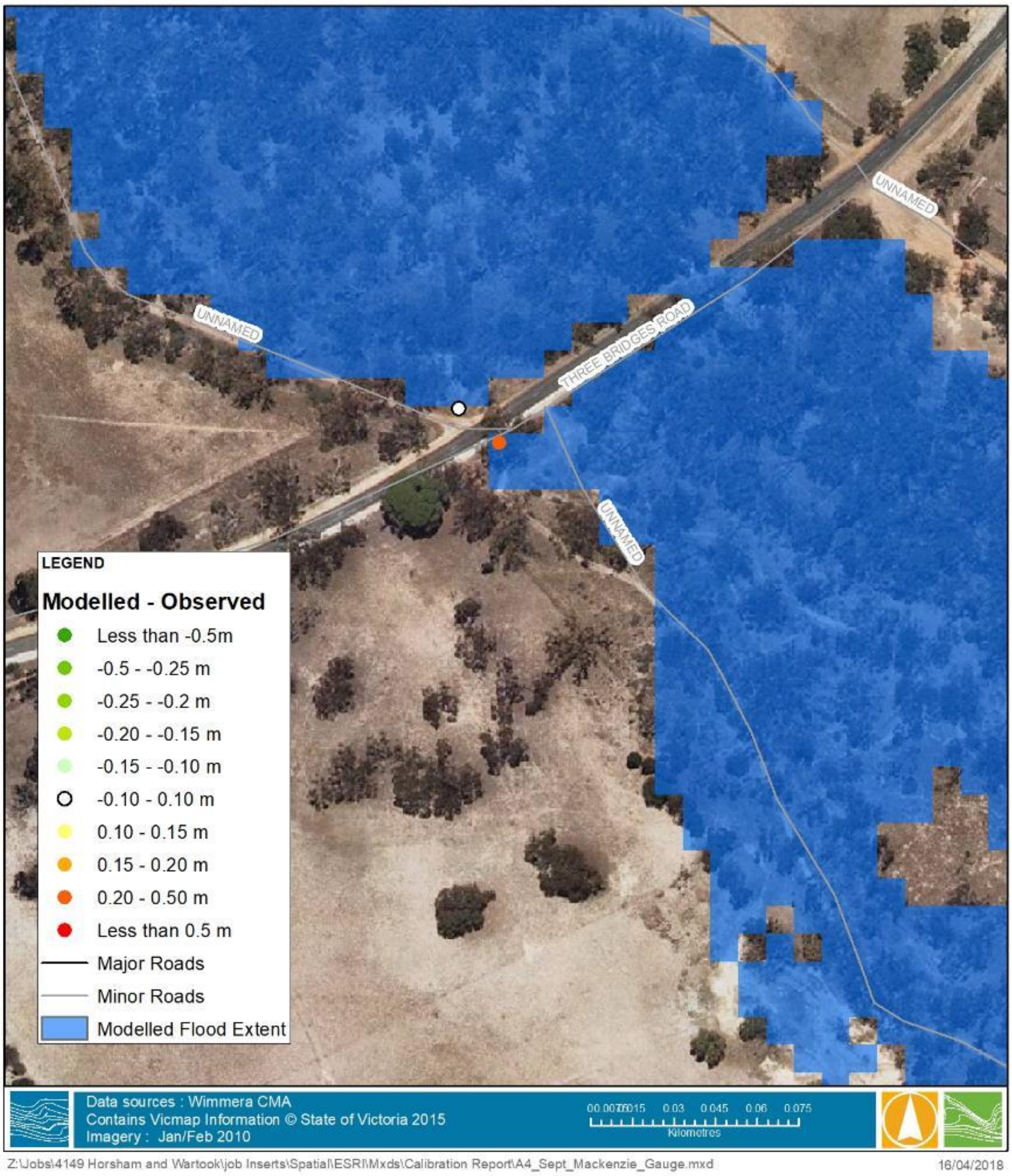


Figure 7-21 September 2016 modelled and surveyed level comparison – Three Bridges Road

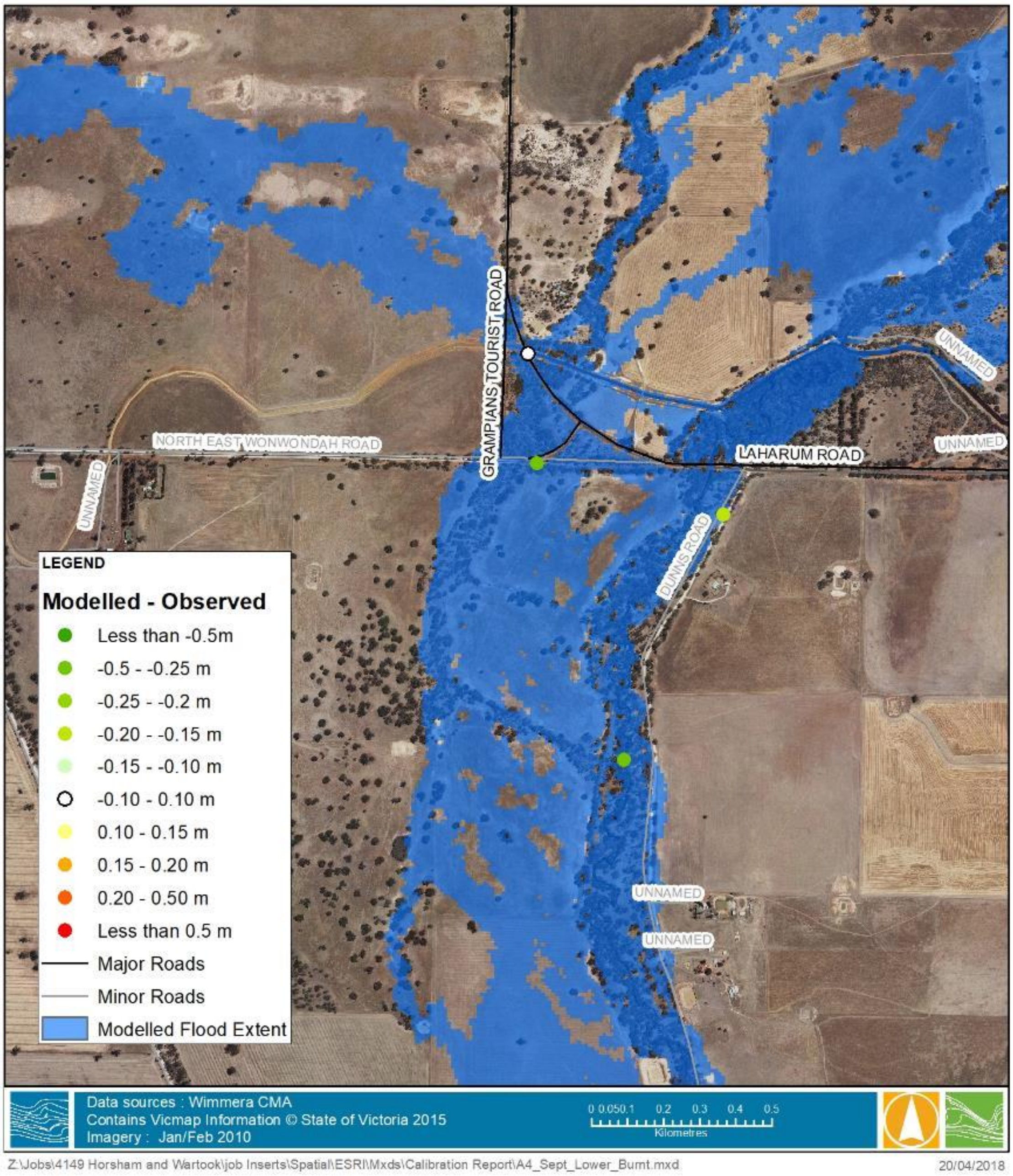


Figure 7-22 September 2016 modelled and surveyed level comparison – Upper Bungalally Creek

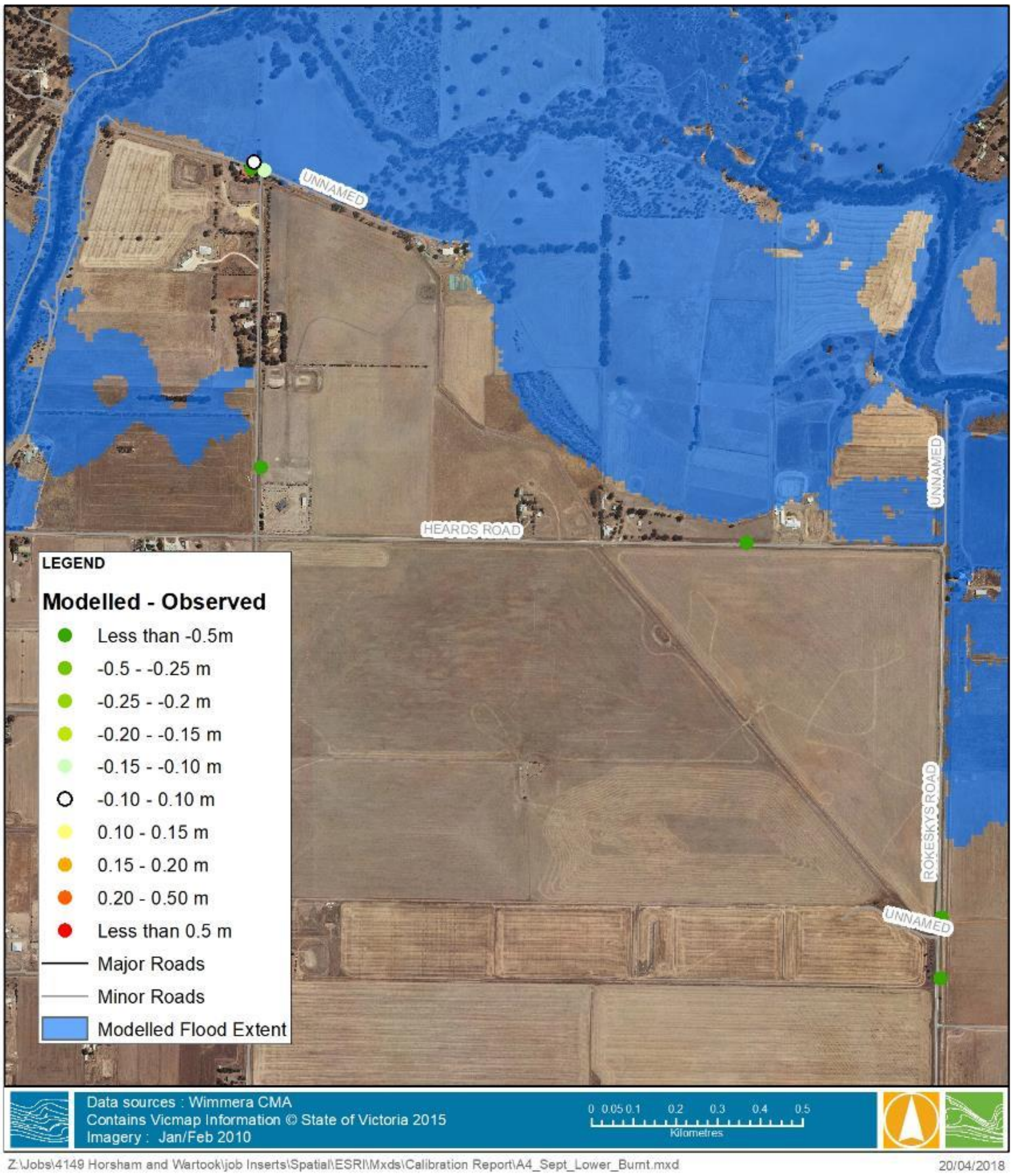


Figure 7-23 September 2016 modelled and surveyed level comparison – Wimmera River East Horsham

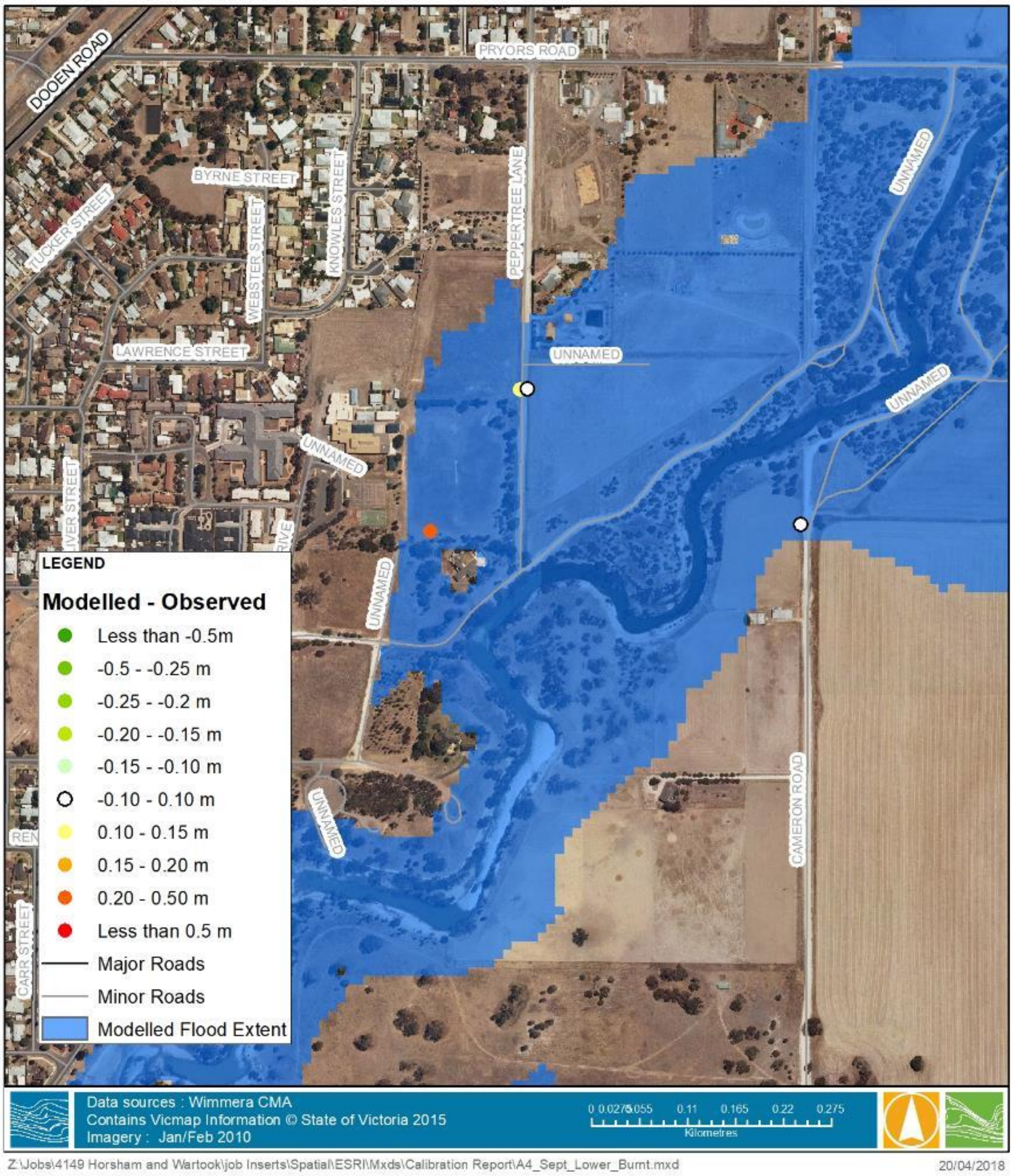


Figure 7-24 September 2016 modelled and surveyed level comparison – Wimmera River US Horsham

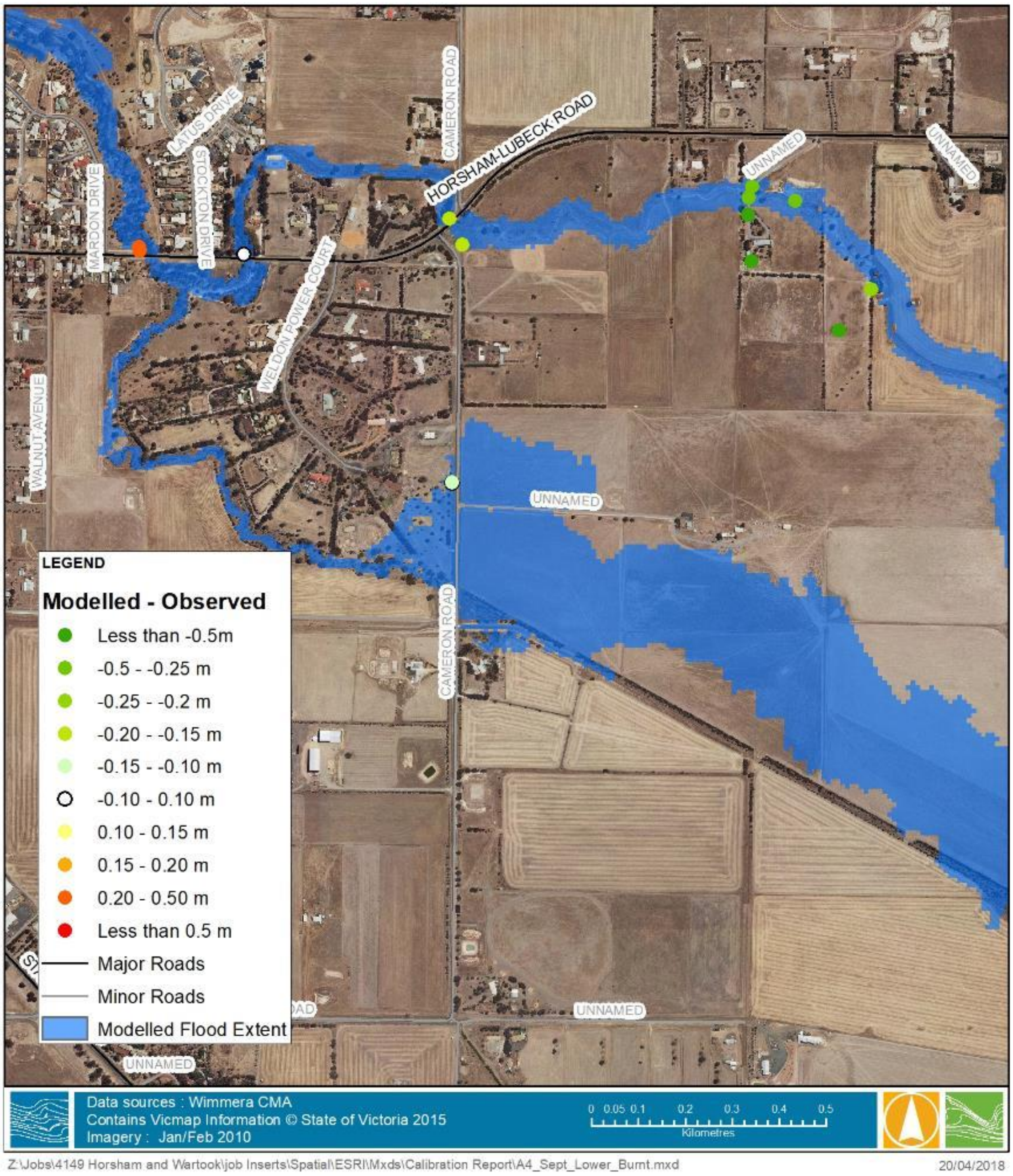


Figure 7-25 September 2016 modelled and surveyed level comparison – Lower Burnt Creek

7.1.2.2 Streamflow Records

As discussed in Section 7.1.2.2 there are four streamflow gauges within the study area able to be used for calibration comparison. A summary of the comparison between modelled and observed levels is shown in Table 7-1. 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 7-3 for details.

Table 7-3 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

7.1.2.3 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 points not matching known recorded gauge heights. This was also observed in the Lower Wimmera Floodplain Mapping Project[17] in the September 2010 flood height survey.

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

7.2 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 and 1.5 mm/hr continuing losses, the Manning's 'n' values are detailed in Section 6.1.3.3.

Horsham was modelled in 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.

[17] Water Technology (2016), Lower Wimmera Flood Mapping Project, Commissioned by Wimmera CMA

7.2.1 Results

The January 2011 modelled inundation depths for the north and south modelled areas are provided in Figure 7-26 and Figure 7-27 respectively.

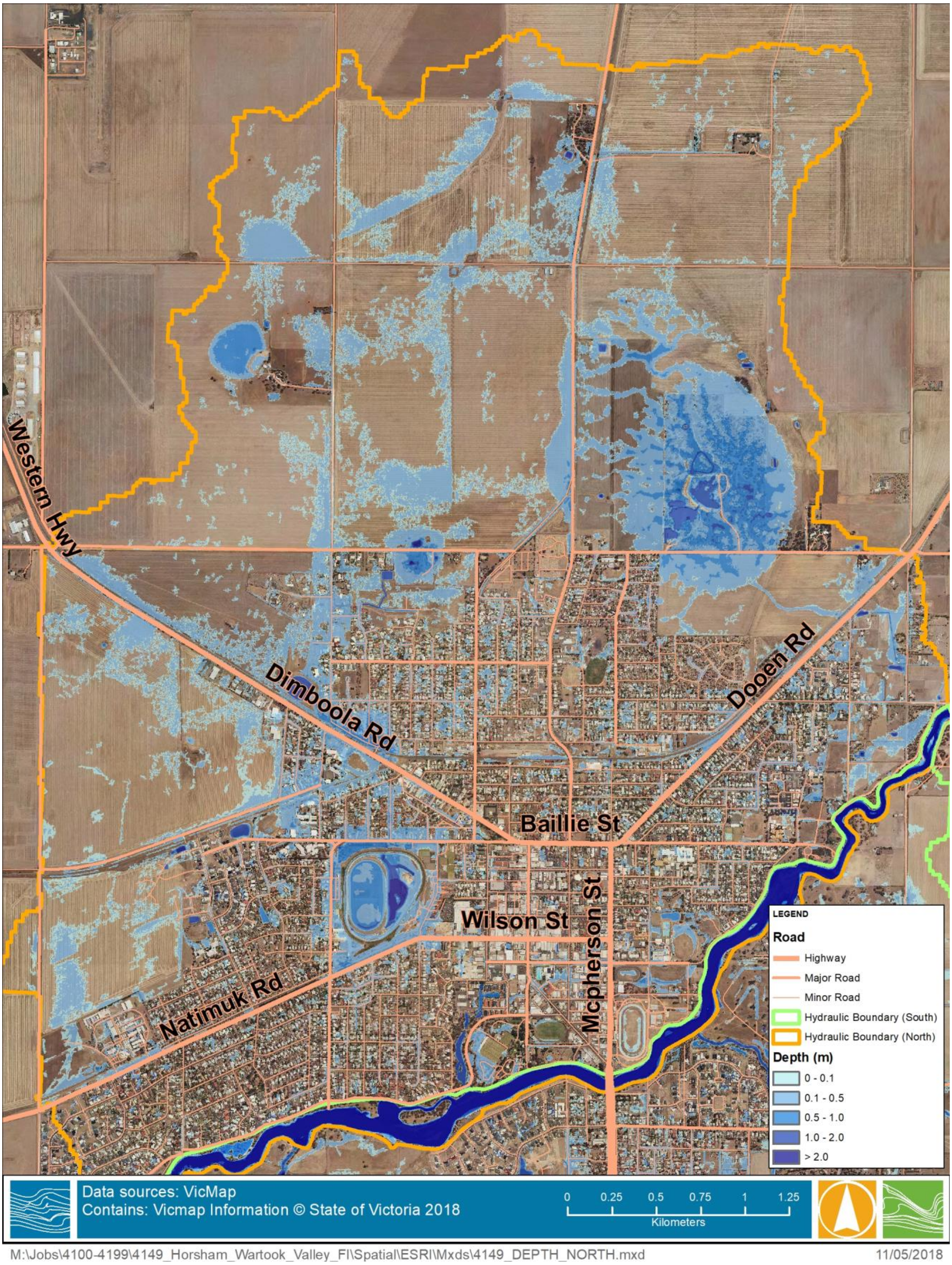


Figure 7-26 North Horsham stormwater modelling – January 2011

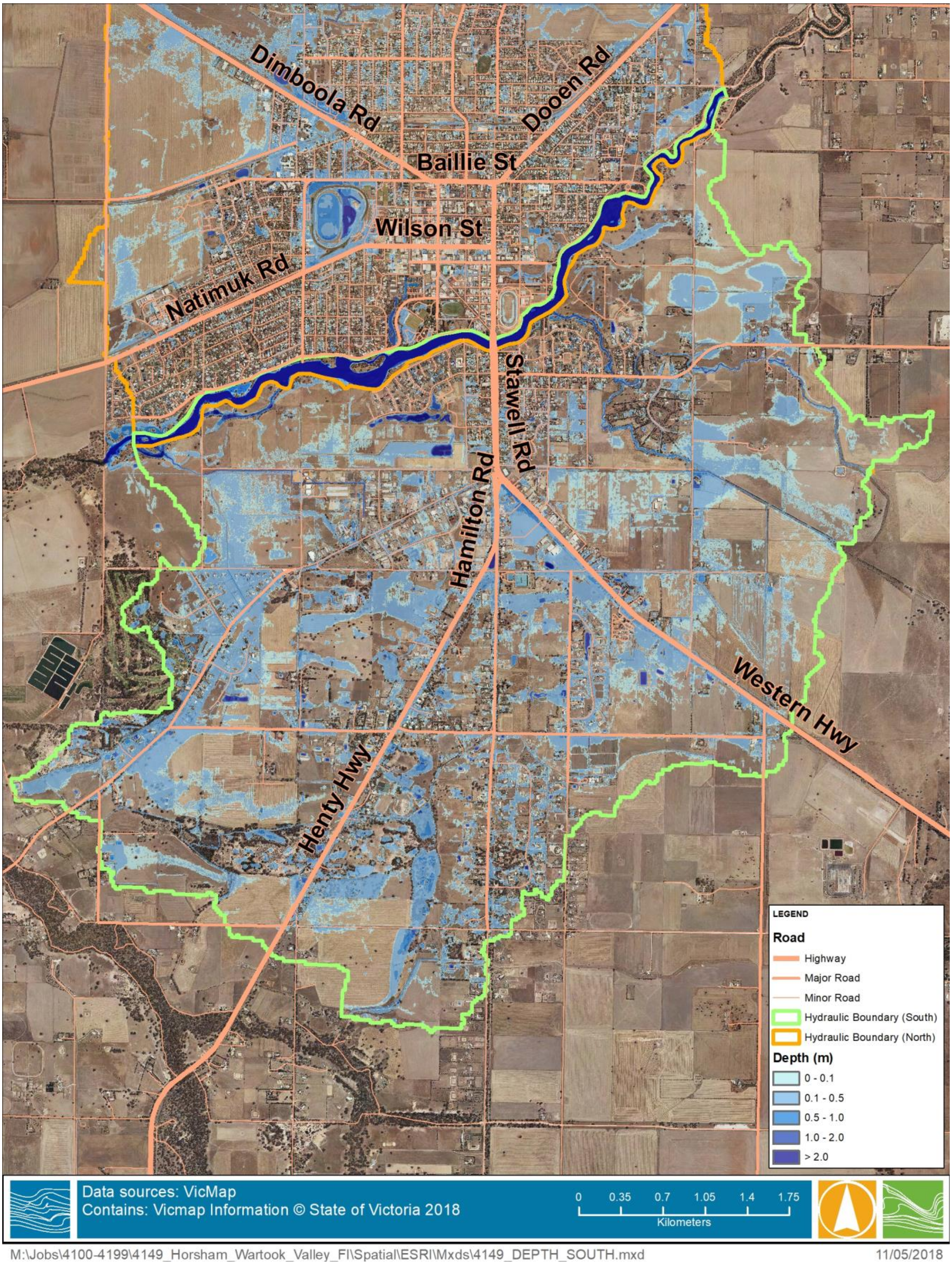


Figure 7-27 South Horsham stormwater modelling – January 2011

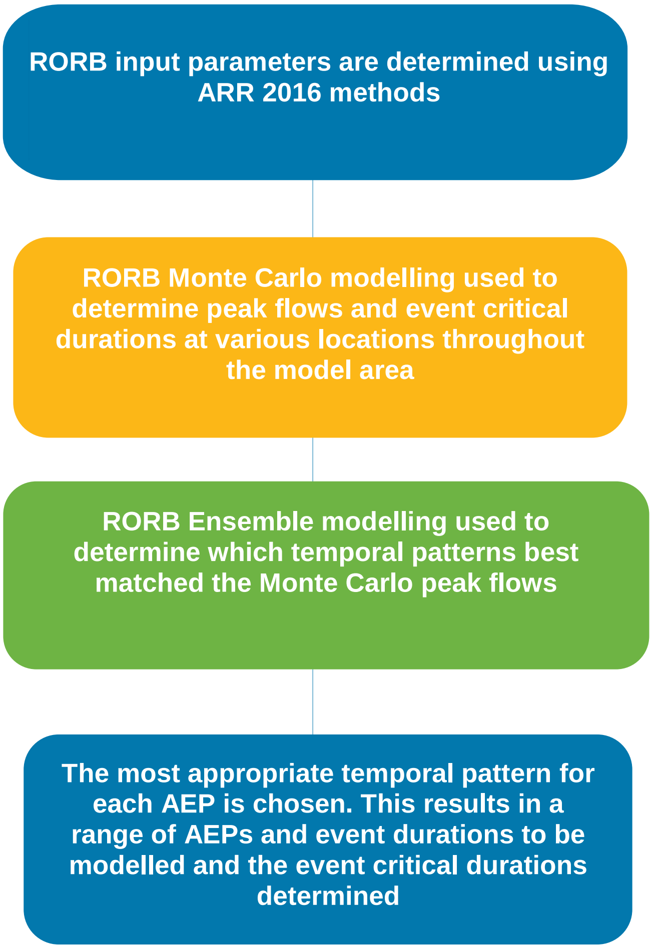
8 NEXT STEPS

8.1 Design Modelling

On approval of this report by Wimmera CMA the design modelling will be completed.

Wimmera River and upper Mackenzie River inflows will be based around Flood Frequency Analysis undertaken at Wimmera River at Horsham and Mackenzie River at Wartook gauges (as described in Section 3.1) while tributary flows and catchment contributions within the study model area will be determined by the RORB model detailed in Section 6.1.2.

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



8.2 Floor Level Survey

We have sent out a floor level survey brief to four surveying companies and expect responses by mid-April. The buildings to be surveyed were selected in conjunction with Wimmera CMA, totalling 217 buildings, as shown broadly in Figure 8-1. These buildings were determined using the January 2011 modelled flood extent.

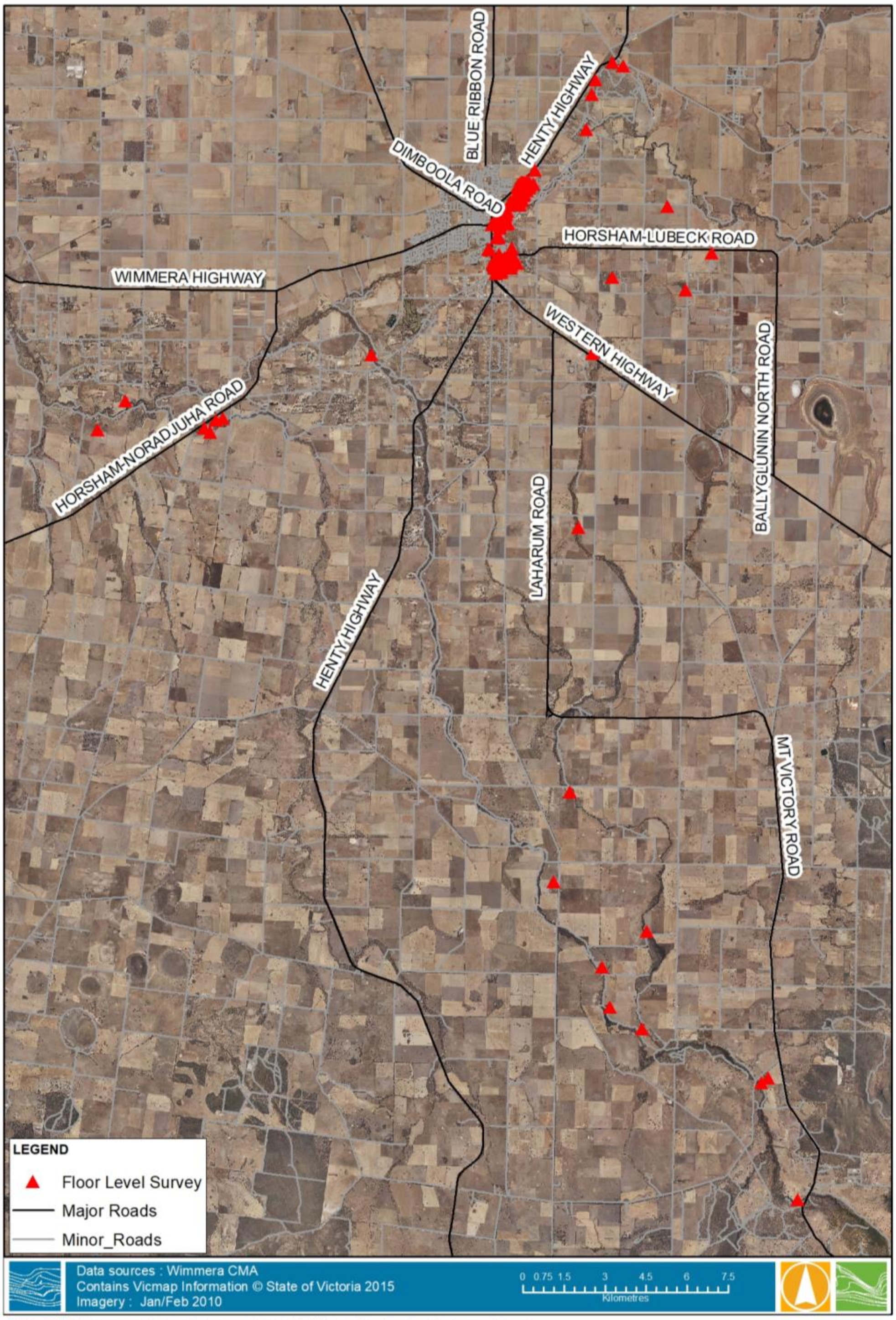


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Figure 8-1 Required floor level survey – Mackenzie River/upper Burnt Creek

8.3 Flood Warning

The flood warning assessment is currently being completed by Molino Stewart. This report will be forwarded to them to assist with the development of their reporting.

8.4 Mitigation Assessment

Wimmera CMA, VICSES and Water Technology met on 16th March 2018 to discuss the range of potential mitigation options. The following options were highlighted:

- Lowering the level of Lake Wartook to allow for flood storage.
- Change the flow split between Bungalally Creek and Burnt Creek at Dunns Corner.
- Create a storage on Burnt Creek - could be located somewhere upstream of the Western Highway.
- Install a new gauge downstream of Dunns Corner.
- Use Dooen Swamp as a flood storage by limiting its outflow.
- Increase the height of exiting levees, including:
  - Menadue Street – raise the southern end.
  - Lutheran School to Peppertree Lane – raise height.
- Create new levees
  - Lutheran at Peppertree Lane through to Pryors Road and then east of Camerons Road North to the Henty Hwy Riverside Road intersection
  - Menadue Street to Horsham Showgrounds – South eastern corner of the Horsham greyhound track
  - Levee to prevent backflow at Watonga Basin
  - Baillie Street to Peppertree Lane

These options will be reviewed using a prefeasibility assessment, before a smaller number are chosen for hydraulic modelling and cost benefit assessment.

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