Regional Flood Mapping Lower Wimmera – Summary Report (R05)

March 2017

DOCUMENT STATUS

Version	Doc type	Reviewed by	Approved by	Distributed to	Date issued
Final	Report	Ben Tate	Ben Tate	Abdul Aziz	10/03/2017

PROJECT DETAILS

Project Name	Regional Flood Mapping - Lower Wimmera
Client	Wimmera CMA
Client Project Manager	Abdul Aziz
Water Technology Project Manager	Ben Tate
Report Authors	Ben Tate and Alison Miller
Job Number	3795-01
Report Number	R05
Document Name	3795-01_R05Final_Summary_Report.docx

Cover Photo: Dimboola Weir shortly after January 2011 flood, http://www.mailtimes.com.au/

15 Business Park Drive
Notting Hill VIC 3168

Telephone (03) 8526 0800
Fax (03) 9558 9365

ACN No. 093 377 283
ABN No. 60 093 377 283

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Water Technology was commissioned by Wimmera CMA to undertake the Lower Wimmera Regional Flood Investigation.

The overall objective of the study was to develop regional scale flood mapping for the Lower Wimmera River between Quantong and Lake Hindmarsh. This mapping will be used to satisfy a range of business requirements from planning and emergency response to community awareness and insurance. The study area was extended upstream by Water Technology to the Wimmera River at Horsham (Walmer) gauge location in order to utilise the long period of record at the gauge as an inflow boundary and link the mapping to the gauge for flood response purposes.

This report summarises all the findings and recommendations from the detailed reports completed within this project. For more detail see the Data Review Report (R01), Hydrology Report (R02), Hydraulic Report (R03), and Flood Intelligence Report (R04).

2. STUDY AREA

The Wimmera River originates in the Pyrenees Ranges, near the township of Elmhurst, and flows generally westward, toward Horsham, and then northwards to Lake Hindmarsh. Downstream of Glenorchy, the river has very little catchment north of the river as the catchment slopes away from the river with a number of distributary systems flowing between ancient sand dunes which are roughly aligned north-south. This is clearly shown in Figure 2-1 and Figure 2-3.

The catchment of the Wimmera River upstream of the Horsham (Walmer) streamflow gauge, located just downstream of Horsham is approximately 4,000 km². The Mackenzie River catchment which flows into the Wimmera River immediately downstream of the Horsham (Walmer) streamflow gauge is approximately 400 km², with Norton, Sandy and Darragan Creeks having smaller catchments again. The Wimmera River catchment downstream of Quantong has limited tributary inflows with the river flowing between the ancient sand dunes of the Wimmera-Mallee. The contributing catchment downstream of Quantong is approximately 1,500 km² but much of this is likely to be ineffective as a series of terminal lakes and depressions in the ancient sand dunes store local rainfall.

The Lower Wimmera River study area as shown in Figure 2-4, extends downstream from Horsham to Lake Hindmarsh. It is characterised by a lower gradient than the upper catchment. The study area is dominated by agricultural land with floodplains of the Wimmera River and its tributaries containing agricultural assets that are likely to be subject to inundation during large rainfall events. Various residential areas are at risk also, including properties on the outskirts of Horsham, Quantong, Dimboola and Jeparit, as well as rural properties at Duchembegarra, Arkona, Antwerp and Tarranyurk.

Rainfall across the Wimmera Catchment varies considerably, with the upper catchment generally receiving 500-600 mm/year (but increasing to 800-900 mm/year at the top of the Grampians), and the lower catchment generally receiving 350-400 mm/year. Months with the highest average rainfall are typically June to August. Although the region north of Horsham does experience significant storms similar to the catchment south of Horsham, the confined nature of the catchment is such that the runoff generated downstream of Horsham is much less and what little runoff is generated is often through the system well before the upper catchment peak arrives from the Wimmera River and Mackenzie River.

Historical records indicate that peak flow rates experienced in the lower section of the river are lower than those in the upstream/middle sections. This is due to attenuation and the presence of distributary waterways upstream (Swedes Cutting, Dunmunkle Creek and Yarriambiack Creek). These distributary waterways allow flow to exit the Wimmera River catchment, with Swedes Cutting transferring flow into the Richardson River catchment. The Mackenzie River and other tributaries, namely Norton, Sandy and Darragan Creeks provide inflow to the Wimmera River downstream of Horsham as shown in Figure 2-2 . Often these tributary inflows peak prior to the Wimmera River, passing through the system before the Wimmera River peak arrives. The dominant flood causing mechanism in the lower Wimmera River is the upper Wimmera River catchment flood flows.

There are a number of irrigation channels within the lower Wimmera River catchment, formerly used for stock and domestic supply. The construction of the Northern Mallee and Wimmera Mallee Pipelines has superseded these channels and a number of domestic water storages. These pipelines have increased water availability by reducing water losses in the supply system and have also increased the control of environmental flow releases.

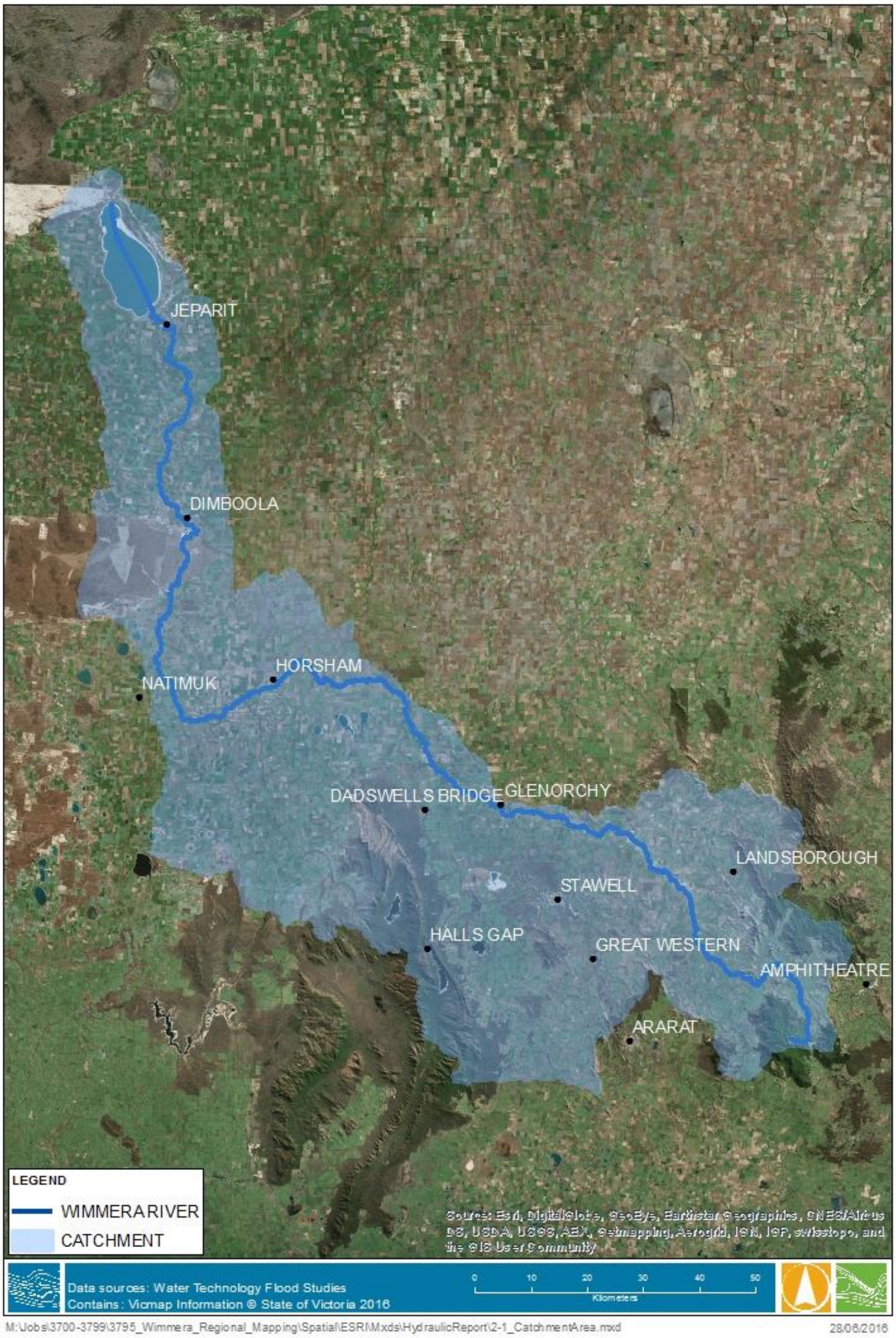


Figure 2-1 Catchment Area of the Wimmera River

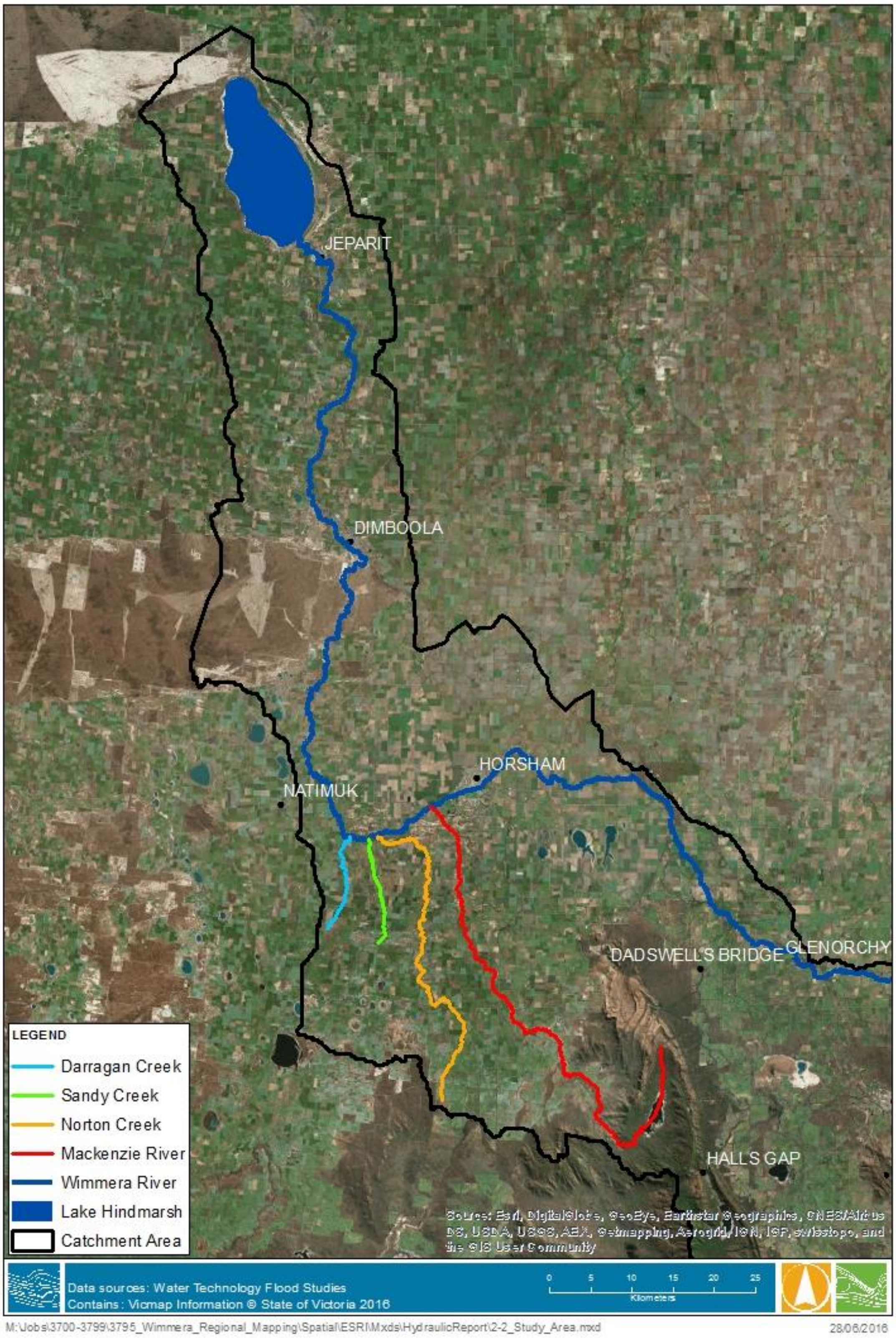


Figure 2-2 Lower Wimmera Study Area and Major Tributaries

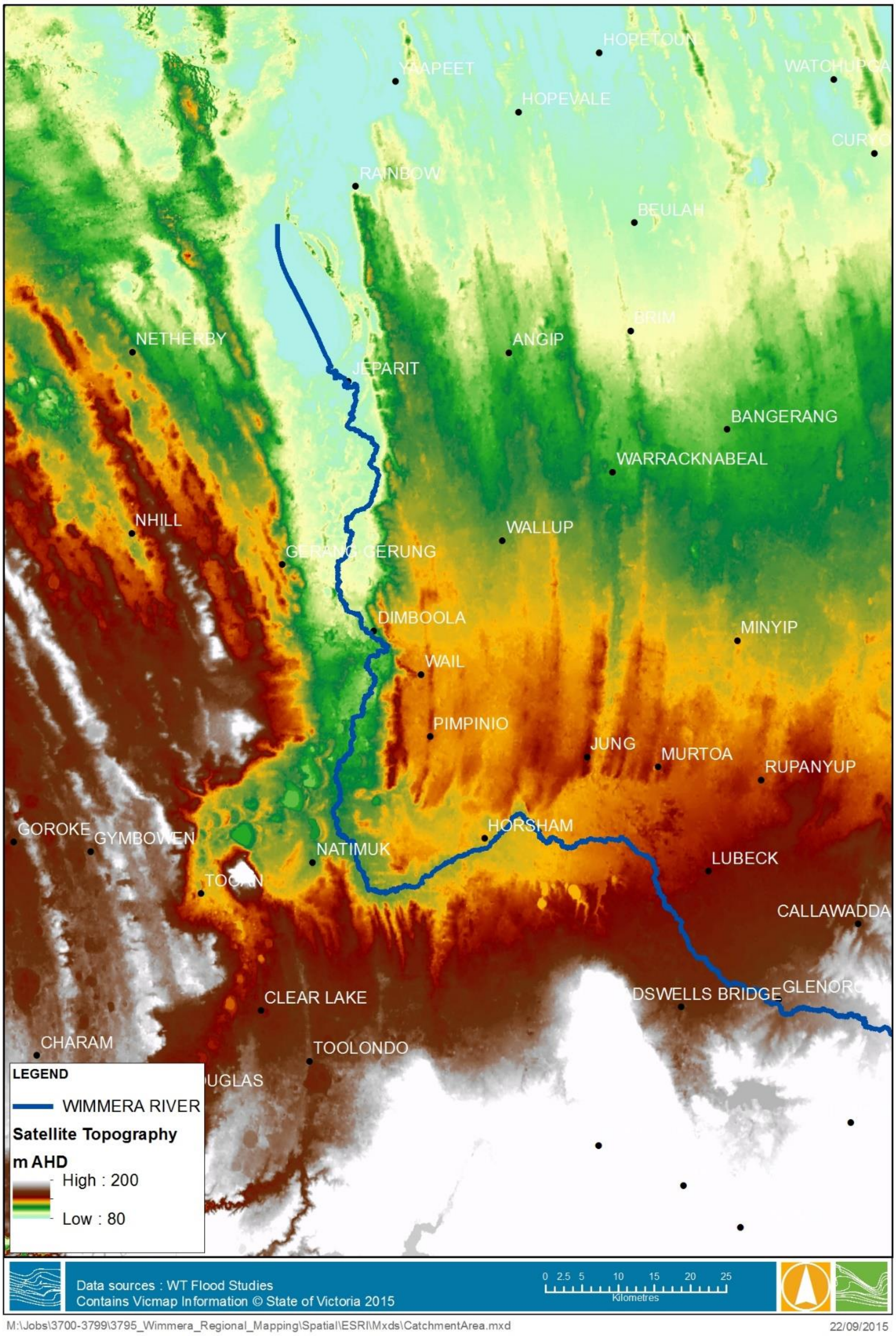


Figure 2-3 Topography of the Lower Wimmera River

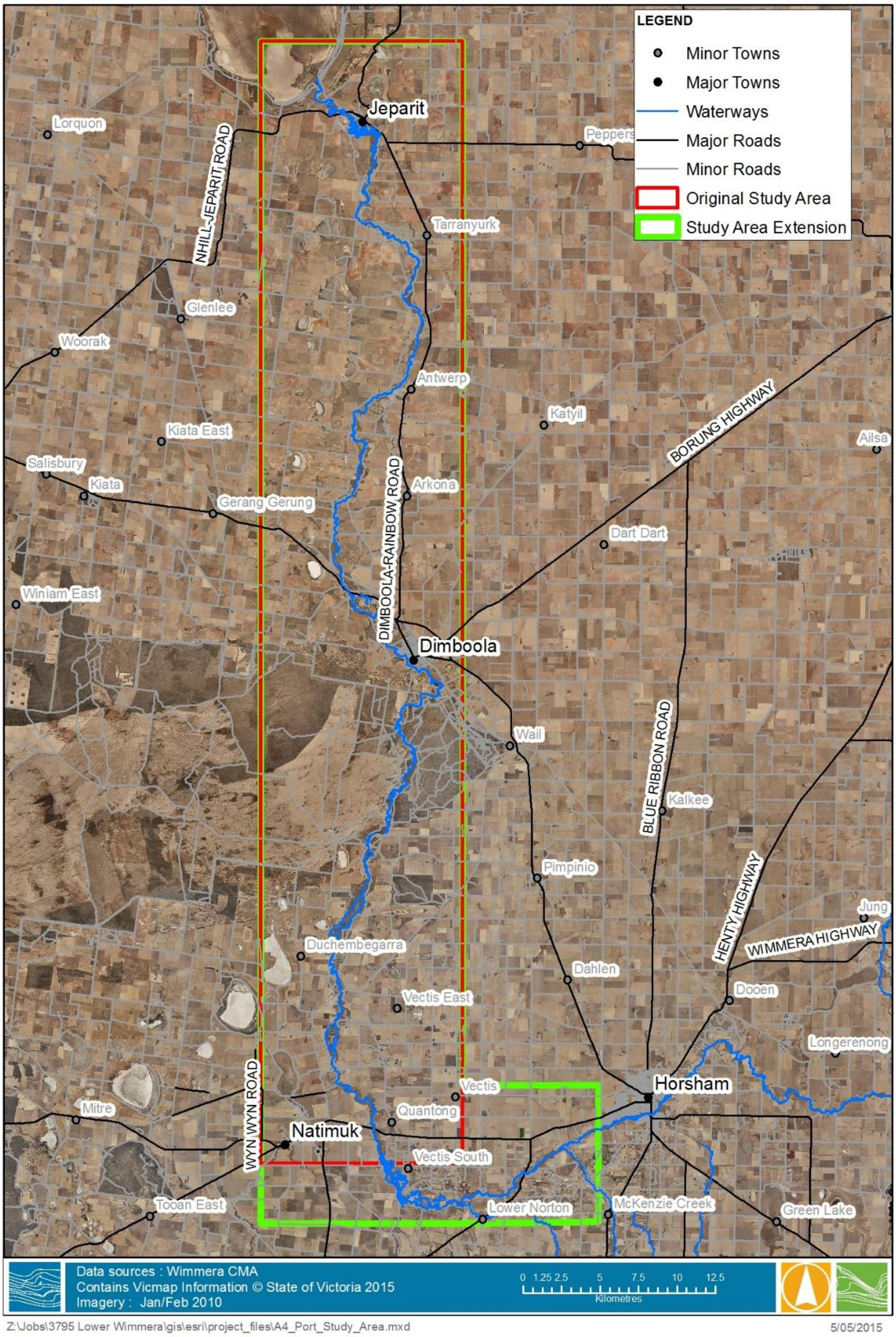


Figure 2-4 Lower Wimmera Study Area

3. PROJECT CONSULTATION

Water Technology and Wimmera CMA held a number of community consultation sessions throughout the project. The project objectives, available flood imagery of the January 2011 event and preliminary flood mapping for the January 2011 event was presented to the community at an initial round of community meetings at Quantong and Antwerp. The community provided some photos, anecdotal information regarding how the flood behaved and what impacts were observed. Several areas were identified where the community felt the preliminary flood modelling could be improved.

Water Technology considered all the available information provided and responded to the comments, updating the flood modelling to incorporate the community feedback.

The final round of community meetings presented the design mapping. The mapping received positive feedback and was accepted by the community who attended the meetings.

In both meetings the mapping was shared via an interactive online map which assisted community members to zoom in on their area of interest in a google maps style online flood map.

Wimmera CMA produced a video summarising the benefits of the Lower Wimmera Regional Flood Study and shared this via social media to raise the profile of the project with the community. A number of stakeholders from Wimmera CMA, Hindmarsh Shire Council, Horsham Rural City Council, VICSES, Water Technology and community members featured in this video.

All stakeholders mentioned above were communicated with at various stages of the project either during community meetings, steering committee meetings or via regular technical updates during the project.

4. DATA COLLATION AND REVIEW

4.1 Overview

The data collation and review undertaken as part of this project is documented in detail in the Data Collation Report (R01). The review discusses previous flood related studies, available streamflow data and catchment hydrology, topographic information, waterway structures, the January 2011 flood event, and the proposed modelling approach.

4.2 Flood Related Studies

There have been several previous studies relevant to flooding of the Wimmera River, including:

- Bureau of Meteorology (BoM) - Wimmera River Basin URBS Model (2004)
- Water Technology – Wimmera River and Yarriambiack Creek Flow Modelling Study (2009)
- Water Technology – Horsham Flood Study (2003)
- Water Technology - Dimboola Flood Study (2003)
- Water Technology – Horsham Bypass Hydrologic and Hydraulic Investigation (2013)
- Water Technology – East Horsham Channel Decommissioning Hydraulic Assessment (2013)
- Water Technology – Jeparit Flood Study (2008)

4.3 Hydrological Data

4.3.1 Streamflow

There are numerous streamflow gauges on the Lower Wimmera River downstream of Horsham. Each of these gauges is shown in Table 4-1, detailing their period of record and maximum flow recorded. The gauge locations are also shown in Figure 4-1.

Table 4-1 Active streamflow gauges within the study area

Gauge Name	Gauge Number	Gauge Record
Wimmera River at Horsham (Walmer)	415200	1910 - Current
Norton Creek at Lower Norton	415273	2008 - Current
Wimmera River at Quantong	415261	2009 - Current
Wimmera River US Dimboola	415256	1989 - Current
Wimmera River at Lochiel Railway Bridge	415246	1987 - Current
Wimmera River at Tarranyurk	415247	1987 - Current
Wimmera River at Jeparit	415212	May 1998 – July 1998

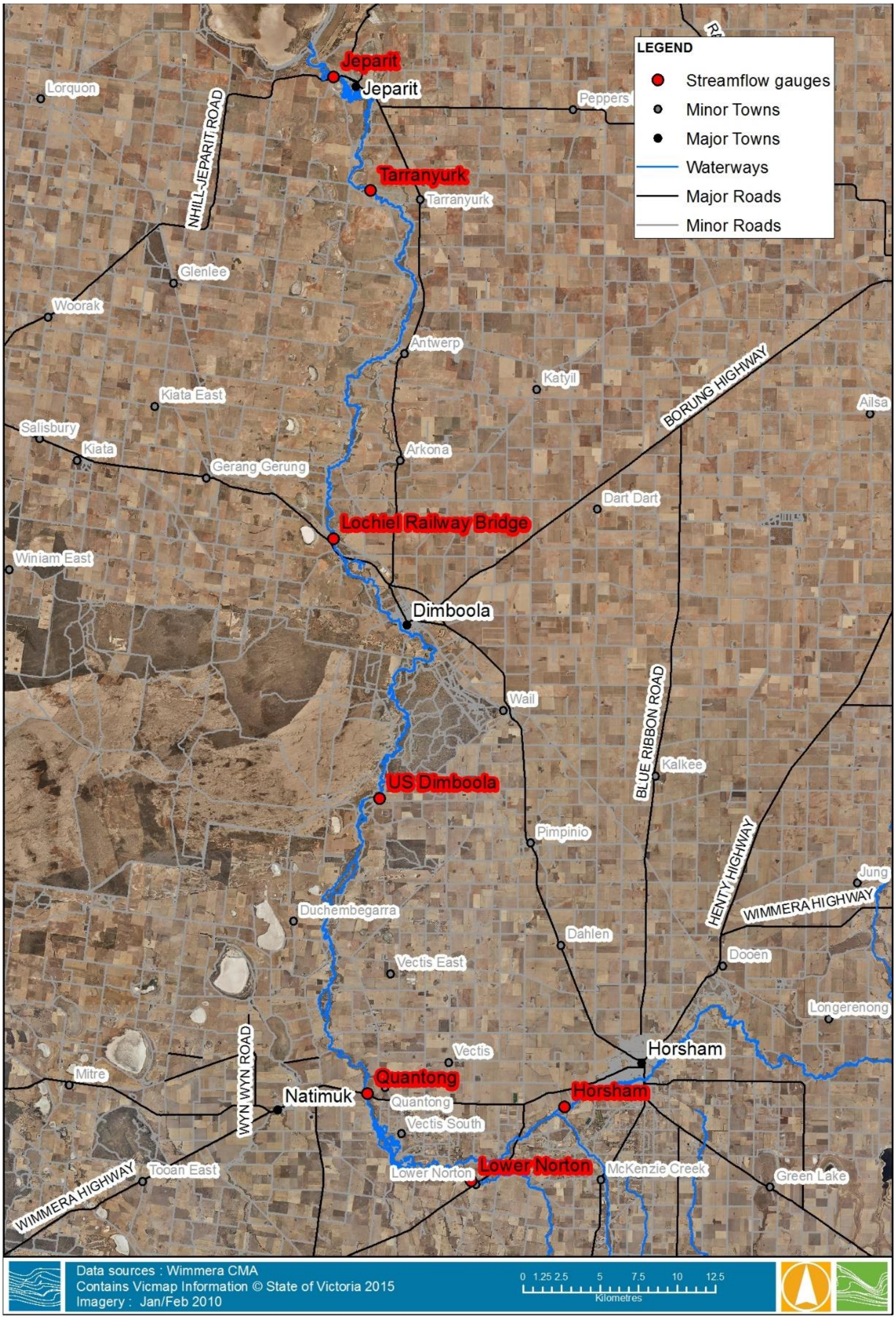


Figure 4-1 Streamflow gauge locations

Wimmera River at Horsham (Walmer)

The Wimmera River streamflow gauge at Horsham (Walmer) has a long period of record with daily flow recorded from 1889 to 1910 and daily gauge height from 1910 to 1963, with flows determined based on a rating curve. There is increased uncertainty in the gauge flows determined prior to 1910. There are instantaneous gauge recordings from 1963 to 2015. This provides 124 years of complete annual record for completion of a Flood Frequency Analysis (FFA). The largest event within the instantaneous record occurred during January 2011, there were also large events in 1909 and 1894.

Figure 4-2 shows the length of gauge record and the recorded Quality Code. Quality Codes greater than 50 should be used with caution. The January 2011 event is highlighted.

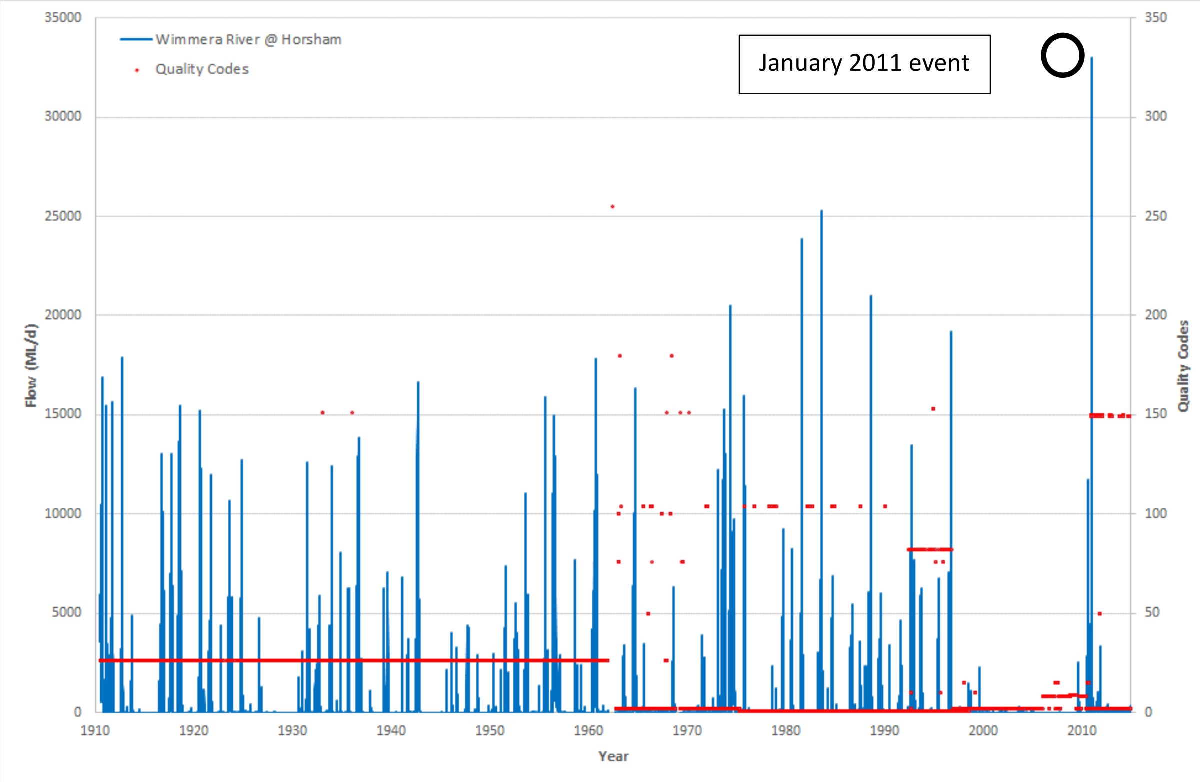


Figure 4-2 Gauge record at Wimmera River at Horsham (Walmer) showing flow and the Thiess Quality Code[1]

Several high flow events have been recorded by the gauge, the highest recoded flows based on gauge height and their respective years are shown in Table 4-2.

Table 4-2 Wimmera River at Horsham - Maximum recorded annual flows

Year	Maximum Discharge		Year	Maximum Discharge	
	ML/d	m^3/s		ML/d	m^3/s
2011	32,971	382	1996	19,198	222
1983	25,312	293	1912*	17,905	207
1981	23,879	276	1960	17,802	206
1988	21,005	243	1942*	16,632	193
1974	20,466	237	1964	16,325	189

* Mean daily recording

[1] Data downloaded from the DWELP data management system.

The 1909 and 1894 events had recorded maximum flows of 43,860 and 44,249 ML/d, however as discussed previously there is some uncertainty in these estimates.

The January 2011 hydrograph is clearly the highest recorded event, a hydrograph of the event is shown in Figure 4-3, along with the recorded Quality Code.

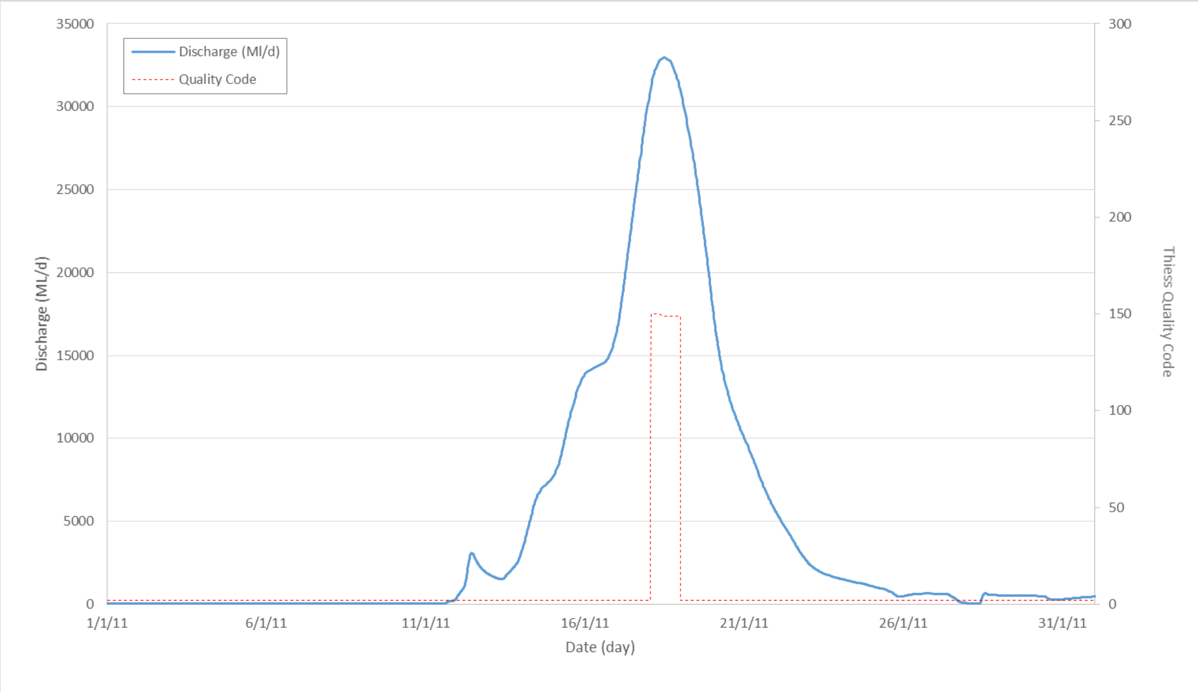


Figure 4-3 **January 2011 hydrograph recorded at the Wimmera River at Horsham (Walmer) streamflow gauge**

Other gauges

In addition to the Horsham (Walmer) gauge, other Wimmera River streamflow gauges are located downstream at Quantong, Dimboola, Lochiel Railway Bridge, Tarranyurk and Jeparit. There is also one gauge located on Norton Creek at Lower Norton.

The seven gauges within the study area all have different periods of record, some recording water level and estimating flow, with others only water level. A summary of each gauge is provided below:

- Wimmera River at Horsham (Walmer) – Excellent period of gauge record, some uncertainty in the gauge rating prior to this study. The gauge was used as the primary source of inflows to the model for calibration and design for the study. The gauge rating curve was reviewed using a local detailed hydraulic model.
- Norton Creek at Lower Norton – No ability to record high flows, with the rating curve maximum height being exceeded at relatively low flows (six times since 2008). Gauge flows are unlikely to be used in this study. The gauge is located in the backwater of the Wimmera River, so the peak at Norton Ck gauge corresponds to when the peak of the Wimmera River passes.
- Wimmera River at Quantong – Water level gauge only, the gauge record begins in 2009 and accurately captured the January 2011 event. The gauge was used for calibration of modelled water levels. This study identified an issue with the gauge zero of the gauging station.
- Wimmera River US Dimboola – Both flow and water level gauge, has 24 years of complete record since 1989. The gauge recorded the January 2011 and October 1996 events. The gauge was used for hydraulic model calibration.

- Wimmera River at Lochiel Railway Bridge – Both flow and water level gauge, has 23 years of complete annual record since 1987. The gauge recorded the January 2011 and October 1996 events. The gauge was used for hydraulic model calibration.
- Wimmera River at Tarranyurk – Historically, both flow and water level gauge. However flow predictions are limited and not fit for use in this study. The gauge has 23 years of complete water level record since 1987. The gauge recorded the January 2011 and October 1996 events. The gauge was used for hydraulic model calibration.
- Wimmera River at Jeparit – Both flow and water level gauge, however very limited gauge record with only 2 months with no high flow events. Gauge was not used.

4.4 Topographic Data/Survey

4.4.1 LiDAR

Four LiDAR datasets were available for the study area. Key metadata for the four datasets is given in Table 4-3 and the extents of the four datasets within the Lower Wimmera study area are shown in Figure 4-4.

Table 4-3 Key metadata for LiDAR datasets

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

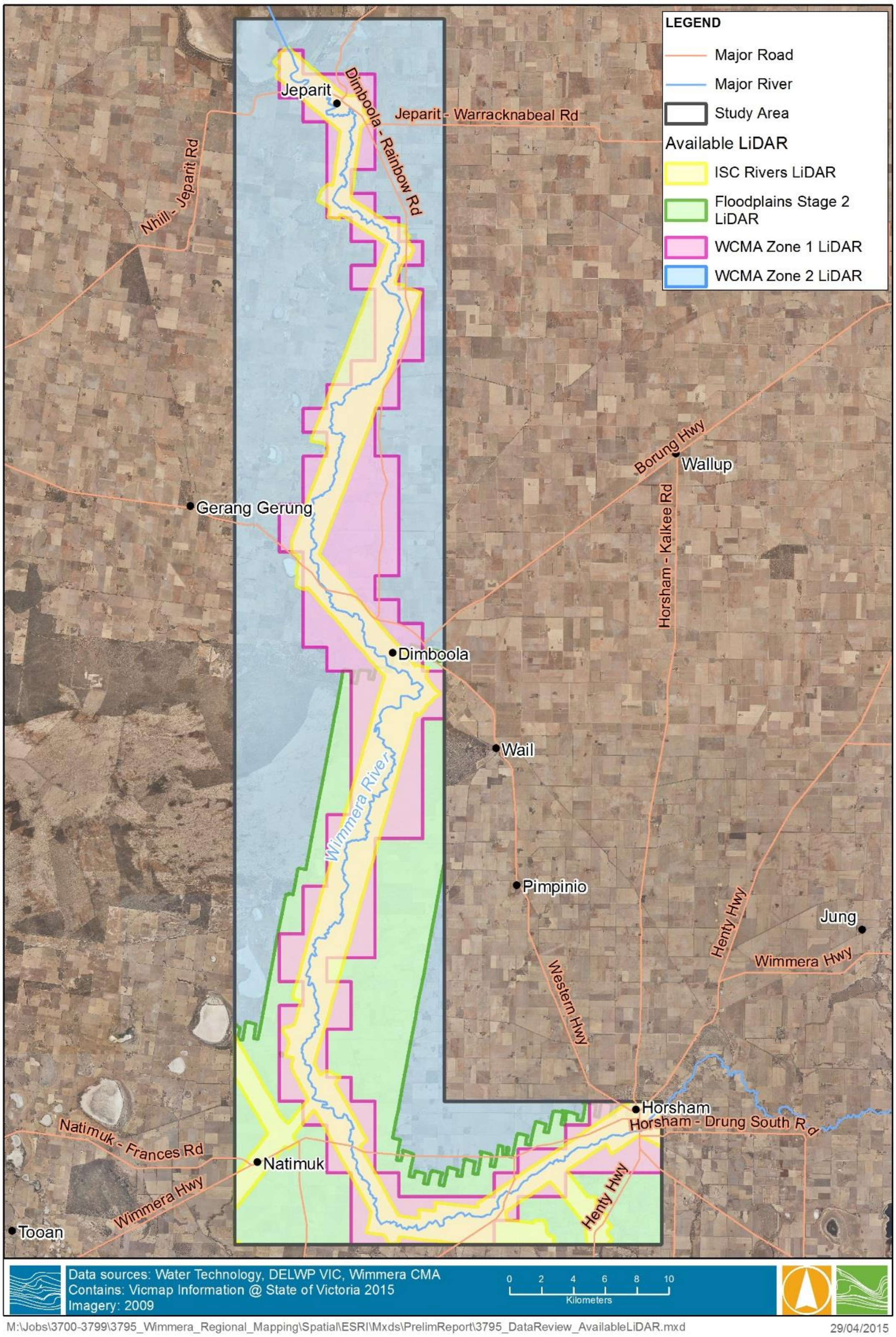


Figure 4-4 Available LiDAR extents

LiDAR Comparison

A comparison was undertaken between the four LiDAR datasets where they had significant overlap. Additional comparisons were made to available field survey.

The LiDAR comparison suggested that the Floodplains LiDAR generally agreed well with the two WCMA datasets, whereas the Rivers LiDAR appeared to have a systematic vertical offset of 0.1 – 0.2 m higher. The survey verification confirmed that the Rivers dataset was around 0.1 m too high.

As the Floodplains LiDAR is the most recently captured and was flown to a higher vertical accuracy, this dataset was used as the base dataset. The Floodplains dataset was combined with the WCMA Zone 1 dataset which gave full coverage of the Wimmera River floodplain.

4.4.2 Survey Data

In addition to the available LiDAR, survey data commissioned during the Jeparit Flood Study (Water Technology, 2008) was also available, this included survey of two levees and five river cross sections.

The levees were included into the model using dike lines to ensure that the crest elevations were represented accurately.

The cross-section survey was used to better represent the bathymetry of the river upstream of the Jeparit Weir. The same process was used at Dimboola Weir to represent the bathymetry of the river there also.

4.4.3 Observed peak flood heights and extents

Within the study area there are a number of surveyed peak flood heights, and an accurate representation of the January 2011 flood extent. Peak flood heights are available for the following events:

- January 2011 - 33 surveyed points spread over the study area extent, reaching as far north as Arkona
- September 2010 – 37 surveyed points evenly spread over the entire study extent
- 1909 - 13 surveyed points focused around Dimboola and Jeparit
- 1946 - 1 surveyed point at Dimboola
- 1981 -4 surveyed points at Dimboola
- 1983 - 1 surveyed point at Dimboola

The January 2011 extent was derived from aerial images, linescan data, ground based photography and anecdotal evidence. The information is considered the best available but some areas must be treated with caution.

4.5 Structures

VicRoads

VicRoads provided details of all their structures within the study area, these include:

- Nhill-Jeparit Road
- Western Highway
- Wimmera Highway
- Horsham-Noradjuha Road

The details provided gave structure width, length and spans. However they did not provide level information to Australian Height Datum.

VicTrack

There are several railway lines within the study area, including the Western SG and Yaapeet Lines. There is only one crossing of the Wimmera River on the Western SG Line downstream of Dimboola.

The January 2011 observed extent comes in close proximity to the Western SG line downstream of Dimboola on the eastern side of the Wimmera River indicating the potential for some interaction.

The Wimmera River railway structure was visited by Water Technology during the site assessment and preliminary measurements were taken.

Weir Structures

There are two major weir structures within the study area; Dimboola and Jeparit. Both weirs were damaged during the January 2011 flood event and have since been repaired. As constructed plans of the weirs were provided by GWMWater and Hindmarsh Shire Council.

4.6 Site Visit

A site visit was undertaken on Friday 5th September, 2014 by Ben Tate, Tim Cooke and Ben Hughes (Water Technology). The length of the Wimmera River from Horsham to Lake Hindmarsh was driven to gain an understanding of the general floodplain features and critical infrastructure that may impact on flood extents.

5. HYDROLOGY

5.1 Overview

The hydrological analysis for the lower Wimmera River downstream of Horsham consisted of a review of the hydrological context of the study area followed by flood frequency analysis. Due to uncertainty in gauged peak flow estimates and the January 2011 peak flow (personal communication with Wimmera CMA), a review was undertaken of the rating curve for the Wimmera River at Horsham gauge (415200).

The lower Wimmera River catchment receives inflows from the Wimmera River and Burnt Creek which flows into the river upstream of the Western Highway at Riverside. Mackenzie River, Norton Creek and Darragan Creek all flow into the Wimmera River off the southern catchment between Horsham and Quantong.

Flooding of the lower Wimmera River downstream of Horsham is dominated by incoming flows from the upper Wimmera River catchment. The East Horsham Flood Intelligence Report (Water Technology, 2013) provides a description of typical flood timing. From the start of intense rainfall to the peak of flooding in Glenorchy takes approximately 45 to 60 hours. The time between flood peaks between Glenorchy and Horsham is then between 3 to 4 days. From Horsham to Dimboola the travel time between peaks is 3 days or more, with another 2 days to Tarrenyurk.

The Mackenzie River peak at Horsham generally arrives well before the Wimmera River peak. An analysis of streamflow gauge data revealed that the Mackenzie River has peaked between 2.5 and 3.5 days earlier than the Wimmera River at Horsham on all significant flood events where concurrent record is available (Sep 1988, Oct 1992, Oct 1996, Sep 2010 and Jan 2011). During those events the Mackenzie River flows had receded by the time the Wimmera River peak arrived, with Mackenzie River flows between 200 to 630 ML/d at the time of the Wimmera River peak flow. These Mackenzie River flow rates are for the gauge located downstream of the Old Hamilton Road which does not capture the Bungalally Creek flows which enter Mackenzie River downstream of the gauge. However these Bungalally Creek flows are likely to be relatively minor, days after it has peaked.

The smaller tributary flood flows only impact on peak flood levels in the Wimmera River if they occur concurrently with the Wimmera River. Given the large difference in catchment size between the Wimmera River upstream of Horsham and the tributaries downstream of Horsham, the tributaries generally peak well before the Wimmera River peak arrives at Horsham. The impact of tributary inflows was assessed through the hydraulic modelling.

5.2 Wimmera River @ Horsham (Walmer) Streamflow Gauge

5.2.1 Desktop Gauge Review

Section 4.3.1 provides a summary of the streamflow gauge. In addition to the available streamflow record, Abdul Aziz of the Wimmera CMA sourced a number of highly valuable documents from the Horsham Historical Society and the State archives. These combined with the gauge record allowed us to recreate a detailed historical record of Wimmera River streamflow at Horsham, Table 5-1.

Table 5-1 Wimmera River at Horsham largest recorded peak flows

Year	Source and comments	Peak Flow	
		ML/d	m³/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, this is described in Section 3.5.2. The remainder of Section 3 discusses the peak flow for January 2011, justifying the adopted 33,000 ML/d.	33,000	382

During January 2011, the Wimmera River flowrate was measured at the Western Highway Bridge 6 km upstream by Ventia[2], the gauging was completed at this location due to the Horsham gauge being too dangerous for hydrographers to access. The gauge is in a poor location for measuring high Wimmera River flows, and also low Wimmera River flows when impacted by the Mackenzie River backwater.

After the January 2011 event the gauged water levels at the Horsham (Walmer) gauge and the recorded flow at the Western Highway Bridge were used to revise the Wimmera River at Horsham (Walmer) gauge rating curve. The previous (v15) and current (v17) rating curves shown in Figure 5-1.

The change between the current rating curve and the rating curve in use prior to the January 2011 gauging is significant, especially at high flows. Given the large differences in estimated flow with the two latest rating curves, a detailed investigation into the rating curve using a hydraulic model was undertaken and a meeting with Ventia hydrographers was held to discuss the changes. Water Technology concluded that the gaugings completed by the hydrographers at the Western Highway bridge and the revised rating curve was suitably verified by the rating curve hydraulic modelling and the revised January 2011 flows were adopted for this study. Initial calibration of the January 2011 event concluded that the revised rating curve and adopted January 2011 peak flow did result in a good preliminary calibration of the hydraulic model between Horsham and Lake Hindmarsh.

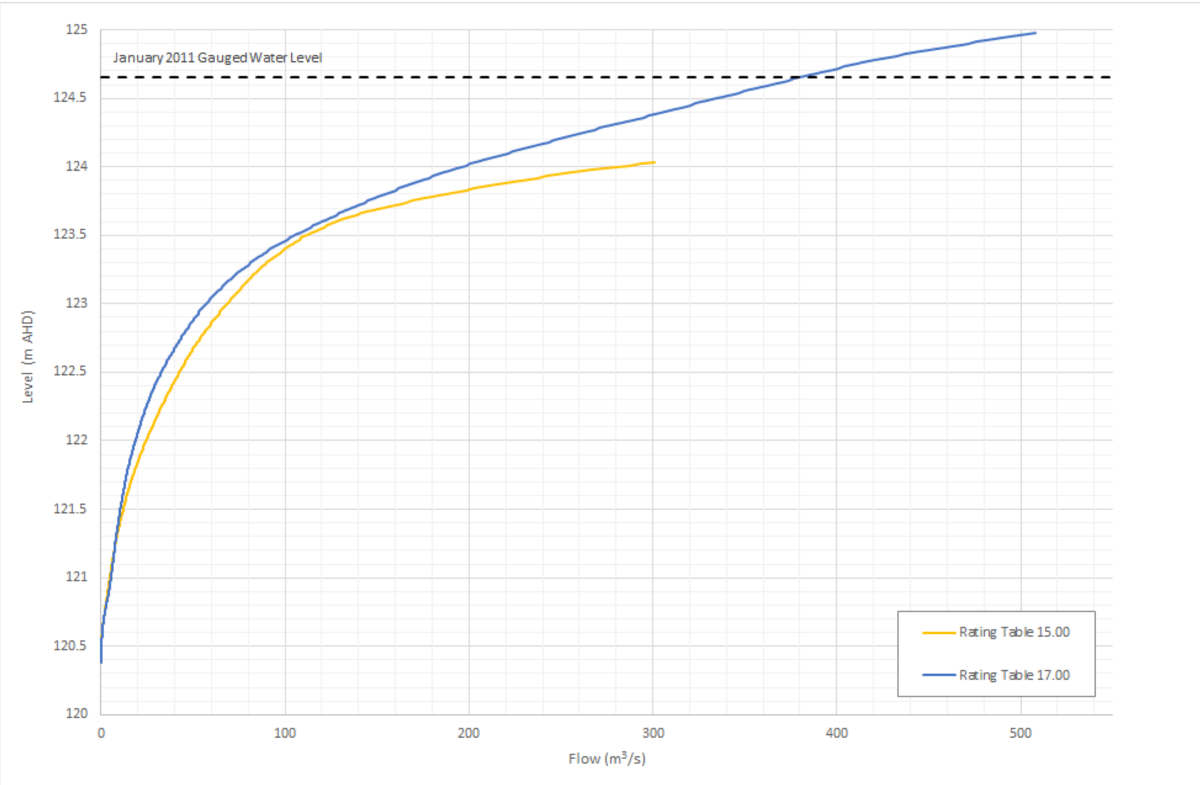


Figure 5-1 Wimmera River at Horsham current and previous rating curves

[2] Pers. Comm. - Ventia (Rebekah Webb)

5.2.2 Impact of Mackenzie River

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

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

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

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

5.3 Flood Frequency Analysis

5.3.1 Peak Flow

A Flood Frequency Analysis (FFA) was used to determine peak design flows for the range of modelled design events. An annual series was constructed from the available instantaneous flow record, and historic information sourced by Abdul Aziz. The larger historic peak flows used to construct the annual series were displayed earlier in Table 5-1, this was supplemented with smaller flows from other years. A complete annual series was constructed from 1889 to 2015. The low flows were filtered using the Grubbs Beck test, censoring 58 of the 127 years of annual series. It should be noted that the annual series used the Wimmera River at Horsham (Walmer) flow data without any adjustment due to the impact of Mackenzie River backwater. For Wimmera River flood flows it has been demonstrated that the impact of Mackenzie River on peak water levels at the gauge is generally quite low. The Mackenzie River tends to peak 2.5 to 3.5 days earlier than the Wimmera River and at the time of the Wimmera River peak the Mackenzie River flow tends to be relatively low, justifying the adoption of the Wimmera River flows unadjusted.

A range of statistical distributions were trialled in Flike including LP3, log-normal, Gumbel, GEV, and Generalised Pareto. The LP3 distribution plotted the best against the historic series, and is shown in Table 5-2 and Figure 5-2.

Table 5-2 Wimmera River at Horsham FFA results (LP3 with low flow censoring)

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

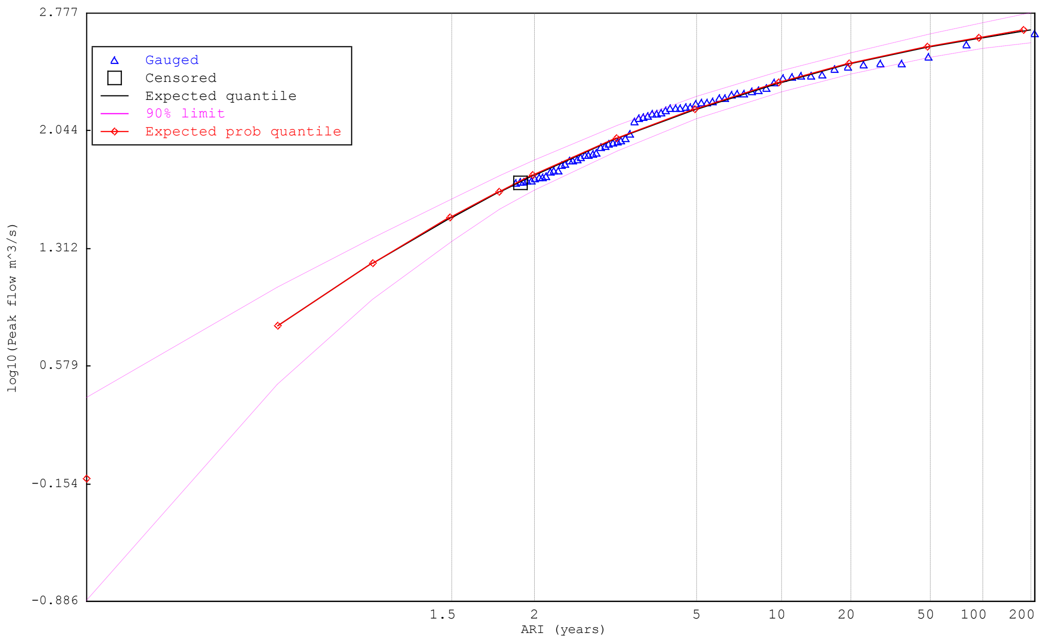


Figure 5-2 Wimmera River at Horsham FFA (LP3 with low flow censoring)

5.3.2 Event Volume

A flood frequency analysis on event volume was completed following a similar procedure as described above for peak flow. A number of historic events were analysed and it was found that large flood events on the Wimmera River at Horsham can last between 6 to 8 days, with flows above 5,000 ML/d. A 7 day volume flood frequency analysis was carried out, using an annual series from 1910 to current and censoring 54 years with low 7 day event volumes. The flood frequency analysis on volume is shown in Table 5-3.

Table 5-3 Wimmera River at Horsham FFA results of seven day volume

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

5.4 Calibration Events

For hydraulic model calibration the streamflow hydrograph for the Wimmera River at Horsham gauge was used directly as the inflow boundary to the hydraulic model.

As documented earlier in the report this hydrograph was tested in a preliminary version of the Horsham to Lake Hindmarsh flexible mesh model. Sensitivity of the model to the design flow hydrograph was also carried out by running a hydrograph with a peak flow approximately 30% higher. This higher flow resulted in flood levels approximately 300 mm higher upstream of Dimboola and only 100 mm higher downstream of Dimboola.

Sensitivity testing with and without tributary inflows was also undertaken for the January 2011 event. This is documented in Section 0.

5.5 Design Flow Hydrographs

It was recommended that the January 2011 event be adopted for the Wimmera River design hydrograph shape. The design hydrographs were adjusted to match the peak design flow estimates and event volume from flood frequency analysis.

5.6 PMF Estimation

The Probable Maximum Flood (PMF) is the flow generated from the theoretical maximum precipitation for a given duration under current climate conditions. A PMF estimate for the Wimmera River at Horsham gauge was prepared using the Quick Method of Nathan et al. (1994). This method was found to produce flow estimates far in excess of what would be expected.

Water Technology investigated an alternative means of developing a PMF flow based on 1% AEP to PMF ratios from other studies within the Wimmera River catchment. A PMF to 1% AEP ratio of 11.2 to 1 was adopted. This ratio was applied to the 1% AEP design hydrograph at Horsham giving a PMF peak flow of 409,000 ML/d. The design hydrograph for the Wimmera River was scaled up to the PMF peak flow.

6. HYDRAULICS

6.1 Overview

A 2-dimensional (2D) flexible mesh hydraulic model was developed for the study area using the industry standard software MIKE21FM (Mike by DHI). Adopting a flexible mesh modelling approach allowed the hydraulic model to incorporate greater detail in areas of importance, whilst maintaining computational efficiency through a larger element size in less sensitive regions of the modelled area. This allows features within the broader floodplain and the river channel to be resolved in varying detail in the same model whilst maintaining manageable run times.

A flexible mesh approach allows for a detailed representation of the ground surface enabling the topographic detail to be captured within the hydraulic model. The approach allows for a high topographic resolution in areas requiring enhanced detail such as the river channel and around hydraulic controls and structures. The resolution in less hydraulically sensitive areas like the wider floodplain beyond the top of bank can be reduced. Spatially varying the resolution allows the model run times to be optimised whilst maintaining element sizes needed to adequately meet the study requirements in areas of importance.

The MIKE21FM model runs on the computers graphical processing unit (GPU), which allows faster processing speeds and enhanced model run times.

The MIKE21FM GPU model ensures model accuracy as well as computational efficiency, and is well suited for large scale riverine mapping where detailed channel representation is required embedded within a wider floodplain.

6.2 Hydraulic Model Schematisation

6.2.1 2D Grid Size and Topography

Combining the available survey and LiDAR data, the topographic mesh comprised of triangular and rectangular elements of varying size. An example of adopted mesh schematisation for this study is illustrated in Figure 6-1.

The mesh resolution along the river was approximately 10 m^2 with quadrilateral elements aligned along the length of the river. A minimum of 4 elements were digitised across the width of the channel to ensure that the mesh representation of the river cross section was appropriate. Schematising less than 4 elements across the river width would over simplify the river geometry and has the potential to over represent, or under represent the conveyance and channel capacity of the river. The mesh was aligned with roads, channels, levees and any other features within the floodplain that had the potential to act as a hydraulic barrier to flow. By aligning the mesh with hydraulic features it ensures that these obstructions to flow are accurately represented spatially in the mesh. This is important for three reasons:

- It minimises computational error as obstructions are aligned with element faces;
- Elevations are accurately represented as element vertices are aligned with the obstruction; and,
- Any additional structures in the model, including levees, culverts and weirs were digitised accurately and aligned with the mesh.

Resolution of the mesh was reduced across the floodplain as it extended away from the Wimmera River towards the edge of the model domain. Along the edge of the model domain the mesh resolution was reduced to approximately 225 m^2. Whilst the river reaches are represented as quadrilateral elements aligned with the direction of flow for computational efficiency, in the wider floodplain a combination of triangular and quadrilateral elements were used to allow the mesh greater freedom to align with the additional schematised features. The model mesh can freely interchange from quadrilaterals to triangles within the same solution scheme. The modeller has a degree of control over the element shape and size and alignment to key features, with the model software taking the user inputs and building the best possible mesh to meet all criteria specified.

Lake Hindmarsh was included as a receiving waterway and downstream extent of the model. Schematising Lake Hindmarsh at a coarse resolution of approximately 0.25 km^2 sized elements allowed good representation of the storage capacity of the lake without influencing run times of the model.

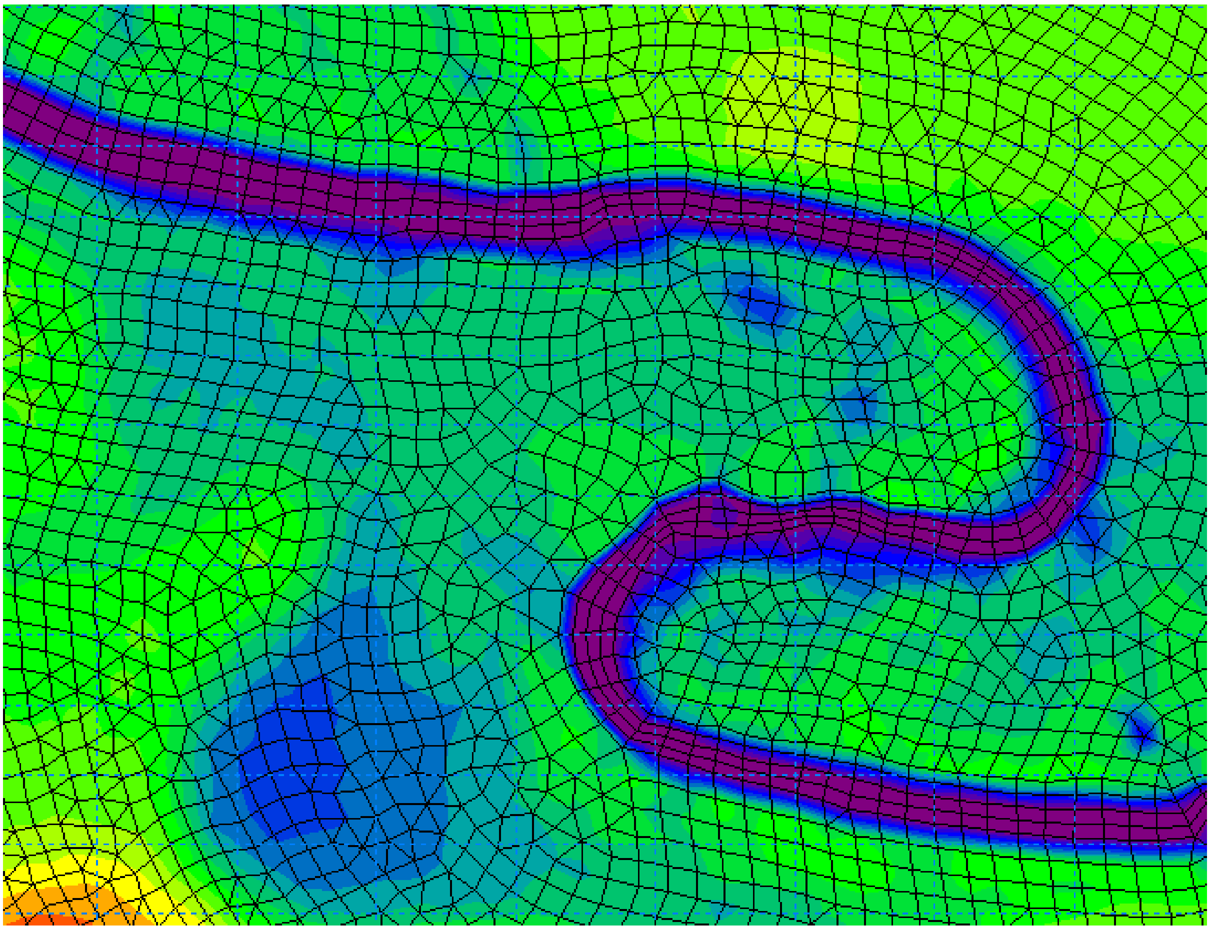


Figure 6-1 Example mesh schematisation

6.2.2 Roughness

Due to the relatively homogenous nature of the vegetation and waterway condition along the length of the Wimmera River from Horsham to Lake Hindmarsh, a consistent representation of hydraulic roughness was deemed appropriate for this study. Hydraulic roughness was represented within the hydraulic model using Manning's 'n'. A range of Manning's 'n' values were applied during the model calibration, discussed in Section 6.4, with a uniform roughness of 0.06 adopted for all events.

6.2.3 Boundary Condition

The lower Wimmera River catchment receives inflows from the Wimmera River and Burnt Creek which flows into the river upstream of the Western Highway at Riverside. Mackenzie River, Norton Creek, Sandy Creekand Darragan Creek all flow into the Wimmera River off the southern catchment between Horsham and Quantong. These flows were applied to the hydraulic model in the locations shown in Figure 6-2.

Horsham (Walmer) Gauge

The accuracy and reliability of the Horsham (Walmer) Gauge at Horsham was discussed at length earlier in this report. Water Technology and Wimmera CMA accept the most recent rating table of the Horsham (Walmer) Gauge to be the best representation of high flows, including the January 2011 flood event. The recorded hydrograph at the Horsham (Walmer) Gauge was used directly as the upstream inflow boundary to the hydraulic model for the January 2011 flood event.

Tributary Inflows

The Mackenzie River, Norton Creek, Sandy Creek and Darragan Creek are the only major waterways that contribute significant flow to the Wimmera River downstream of Horsham. All of these waterways enter the river between Horsham and Quantong. The smaller tributaries only impact on peak flood levels in the Wimmera River if their flow occurs concurrently with the Wimmera River. Given the large difference in catchment size between the Wimmera River upstream of Horsham and the tributaries downstream of Horsham, the tributaries generally peak well before the Wimmera River peak arrives at Horsham. The impact of tributary inflows on Wimmera River water levels was tested by adding design tributary flows to the hydraulic model.

Application of appropriate flows deriving from these catchments into the hydraulic model was made more difficult through the lack of available and reliable stream gauge data. The RORB model developed during the ongoing Horsham and Wartook Valley Flood Investigation (Water Technology, 2016), and at the time of this project was yet to be fully calibrated. RORB modelling of the tributaries used a kc value calculated using a kc to dav ratio based on calibrated RORB modelling undertaken during the Natimuk Creek Flood Investigation (Water Technology, 2012). The Natimuk and Little Natimuk Creek catchments have a similar relief and catchment flood response to the Norton Creek and Darragan Creek catchments.

The RORB model parameters from Natimuk and those adopted for this study are shown in Table 6-1.

Table 6-1 Natimuk Flood Investigation and adopted RORB model parameters tributary flows

<table>
<tr><th colspan="2">RORB Parameter</th><th>Natimuk Flood Investigation</th><th>This Study</th></tr>
<tr><td colspan="2">m</td><td>0.8</td><td>0.8</td></tr>
<tr><td rowspan="3">Dav</td><td>Norton Creek</td><td rowspan="3">21.29</td><td>34.61</td></tr>
<tr><td>Sandy Creek</td><td>19.28</td></tr>
<tr><td>Darragan Creek</td><td>22.19</td></tr>
<tr><td rowspan="3">kc</td><td>Norton Creek</td><td rowspan="3">26.61</td><td>43.20</td></tr>
<tr><td>Sandy Creek</td><td>24.10</td></tr>
<tr><td>Darragan Creek</td><td>27.70</td></tr>
</table>

The RORB modelling for Norton, Sandy and Darragan Creeks used a continuing loss of 4.5 mm/hr for the historic calibration modelling. An initial loss of 10 mm was used for the initial loss, which was the lowest of the initial losses used in the calibration events in the Natimuk study. This was applied as a conservative approach given the lack of observed streamflow and the uncertainty in the tributary flow estimation.

The same losses and model parameters were used for design modelling purposes. It is noted that the estimation of losses in this study was carried out using a rapid assessment. Conservative losses were applied. This is justified as the impact of the tributary flows has been shown to be very small, Section 6.4.2 discusses this further.

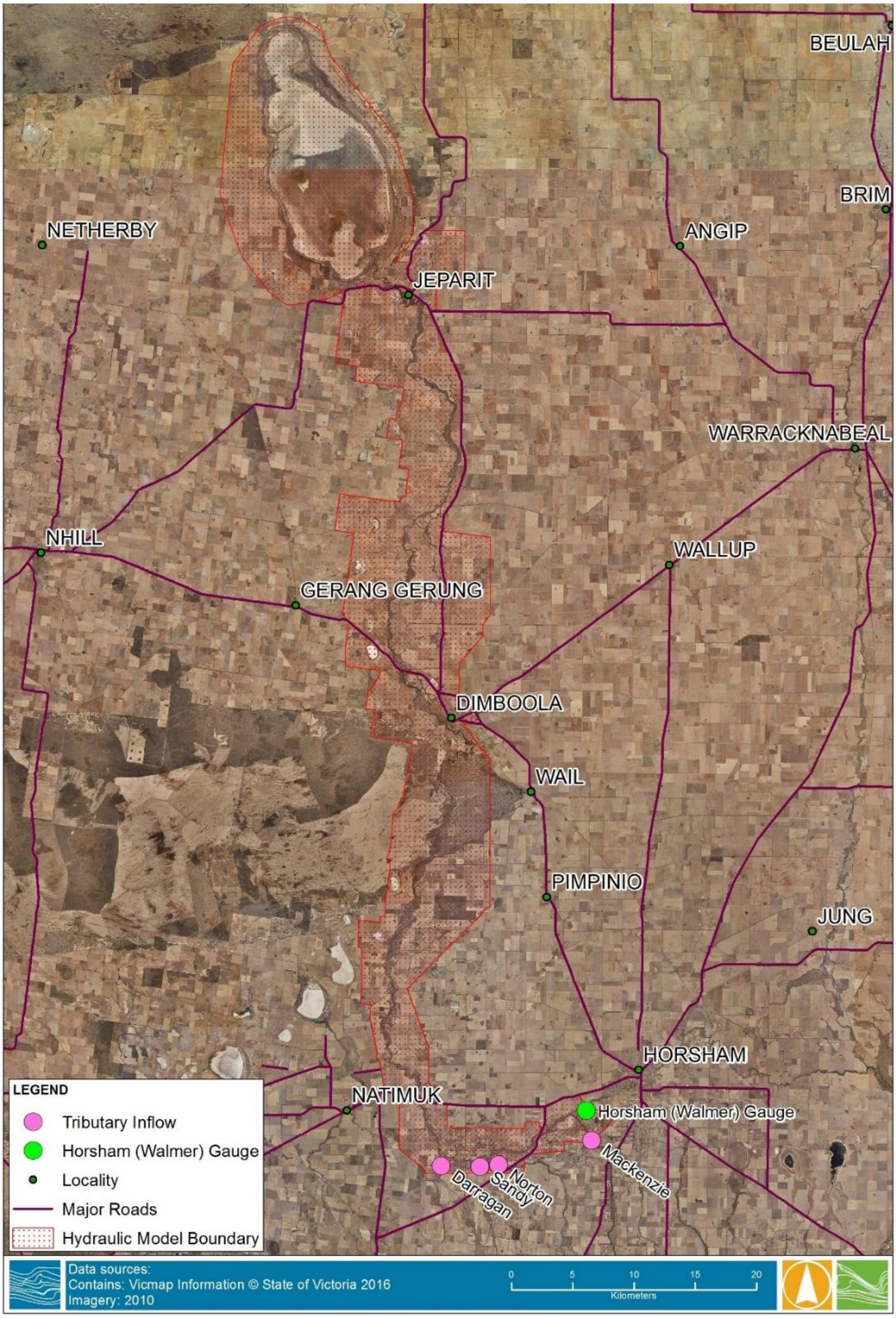


Figure 6-2 Hydraulic Model Extent and Inflow Boundary Locations

6.3 Hydraulic model calibration

Two observed floods were used to calibrate the hydraulic model parameters, January 2011 and September 2010. The January 2011 event was used as the primary calibration event; this was followed by verification of the calibration using the September 2010 event. Surveyed flood marks (provided by Wimmera CMA), flood imagery, available gauge levels, and anecdotal evidence were used in the calibration.

6.3.1 January 2011 Event Calibration

Comparison to Surveyed Flood Heights

The hydraulic model calibration for the January 2011 event was based on matching observations of peak flood heights, gauge data and aerial photography captured during the January 2011 event. 33 surveyed points were available throughout the study area, reaching as far north as Arkona. The hydraulic model results were compared to the surveyed flood heights to confirm how well the model was matching observations. Aerial photography captured along the lower Wimmera River on a daily basis from the 18th to the 22nd of January also provided a temporal and spatial representation of the January 2011 flood event and the progression of inundation and the peak inundation.

33 surveyed peak flood heights were recorded by Wimmera CMA post the January 2011 event. A comparison between the peak hydraulic model water levels and surveyed flood heights showed an excellent match, with the modelled water levels within 100 mm of the surveyed flood levels at 20 of the 33 points. A further 10 points showed modelled peak water levels within 200 mm of that surveyed. The locations of the survey marks with the surveyed and modelled water level comparison is shown in Figure 6-3. The remaining three points with a greater than 200 mm difference between modelled and surveyed water levels were located off Three Bridges Road and north of Polkemmet. Overall, the model performed exceptionally well against the surveyed flood marks recorded for the January 2011 flood event.

Comparison to Water Level Gauges

The modelled water levels were compared to the gauged water levels at the Wimmera River at Quantong stream gauge (415261). Comparison was made over the duration of the January 2011 event, as shown in Figure 6-4. The modelling identified that the documented gauge datum was likely to be incorrect by close to 2 m. Once surveyed, this suspicion was confirmed. The official gauge datum at Quantong should be updated to 110.01 m AHD.

Two other streamflow gauges on the Wimmera River had available water level data surveyed to m AHD. The modelled water levels at these gauges were compared against observations. The modelled peak water level for the January 2011 event was 0.099 m lower than the observed (96.906 m AHD) at Lochiel Bridge. At the U/S of Dimboola gauge the modelled water level was 0.036 m higher than observed (106.305 m AHD).

The modelled and observed hydrographs are shown below in Figure 6-5. As shown the modelled hydrograph reproduces the observed hydrograph very closely at both locations. The start of the hydrograph is different due to the initial conditions in the model but this does not impact on the model performance as demonstrated by the close fit later on the rising limb and across the peak of the hydrograph.

These streamflow gauge levels have less uncertainty associated with their measurement as compared to the post flood height survey. The closeness of the calibration provides confidence that the model is accurately representing the January 2011 flood levels.

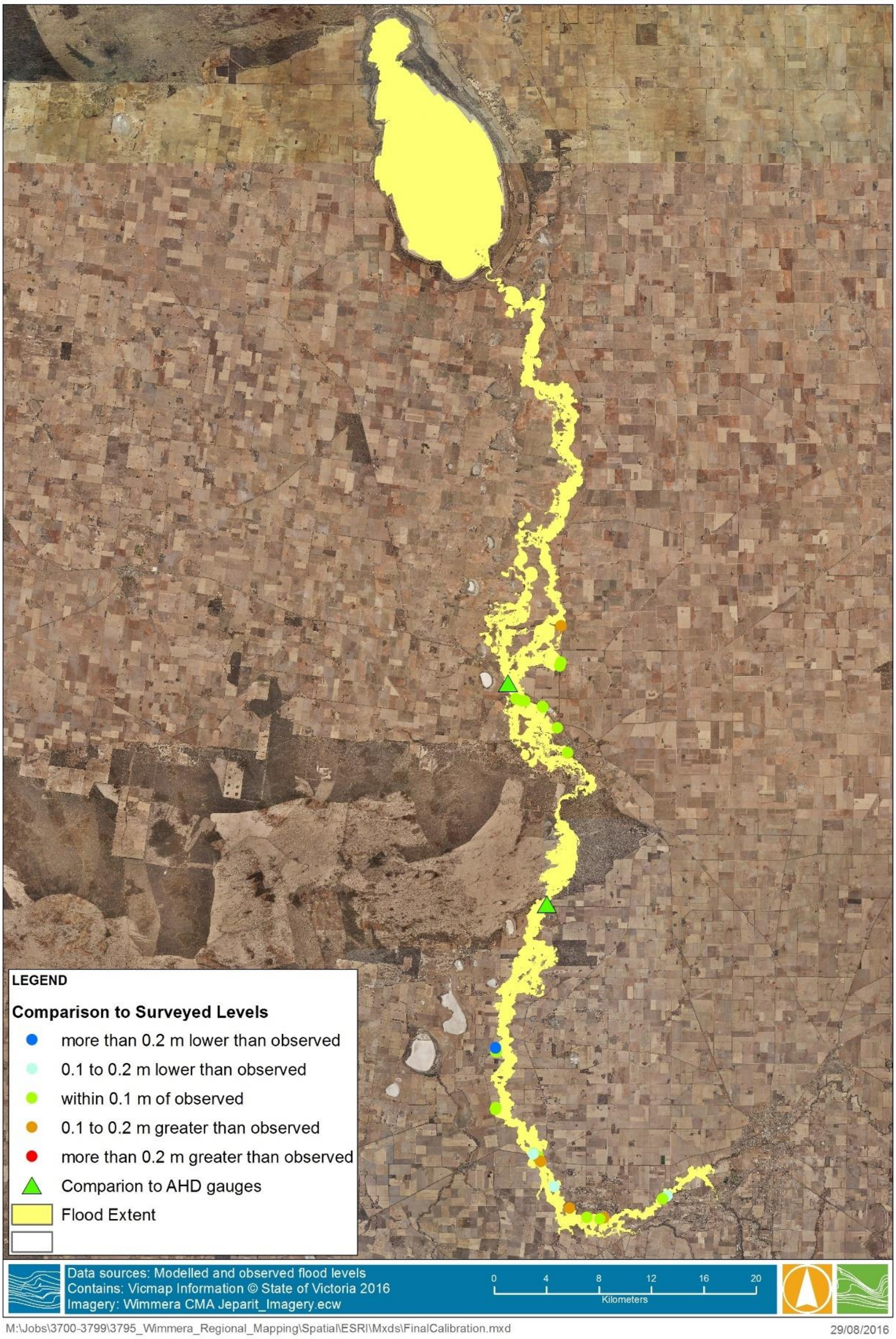


Figure 6-3 Modelled minus observed flood levels – January 2011

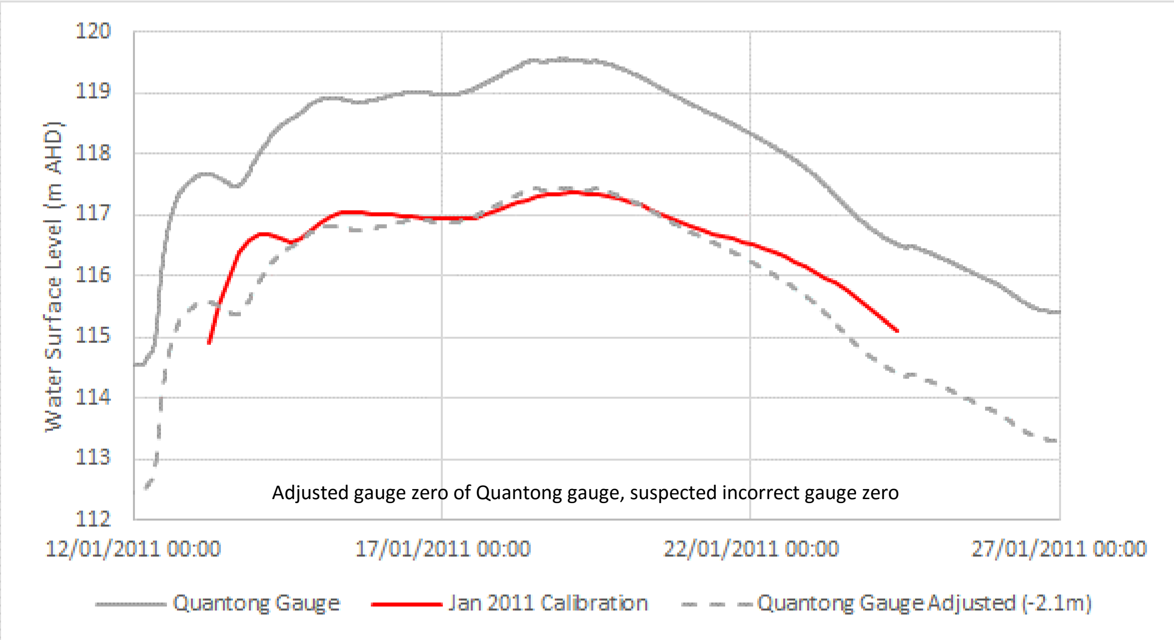


Figure 6-4 Recorded and Modelled Flood Levels at Quantong Gauge

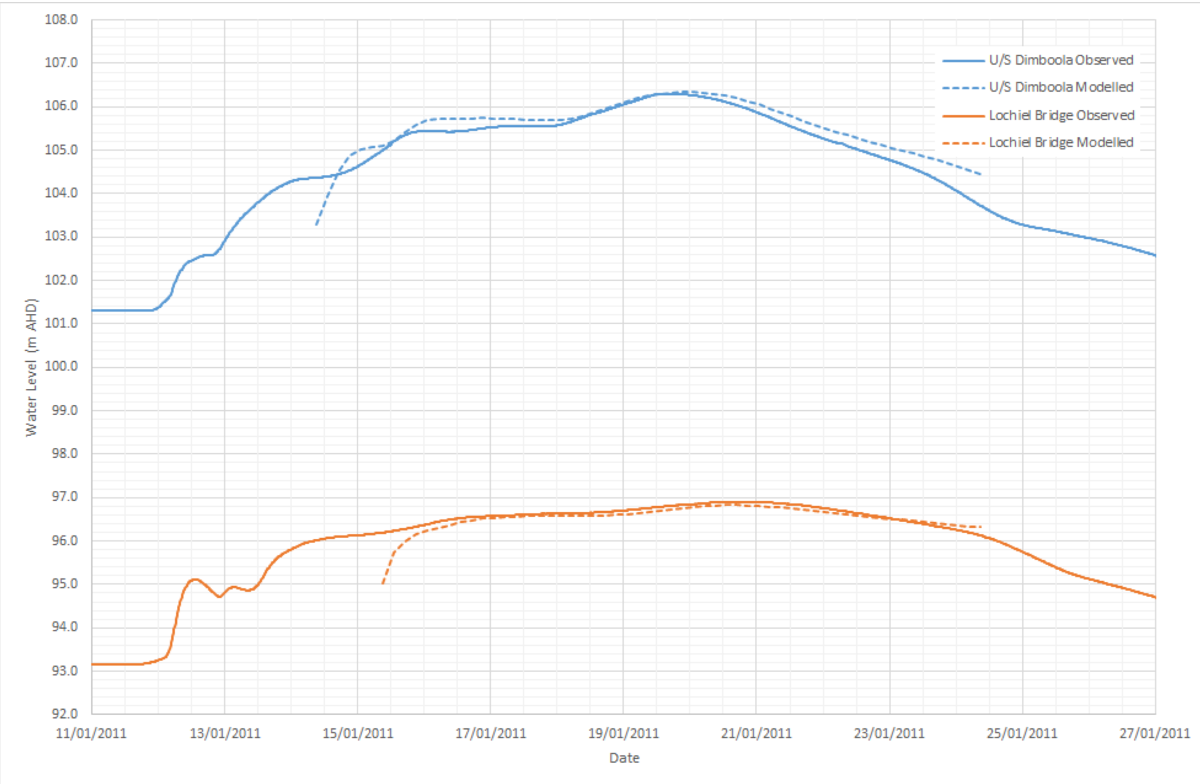


Figure 6-5 Modelled and Gauged hydrographs at U/S of Dimboola and Lochiel Bridge

Comparison to Flood Imagery

The hydraulic model was compared flood extents from observed aerial photography. The aerial photography was taken on multiple days as the peak of the January 2011 flood moved north, downstream along the floodplain. The adopted Manning's 'n' value of 0.06 created a flood extent that matched well with the aerial photography across the entire model extent. This is illustrated in Figure 6-6. Additional comparisons are provided in the Hydraulic Report (R03).

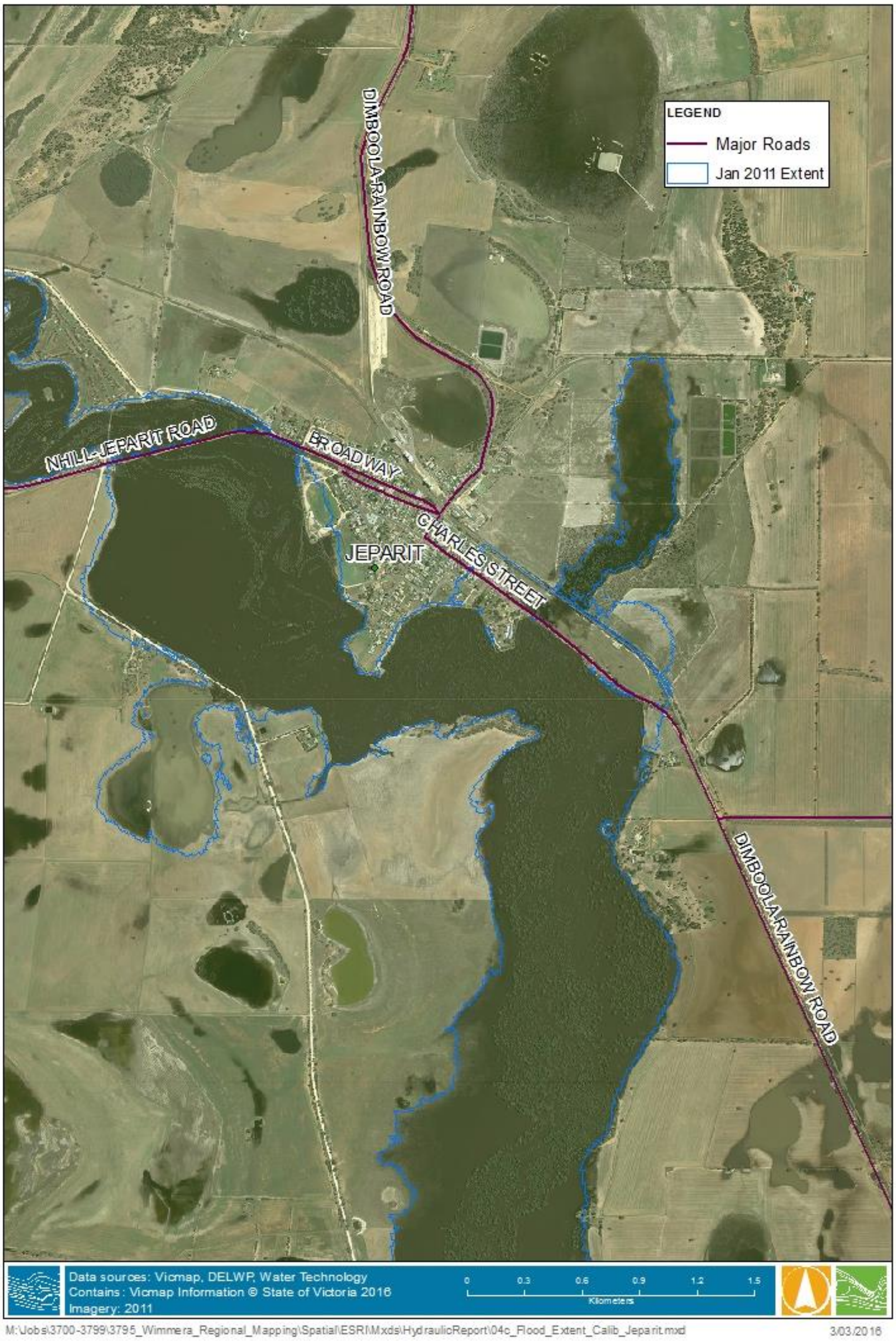


Figure 6-6 Example comparison between modelled flood extents and aerial photography at Jeparit

Anecdotal Community Observations

During this study, community meetings were held in two locations; Quantong and Antwerp. With three meetings held in each location. At the time of this reports production two rounds of meetings had been held. The first round of meetings was held in Quantong and Antwerp on the 20th and 21st of May, 2015 respectively. The second round was held in Quantong and Antwerp on the 15th and 16th of March 2016 respectively.

The intent of the first meetings was to introduce the public to the project scope, aims and potential outcomes, share information to help improve the understanding of flooding between Horsham Weir and Lake Hindmarsh. The meeting also outlined how the community can play a role ensuring the project results are the best possible representation of flooding along the Lower Wimmera.

The intent of the second round of meetings was to confirm the hydraulic models calibration to observations made during the January 2011 event, discuss the draft 1% AEP flood extent and receive feedback on flood warnings received during January 2011 and potential changes to how the community was warned and the information that was available to them. During the second round of meetings the communities in Quantong and Antwerp highlighted areas where the modelling matched community observations well, and others where they felt improvements could be made. At the meeting the final calibration was yet to be completed with modelling without tributary inflows used for discussion.

In general, the Quantong community thought the maps matched the community observations very closely with no areas of concern. The Antwerp community felt the match between modelled and observed levels was very close at Antwerp but in general it was thought the modelled water levels were too low immediately downstream of Dimboola on the Wimmera River and Datchak Creek, in particular a dwelling was highlighted that was sandbagged but the model results were not showing water around the dwelling. The property highlighted as being sandbagged had a surveyed floor level of 96.34 m AHD, the modelled January 2011 level was 95.38 m AHD. There is also a building located to the north of the highlighted dwelling that has a floor level of 95.57 m AHD, significantly lower. This building has a modelled flood level of 95.17 m AHD for the January 2011 event. The aerial images of flooding on the 20th, 21st and 22nd January 2011 all show water over River Road, extending to the driveway of the property in question, and the flood mapping shows the same. The aerial images clearly show that the property to the north which has a lower floor level is surrounded by floodwaters to the east and the south, and appears to have a sandbagged levee constructed around it. It is most likely that this is the property that the community member was commenting on. The levee doesn't appear to be effective in the imagery, with floodwaters outflanking it to the south, however the floor level is well above the flood level. The flood modelling and mapping represents the flood behaviour in this region well as compared to the aerial imagery and the surveyed flood levels. Areas highlighted by the community are shown in Figure 6-7.

There were three surveyed flood heights along Datchak Creek for the January 2011 event, and six located on the Wimmera River upstream of the Dakchak Creek distribution point. Of the surveyed flood heights along Datchak Creek the greatest disparity between modelled and observed levels was 0.11 m. Of the surveyed levels upstream of the Datchak Creek distribution the greatest disparity between modelled and observed levels was 0.03 m.

Additional to January 2011, there were 5 surveyed flood marks for September 2010 available along Datchak Creek and 4 available along the Wimmera River. Along Datckak Creek the largest disparity between modelled and observed levels was 0.09 m and along the Wimmera River the largest disparity was 0.13 m.

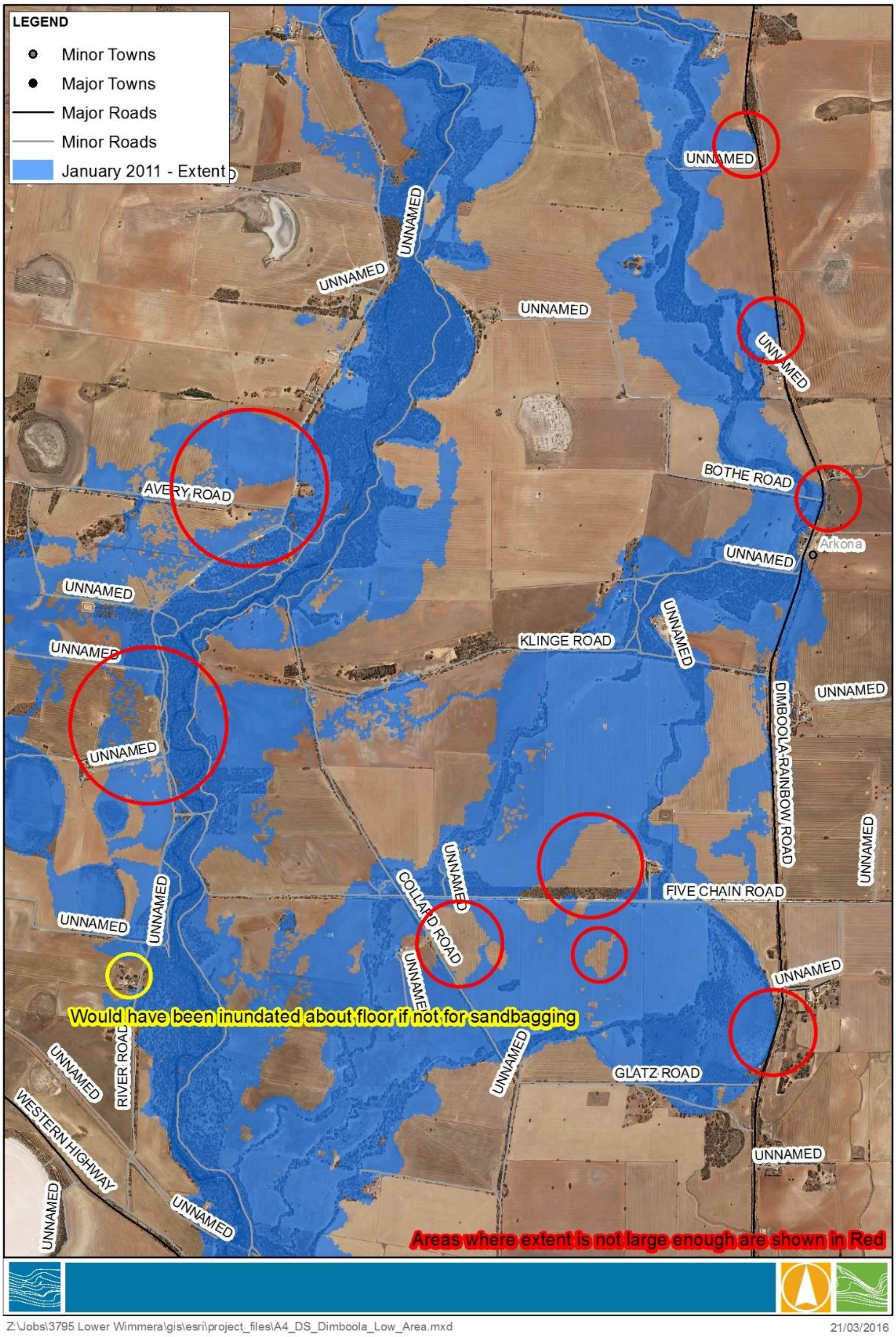


Figure 6-7 Areas highlighted by the Antwerp community as too low based on interim flood mapping presented at the second community meeting

Discussion

Given the close match between the modelled and observed flood heights and aerial photography the hydraulic model is considered to be calibrated as close as possible. There are several points which do not show a good match between modelled and observed flood height, however surveyed points do not appear to be representative of the peak flood levels. The fact that the modelled levels at U/S Dimboola and Lochiel Bridge gauges compare very closely to the peak levels and the shape of the hydrographs provides confidence in the hydrology and hydraulic model assumptions.

Anecdotal comments from the community on peak flood heights generally matched well with the hydraulic model result. There was one area of concern downstream of Dimboola, however there were several surveyed peak heights in this area that matched well. A comment made by a member of the community about the sand bagging of a property on River Road north of Dimboola was checked and it was found that the property highlighted was incorrect, the property to the north was the one that was sandbagged, and mapping matches the aerial imagery well. Comments made by the community were very general e.g. “I remember it being wetter in that area” without specific references to heights or any photographs available. Regardless, these general comments have been used throughout the calibration in combination with the aerial imagery and surveyed heights to achieve the best calibration possible.

6.3.2 September 2010 Event Calibration

Comparison to Surveyed Flood Heights

A comparison between the modelled water levels and surveyed flood heights showed a good match with 12 of the 37 points within 100 mm and a further 9 points within 200 mm of recorded heights. A comparison between the surveyed and modelled water level is shown in Figure 6-8. The remaining 16 points with discrepancy greater than 200 mm are discussed in detail in the Hydraulics Report (R03). The large number of points with a disparity of greater than 200 mm between modelled and observed levels is thought to be a result of the survey quality. There is no bias to the model results being higher or lower than the surveyed levels with a reasonable spread in the results. The points are described as “engineering pegs” with 50 mm vertical accuracy. It is likely that the survey instrumentation has a vertical accuracy of 50 mm but the interpretation of the flood debris marks and peak flood level is likely to be far less accurate. A number of the surveyed flood levels are clearly incorrect with regards to surrounding surveyed levels.

Comparison to Water Level Gauges

The modelled water levels were again compared to the gauged water levels at the Wimmera River at Quantong streamflow gauge (415261). As discussed previously for the January 2011 calibration event comparison, it was found that the Quantong gauge zero was too high, and when adjusted the model shows a very good match to the gauged hydrograph.

The modelled water levels at the U/S Dimboola and Lochiel Bridge gauges were compared to the observed data. The modelled peak water level for the September 2010 event was 0.096 m lower than the observed (96.437 m AHD) at Lochiel Bridge. At the U/S of Dimboola gauge the modelled water level was 0.009 m lower than observed (105.175 m AHD).

The modelled and observed hydrographs are shown below in Figure 6-9 and Figure 6-10. As shown the modelled hydrograph reproduces the observed hydrograph very closely at both locations. The start of the hydrograph is different due to the initial conditions adopted in the model, but this does not impact on the model performance later on the rising limb and over the peak of the flood event.

These streamflow gauge levels have less uncertainty associated with their measurement as compared to the post flood height survey. The closeness of the calibration provides confidence that the model is accurately representing the September 2010 flood levels and reinforces the suspicion over the accuracy of the post flood survey marks.

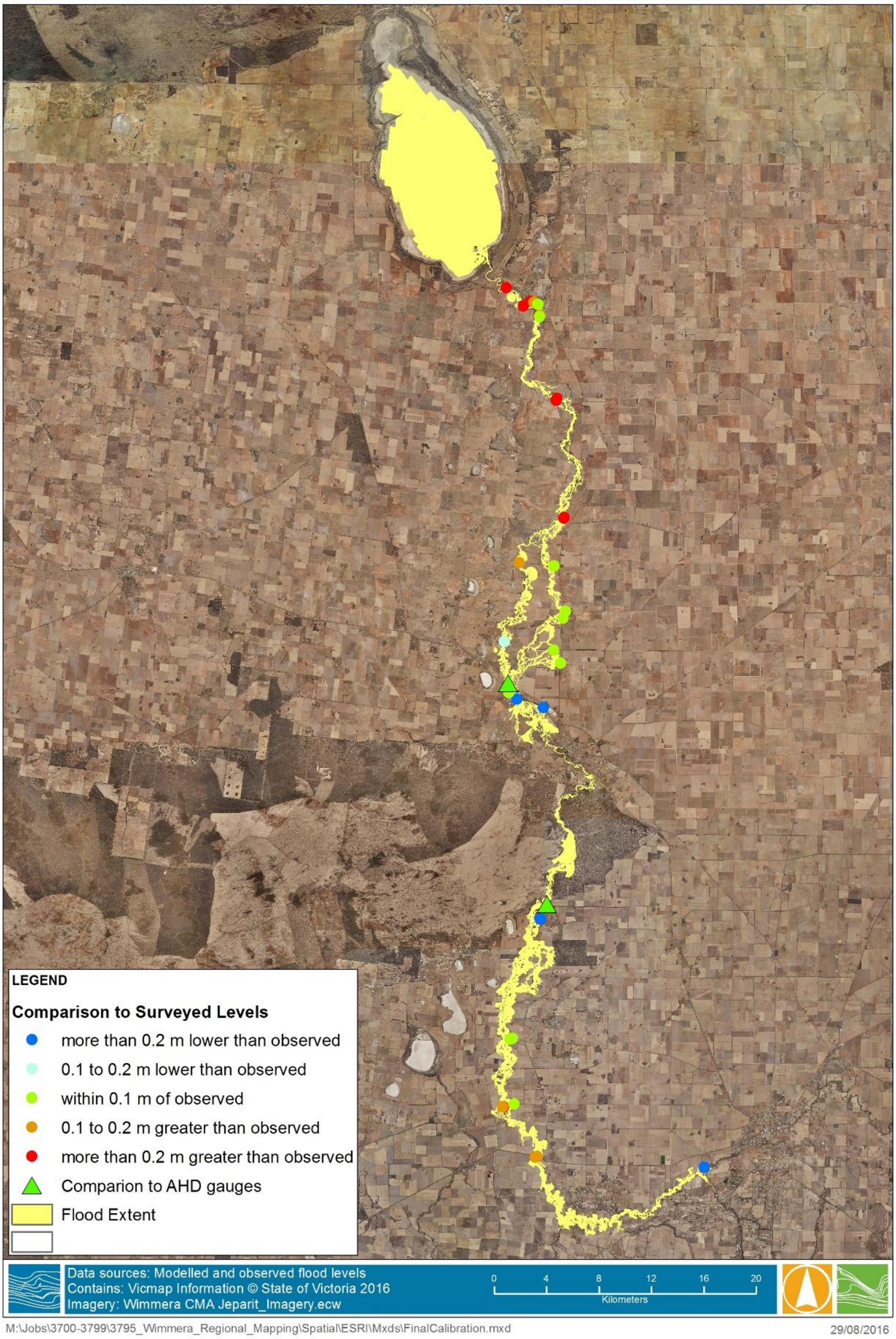


Figure 6-8 Modelled minus observed flood levels and modelled flood extent – September 2010

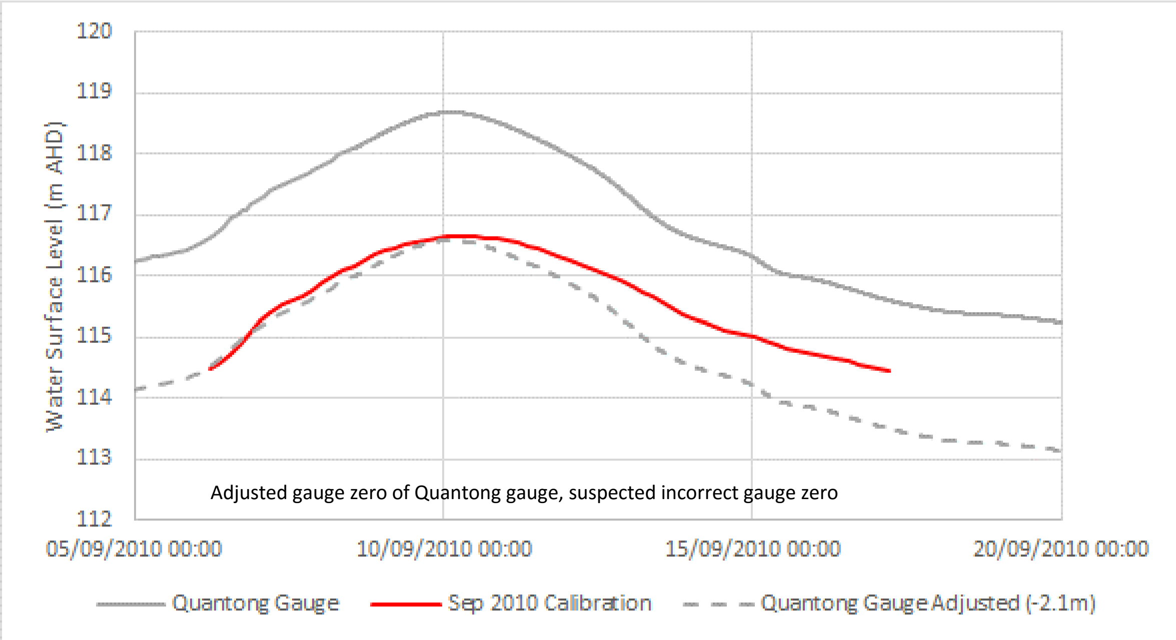


Figure 6-9 Recorded and Modelled Flood Levels at Quantong Gauge

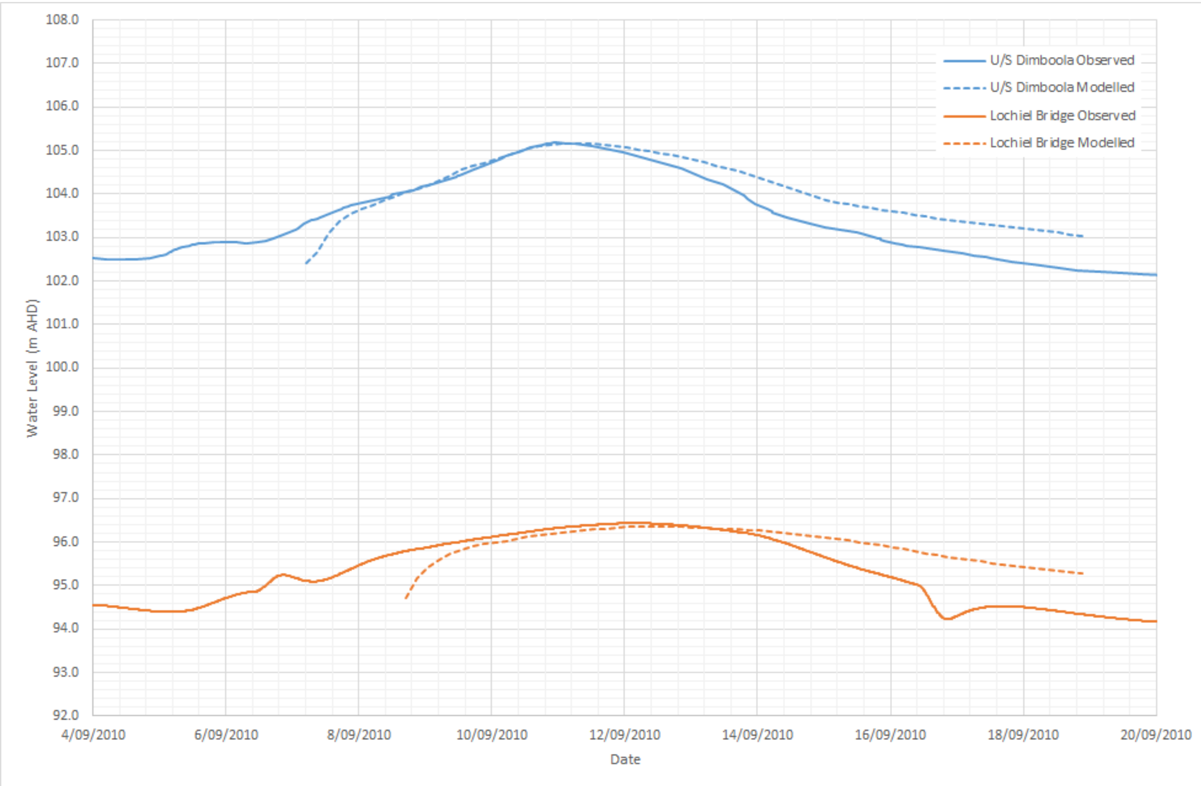
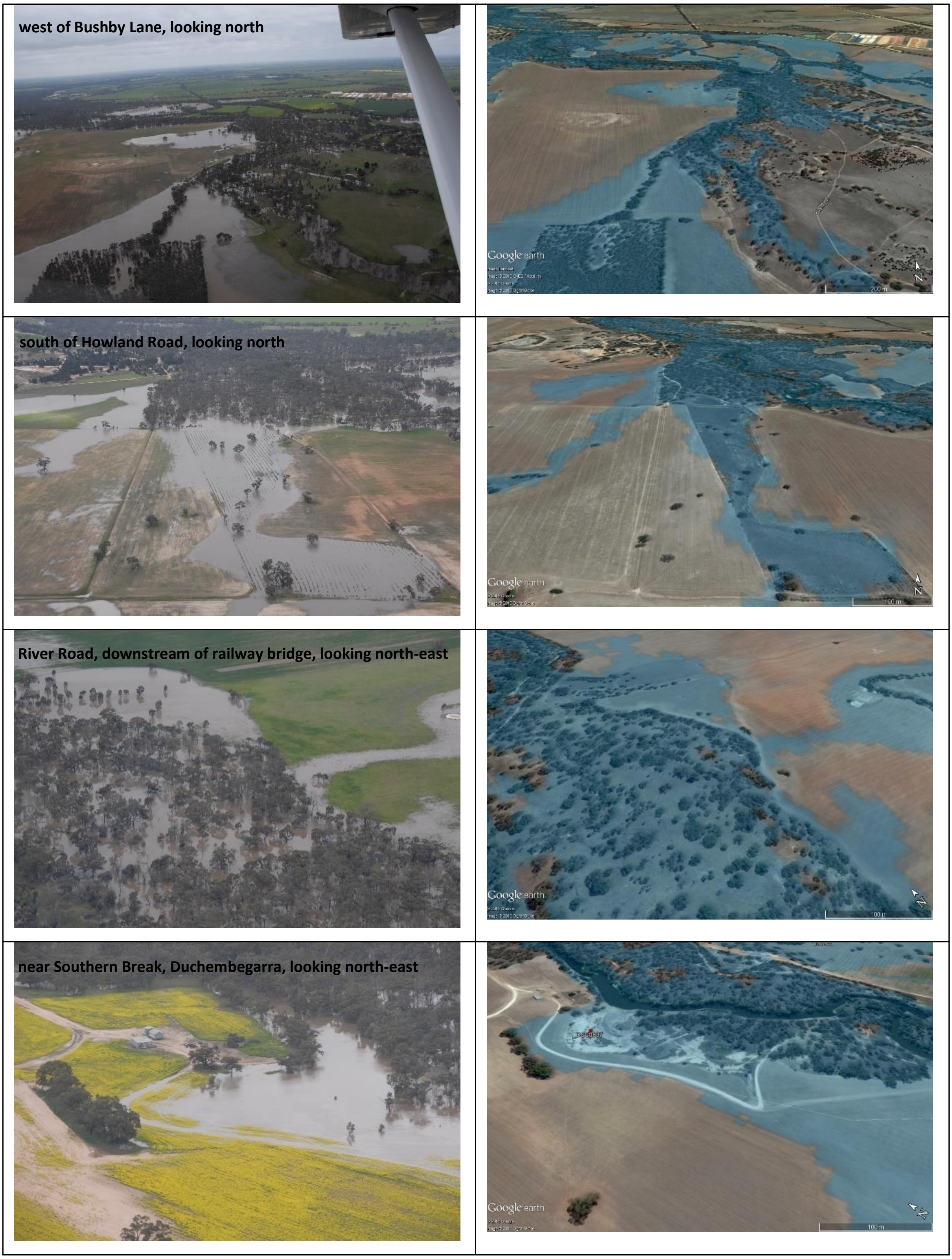


Figure 6-10 Modelled and Gauged hydrographs at U/S of Dimboola and Lochiel Bridge

Comparison to Flood Imagery

Unlike the January 2011 calibration event, the September 2010 event did not have quality oblique aerial photographs of the floodplain taken during the event. A number of photos were taken from the window of an aircraft on the 11th September 2010 between Quantong and Tarranyurk. The river was peaking around Dimboola on the 11th of September, so the comparisons shown below in Figure 6-11 concentrate on the area upstream and downstream of Dimboola. The comparisons demonstrate that the modelled flood extents replicate the observed flooding in September 2010.



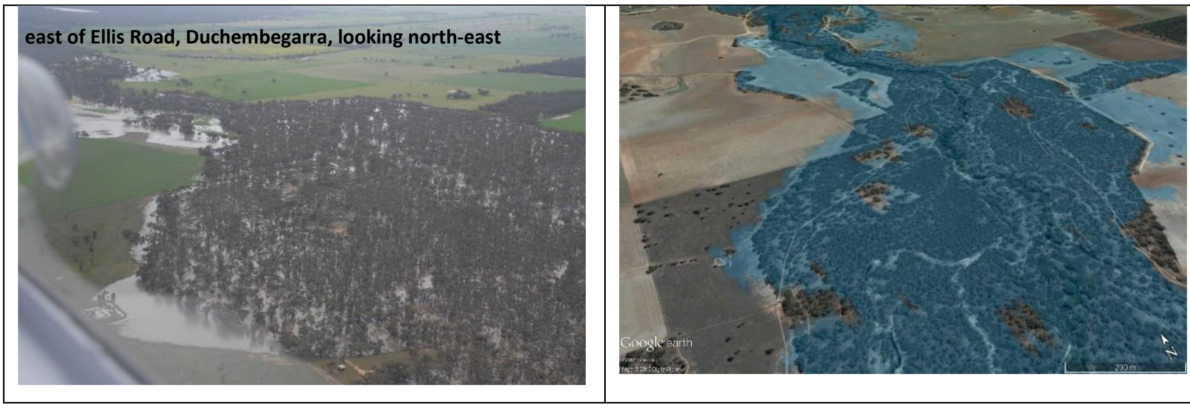


Figure 6-11 Comparison between flood photos and modelled flood extents near Dimboola on 11th September 2010

Discussion

The September 2010 model calibration was reliant on less information than the January 2011 event. Of the peak flood height survey points the model generally matched well with some exceptions noted above. In the areas where the September 2010 modelled results didn't match the surveyed levels well, the model was shown to have good match to the January 2011 event. Further the model replicated the observed peak levels and hydrograph shape well at the U/S Dimboola and Lochiel Bridge gauges, and the flood extents matched the available flood photography.

Either the model is not performing as well at low flows, localised influences may have caused discrepancies, or the flood level pegging and post event survey was not as accurate for the September 2010 event as the January 2011 event. On the weight of evidence it is likely that the September 2010 flood level pegging and survey was of lower accuracy than the January 2011 survey. The September 2010 event was considered to provide a reasonable verification of the hydraulic model performance.

6.4 Sensitivity Testing

The sensitivity of the hydraulic model to changing hydraulic roughness and to including local tributary inflows was tested for the January 2011 flood event.

6.4.1 Roughness

The final hydraulic model calibration utilised a constant Manning's 'n' of 0.06. Sensitivity of modelled peak flood levels to variations in Manning's 'n' were tested for the January 2011 flood event, including values ranging from 0.05 to 0.07. Local tributary inflows were excluded from this analysis.

A Manning's 'n' of 0.05 yielded peak levels consistently 100 mm below the calibrated model. An increase in Manning's 'n' to 0.07 increased water levels to consistently 100 mm above the calibrated model.

The Hydraulics Report (R03) provides further discussion and figures describing the sensitivity analysis.

The median value of 0.06 was adopted as it fitted very closely with recorded flood marks throughout the model and presented the best representation of flood extents compared to the aerial photography across the whole model extent.

A Manning's 'n' value of 0.06 is consistent with recommendations from Chow (1959) which suggests this as an appropriate value for a main channel with weedy winding reaches, deep pools and shoals. It is also consistent with light brush and trees on floodplains.

6.4.2 Tributary Inflows

Initial sensitivity analysis was completed with and without the inclusion of tributary inflows to the lower Wimmera River from the Mackenzie River, Darragan Creek Sandy Creek and Norton Creek.

The modelled and recorded levels were compared at the Quantong Gauge, and it was shown the tributary inflows resulted in the rising limb of the hydrograph rising quicker as a result of the increased volume in the modelled scenario. The peak water level at Quantong was not altered. The flood extent was very similar for both scenarios. Including the tributary inflows resulted in a consistent increase in water level of less than 0.05 m, except for a 6 km stretch of river south of Dimboola and a region around Jeparit, both of which were less than 0.10 m higher with tributary inflows. Due the reduced volume of water input to the model when tributaries inflows were not included, levels in Lake Hindmarsh were between 0.10-0.50 m lower in this case.

6.5 Design Hydraulic Modelling

The calibration process determined a constant Manning's 'n' value of 0.06 across the hydraulic model extent resulted in the best match to historic flood level and extent information. This is representative of the homogenous nature of the vegetation and waterway condition along the length of the Wimmera River from Horsham to Lake Hindmarsh. As a result, the same value of 0.06 was adopted for the design modelling.

The sensitivity analysis confirmed there is little impact on the peak flood flows and therefore flood level and extent from the contributing catchment flows between Horsham and Quantong in most locations. However, there is a contribution of volume from these tributaries early in a flood event. Therefore, taking a conservative approach, these tributaries were included for the design hydraulic modelling.

The design flows determined in the Hydrology Report (R02) for the Horsham (Walmer) Gauge were applied to the hydraulic model with the model topography and Manning's 'n' value from the calibration process. The tributary inflows were added using the same methodology determined for the calibration events, utilising the RORB model constructed during the Horsham and Wartook Valley Flood Investigation and parameters determined during the Natimuk Flood Investigation, altered for this catchment. The same model parameters and losses used for calibration were used for design. The Bureau of Meteorology IFD values were used from the centroid of the tributary catchment for design event modelling. The Mackenzie River at McKenzie Creek design flows as determined in the Hydrology Report (R02) were used.

The design flood extents for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events are presented in Figure 6-12 to Figure 6-14, with all design events overlayed. The flood mapping provides a comprehensive set of flood mapping for the lower Wimmera River downstream of Horsham. A PMF event was also run, and it was found that the modelled flood extent reached the side of the model in several locations and the extent may be underestimated in some places. The supplied PMF outputs should be viewed with the mapping limits to understand where the flood extent may be limited by the sides of the model. Initial PMF simulations showed elevated flood levels through Lake Hindmarsh and Jeparit. The model was revised to include the outlet of Lake Hindmarsh to model the spill that would flow through to Lake Albacutya in an extreme event. The design water levels were checked, and in all events with the exception of the PMF, the Lake Hindmarsh water level was maintained below the outlet sill. The PMF extent is shown in Figure 6-15.

The intent of the regional flood mapping is not to replace the detailed flood mapping completed for Jeparit and Dimboola, however as discussed in the Flood Intelligence Report (R04), the previous modelling had limitations in the extent of LiDAR information that may have impacted on model results. It is suggested that in this instance the mapping produced as part of this study replace the earlier flood mapping at Jeparit and Dimboola.

The design flood mapping has extended from the Wimmera River at Horsham (Walmer) gauge to Lake Hindmarsh. It is recommended that this mapping be used from Quantong to Lake Hindmarsh and that the mapping produced as part of the current Horsham and Wartook Valley Flood Investigation (Water Technology, ongoing), be used in preference for the reach between Horsham and Quantong. This is because it has been noted that there are some discrepancies in modelled water levels immediately around the upstream boundary at the Horsham (Walmer) gauge in the current mapping. This is due to a localised model boundary issue, with the latest version of the model software correcting the issue. Not that this issue is localised and has no impact on model results elsewhere in the model.

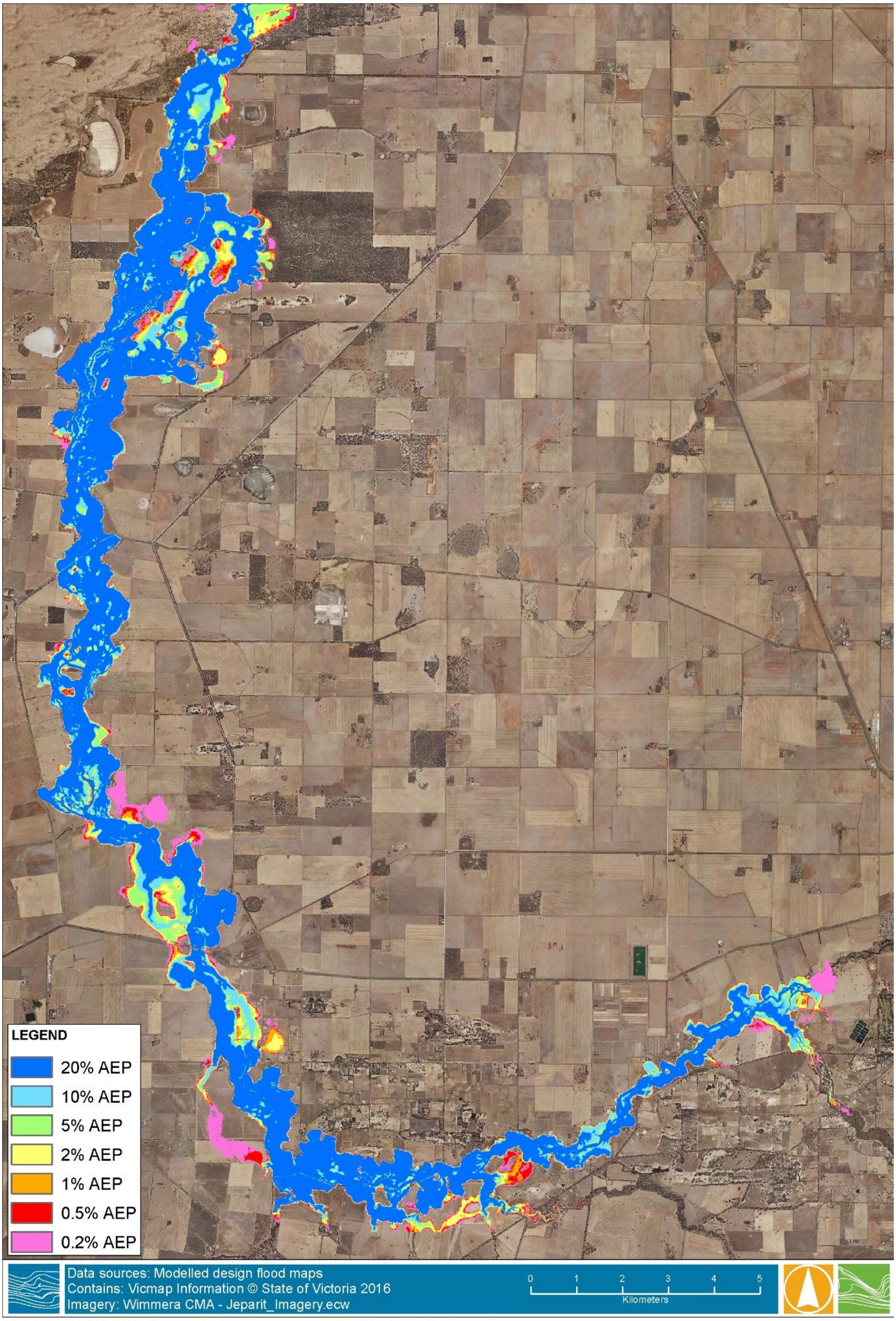


Figure 6-12 Lower Wimmera River Design Flood Extents – Horsham to Duchembegarra

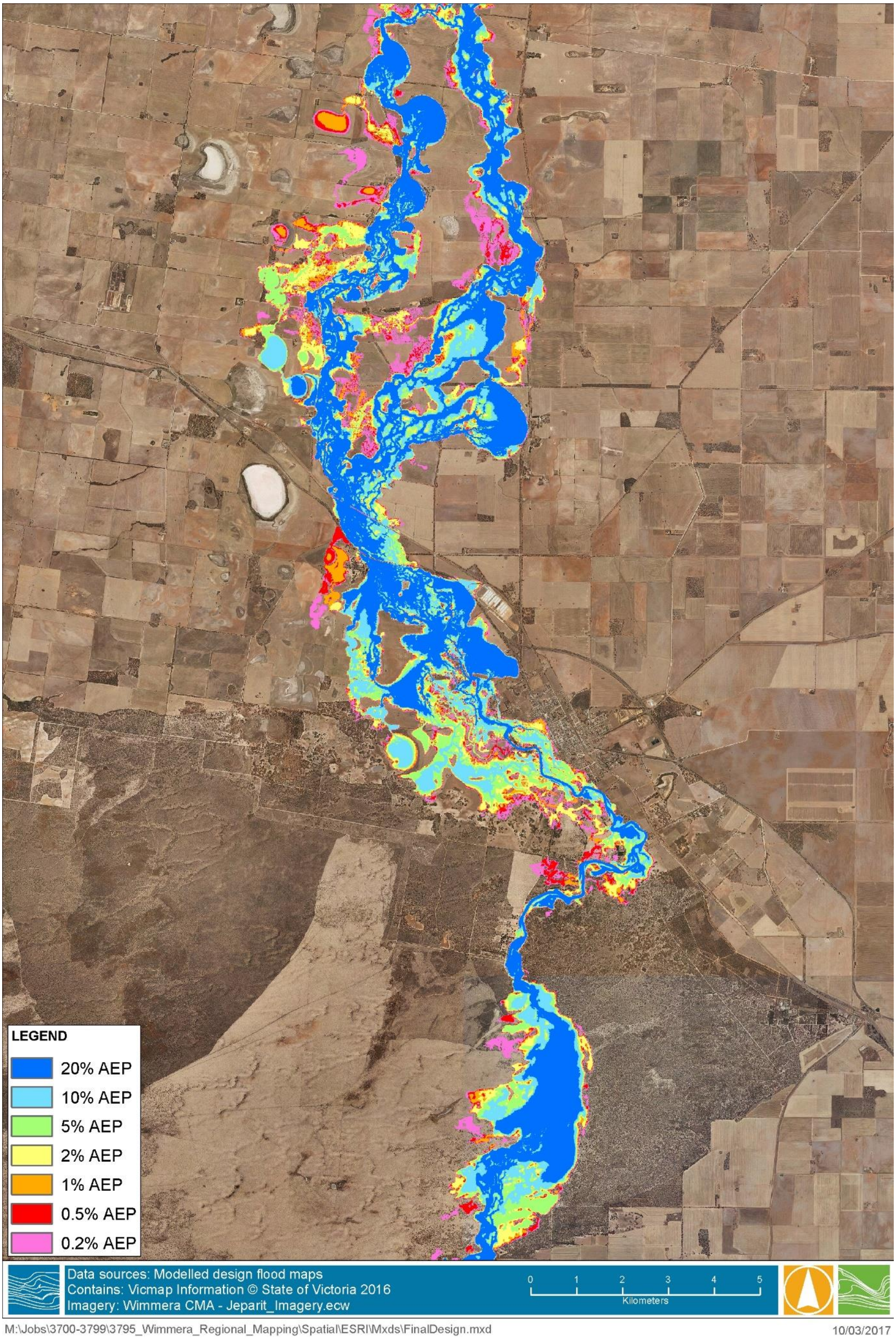


Figure 6-13 Lower Wimmera River Design Flood Extents – Duchembegarra to Antwerp

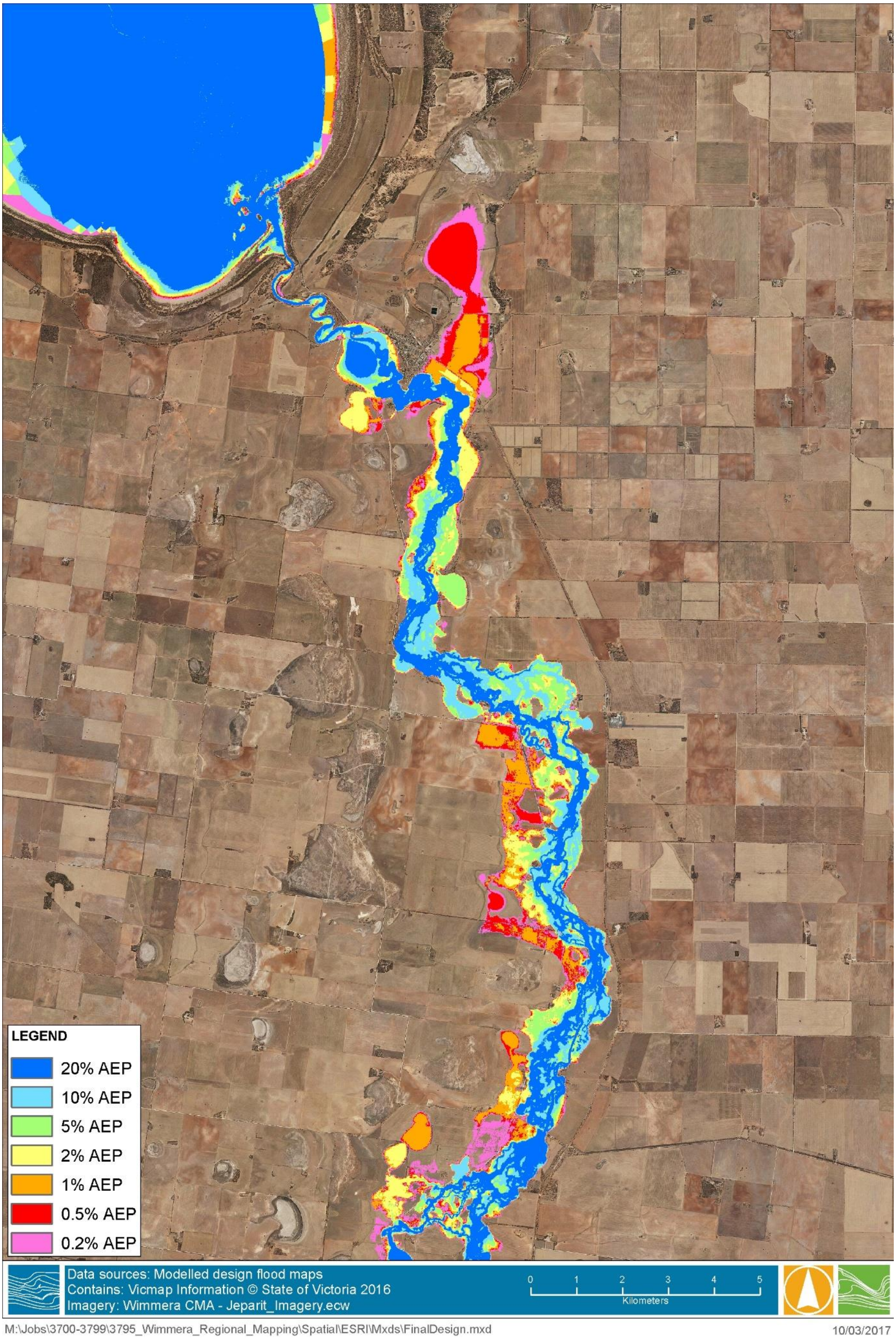


Figure 6-14 Lower Wimmera River Design Flood Extents – Antwerp to Lake Hindmarsh

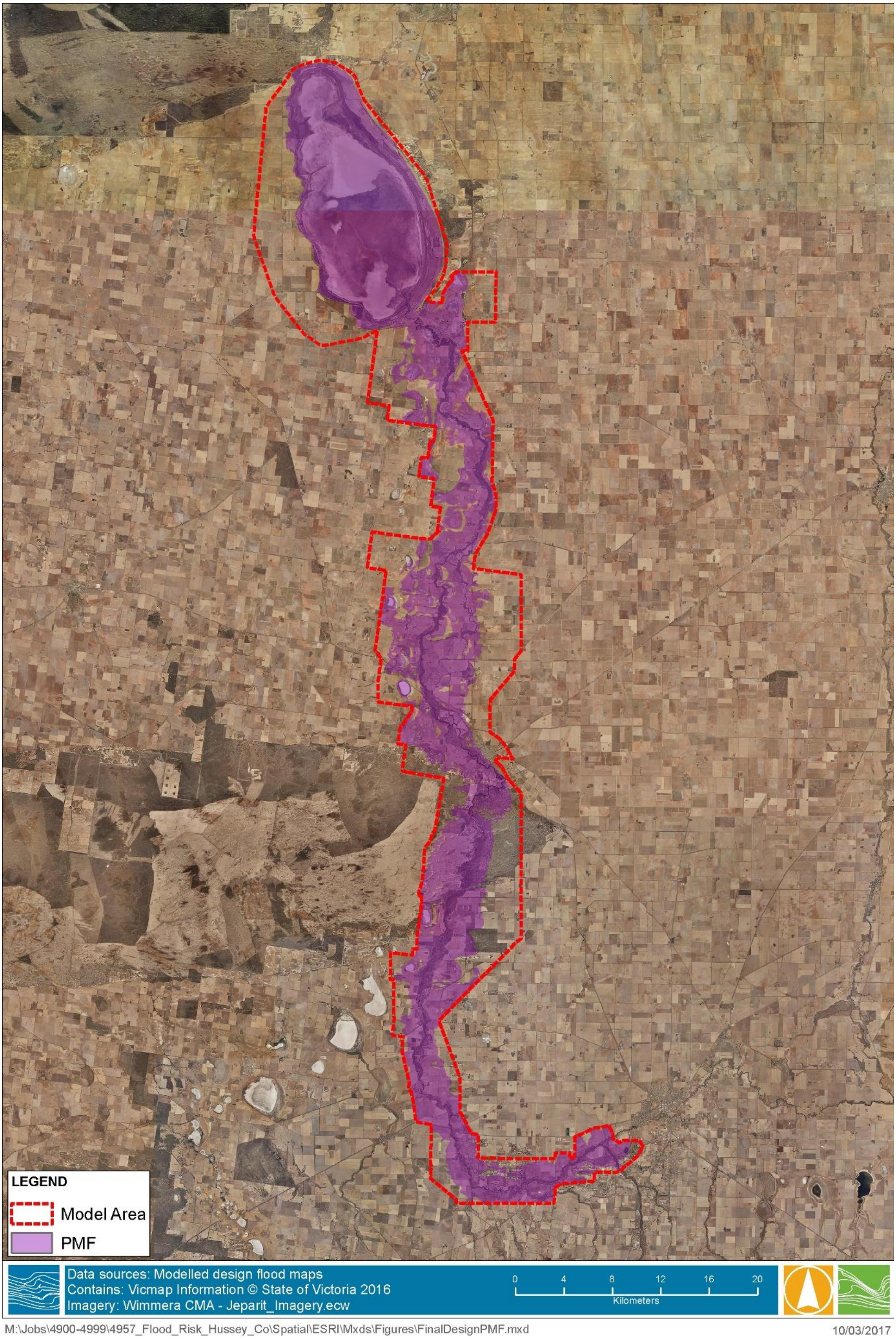


Figure 6-15 Lower Wimmera River PMF Flood Extent

7. FLOOD BEHAVIOUR AND INTELLIGENCE OUTPUTS

7.1 Overview

The flood behaviour and intelligence outputs developed as part of the Lower Wimmera Regional Flood Investigation are described in this section. The Flood Intelligence Report (R04) should be used to update the relevant sections of the local Municipal Flood Emergency Plans.

The 1% AEP modelling was compared to previous township mapping carried out in 2008. The flood levels at Jeparit was approximately 5 cm higher than the 2008 study in the middle of the previous study area between the Wimmera Mallee Pioneer Museum and the Nhill-Jeparit Road. Closer to the boundaries, the model results diverged more and it is likely that the regional modelling is more accurate in these locations due to the localised influence of the model boundary with the smaller township model. At Dimboola, the flood levels matched closely, within 10 cm, however the flood extents from the 2003 study were restricted due to a lack of topography survey.

It is recommended that for future flood response and land use planning that the regional flood mapping be used in preference over the earlier township modelling given the age of the studies, the lack of survey in the earlier studies and the fact that the flood levels are in general agreement. The earlier studies adopted a very simple steady state approach to the hydrology, not as rigorous as this study.

7.2 Gauge Height Relationships

For each design flood event the model results were interpreted to provide information on the relationship between the flood level at each of the gauges on the Wimmera River within the study area.

Table 7-1 Wimmera River @ Horsham (Walmer) Gauge Heights for Design Flood Events

Gauge Level		Design Flood Event		Design Flood Flow	
Relative (m)	m AHD	AEP (%)	ARI (years)	ML/d	m^3/s
3.40	123.78	20	5	13,100	152
3.72	124.10	10	10	19,200	222
3.96	124.34	5	20	25,000	289
4.23	124.61	2	50	31,900	369
4.40	124.78	1	100	36,500	423
4.52	124.90	0.5	200	40,700	471
4.67	125.05	0.2	500	45,400	525

Note: Gauge located immediately upstream of Mackenzie River confluence, large Mackenzie River flows can impact on water levels recorded at the gauge. Gauge zero equal to 120.381 m AHD, rating curve extrapolated beyond 4.20 m. Hydraulic model not well calibrated at this gauge due to boundary of model, design flow and gauge level relationship based on the gauge rating curve not modelled results.

Table 7-2 Wimmera River @ Quantong Gauge Heights for Design Flood Events

Gauge Height		Design Flood Event		Design Flood Flow	
Relative (m)	m AHD	AEP (%)	ARI (years)	ML/d	m^3/s
6.72	116.73	20	5	12,300	142
6.98	116.99	10	10	18,300	212
7.18	117.19	5	20	24,000	278
7.34	117.35	2	50	30,100	349
7.43	117.44	1	100	34,000	394
7.50	117.51	0.5	200	37,400	433
7.58	117.59	0.2	500	41,000	475

Note: Gauge located downstream of the Wimmera Highway at the timber rail bridge. Gauge zero of 110.01 m AHD was surveyed during this study, prior to that the gauge zero was incorrect by almost 2 m. Quantong gauge does not have a rating curve, it is a level gauge only. Design flows are extracted from hydraulic model.

Table 7-3 Wimmera River @ U/S Dimboola Gauge Heights for Design Flood Events

Gauge Level		Design Flood Event		Design Flood Flow	
Relative (m)	m AHD	AEP (%)	ARI (years)	ML/d	m^3/s
4.78	105.27	20	5	11,900	138
5.19	105.68	10	10	18,000	208
5.49	105.98	5	20	23,600	274
5.77	106.25	2	50	29,500	341
5.93	106.42	1	100	33,400	387
6.07	106.55	0.5	200	36,800	426
6.21	106.69	0.2	500	40,600	470

Note: Gauge located off dirt track immediately north of Hinnebergs Road. Gauge zero equal to 100.486 m AHD, the rating curve is extrapolated beyond 5.50 m. Design flows are extracted from hydraulic model and may be slightly different to flows from rating curve.

Table 7-4 Wimmera River @ Lochiel Bridge Gauge Heights for Design Flood Events

Gauge Height		Design Flood Event		Design Flood Flow	
Relative (m)	m AHD	AEP (%)	ARI (years)	ML/d	m^3/s
4.10	96.39	20	5	10,500	122
4.26	96.55	10	10	15,800	183
4.39	96.68	5	20	21,200	245
4.50	96.79	2	50	26,800	310
4.56	96.85	1	100	30,200	349
4.61	96.90	0.5	200	32,800	379
4.65	96.94	0.2	500	35,500	410

Note: Gauge located immediately upstream of the rail bridge downstream of Dimboola. Gauge zero of 92.289 m AHD, the rating curve is extrapolated beyond 4.60 m. Design flows are extracted from hydraulic model and may be slightly different to flows from rating curve.

7.3 Summary of Flood Behaviour

Table 7-5 describes the key flood characteristics of the Wimmera River between Horsham and Lake Hindmarsh. The table has been developed to be read from top to bottom, with each subsequent larger magnitude event reporting on the incremental changes in consequences. For example, if the reader is wishing to understand the consequences of a 2% AEP event, then the flood characteristics should be read for the 20%, 10%, 5% and 2% AEP events in succession. It is also recommended that the reader refer to the standard PDF maps provided alongside this study. There is a separate map for each modelled design event and thy provide peak flood depths, extents and water surface elevations for each flood event.

Due to the confined nature of the Wimmera River floodplain, there is not a significant difference in the flood extent across the design flood events in many locations. In some lower flatter areas, larger differences in flood extents are observed as the flow magnitude increases

Table 7-5 Summary of Flood Behaviour for Various Flood Events

Event	Flood Characteristics	Key roadways inundated
20% AEP	• Intersection at Horsham-Noradjuha Road and Three Bridges Road becomes inundated • Dimboola golf course inundated in low areas • Between Dimboola and Antwerp, potential for rural properties to be isolated around Five Chain, Klinge and Bothe Roads • No properties are flooded above floor • 2 properties in Dimboola and 1 property in Quantong experience below floor flooding • Rural cropping land inundated	• Horsham-Noradjuha Rd at intersection with Three Bridges Rd and north of the bridge • Dimboola-Rainbow Rd (300m upstream of Arkona-Katyil Rd) • Obrees Rd, Vectis • Forts Ln, Vectis • Old Duchembegarra School Rd, Duchembegarra • Riverside Rd, Dimboola • Swallows Ln, Dimboola • Howland Rd, Dimboola • Bothe Rd, Dimboola • Ebenezer Mission Rd, Dimboola • Tarranyurk West Rd, Jeparit • Spears Crossing Rd, Antwerp
10% AEP	• Extent of flooding increases directly downstream of Horsham-Noradjuha Rd • Breakout flow in Quantong across Struthers Ave, re-connects with Wimmera River downstream of Overall Ave • Extent of flooding increased across floodplain adjacent to Little Desert National Park • Floodwaters begin to encroach on the western side of Dimboola • Property on Hateleys Road near river is isolated • Properties between Antwerp and Jeparit isolated • No properties are flooded above floor • 6 properties in Dimboola, 1 in Vectis and 1 in Quantong experience below floor flooding	In addition to above: • Collard Rd, Dimboola • Five Chain Rd, Dimboola • Klinge Rd, Dimboola • Park Street, Dimboola • Wimmera St, Dimboola • Antwerp-Woorak Rd, Antwerp • River Rd, Antwerp • Polkemmet Road

Event	Flood Characteristics	Key roadways inundated
5% AEP	• Floodwaters extend across farmland around the confluence of Mackenzie River and Wimmera River • Floodwaters from Norton Creek cross the floodplain adjacent to Wimmera River and connect with Sandy Creek (north of Horsham-Noradjuha Road) • 1 property in Dimboola is flooded above floor, 3 properties in Dimboola experience inundation within 100mm of the floor level • 20 properties in Dimboola, 3 in Vectis and 1 in Quantong experience below floor flooding	In addition to above: • Lloyd St, Dimboola • Blocks Rd, Quantong
2% AEP	• Extent of flooding very similar to 5% AEP event • 8 properties in Dimboola and 2 in Jeparit experience over floor flooding • 4 properties in Dimboola and 1 property on the river 6 km from Natimuk experience inundation within 100mm of the floor level • 43 properties in Dimboola, 1 in Jeparit, 1 in Quantong and 4 in Vectis experience below floor flooding	In addition to above: • Nhill-Jeparit Rd, Jeparit

Event	Flood Characteristics	Key roadways inundated
1% AEP	• Breakout from Wimmera River south at Lindners Road towards Norton Creek • Floodwaters overtop levee and inundate land between Dimboola-Rainbow Rd and Jeparit East Rd near Jeparit • 11 properties in Dimboola and 16 in Jeparit experience over floor flooding • 5 properties in Dimboola, 5 in Jeparit are flooded and 1 property on the river 6 km from Natimuk are flooded within 100 mm of the floor level • 2 properties in Antwerp, 61 properties in Dimboola, 10 in Jeparit, 1 in Lower Norton, 3 in Quantong and 5 in Vectis experience below floor flooding	In addition to above: • Charles St, Jeparit
0.5% AEP	• Banksia Court properties south of Dimboola are inundated • 14 properties in Dimboola, 20 in Jeparit and 1 property on the river 6 km from Natimuk experience over floor flooding • 6 properties in Dimboola and 2 in Jeparit are flooded within 100 mm of the floor level • 2 properties in Antwerp, 66 in Dimboola, 11 in Jeparit, 1 in Lower Norton, 3 in Quantong and 6 in Vectis experience below floor flooding	In addition to above: • Banksia Court, Dimboola • Jeparit East Road, Jeparit
0.2% AEP	• Flood waters starting to get close to sewerage treatment plant outside of Horsham • Wimmera River breakout near Darragan Ck to the west, across farm land and back to the river at Hateleys Rd • Property south of Obrees Rd, Vectis, isolated by breakout • Increased inundation of Banksia Court, Dimboola	In addition to above: • Horseshoe Bend Rd, Dimboola

7.4 Flood Impacts

Floor level survey was captured for properties deemed at risk of flooding in Vectis, Lower Norton, Quantong, Natimuk, Duchembegarra, Pimpino, Antwert, Dimboola and Jeparit. Comparison of these levels to the modelled flood level at the property location provides an indication of the type of flooding (above or below floor) that may be expected across the range of design events. Tables of flood impacts to surveyed properties are provided in Appendix 1, sorted by locality and in order of flood risk.

Note that water surface elevations have been sampled at the location of the property and is not representative of flooding across the entire parcel. It is therefore possible that a property that is identified as not flooded in the following tables experiences inundation across the associated land, but away from the building footprint.

All properties surveyed were included in the tables, regardless of their risk of flooding.

During the study a number of observations regarding flood impacts were made by community members during discussion at community meetings that are worth noting. The Wimmera Hwy at Asplins Rd was inundated via overland flow during the January 2011 event, this was potentially hazardous to traffic. A slide gate located on Hughes Lane between Lanes Avenue and Struthers Avenue, Quantong, was opened in an attempt to reduce flooding around Quantong. The slide gate is a part of a decommissioned channel system, it is unlikely that this would impact flood levels upstream. It is recommended that the effectiveness of the gate is reviewed, as it may not warrant operation in future floods. Significant levee removal works were undertaken during January 2011 on a private property north of the Wimmera Highway in an attempt to alleviate flooding. This most likely had no impact on flood levels and it is recommended that this levee not be removed again in future floods.

7.5 Flood Class Levels

Currently the Bureau of Meteorology have determined flood class levels for the Wimmera River at Horsham (Walmer) gauge, Quantong and U/S of Dimboola as shown below in Table 7-6. As can be seen in Table 7-6 the AEP associated with the flood class levels at gauges down the river is highly variable. This is most likely a result of a lack of available data in the past when flood class levels have been set. It is also a result of flood class levels being associated with flood risk at different locations, i.e. a certain magnitude event may not impact Horsham, but may impact Dimboola to a higher level.

The Bureau of Meteorology uses the following definitions to define the flood class levels.

Minor flooding

Causes inconvenience. Low-lying areas next to water courses are inundated. Minor roads may be closed and low-level bridges submerged. In urban areas inundation may affect some backyards and buildings below the floor level as well as bicycle and pedestrian paths. In rural areas removal of stock and equipment may be required.

Moderate flooding

In addition to the above, the area of inundation is more substantial. Main traffic routes may be affected. Some buildings may be affected above the floor level. Evacuation of flood affected areas may be required. In rural areas removal of stock is required.

Major flooding

In addition to the above, extensive rural areas and/or urban areas are inundated. Many buildings may be affected above the floor level. Properties and towns are likely to be isolated and major rail and traffic routes closed. Evacuation of flood affected areas may be required. Utility services may be impacted.

Table 7-6 Current Bureau of Meteorology Flood Class Levels and Associated Design Flood Event from Lower Wimmera Regional Flood Mapping Study

Gauge	Major Flood Class Level (m)	Moderate Flood Class Level (m)	Minor Flood Class Level (m)
Wimmera River at Horsham (Walmer)	3.60 *(20-10% AEP)*	3.10 *(<20% AEP)*	2.80 *(<20% AEP)*
Wimmera River at Quantong	5.90 *(<20% AEP)*	5.40 *(<20% AEP)*	4.50 *(<20% AEP)*
Wimmera River at U/S Dimboola	6.00 *(1-0.5% AEP)*	5.70 *(5-2% AEP)*	5.30 *(10-5% AEP)*

Wimmera River at Horsham (Walmer)

The moderate and minor flood class levels at the Wimmera River at Walmer are both below the smallest event modelled in this study (20% AEP). The major flood class level is between the 20% and 10% AEP event. This study did not include mapping of Horsham township, so it is recommended that the flood class level for this gauge be reviewed as part of the Horsham and Wartook Valley Flood Investigation (Water Technology, ongoing).

Wimmera River at Quantong

The following recommendations for flood class levels at this gauge have been based on the impacts around Quantong itself and rural areas to around Duchembegarra. In the 20% AEP event there is significant floodplain inundated, but no houses are impacted, and only minor farm roads are inundated. In the 10% AEP event Polkemmet Road is inundated, which is a major road in the area. Inundation of this road would not be a significant impact as drivers could use the Wimmera Hwy crossing upstream near Quantong. The flood class levels of the Quantong gauge appear far too low, with concerns raised shortly after the September 2016 flood event that the flood class levels were not in line with flood impacts. The smallest event modelled was the 20% AEP event which is equivalent to 6.7 m on the gauge. The modelled results were assessed and lowered until a flood extent fitting of the minor flood class category was observed. It is recommended that the flood class level be increased to 5.7 m on the gauge. The moderate flood class level could be set at the 10% AEP event level of 7.0 m, at which point Polkemmet Road is inundated, a house on Hateleys Road is isolated and a property in Quantong experiences below floor flooding. The flood extents in the area around Quantong do not change dramatically for events above the 10% AEP, with the impacts to buildings and major infrastructure very minimal. It is suggested that the major flood class level could be set at the 1% AEP event at 7.4 m.

Wimmera River at U/S Dimboola

The current flood class levels all seem too high for the area downstream of Dimboola compared to the impacts shown through the flood modelling. The 20% AEP flood mapping shows impacts at the golf course, along with a number of minor rural roads impacted. It is recommended that the 20% AEP level at 4.8 m on the gauge be used for the minor flood class level. In this event the river is contained within banks through the town, but the rural area downstream, sees flood water breaking out across wide areas. The moderate flood class level could be based on the 10% AEP flood mapping with a level at the gauge of 5.2 m. At this level flood waters are encroaching on the town, inundating a number of public recreational areas, and isolates a number of houses. The major flood class level could be based on the 5% AEP event, at 5.5 m, which the modelling shows is when the first building experiences above floor flooding. This is a significant reduction in the current flood class levels and should be discussed with the Bureau of Meteorology.

Wimmera River at Tarrenyurk

The Bureau of Meteorology do not monitor this gauge for flood warning purposes, however Wimmera CMA requested that equivalent flood class levels be developed for this gauge. Flood impacts for the area from Tarrenyurk to Jeparit were assessed in the development of the suggested flood class levels for this gauge site. There are no real impacts in the 20% AEP event between Tarrenyurk and Jeparit other than inundation of the lowest part of the floodplain. It is recommended that the 20% AEP event at 83.19 m AHD be used for the minor flood class level. The 10% AEP begins to inundate farmland and public recreational areas along the river with a few rural properties isolated. It is recommended that the 10% AEP event at 83.45 m AHD be used for the moderate flood class level. The 2% AEP event inundates two buildings above floor in Jeparit. It is recommended that the 2% AEP at 83.78 m AHD could be adopted as the major flood class level.

It is recommended that the Bureau of Meteorology be consulted regarding the above flood class level recommendations as they differ significantly from current flood class levels at the Wimmera River at Quantong and Wimmera River at U/S of Dimboola gauges.

8. RECOMMENDATIONS

The following recommendations are made because of the findings of this study.

- The flood mapping between Quantong and Lake Hindmarsh be used for all current and future flood mapping, flood intelligence, land use planning and insurance purposes. The flood mapping and flood intelligence outputs from this study should replace the previous Dimboola and Jeparit flood study outputs.
- The flood mapping from this study between the Wimmera River at Horsham (Walmer) gauge and Quantong, will be superseded by the Horsham and Wartook Valley Flood Investigation on completion of that study in the coming year. Until that time, the flood mapping from this study can be used.
- The flood mapping in this study be used to develop Land Subject to Inundation Overlays and Floodway Overlays for the Hindmarsh Planning Scheme.
- The Victorian Flood Database (VFD) should be updated using the outputs of this study which have been formatted into the standard VFD outputs.
- The VFD deliverables should be uploaded to FloodZoom.
- The gauge datums at several Wimmera River gauges should be updated in the Water Information Monitoring System (WIMS) using the recently acquired survey data.
- The Bureau of Meteorology Flood Class Levels at Quantong and Dimboola gauges be reviewed and the recommendations made for revision of these levels be considered by the Bureau of Meteorology.
- The relevant Municipal Flood Emergency Plans be updated using the flood intelligence developed during this study.
- Review the effectiveness of the slide gate in Quantong that was operated during the January 2011 event and the large levee removal near Quantong also completed in January 2011, and communicate the findings to all parties involved to streamline future flood response efforts.