Regional Flood Mapping
Lower Wimmera – Hydraulics (R03)

January 2017

Wimmera CMA

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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 details the hydraulic calibration undertaken for the project as well as presenting initial design event modelling for the 1% AEP event. This report should be read in conjunction with the previous Data Review Report (R01) and Hydrology Report (R02).

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.

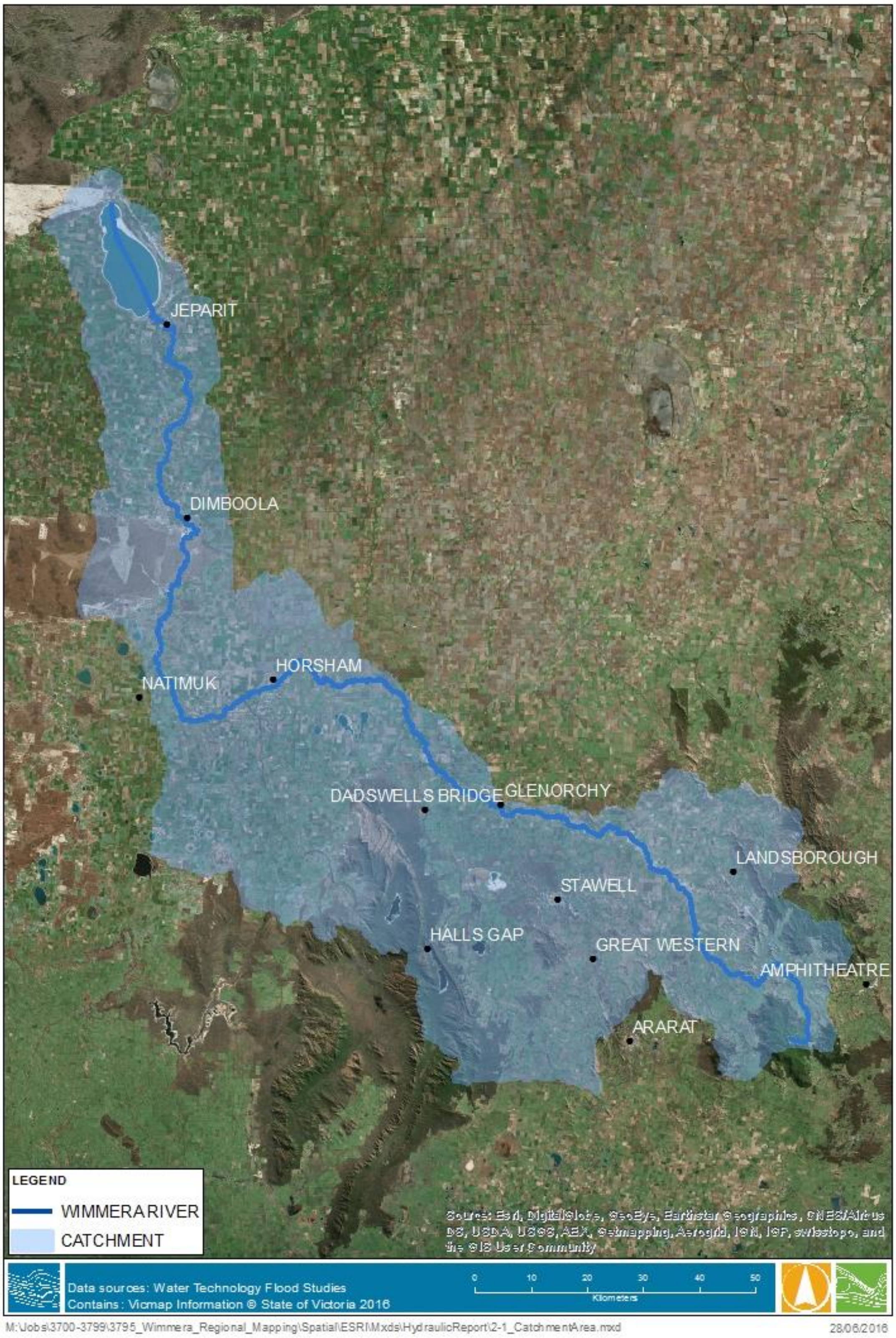


Figure 2-1 Catchment Area of the Wimmera River

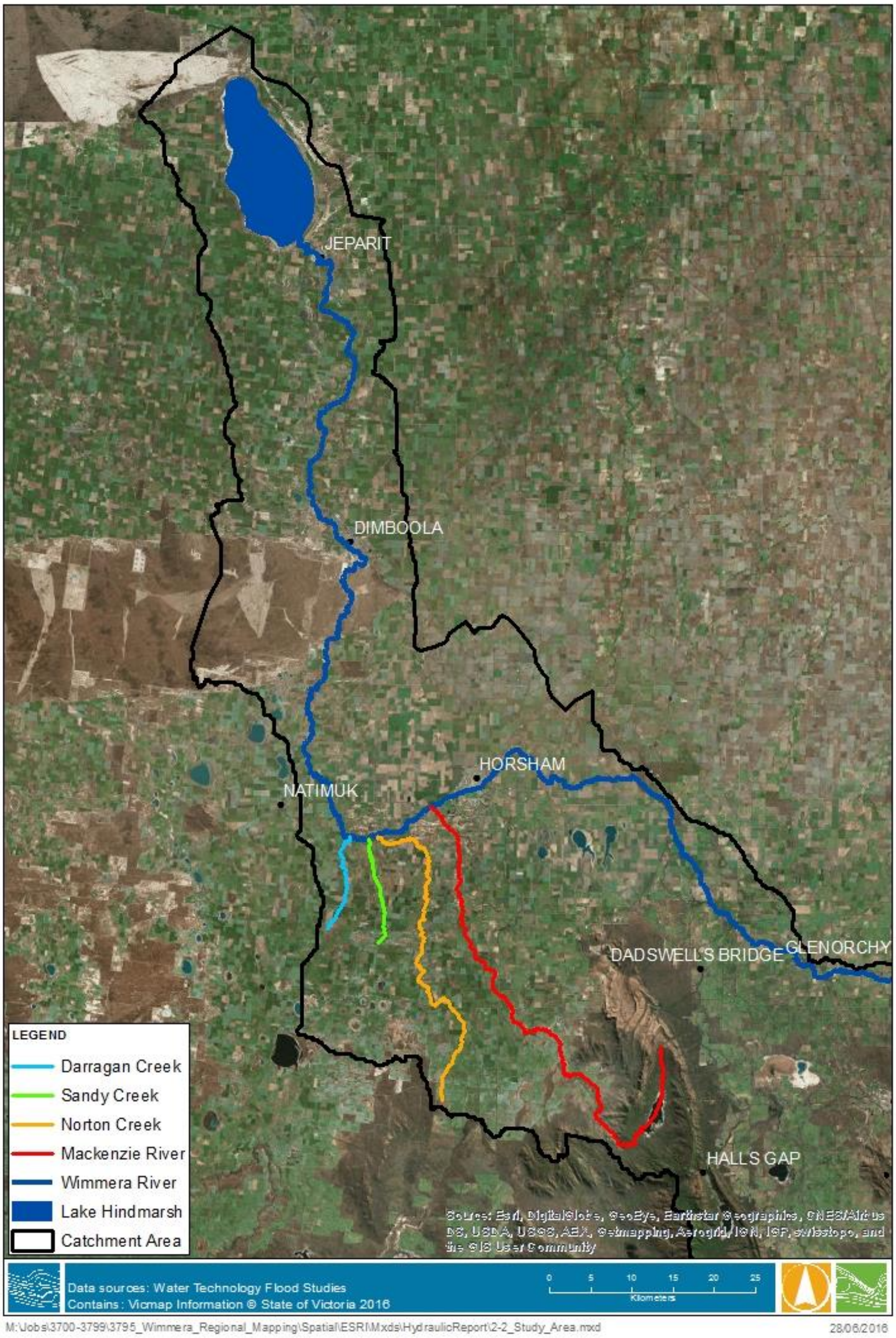


Figure 2-2 Lower Wimmera Study Area and Major Tributaries

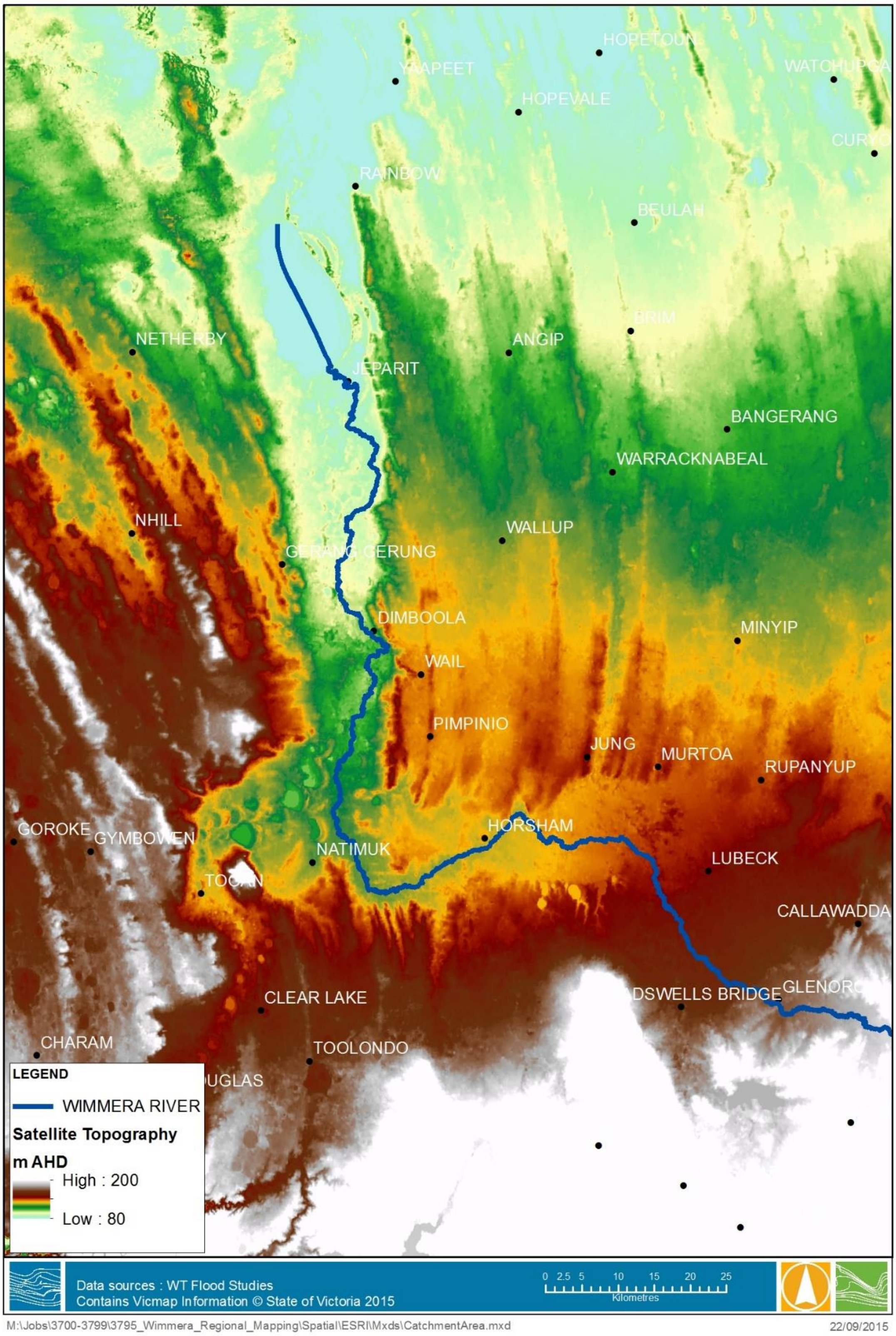


Figure 2-3 Topography of the Lower Wimmera River

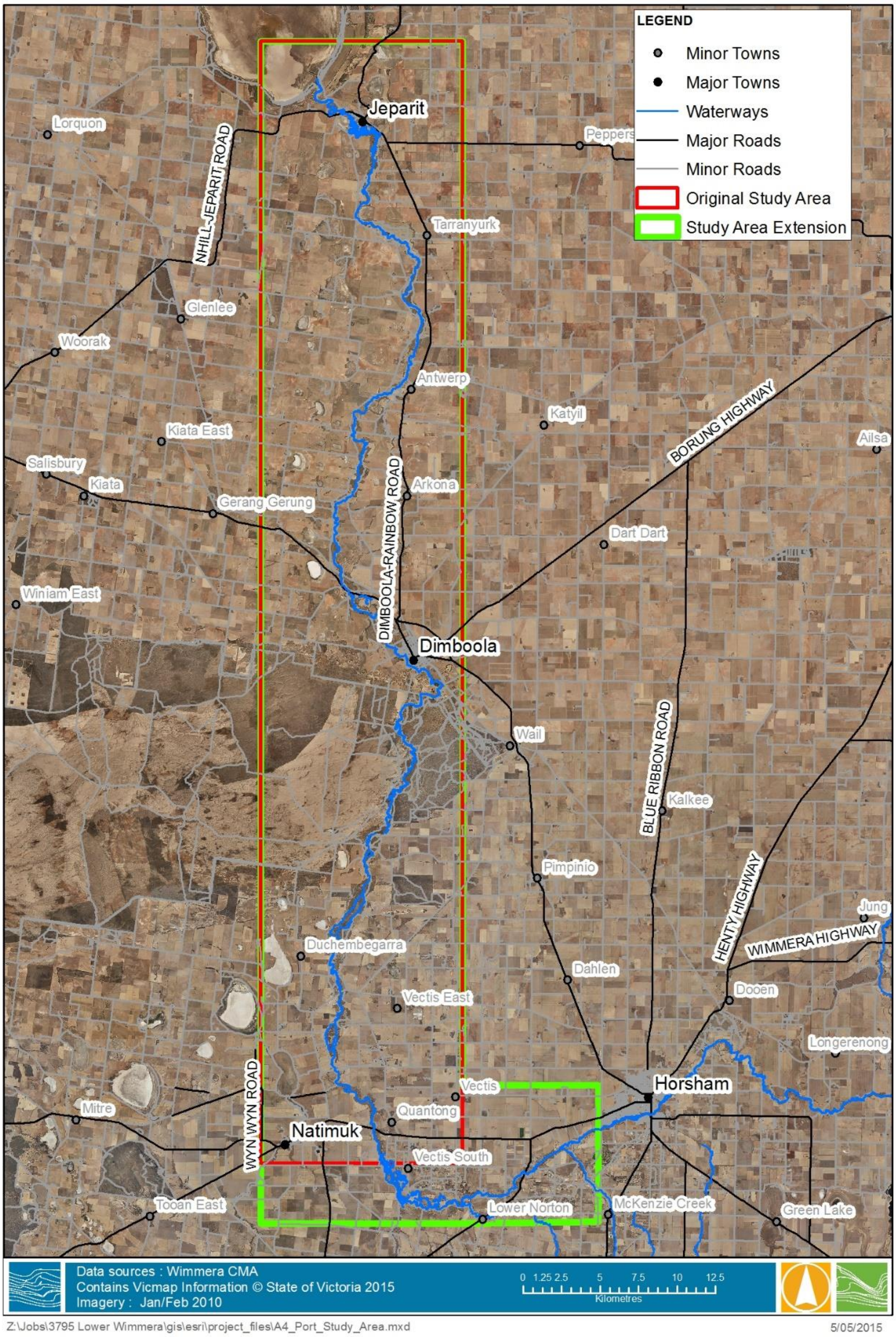


Figure 2-4 Lower Wimmera Study Area

3. MODEL DEVELOPMENT

3.1 Modelling Approach 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.

3.2 Topography

3.2.1 LiDAR Availability

There are four LiDAR datasets available for the study area:

- 2004 Wimmera CMA LiDAR Project Zone 1 (Wimmera River and Yarriambiack Creek trenches)
- 2004 Wimmera CMA LiDAR Project Zone 2 (Remaining Wimmera CMA area)
- 2009-10 Victorian State Wide ISC Rivers LiDAR Project
- 2010-11 Floodplains Stage 2 LiDAR Project

A comprehensive analysis of the available LiDAR was undertaken in the Site Visit and Data Collation Report (R01). From this analysis, a single topographic layer was produced using the most appropriate combination of the available LiDAR datasets across the model area.

The LiDAR comparison suggests that the Floodplains LiDAR generally agrees well with the two WCMA datasets, whereas the Rivers LiDAR appears to have a systematic vertical offset of 0.1 – 0.2m. The survey verification confirms that the Rivers LiDAR is approximately 0.1m too high.

The Floodplains LiDAR is the most recently captured and was flown to a higher vertical accuracy than the 2005 WCMA data. This dataset was used as the base dataset. The Floodplains dataset was then combined with the WCMA Zone 1 dataset which gave full coverage of the Wimmera River floodplain.

3.2.2 Survey Data

Overview

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.

Levees

Levees surveyed during the Jeparit Flood Study separate the township from the Wimmera River, as shown in Figure 3-1. The model mesh was aligned with both of these levees to ensure accurate spatial representation. Surveyed heights along each levee were incorporated into the model as 'dike' structures. This overwrites the existing topography data along the applicable element faces and updates the model topography with the surveyed heights, ensuring water cannot be transferred across these element faces until the water level exceeds the height of the surveyed levee.

River Cross Sections

The five river cross sections surveyed within Jeparit were located at:

- Lake Road crossing
- Nhill-Jeparit Road crossing
- Approximately 750 m upstream of Nhill-Jeparit Road
- The point bend extending Jeparit
- Due west of the Jeparit-Warracknabeal Road

Cross section locations are also shown in Figure 3-2, along with a comparison between the surveyed river cross sections and LiDAR data. The comparison suggested a significant depth of water was pooling upstream of the Jeparit Weir at the time the LiDAR was flown, and this water surface level was represented rather than the river bed level. As the survey cross section locations move further upstream and away from the Jeparit Weir, the difference between survey levels and LiDAR was reduced further confirming the influence of the weir pool.

To ensure the river bed was represented within the topography the relevant elevations within the model mesh were lowered from the original LiDAR values to represent a linear interpolation of river bed level between, and including the lowest point of each survey cross section.

After adjustment of the river bed level upstream of Jeparit Weir, comparison to the LiDAR downstream of Jeparit Weir also suggested the LiDAR was also detecting the water surface level. To resolve this the river bed level between Jeparit Weir and Lake Hindmarsh was lowered to match survey-adjusted levels upstream of the weir.

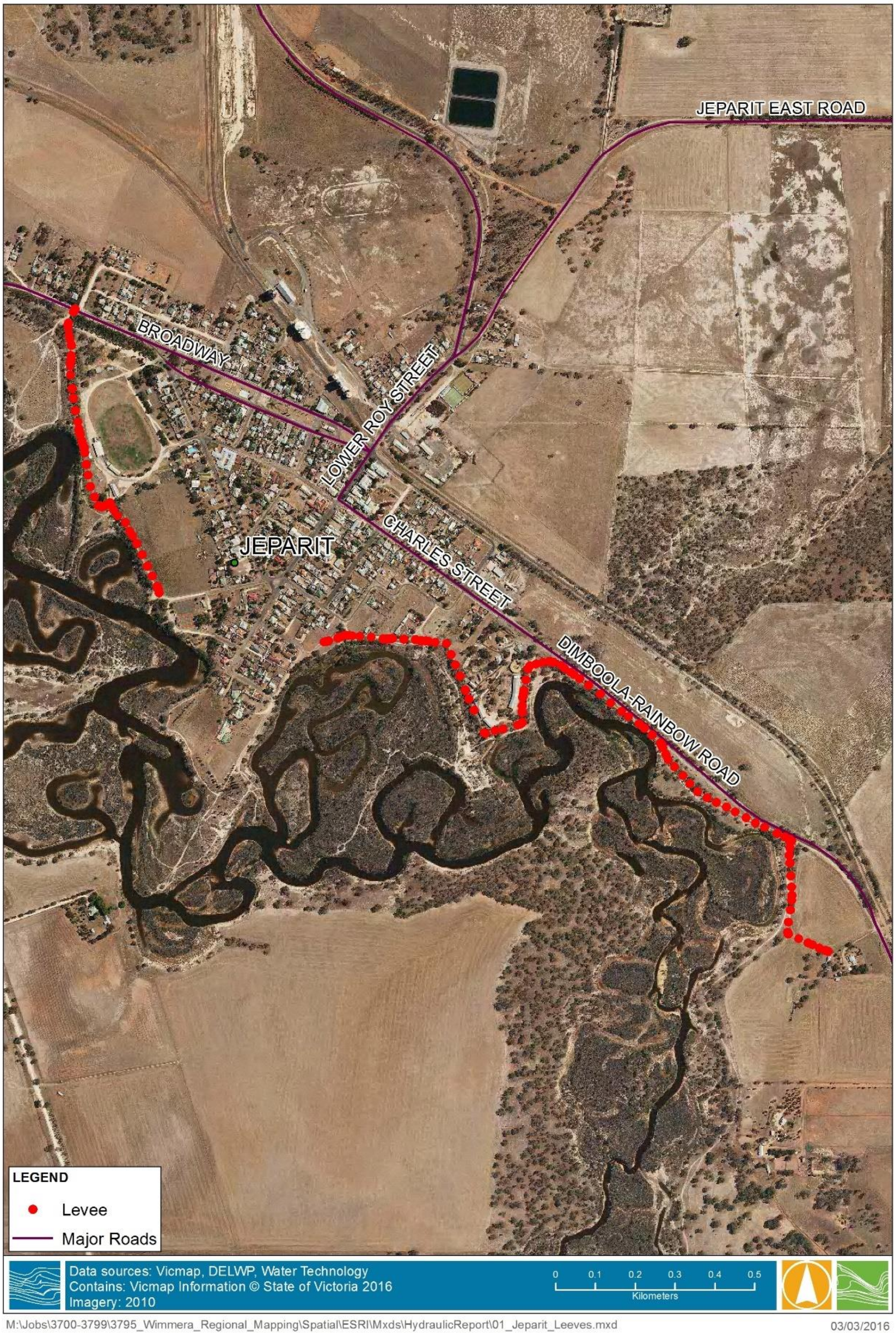


Figure 3-1 Jeparit Levees

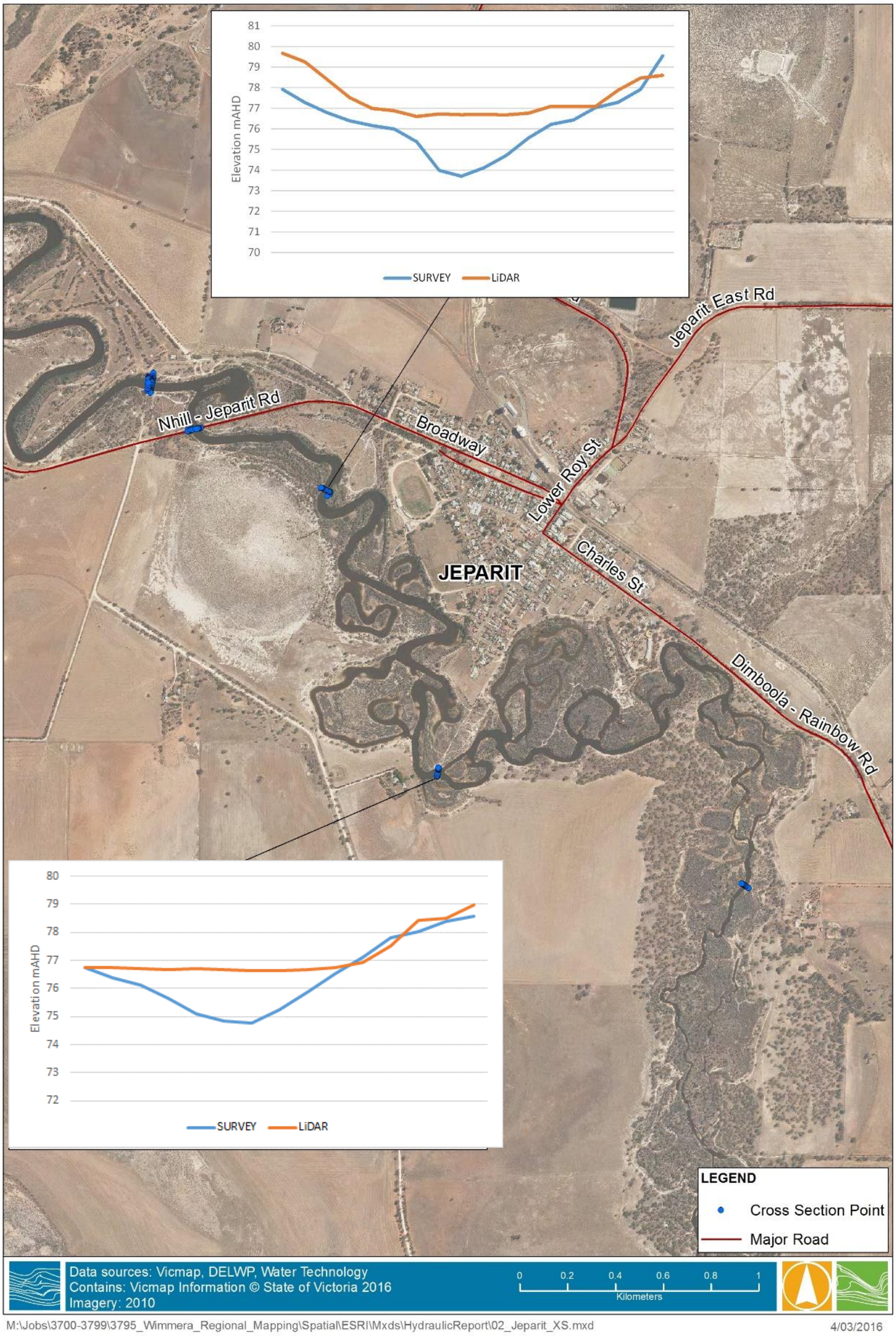


Figure 3-2 Wimmera River cross section – Survey, LiDAR data and corrected model topography comparison

Subsequent review of the LiDAR on either side of Dimboola Weir concluded that water was also pooled upstream of Dimboola Weir at the time the LiDAR was flown. The bed level of the river upstream of Dimboola Weir was lowered to the surface level in the river immediately downstream of the weir (97.5 m AHD). Surface levels upstream of Dimboola Weir were adjusted until the LiDAR appeared to appropriately represent the river bed level. Figure 3-3 shows water level differences from LiDAR either side of the weir indicating water behind the weir was approximately 1.5 m deep.

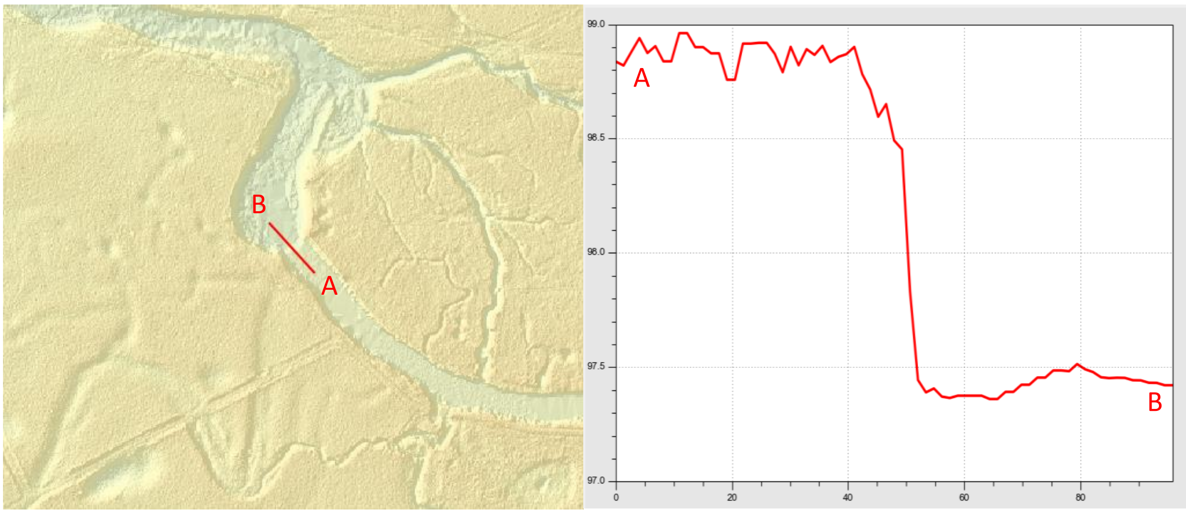


Figure 3-3 Dimboola Weir Pool captured in LiDAR

3.2.3 Mesh Extent and Resolution

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 3-4.

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 is 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 reduces across the floodplain as it extends away from the Wimmera River towards the edge of the model domain. Along the edge of the model domain the mesh resolution is 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 are 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 is 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 allows good representation of the storage capacity of the lake without influencing run times of the model.

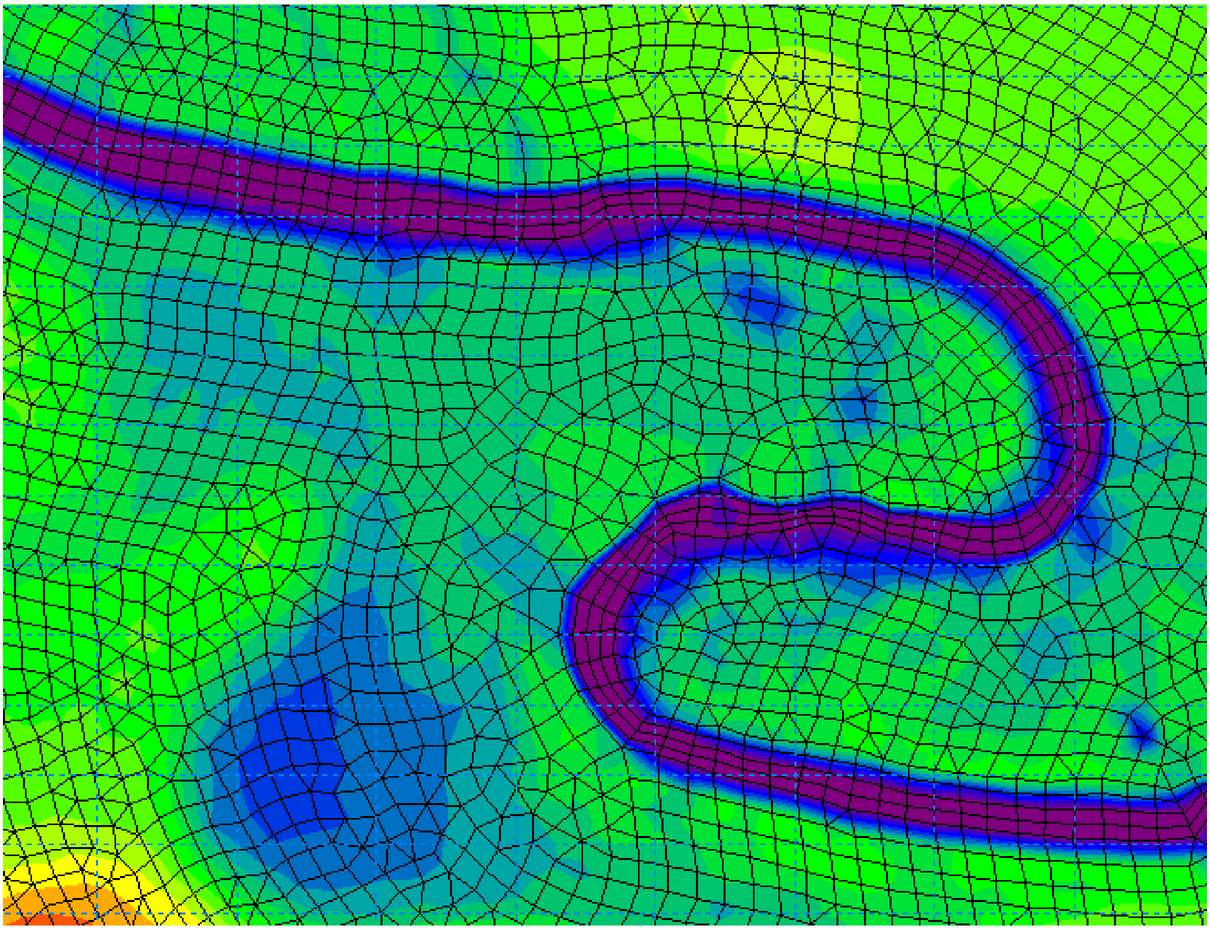


Figure 3-4 Example mesh schematisation

3.3 Hydraulic 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; this is discussed further in Section 4.

3.4 Boundary Conditions

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 3-5.

3.4.1 Horsham (Walmer) Gauge

The accuracy and reliability of the Horsham (Walmer) Gauge at Horsham was discussed at length within the Hydrology Report (R02). 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.

3.4.2 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 Norton Creek gauge is situated within the backwater of the Wimmera River, and for relatively minor flows in the Wimmera River (greater than 1,500 ML/d), the Norton Creek gauge responds in unison with the Wimmera River gauge at Horsham (Walmer), suggesting it is indeed impacted by a backwater from the river.

Darragan Creek is ungauged, and has a catchment significantly smaller than Norton Creek. Although there is no gauge data to verify the assumption, it can be assumed that the peak flow generated from this catchment will be insignificant in comparison to a peak flow generated by the Wimmera River catchment and it will peak well before the Wimmera River.

The Mackenzie River is a much larger waterway than Norton and Darragan Creeks, with a large catchment that extends up into the Grampians. With much of the runoff generated in the headwaters of the Grampians, the level of Wartook Reservoir is critical to the peak flow generated in Mackenzie River. The Mackenzie River at Mackenzie Creek streamflow gauge rating table is reliable only up to 1,000 ML/d. The recorded January 2011 flow of 4,270 ML/d is well beyond the reliable section of the rating curve.

Although doubts exist over the reliability of the Mackenzie Creek rating table for flows recorded during the January 2011 event, it provides a reasonable streamflow estimate and an accurate representation of the timing of the flows. Due to the lack of any better available information, the recorded stream flows from the Makenzie Creek gauge for the 2011 event were directly incorporated into the hydraulic model through the addition of a source point boundary.

With no reliable recorded flow from either Norton Creek or Darragan Creek, a RORB model was used to determine the tributary inflows. The RORB model was 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 used in the Natimuk Flood Investigation and adopted for this study are shown in Table 3-1.

Table 3-1 Natimuk Flood Investigation and adopted RORB model parameters tributary flows

RORB Parameter		Natimuk Flood Investigation	This Study
m		0.8	0.8
Dav	**Norton Creek**	21.29	34.61
	Sandy Creek		19.28
	Darragan Creek		22.19
kc	**Norton Creek**	26.61	43.20
	Sandy Creek		24.10
	Darragan Creek		27.70

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 will be used for design modelling purposes. It is noted that the estimation of losses in this study has been carried out using a rapid assessment. Conservative losses have been applied. This is justified as the impact of the tributary flows has been shown to be very small, Section 4.3.2 discusses this further.

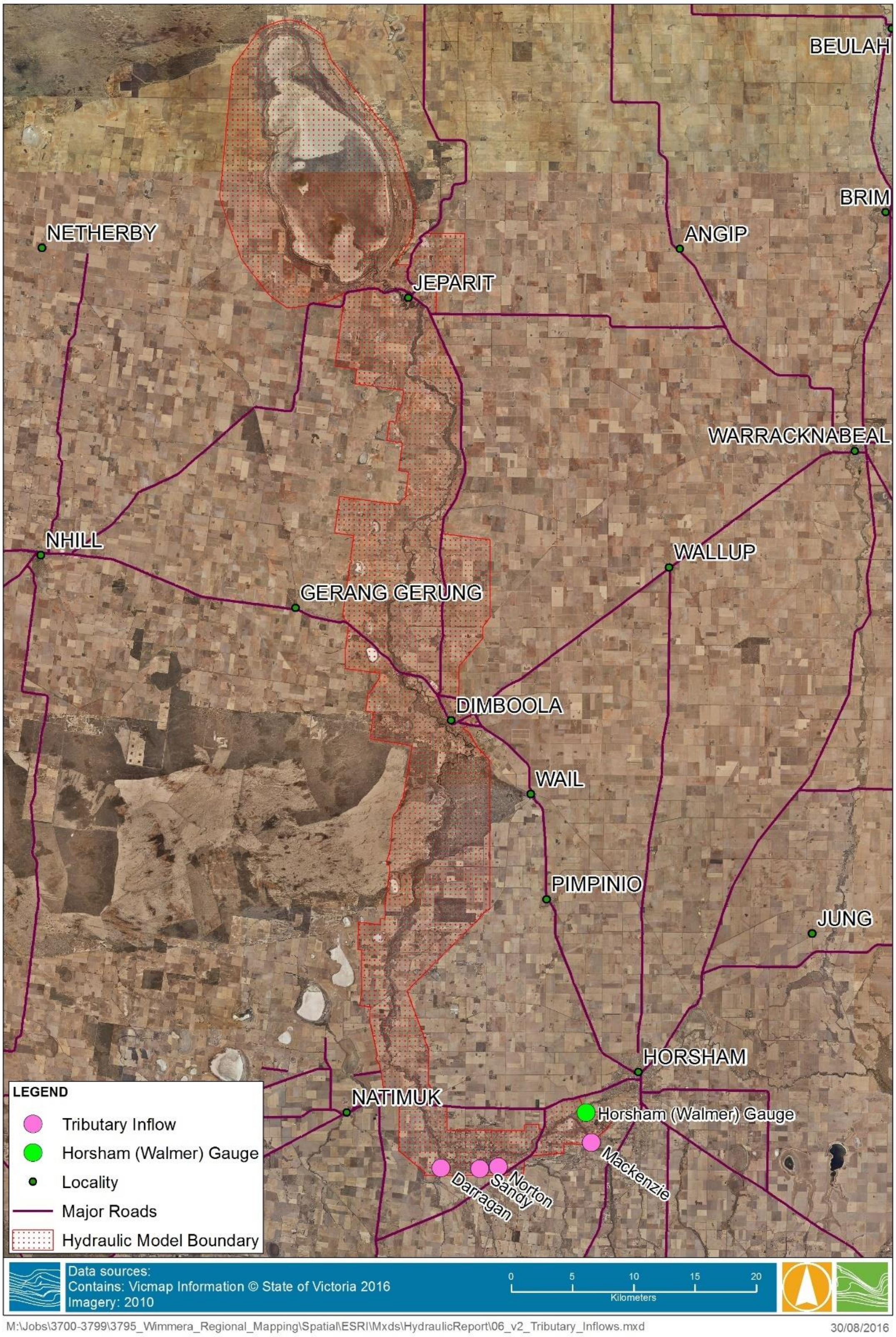


Figure 3-5 Hydraulic Model Extent and Inflow Boundary Locations

4. 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. The best match to the observed data was achieved by refinement of the model topography, modifications to hydraulic roughness and inclusion of tributary inflows between Horsham and Quantong. Hydrology was investigated in detail as documented in the Hydrology Report (R02).

It should be noted that while flood mark survey was available for the calibration events there is always inherent inaccuracies in the collection of peak flood levels. Levels are often based on flood debris marks which may be significantly higher or lower than the true peak due to debris piling up on the upstream side of an obstruction or debris being deposited during the recession of a flood. Survey is often collected well after the event which can increase the uncertainty in the peak levels.

A certain level of judgement is required in the collection of this data by the surveyor and inaccuracies in such data are common. As discussed below a number of the surveyed flood marks are considered to be invalid due to obvious errors.

4.1 January 2011 Calibration

4.1.1 Overview

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.

4.1.2 Surveyed Peak Flood Heights

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 4-1. 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. These points are further discussed in Table 4-1 and shown respectively in Figure 4-2 and Figure 4-3.

Appendix A presents a closer view of the two groupings of floodmarks. An extremely good calibration was achieved around Dimboola, with only 2 flood markers not within 100 mm of the recorded peak flood height and the remaining within 50 mm accuracy. There is a slightly wider range in results further upstream.

Overall, the model is performing exceptionally well against the surveyed flood marks recorded for the January 2011 flood event.

Table 4-1 Discussion of flood markers differing by greater than 200mm – January 2011 Calibration

Point	Surveyed Level (m AHD)	Modelled Level (m AHD)	Difference Modelled Less Surveyed (m)	Discussion
61	123.623	123.39	-0.23	Located north of Three Bridges Road, the point is in direct proximity to another survey mark matching the observed height within -0.15 m, two further points are located downstream of the Horsham Noradjuha Road matching within -0.08 and 0.06 m. It is possible that the model results are slightly low in this localised area, but given the good match between modelled and surveyed flood levels close by, no change to model calibration parameters was determined necessary.
76	112.591	111.82	-0.77	Both points are located north of the Wimmera Highway in very close proximity, an additional two points are located on the upstream side of Polkemmet Road with a match between modelled and observed levels closer than 0.05 m. Aerial photography captured on the 19th of January 2011 and model results show a close match. The difference between modelled and observed levels at this point is significant, and if correct it would be expected that discrepancies in the flood extents would be observed. Given the close match at the upstream surveyed points and between the modelled and observed flood extents it is considered likely the peak level has been incorrectly surveyed.
77	112.187	111.81	-0.38	

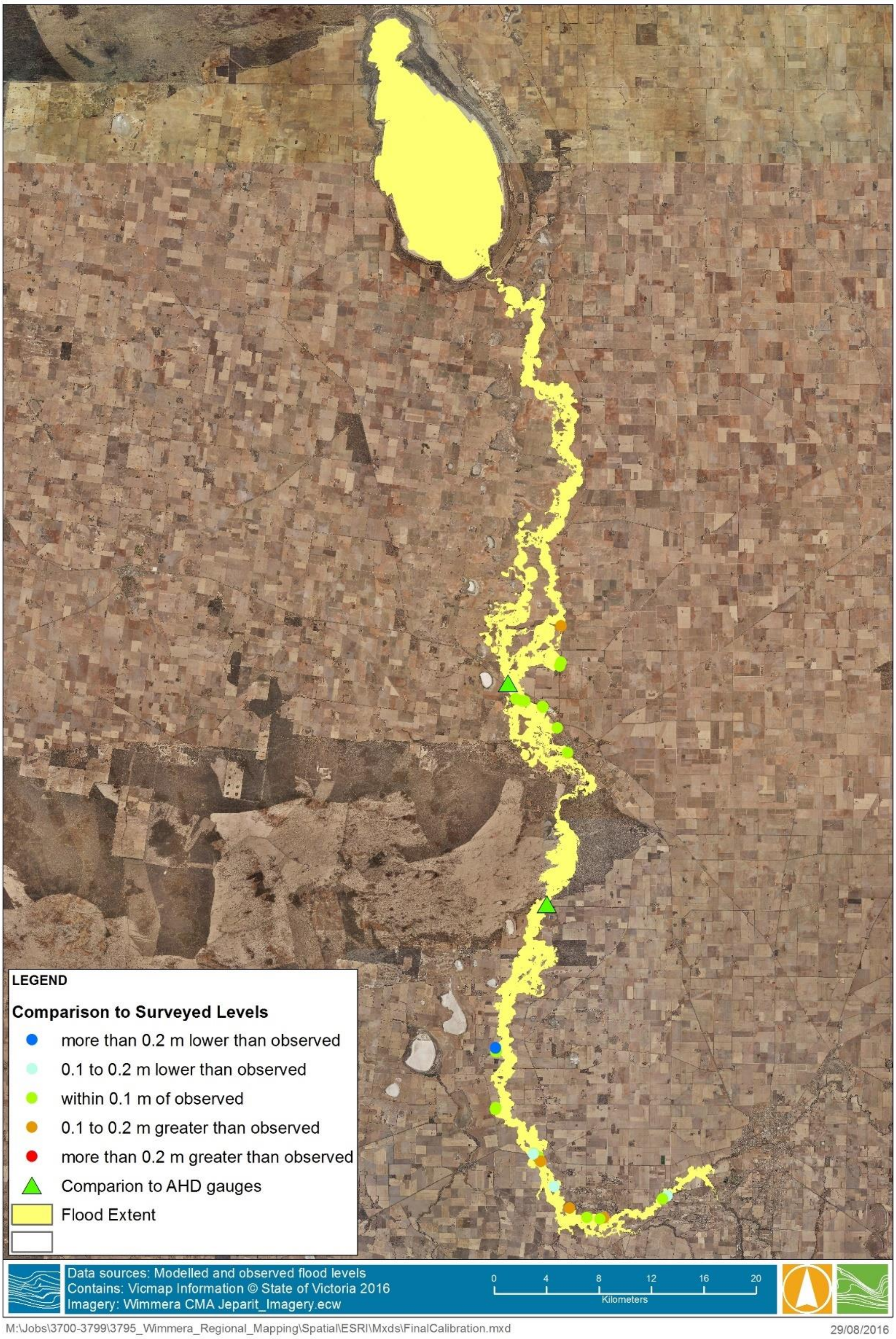


Figure 4-1 Modelled minus observed flood levels – January 2011

Figure 4-2 Modelled minus observed flood levels, points greater than 200mm – January 2011

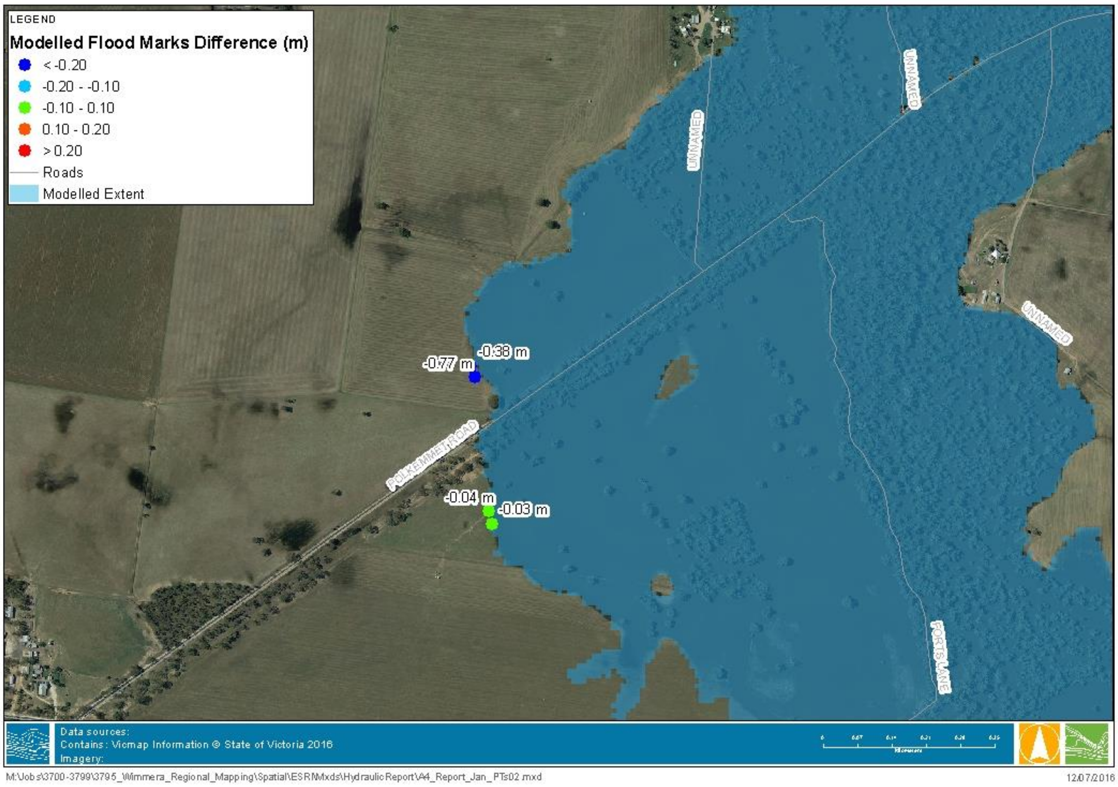


Figure 4-3 Modelled minus observed flood levels, points greater than 200mm – January 2011

4.1.3 Gauge Levels

Quantong Gauge

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 4-4. The maximum gauged level for the site during January 2011 was 7.42 m on the 19/01/2011. Details of the gauge available on the DELWP Water Measurement Information System[1], list the gauge zero to be 112.183 m AHD, resulting in a recorded peak flood level of 119.602 m AHD. This compared to a modelled peak water level of 117.45 m AHD. This suggests that modelled water levels are around 2 m below that observed. This is highly unlikely given the good calibration achieved elsewhere throughout the model area.

As shown in Figure 4-5, five flood marks were surveyed for the January 2011 event in close proximity to this location, with 2 points upstream and 3 downstream of the Wimmera Highway. All 5 points have a recorded flood peak level of between 117.395 m AHD – 117.595 m AHD, indicating a discrepancy between the surveyed flood marks and the Quantong gauge peak level of around 2.1 m, with the recorded gauge level higher than that surveyed. The modelled flood extents and peak flood levels match closely with the survey flood marks at this location. Water Technology recommended that the gauge datum for the Wimmera River at Quantong gauge (415261) be reviewed.

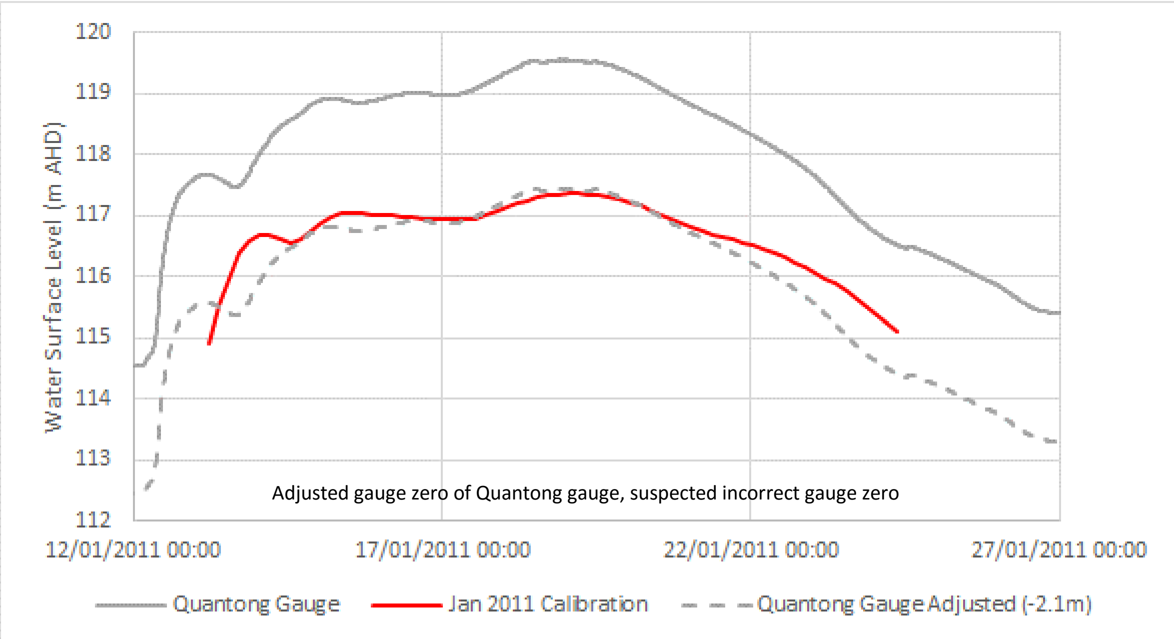


Figure 4-4 Recorded and Modelled Flood Levels at Quantong Gauge

The gauge datum was surveyed along with a number of other gauges in the Wimmera basin and it was found that the gauge zero should read 110.01 m AHD, 2.173 m lower than the previously reported gauge zero. This corresponds very closely to what the modelled data was suggesting.

[1] http://data.water.vic.gov.au/monitoring.htm

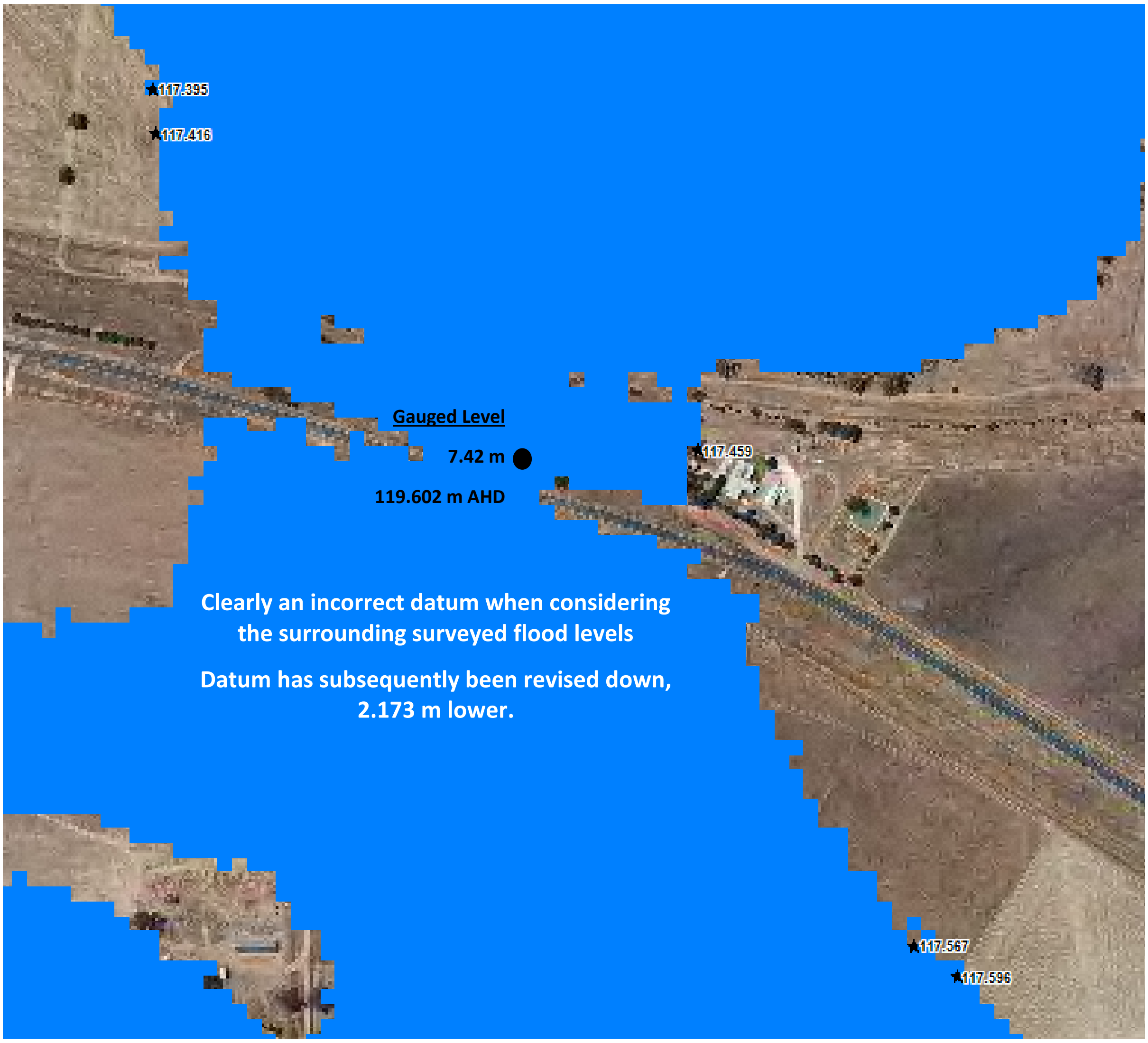


Figure 4-5 **Survey flood marks of the January 2011 flood event near the Wimmera Highway and the Quantong gauge**

U/S Dimboola and Lochiel Bridge Gauges

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 4-6. 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.

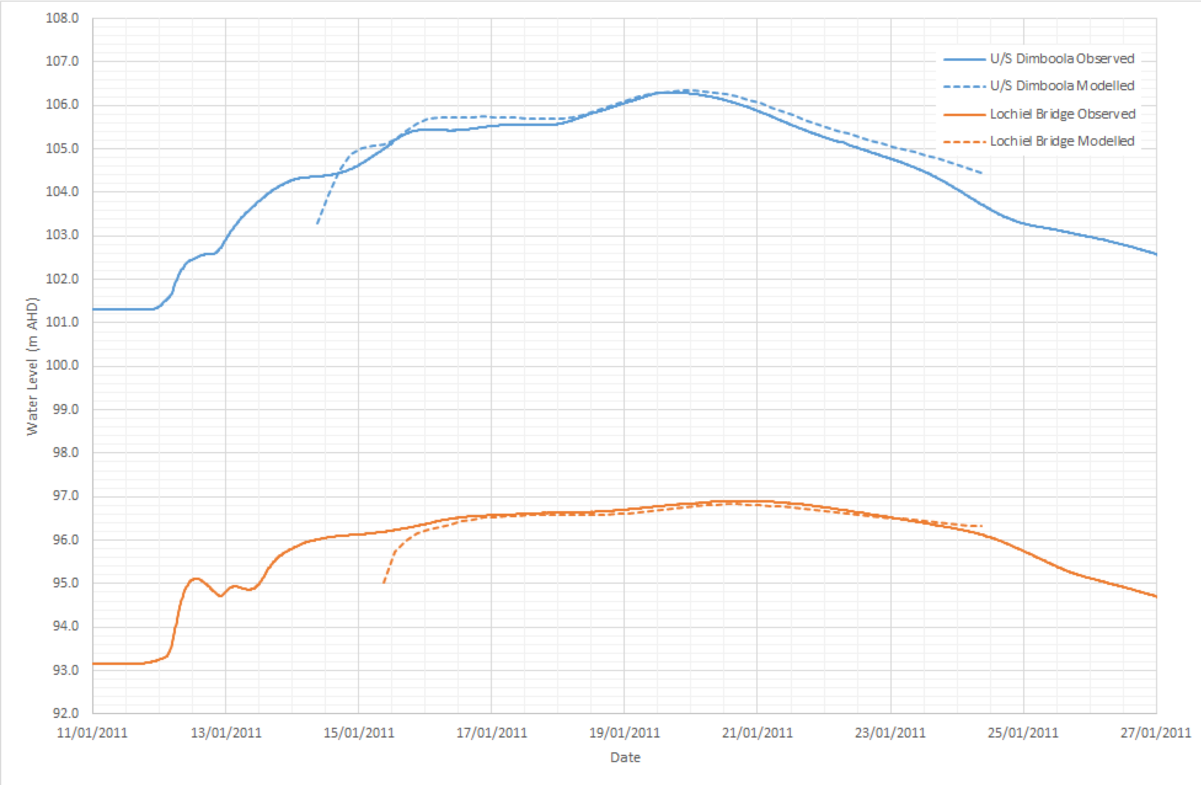


Figure 4-6 Modelled and Gauged hydrographs at U/S of Dimboola and Lochiel Bridge

4.1.4 Flood Extent

Calibration of the hydraulic model was completed, comparing modelled levels to surveyed levels and also modelled flood extents to 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 4-7, with further images provided in Appendix B.

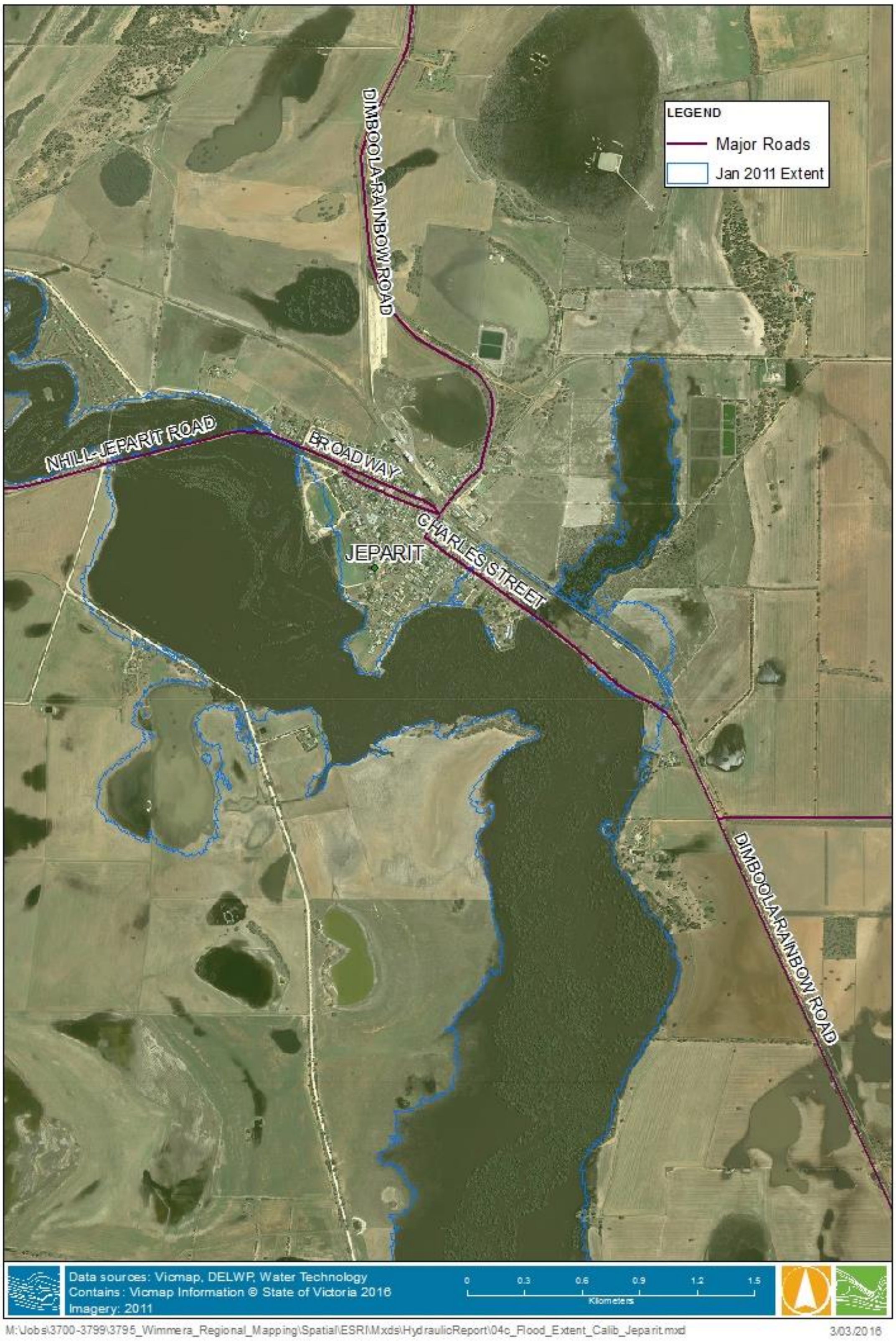


Figure 4-7 Example comparison between modelled flood extents and aerial photography at Jeparit

4.1.5 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 4-8.

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.

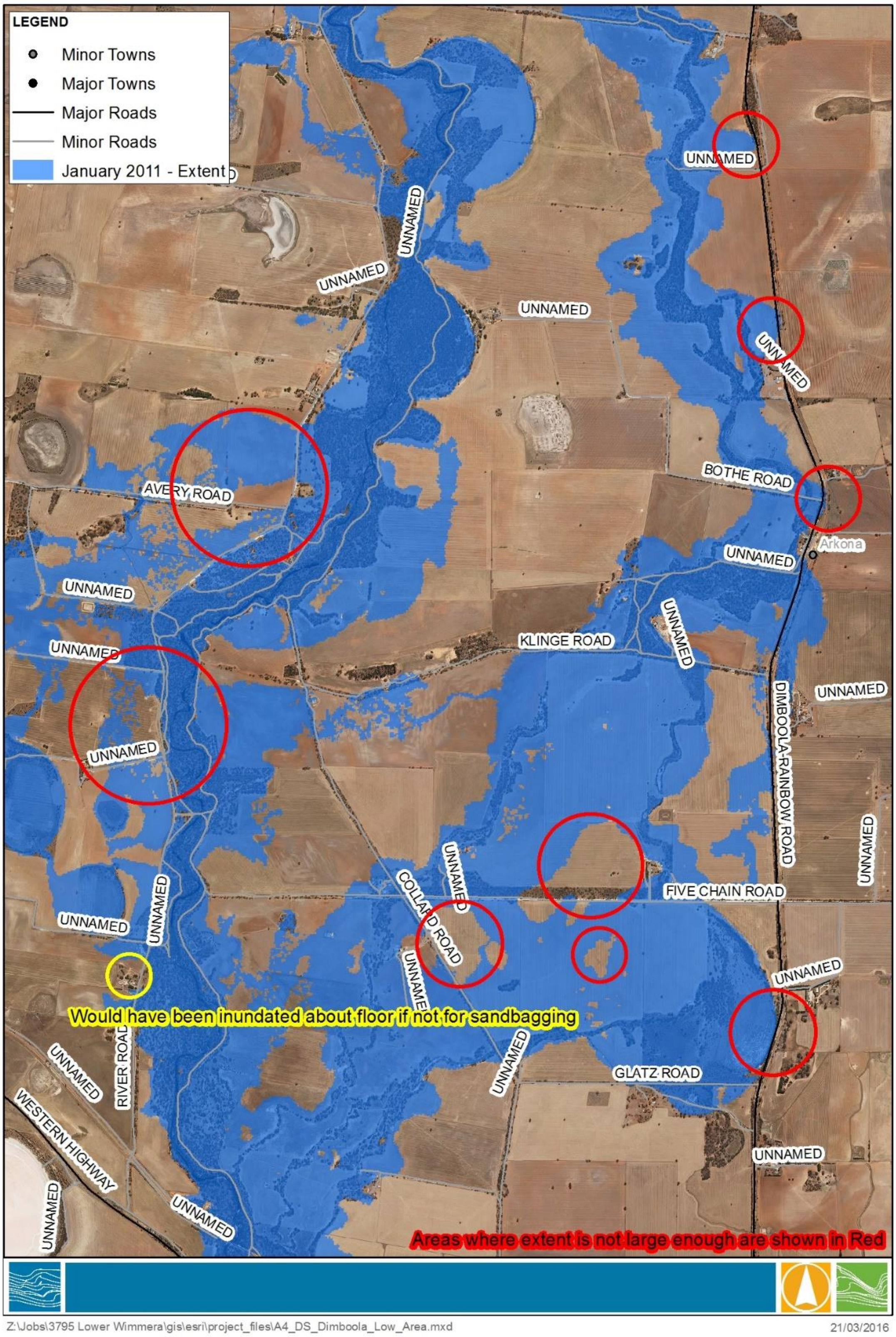


Figure 4-8 **Areas highlighted by the Antwerp community as too low based on interim flood mapping presented at the second community meeting**

4.1.6 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.

4.2 September 2010 Calibration

4.2.1 Overview

Calibration information for the September 2010 event was limited to surveyed peak flood height information and gauged water levels. 37 surveyed peak flood heights were recorded by Wimmera CMA for the September 2010 event, similar to the January 2011 event, gauged levels were available at the Quantong gauge, however there are doubts over the gauge datum. No flood extent information was available.

4.2.2 Surveyed Peak 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 4-9. The remaining 16 points with discrepancy greater than 200 mm are discussed in Table 4-2. The disparity between modelled and observed levels are discussed in the Table with references to specific figures in Appendix D. 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.

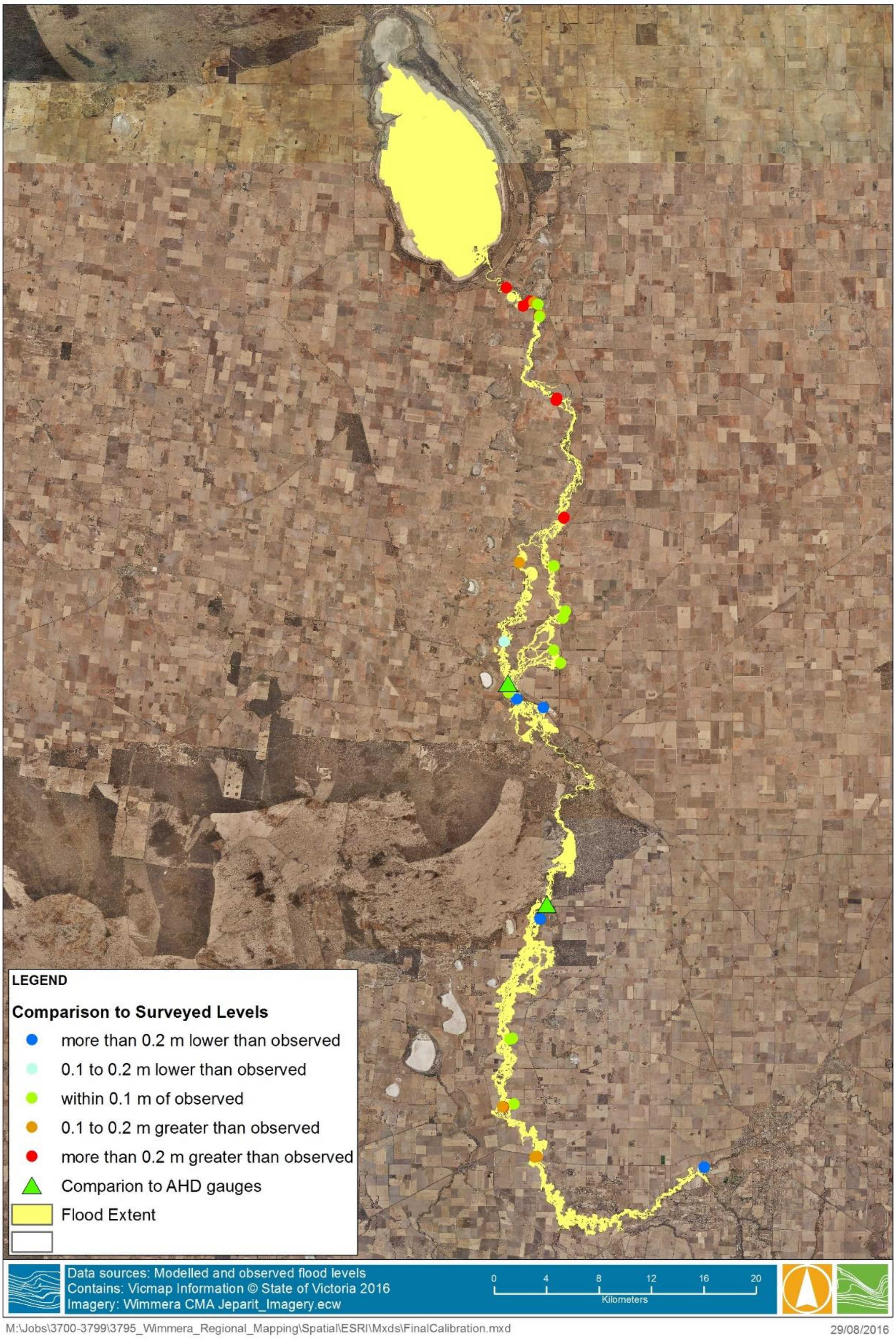


Figure 4-9 Modelled minus observed flood levels and modelled flood extent – September 2010

Table 4-2 Discussion of flood markers differing by greater than 200 mm – September 2010 Calibration

Point	Surveyed Level (m AHD)	Modelled Level (m AHD)	Difference Modelled Less Surveyed (m)	Discussion
23	98.09	95.15	-2.94	Point 23 is located on the south western side of the Western Highway downstream of Dimboola. Comparison of the model results and surveyed level show the model to be nearly 3 m too low. Given the point is on the edge of the inundation extent this is considered unlikely and surveyed level erroneous. See Figure 7-12.
21	123.67	122.66	-1.01	Points 21 and 22 are in close proximity to one another at the very end of the Horsham Rifle Club shooting range. This is in close proximity to the Horsham (Walmer) gauge, which the hydraulic model uses as the model inflow and represents the model boundary. The Horsham (Walmer) gauge reached a peak level of 123.71 m AHD, matching closely with the surveyed levels. Given the close proximity to the model boundary it is likely the modelled water levels are not accurate in this location and mapping outputs will be clipped an appropriate distance downstream of the model boundary. See Figure 7-13.
22	123.64	122.66	-0.98	
25	97.25	96.96	-0.29	Points 25 and 24 are in close proximity to one another located downstream of the Western Highway, north of Dimboola. Additional to the September 2010 surveyed flood heights there were surveyed heights available for January 2011 event in this location along the Western Highway. These points were all matched within 0.03 m. The Western Highway creates a hydraulic control, it is well represented at high flows but at lower flows the capacity and overtopping may not be represented as well resulting in the discrepancies for September 2010. However, given the good match during January 2011 the modelling is considered sufficiently accurate.
24	97.21	96.97	-0.24	
13	105.94	105.72	-0.22	Points 12 and 13 are located on the eastern side of the Wimmera River, upstream of the Little Desert National Park. The points are near one another and are on the edge of the flood extent. The model is likely to be producing levels slightly too low in this area for the September 2010 event. See Figure 7-15.
12	105.92	105.72	-0.20	

Point	Surveyed Level (m AHD)	Modelled Level (m AHD)	Difference Modelled Less Surveyed (m)	Discussion
35	88.09	88.39	0.30	Points 34 and 35 are located either side of the Antwerp Woorak Road, both points are showing modelled water levels higher than that observed. Aerial photography was available for the January 2011 event at this location with the modelling well representing the observed heights and extents. The model may be over representing water levels at low flows in this area. See Figure 7-16.
34	88.14	88.47	0.33	
37A	83.47	83.83	0.36	Points 37 and 37a are in close proximity to one another and located either side of Tarranyurk West Road, at Tarranyurk. Given both levels are showing the modelled water levels are overestimating that observed, it is likely the model is under representing the capacity of the Wimmera River bridge at this location at lower flows. See Figure 7-17.
37	83.30	83.86	0.56	
40	79.04	79.39	0.35	Points 40, 45, 38, 19 and 43 are all in and around Jeparit. There a total of eight points in and around the Jeparit township with three matching within 0.2 m and the aforementioned 5 outside this threshold. At the most upstream end of these points, point 43 is showing a modelled water level 0.58 m above that surveyed. However, immediately upstream of this point a point is matching within 0.03 m and immediately downstream there is a point within 0.2 m. Similarly, downstream there are two points matching within 0.1 and 0.16 m, with further points showing a greater disparity between modelled and observed levels, 0.35 and 0.5 m. Given all of the points through Jeparit are showing the model results to be higher than the surveyed levels it is likely the model is over predicting water levels in this area. However, given the large range of differences between modelled and observed levels the amount of overestimation is difficult to determine. See Figure 7-18.
45	78.57	78.98	0.41	
38	78.81	79.31	0.50	
19	114.08	114.64	0.56	
43	79.18	79.76	0.58	

4.2.3 Gauge Levels

Quantong Gauge

The modelled water levels were again compared to the gauged water levels at the Wimmera River at Quantong stream gauge (415261). The modelled hydrograph was compared to the observed gauge hydrograph as shown in Figure 4-10. As discussed previously for the January 2011 calibration event comparison, it was found that the Quantong gauge zero was 2.173 m too high, and when adjusted the model shows a very good match to the gauged hydrograph.

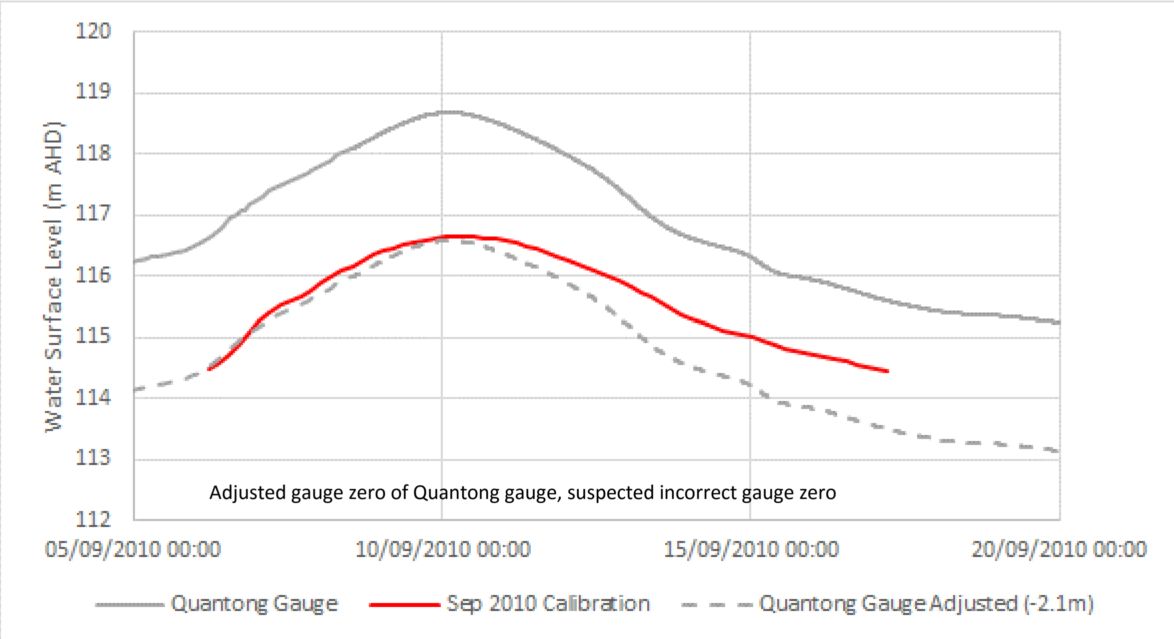


Figure 4-10 Recorded and Modelled Flood Levels at Quantong Gauge

U/S Dimboola and Lochiel Bridge Gauges

The modelled water levels at the U/S Dimboola and Lochiel Bridge gauges were compared to the observed data same as for the January 2011 calibration. 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 4-11. 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.

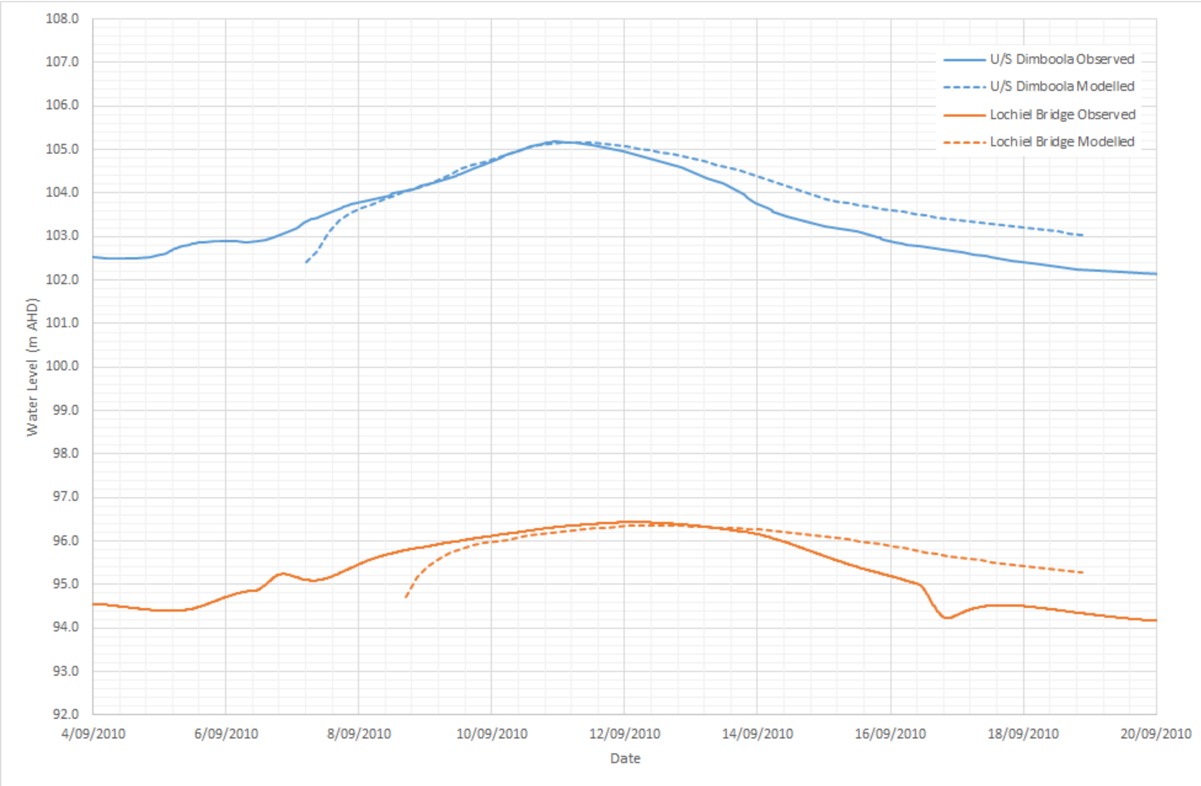
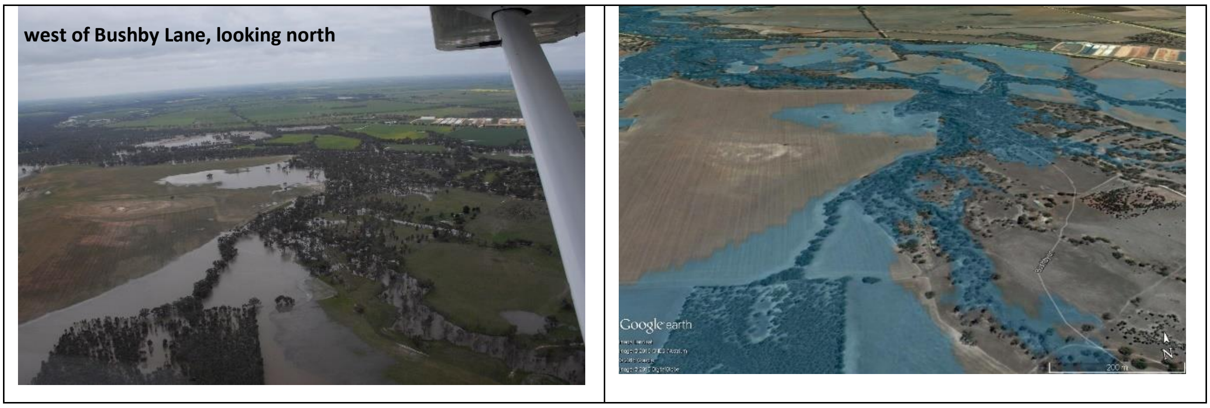


Figure 4-11 Modelled and Gauged hydrographs at U/S of Dimboola and Lochiel Bridge

4.2.4 Flood Extent

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 4-12 concentrate on the area upstream and downstream of Dimboola. The comparisons demonstrate that the modelled flood extents replicate the observed flooding in September 2010.



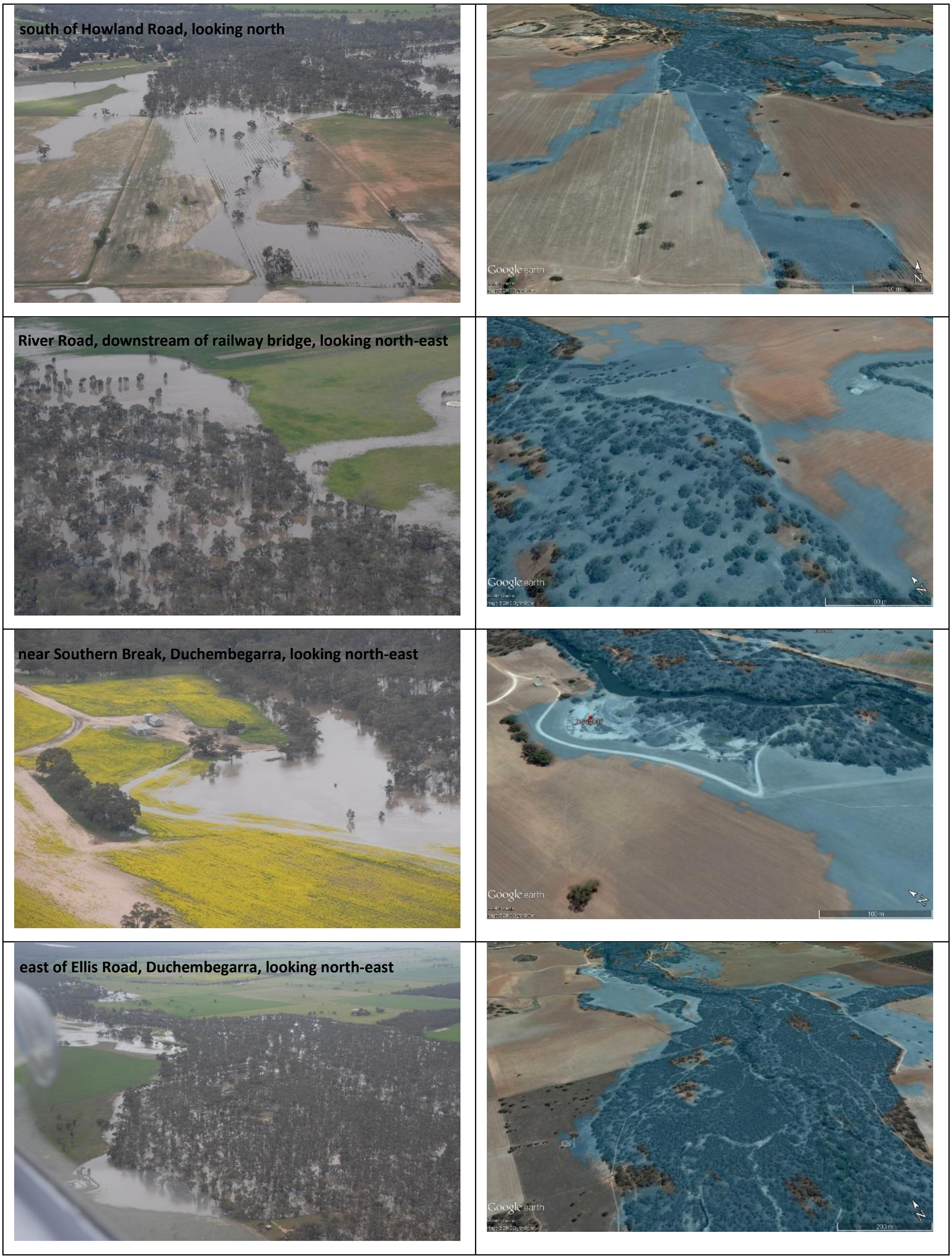


Figure 4-12 **Comparison between flood photos and modelled flood extents near Dimboola on 11th September 2010**

4.2.5 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.

4.3 Sensitivity Analysis

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

4.3.1 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 as shown in Appendix C, while an increase to 0.07 consequently increased water levels to consistently 100 mm above recorded flood levels. Difference in peak water surface elevation between roughness's of 0.05 and 0.07 and the final calibration roughness of 0.06 are shown respectively in Appendix C, Figure 7-6 to Figure 7-11 highlight this difference.

Appendix C presents 4 flood maps comparing the flood extents of the three tested roughness parameters along the Wimmera River, ranging from the Wimmera Highway crossing near Natimuk, down to Lake Hindmarsh. As expected, the increase in roughness also increases the modelled flood extent. The biggest observable difference is located upstream of the Jeparit-Warracknabeal Road south of Jeparit. At this location, shallow overland flows are breaking out to the west of the Wimmera River and pooling on the adjacent farmland. It is difficult to objectively quantify and separate the contribution of water pooling at this location from local rainfall and not out of bank flow from the river.

The flood extent corresponding to a Manning's 'n' of 0.05 under represents the observed flood extent around Jeparit provided in the aerial photography, whilst the flood extent corresponding to a Manning's 'n' of 0.07 identifies considerable overtopping of the Dimboola-Rainbow Road and the Jeparit levee at Charles Street. The sensitivity in the modelled water levels and resulting flood extents at Jeparit highlight the small margin of freeboard on the Dimboola-Rainbow Road and the Charles Street levee. These areas should be regularly observed during a flood event and potentially sandbagged if a flood of a similar magnitude of the January 2011 event occurs in the future.

The sensitivity of the flood extent to roughness decreases upstream at Dimboola and the Wimmera Highway crossing near Natimuk. There is a minor increase in the flood extent corresponding to a Manning's 'n' of 0.07 however the two other sensitivity scenarios present very similar flood extents and match well with the aerial photography of the flood peak in the background.

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.

4.3.2 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 peak flood extents were compared to the observed January 2011 aerial imagery captured across several days, this comparison showed minimal difference. As shown in Figure 4-14 the difference in water levels when including and not including the tributary inflows is consistently 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 0.10-0.50m lower in this case. The modelled and recorded levels were also compared at the Quantong Gauge, as shown in Figure 4-13.

Aside from the issue of gauge zero, the model results both match shape and timing of the recorded water levels well and the modelled water levels with and without tributary inflows showed no significant difference in peak water level. Additional flow from the tributaries showed an increase in water levels prior to the peak, but do not affect the peak itself. This is also evident in the recorded stream level data. The recorded water levels show the volume of flow and peak timing from the tributaries occurs earlier than in the sensitivity testing with minimal impact on the peak flood level.

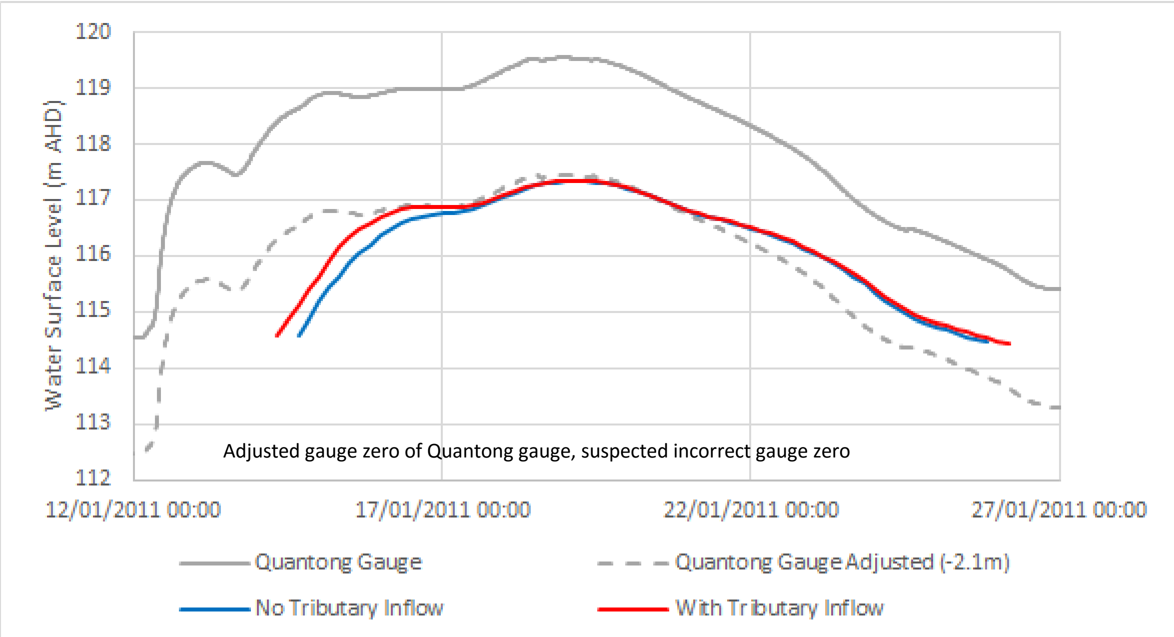


Figure 4-13 Recorded and Modelled Flood Levels at Quantong Gauge with and without tributary inflows

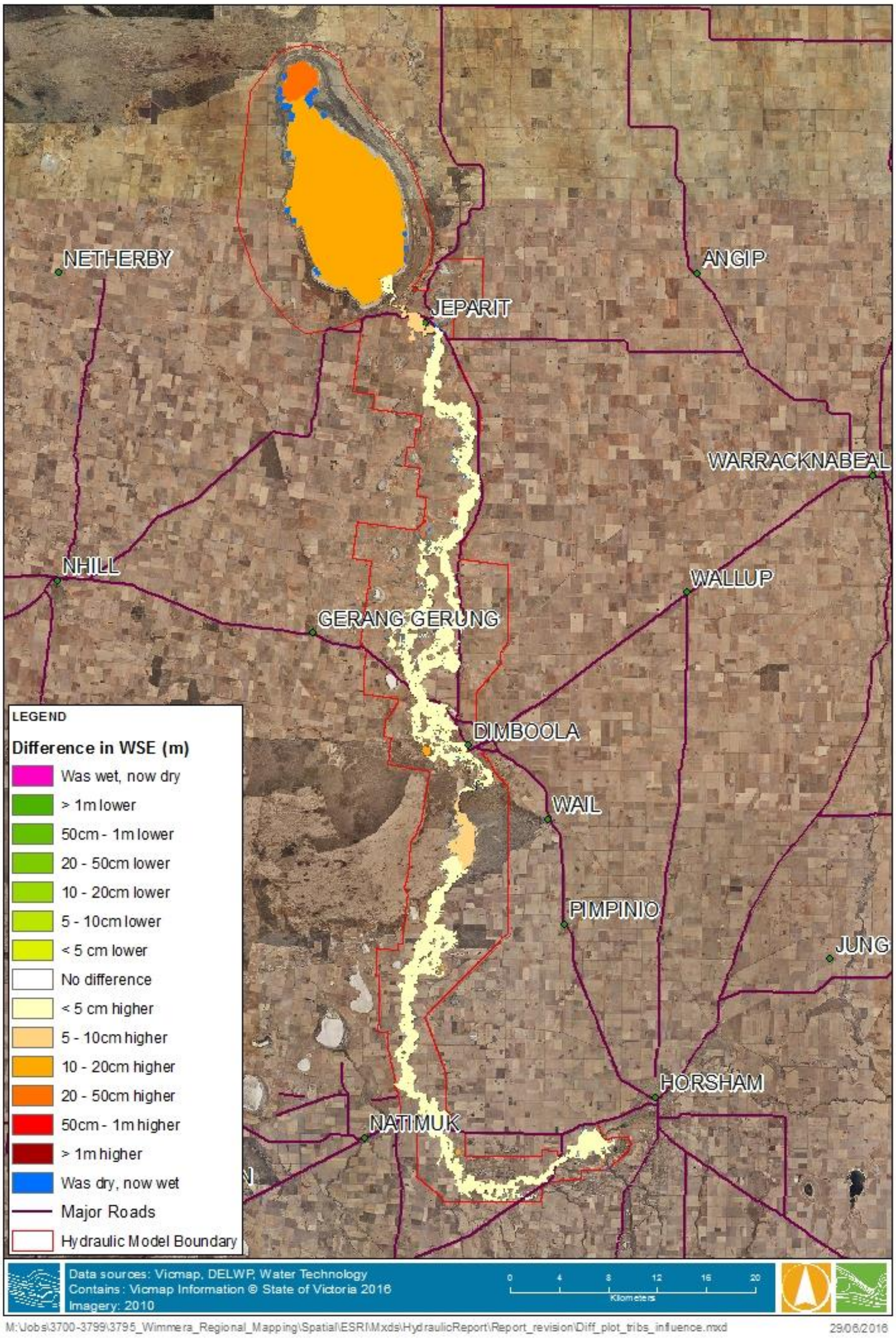


Figure 4-14 Difference in water surface elevation with and without tributary inflows

5. DESIGN EVENT 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 5-1 to Figure 5-3, 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 5-4.

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.

The design flood mapping was assessed and described in detail in the subsequent Flood Intelligence Report (R04).

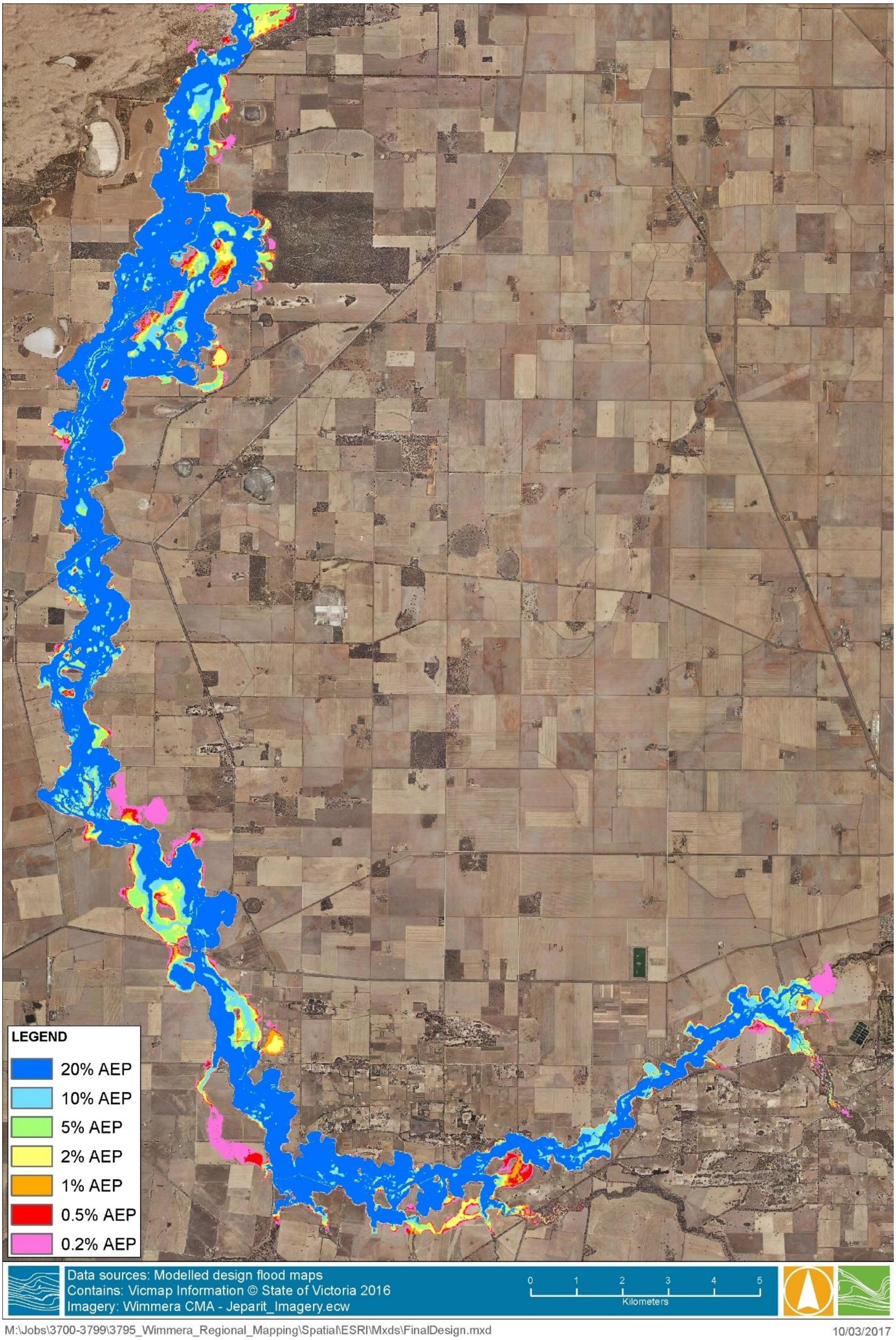


Figure 5-1 Lower Wimmera River Design Flood Extents – Horsham to Duchembegarra

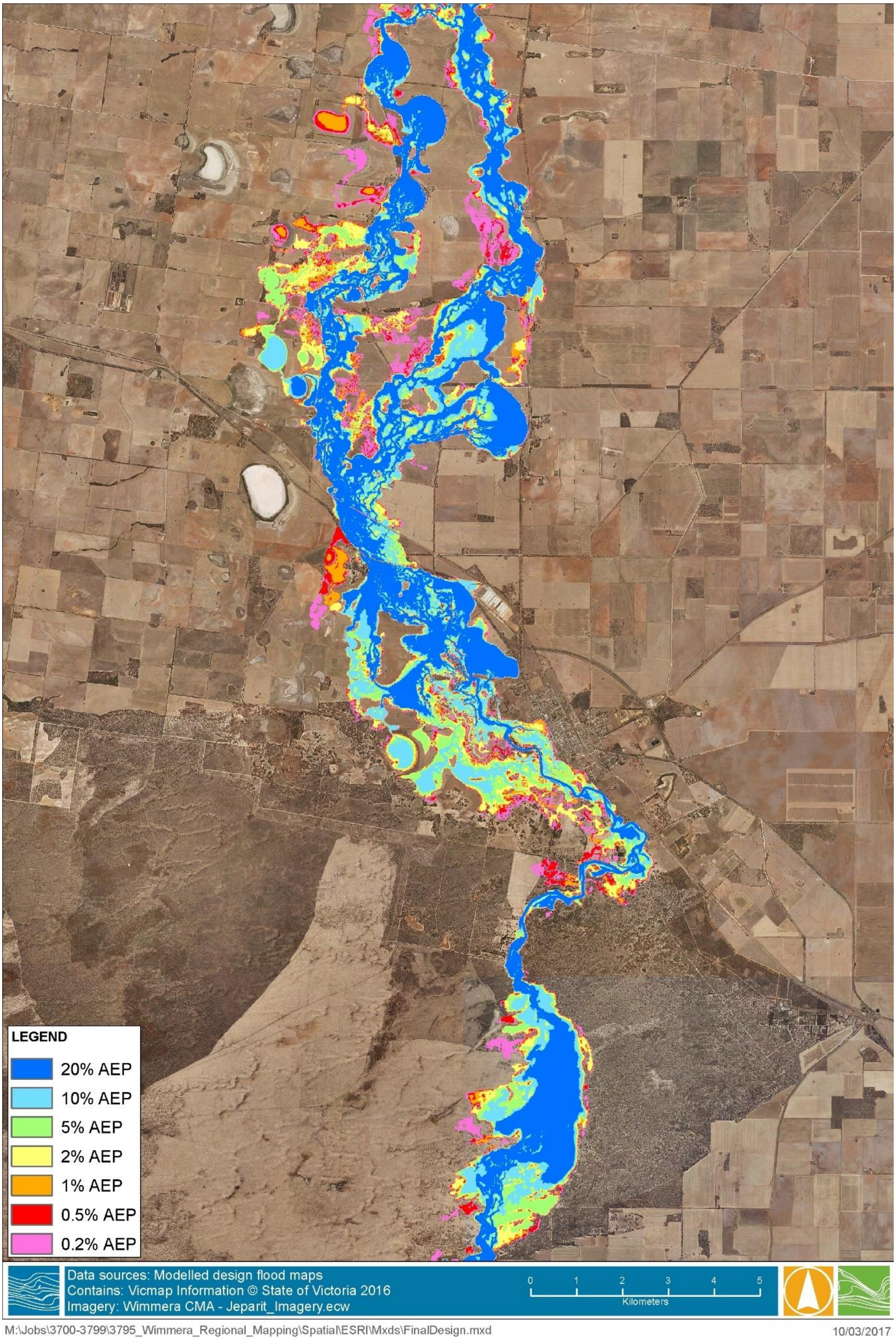


Figure 5-2 Lower Wimmera River Design Flood Extents – Duchembegarra to Antwerp

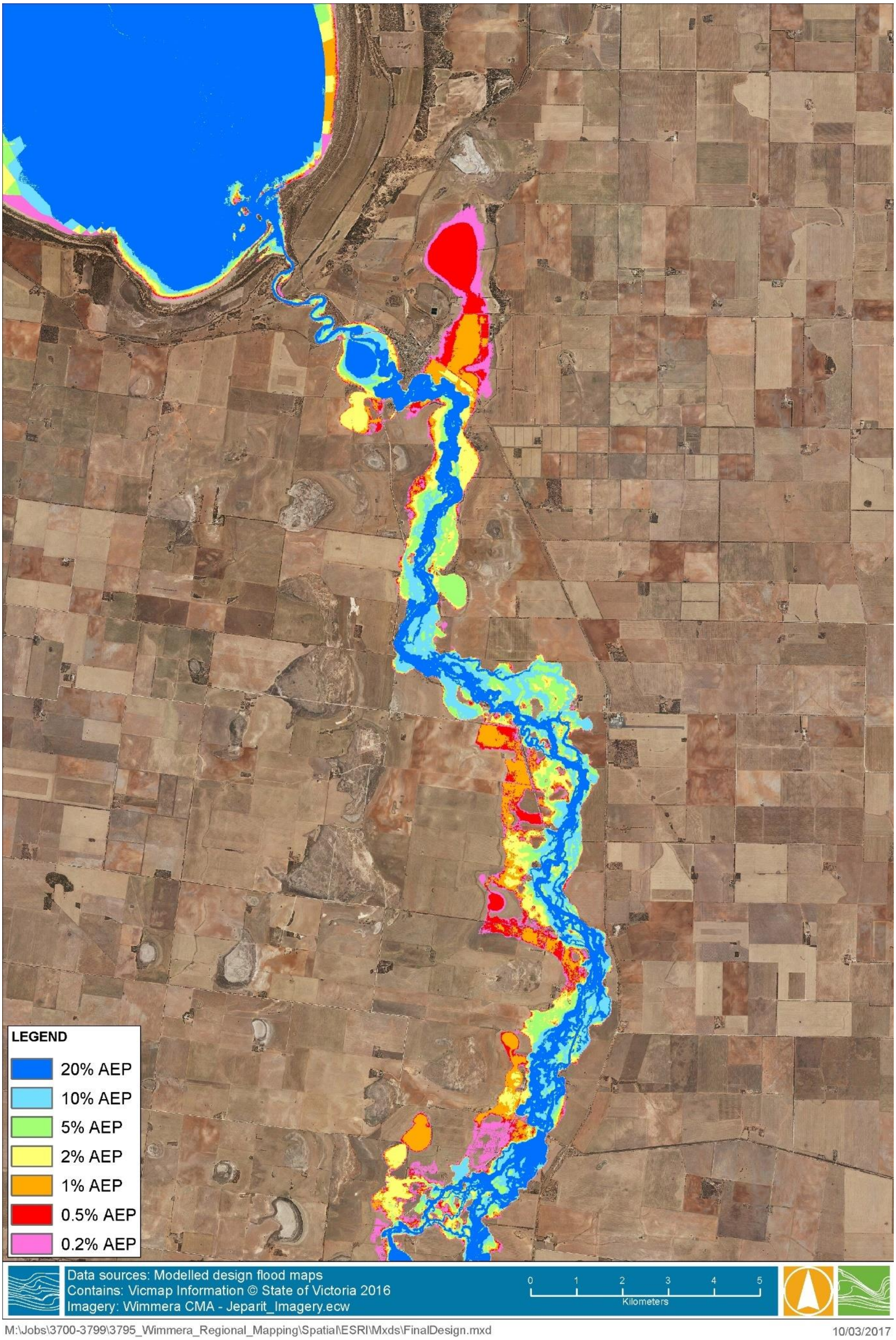


Figure 5-3 Lower Wimmera River Design Flood Extents – Antwerp to Lake Hindmarsh

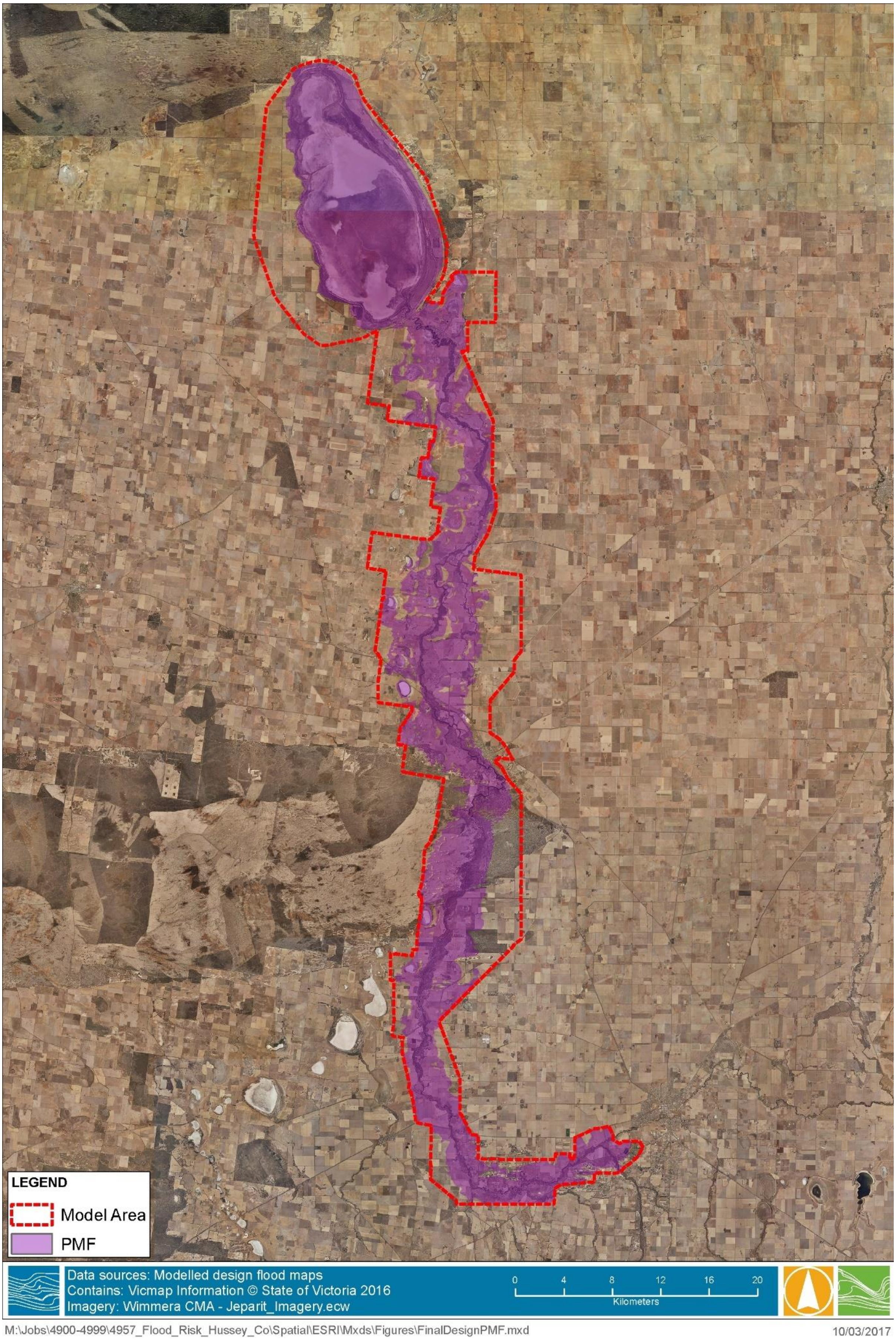


Figure 5-4 Lower Wimmera River PMF Flood Extent

6. CONCLUSIONS

Calibration of the hydraulic model for the January 2011 and September 2010 flood events was undertaken using a methodical and comprehensive analysis. The application of a detailed flexible mesh approach has allowed accurate representation of the river geometry for 100 km of the Wimmera River between Horsham and Lake Hindmarsh, whilst maintaining manageable runtimes for the model.

Water Technology believes the hydrology and hydraulic model developed during this project has replicated the January 2011 and September 2010 observations well. The model calibration is deemed fit for purpose, and the model suitable for modelling design conditions.

Design scenarios were modelled for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP and PMF events. The flood mapping from this study should replace previous flood mapping for Dimboola and Jeparit. It is likely that the flood mapping from the Horsham and Wartook Valley Flood Investigation (Water Technology, ongoing), will replace flood mapping from this study between Horsham and Quantong.

The subsequent Flood Intelligence Report (R04) includes all relevant flood intelligence from the flood modelling and documents it in an easy to understand manner.

The hydraulic modelling of the historic and design events was processed and formatted in line with the VFD specification.

7. REFERENCES

Water Technology (2008), Jeparit Flood Study, Report prepared for Wimmera CMA

Water Technology (2015a), Regional Flood Mapping of the Lower Wimmera River - Data Review Report (R01), Report prepared for Wimmera CMA

Water Technology (2015b), Regional Flood Mapping of the Lower Wimmera River - Hydrology Report (R02) , Report prepared for Wimmera CMA

Water Technology (ongoing), Horsham and Wartook Valley Flood Investigation, Report prepared for Wimmera CMA

APPENDIX A – JANUARY 2011 FLOOD MARK COMPARISON

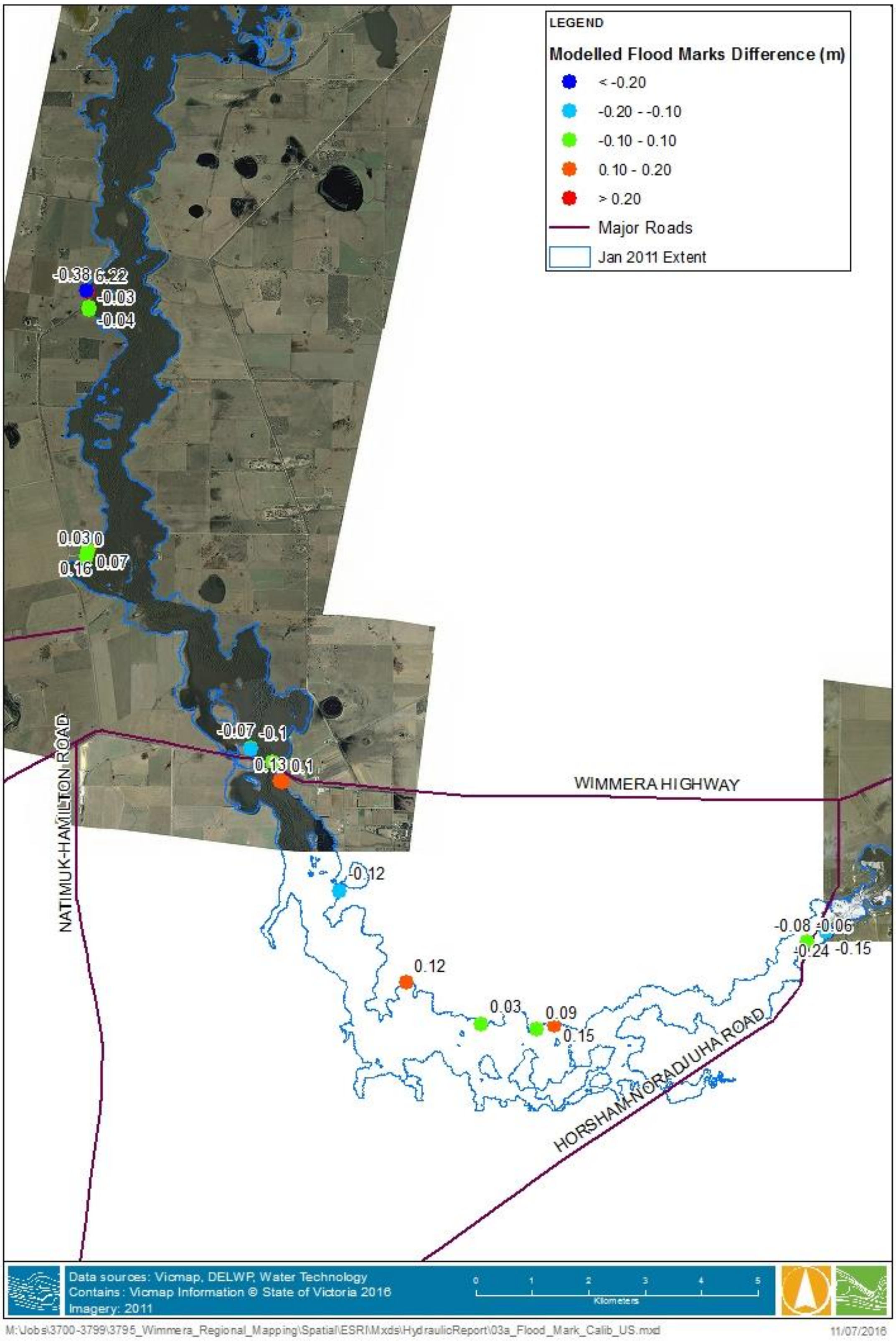


Figure 7-1 Flood Markers Upstream of Dimboola - January 2011 Calibration

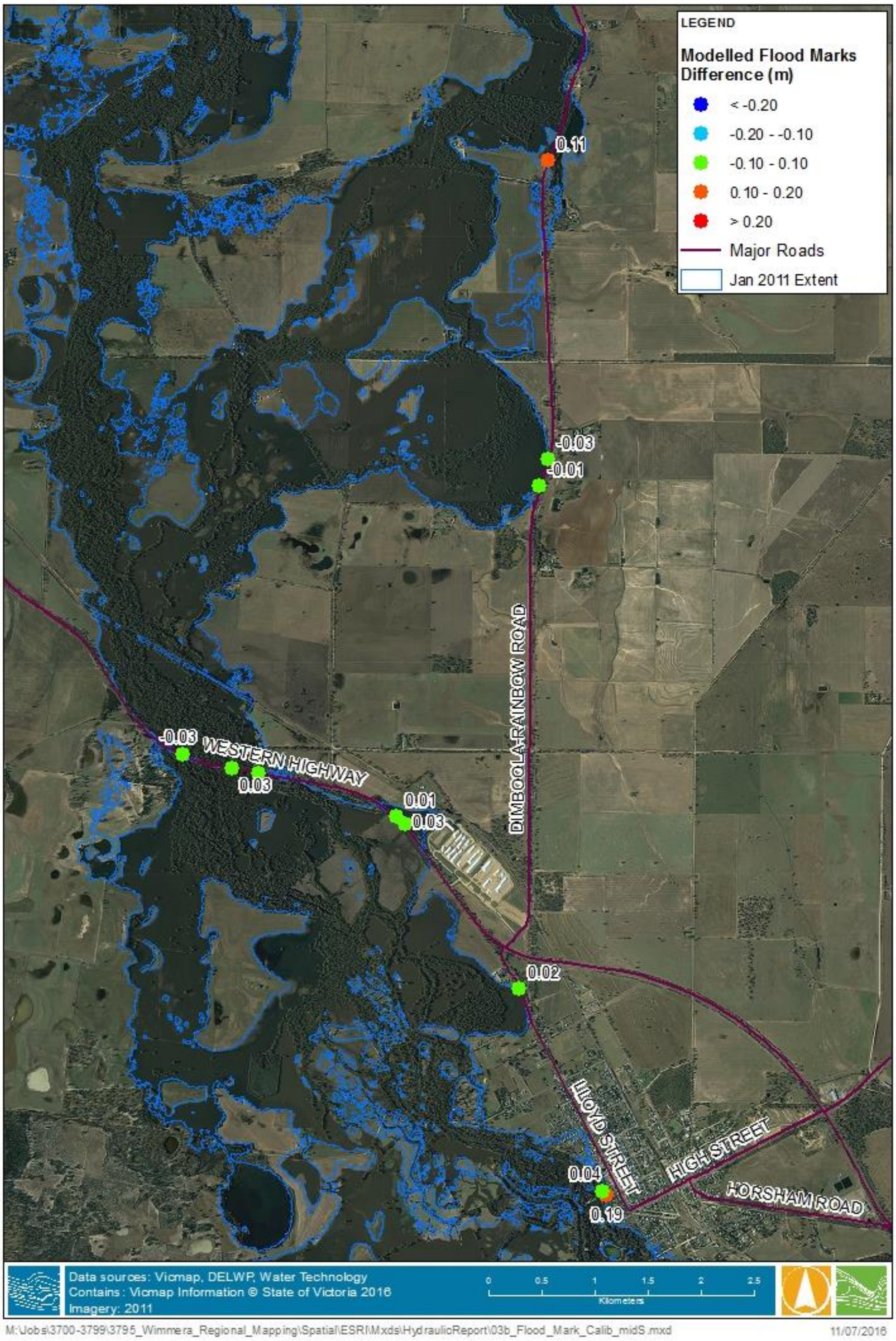


Figure 7-2 Flood Markers Upstream of Dimboola - January 2011 Calibration

APPENDIX B – JANUARY 2011 FLOOD EXTENT CALIBRATION

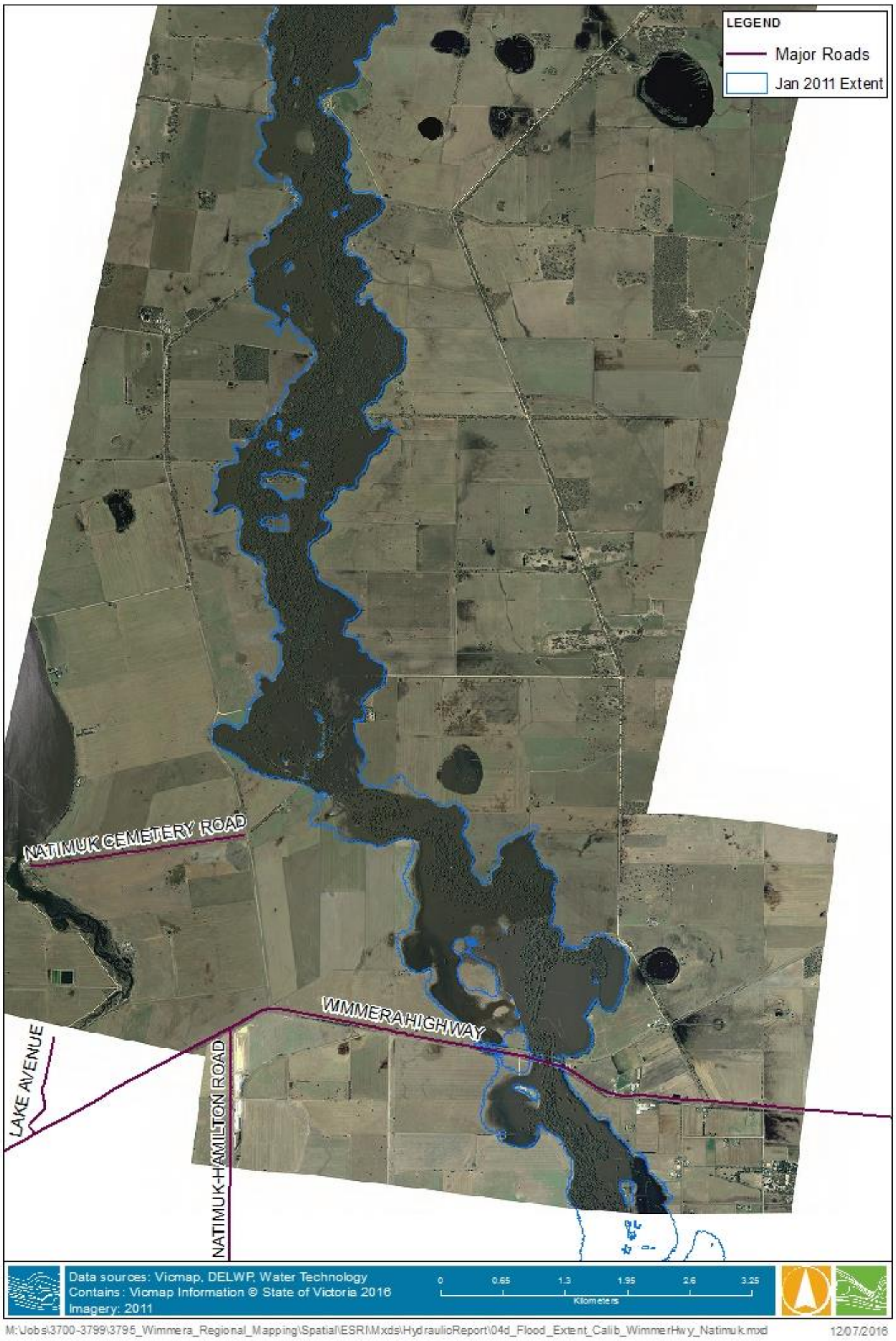


Figure 7-3 Hydraulic Model Extent – January 2011 calibration south east of Natimuk

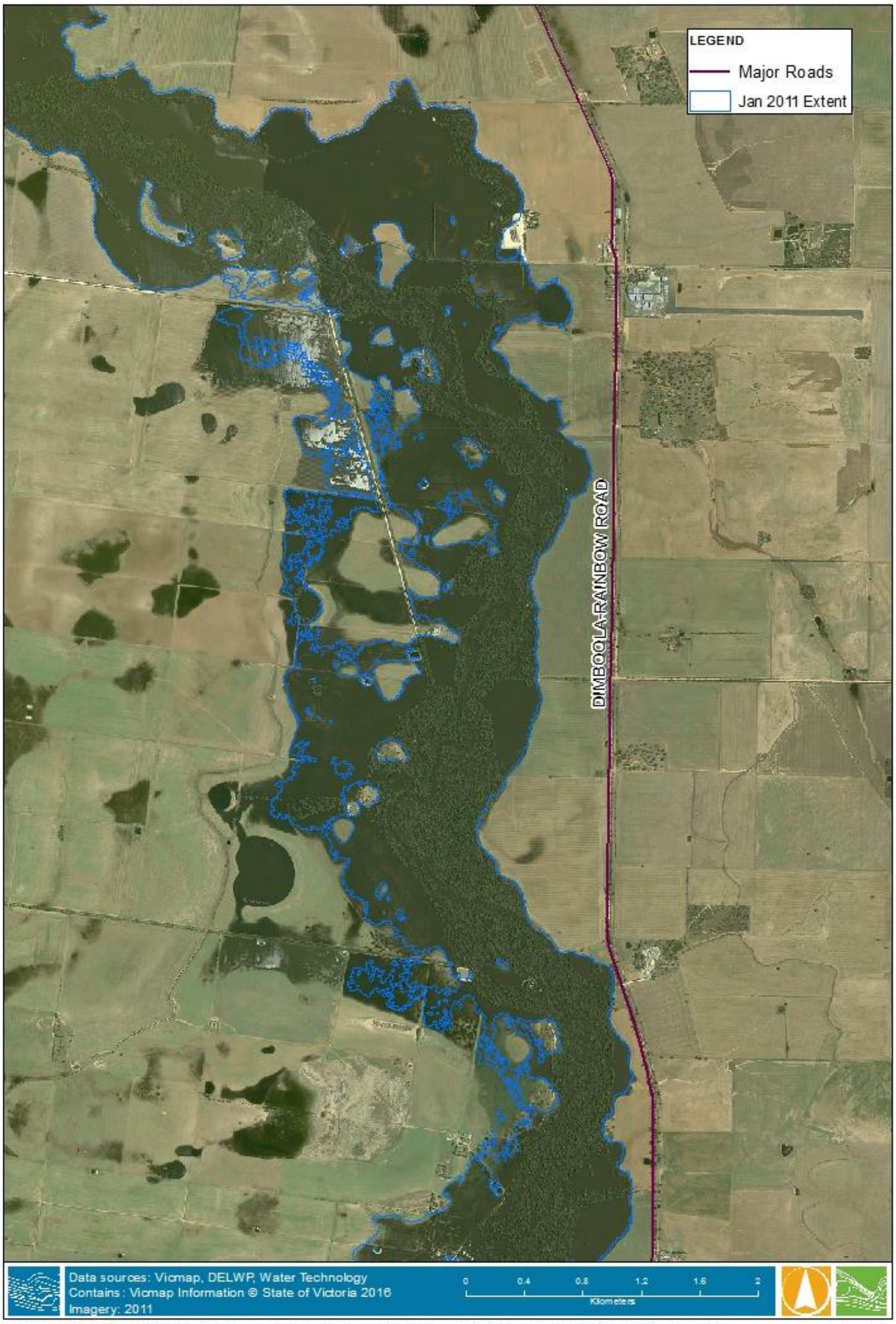


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Figure 7-4 Hydraulic Model Extent – January 2011 Calibration Upstream of Jeparit

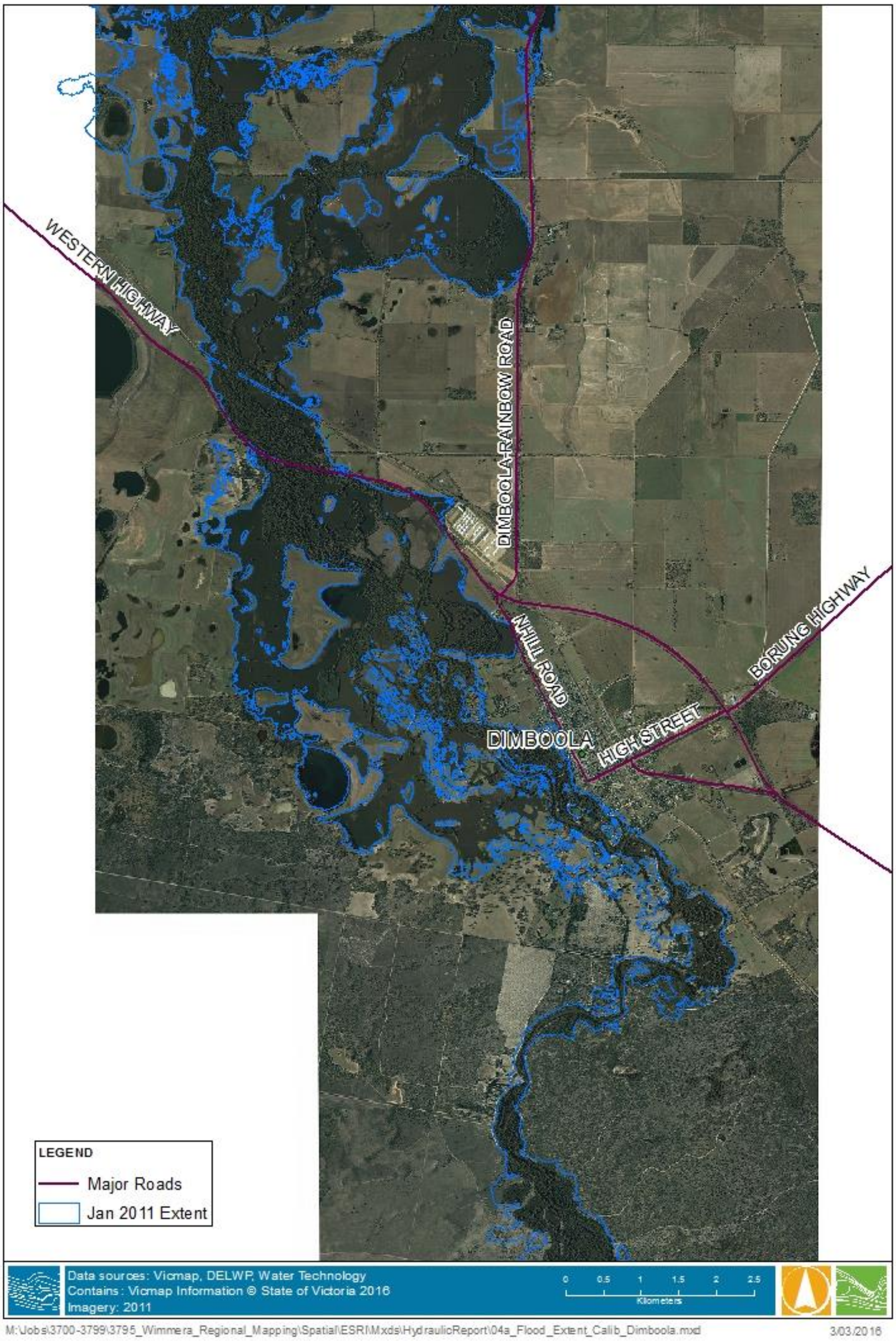

Figure 7-5 Hydraulic Model Extent – January 2011 calibration at Dimboola

APPENDIX C – MANNINGS SENSITIVITY

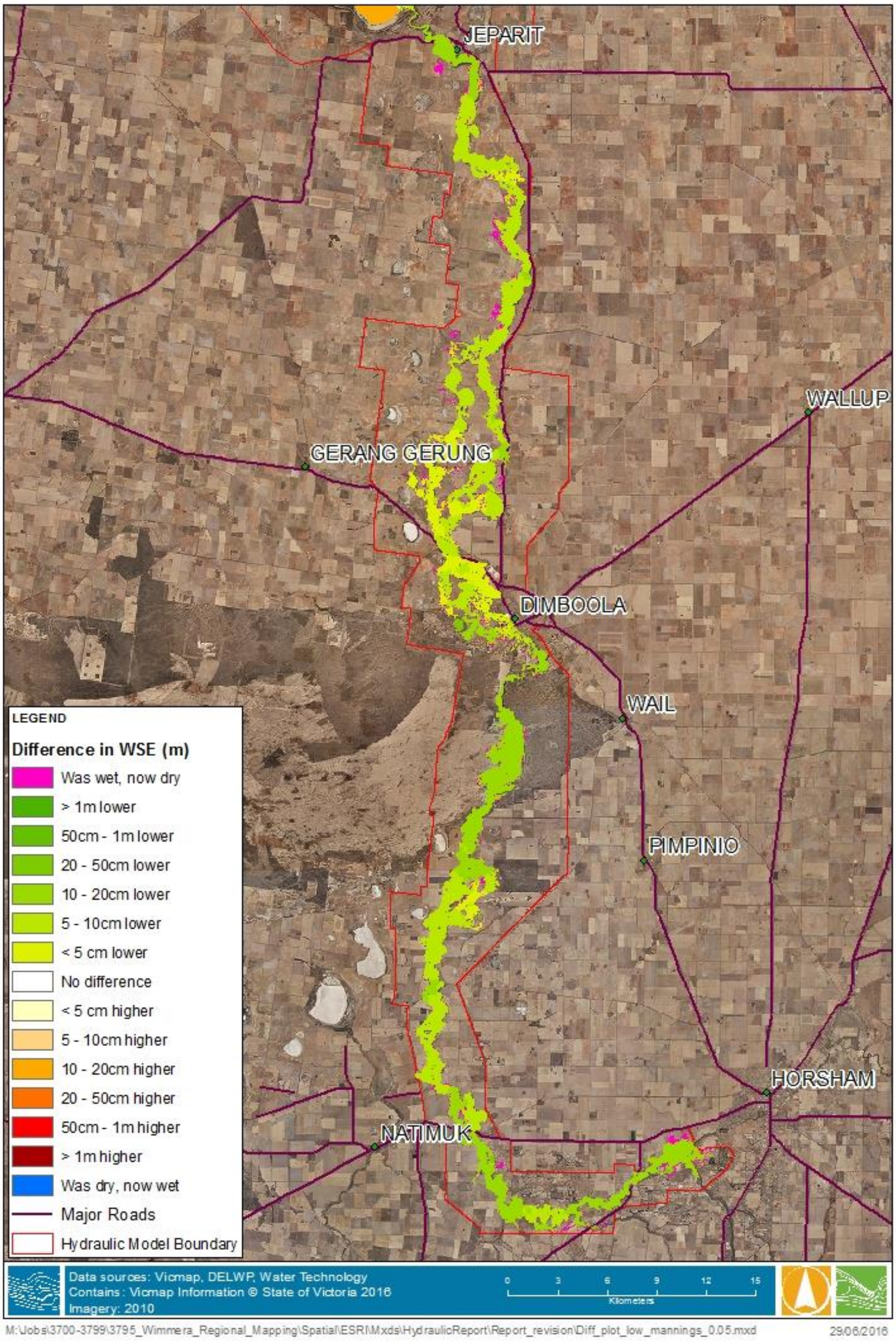

Figure 7-6 **Difference in water surface elevation between Manning's n=0.05 and Manning's n=0.06**

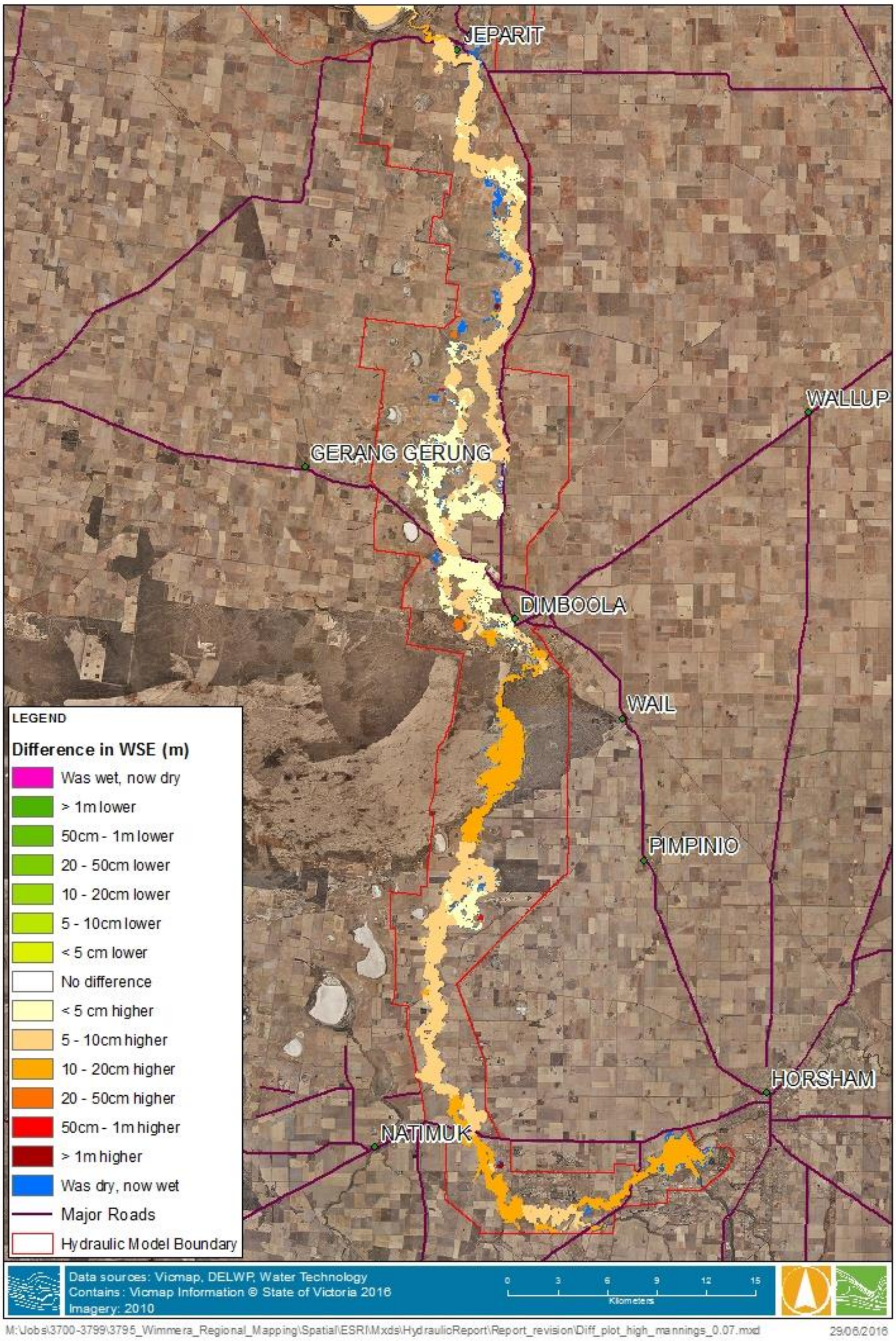

Figure 7-7 Difference in water surface elevation between Manning's n=0.06 and Manning's n=0.06

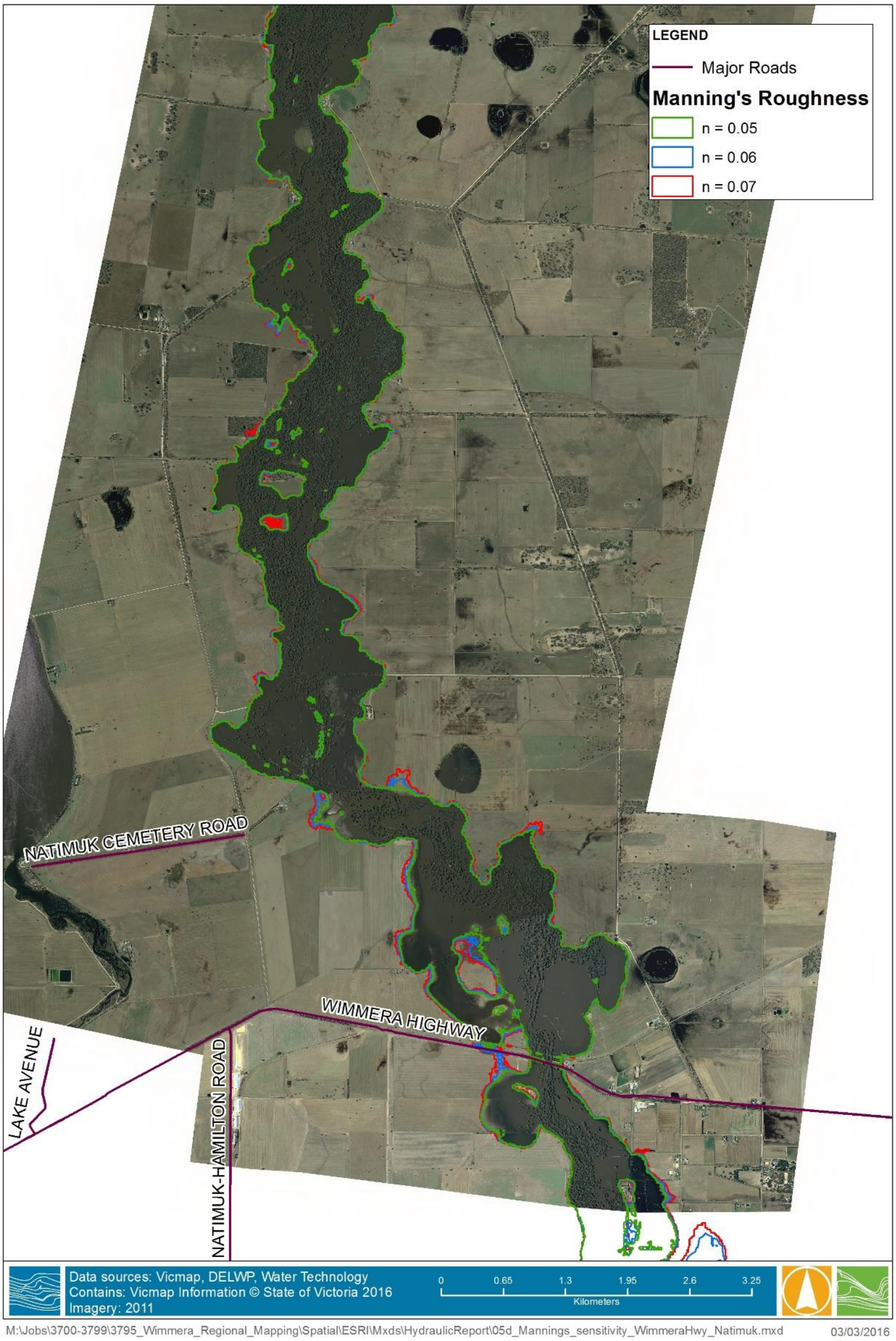

Figure 7-8 **Difference in hydraulic model extent with varied Manning's 'n' values -– January 2011 north-east of Natimuk**

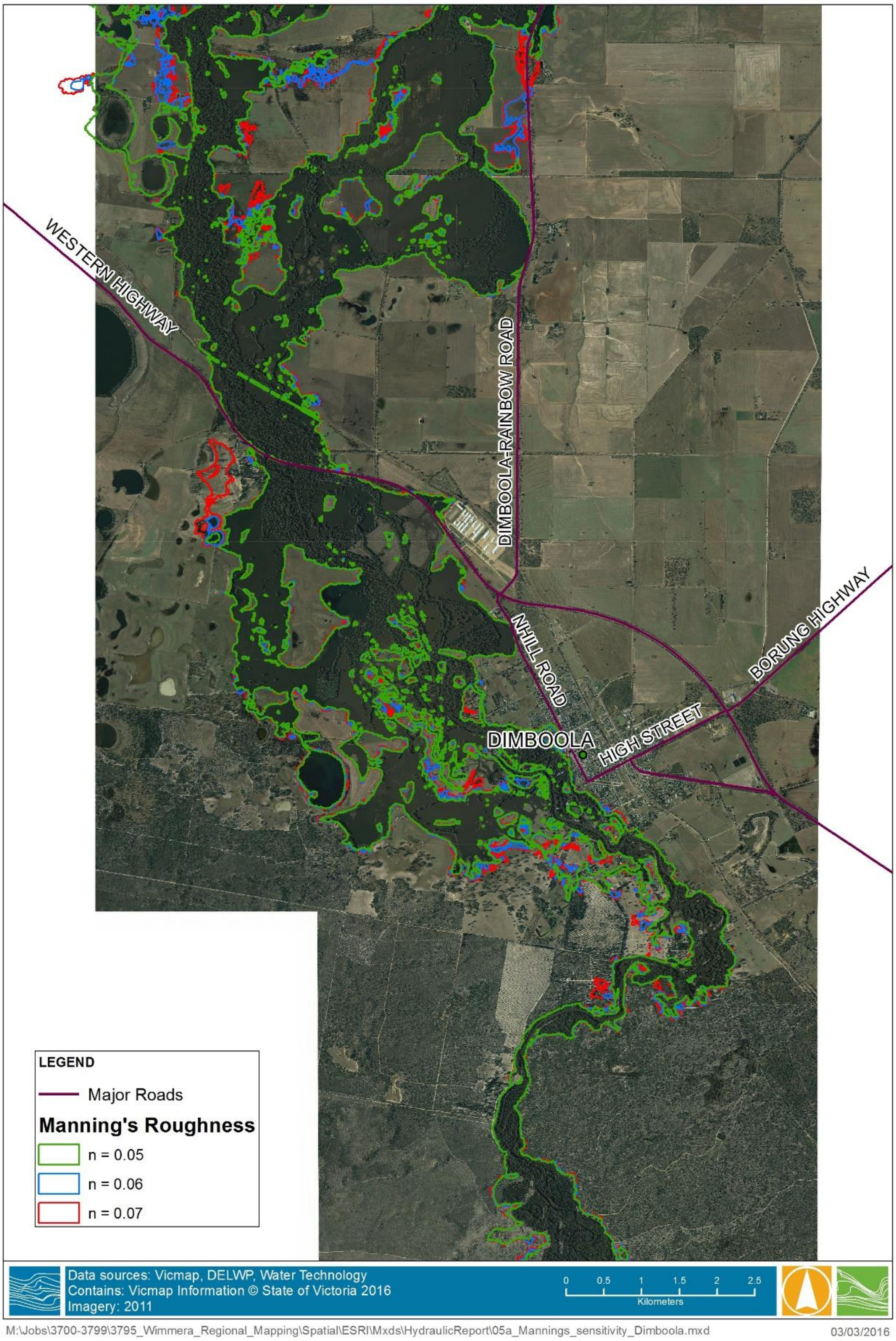

Figure 7-9 **Difference in hydraulic model extent with varied Manning's 'n' values – January 2011 at Dimboola**

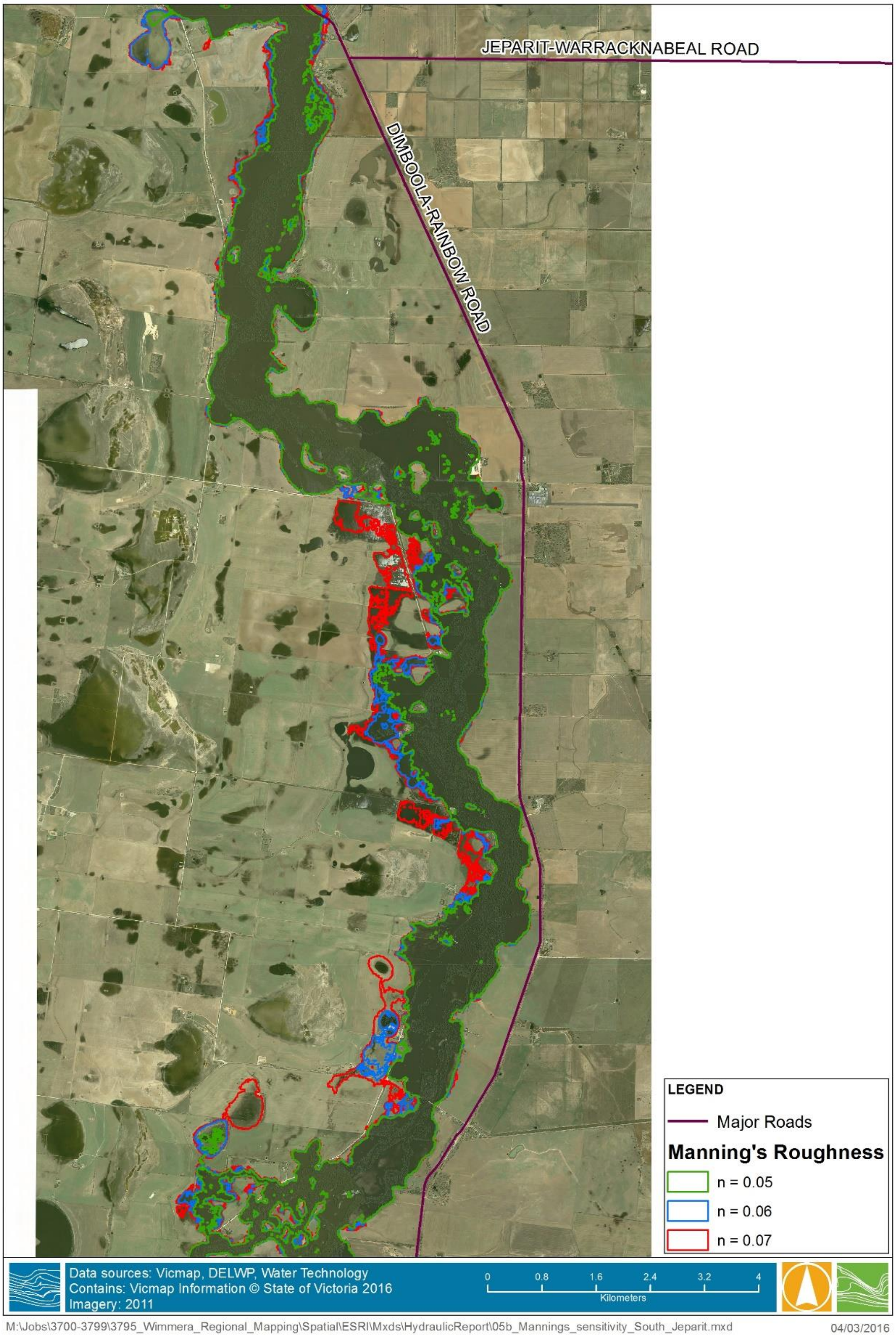

Figure 7-10 **Difference in hydraulic model extent with varied Manning's 'n' values – January 2011 upstream of Jeparit**

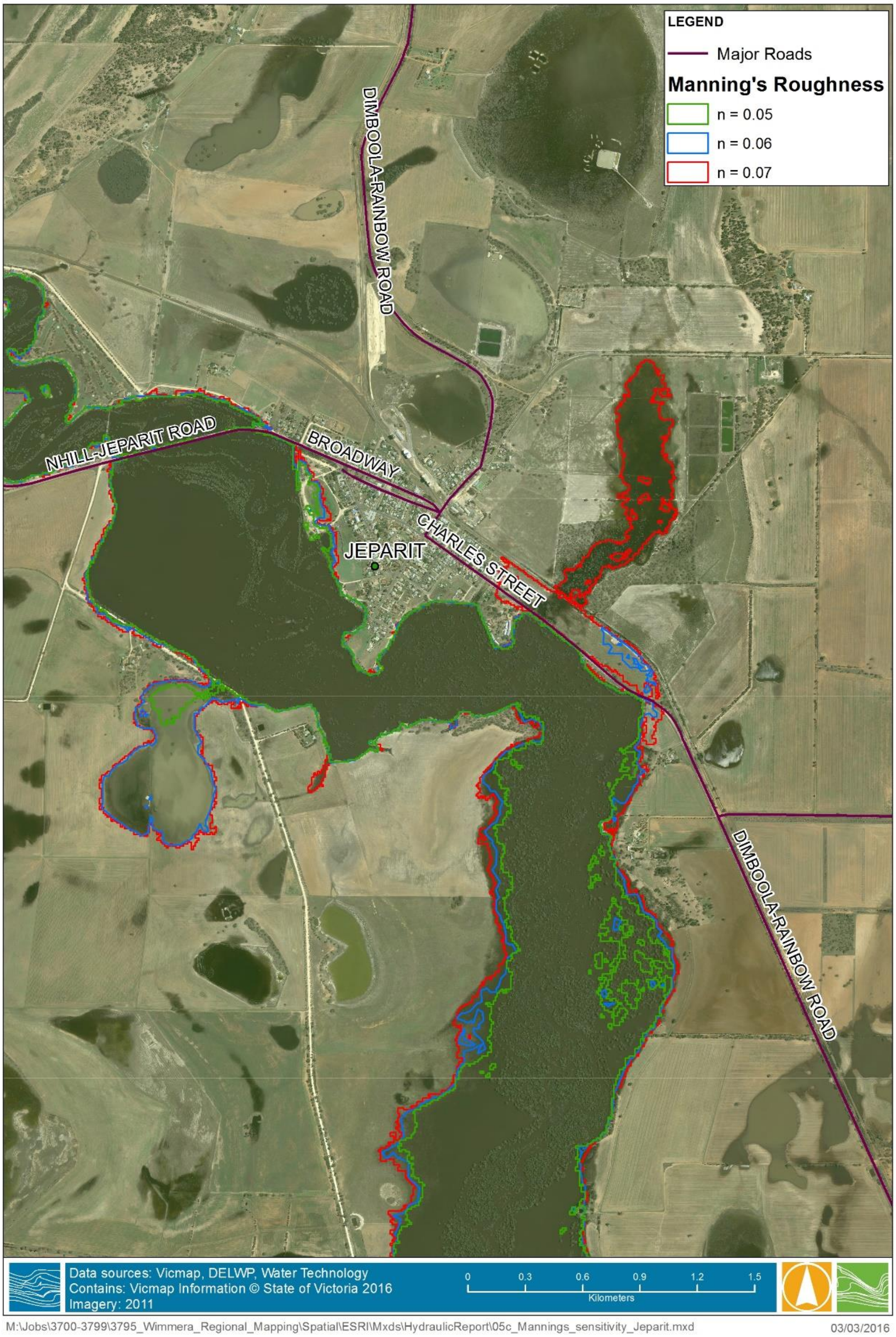

Figure 7-11 Difference in hydraulic model extent with varied Manning's 'n' values – January 2011 at Jeparit

APPENDIX D – SEPTEMBER 2010 FLOOD MARK COMPARISON

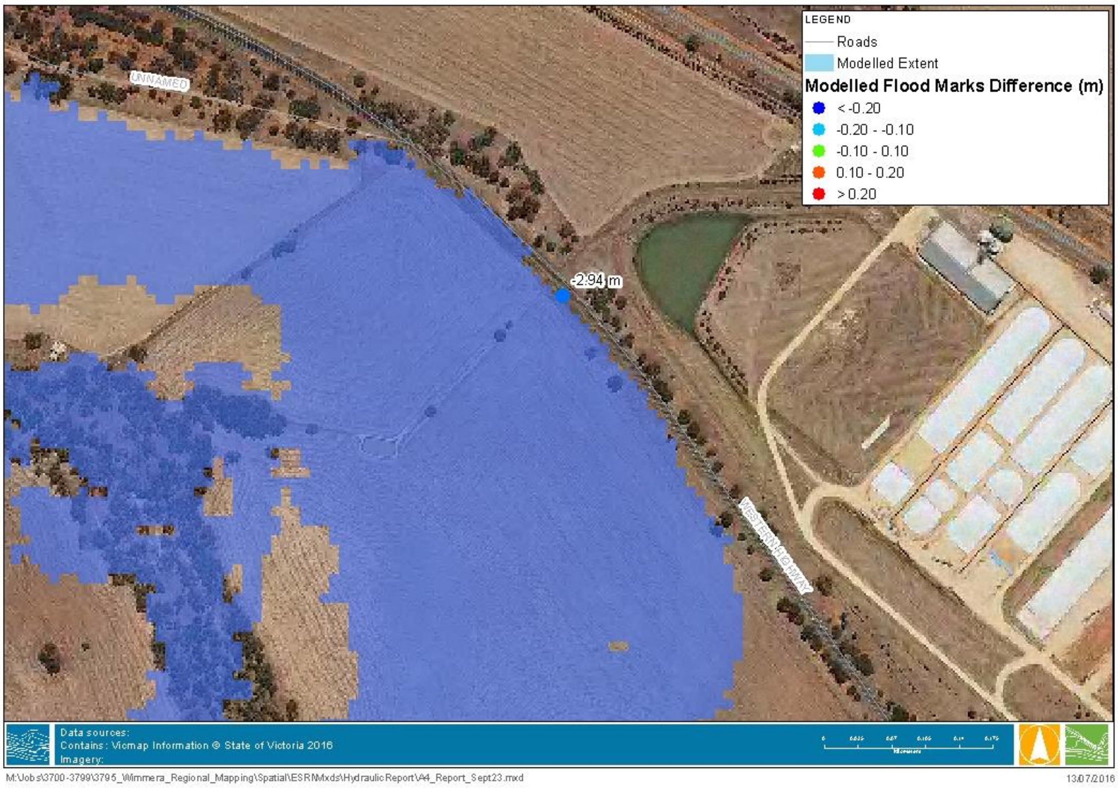

Figure 7-12 Comparison between observed flood markers and modelled flood extent – September 2010 – Survey point 23

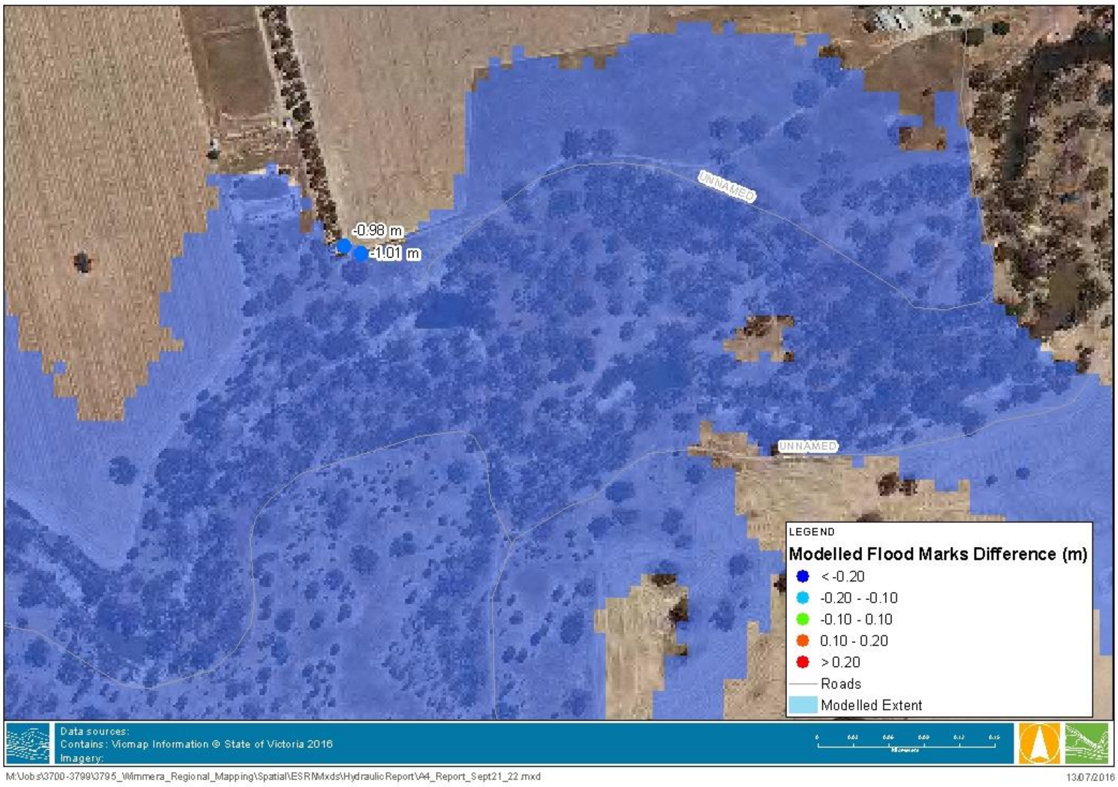

Figure 7-13 Comparison between observed flood markers and modelled flood extent – September 2010 – Survey point 21 and 22

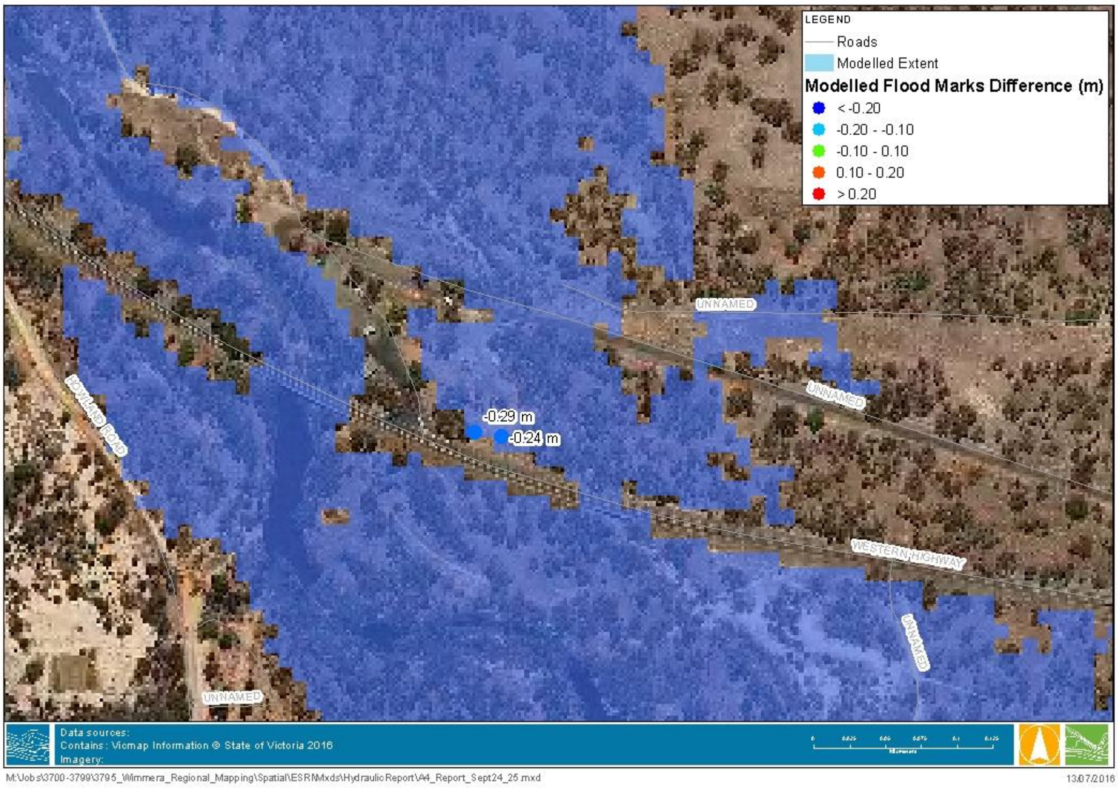

Figure 7-14 **Comparison between observed flood markers and modelled flood extent – September 2010 – Survey point 25 and 24**

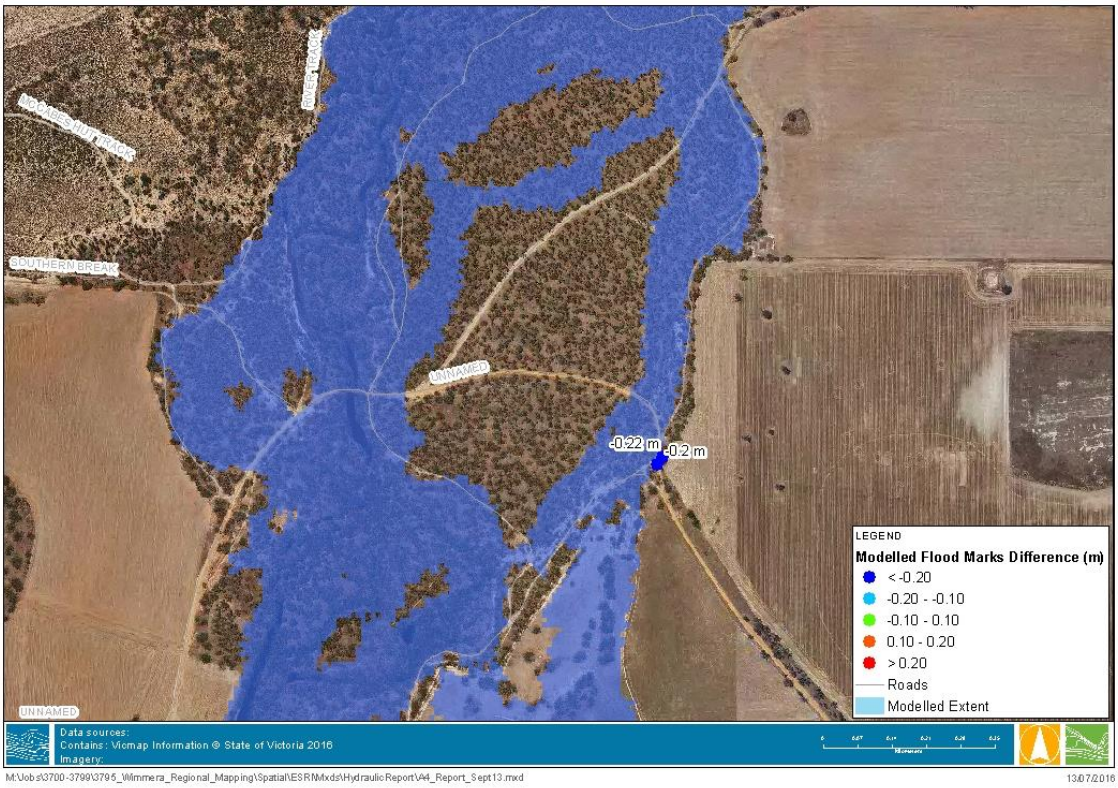

Figure 7-15 Comparison between observed flood markers and modelled flood extent – September 2010 – Survey point 13 and 14

Figure 7-16 Comparison between observed flood markers and modelled flood extent – September 2010 – Survey point 34 and 35

Figure 7-17 Comparison between observed flood markers and modelled flood extent – September 2010 – Survey point 37 and 37a

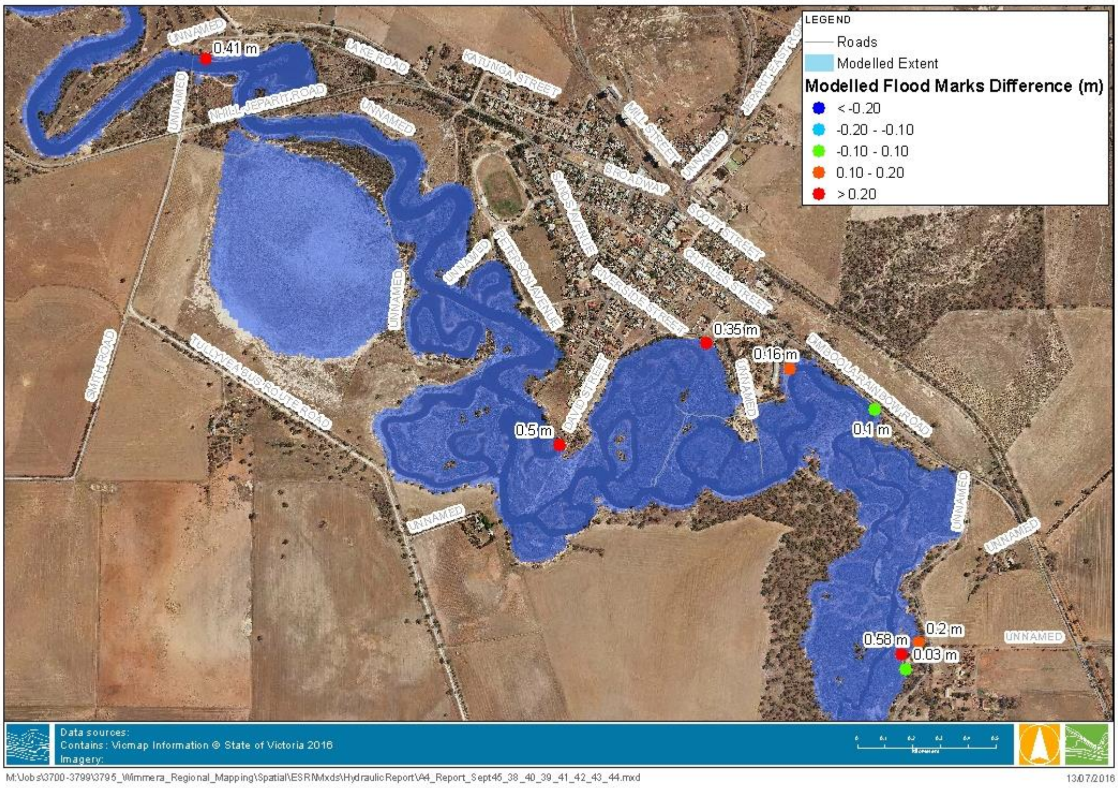

Figure 7-18 Comparison between observed flood markers and modelled flood extent – September 2010 – Survey point 40, 45, 38,19 and 43