Wimmera Catchment Management Authority

Wimmera River - Yarriambiack Creek flow modelling

Study report

Report No. J642/R05

June 2009

Volume 1 – Study report

Final

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

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Wimmera CMA

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Cover photo: Wimmera River near Dave's Lane (Downstream of Glenorchy) Source: Water Technology

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EXECUTIVE SUMMARY

Background

This report documents the collated and gathered data, methodology, findings and recommendations arising as part of the Yarriambiack Creek – Wimmera River flow and flood modelling study.

Wimmera Catchment Management Authority (Wimmera CMA) has commissioned the Yarriambiack Creek – Wimmera River flow and flood modelling project. This project undertook hydrologic and hydraulic and modelling of the Wimmera River and Yarriambiack Creek between Glenorchy, Horsham and Warracknabeal. Both current and "pre-European" catchment-waterway-floodplain regimes were assessed. Several flooding scenarios were also assessed with the current-catchment-waterway-floodplain regimes with the Wimmera Highway Bridge removed.

The study team was led by Water Technology with sub-consultants Fluvial Systems, and Price Merrett.

Data collation

A number of previous flood and waterway management related investigations have been undertaken. Aspects of these studies have contributed to this project. Further, this project enabled examination of the outcomes from several previous projects.

Topographic data collation and assessment

The base topographic data for the study area was sourced from Airborne Laser Survey (ALS) data captured for the Wimmera CMA for the study area. This ALS data has a specified vertical accuracy of 0.15 m along the Wimmera River floodplain and Warracknabeal and a vertical accuracy of 0.5 m along the Yarriambiack Creek floodplain. The accuracy is defined as 67% of the points lying within the specified range. The data was captured in January 2004. Further, 89 cross-sections were surveyed in 2007 including 45 detailed cross-sections and 44 indicative cross-sections.

At the same time a total of 348 verification points were surveyed along roads within the study area. At each point, a comparison was made for the elevations extracted from the ground surface Triangular Irregular Network (TIN) and from the field survey. A positive difference indicates that the ALS elevation is higher than the field surveyed elevation. Statistics across the entire data set are as follows:

- Mean difference: -0.030 m
- Median difference: -0.033 m
- Standard derivation: 0.119 m

A total of 285 out of 348 ALS (81.8 %) points laid within +/- 0.1 m of the field surveyed data. This comparison verified the ALS data generally conforms with the accuracy specification of +/- 0.1 m.

Hydrologic analysis

The hydrologic analysis considered both low-medium and high flow (flood) regimes.

Low –Medium Flows

Existing and pre-European conditions daily flow sequences, for the period January 1990 to December 2000 were derived by SKM (2003a). The flow sequences were developed at a number of locations throughout the Wimmera River catchment.

The existing conditions streamflow sequences were generally estimated using the available streamflow and diversion data. Infilling of missing streamflow data employed correlations with nearby gauges and/or rainfall runoff modelling.

The natural streamflow sequences were estimated by removing the influence of water resource development. The considered water resource developments include on-stream storages, diversions and farm dams (SKM 2003a).

Availability of streamflow data governed the selection of the period of streamflow derivation. The selected period (January 1990 to December 2000) was considered representative of the climate trends over the period of available climate (SKM 2003a). It should be noted the derivation of this 10 year period occurred in 2003, prior to the current dry spell. The consideration of conditions following 2003 may lead to a revised conclusion regarding the representative nature of this flow period.

The derivation of current and natural flow sequences, outlined in SKM (2003a), is considered of adequate rigour for the purposes of this study. It is considered unlikely a re-derivation of the natural flow sequences would yield a more definitive natural sequence. This is due to considerable uncertainty involved in the hydrologic assessment of catchment runoff with changes in land use and water resource development. As such, future investigation of the natural and current low-medium flow sequences was unwarranted.

Flood (High) Flows

The catchment hydrologic model, URBS, was the principal tool employed to estimate flood hydrographs for the Wimmera River catchment.

The calibration of the URBS model parameters underpins the reliability of the flood estimates. The calibration events selected were the largest events in the available streamflow record with concurrent pluviographic rainfall data. The calibration events were representative of small to frequent events with Average Recurrence Intervals (ARIs) up to 50 years. The calibration to larger flood events would aid in the refinement of the model parameters. However, reconciling the URBS model design flood estimates against flood frequency estimates lends strength to the reliability of the adopted approach.

The assessment of pre-European catchment conditions centred on the effect of the major water storages in the Wimmera catchment. For the pre-European conditions, the major on-stream water storages in the Wimmera River catchment upstream of the study area were removed from the URBS model. As discussed later, the considerable uncertainty surrounds the assessment of changes in forested area, and its effect on rainfall losses. For this study, same rainfall losses were employed for pre and post European conditions. Table 1 displays the changes in peak flows between the existing and pre-European catchment conditions

Table -1 Wimmera River –URBS model design peak flows – Differences between Existing and pre-European catchments

Location	Difference in design peak flow (ML/d)					
	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI
Wimmera River at Glenorchy	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Golton Creek at Western Highway	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Mount William Creek at Western Highway	-4717 (-188%)	-5979 (-174%)	-9772 (-116%)	-12442 (-100%)	-15120 (-87%)	-17712 (-80%)
Burnt Creek at Western Highway	466 (27%)	639 (28%)	1252 (29%)	1987 (32%)	2592 (32%)	2592 (28%)
Wimmera River at Walmer	-432 (-3%)	-90 (0%)	-432 (-2%)	-260 (-1%)	-691 (-2%)	-1209 (-3%)

Considerable increases in peak flows were found to occur for Mount William Creek downstream of Lake Lonsdale under the pre-European conditions. However, similar peak flows at Walmer were found under the both existing and pre-European catchment conditions. The increases in peak flow for Burnt Creek under the existing conditions is due to the additional contribution from the MacKenzie River at Distribution Heads

Hydraulic analysis

Framework modelling

Given the complexity of the flow and flood behaviour, a flexible hydraulic modelling framework has been employed. This framework allowed the accurate representation of flow behaviour over a full range of flows balanced against excessive simulation times. The framework comprised:

- One dimensional (1D) hydraulic model for the key waterways: simulate up to bankfull flows along the Wimmera River, where the flow behaviour is one dimensional in nature i.e. confined
- Two dimensional (2D) floodplain hydraulic models for floodplain flows along both the Wimmera River and Yarriambiack Creek, where the channel capacity is a minor proportion to the total flow.
- Two dimensional (2D) site specific hydraulic models for a given location where the flow behaviour is complex i.e. multiple flow paths in a channel.
- Linked one – two dimensional (1D/2D) models for floodplain flow, where the flow just exceeds the channel capacity.

Calibration

1D model

The *1D model* calibration focused on the simulation of flow behaviour for flows up to bankfull along the Wimmera River. The comparison of observed and model flow behaviour targeted three freshes in April-May 1983. The availability of observed streamflow and water level data was limited to two streamflow gauges along the Wimmera River, at Glenorchy and Faux' Bridge.

The comparison of the modelled and observed streamflows revealed that the modelled peak flow is higher than the observed peak flow. This overestimation of the modelled peak flow at the gauges, by up to 20%, arises from the underestimation of diverted flow at Huddleston's Weir.

For the purposes of this project, the 1D hydraulic model was employed to assess a number of steady flow scenarios. These scenarios provide an understanding of the flow-stage relationships at specific locations along the waterways within the study area. These relationships were assessed at specific locations, and are unaffected by any errors associated with the diversion of flow at Huddleston's Weir.

The comparison of the modelled and observed streamflows show the timing of observed peak flows at two gauges is well preserved by the 1D model. This preservation of the timing indicated a good ability of the 1D model to simulate travel time along the Wimmera River. The reasonable simulation of the travel time indicated the 1D model schematisation and parameters (roughness) adequately reflected the available in-channel storage within the Wimmera River.

The comparison of modelled and observed stage-discharge curves at Faux' Bridge shows the water levels for low flows (up to 2000 ML/d) are underestimated. Good agreement between modelled and observed water levels occurred for flows above 2000 ML/d.

Broad scale 2D floodplain model

The *broad scale 2D floodplain model* calibration focused on the simulation of flow and flood behaviour for large flood events. The comparison of observed and modelled flow behaviour targeted four large events, August 1981, September 1983, September 1988 and October 1996. The available observed streamflow and water level data consisted of some 37 observed flood levels, observed flood extents for part of the floodplain, and water level and streamflow data from three gauges.

The magnitude of the flood events used in the model calibration is generally up to a 30 year ARI event. The calibration events exhibited extensive floodplain flow and inundation.

The comparison of the modelled and observed streamflows revealed that the modelled peak flow was lower than the observed peak flow for Yarriambiack Creek at the Wimmera Highway. Further the general hydrograph shape was not well re-produced. As part of the model calibration process, the model schematisation and roughness were varied to improve the fit of modelled and observed hydrographs. A contributing factor to the differences may be the uncertainty surrounding the inflows to the hydraulic model from the hydrologic modelling, In particular, modelled inflows for Mount William Creek. Peak flows and general hydrograph shape were well modelled for the Wimmera River at Walmer. As noted, the modelled hydrograph peaked some 24 hours early than the observed hydrograph. Again, uncertainty surrounding modelled Mount William Creek inflows was considered a contributing factor.

The mean differences in the modelled flood levels are -0.07 m and -0.10 m for the 1981 and 1983 flood events respectively. The median differences were of the same magnitude with -0.03 m and -0.12 m for the 1981 and 1983 flood events respectively. For the August 1981 flood event, 12 of 20 modelled levels, and 10 of 17 modelled levels for the September 1983 were within +/- 0.20 m.

Application

Low –medium flow regime

Table 2 displays the low-medium flow scenarios considered in this project.

Table -2 Low-medium flow scenarios modelled

Flow Description	Wimmera River	Mount William Ck (below Lake Lonsdale)
Long term daily flow sequences	Existing and pre-European conditions- Jan 1990-Dec 2000 (SKM 2003a).	
Summer low flow & fresh	6 ML/day flow with 3 freshes of 16 ML/day for 5 days @ Glenorchy	0 ML/day with 3 freshes of 5 ML/day for 5 days
Winter base flow and high flow	60 ML/day with 2 high flows of 164 ML/day for 14 days @ Huddleston's weir	29 ML/day with 2 high flows of 52 Ml/day for 7 days
Winter bankfull flow	60 ML/day with 1 bankfull flow of 5500 ML/day for 2 days@ Glenorchy	29 ML/day with 1 bankfull flow of 500 ML/day for 2 days
Winter very high flow	60 ML/day with 1 very high flow of 1000 ML/day for 5 days @ Huddleston's Weir	29 ML/day with 1 very high flow of 143 ML/day for 5 days
Winter extremely high flow	60 ML/day with 1 extremely high flow of 3000 ML/day for 2 days @ Glenorchy	29 ML/day with 1 extremely high flow of 300 ML/day for 5 days

The long term daily flow sequences were derived by SKM (2003a), and considered water resources development (storage farm dam). The daily flows sequences extended from 1 January 1990 to 31 December 2000.

Comparisons of flow duration curves display the changes in flow behaviour due to floodplain-waterway-catchment conditions over the period January 1990 to December 2000. Figures 1 and 2 show the flow duration curves for the Wimmera River at Horsham Lubeck Road and for Yarriambiack Creek at the Wimmera Highway Bridge respectively.

The reduced flows under the existing conditions for the Wimmera River at Horsham Lubeck Road was due to the diversion of Wimmera River flows at Huddleston's Weir. The percentage of time daily flows exceed 10 ML/d reduced from 82 % (pre-European conditions) to 29 % (existing conditions).

For Yarriambiack Creek at the Wimmera Highway, small reduction in high flows (>1000 ML/d) has occurred in the existing conditions from the pre-European conditions. However, for the remaining flow regime (< 1000 ML/d), there was an increase in the flow exceedance. The percentage of time daily flows exceed 10 ML/d increased from 2 % (pre-European conditions) to 6 % (existing conditions).

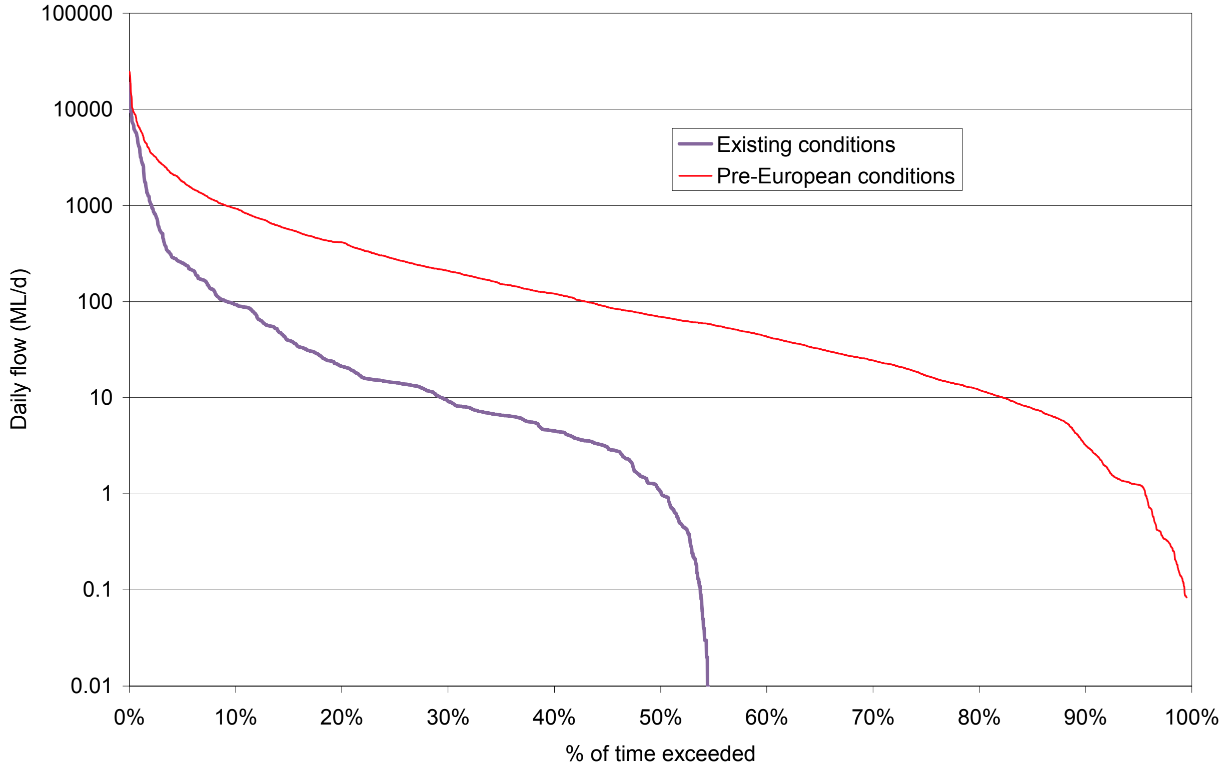

Figure -1 Wimmera River at Horsham Lubeck Road – Flow duration curve- Existing and pre-European conditions

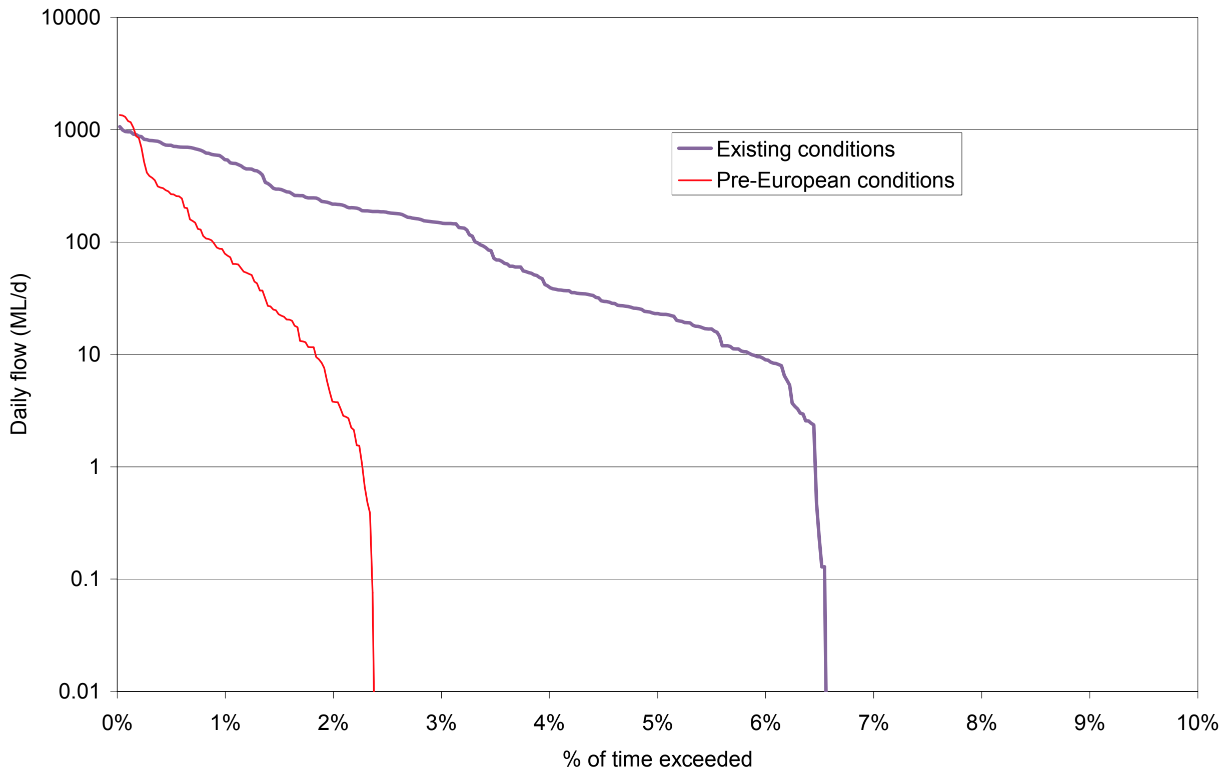

Figure -2 Yarriambiack Creek at the Wimmera Highway – Flow duration curve- Existing and pre-European conditions (Note difference in X axis scale)

For the six environmental flows sites, the water levels at each cross section under the steady state flow scenario were determined. Figure 3 displays the water levels at the upstream cross section for Site 3 Wimmera River at Hall's Island (SKM 2002)).

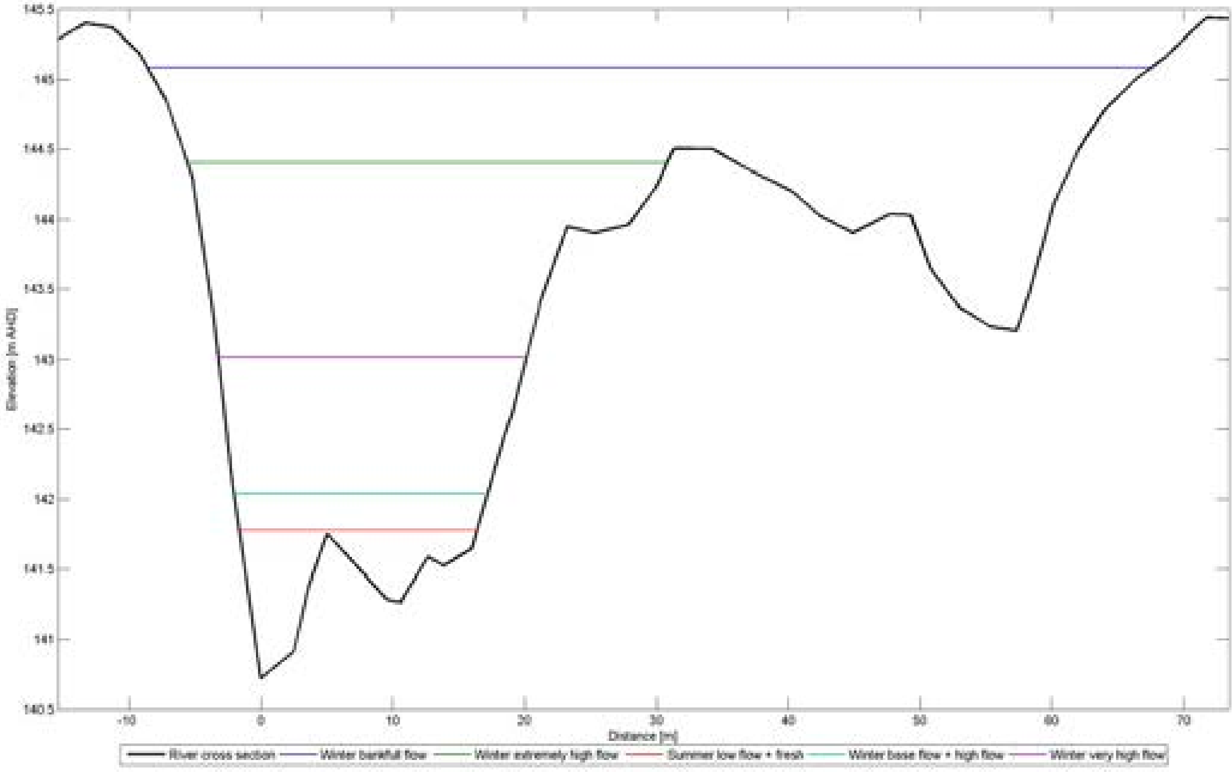

Figure -3 Wimmera River at Halls Island (Mount William Creek) (Environmental Flows site 3 (SKM 2002)) upstream cross section) – Water level cross section plots

Through the simulation of flow behaviour for the low-medium flow scenarios, the bankfull capacity and floodplain connectivity has been assessed. The key flow characteristics for the Wimmera River (Glenorchy to Horsham-Lubeck Road) and Station Creek were assessed as shown in Table 3.

Table -3 Key flow characteristics – Wimmera River and Station Creek

Reach	Indicative bankfull capacity/commence to flow
Wimmera River – Glenorchy to Huddleston Weir	3200 ML/d (37 m^3/s)
Wimmera River –Huddleston's Weir to Station Creek confluence	4700 ML/d (55 m^3/s)
Station Creek	Bankfull capacity: 1900 ML/d (22 m3/s) Commence to flow threshold for the Wimmera River: 2160 ML/d (25 m^3/s)
Wimmera River – Station Creek confluence to Middle Creek confluence	4700 ML/d (55 m^3/s)
Wimmera River –Middle Creek confluence to Mount William creek confluence (Hall's Island)	4700 ML/d (55 m^3/s)
Wimmera River – Horsham – Lubeck Road to Yarriambiack Creek offtake	3900 ML/d (45 m^3/s)

Indicative flow travel time characteristics for flow events up to bankfull flow (< 6000 ML/d at Horsham Lubeck Road):

- 15 hours from offtake to Wimmera Highway
- 80 hours from offtake to Two Mile Creek at Longerenong Road via Darlot Swamp
- 15 hours Wimmera River at offtake to the Two Mile Creek confluence

High flow

Further, the high flow hydraulic model application assessed the change in flood behaviour due to catchment, waterway and floodplain changes since European settlement. The change in flood behaviour was assessed, by the broad scale 2D floodplain hydraulic model, for the following four scenarios:

1. Existing waterway-floodplain-catchment conditions;
2. Pre-European settlement waterway-floodplain with current catchment conditions;
3. Pre-European settlement waterway-floodplain- catchment conditions; and
4. Existing waterway-floodplain-catchment conditions with the Wimmera Highway Bridge across Yarriambiack Creek removed.

The following sections discuss the high flow flood behaviour for the reaches in the study area.

<u>Wimmera River – Glenorchy to Horsham –Lubeck Road</u>

A key influence on floodplain behaviour on the northern floodplain is the Murtoa – Glenorchy Road. Increased flood levels occur to the east of the current road alignment in comparison to the pre-European waterway floodplain conditions. To the west of the current road alignment, there has been a decrease in flood levels. This behaviour is in line with community concerns raised during previous investigations.

The Wimmera Inlet Channel has a number of syphons allowing flow through the embankment. Minimal change (less than 50 mm) in flood levels occurred adjacent to the channel for the 5 year ARI flood event. In larger flood events, some re-distribution of flood waters and hence changes in flood level occurred with the removal of the channel. Flood levels along Middle Creek immediately downstream of the inlet channel have increased (up to 200 mm for the 100 year ARI flood event) under the existing conditions. Correspondingly reductions in flood levels occurred along Mount William Creek immediately downstream of the inlet channel. These changes in flood levels indicate some re-distribution of flood flows under the existing conditions.

<u>Wimmera River –Horsham –Lubeck Road to Dooen Swamp</u>

The Wimmera River breakouts across the northern bank adjacent to adjacent to Horsham – Lubeck Road continue through the Barrabool Flora and Fauna Reserve, across Burnt Clay Road and along Corkers Drain Creek. Corkers Drain Creek crosses the Taylor’s Lake outlet channel at a syphon crossing and continues in a north westerly direction to join Yarriambiack Creek immediately south of Darlot Swamp. For the 50 year event and larger (flow at Horsham -Lubeck Road ~ 35,900 ML/d), shallow (up to 250 mm deep) broad floodplain flow occurs parallel to Corkers Drain Creek.

Adjacent to the offtake, breakouts over the northern bank of the Wimmera River occur for the 20 year ARI flood event and greater. These breakouts continue north as shallow overland flow, with some flow rejoining Yarriambiack Creek adjacent to Longerenong Road.

Downstream of the Corkers Drain Creek confluence, some flows in Yarriambiack Creek enter Darlot Swamp. Once full, the Darlot Swamp overflow continues to the south along Two Mile Creek, and returns to the Wimmera River. The remainder of the flow in Yarriambiack Creek continues to the north.

Local increases in flood levels occur along the southern side of Longerenong Road and to the south of the Wimmera Highway Bridge. Local decreases in flood levels occur along the northern side of Longerenong Road and to the north of the Wimmera Highway Bridge. The change in flood levels adjacent to Longerenong Road indicates the current road and channel arrangement leads some obstruction to flood flows, and hence increased flood levels on the upstream and lower flood levels on the downstream side.

The Wimmera Highway Bridge and its approaches obstruct the floodplain flows. This obstruction leads increases in the 100 year flood level immediately upstream of the bridge. The increased flood levels were limited to about 750 m south of the bridge. Decreased flood levels (up to 100 mm) occurred to the north of the bridge along Yarriambiack Creek. The decreased flood levels to the north of the bridge resulted from a reduction in the peak flow along Yarriambiack Creek under the existing conditions. Further discussion of the hydraulic impact of the Wimmera Highway Bridge is provided in a following section.

Yarriambiack Creek

The flooding behaviour is characterised by inundation confined to the immediate surroundings of the creek. There are no extensive breakouts and/or floodplain areas. For the design flood events considered by this study, the travel time of the peak flow from Jung Weir to Warracknabeal is about 36-40 hours.

Under the existing conditions, there were decreases in peak flows and flood volumes entering Yarriambiack Creek, in comparison to the pre-European floodplain-waterway conditions. As discussed above, the existing Wimmera Highway Bridge arrangements acts as an obstruction to the flood flows. Hence, a reduced flow enters Yarriambiack Creek under the existing conditions compared with pre-European floodplain-waterway conditions for flood events (~ 5 year events and greater). The decreased flows result in lower flood levels along Yarriambiack Creek under the existing conditions. For the 5 year ARI flood event, the decreases in flood levels are less than 50 mm. The larger decreases in peak flows for the 100 year ARI event results in decreases in flood levels along Yarriambiack Creek up to 100 mm.

Wimmera River –Horsham –Dooen Swamp to Walmer

The 100 year ARI flood event has considerable floodplain flow due to the low channel capacity of the Wimmera River in this reach. To the south of the Dooen Swamp, overland flow paths occurred adjacent to Browns, Heards and Rokeskys Roads. These breakaways leave the Wimmera River near the Two Mile Creek confluence and continue west crossing Riverside East and Cameron Roads. It is likely that the actual flood extents for the 100 year ARI flood event and larger events would extend beyond the limit of the detailed ALS data, particularly adjacent to Andrews Road. Future extension of the hydraulic modelling area using additional topographic data is recommended to refine the mapped flood extents (100 year ARI and greater events) adjacent to Andrews Road. These southern overland flowpaths were not included in the flood mapping undertaken by the Horsham Flood Study (Water Technology 2003b), as the flowpaths were beyond the study area.

Along the northern floodplain, overbank flooding occurred adjacent to Camerons Road, and Pryors Road and Peppertree Lanes. The town levee is overtopped and outflanked adjacent to

Pryors Lane. This overtopping leads to flooding along Knowles, Webster, Lawrence and Culliver Streets. Further breakout occurred at Baillie and Menadue Streets, with flooding along Carr, Glancy, Rennison and Arnott Streets.

In a 50 year ARI event (~32,000 ML/d at Walmer), breakouts commence near Hamilton Street. This breakout continues to the west along Hamilton Street and McBryde Street across the Western Highway. Flooding affects Urquhart, Sloss, Madden and Firebrace Streets, and O'Callaghan's Parade. This breakout follows the Old Town anabranch. The breakout rejoins the Wimmera River via Wotonga Basin.

The flood behaviour determined by this project was in line with the findings of the Horsham Flood Study (Water Technology 2003b). A spot check of 100 year ARI flood levels shows this project's flood levels are generally within 100 mm of the previous study's estimates.

Wimmera River - Yarriambiack Creek flow distribution

<u>Existing conditions</u>

For Wimmera River flows up to 16,000 ML/d, flow into Yarriambiack Creek can only enter at the offtake. In higher flows, the breakout from the Wimmera River upstream of the offtake occurs and leads to overland inflows into Yarriambiack Creek.

The flow entering Yarriambiack Creek at the offtake was obtained from the three hydraulic models for Wimmera River flows up to 16,000 ML/d, i.e. Yarriambiack inflows at the offtake only. This study's modelled inflows were compared with the results from SMEC (2002). Table 4 displays the modelled peak flows for the Wimmera River upstream of the offtake, and for Yarriambiack Creek immediately downstream of the offtake, from this study and SMEC (2002).

Table -4 Wimmera River – Yarriambiack Creek flow distribution - at offtake – Existing conditions (Wimmera River < 16,000 ML/d)

Modelling approach	Wimmera River flow upstream of offtake	Yarriambiack Creek at offtake (ML/d)	
	Peak flow (ML/d)	Existing conditions Peak flow (ML/d)	Existing conditions % of Wimmera river flow upstream of offtake
2D local modelling (Section 8.2.4.5)	173	97	56%
	432	131	30%
	864	188	22%
	1728	302	17%
	2592	415	16%
1D-2D modelling (Section 8.2.4.3)	3115	803	26%
	5870	1198	20%
2D broad scale modelling (Section 8.3.2.2)	15260	2076	14%
SMEC (2002)	5103	496	10%

The local 2D modelling, for flows less than 3000 ML/d, shows a decreasing percentage of the Wimmera River flow entering Yarriambiack Creek as the Wimmera River flow increases. The percentage falls from 56% to 16% for the Wimmera River flow ranging from 173 ML/d to 2592 ML/d.

The local 2D modelling and linked 1D-2D modelling shows a differing flow distribution around 3000-6000 ML/d. The linked 1D-2D modelling yields higher flow into Yarriambiack Creek than the local 2D modelling. The differences between the approaches may arise from the different representation of the waterway geometry. Both modelling approaches were unable to be calibrated, due to lack of available observed data. The differing flow distributions highlight the complexity of the hydraulic behaviour at the offtake. Agreement of the modelling approaches does not necessarily ensure a reliable simulation of the hydraulic behaviour. Refinements to the hydraulic models require the collection of observed flow data, and then calibration of the hydraulic model to this observed data. Through a calibration process, differences between the modelling approaches may be reduced.

SMEC (2002) considered a “small” flood event with a peak Wimmera River flow upstream of the offtake of 5103 ML/d. For this small flood event, SMEC (2002) assessed 10 % of the Wimmera River flow entered Yarriambiack Creek. The linked 1D-2D model, for a similar Wimmera River flow (5870 ML/d) yielded a flow distribution of 20 %. The use of comprehensive modelling approach by this study, it likely to improve the predictive ability of the hydraulic modelling, However, again, the absence of observed flow data limits the definitive assessment of the reliability of both the linked 1D-2D model and SMEC (2002) modelling.

The local scale 2D model only considered the immediate area (~ 25 ha) to the offtake. The local scale 2D model does not extent to the Wimmera Highway Bridge. Hence, modelled peak flow at Wimmera Highway was only available from the linked 1D/2D and broad scale 2D models. Table 5 and Figure 4 show the flow distribution Wimmera River upstream of the offtake and the Yarriambiack Creek at the Wimmera Highway Bridge, from this study and SMEC (2002).

Table -5 Wimmera River – Yarriambiack Creek flow at Wimmera Highway – Existing conditions (Wimmera River flow 3000- 43900 ML/d).

Modelling approach	Wimmera River flow upstream of offtake	Yarriambiack Creek at Wimmera Highway (ML/d)	
	Peak flow (ML/d)	Existing conditions Peak flow (ML/d)	Existing conditions % of Wimmera river flow upstream of offtake
1D-2D modelling (Section 8.2.4.3)	3115	508	16%
	5870	677	12%
2D broad scale modelling (Section 8.3.2.2)	15260	946	6%
	27460	1460	5%
	42900	3160	7%
SMEC (2002) Small, Medium & Large floods	5103	400	8%
	16960	1409	8%
	43814	17196	39%

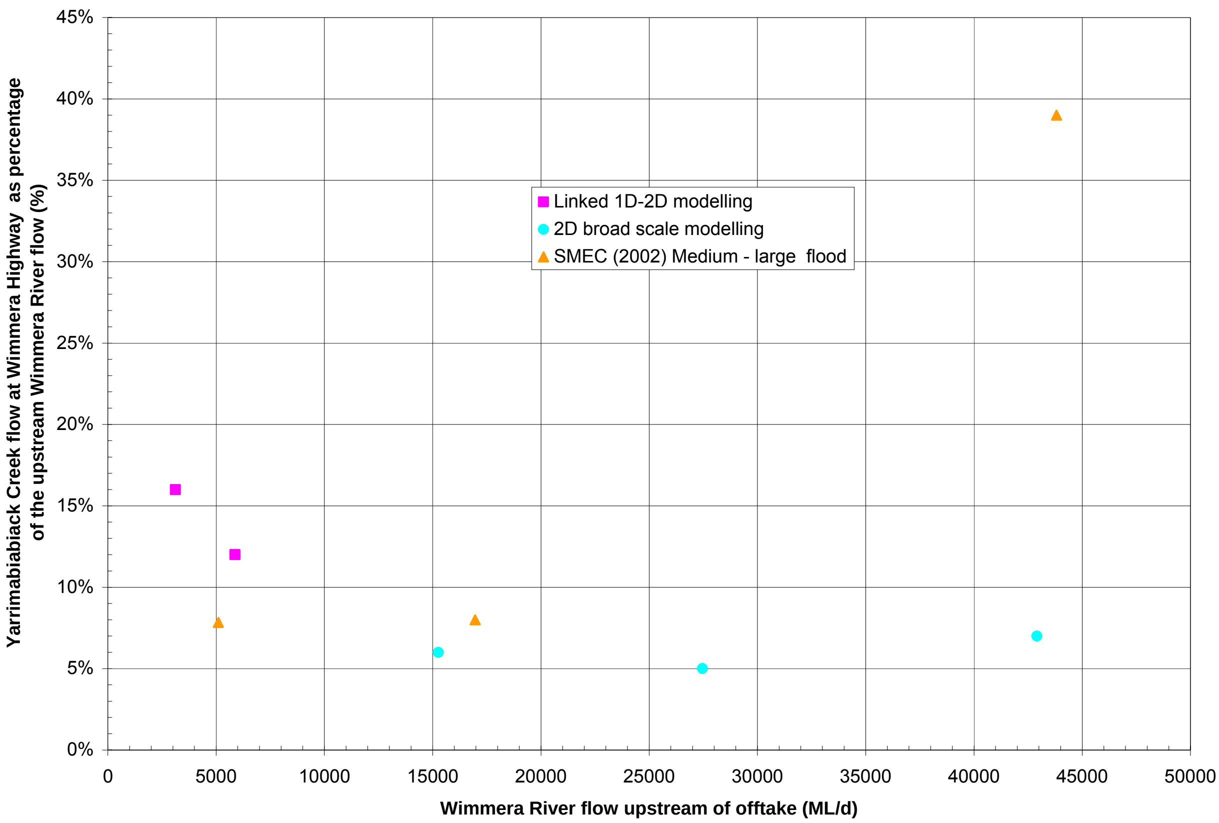

Figure -4 Wimmera River – Yarriambiack Creek flow distribution - at Wimmera Highway – Existing conditions (Wimmera River flow 3000 -43000 ML/d)

The broad scale 2D modelling provides a relatively constant flow distribution (as percentage of upstream Wimmera River flow) ranging from 5-7% for flows from 15260 ML/d to 42900 ML/d). A similar flow distribution, about 8%, was obtained by SMEC (2002) for a Wimmera River flow of 16960 ML/d. However, for the higher flow (43814 ML/d), SMEC (2002) yielded a considerable higher flow distribution of 39%.

Both the broad 2D modelling and SMEC (2002) modelling were calibrated to observed flows at the Wimmera Highway Bridge for the August 1981 and September 1983 events. These two calibration events can be considered medium in magnitude with peak flows at Walmer around 22,000 -25,000 ML/d. The definitive assessment of the reliability of both the broad 2D modelling and SMEC (2002) modelling to larger flood events than the calibration events ie. >40,000 Ml/d, is limited.

The broad scale 2D modelling is considered better able to capture the numerous flow paths across the floodplain between the Wimmera River and the Wimmera Highway, given the two dimensional nature of the modelling. SMEC (2002) employed a 1D hydraulic model with principal flowpaths including Corkers Drain Creek, Yarriambiack Creek and Two Mile Creek. The SMEC (2002) modelling did not consider the flowpath adjacent to Longerenong Road joining Yarriambiack Creek and Two Mile Creek. This flowpath becomes increasing important for large flood events, in excess of the calibration events. It is likely that the absence of this flowpath from the SMEC (2002) modelling may overestimate flows arriving at the Wimmera Highway in large flood events (say > 30,000 ML/d).

Pre-European waterway –floodplain conditions

The flow-flood behaviour under pre-European waterway-floodplain conditions was assessed. SMEC (2002) modelled "natural' conditions, which were taken as similar to this project's pre-European waterway-floodplain conditions.

Examination of the local 2D modelling, from the existing conditions scenario indicated that the water level at the offtake does not exceed the pre-European invert under a flow of 2592 ML/d. Hence, the pre-European waterway–floodplain conditions were not modelled using the local 2D model. The linked 1D- 2D model and the broad 2D model were employed to assess the pre-European waterway-floodplain conditions. Table 6 and Figure 5 show the flow distribution Wimmera River upstream of the offtake and the Yarriambiack Creek at the Wimmera Highway Bridge, from this study and SMEC (2002).

Table -6 Wimmera River – Yarriambiack Creek flow at Wimmera Highway – Pre-European waterway-floodplain (Wimmera River flow 3000- 42900 ML/d).

Modelling approach	Wimmera River flow upstream of offtake	Yarriambiack Creek at Wimmera Highway (ML/d)	
	Peak flow (ML/d)	Pre-European waterway-floodplain Peak flow (ML/d)	Pre-European waterway-floodplain % of Wimmera river flow upstream of offtake
1D-2D modelling (Section 8.2.4.3)	3250	0	0%
	5812	78	1%
2D broad scale modelling (Section 8.3.2.2)	15200	1016	7%
	27660	1640	5%
	43630	3960	9%
SMEC (2002) Small, Medium & Large floods	5103	9	0.2%
	16960	2822	17%
	43841	19234	39%

For a medium flow in the Wimmera River (5000 – 6000 ML/d), both the linked 1D-2D model and SMEC (2002) indicated that an only minor flow (80 ML/d) passes the Wimmera Highway in the pre-European conditions. In higher flows (> 15,000 ML/d), the linked 1D-2D model provides a relatively constant flow distribution (5-9%) at the Wimmera Highway. SMEC (2002) shows a considerably higher proportion of the Wimmera River flow passing the Wimmera Highway Bridge (17%-39%), particularly for a large flood event (say 42,000 ML/d). These differences in the flow distribution between this project and SMEC (2002) may arise from the use of the 2D modelling, as discussed above.

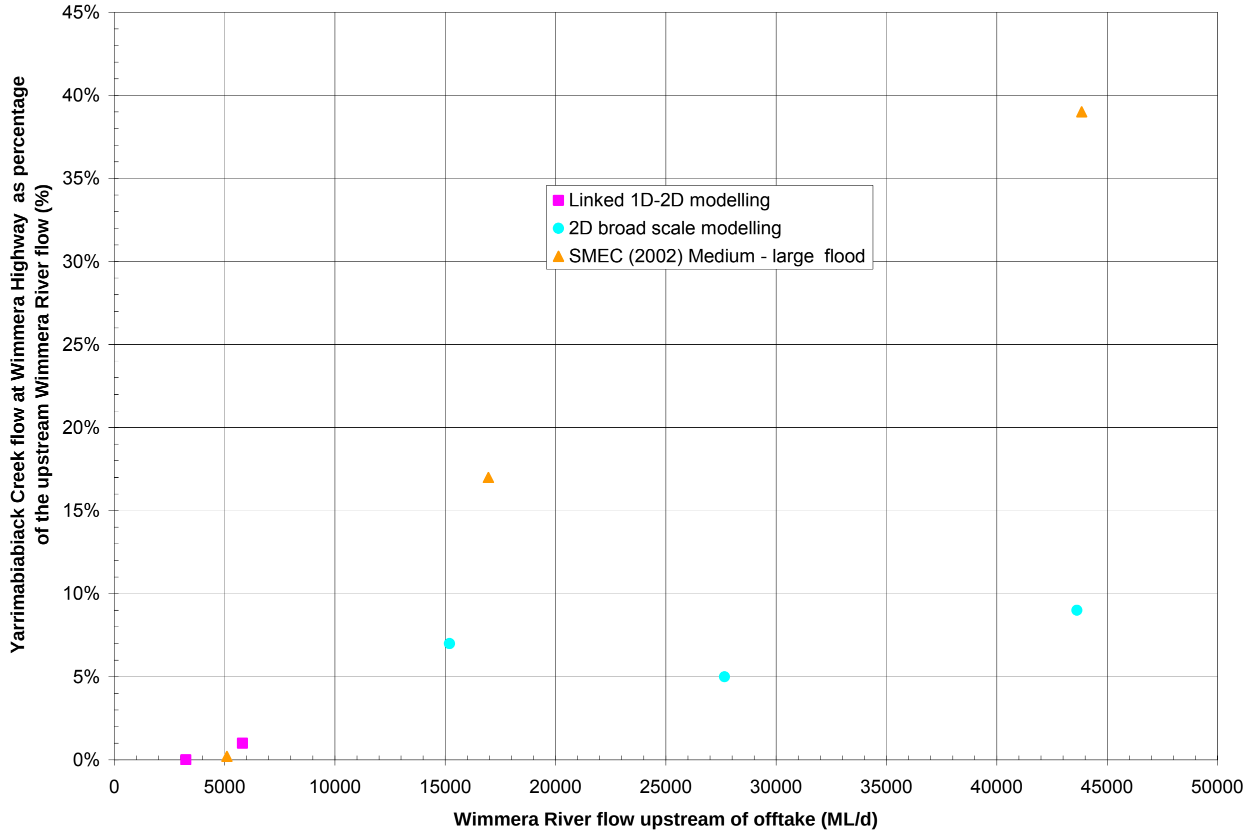

Figure -5 Wimmera River – Yarriambiack Creek flow distribution - at Wimmera Highway – Pre-European waterway-floodplain conditions (Wimmera River flow 3000 - 43,000 ML/d)

<u>Existing conditions and Pre-European waterway –floodplain conditions comparison</u>

The existing and pre-European waterway-floodplain conditions were assessed using the linked 1D-2D model and the broad scale 2D model. Figure 6 displays a comparison of peak flows at the Wimmera Highway Bridge under existing and pre-European waterway and floodplain conditions. For the low-medium flows (3000-6000 ML/d), the higher peak flows occur for the existing conditions, with zero flow occurring for the pre-European conditions. This is due to the lower Yarriambiack Creek invert adjacent to the offtake.

For the high flow (> 15,000 ML/d), the pre-European waterway-floodplain conditions yield the higher peak flow at the Wimmera Highway Bridge compared to the existing conditions. The magnitude of the higher peak flows increases with the increasing Wimmera River flows.

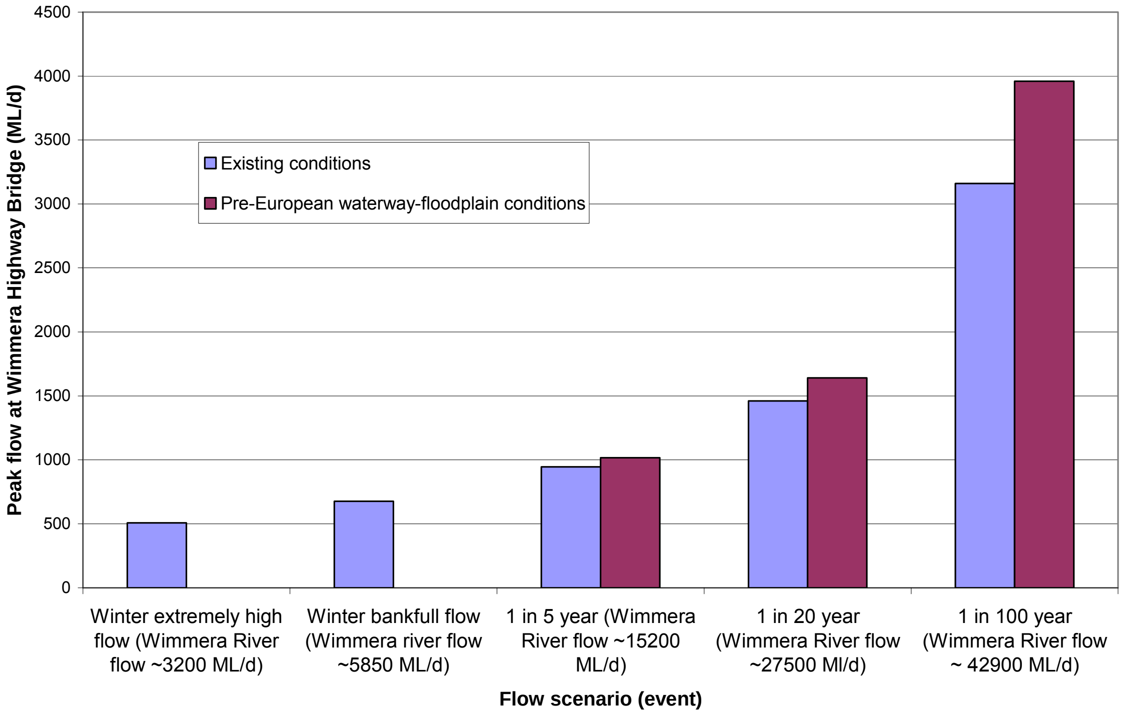

Figure -6 Wimmera River – Yarriambiack Creek flow distribution - at Wimmera Highway – Existing -Pre-European waterway-floodplain conditions (Wimmera River flow 3000 -43,000 ML/d)

Wimmera Highway Bridge and approaches removed

A hydraulic assessment was undertaken to assess the removal of the Wimmera Highway Bridge and approaches. No other changes were made to the current waterway and floodplain conditions.

As discussed in the section describing high flow flooding in the study area, the Wimmera Highway Bridge and its approaches obstruct the floodplain flows. This obstruction leads increases in the 100 year flood level immediately upstream of the bridge of approximately 600 mm compared to pre-European waterway-floodplain conditions. The increased flood levels were limited to about 750 m south of the bridge. Decreased flood levels (up to 100 mm) occurred to the north of the bridge along Yarriambiack Creek. The decreased flood levels to the north of the bridge resulted from a reduction in the peak flow along Yarriambiack Creek under the existing conditions.

Table -7 displays the flow distribution with the Wimmera Highway Bridge and approaches removed. The change in peak flow and flood volume compared to the existing conditions is provided as percentage in brackets.

Table -7 Flow distribution: Horsham Lubeck Road – Dooen Swamp – upstream Jung Weir – Wimmera Highway Bridge removed

Location	Design flood event (ARI)			
	20 year		100 year	
	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)
Wimmera River: Horsham Lubeck Road	27,460 (0%)	80,680 (0%)	42,900 (0%)	119,043 (0%)
Yarriambiack Creek: Wimmera Highway	1,619 (11%)	4,257 (10%)	3,764 (19%)	8,644 (22%)
Wimmera River: Downstream of Two Mile Creek	22,557 (0%)	64,899 (3%)	35,861 (-1%)	103,402 (4%)

Table -7 shows the peak flows and flood volumes for Yarriambiack Creek at the Wimmera Highway Bridge were higher with the bridge and approaches removed. The magnitudes of the increases in peak flow flows and flood volume follow the increase in flood magnitudes. These increases are slightly less than seen for the pre-European waterway – floodplain conditions. For example in the 20 year event, the peak flow is 1,619 ML/d without the bridge, compared to 1,640 ML/d for the pre-European waterway-floodplain conditions. This indicates that the current Wimmera Highway bridge arrangement is the key influence in the change in flow distribution since European settlement, and other modification to waterway and floodplain play a secondary role.

For the Wimmera River downstream Two Mile Creek, only minor changes to the peak flow and flood volume were seen.

The current Wimmera Highway Bridge has a significant influence flow in Yarriambiack Creek downstream of the bridge, as discussed above. However, the bridge arrangement has no significant impact on flows in the Wimmera River downstream of Two Mile Creek, and in turn through Horsham.

Recommendations

The following recommendations aim to enhance the modelling framework capacity over time, and to maximise the Wimmera CMA's future use of the modelling framework in waterway and floodplain management application.

Streamflow and water level data collection - Yarriambiack Creek at the Wimmera Highway Bridge

Flows along Yarriambiack Creek are sourced principally from the Wimmera River during overbank flooding. The modelling framework provides insight into the flows entering Yarriambiack Creek from the Wimmera River. However, the calibration of the modelling framework was constrained by the lack of observed streamflow in Yarriambiack Creek.

The study team recommends the re-establishment of the stream flow gauge at the Wimmera Highway Bridge, and the Wimmera CMA should consult with relevant agencies to promote the gauge re-establishment. Future streamflow data from this re-established gauge is considered by the study team as a valuable input into the flow management and refined model calibration.

The study team understands the current flood warning upgrade project is installing/re-establishing gauges at the following locations:

- Wimmera River at Drung Drung (Gross Bridge) (Measuring stage only)
- Yarriambiack Creek at Wimmera Highway Bridge (Measuring stage only)

The Wimmera River channel adjacent to the Drung Drung site is subject to considerable change (Paul Fennell Wimmera CMA pers. comms). Such change in channel shape constraints the establishment of a reliable stage-flow rating curve. However, the collection of stage (water level) is seen as valuable data in refining the model calibration.

The location of Wimmera Highway Bridge adjacent to the proposed gauge provides a stable control, and enables the establishment of a reliable stage-flow rating curve, using the hydraulic model.

The study team recommends refinement of the hydraulic model calibration once sufficient streamflow data is collected at the additional gauges. Ideally the gauged streamflow data would include several medium-large flow freshes, say 6000-10000 ML/d.

Streamflow and water level data collection – Mount William Creek downstream of Lake Lonsdale

The current streamflow gauge downstream of Lake Lonsdale is limited to low-medium flows. High flow data is not available at this gauge. Flows from Mount William Creek provide a significant contribution to Wimmera River flows. The modelling framework provides insight into the contribution from Mount William Creek catchment. However, the calibration of the modelling framework was constrained by the lack of observed streamflow for high flow events.

The study team recommends the establishment of a high flow rating curve for the stream flow gauge downstream of Lake Lonsdale. Future streamflow data is considered by the study team as a valuable input into the flow management and refined model calibration.

Streamflow and water level data collection – Opportunistic environmental flows monitoring

The calibration of the 1D hydraulic model (for up to bankfull flows) was constrained by the available flow data.

The study team recommends opportunistic flow and water level gaugings during environmental flows releases be undertaken by the Wimmera CMA. Such provision could be included in the implementation of Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) for the Wimmera River. Future streamflow data from opportunistic flow gauging is considered by the study team as a valuable input into the flow management and refined model calibration.

Streamflow and water level data collection – Opportunistic flood level monitoring

The calibration of the 2D hydraulic model (for floodplain flows) was constrained by the available flood level data.

The study team recommends opportunistic flood level collection during flood events be undertaken by the Wimmera CMA, and such provision should be in the implementation of the Wimmera CMA Flood guidelines. Under the Victorian Flood Management Strategy (DNRE 1998), collection of flood data (levels and extents) is the responsibility of the CMA. Future flood level collection is considered by the study team as a valuable input into the flow management and refined model calibration.

Hydraulic model calibration refinement

The hydraulic model calibration utilised available observed streamflow and water level data for comparison to modelled streamflow and water levels. Additional streamflow and water level data enables the refinement of the hydraulic model calibration.

The study team recommends refinement of the hydraulic model calibration following the collection of observed streamflow and water levels from natural flows, environmental water releases and/or a significant overbank flood event. In particular, the availability of additional streamflow data at the Yarriambiack Creek at Wimmera Highway Bridge is seen as a critical element in the hydraulic model refinement.

Such model refinement will underpin the hydraulic model capability for use in waterway and floodplain management.

Influences on environmental water releases re-assessment

The identification of influences on environmental water releases has been identified by SKM (2008) and Earthtech (2007). These previous projects assessed the hydraulic impact of identified influences via simple hydraulic analysis. This project has undertaken a preliminary re-assessment of the hydraulic impact using the refined hydraulic modelling framework. However, a comprehensive re-assessment of the influences should ensure consistency between this study flow modelling and the understanding of the influences.

The study team recommends a thorough re-assessment of the hydraulic impact of the identified influences. Further, the study team recommends the examination of the hydraulic modelling outputs from this project to identify other potential influences, as such channel constrictions and culvert crossings.

Environmental flows – Flow requirement re-assessment

The hydraulic analysis has refined the local flow behaviour adjacent to the environmental flow sites. This refined flow behaviour may inform a revision of the environmental flow requirements.

The detailed cross sections collected in this project are suitable for use as part of VEFMAP.

The study team recommends a re-assessment of the flow behaviour at environmental flow sites using the hydraulic analysis outputs. In particular, the absence of specific environmental flow recommendations for the Wimmera River between Mount William Creek and MacKenzie River can be underpinned by the use of the flow behaviour assessment undertaken in this study.

Environmental flows - Environmental water release management assessment

The hydraulic modelling framework provides a robust tool for the assessment of potential changes to waterway form and structures with the view to enhance environmental flow outcomes.

Earthtech (2007) and SKM (2008) identified number of environmental flow delivery constraints. This hydraulic modelling framework provides an approach to assess the change in flow behaviour due to potential works/management actions at these constraints.

The study team recommends a thorough examination of the hydraulic modelling outputs to inform potential management actions to enhance environmental flow outcomes.

Waterway management – works assessment

The hydraulic modelling framework provides a robust tool for the assessment of potential waterway works. The hydraulic analysis can provide insight into flow depths and flow velocities. Such insights may aid understanding of stream processes influencing erosion and deposition patterns.

The study team recommends a thorough exanimation of the hydraulic modelling outputs to inform potential waterway management actions

Floodplain management - Land use planning

The flood mapping provides a sound basis for the delineation of flood related planning zone/overlays.

The study team recommends the Wimmera CMA liaises with local authorities to prepare planning scheme amendments to enact the flood related planning zone/overlays.

Floodplain management - Flood response

The flood mapping provides a sound basis for the preparation of flood intelligence for use in flood response. **The study team recommends the Wimmera CMA liaises with local authorities to prepare revised Municipal Emergency Management Plan Flood sub-plan to reflect the flood mapping.**

Floodplain management – Hydraulic model extension adjacent to Andrews Road (east of Horsham)

The study team recommends the Wimmera CMA consider future extension of the hydraulic modelling area using additional topographic data to refine the mapped flood extents (100 year ARI and greater events) adjacent to Andrews Road.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table 8-14 Wimmera River – Yarriambiack Creek flow at Wimmera Highway – Pre-European waterway-floodplain (Wimmera River flow 3000- 42900 ML/d).

1 INTRODUCTION

This report documents the collated and gathered data, methodology, findings and recommendations arising as part of the Yarriambiack Creek – Wimmera River flow and flood modelling study.

Wimmera Catchment Management Authority (Wimmera CMA) has commissioned the Yarriambiack Creek – Wimmera River flow and flood modelling project. This project undertook hydrologic and hydraulic and modelling of the Wimmera River and Yarriambiack Creek between Glenorchy, Horsham and Warracknabeal (see Figure 1-1). Both current and "pre-European" catchment-waterway-floodplain regimes were assessed.

The study team was led by Water Technology with sub-consultants Fluvial Systems, and Price Merrett.

The project developed a comprehensive hydrologic and hydraulic modelling framework. This framework will enable Wimmera CMA and the community to examine enhanced management of flow regimes and structures that maximise environmental benefits and reduce flood risk.

The key study components included:

- Review previous relevant hydrology and hydraulic studies and reports on Yarriambiack Creek and the Wimmera River held by Wimmera CMA;
- Review and incorporate where possible other sources of data held by Wimmera CMA including aerial photography, survey data, digital elevation data and previously developed models;
- Obtain any further information identified as required to develop sound models such as field and aerial surveys;
- Develop calibrated hydrological model(s) based on current and historical (pre-European) scenarios;
- Develop calibrated coupled hydraulic model(s) for the study area for existing and pre-European settlement catchment –waterway-floodplain catchment conditions;
- Prepare a report that details the development of the two models; and
- Provide animations, maps, etc that assist Wimmera CMA to communicate to the public the current key flow and flood behaviours in the study area and the changes from the historic flow and flood behaviours.

This report addresses all the above study tasks. The structure of the report is as follows:

- Section 2 – provides a broad overview of the study area features modelling framework
- Section 3 – discusses available data and information sources, and outlines field inspection
- Section 4 – reviews and verifies the topographic data sources
- Section 5 – summarises the low-medium hydrologic analysis
- Section 6 – details the high flow (flood estimation) hydrologic analysis
- Section 7 – details the hydraulic model development and calibration
- Section 8 - outlines the hydraulic model application
- Section 9 – summarises the key study conclusions and provides recommendations

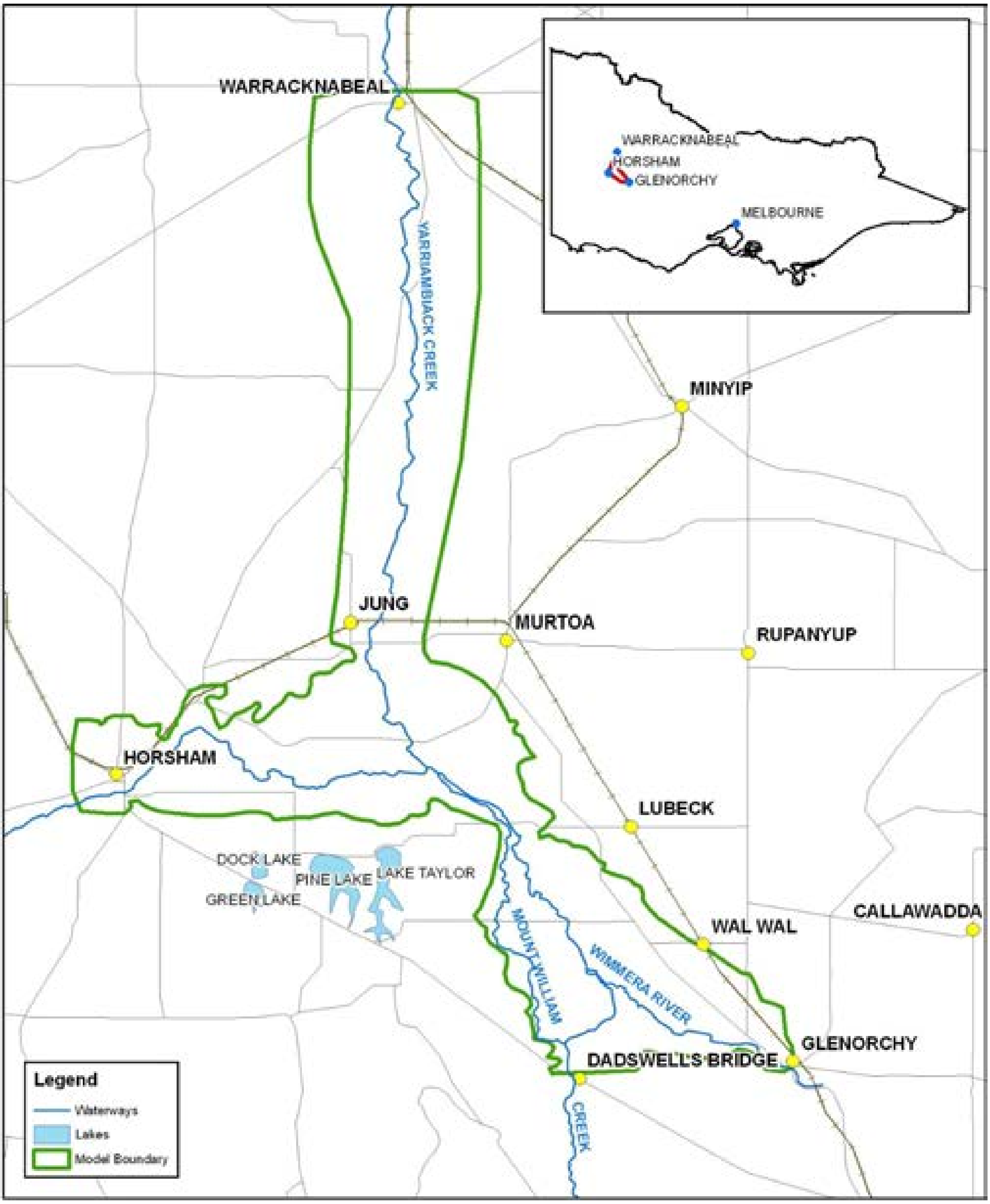

Figure 1-1 Study area

2 STUDY AREA FEATURES AND MODELLING FRAMEWORK

2.1 Overview

This section summarises the approach underpinning the modelling framework employed for the hydrologic and hydraulic analysis components.

The modelling framework developed reflects the catchment, waterway and floodplain features that influence flow and flood behaviour in the study area. Section 2.2 describes the key catchment, waterway and floodplain features, and how these features drive flow and flood behaviour.

There are two principal technical components to this study, a hydrologic analysis and a hydraulic analysis. The hydrologic analysis assessed runoff volumes (flow hydrographs) from the Wimmera River and its tributaries upstream of the study area shown in Figure 1-1. The hydraulic analysis utilised these flow hydrographs as model inputs. The hydraulic analysis routes these flow hydrographs along waterways and their floodplains, and evaluates flow depths, velocities and extents.

The principal outputs from the hydrologic analysis were flow hydrographs for the key tributaries to the study area. The study required flow hydrographs for events up to bankfull and, design flood hydrographs for the 5, 10, 20, 50, 100 and 200 year ARI (Average Recurrence Interval) events. The flow hydrographs were required for pre-European and current catchment conditions. Section 2.3 outlines the hydrologic analysis methodology.

The principal outputs for the hydraulic analysis were flow depths, extents and velocities within the study area. The hydraulic analysis, in line with the hydrologic analysis, is required for both pre-European and current waterway and floodplain conditions. Section 2.4 details the hydraulic analysis approach.

2.2 Catchment and study area features

As shown in Figure 1-1, the study area includes the waterways and floodplains from Glenorchy to Horsham along the Wimmera River, and from the Wimmera River to Warracknabeal along Yarriambiack Creek.

This section discuss key catchment, waterway and floodplain features, with a particular focus on how these features underpinned the hydrologic and hydraulic modelling frameworks.

2.2.1 Contributing catchments

The Wimmera River rises in the Pyrenees Range near Ararat and flows for about 300 kilometres before reaching the terminal lakes of Hindmarsh (Victoria's largest freshwater lake) and Albacutya, and continuing into the Wirrengren Plain. The main tributaries of the Wimmera River, Mount William Creek and MacKenzie River, rise in the Grampians and flow northward to the Wimmera River. The Wimmera River has a high environmental significance with Lake Albacutya, a Ramsar listed wetland, Lake Hindmarsh, a wetland of national significance, and the lower reaches of the Wimmera River listed as a Heritage River under the *Heritage Rivers Act* 1992 (WCMA 2002).

The rainfall over the study area is comparatively low, varying from an annual average of 890 mm over the Grampians to as low as 310 mm in the northern parts of the study area. Rainfall fluctuates widely from year to year and there are no permanent streams (WCMA 2004). As a result, surface runoff is too unreliable to provide regular and sufficient water supplies for farms. The dryland farming which the region supports therefore depends upon a reliable water supply system for its domestic and stock use.

The Wimmera-Mallee Stock and Domestic Distribution System (WMSDDS) services a total area of 3 million ha and supplies approximately 15,760 properties and some 50 towns. There is a population of around 70,000 and an estimated 4,500 farming enterprises in the area serviced by the WMSDDS. Lakes Bellfield (capacity 78,500 ML) and Lonsdale (65,500 ML) are on-stream reservoirs on Fyans Creek and Mount William Creek respectively, and Fyans Lake (21,000 ML) is an off-stream storage where water is diverted from Fyans Creek. Wartook Reservoir (29,500 ML) is located in the headwaters of the MacKenzie River (GWMWater 2005). There are no reservoirs on the Wimmera River but flow is diverted northwards at Glenorchy Weir and to the south at Huddleston's Weir and stored off-river at Pine, Dock, Green and Taylor's Lakes near Horsham. The WMSDDS is managed by Grampians Wimmera Mallee Water (GWMWater). Water is transferred via the WMSDDS to and from the adjacent Glenelg, Avon-Richardson and Avoca River catchments.

The northern component of the WMSDDS has been pipelined in several stages with the majority completed in the early 1990's (Northern Mallee pipelining project) and the areas around Speed, Patchewollock and Cannie Ridge piped in the early-mid 2000's. The remaining open channels are being piped as part of the current Wimmera Mallee piping project. These projects will lead to significant improvement in the efficiency of the WMSDDS system with significant volumes of water saved (GWMWater 2006). The bulk of the saved water will be returned as environmental water releases including along many of the waterways in the study area.

Figure 2-1 display the key features of the Wimmera River catchment and component of the WMSDDS. The adjacent Avon-Richardson and Avoca River catchments as well as parts of the Millicent Coast, Glenelg and Hopkins Catchments are also shown.

Streamflow in the Wimmera is highly variable. The mean annual flow for the Wimmera River at Glenorchy is 93.3 GL/a (SKM 2002b). Further downstream at Horsham, the same seasonal variation is observed with a mean annual flow of 135.6 GL/a. However, there is significant variation in annual flow. A zero annual flow was recorded in 1944 and the maximum annual flow of 570,000 ML in 1956 (SKM 2003b). A comparison of the mean annual flows to median flow for the Wimmera River at Huddleston's Weir reveals an annual mean of 108.6 GL/a and median of 13.6 GL/a, and similar comparison for the Wimmera river at MacKenzie River confluence show a mean of 121.2 GL/a with a median of 13.9 GL/a (Greg Fletcher WCMA *pers comm.*).

Considerable infiltration and evaporation can occur in the lower reaches of the Wimmera River. Only significant flow events, originating in the upper catchment, result in inflows to Lakes Hindmarsh and Albacutya. Flow regulation has considerably altered the behaviour of the terminal lakes. Hydrologic simulations show that under natural conditions (pre-regulation) Lake Hindmarsh always contains some water, however, regulation now leads to lengthy dry spells (Ecological Associates 2004). Similarly, regulation has reduced the frequency of "lake full" events for Lake Albacutya from 1 in 4 years under natural conditions to 1 in 49 years for current regulation conditions (Ecological Associates 2004). Significant water volumes have not been in Lake Hindmarsh for approximately a decade and Lake Albacutya for approximately three decades.

Figure 2-1 Wimmera River catchment and WMSDDS features (GWMWater 2005)

2.2.2 Wimmera River – Swedes/Dunmunkle Creek Takeoffs to Glenorchy Weir (including Glenorchy)

This reach covers the township of Glenorchy and its immediate surrounding area. The Glenorchy township suffers significant inundation in moderate to major flood events and there is a significant amount of documentation of historic flood events through the area. Figure 2-2 shows the key waterway features in this reach.

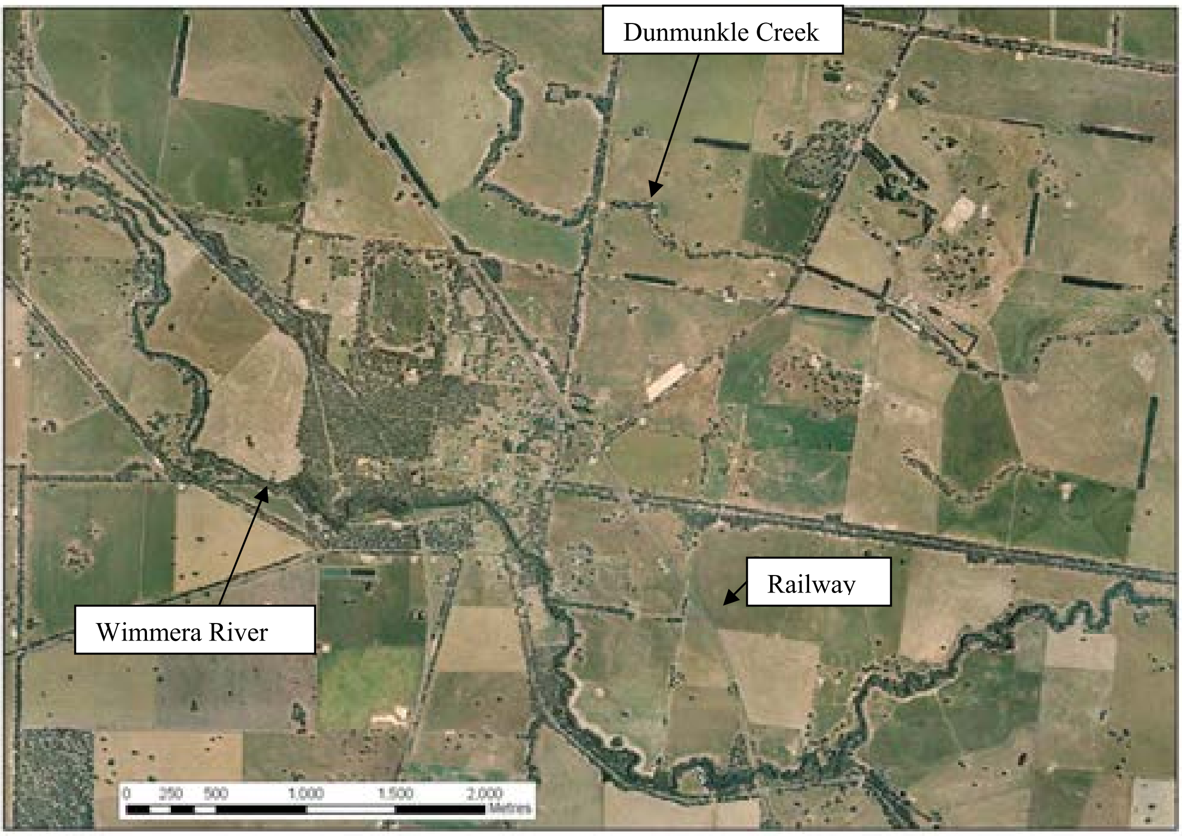

Figure 2-2 Key waterway features: Wimmera River – Swedes/Dunmunkle Creek Takeoffs to Glenorchy Weir

Flooding through the Glenorchy township is a result of both direct inundation from the Wimmera River, and breakout flow from upstream areas flowing through the town. Between 2 and 3 km upstream of Glenorchy, Dunmunkle Creek (a distributary that dissipates north of Rupanyup) and the Swedes Cut (a high level cut diverting water to Swedes Creek which is a tributary of the Avon-Richardson River) divert floodwaters to the north. A substantial portion of the floodwaters flows through railway embankment bridges, returning to the Wimmera River through the Glenorchy township.

Figure 2-3 is an aerial photograph of the upstream portion of Glenorchy, taken during the 1988 event. The passage of flood flows through the township itself has been highly altered over time. The principal drainage works consist of two channels running along Boyd and Cameron Streets, joining downstream of the town. In addition, there have been numerous private bund/levee systems constructed over time by individual landowners in order to protect their residences. These are generally of poor construction quality.

The major crossing of the Wimmera River just downstream of the Glenorchy township is the Stawell – Warracknabeal Rd. Although this is a sizeable bridge crossing, there are significant embankments intruding onto the Wimmera River floodplain. The embankments associated with the previous bridge crossing are still present upstream of the existing crossing.

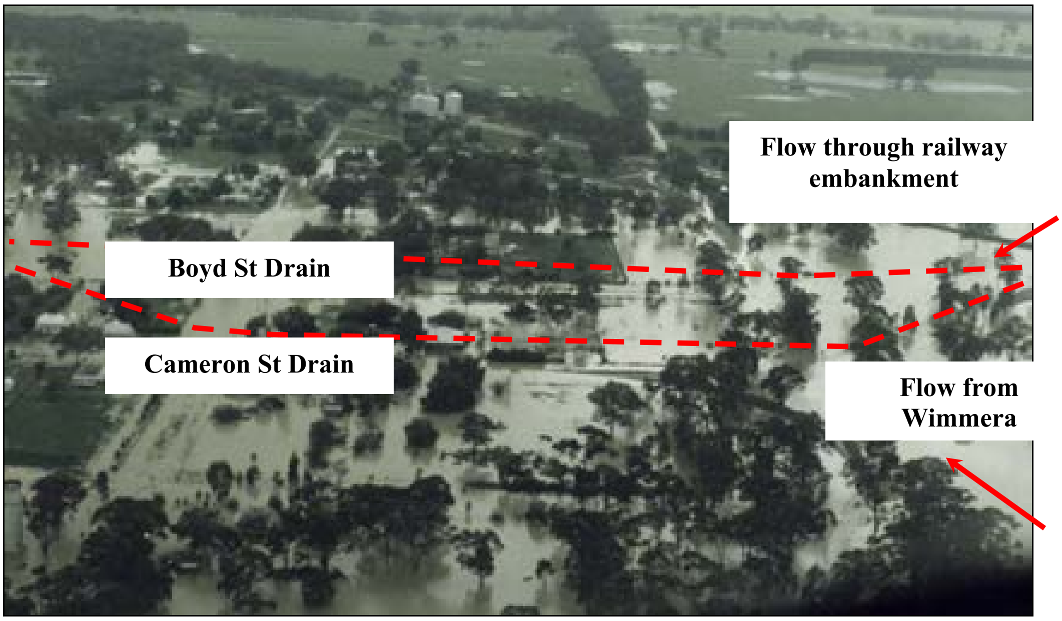

Figure 2-3 Aerial View of the 1988 Event through Glenorchy – Upstream Portion (Provided by Wimmera CMA)

Table 2-1 lists the key features in this reach, key focuses to meet this study's objectives, and the responses in the modelling framework.

Table 2-1 Wimmera River – Swedes/Dunmunkle Creek Takeoffs to Glenorchy Weir: Key features and modelling responses

Waterway and Floodplain Feature	Study focus	Modelling response
Wimmera River through township	Need to define accurately frequency of adjacent overbank flooding.	Hydraulic analysis: use one dimensional hydraulic model based on cross sections to define in bank flow behaviour
Northern flow diversion to Dunmunkle and Swedes Creek systems	Need to accurately defines flows impacting on upstream side of the rail embankment	Hydraulic analysis: Two dimensional hydraulic model to define floodplain flow behaviour
Railway embankment and the hydraulic structures allowing passage of flood flows.	Defines flood flows that continue through the Glenorchy township	Hydraulic analysis: Two dimensional hydraulic model to define floodplain flow behaviour
Impact of road embankments downstream of Glenorchy.	Anecdotal evidence suggests significant changes to flood flowpaths associated with roadworks.	Hydraulic analysis: Two dimensional hydraulic model to define floodplain flow behaviour

Section 2.4 further discusses the hydraulic analysis framework employed for this reach.

2.2.3 Wimmera River – Glenorchy Weir to the Horsham Lubeck Road crossing.

This reach includes the floodplain of both the Wimmera River and Mount William Creek. Figure 2-4 shows the key waterway features in this reach.

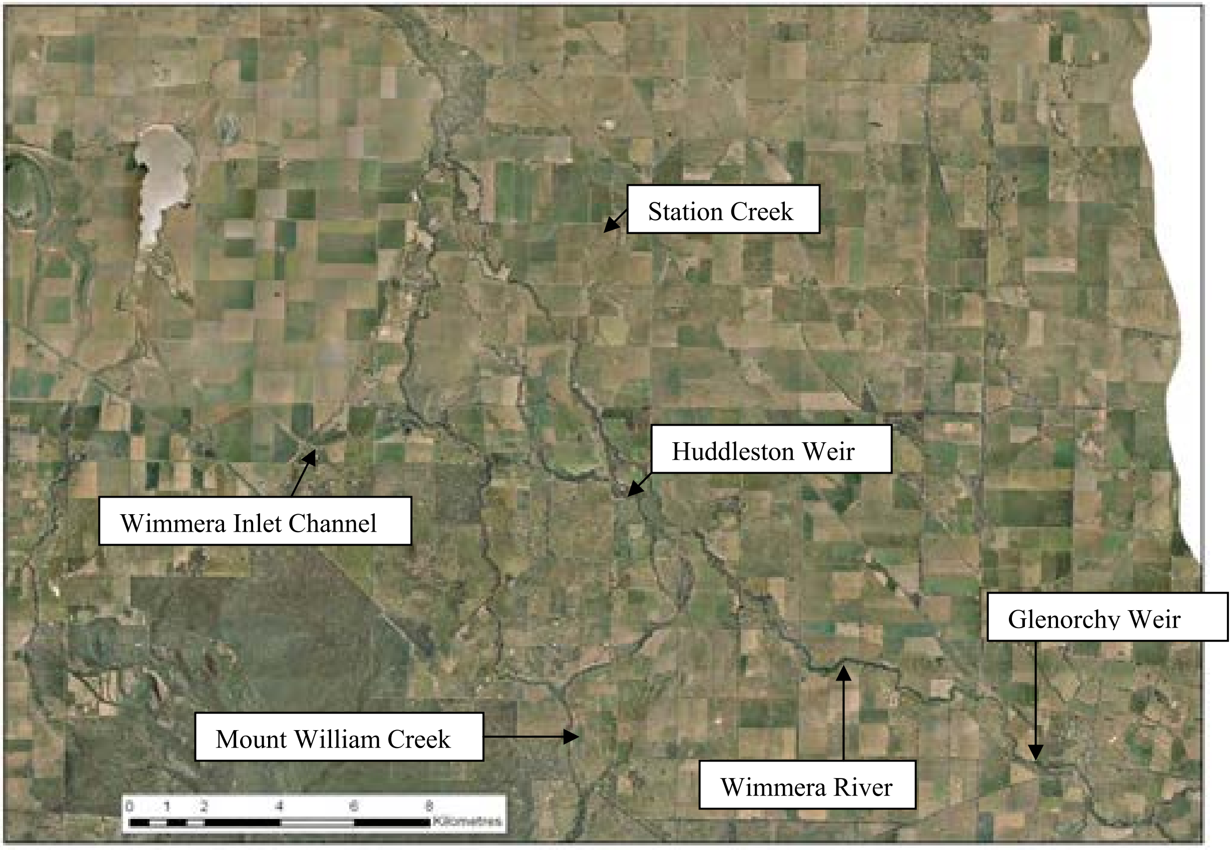

Figure 2-4 Key waterway features: Wimmera River – Glenorchy Weir to Horsham Lubeck Road

There are two major weirs controlling flow in the Wimmera River in this reach. Located downstream of Glenorchy on Wimmera River is the Glenorchy Weir. The *Wimmera Mallee Headworks System Reference Manual,* WMW (1987) describes the Glenorchy Weir as:

> *"… a low level, fixed crest concrete weir across the Wimmera just downstream of the inlet of the Lonsdale-Glenorchy channel. Regulation is by the operation of the offtake regulator to the Main Central channel some 200 metres upstream. Water from Glenorchy can be directed anywhere within the entire system except for the area supplied with the headworks south of Horsham."*

The Glenorchy Weir has the capacity to divert all flows up to 350ML/day into the Lonsdale-Glenorchy channel (SKM 2002).

Huddleston's Weir, as at July 2007, diverts all flows up to 1,600 ML/day (SKM 2002) into two offstream storages, Pine and Taylor's Lakes, via the Wimmera Inlet Channel. The diversion works have a significant impact on low to moderate flows with minimal impact during major floods (SKM 2001). Water Technology (2003a) provides communication with GWMWater staff indicates that Huddleston's Weir is fully submerged at a flow of 4,000 ML/day.

In major flood events, there is extensive breakaway to the north of the Wimmera River main channel. Water Technology (2003a) notes a community perception that roadworks (embankments) on the Glenorchy Murtoa Road have significantly altered flooding patterns by preventing floodwaters flowing back to the Wimmera River. Instead, inundation is extended towards Wal Wal. A number of anabranches are located to the north and east of the Wimmera River between Huddleston's Weir and the Horsham – Lubeck Road, including Station Creek.

To the south of the Wimmera River main channel, Wimmera River floodplain merges with the Mount William Creek floodplain. The confluence of Mount William Creek and the Wimmera River is approximately 1 km upstream of the Horsham-Lubeck Rd crossing of the Wimmera River.

The presence of GWMWater infrastructure throughout this area has the potential to significantly alter the distribution of flood flows across the floodplain (Water Technology 2003a). In particular, the Wimmera Inlet Channel and the Rocklands Channel travel obliquely across the Mount William Creek and Wimmera River floodplain.

The Wimmera Inlet Channel has a number of syphons allowing flow through the embankment. However, most flows enter the channel, and except for the minor part which may be utilised, they are discharged over fixed crest escapes and drops, drop broad escapes, a radial gate escape and a pipe outlet (WMW, 1987). The intention is that surplus natural flow followed the original watercourses, inevitably, some redistribution of flow has occurred following construction of the channel (Water Technology 2003a).

The Rocklands channel was constructed in the 1950's, with a syphon under the Wimmera River.

The Mount William Creek floodplain includes the township of Dadswell's Bridge on the Western Highway. Downstream of this point, flood flows from Mount William Creek breakout to the north east and flow towards the Wimmera River. Flooding in this reach is primarily a function of Mount William Creek and thus is modified by the presence of Lake Lonsdale to a larger extent than downstream areas on the Wimmera River.

Table 2-2 lists the key feature in this reach and the response in the modelling framework.

Table 2-2 Wimmera River – Glenorchy Weir to the Horsham Lubeck Rd crossing: Key features and modelling responses

Floodplain Feature	Study focus	Modelling response
Wimmera River capacity	Need to define frequency of adjacent overbank flooding	Hydraulic analysis: use one dimensional hydraulic model based cross sections to define in bank flow behaviour
Northern floodplain anabranches	Significant overbank flowpath for Wimmera River flood flows.	Hydraulic analysis: use one dimensional hydraulic model based on cross sections to define key anabranches
Mount William Creek capacity	Need to define frequency of adjacent overbank flooding.	Hydraulic analysis: use one dimensional hydraulic model based on cross sections to define key anabranches
Glenorchy Weir and Huddleston's Weir	Need to define the hydraulic performance over a range of flood flows.	Hydraulic analysis: use one dimensional hydraulic model with structures to represent operations. Include diverts to the Wimmera Inlet channel.
Lake Lonsdale and Lake Bellfield	Influence on downstream flows due to storage and attenuation	Hydrologic analysis: modify hydrologic model to reflect catchment with and without Lake Lonsdale and Lake Bellfield
Impact of road, rail and GWMW embankments.	The extent to which flood flows have been modified by the presence of embankments needs to be quantified.	Hydraulic analysis: Two dimensional hydraulic model using to define floodplain flow behaviour

2.2.4 Wimmera River –Horsham Lubeck Rd crossing to Dooen Swamp and Yarriambiack Creek – Offtake to Jung Weir

The key feature in this area is the northern floodplain, including Yarriambiack, Corkers and Two Mile Creeks, and Darlot Swamp. Further discussion of the southern floodplain is provided later in this section. Figure 2-5 shows the key waterway features in this reach.

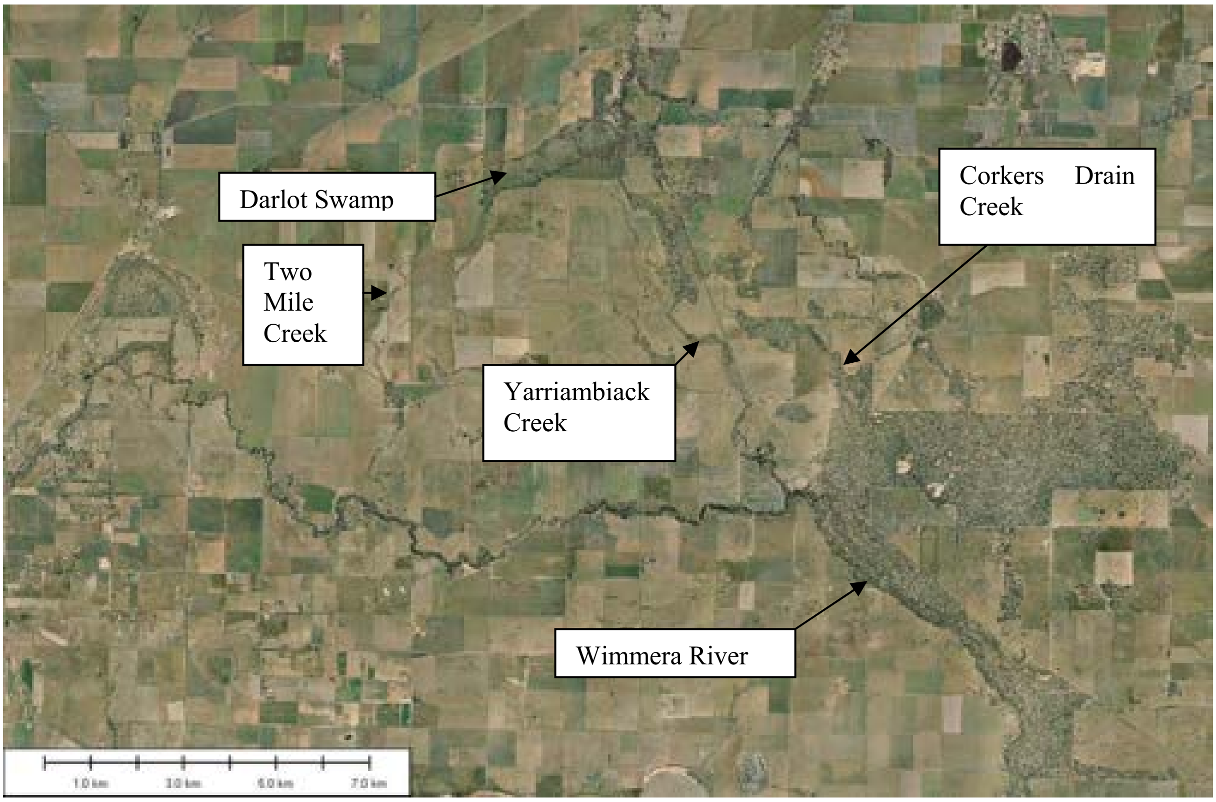

Figure 2-5 Key waterway features: Wimmera River –Horsham Lubeck Road to Dooen Swamp

The general flow and flood behaviour of this area has been described by SKM (2004) and SMEC (2002), and is summarised below.

During large flood events, flood waters leave the Wimmera River at a number of locations. A key breakout occurs to the north of the Wimmera River through Station Creek, in turn through the Barrabool Flora and Fauna Reserve and into Corkers Drain Creek. During flood events, Corkers Drain Creek joins Yarriambiack Creek, immediately to the south of Darlot Swamp. At lower flows, flows in the Wimmera River directly enter Yarriambiack Creek at the offtake. From the offtake, Yarriambiack Creek continues to the north. The capacity of Yarriambiack Creek is limited in this reach with breakouts occurring to the west into Two Mile Creek. Downstream of the Corkers Drain Creek confluence, some flows enter Darlot Swamp. Once full, the Darlot Swamp overflow continues to the south along Two Mile Creek, and returns to the Wimmera River. The remainder of the flow in Yarriambiack Creek continues to the north.

Significant alterations to the waterways and floodplain have occurred in this area following European settlement.

The construction of the Taylor's Lake Outlet Channel resulted in modifications to Corkers Drain Creek. This channel crosses the entire Corkers Drain Creek depression with approximate 1m high earthen embankment. A 20m wide floodway is located at the channel crossing. SMEC (2002) suggests that the channel "… *significantly reduces the passage of water through Barrabool Flora and Fauna Reserve and provides significant flood protection benefits to the areas of land immediately downstream…* "(p 7). Further discussion of the impact on flood behaviour of the Taylor's Lake Outlet Channel is provided in Section 8.3.2.2.

Adjacent to the Wimmera River, Yarriambiack Creek has widths of 35 - 45 m and channel depths of 3.5 - 4 m. However, the channel width and depths decline adjacent to Darlot Swamp, the width varies from 30 – 100 m and the depth ranges from 0.5 m – 1 m.

(Earth Tech 2007). In higher flow, between the offtake and the Corkers Drain Creek confluence breakouts from the creek occur to the west. These breakouts flow to the west to join Two Mile Creek.

Flows downstream of the confluence of Corkers Drain Creek and Yarriambiack Creek experience relatively free passage. Larger flows spill into Darlot Swamp, and in turn overflow into Two Mile Creek, and back into the Wimmera River. The remainder of the flow continues down the Yarriambiack Creek.

The Wimmera Highway crossing of Yarriambiack Creek is located some 2 km downstream of Darlot Swamp. Several crossing (bridge) arrangements have existed at this location. In 1959, the now current arrangements were constructed. This current arrangement consists of a single span concrete bridge, and was widened in 1989 (laterally across the road). Gippel (2006) notes the current waterway area under the bridge was reduced from the pre 1959 structure.

Previous investigations, SMEC (2002), SKM (2002a), SKM (2002b) and KBR (2004), discuss the waterway modifications at the offtake and at the Wimmera Highway.

There was considerable variation in the Wimmera River- Yarriambiack Creek flow relationships yielded by these previous investigations. This project provided an opportunity to apply a refined hydraulic modelling framework to gain further insight into the flow relationship. Discussion of this study's modelled flow distribution between Wimmera River and Yarriambiack Creek, and comparison to previous studies' flow distributions is provided in Section 8.4.

Figure 2-6 shows flooding along the Yarriambiack Creek (foreground) and Darlot Swamp (background) during the 1988 event.

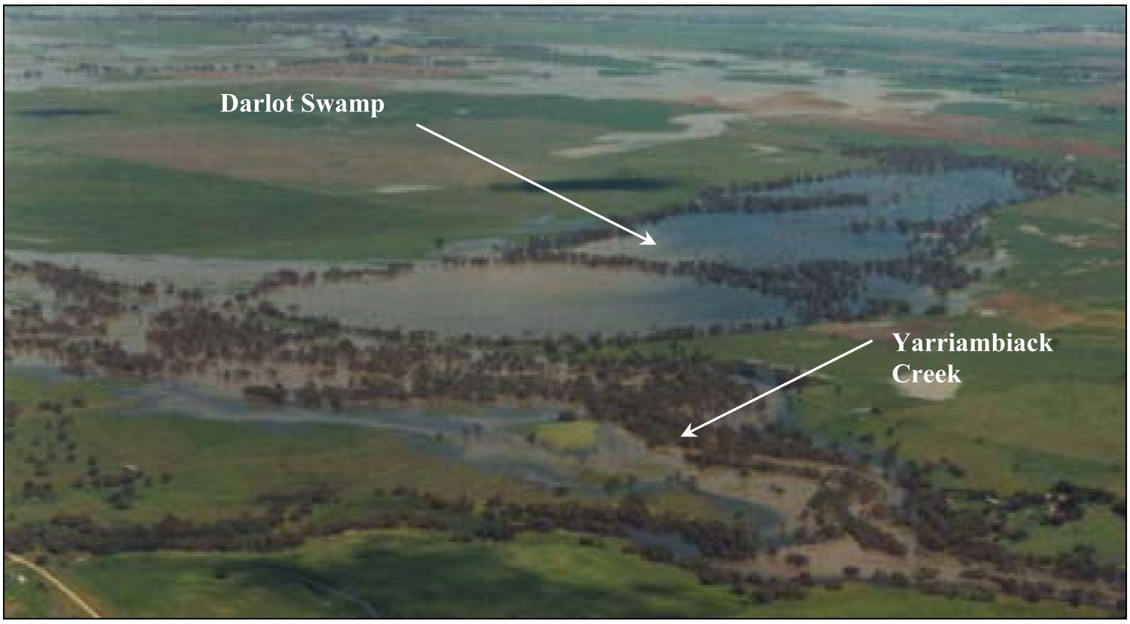

Figure 2-6 Aerial View of Darlot Swamp – 1988 Event (Provided by Wimmera CMA)

To the south of the Wimmera River, a flowpath running parallel to the Wimmera River main channel that takes floodwaters along North Rd towards Horsham. Flow through this area is significantly altered by the presence of roads and drainage infrastructure on the floodplain. There has been significant development (both subdivisional and laser grading) in this area in recent years (Water Technology 2003b).

Downstream of the Two Mile Creek and Yarriambiack Creek takeoffs is Dooen Swamp. This is a large, natural storage although anecdotal evidence and site inspections indicate that the inlet and outlet conditions have been altered over time (Water Technology 2003). SRWSC, (1982) concluded that the impact of the Dooen Swamp on the peak flow for large flood events was minimal as the storage filled early in a flood event. Figure 2-7 presents an aerial photograph of this area during the 1988 event.

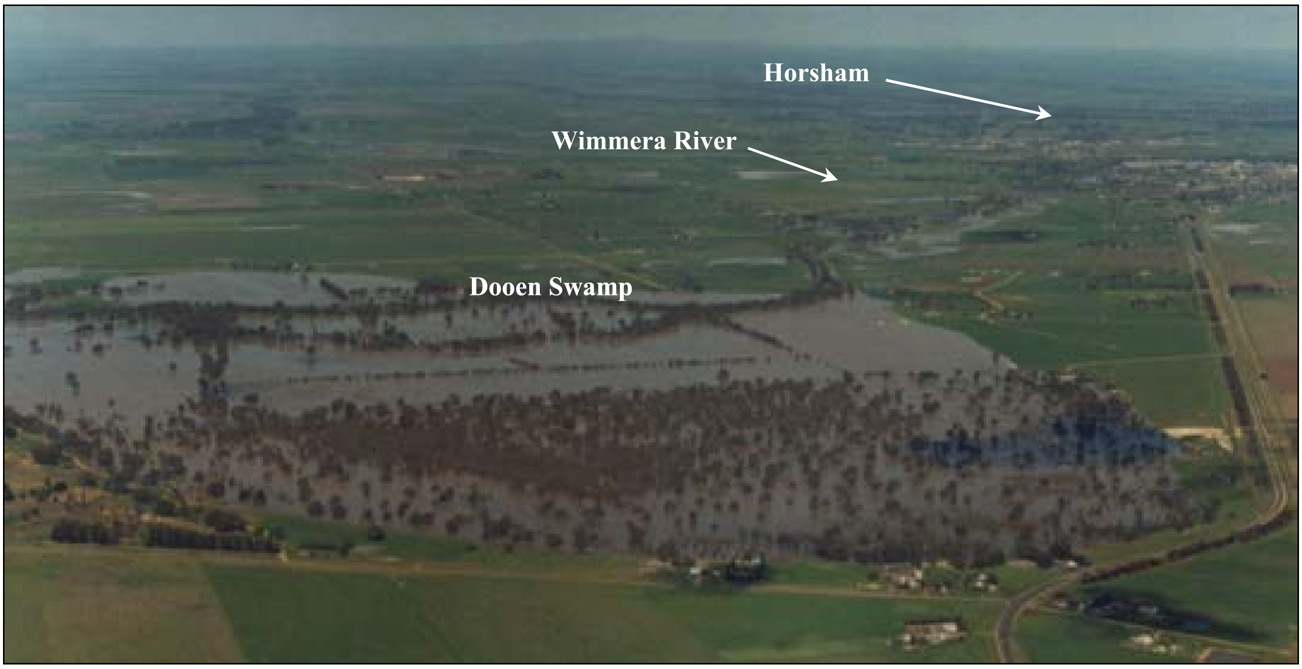

Figure 2-7 Aerial View of Dooen Swamp – 1988 Event (Provided by Wimmera CMA)

Table 2-3 lists the key feature in this reach and the response in the modelling framework.

Table 2-3 Wimmera River – Horsham Lubeck Rd crossing to Dooen Swamp: Key features and modelling responses

Floodplain Feature	Comments	Modelling response
Wimmera River capacity	Need to define frequency of adjacent overbank flooding and commence to flow threshold for key overbank flowpaths	Hydraulic analysis: use one dimensional hydraulic model based on available cross sections to define in bank flow behaviour. Link one dimensional model to two-dimensional hydraulic model to simulate breakout flows
Yarriambiack Creek offtake – flow relationships with Wimmera river at low flows	Need to resolve flow distribution between Yarriambiack Creek and Wimmera River for up to bankfull flows.	Hydraulic analysis: use small scale two dimensional based on available topographic data of the Wimmera River and Yarriambiack Creek channels adjacent to the offtake.
Two Mile Creek, Corkers Drain Creek and Yarriambiack Creek floodplain behaviour	Defines outflow from the Wimmera River system to the Yarriambiack Creek system.	Hydraulic analysis: use linked one –two dimensional hydraulic model based on available cross sections to define overland flows
Yarriambiack Creek at the Wimmera Highway Bridge	Need to resolve flow behaviour adjacent to the bridge.	Hydraulic analysis: use small scale two dimensional based on available topographic data of Yarriambiack Creek and bridge
Taylor's Lake outlet channel.	GWMW infrastructure in general, and the Taylor's Lake outlet channel in	Hydraulic analysis: use two dimensional hydraulic model with available topographic data

	particular define flood patterns in this area.	to define influence of channel embankments.
Impact of road embankments.	The extent to which flood flows have been modified by the presence of embankments needs to be quantified.	Hydraulic analysis: use two dimensional hydraulic model with available topographic data to define influence of road and rail embankments.

2.2.5 Yarriambiack Creek – Jung Weir to Warracknabeal

The Yarriambiack Creek from Jung Weir to Warracknabeal, is described as a confined waterway within a broad shallow valley (KBR 2004). The creek's main channel capacity is limited. Figure 2-8 shows the key waterway features in this reach.

Figure 2-8 Key waterway features: Yarriambiack Creek – Jung Weir to Warracknabeal

Major floods along the Yarriambiack Creek are generated from floods which occur on the Wimmera River. These floods are generally longer in duration and have sufficient volume such that the floods can reach the end of the system at Hopetoun.

From the 1880's through to the 1930's, Yarriambiack Creek was used as distribution channel for the Wimmera Mallee Stock and Domestic Water system. The current weirs are located at Jung, Warracknabeal, Brim and Beulah. The associated weir pools are primarily serve recreational purposes. The Jung and Warracknabeal Weirs are located in the study area.

Jung Weir is located approximately 5 km downstream of the Wimmera Highway Bridge. The weir was modified in 2000, forms a weir pool some 2 km upstream (Gippel 2006). Warracknabeal Weir forms a weir pool for a distance of 2 km upstream. Both weirs fill through Yarriambiack Creek flows and limited local runoff. Further, the Warracknabeal Weir can be filled from the channel system. SMEC (2001) considered that Jung and Warracknabeal Weirs have significant impact on flow behaviour. Further discussion of the impact on flood behaviour of Jung Weir is provided in Section 8.3.2.3.

WBM (2004) assessed the flood travel times as slow, based on community observations. Gippel (2006) evaluated the mean flood wave speed as 0.13 m/s. This slow flood wave speed reflects the low relief with an average slope of ~ 1 in 2500 (WBM 2004).

Discussion of this project's findings on the flood behaviour along Yarriambiack Creek and comparison to the previous studies' outcomes is provided in Section 3.2.

Table 2-4 lists the key feature in this reach and the response in the modelling framework.

Table 2-4 Yarriambiack Creek – Jung Weir to Warracknabeal - Key features and modelling responses

Floodplain Feature	Comments	Modelling response
Yarriambiack Creek – channel	Limited channel capacity. Significant overbank flows	Hydraulic analysis: use two dimensional hydraulic model with topographic data to assess floodplain behaviour. Hydraulic analysis: use one dimensional hydraulic model based on cross sections to define in bank flow behaviour. Link one dimensional model to two-dimensional hydraulic model to simulate breakout flows
Jung Weir and Warracknabeal Weir	Influence on local flood behaviour.	Hydraulic analysis: incorporate structure arrangements (crest level etc) within 2D model topography

2.2.6 Wimmera River –Dooen Swamp to Walmer

The key features in this reach include Dooen Swamp and the flood mitigation works at Horsham. Figure 2-9 shows these key waterway features in this reach.

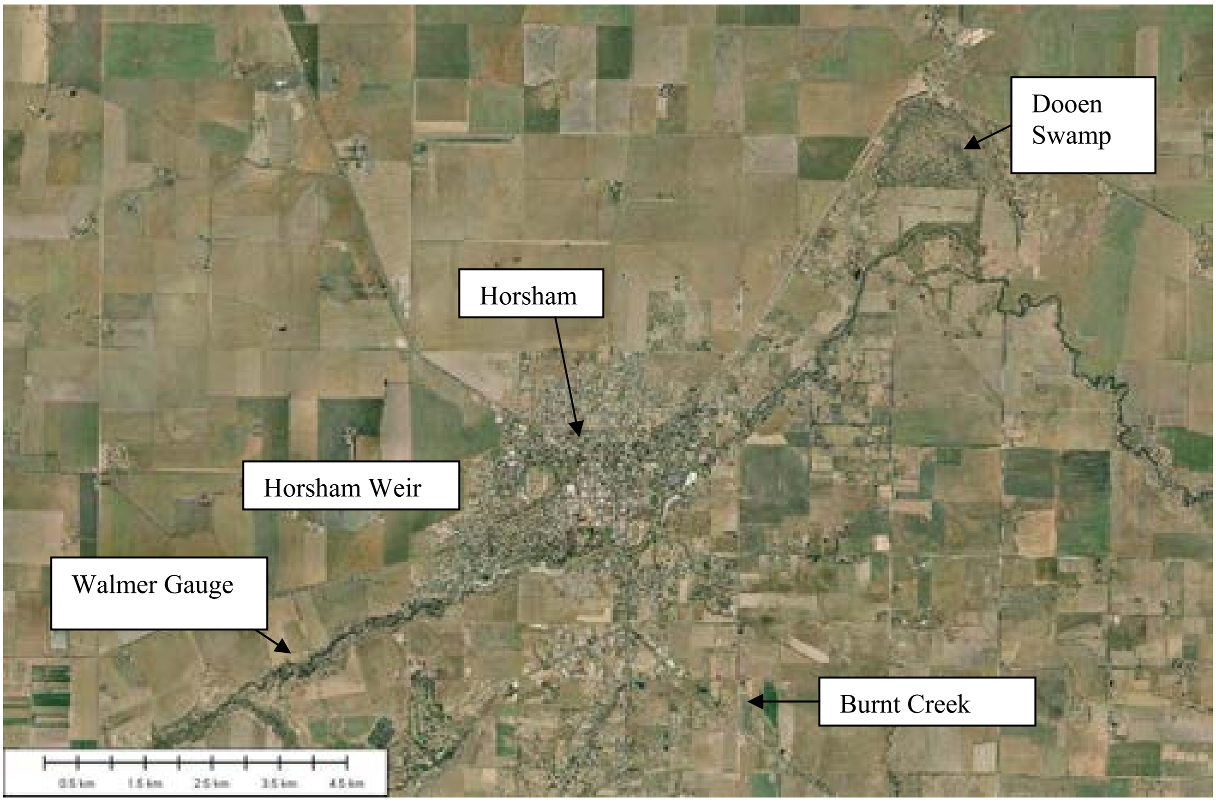

Figure 2-9 Key waterway features: Wimmera River –Dooen Swamp to Walmer

Dooen Swamp is a large natural storage, located some 7 km upstream from Horsham. The swamp fills from overbank flooding in the Wimmera River.

Downstream of Dooen Swamp, the Wimmera River consists of a single main channel. Breakouts to the south occur adjacent the Riverside Road Bridge. Also breakouts occur to north.

Flood mitigation works, constructed in 1980's, in the Horsham reach, involved channel widening and constructing a levee on the northern floodplain. These flood mitigation measures reduced the frequency of overbank flooding, along the Old Town anabranch (adjacent to Hamilton Street). The Horsham Flood Study (Water Technology 2003b) found that the flow along the Old Town anabranch occurs during a 1 in 50 year (indicative peak flow at Walmer 31,200 ML/d) under the current waterway/floodplain conditions.

Horsham Weir is a concrete structure with a number of removable drop boards, with automated lay flat gates across a few bays recently installed for improved environmental water release management. During high flow events, the boards are removed and the Horsham Flood Study showed that the weir has no significant affect on upstream flood behaviour (Water Technology 2003b).

Table 2-5 lists the key features in this reach and the response in the modelling framework.

Table 2-5 Wimmera River – Dooen Swamp to Walmer - Key features and modelling responses

Floodplain Feature	Comments	Modelling response
Wimmera River capacity	Need to define frequency of adjacent overbank flooding and commence to flow threshold for key overbank flowpaths	Hydraulic analysis: use one dimensional hydraulic model based on available cross sections to define in bank flow behaviour. Link one dimensional model to two-dimensional hydraulic model to simulate breakout flows
Horsham – Town levee	Need to define levee crest within hydraulic model	Hydraulic analysis: use two dimensional hydraulic model with available topographic data to assess floodplain behaviour. Levee crest obtained from Water Technology (2003b).

2.3 Hydrologic analysis

The hydrologic analysis was concerned with the estimation of streamflows from the Wimmera River catchment. These streamflow estimates (hydrographs) were a principal input to the hydraulic analysis. As such, the streamflow estimates were required for significant waterways at the upstream study area limits, and includes:

- Wimmera River at Glenorchy
- Golton Creek at Western Highway
- Mount William Creek at Western Highway
- Burnt Creek at Western Highway

The hydrologic analysis components utilised a variety of streamflow and rainfall data inputs. The available data inputs and sources are discussed in Section 3.

The hydrologic analysis provides estimates of the low to medium flows (up to bankfull) as well as historical and design flood hydrographs under both pre-European and current catchment conditions. To reflect the different underlying hydrologic processes, the hydrologic analysis has the following two components:

- Low to medium flows (In channel flows)

  Current and natural daily sequences, for the period January 1990 to December 2000 were derived by SKM (2003a), refer to Sections 3.2 and 5. In conjunction with the Wimmera CMA, a range of low to medium flow scenarios were developed, as detailed in Section 8.2.

- High flows (Design flood events):

  An event based hydrologic model, URBS, was constructed for design flood hydrograph estimation as part of the *Warracknabeal and Beulah Flood Study* (Water Technology 2007). This URBS model was based on the model developed by the Bureau of Meteorology. The URBS model was calibrated to historical flood events at Glenorchy (Gauge number 415201) and Walmer (Gauge number 415200). The design flood estimates were validated against flood frequency analysis at Glenorchy. Given this calibration and validation, the URBS model is considered to provide a robust tool for design flood estimation under the current catchment conditions. Further details are provided in Section 6.

A preliminary review of the available URBS model shows no provision for effluent flows into Yarriambiack Creek, or inflows from MacKenzie River into Burnt Creek at Distribution Heads. As discussed in Section 2.2.5, the streamflows along Yarriambiack Creek, principally, are sourced from streamflows leaving the Wimmera River. The mechanisms, which underpin the volume and timing of streamflows in Yarriambiack Creek, were discussed in Section 2.2.4. Table 2-3 proposes the hydraulic analysis provides a suitable modelling tool to assess the flow entering Yarriambiack Creek. As such, the hydrologic analysis employed in this study required the hydraulic analysis to estimate flows to Yarriambiack Creek.

Estimation of streamflows in Burnt Creek requires consideration of the flow behaviour at Distribution Heads and its use as part of the WMSDDS. Advice from GWMWater indicated the flow behaviour at Distribution Heads is complex and subject to wider operational considerations of the WMSDDS. A simplified relationship has been developed to assess the flow split at the Distribution Heads. Section 6.2 provides further details on the URBS model structure.

Section 2.2.1 outlined a number of modifications to the contributing catchment since European settlement. For pre-European catchment conditions, relevant water resource developments (i.e. weirs and storages) were removed from the URBS model structure. The re-structured URBS model was applied to design flood estimation, refer to Section 6.6.

2.4 Hydraulic analysis

Given the complexity of the flow and flood behaviour, a flexible hydraulic modelling framework has been employed. This framework allowed the accurate representation of flow behaviour over a full range of flows balanced against excessive simulation times. To enable efficient simulation of the required flow and flood events, model run times of 8-12 hours are desirable. Longer model run times constrain the efficiency of the modelling process without any improvement in model accuracy.

The framework comprises:

- One dimensional (1D) hydraulic model for the key waterways: simulate up to bankfull flows, where the flow behaviour is one dimensional in nature i.e. confined
- Two dimensional (2D) floodplain hydraulic models for floodplain flows, where the channel capacity is a minor proportion to the total flow.
- Two dimensional (2D) site specific hydraulic models for a given location where the flow behaviour is complex i.e. multiple flow paths in a channel.
- Linked one – two dimensional (1D/2D) models for floodplain flow, where the flow just exceeds the channel capacity.

Section 7 details the development and calibration of the hydraulic modelling framework.

The accurate and efficient collection of topographic data was a key element of the hydraulic analysis component. As outlined in Section 4, Airborne Laser Scanning (ALS) data was available with a vertical accuracy of 0.15 m along the Wimmera River floodplain and at Warracknabeal, and a vertical accuracy of 0.5 m along the Yarriambiack Creek floodplain.

The ALS provides an excellent topographic base for the floodplain areas. Further discussion of the impact of the topographic survey accuracy on the hydraulic modelling outputs is provided in Section 7.2.

However, additional field survey was required to supplement the ALS data, particularly to resolve in-channel features and structures. The field survey component targeted topographical data that is not well resolved by the available ALS, principally waterway bed levels and structures. The field survey also provides further verification points for the ALS data. Further discussion of the influence of topographic data on model accuracy is provided in Section7.2.

The field inspection, detailed in Section 3.5, revisited the locations of environmental flow study sites developed by SKM (2002b) to determine their suitability for detailed 1D hydraulic analysis, as a refinement of the SKM (2002b) investigations. In addition, two further sites were selected for detailed 1D hydraulic analysis. This detailed analysis was based on relatively dense sets of cross-sections within the 1D hydraulic model network. The sites for the detailed 1D hydraulic analysis were as follows:

- Site 1: Wimmera River downstream of Glenorchy Weir (Environmental Flows site 1 (SKM 2002))
- Site 2: Wimmera River upstream of Faux Bridge (Environmental Flows site (Re-located (SKM 2002))
- Site 3: Confluence of Wimmera River with Mount William Creek/Hall's Island (Environmental Flows site 3 (SKM 2002))
- Site 4: Wimmera River upstream of Gross's Bridge (Environmental Flows site 4 (SKM 2002))
- Site 5: Wimmera River adjacent to Burnt Clay Road (new site)
- Site 6: Wimmera River at River Heights (Dooen Swamp) (new site)

Site 2 was relocated further downstream from the SKM (2002b) site. The SKM (2002b) site 2 is located immediately downstream of Huddleston's Weir. The study team considered the channel form at the SKM (2002b) site 2 was significantly impacted upon by the flow behaviour due to the weir structure. This relocated site was considered was more representative of the channel form in this reach.

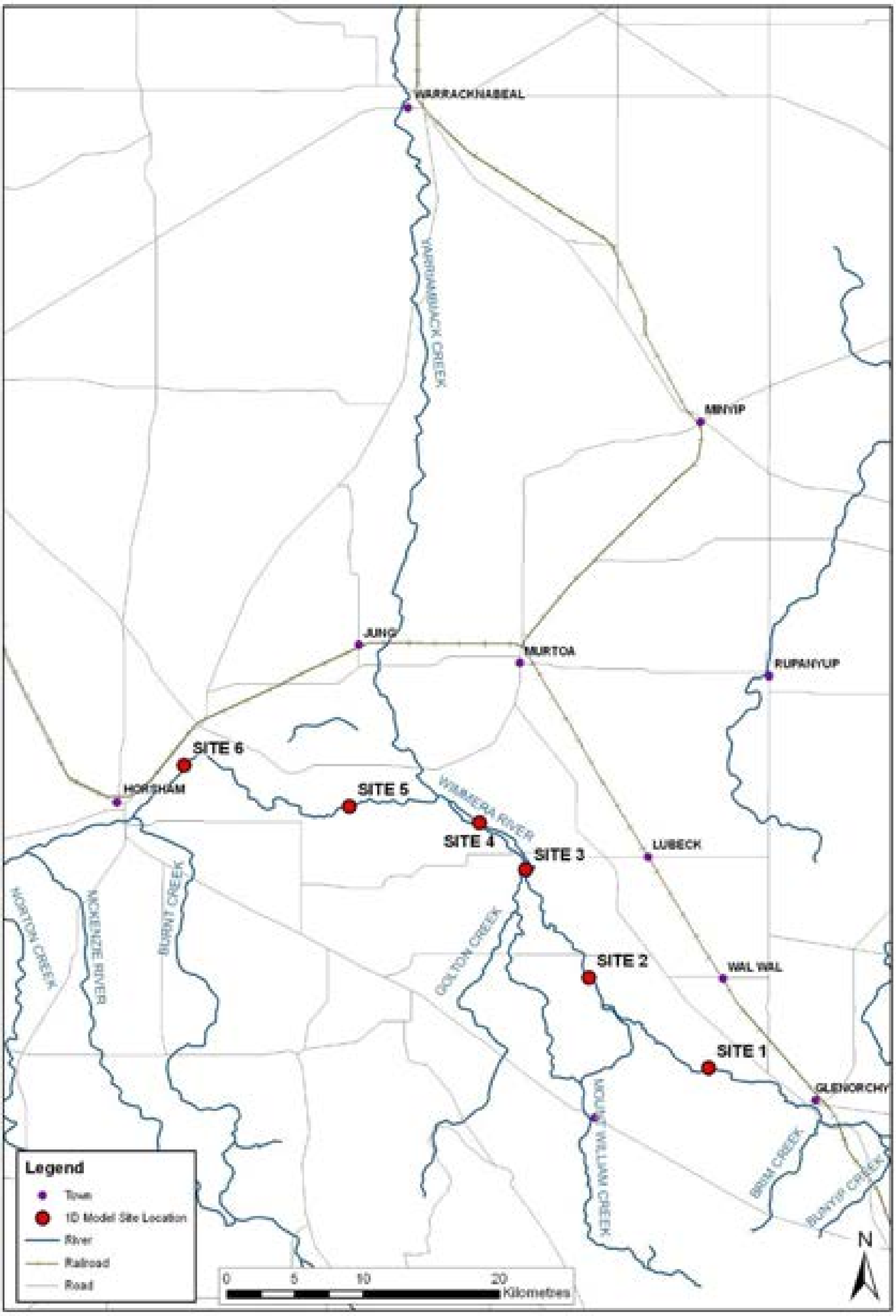

Figure 2-10 Hydraulic model structure –Detailed one-dimensional model locations

The hydraulic models were required to simulate flow behaviour from low discharge, relatively frequent events to large floods. The hydraulic model structure and roughness parameters were refined through comparison of the modelled and observed flow characteristics (flow rates, flood levels and extents), as part of the hydraulic model calibration. The calibration process has the following two components:

- Low flows up to bankfull flow.
- High flows and major floods (nominally ≈ 30 year ARI : 1981, 1983, 1988 and 1996)

Calibration and verification information exists for the study area with long-term gauge data and flood observations at a number of locations, as detailed in Sections 3.4. Further details on the hydraulic model calibration and verification are provided in Section 7.4.

The simulation of flow behaviour is required for the pre-European and current waterway-floodplain form. Any features and/or structures built since European settlement were identified as part of the hydraulic model construction and review of previous investigations, as discussed in Section 2.2 and 3.2. The removal of road and channel embankments is reasonably straight forward. The natural surface levels adjacent to these road and channel embankments were assumed to represent the ground level along the embankment alignment.

However, the extract nature of the modifications within waterways, particularly at the Yarriambiack Creek offtake is uncertain. This uncertainty arises from lack of the definitive accounts of the modifications, and reliable topographic data before the modifications were undertaken.

The hydraulic analysis of the pre-European waterway-floodplain conditions provided a broad indication of the flow and flood behaviour prior to European settlement. Further detail is provided in Section 8.

3 AVAILABLE DATA COLLATION

3.1 Overview

This section identifies and briefly reviews relevant available data and information collated. Sources of background data and information collated have included:

- Previous waterway and floodplain studies and investigations
- Historical flood information
- Streamflow and rainfall data
- Field inspections

The topographic data collation and review is discussed in Section 4.

3.2 Previous waterway and floodplain studies

A brief summary of the relevant waterway management, environmental flows and floodplain management studies, and their relevance to the approach employed by this current study follows:

- ***Stressed Rivers Project – Wimmera River System*** **(SKM 2002b)**

  - *Summary:* The project defines environmental flow requirements for the Wimmera River downstream of Glenorchy except for the reach between the Mount William Creek confluence and the MacKenzie River confluence.

  Environmental flow assessment sites, relevant to this current study, were established through this project on the Wimmera River at Dave's Lane, downstream of Huddleston's Weir, Hall's Island and Gross' Bridge.

  - *Relevance to this current study:* Identifies environmental flow site locations and provides waterway cross-section data for detailed hydraulic analysis as part of this current study. Refer to Section 4.2.2 for discussion of available cross-section data and Section 7 for its use in the hydraulic analysis.

- ***Derivation of current and natural daily flows in the Wimmera and Glenelg catchments*** **(SKM 2003a)**

  - *Summary:* The project estimates daily streamflow sequences, throughout the Wimmera River catchment, for the period January 1990 to December 2000 under the current (2003) level of water resource development and natural (without water resource development) conditions. The relevant locations to this current study, where flows were estimated, include upstream of Glenorchy, downstream of Huddleston's Weir and Yarriambiack Creek at Longerenong Road. A comparison of the current and natural flow duration reveals minor changes upstream of Glenorchy with significant reductions in the frequency of low–medium flows downstream of Huddleston's Weir. For Yarriambiack Creek, the frequency of events has remained unchanged, however, the magnitudes of peak flows have reduced.

  - *Relevance to this current study:* Provides daily streamflow sequences under current and natural conditions for use in the hydrologic analysis. Refer to Section 5.

- ***Assessing influences on environmental water releases in the Wimmera Phase 2 Stage 1* (EarthTech 2006)**

  - *Summary:* The project identifies and provides preliminary assessment of influences on the delivery of environmental water releases along Mount William, Yarriambiack, Fyans and Dunmunkle Creeks. Many features along these creeks were identified and assessed to see what influence they had on the passage of environmental water releases.

  - *Relevance to this current study:* A total of 107 features were identified along Yarriambiack Creek with 14 of these features assessed as having an influence of the passage of environmental water releases. These identified influencing features were included in the hydraulic analysis. Refer to Section 7.

- ***Horsham flood study and floodplain management plan* (Water Technology 2003 b and 2004), *Wimmera River (Glenorchy to Horsham) flood scoping study* (Water Technology 2003b), *Glenorchy flood study and floodplain management plan* (Water Technology 2006), and *Warracknabeal and Beulah flood study* (Water Technology 2007)**

  - *Summary*: These projects undertook hydrologic and hydraulic analysis of adjacent floodplains to assess flood risk. Historical flood information was collated, cross-section and structure data was surveyed, and flood extents were mapped for the 5,10,20,50,100 and 200 year ARI events.

  - *Relevance to this current study:*

    - Provides cross-sections and structures for use in the hydraulic analysis. Refer to Section 7
    - Provides design flood estimation models (based on BoM models) and relevant design flood hydrographs Refer to Section 6.1
    - Provide historical flood information for use in the calibration of hydrologic and hydraulic models. Refer to Section 6.1

- ***Wimmera River Basin URBS Model* (BoM 2004)**

  - *Summary*: The Bureau of Meteorology (BoM) developed a URBS rainfall-runoff model for the Wimmera River basin to Dimboola. The purpose of the URBS model was flood forecasting. The URBS model was calibrated using a number of recent flood events including 1981, 1983, 1988, 1992 and 1996. The URBS model performance in real time flood forecasting is subject to uncertainties due to streamflow and rainfall losses from infiltration, and temporal and spatial rainfall variations.

  - *Relevance to this current study:* Provides a URBS catchment runoff model for use in the flood estimation. Refer to Section 6.1

- ***Hydrology of Yarriambiack Creek, Lake Corrong and Lake Lascelles* (Gippel 2006)**

  - *Summary*: Gippel (2006) assessed the hydrologic behaviour of Yarriambiack Creek from the offtake to the Lake Corrong. A simple hydrologic model was developed to route flows along Yarriambiack Creek. Gippel (2006) found considerable uncertainty surrounding the flow split between Wimmera River and Yarriambiack Creek.

  - *Relevance to this current study:* Detailed modifications at the offtake and discusses the flow split

- ***Influences on Environmental Water Releases in the Wimmera River - Recommendations*** **(SKM 2008)**

  - *Summary*: SKM (2008) identified influences on environmental water delivery along the Wimmera River downstream of Glenorchy. The study considered water extractions, channel constrictions, vegetation obstructions and culvert crossings. Preliminary hydraulic analyses were undertaken to assess the impacts of these influences on various environmental flow recommendations.

  - *Relevance to this current study:* Identified environmental water release passage constraints

- ***Assessment of the impact of priority structures on natural flow regimes and flooding in Yarriambiack Creek (Parts 1 and 2) (SMEC 2002)***

  - *Summary*: The WCMA in partnership with the Mallee CMA commissioned SMEC to undertake an assessment of priority structures on Yarriambiack Creek. Matters covered in the SMEC (2002) report relevant to this study included the following:

    - information regarding timing and magnitudes of historic flood events on Yarriambiack Creek
    - flood frequency analysis undertaken for Yarriambiack Creek at the Wimmera Highway gauge
    - identification of primary flood control structures on Yarriambiack Creek
    - conclusions made regarding the hydraulic behaviour of the offtake over a range of flow magnitudes.

A partial series flood frequency analysis was undertaken on seven years of data was available for Yarriambiack Creek at the Wimmera Highway (gauge number 415241). The fifteen of the highest, independent flows were selected for analysis. The results of the partial flood frequency analysis are presented in Figure 3-1.

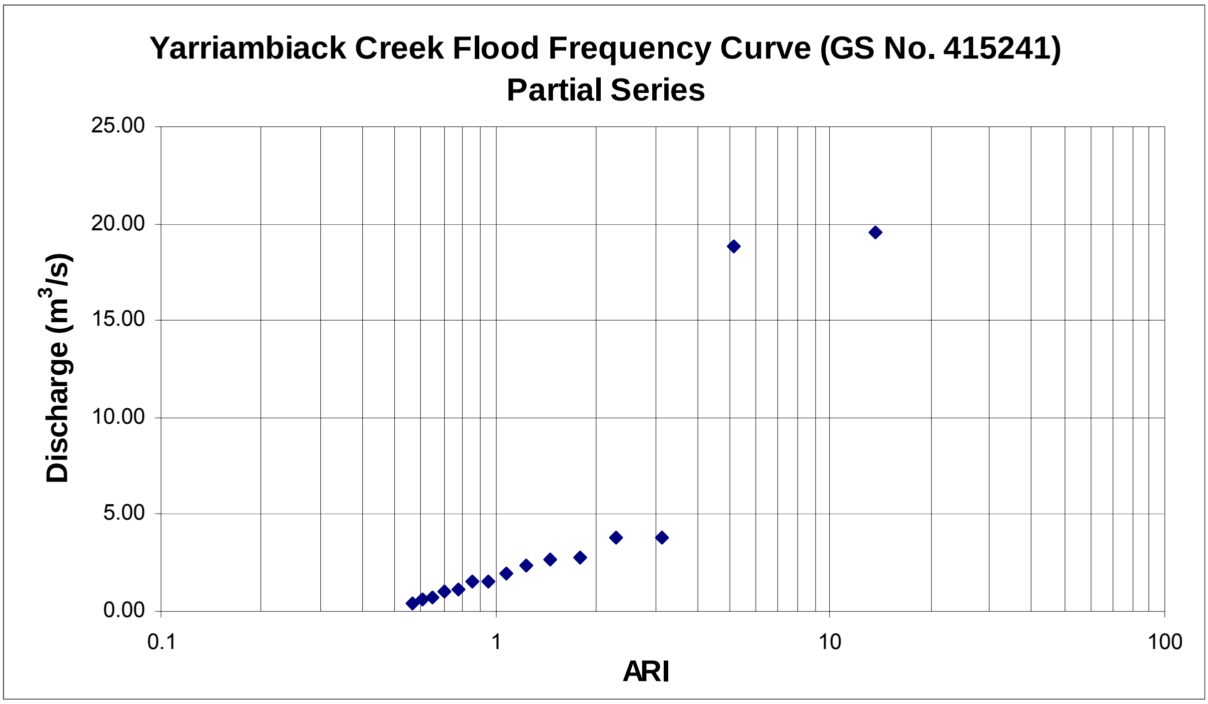

Figure 3-1 Yarriambiack Creek flood frequency analysis (415241) SMEC (2002)

In addition to the flood frequency assessment, a comparison of the larger floods recorded for the Wimmera River at Horsham (Walmer) and Yarriambiack Creek at the Wimmera Highway Bridge was undertaken. Three significant events occurred within the period of record: August 1980, August 1981 and September 1983. By comparing the corresponding flood peaks SMEC (2002) derived a proportional relationship between flows observed at Horsham and corresponding flows in Yarriambiack Creek. SMEC (2002) concluded for large flood event that the peak flows in Yarriambiack Creek are approximately equal to 7.5% of peak flows for Wimmera River at Horsham.

Using the partial flood frequency results on the above relationship between flows observed at Horsham and Yarriambiack Creek, SMEC (2002) summarises its findings regarding Yarriambiack flood magnitudes thus:

- From the partial flood frequency analysis the 2 year ARI flood event is approximately 230 ML/d (~ 2.7 m3/s)
- A 10 year ARI event at Horsham corresponds to a flow of approximately 24,000 ML/d, 7.5% flow in Yarriambiack Creek equates to 1,800 ML/d (~ 20.9 m3/s).
- A 50 year ARI event at Horsham (32,600 ML/d) corresponds to a flow of approximately 7,780 ML/d in Yarriambiack Creek (~ 90 m3/s)
- The degree of uncertainty in estimating the frequency of floods increases substantially the further beyond the period of record the extrapolation is made.

The hydraulic assessment of waterway structures on Yarriambiack Creek was aimed to estimate their influence on flood flows and levels. Structures identified as relevant to this study are:

- Structures near the offtake from the Wimmera River
- Wimmera Highway Crossing
- Jung Weir
- Warracknabeal Weir pool
- Brim Weir pool
- Beulah Weir pool

All of the structures listed are deemed by SMEC (2002) to have a significant effect on flood flows in the Yarriambiack system. As such, these structures require consideration in any attempt to route flows from the offtake at the Wimmera River to Warracknabeal and subsequently Beulah.

- *Relevance to this current study:* Assessed the Wimmera River – Yarriambiack Creek flow split and impact of key structures.

- ***Yarriambiack Creek Flood Investigation Study (WBM 2003)***

- *Summary:* The aim of the Yarriambiack Creek Flood Investigation Study (WBM 2003) was to increase knowledge of flooding issues throughout the Yarriambiack Creek system and to develop and recommend strategies to reduce future impacts of flooding.

Deliverables of the WBM study relevant to this investigation were:

- Collection of flood information from community members
- Flood extent maps from historic and anecdotal information

WBM (2003) stated that there is little anecdotal or reported information indicating historic flooding originating from the Yarriambiack Creek catchment itself. However, some information relating to flash flooding and some overland flooding was received. The study (WBM 2003) confirms previous classification of Yarriambiack Creek as a distributary of the Wimmera River. Anecdotal information indicated that waterway structures and land use characteristics of the Wimmera River and Yarriambiack Creek catchments are significant flood modifying factors.

Qualitative inspection of the waterway revealed that Yarriambiack Creek has no significant tributaries and a relatively low capacity channel resulting in a high degree of interaction between the channel and the floodplain, with exceptions where levees/waterway modifications have been established.

On the flooding history of Yarriambiack Creek, WBM (2003) stated that there has been a significant lack of major flood events along the Yarriambiack Creek in recent time. WBM (2003) quoted some unpublished work which stated that the 1909 event was a 1 in 280 year ARI event and 1981 event a 1 in 25 year ARI event. The recurrence intervals stated were not verified by WBM (2003).

- *Relevance to this current study:* Assessed the Wimmera River – Yarriambiack Creek flow split, and collated historical flood information

- ***Yarriambiack Creek Management Plan (KBR 2004)***

- *Summary*: The Yarriambiack Creek Management Plan (KBR 2004) provided recommendations for the management of Yarriambiack Creek over the five years following 2004. The Plan (KBR 2004) took a whole of catchment approach to the management of Yarriambiack Creek, considering its entire length, its adjoining Crown land and associated terminal lakes and floodplains.

The Plan (KBR 2004) described the Yarriambiack Creek flow regime as segregated into four states; No flow, Low flows, Moderate flows, and High flows. Periodic cessation of flow is common in Yarriambiack Creek.

The Plan (KBR 2004) assumed that the diversions (during large flows) to Yarriambiack Creek from the Wimmera River is 7 per cent of Wimmera flow in accordance with previous investigations.

- *Relevance to this current study:* Assessed the Wimmera River – Yarriambiack Creek flow split, and collated historical flood information

3.3 Historical flood information

Available historical flood information has been collated in the *River Basin Report – Wimmera River, Lower SubCatchment - Flood Data Transfer Project* (SKM 2000) and the *Wimmera River (Glenorchy to Horsham) Flood Scoping Study* (Water Technology 2003). Table 3-1 outlines available historical flood information.

Table 3-1 Historical flood information sources

Information	Events
Interpretive flood extent maps	- February 1973 - August 1981 - September 1983 - September 1988 - October 1996
Historical Flood Levels	- 1909 - August 1981 - September 1983- September 1988 - October 1996
Flood Photography	Terrestrial photography: - Historic flood photos 1894, 1909, 1923, 1930 and 1981 Aerial photography: - May 1956 - February 1973 (vertical photography) - August 1981 (vertical photography) - September 1983 (vertical photography) - September 1988 (oblique photography) - December 1992 (vertical photography) - October 1996 (oblique photography)

The above historical flood information was compared to the modelled flood behaviour in the hydraulic model calibration. The agreement of modelled and historical flood information informs conclusions on the model's predicative capacity. Further details of the hydraulic model calibration are provided in Section 7.4.

3.4 Observed streamflow and rainfall data

3.4.1 Streamflow data

Table 3-2 and Figure 3-2 display the relevant streamflow gauges within the study area.

Table 3-2 Streamflow gauges

Gauge Station (No.)	River/Creek, Location	Period of Observation	Gauge Station Area (km^2)	Comments
415201	Wimmera River at Glenorchy	1910 – 1918 1946 to date	1,953	Good for frequency analyses
415240	Wimmera River at Faux' Bridge	1978-1987	2,270	Short record
415239	Wimmera River at Drung Drung	1978-1992	Not defined	Short record
415200	Wimmera River at Walmer (downstream of Horsham)	1881-date[1]	4,066	Good for frequency analyses
415241	Yarriambiack Creek at Wimmera Highway	1978-1986	Not defined	Short record
415242	Two Mile Creek at Murtoa Road	1978-1989	Not defined	No stage discharge established
415203	Mount William Creek at Lake Lonsdale (Tailwater gauge)	1984 - date	1,026	Long term record. Unreliable/missing data at high flows
415223	Burnt Creek at Wonwondah East	1965-date	80[2]	Good for frequency analyses

[1] Discontinuous record
[2] Catchment downstream of Distribution Heads.

3.4.2 Rainfall data

A number of daily and pluviographic (intensity) rainfall stations are located within or adjacent to the Wimmera River catchment. Figure 3-3 shows the location of both the pluviographic and daily rainfall stations.

The above streamflow and rainfall information was utilised in the hydrologic model calibration. Further details of the hydrologic model calibration are provided in Section 6.3.

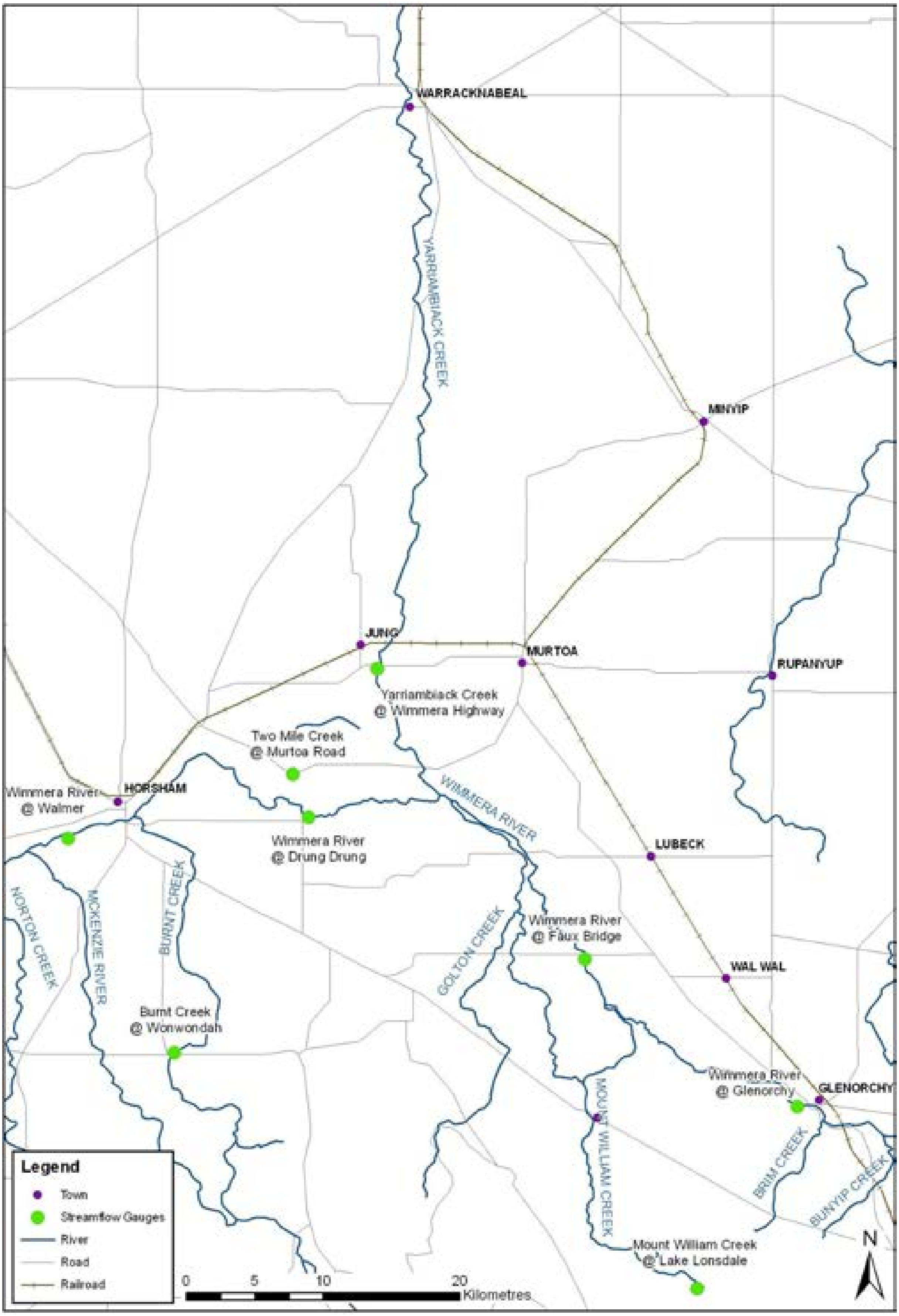

Figure 3-2 Streamflow Gauge Locations

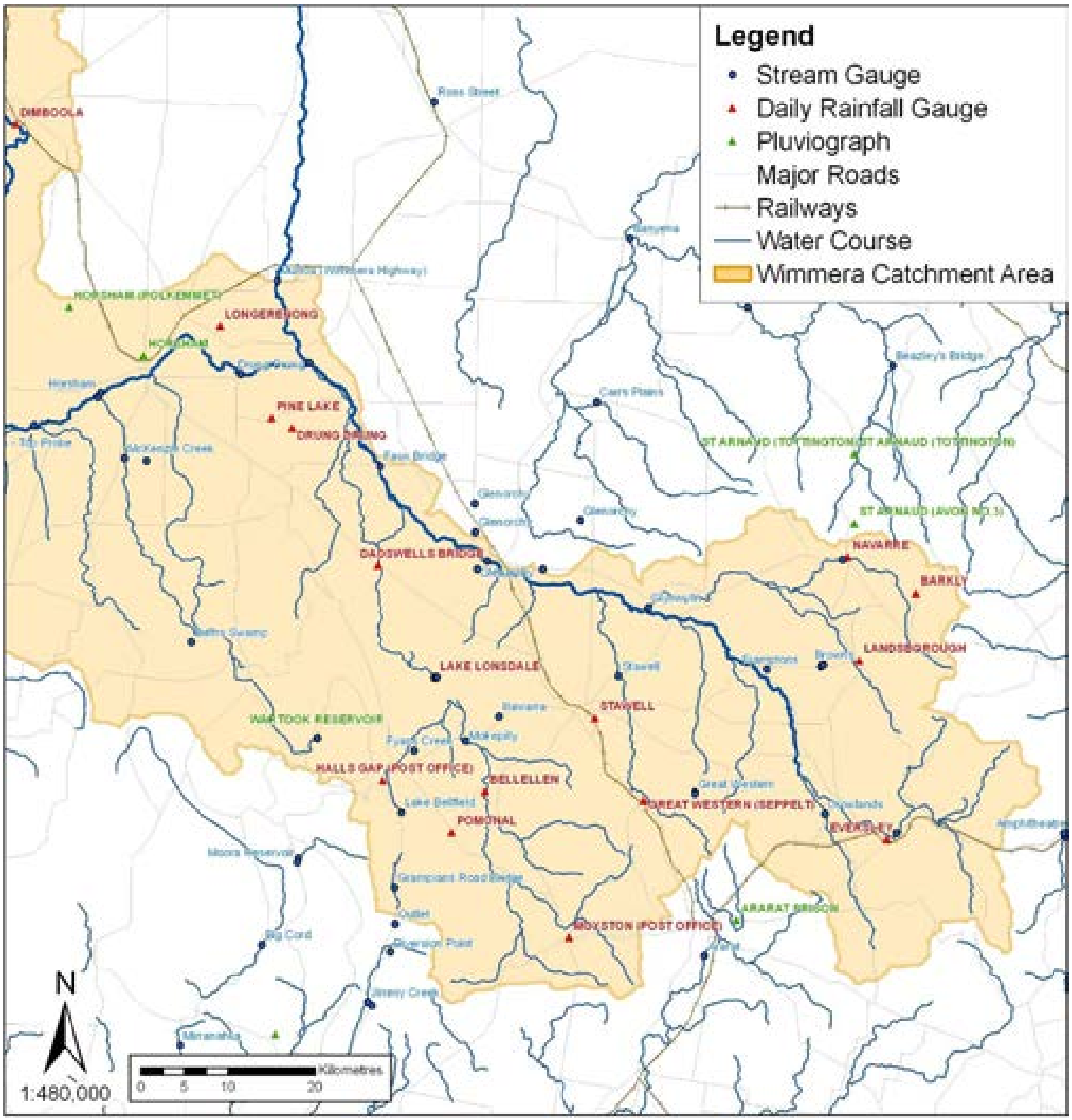

Figure 3-3 Rainfall Gauge Locations

3.5 Field inspection

Brett Anderson and Steve Muncaster (Water Technology), Chris Gippel (Fluvial Systems) and Greg Fletcher (Wimmera CMA) conducted the field inspection over the period 15 – 18 August 2007.

The field inspection focused on the identification of key physical features that may influence in channel flow and flood behaviour. The location of cross-sections and structures requiring field survey were identified by recording GPS locations. Geo-referenced digital photographs (GPS location and bearing) were taken of key features.

Field sites visited:

- Yarriambiack Creek
    - Horsham-Minyip Road (upstream of road crossing)
    - Mayberry's Road (upstream of road crossing)
    - Yarriambiack Creek at Ailsa Road crossing
    - Yarriambiack Creek at Wimmera Highway Bridge
    - Yarriambiack Creek offtake to Darlot Swamp
    - Darlot Swamp, King Swamp and Two Mile Creek.
- Wimmera River
    - Wimmera River downstream of Glenorchy Weir (Environmental Flows site 1)
    - Wimmera River at Huddleston's Weir
    - Wimmera River upstream of Faux' Bridge (modified Environmental Flows site 2)
    - Sheepwash Creek near Faux' Bridge
    - Wimmera between Faux' Bridge and confluence with Mount William Creek
    - Confluence of Wimmera with Mount William Creek (Hall's Island) (Environmental Flows site 3)
    - Wimmera River upstream of Gross's Bridge (Environmental Flows site 4)
    - Wimmera River at River Heights (Dooen Swamp)
- Yarriambiack Creek Offtake
    - Old regulator on Yarriambiack Ck
    - Yarriambiack offtake on Wimmera River
- Corkers Drain Creek and Ashens Creek
    - Ashens Creek offtake from the Wimmera River
    - Downstream on Corkers Drain Creek

Appendix A contains notes and photographs taken during the field inspection.

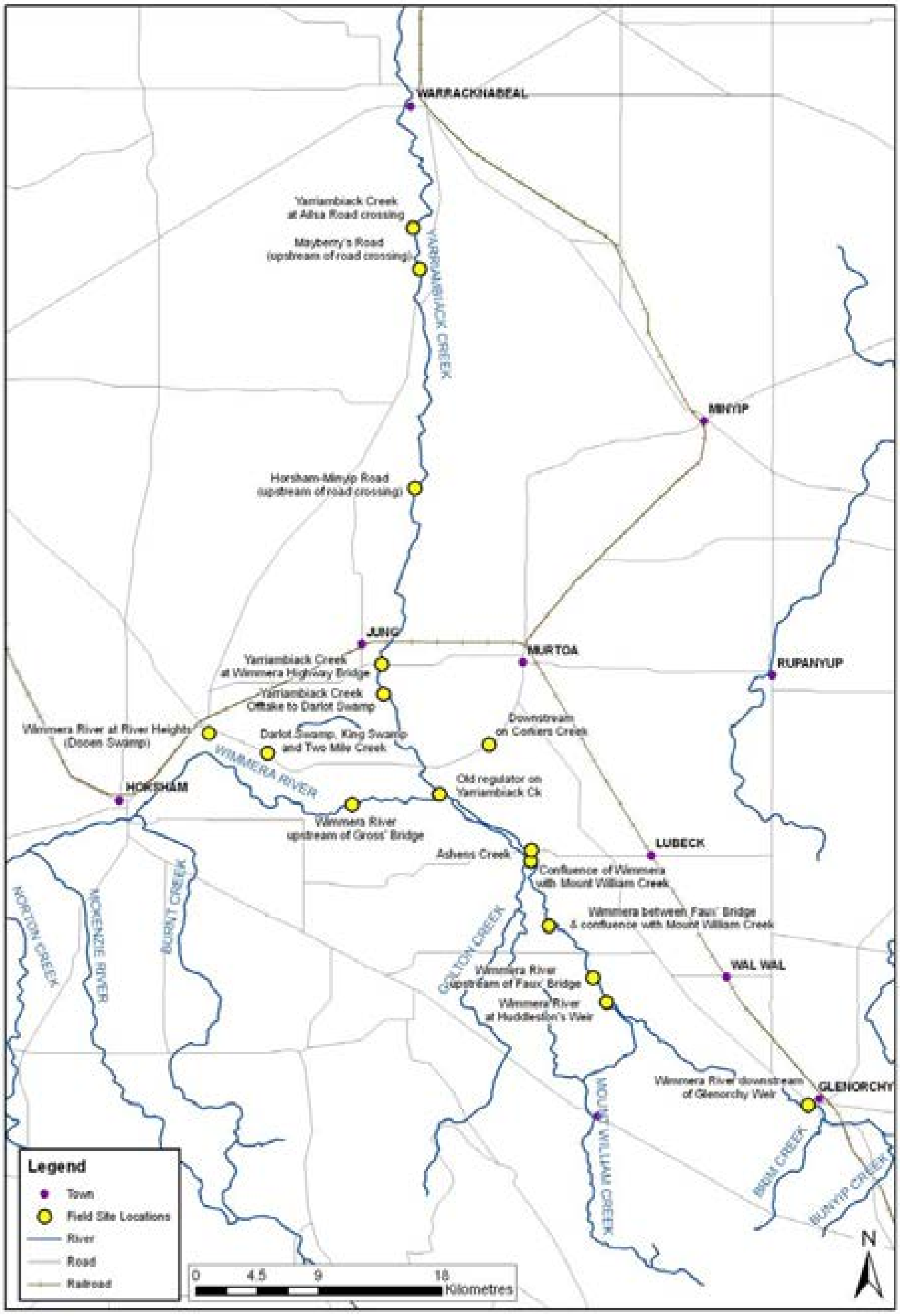

Figure 3-4 Field sites visited

4 TOPOGRAPHIC DATA REVIEW AND ASSESSMENT

4.1 Overview

This section identifies and reviews relevant available topographic data. During the topographic data review, key data gaps were identified, and additional topographic data capture scoped. Verification of topographic data from various sources provided guidance on the suitability of the data for use in the hydraulic analysis.

4.2 Available topographic data review

4.2.1 Available remote sensed topographic data

The base topographic data for the study area was sourced from ALS data undertaken by the Wimmera CMA for the study area. This ALS data has a vertical accuracy of 0.15 m along the Wimmera River floodplain and Warracknabeal and a vertical accuracy of 0.5 m along the Yarriambiack Creek floodplain. The data was captured in January 2004.

The ALS data was available in the following format:

- All ground strikes with a point density approximately 1 m
- Gridded data with 2 m and 10 m spacing

A photogrammetric survey was undertaken specially for the *Horsham Flood Study (*Water Technology 2003b) by AAM Pty Ltd. The nominated accuracy for this survey was a standard error (68% confidence level or 1 sigma) of 0.1m in both the horizontal and vertical planes. The data was captured in March 2003. Given the later capture of the ALS data set, the above ALS data supersedes the photogrammetric survey from the *Horsham Flood Study* (Water Technology 2003). Figure 4-1 displays the extent of the photogrammetric survey for Horsham (Water Technology 2003).

For the *Glenorchy Flood Study* (Water Technology 2006), ALS data capture was undertaken by AAM Hatch Pty Ltd on 24 August 2004. The average ALS data point separation was 1.4 m. The gathered ALS data was filtered to remove non-ground strikes. A sample of 134 test points indicated the standard error was 0.06 m on clear open ground. The deduced vertical accuracy was 0.15 m with a horizontal accuracy of 0.55 m. This ALS data was incorporated into the ALS data set employed by this study.

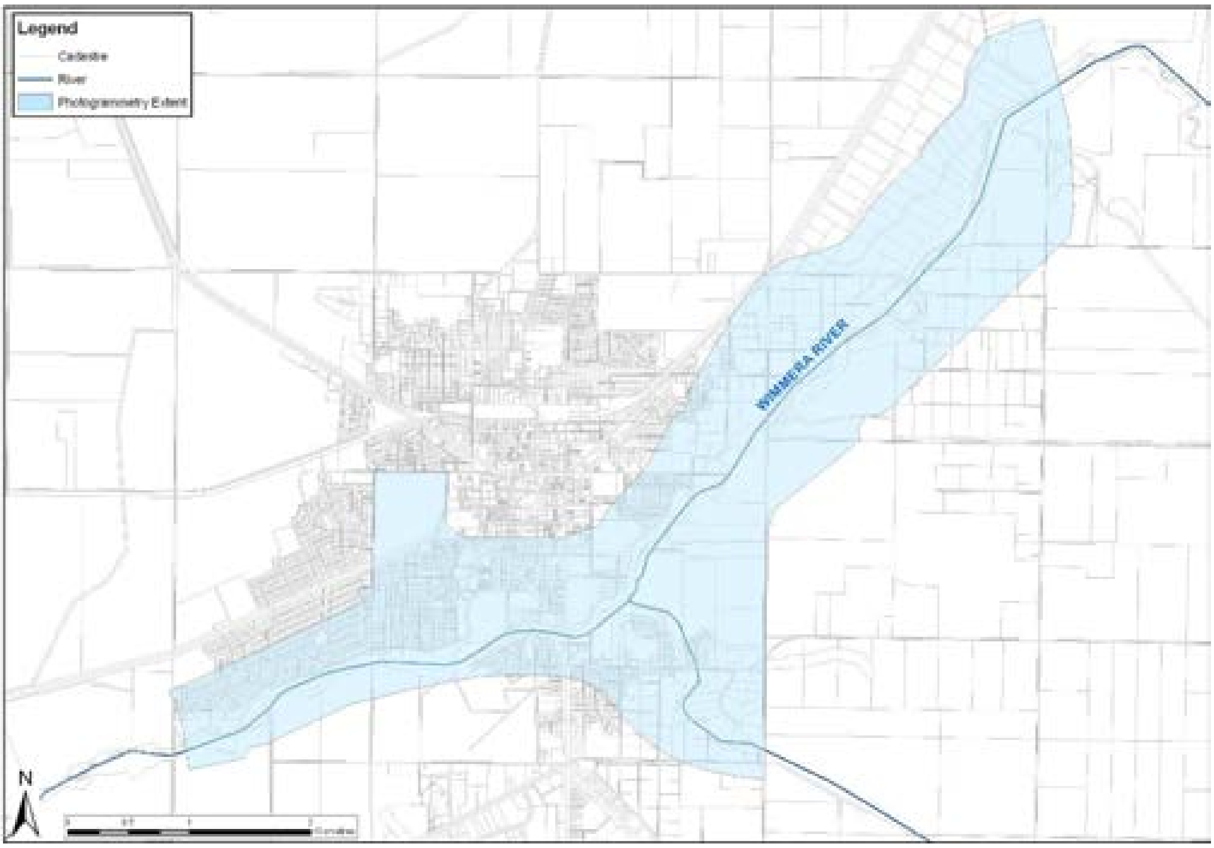

Figure 4-1 Available photogrammetric survey for Horsham.

4.2.2 Available field surveyed topographic data

In addition to the ALS data, waterway cross-sections and structures that had been previously field surveyed were available at the following locations:

- Wimmera River adjacent to Glenorchy (Source: *Glenorchy Flood Study*, Water Technology (2005))

  A field survey was conducted by LICS. This field survey included 27 waterway cross-sections (Wimmera River and Dunmunkle Creek), culvert/bridge structure details and road/rail embankments.

- Wimmera River adjacent to Horsham (Source: *Horsham Flood Study*, Water Technology (2003b))

  The *Horsham Flood Study* (Water Technology 2003b) provided six cross-sections for the Wimmera River. The six locations were chosen to correspond with the locations where cross-sections were surveyed as part of the *Horsham Floodplain Management Study* (SRWSC 1982).

  Similarly for Burnt Creek, 8 cross-sections were surveyed at locations previously surveyed as part of the *Horsham Floodplain Management Study* (SRWSC 1982). To provide data for the hydraulic analysis, a further 7 cross-sections along Burnt Creek, were surveyed.

  Details of the bridge/culvert structures along Burnt Creek were surveyed at the three Williams Road crossings and Cameron Road (Burnt Creek South Arm). The details surveyed included invert and obvert levels and general arrangement of the structure.

- Yarriambiack Creek adjacent to Warracknabeal (Source: *Warracknabeal and Beulah Flood Study* Water Technology (2007))

  The field survey was conducted by Price Merrett Consulting. For Warracknabeal, a number of historical cross-sections and the available ALS data was considered adequate to define the waterway geometry. Hence, no waterway cross-section surveys were required at Warracknabeal.

  For Warracknabeal a number of bridges, culverts and weir structures were surveyed including the following:

  - Rainbow Road bridge
  - Three footbridges
  - Borung Highway bridge
  - Jamouneau Street bridge

- *Stressed River Project – Environmental Flows Study* (SKM 2002)

  Wimmera River at Dave's Lane (downstream Glenorchy), downstream of Huddleston's Weir, Hall's Island immediately upstream of Mount William Creek confluence, and upstream of Gross' Bridge The cross-section data, at the above locations, has been supplied by the Wimmera CMA and is geo-referenced to GDA94.

- *Assessment of the impact of priority structures on natural flow regimes and flooding in Yarriambiack Creek: Hydraulic modelling between Wimmera River and Wimmera Highway* (SMEC 2002)

  Structure details at the Yarriambiack Creek regulator and Wimmera Highway Bridge and approaches were obtained.

4.3 Additional topographic data capture

This section discusses the data gaps in the available topographic data, and outlines the scope of additional topographic data capture undertaken in this project.

The available remote sensed topographic data provides an excellent base for topographic data in this project. However, ALS data does not capture waterway bed profiles and/or in channel features if water is present at the time of data capture. Examination of ALS extracted cross sections revealed that at the time of the ALS capture, the Wimmera River channel was generally dry. The major reach with water present was due to the backwater from the Horsham weir pool. Hence the ALS extracted cross sections were able to resolve waterway and bed levels, apart from the Horsham weir pool and some pools between Glenorchy Weir and Huddleston's Weir and between Taylor's Lake Outlet and the Horsham Weir pool.

The previously available cross-section data was collected for the specific purposes of previous studies. Hence the available data is limited to relatively short river reaches as opposed to the data requirements for a large-scale modelling project.

To supplement the available cross-section data, this project undertook an extensive additional field survey. Price Merrett Consulting undertook the field surveying.

The field survey component was designed at capturing topographical data not well resolved by the available ALS, principally waterway bed levels and structures. Also, the field survey provided further verification points for the ALS data.

There were five components to the field survey:

- *Detailed cross-section survey:* At each of the 6 detailed environmental flow sites, 9 cross-sections (bank to bank) over a reach length of about 500 m were surveyed. These cross sections were used in the 1D model hydraulic modelling, and aided in the simulation of the in-channel flow behaviour. Total of 45 detailed cross–sections were surveyed. The six sites included:
  - Site 1: Wimmera River downstream of Glenorchy Weir (Environmental Flows site 1 (SKM 2002))
  - Site 2: Wimmera River upstream of Faux' Bridge (Environmental Flows site 2 (Re-located SKM 2002))
  - Site 3: Confluence of Wimmera River with Mount William Creek (Environmental Flows site 3 (SKM 2002))
  - Site 4: Wimmera River upstream of Gross' Bridge (Environmental Flows site 4 (SKM 2002)
  - Site 5: Wimmera River adjacent to Burnt Clay Road (new site)
  - Site 6: Wimmera River at River Heights (Dooen Swamp) (new site)
- *Bed level survey:* The bed levels were surveyed immediately upstream and downstream of the significant waterway junctions. For each significant waterway, there was at least one immediate bed level surveyed between junctions. The maximum nominal spacing of 1200 m was adopted along the Wimmera River and Yarriambiack Creek. In total, there were 191 bed levels taken. The locations of the significant waterways surveyed are provided in Appendix B. The bed level survey was used to define channel inverts within the 1D hydraulic model.
- *Indicative cross-section survey*: At 44 locations corresponding to the bed level survey, indicative waterway cross-sections were surveyed. These indicative cross-sections consisted of :
  - 4-5 points on local floodplain (one side),
  - top of bank (both sides) (for channel width),
  - 4-6 point on bed level including toe of bank on each side,

  The indicative cross sections were used to verify waterway cross section extracted from the ALS data.
- *ALS verification data:* Strings of surface levels along linear features, such as roads were surveyed. These strings provide a verification source for the ALS data. In total 348 points were captured as verification points. This ALS verification data was used to assess the reliability of the ALS data across the floodplain, and in the 2D hydraulic model construction.
- *Structure survey:* There were 4 structures (bridges and weirs) where general arrangements were surveyed; Huddleston's Weir (prior to the installation of the v-notch), Faux' Bridge, Horsham-Lubeck Road bridge, and Yarriambiack Creek offtake weir. These structure along the previously collected structure data (as discussed in Section 4.2.2) was used in the 1D hydraulic model to define the structure geometry and hydraulic behaviour.

Across the five components, 2677 points were surveyed. The location of the field survey points are provided in Appendix B.

4.4 Topographic data verification

This section discusses the verification of topographic data from the ALS and field survey sources.

A triangular three dimensional ground surface (TIN) was derived from the ALS ground strikes data using ArcGIS. This TIN provided a continuous ground surface across the entire study area.

A series of comparisons were undertaken between the ALS topographic data and the five field survey components.

4.4.1 Waterway cross-section

A total of 89 cross-sections were surveyed including 45 detailed cross-sections at environmental flow locations, and 44 indicative cross-sections. At each cross-section, a comparison was undertaken for the field surveyed and ALS extracted data.

Comparison plots of field surveyed and ALS extracted cross-sections are provided in Appendix B.

For 28 of 89 cross-sections, the ALS cross-sections displayed flat or inclined straight line segments across the invert of the channel. These line segments were assumed to result from the reflection from the water surface.

Generally, the ALS extracted cross-sections compared favourably with the field survey, for elevations above the water level and/or at locations where no water was present at the time of the ALS data capture. This favourable comparison provides confidence that the ALS topographic data set provides reliable cross-sections for hydraulic modelling. Where water was present, an adjustment to the cross section invert was made using the surveyed cross sections. In particular, adjustments were made in the reach influenced by the Horsham weir pool.

4.4.2 Bed level survey points

At the locations of the 191 bed levels, a cross-section was extracted from the ALS data set. A comparison was made between the surveyed bed level and the ALS cross-sections.

Similar to the cross-section comparisons, there were generally favourable agreements found. The presence of water resulted in the ALS cross-section displaying straight line segments, as discussed in Section 4.4.1.

As outlined in Section 4.4.1, the favourable agreement underpins the use of the ALS data in the hydraulic modelling. As above, adjustment to the bed level was undertaken where water was present at the time of the ALS data capture. In particular, adjustments were made in the reach influenced by the Horsham weir pool.

4.4.3 ALS linear feature verification

As discussed, 348 points were surveyed along roads within the study area. The nature of the field survey points provide for a consistent comparison basis.

At each point, a comparison was made for the elevations extracted from the ground surface TIN and from the field survey. A positive difference indicates that the ALS elevation is higher than the field surveyed elevation.

Statistics across the entire data set are as follows:

- Mean difference: -0.030 m
- Median difference: -0.033 m
- Standard derivation: 0.119 m

A total of 285 out of 348 ALS (81.8 %) points lie within +/- 0.1 m of the field surveyed data. This comparison verifies the ALS data generally conforms with the accuracy specification of +/- 0.1 m. Figure 4-2 show a histogram of the differences.

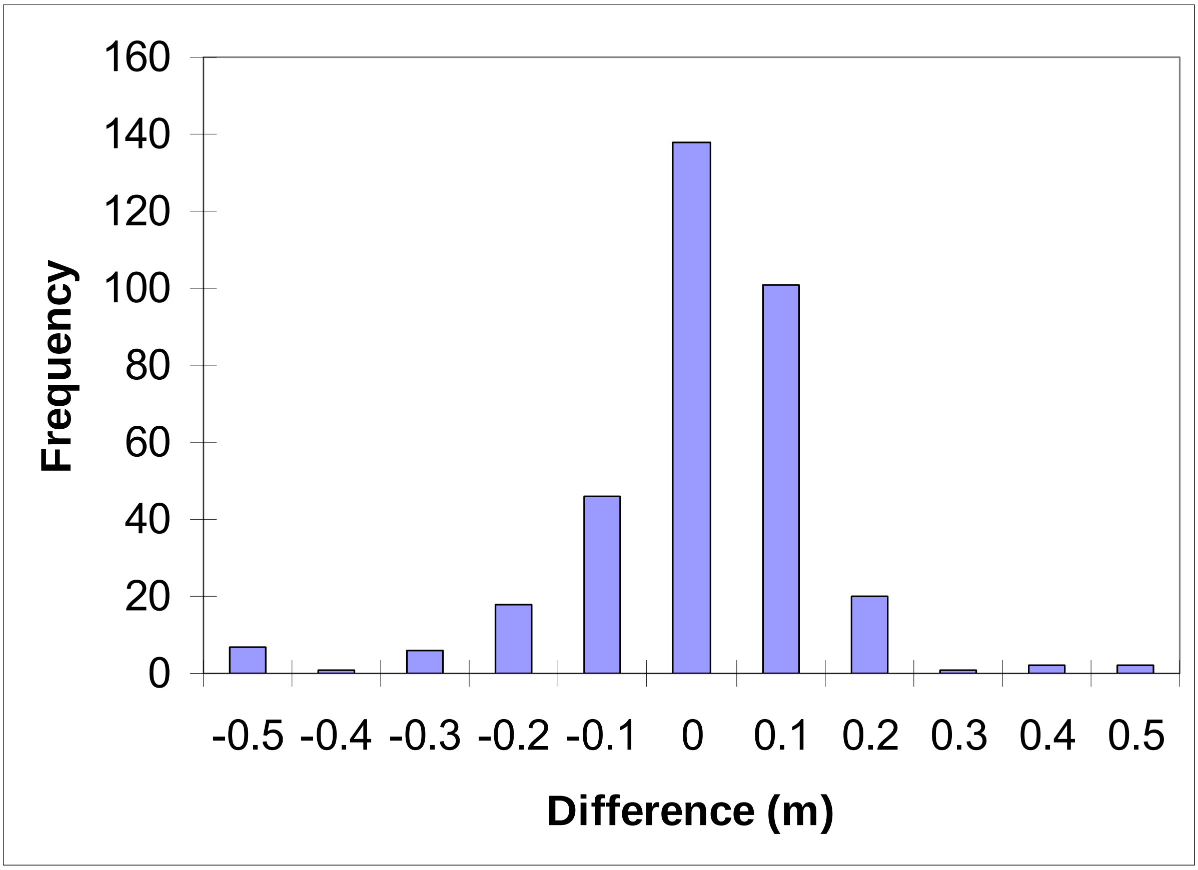

Figure 4-2 ALS verification histogram

5 LOW – MEDIUM FLOW HYDROLOGIC ANALYSIS

5.1 Overview

As discussed in Section 3.2, current and natural daily flow sequences, for the period January 1990 to December 2000 were derived by SKM (2003a). The flow sequences were developed at a number of locations throughout the Wimmera River catchment. The following locations corresponding, for the purposes of this study, to study area inflow points:

- Mount William Creek between Lake Lonsdale and Wimmera River downstream of Lonsdale-Glenorchy Channel (corresponds to Mount William Creek at the Western Highway)
- Wimmera River at Glenorchy
- Burnt Creek downstream of Toolondo Channel (corresponds to Burnt Creek at the Western Highway)

The current streamflow sequences were generally estimated using the available streamflow and diversion data. Infilling of missing streamflow data employed correlations with nearby gauges and/or rainfall runoff modelling.

The natural streamflow sequences were estimated by removing the influence of water resource development. The considered water resource developments include on-stream storages, diversions and farm dams (SKM 2003a).

Availability of streamflow data governed the selection of the period of streamflow derivation. The selected period (January 1990 to December 2000) was considered representative of the climate trends over the period of available climate (SKM 2003a). It should be noted the derivation of this 10 year period occurred in 2003, prior to the current dry spell. The consideration of conditions following 2003 may lead to a revised conclusion regarding the representative nature of this flow period.

The flow sequences were compared using flow duration curves. The following comments from SKM (2003a) summarise the key conclusions:

- Mount William Creek between Lake Lonsdale and Wimmera River downstream of Lonsdale-Glenorchy Channel: Considerable difference due to upstream storages. Frequency of flow events is reduced from the natural conditions with zero flow periods increased in the current conditions.
- Wimmera River at Glenorchy: Similar flow duration under the current and natural conditions. The natural flow sequence slightly higher than current due to diversions and farm dams.
- Burnt Creek downstream of Toolondo Channel: considerable reductions in current condition flows due to Distribution Heads. Zero flow periods increased in the current conditions.

The derivation of current and natural flow sequences, outlined in SKM (2003a), is considered adequate rigour for the purposes of this study. It is considered unlikely a re-derivation of the natural flow sequences would yield a more definitive natural sequence. This is due to considerable uncertainty involved in the hydrologic assessment of catchment runoff with changes in land use and water resource development. As such, future investigation of the natural and current low-medium flow sequences was unwarranted.

Low – medium flow scenarios employed as part of the hydraulic model application are discussed in Section 8.2.

6 HIGH FLOW HYDROLOGIC ANALYSIS – DESIGN FLOOD ESTIMATION

6.1 Overview

Flood hydrographs were required for large historical flood events and the design flood events: 5, 10, 20, 50, 100 and 200 year ARI floods for the Wimmera River catchment at the inflow points to the study area. The historical flood hydrographs were required for the hydraulic model calibration.

As outlined in Section 1, these inflow locations include:

- Wimmera River at Glenorchy
- Golton Creek at Western Highway
- Mount William Creek at Western Highway
- Burnt Creek at Western Highway

In addition to the inflow points, flood hydrographs were required for the local study area catchment. The local area hydrographs reflected the runoff generated from within the hydraulic model study area.

The catchment hydrologic model, URBS, was the principal tool employed to estimate flood hydrographs for the Wimmera River catchment. The URBS model is an event based conceptual runoff routing model in which rainfall is routed through a network of lumped storages to the catchment outlet. The application of such catchment models is common practice in the flood estimation, as discussed in *Australian Rainfall and Runoff* (IEAust 1997).

As outlined in Section 3.2, an URBS model was developed by BoM (2004) for the Wimmera River Catchment. The BoM URBS model was principally developed for flood forecasting in a real time environment. The BoM URBS model was revised by this study, where appropriate to provide the flood hydrograph estimates outlined above.

This hydrologic analysis has four principal components:

- URBS model development structure: discusses the structure of the URBS model and revisions made by this study (refer to Section 6.2).
- URBS model calibration: outlines the determination of the URBS model parameters through comparison of modelled and observed flood hydrographs (refer to Section 6.3).
- URBS model verification: details the verification of model parameters by the reconciling of URBS model design flood estimates against flood frequency estimates (refer to Section 6.4).
- URBS model application: summarises the application of the calibrated and verified URBS model to the evaluation of the design flood hydrographs for pre-European and current catchment conditions (refer to Sections 6.5 and 6.6)

6.2 URBS model development

6.2.1 Description of the URBS Runoff Routing Model

URBS is a networked conceptual runoff and streamflow routing program that calculates flood hydrographs from rainfall and other channel inputs. The model is based on catchment geometry and topographic data. It is an areally distributed, non-linear model that is applicable to both urban and rural catchments. The model can account for both temporal and spatial distribution of rainfall and losses (Carroll 2002).

The rainfall excess (runoff) is determined by the application of rainfall loss model. URBS offers two rainfall loss models including the initial loss/continuing loss model and the initial loss/volumetric runoff coefficient model.

Two runoff routing approaches are available within URBS to describe catchment and channel storage routing behaviour. These are the URBS *Basic* and *Split* routing models.

The *Basic* model is a simple RORB-like model where stream length (or derivative) is assumed to be representative of both catchment and channel storage.

The *Split* model separates the channel and catchment storage components of each sub-catchment. The *split* model applies the rainfall to a sub-catchment, routes the rainfall excess runoff routed overland to the sub-catchment centroid, then routes along the stream to the sub-catchment outlet. The sub-catchment storage is assumed to be proportional to the square root of the sub-catchment area. Once at the sub-catchment outlet, the runoff is then routed along the channel network to the catchment outlet with downstream sub-catchment runoff entering at sub-catchment outlets. The channel storage is assumed to be proportional to the length of the channel. There are three principal model parameters in the split model, α (channel storage parameter), β (catchment storage parameter) and m (degree of non-linearity of flood response).

The storage characteristics for the sub-catchment and channel can be modified by the channel slope, catchment slope, fraction urbanised (various degrees), proportion forested and channel roughness. These other variables are included optionally in the modelling process at the discretion of the modeller (Carroll 2002). Further details of URBS can be obtained from Carroll (2002).

6.2.2 URBS model structure

As outlined, the URBS model consists of two sub-models; the upper model extends to Glenorchy, and the lower model extends from Glenorchy to Dimboola. The outflow from the upper Wimmera model is an input to the lower Wimmera model. Figure 6-1 shows the upper and lower Wimmera sub-models.

Within the Wimmera River catchment, model sub-catchments were then defined to coincide with watershed boundaries, stream junctions and the location of gauging stations. In total, the Wimmera River catchment to Dimboola was sub-divided into 97 sub-catchments. Figure 6-1 shows the URBS model catchment sub-division.

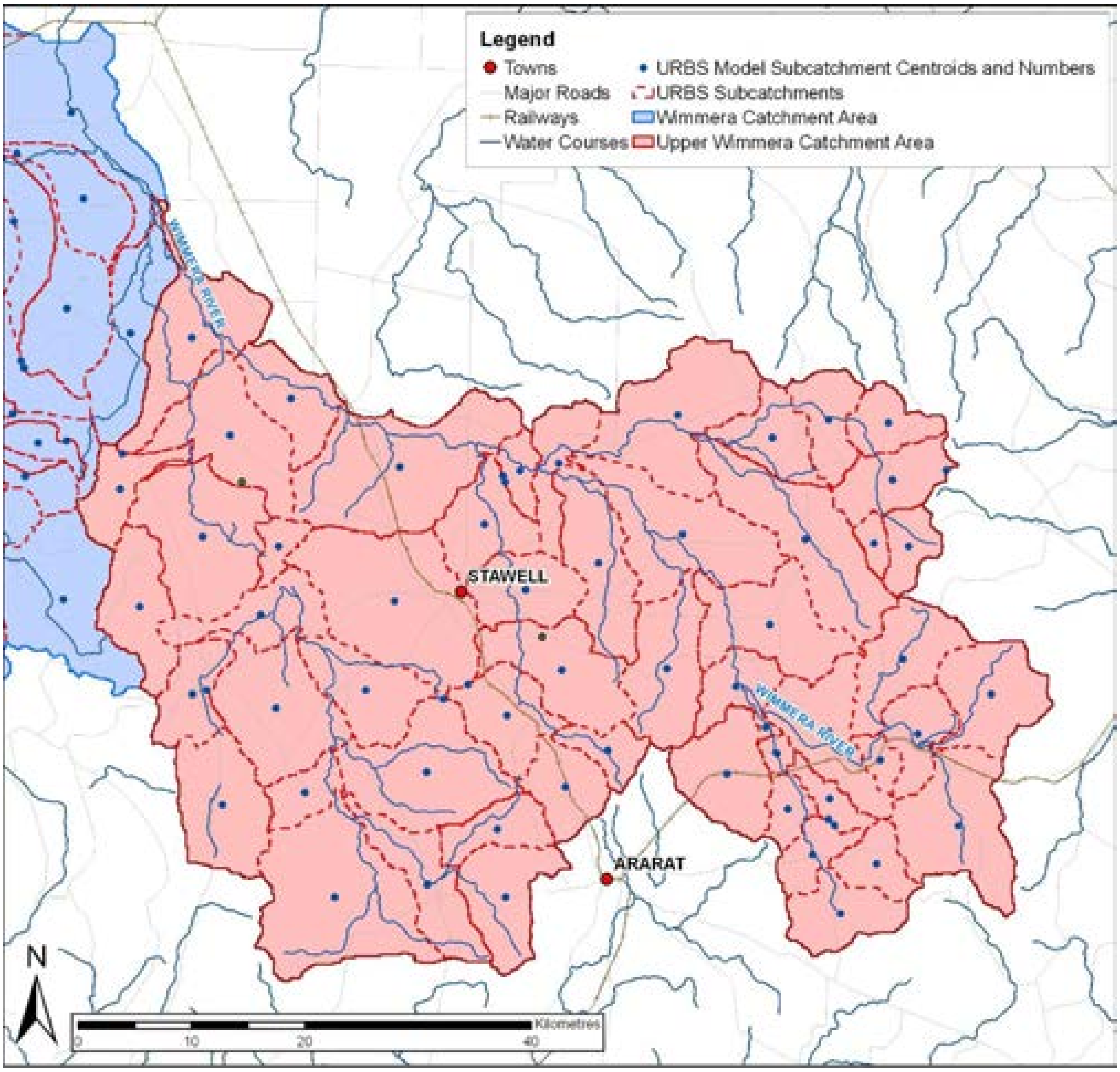

Figure 6-1 URBS Model Structure – Catchment Subdivision

The BoM URBS model was developed for flood forecasting purposes. This project required the use of the URBS model to estimate historical flood hydrographs and design flood hydrographs. A review of the BoM identified revisions required to achieve the required outcomes for this project. The following discusses the nature of the revision undertaken to the BoM URBS model for this project:

- **Effluent flows from the Wimmera River to Yarriambiack Creek**

  Effluent flows to Yarriambiack Creek leave the Wimmera River between Faux' Bridge and the Yarriambiack Creek Offtake, and apart from flow returning via Two Mile Creek do not contribute to flows at Horsham (Walmer). For the URBS model calibration, a proper comparison of observed and modelled flood hydrographs at Walmer (downstream Horsham) must make allowance for any effluent flows to Yarriambiack Creek. The BoM URBS model structure was modified to make this allowance, by removing the observed flood hydrograph for Yarriambiack Creek at the Wimmera Highway Bridge from the modelled hydrograph downstream of the Yarriambiack Creek Offtake Weir. This allowance required observed streamflow data for Yarriambiack Creek. As outlined in Table 3-2, streamflow data for Yarriambiack Creek at the Wimmera Highway Bridge was only available for the period 1978 to 1986. As outlined in Section 6.3.2, four URBS model calibration events, August 1981, August 1983, September 1988 and October 1996, were considered. Hence, this allowance was made, using observed streamflow data for the August 1981 and August 1983 calibration events. For the other two URBS model calibration events, September 1988 and October 1996, modelled streamflow hydrographs, sourced from the hydraulic model, were employed. Further details of the URBS model calibration are discussed in Section 6.3. For the design flood hydrograph estimation, as discussed in Section 6.5 and 6.6, modelled hydrographs for Yarriambiack Creek from the hydraulic analysis were employed.

- **Flow transfer from the MacKenzie River to Burnt Creek at the Distribution Heads.**

Distribution Heads regulates low – medium flows from the MacKenzie River and Moora Channel into Burnt Creek, the MacKenzie River and Old Natimuk Channel. The Wimmera/Mallee Headworks System Reference Manual (RWC 1987) provides the following commentary on the operation of Distribution Heads:

- o Up to 600 ML/d are directed to Burnt Creek for harvesting to Taylor's/Pine Lakes
- o Above 600 ML/d, operation of Distribution Heads is focused on directing the excess flow down the MacKenzie River.
- o "Big" flows overtop and bypass the regulator to continue down Burnt Creek.

Further discussions with GWMWater (Dr Andrew Barton pers. comm.) revealed complex operational arrangements at Distribution Heads. GWMWater was unable to provide a definitive relationship between flows in the MacKenzie River and Burnt Creek (Dr Andrew Barton GWMWater pers. comm.).

As definitive advice regarding the flow arrangements at Distribution Heads was not available, the following approximate approach was employed for the URBS model calibration:

- o Run URBS model without any diversion at Distribution Heads
- o Compare modelled and observed hydrographs for Burnt Creek at Wonwondah East
- o Evaluate the differences in observed and modelled flows, and develop inflow hydrograph to Burnt Creek.
- o Re-run the URBS model with the estimated Burnt Creek inflow hydrograph as a diversion.
- o Compare revised modelled and observed hydrographs for Burnt Creek at Wonwondah East

This above approach was employed for the 1983, 1988 and 1996 calibration events as observed flow was available at Wonwondah East. For these events, estimated Burnt Creek inflows were plotted against the flows on the MacKenzie River upstream of Distribution Heads (Wartook tailwater gauge). By plotting these flows any flow split relationship may be assessed, and if appropriate applied for design flood estimation. Further discussion of the flow splits at the Distribution Heads are provided in Section 6.3.4.

It was not possible to apply the above approach for the 1981 calibration event, due to no observed streamflow data at Wonwondah East.

Under natural conditions, SKM (2003a) referenced personnel communications from John Martin (Wimmera Mallee Water now GWMWater) noted that:

Under natural conditions Burnt Creek was not connected to MacKenzie Creek and drained an area of 80 km^2. (SKM 20003 p.23)

As such, the URBS modelling for the pre-European conditions adopts no flow transfer between the MacKenzie River and Burnt Creek.

- **Faux' Bridge Gauge**

During large flood events, floodplain flows can bypass the stream gauge at Faux' Bridge. In particular, flows originating from the Mount William Creek catchment can flow overland to the west of the Faux' Bridge gauge. Given this potential bypass, comparison of URBS modelled and observed hydrographs, at the Faux' Bridge, provide quantitative guidance on model performance, rather than a definitive measure. The complexity of the flow behaviour of the Mount William/Wimmera River adjacent to Faux' Bridge is unable to be rigorously represented within the URBS model. The hydraulic analysis provides a robust framework for the assessment of flow behaviour. Further details of the flow behaviour adjacent to Faux' Bridge are provided in Section 7.4.

The URBS model, as constructed by BoM (2004), reflected the current catchment conditions and contains the storages at Lake Bellfield and Lake Lonsdale. To reflect pre-European conditions, these storages plus the flow transfer at the Distribution Heads, as discussed above, were removed. These changes to the URBS model provide an estimate of inflow into the study area under pre-European conditions. The hydraulic analysis considered the pre-European conditions within the study area through the removal of roads, levees, channels and other waterway/floodplain modifications. Further discussion of the pre-European URBS model is provided in Section 6.6.

6.3 URBS model calibration

6.3.1 Background

As discussed previously, the URBS split model routes excess runoff through the sub-catchment to the sub-catchment outlet and then routes the excess runoff along the channel network to the catchment outlet. The three model parameters α (channel storage parameter), β (catchment storage parameter) and m (degree of non-linearity of flood response) required determination during the model calibration.

Model parameters (α, β & m) were determined by BoM as part of the Wimmera River flood warning investigations (Baker pers. comm. 2006, BoM 2004). For this previous investigation, the main focus of the model was on estimation of flood heights at major population centres adjacent to the Wimmera River (e.g. Dimboola). In turn, the calibration undertaken as part of the flood warning investigations focused on the reliable estimation of observed flood heights at these major centres.

This hydrologic analysis focused on the flood hydrograph estimation at the study area inflow points. As discussed in Section 6.2.2, the URBS model was revised to reflect the effluent flows to Yarriambiack Creek. This revision used the observed streamflow at the Wimmera Highway Bridge, when available, and modelled hydrographs from the hydraulic analysis when no observed hydrograph was available.

The flows from the MacKenzie River at Distribution Heads were reflected in the URBS model, as outlined in Section 6.2.2.

Given the different focus and the revised model structure, this study undertook a revised model calibration with the two sub-models calibrated separately at the following locations:

- Upper Wimmera sub-model:
    - Wimmera River at Glenorchy
- Lower Wimmera sub-model:
    - Wimmera River at Faux' Bridge (indicative only)
    - Burnt Creek at Wonwondah East
    - Wimmera River at Walmer (downstream of Horsham)

Calibration at the above locations is reliant upon the availability of observed streamflow data. In some instances, streamflow data may be unavailable due to a gauge malfunction during a given event.

Furthermore, the observed streamflow is derived from the measurement of water level, and then a flow rate is evaluated using a rating curve. Rating curves are derived from flow gaugings and extrapolation using hydraulic analysis. The reliability of the rating curve reflects the number and range of flow gaugings used in the determination. This study has employed the rating curves developed by Thiess Hydrographic Services. Also, rating curves may change over time with changes in the channel form (bed level, vegetation). The strength of the model calibration must consider the uncertainty in the applied rating curves. No reliable rating table was sourced for the Wimmera River at Drung Drung, and hence no streamflow was available for calibration at this site. For the Wimmera River at Drung Drung, the mobility of the bed makes it likely that an accurate rating table may never really be established, or if it is will only be good for a very short period of time due to vegetation and bed movement (P. Fennell, Wimmera CMA, pers. comm.).

As discussed in Section 6.2.2, observed hydrographs, when available, for Yarriambiack Creek at the Wimmera Highway were used to estimate outflows to Yarriambiack Creek.

No streamflow data, only water level data is available at Drung Drung gauge. Hence it is not possible to use this gauge in the URBS model calibration, however the water level data can be used in the hydraulic model calibration (refer to Section 7.4.2.

6.3.2 Selection of model calibration events

The selection of suitable flood events for model calibration was dependent on the availability of concurrent streamflow and pluviographic records. Four flood events were selected for calibration: August 1981, September 1983, September 1988 and October 1996. The details of the selected calibration flood events are given in Table 6-1.

Table 6-1: URBS model calibration event

Event	Glenorchy (415201)	Faux Bridge (415240)	Wonwondah East (415223)	Wimmera Highway (415241)	Walmer (415200)
	Recorded Peak flow (m^3/s)	Recorded Peak flow (m^3/s)	Recorded Peak flow (m^3/s)	Recorded Peak flow (m^3/s)	Recorded Peak flow (m^3/s)
August 1981	198 (17110 ML/d)	184 (15900 ML/d)	N.A	20 (1728 ML/d)	262 (22640 ML/d)
September 1983	206 (17800 ML/d)	217 (18750 ML/d)	14.1 (1218ML/d)	20 (1728 ML/d)	296 (25580 ML/d)
September 1988	316 (27300 ML/d)	N.A	11.6 (1002 ML/d)	N.A	244 (21080 ML/d)
October 1996	171 (14780 ML/d)	N.A	17.4 (1503 ML/d)	N.A	227 (19610 ML/d)

N.A. Missing / unreliable streamflow data for this event e.g. gauge decommissioned or not yet constructed.

6.3.3 URBS model parameter calibration

The URBS model contains three model parameters, α (channel storage parameter), β (catchment storage parameter) and m (degree of non-linearity of flood response), that require determination during the model calibration.

The URBS model calibration requires the comparison of the modelled flood hydrographs with observed flood hydrographs at streamflow gauge(s) throughout the catchment. As discussed, the upper and lower catchment sub-models were calibrated separately.

As discussed in Section 6.2.2, the URBS model allowed for effluent flows to Yarriambiack Creek in the August 1981 and September 1983 events using observed streamflows at the Wimmera Highway gauge. For the 1988 and 1996 events, the modelled hydrograph at the Wimmera Highway gauge were sourced from the hydraulic analysis. This allowance involved removing of the observed/modelled Wimmera Highway gauge hydrograph from the URBS modelled hydrographs. The inclusion of this allowance provided a minimal change to the URBS model parameters.

Flow into Burnt Creek was estimated using the approach outlined in Section 6.3.1. Further discussion of the flow split at Distribution Heads is provided in Section 6.3.4.

There are three model parameters (α, β & m) requiring calibration. The calibration approach adopted by this study was as follows:

- Set m = 0.8. This value is an acceptable value for the degree of non-linearity of catchment response (IEAust 1999)
- For each calibration event, the initial loss (IL) was determined to result in a reasonable match between the modelled and observed rising limb of the flood hydrograph. The continuing loss (CL) was determined to match the modelled and observed runoff volume.
- For each calibration event, a number of combinations of α and β were trialled to achieve reasonable re-production of the peak flow and general hydrograph shape.

The initial loss/uniform continuing loss model was found to provide a good fit of observed and modelled flood hydrographs, and was adopted for use in this hydrologic analysis.

Table 6-2 displays the calibration results for the upper catchment sub model. Figure 6-2, Figure 6-3, Figure 6-4 and Figure 6-5 provide comparison plots of the observed and modelled hydrographs for the four calibration events.

Table 6-2 URBS model calibration – Upper Wimmera catchment sub-model

Event	Routing parameters		Rainfall loss parameters		Wimmera River at Glenorchy	
	α	B	IL (mm)	CL (mm/hr)	Recorded peak (m^3/s)	Calculated peak (m^3/s)
August 1981	0.45	3.0	10	1.0	198 (17110 ML/d)	204 (17625 ML/d)
September 1983	0.4	3.0	10	1.0	206 (17800 ML/d)	211 (18230 ML/d)
September 1988	0.4	3.0	20	1.5	316 (27300 ML/d)[1]	344 (29720 ML/d)
October 1996	0.4	3.0	5	0.9	171 (14780 ML/d)	175 (15120 ML/d)

1. Figure 6-4 displays the recorded hydrograph for the September 1988 event at Glenorchy. The recorded hydrograph displays a constant flow at the time of the peak. The quality code provided with the streamflow data from Thiess indicates that it is good quality data. However, the study team considers that this constant flow is likely to reflect unreliable data. Similarly observed streamflow for August 1981 & September 1983 displays a 'flat top'.

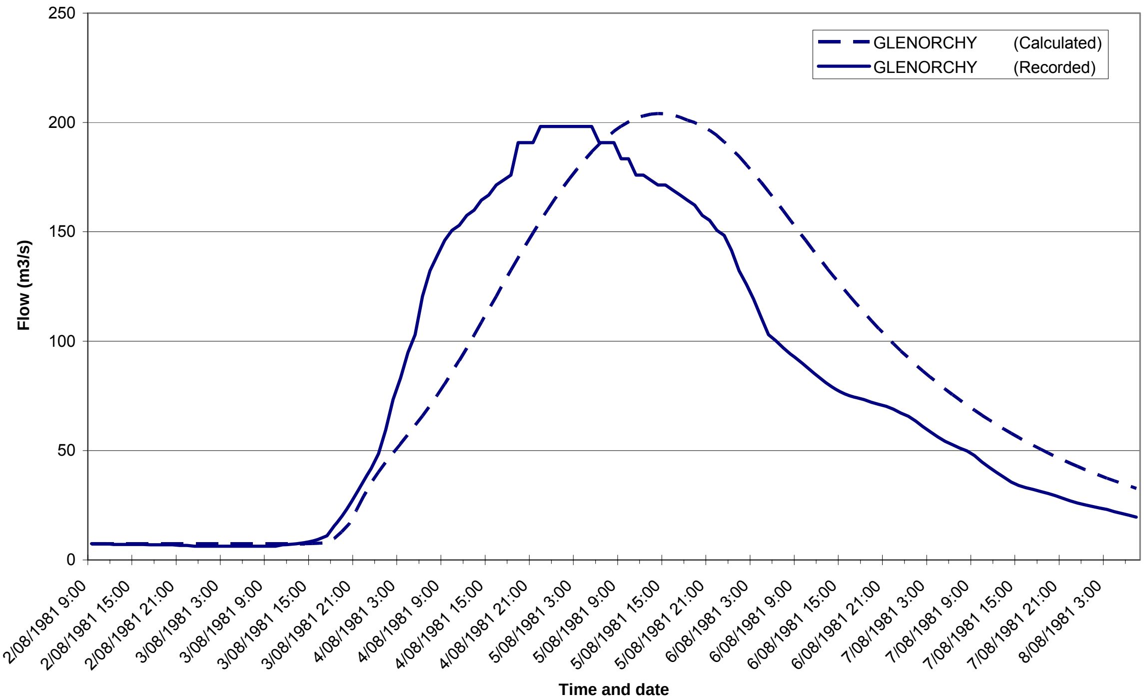

Figure 6-2 URBS Upper sub-catchment model calibration – August 1981

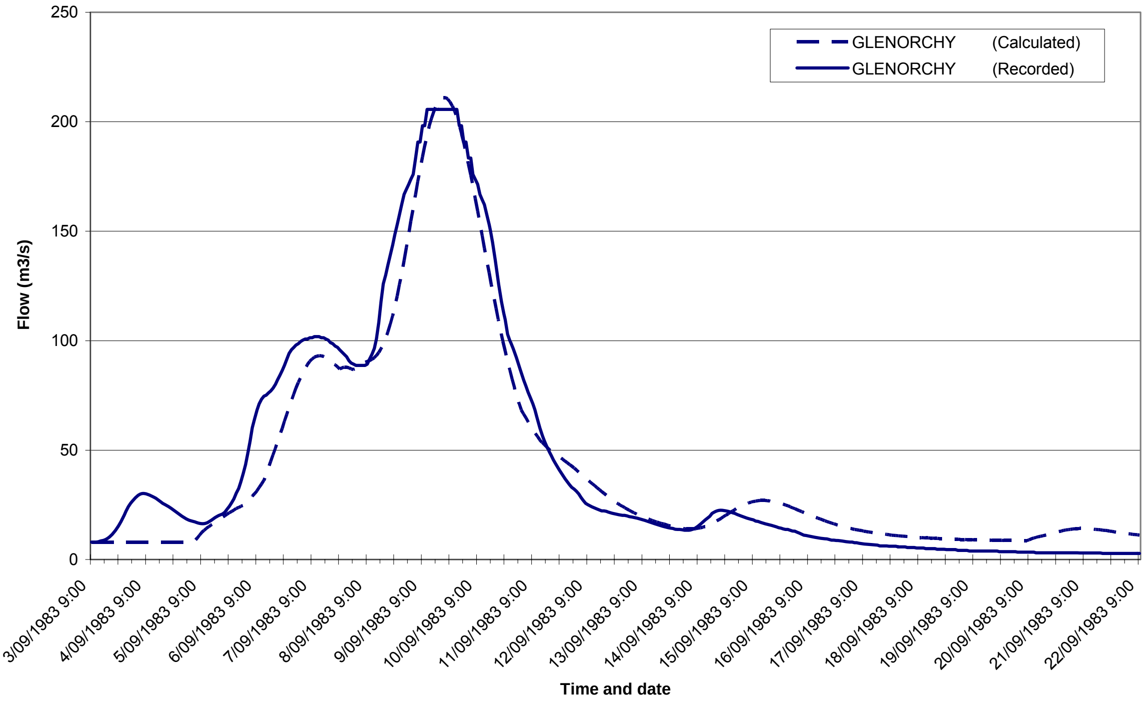

Figure 6-3 URBS Upper sub-catchment model calibration – September 1983

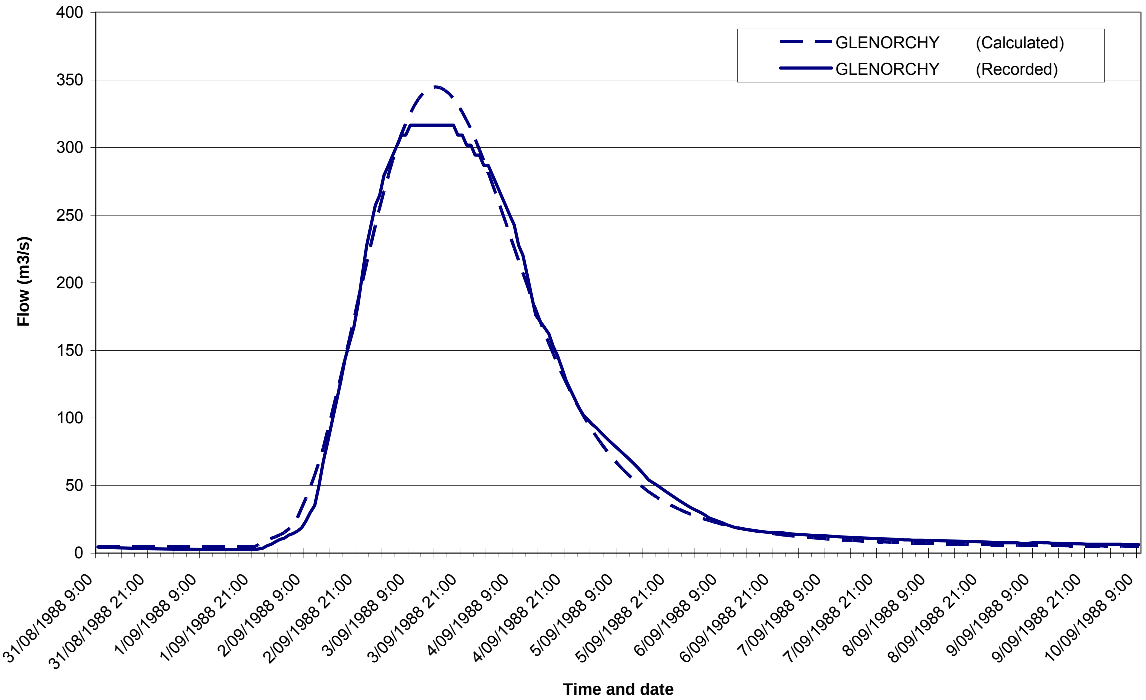

Figure 6-4 URBS Upper sub-catchment model calibration – September 1988

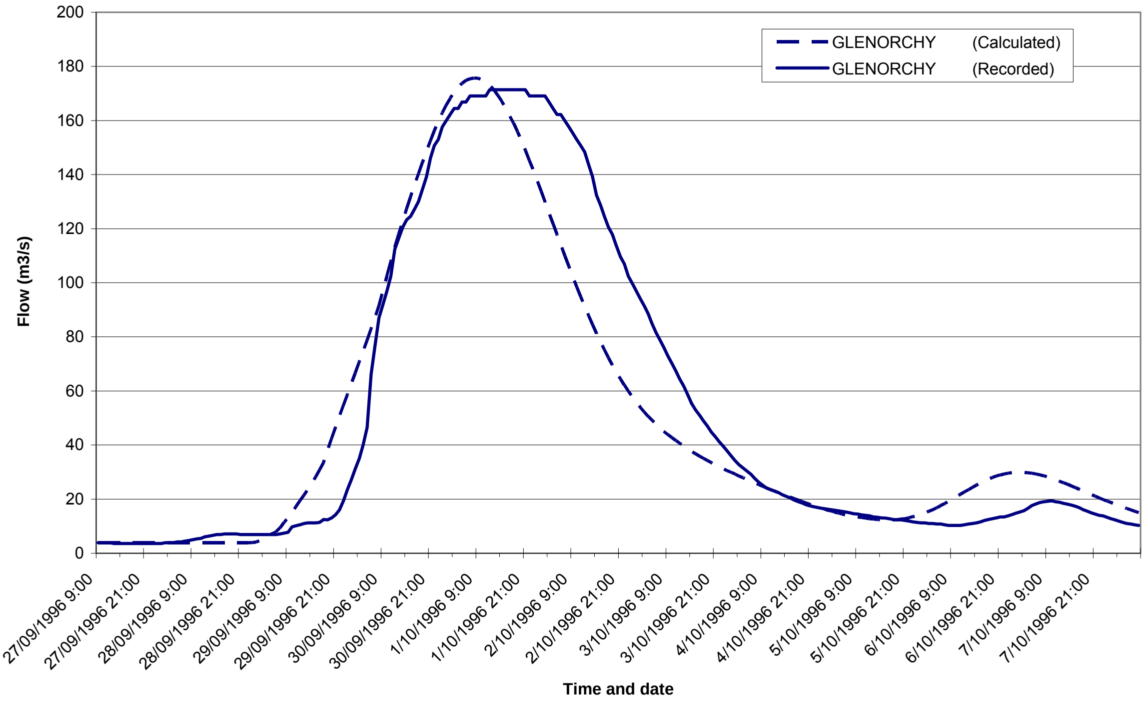

Figure 6-5 URBS Upper sub-catchment model calibration – October 1996

A summary of calibration results for the lower catchment sub-model are provided in Table 6-3. Comparison of observed and modelled flood hydrographs for the four calibration events are provided in Figure 6-6, Figure 6-7, Figure 6-8 and Figure 6-9.

Table 6-3 URBS model calibration – Lower Wimmera catchment sub-model

Event	Routing parameters		Rainfall loss parameters		Wimmera River at Faux Bridge		Burnt Creek at Wonwondah East		Wimmera River at Horsham	
	α	B	IL (mm)	CL (mm/h)	Rec. peak flow (m^3/s)	Modelled peak flow (m^3/s)	Rec peak flow (m^3/s)	Modelled peak flow (m^3/s)	Rec peak flow (m^3/s)	Modelled peak flow (m^3/s)
Aug. 1981	0.3	3	15	1.0	184 (15900 ML/d)	195 (16850 ML/d)	N.A	18.6 (1610 ML/d)	262 (22640 ML/d)	276 (23850 ML/d)
Sept. 1983	0.3	3	20	1.0	217 (18750 ML/d)	207 (17890 ML/d)	14.1 (1218 ML/d)	12.8 (1110 ML/d)	296 (25580 ML/d)	287 (24800 ML/d)
Sept. 1988	0.36	3	20	2.0	N.A	316 (27300 ML/d)	11.6 (1002 ML/d)	10.3 (890 Ml/d)	244 (21080 ML/d)	262 (22640 ML/d)
Oct. 1996	0.4	3	10	1.4	N.A	172 (14860 ML/d)	17.4 (1503 ML/d)	18.9 (1630 ML/d)	227 (19610 ML/d)	226 (19530 ML/d)

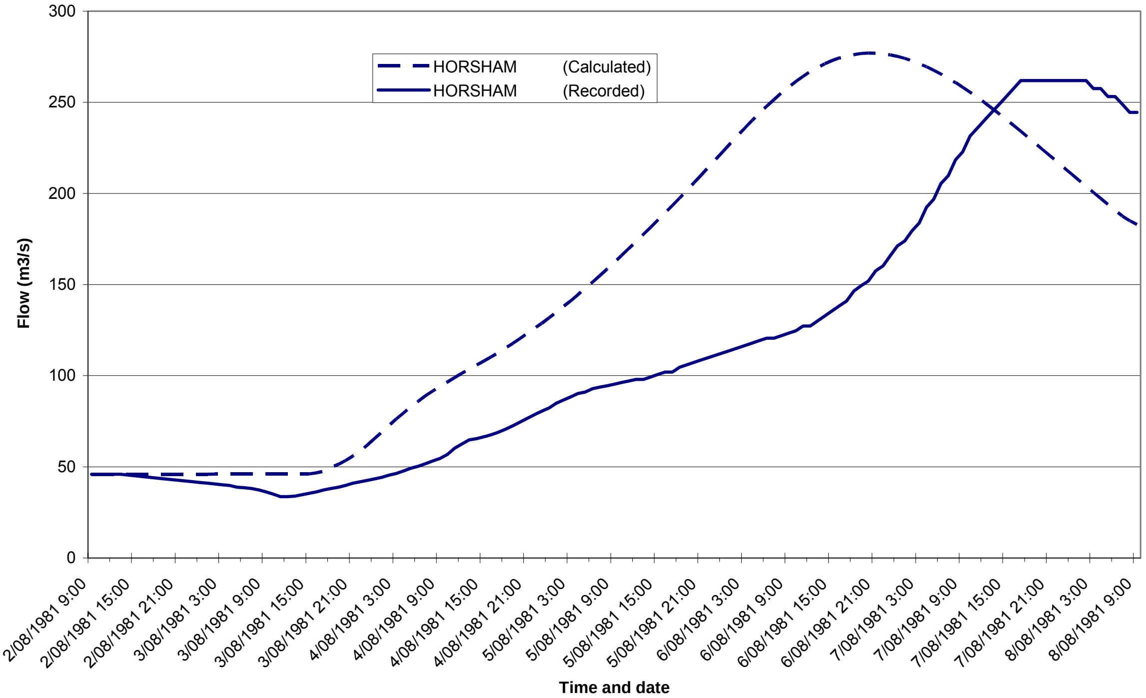

Figure 6-6 URBS Lower sub-catchment model calibration – August 1981

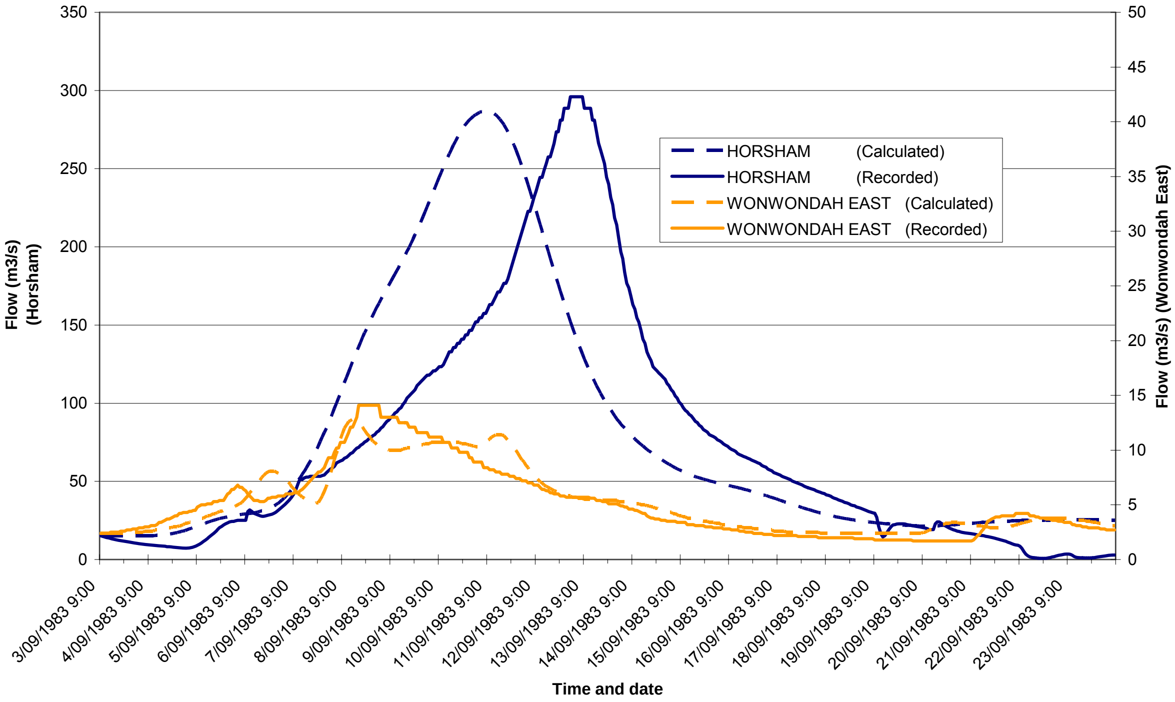

Figure 6-7 URBS Lower sub-catchment model calibration – September 1983

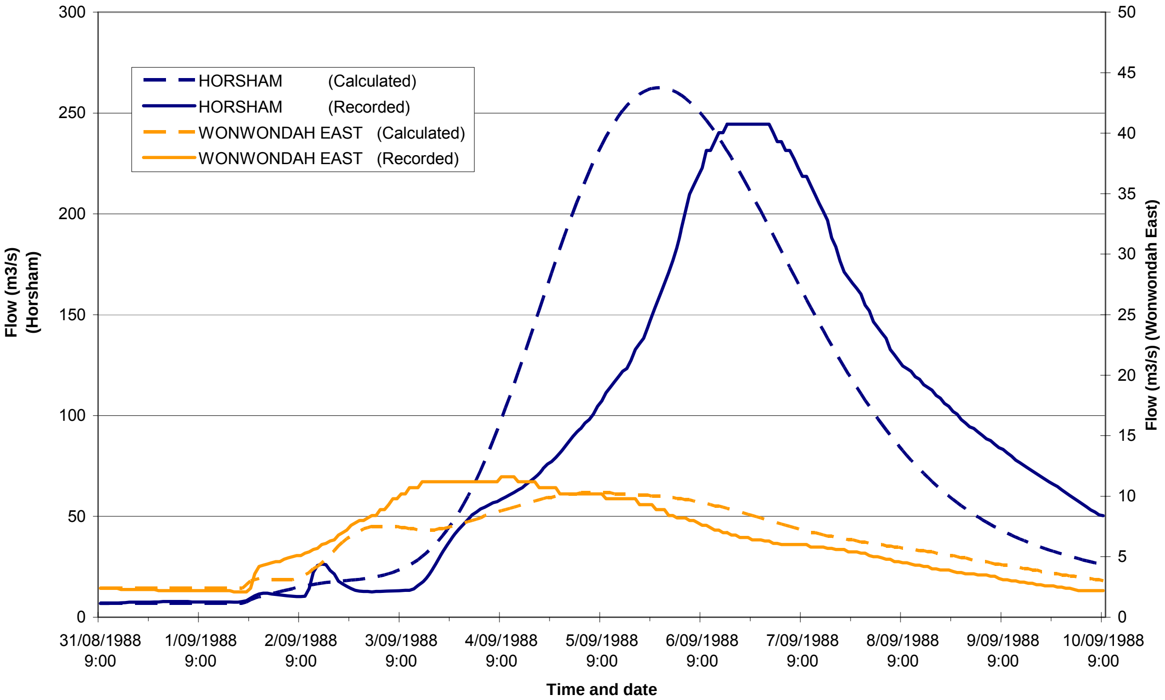

Figure 6-8 URBS Lower sub-catchment model calibration – September 1988

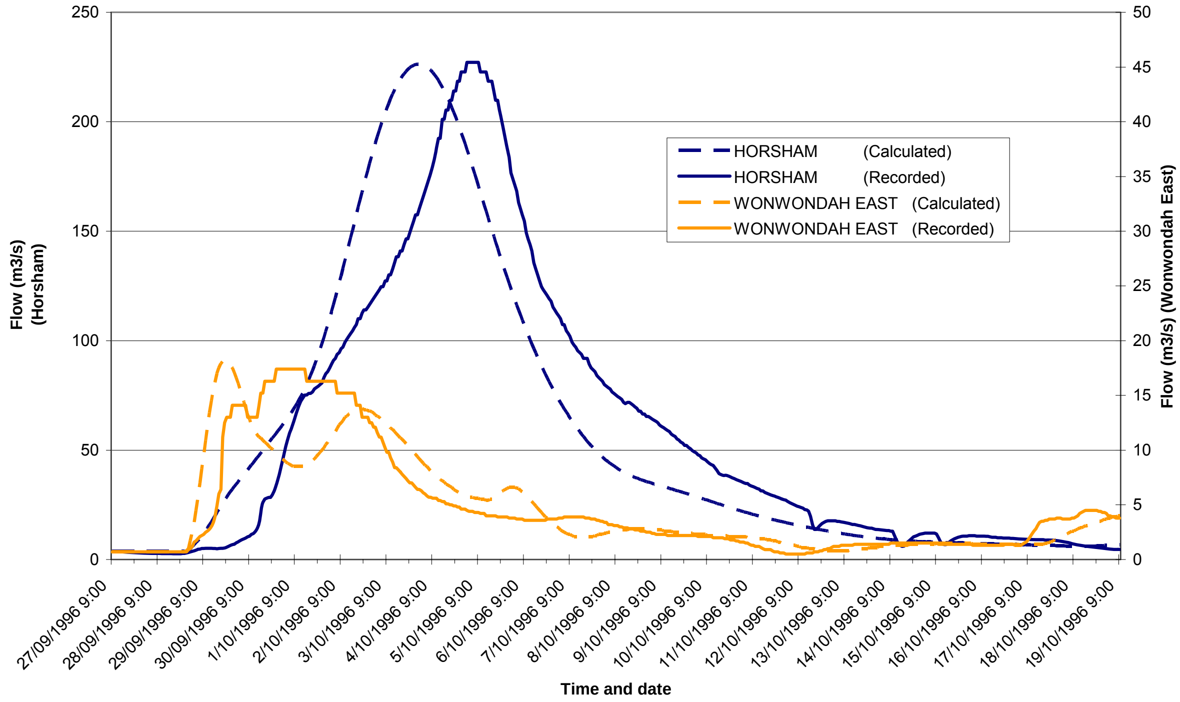

Figure 6-9 URBS Lower sub-catchment model calibration – October 1996

6.3.4 Discussion

The upper Wimmera URBS model was calibrated to observed hydrographs at Glenorchy. Comparison of modelled and observed hydrographs (refer to Figure 6-2, Figure 6-3, Figure 6-4 and Figure 6-5), displays a good agreement in hydrograph shape and peak flow. The timing of the peak flow was well simulated in the 1983, 1988 and 1996 events. The 1981 modelled peak flow occurs some 12 hours after the observed peak flow. This difference in the peak flow timing may arise from the available pluviographic rainfall data not truly reflecting the observed rainfall temporal pattern. As noted in Section 3.4.2, there are a limited number of available pluviographic rainfall stations. Given the catchment area, this limited number of pluviographic rainfall stations was considered unlikely to capture the temporal rainfall patterns occurring across the catchment.

The URBS model routing parameter, α. lay within a small range from 0.4 to 0.45, and the routing parameter β, found to be consistent across the calibration at a value of 3. These small ranges in the two routing parameters indicate the URBS model ability to simulate flood hydrographs for the range of flood magnitudes displayed by the calibration events. The URBS parameters applied for design flood estimation were biased toward the largest observed event, September 1988, with α and β values of 0.4 and 3.0 respectively adopted.

The good comparison in modelled and observed hydrographs, and the relative consistency in routing parameter, supports the robustness of the upper Wimmera URBS model calibration. Further, the robust calibration suggests the upper Wimmera URBS model is an appropriate tool for the estimation of design flood events from the upper catchment. Discussion of the URBS model verification and application to design flood estimation is provided in Section 6.4 and 6.5.

The lower Wimmera URBS model was calibrated to observed hydrographs at Walmer (Horsham) and Wonwondah East (Burnt Creek). As part of the calibration, the observed hydrograph at Glenorchy was an input. The calibration to Walmer (Horsham) examined the URBS model's ability to route flow from Glenorchy, plus simulate significant runoff from the tributary catchment downstream of Glenorchy, including Mount William Creek and Golton Creek. The lack of reliable streamflow for flood events in the Mount William Creek limited the robust calibration of Mount William Creek contributions.

Comparisons of flood hydrographs at Walmer (refer to Figure 6-6, Figure 6-7, Figure 6-8 and Figure 6-9) show generally good agreement in peak flows. However, for all four calibration events, the modelled hydrographs peak before the observed hydrographs. The differences in peak flow timing vary from 24 to 48 hours. These differences may arise from the available pluviographic rainfall data not truly reflecting the observed rainfall temporal pattern. Further, the lower Wimmera URBS model includes ungauged inflows from the Mount William Creek catchment. Errors in the modelled Mount William Creek hydrographs are likely to contribute to early modelled hydrograph peaks and differences in total flood volumes.

An examination of the observed streamflow data for Mount William Creek downstream of Lake Lonsdale (415203) revealed considerable missing data during a high flow periods, as noted in Table 3-2. The missing high flow is likely to reflect the difficult in gauging high flow at the site, and in turn developing a reliable rating curve. This lack of available streamflow data limits the ability to assess the simulation of the Mount William Creek contributions. As discussed above, errors in the Mount William Creek hydrographs limits the modelling of hydrographs at Walmer.

As discussed, the effluent flows from the Wimmera River to Yarriambiack Creek occurs during large floods. These effluent flows were accounted for the model calibration through the use of observed and modelled hydrographs. The observed hydrographs were obtained for the August 1981 and September 1983 flood events for the gauge at the Wimmera Highway Bridge (415241). The modelled hydrographs for the September 1988 and October 1996 events were sourced from the hydraulic model (refer to Section 8.3.2.2 for details).

The URBS model routing parameter, α. lay within a small range from 0.3 to 0.4, and the routing parameter β, found to be consistent across the calibration at a value of 3. These small ranges in the two routing parameters indicate the URBS model ability to simulate flood hygrographs for the range of flood magnitude displayed by the calibration events. The URBS parameters applied for design flood estimation were biased toward the largest observed event, August 1981 and September 1983, with α and β values of 0.3 and 3.0 respectively adopted.

The comparison of the observed and modelled hydrographs for Burnt Creek at Wonwondah East shows a reasonable agreement in hydrograph shape and peak flow. The contributions to Burnt Creek at Distribution Heads were assessed as outlined in Section 6.3.1. No clear relationship was revealed between MacKenzie River flows upstream of the Distribution Heads and contributions to Burnt Creek, refer to Figure 6-10. No observed streamflow data available for Burnt Creek at Wonwondah East for the 1981 event, hence the 1981 event was not included in Figure 6-10.

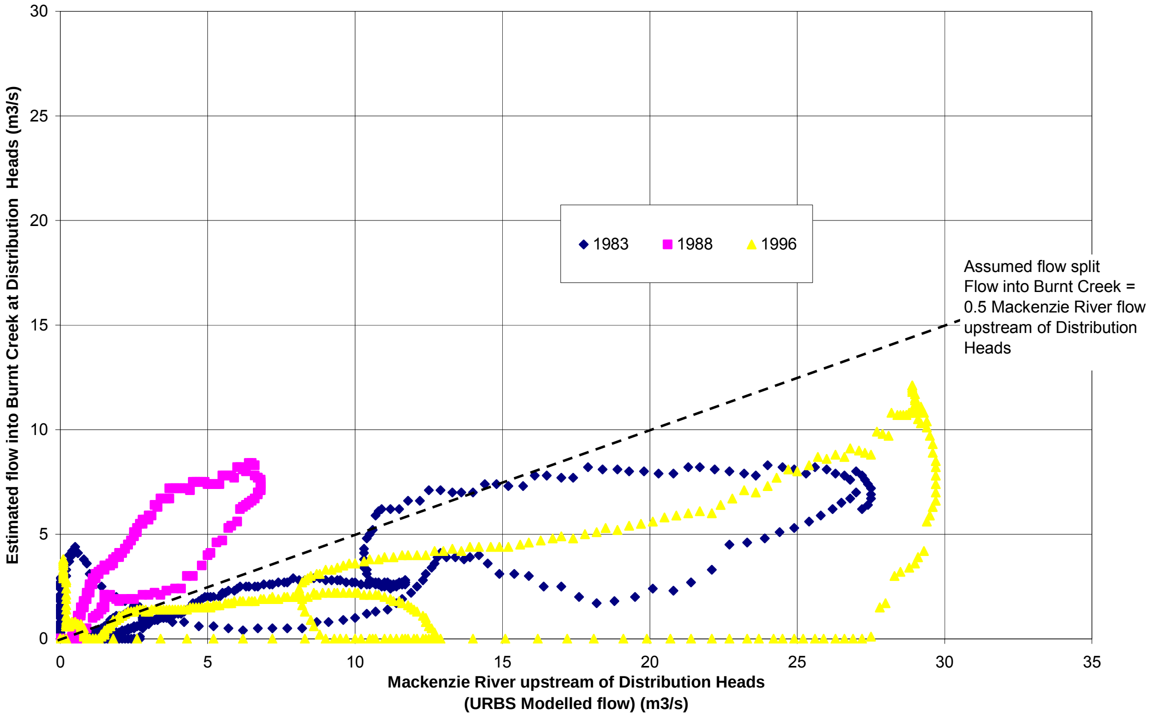

Figure 6-10 Flow split at the Distribution Heads for the URBS calibration events.

For each calibration event, the relationship varied for rising and falling hydrographs limbs i.e. hysteresis loop. For the 1988 event, the relationship suggests the contribution to Burnt Creek was greater than the flow in MacKenzie River. Such a situation is not possible (the flow into Burnt Creek from the MacKenzie River can not be greater than the MacKenzie River flow itself), and highlights the uncertainty in the evaluation of the flow split. The lack of a clear relationship echoes the advice received from GWMWater (Dr Andrew Barton GWMWater pers.comm.). On this basis, the 1988 event was not used in the assessment of the flow split.

To provide an upper limit of Burnt Creek contributions for design flood estimation purposes along Burnt Creek, a conservative flow split of 2:1 (MacKenzie River flows: Burnt Creek contribution) was adopted. The adopted flow split is an upper limit to the flow split assessed from the 1983 and 1996 events. This assumed flow split seeks to maximise flows down Burnt Creek and hence yields upper limits to design flood extents along Burnt Creek.

Further discussion of the application of the adopted flow split for design flood estimation is provided in Section 6.5

6.4 URBS model verification

6.4.1 Overview

The URBS model parameters were verified for their suitability for design flood estimation. The URBS model's rainfall loss parameters (IL and CL) were adjusted to provide consistency between the design peak flow estimates from the URBS model and flood frequency analyses. This section discusses the following aspects of the verification:

- Flood frequency analysis for the Wimmera River at Glenorchy (Upper Wimmera sub-model) and the Wimmera River at Walmer (Lower Wimmera sub-model)
- Design rainfall depths, spatial and temporal patterns
- URBS routing parameters
- Design rainfall losses determination

6.4.2 Flood frequency analysis

Annual flood frequency analysis has been undertaken for the streamflow gauge at Glenorchy (Water Technology, 2006) over the period 1950-2005. For the annual flood series, a Log Pearson 3 (LP3) distribution was fitted by the method of moments (IEAust 1999). The annual flood series were extracted from the available continuous streamflow data.

Figure 6-11 shows the flood frequency analyses for the Wimmera River at Glenorchy.

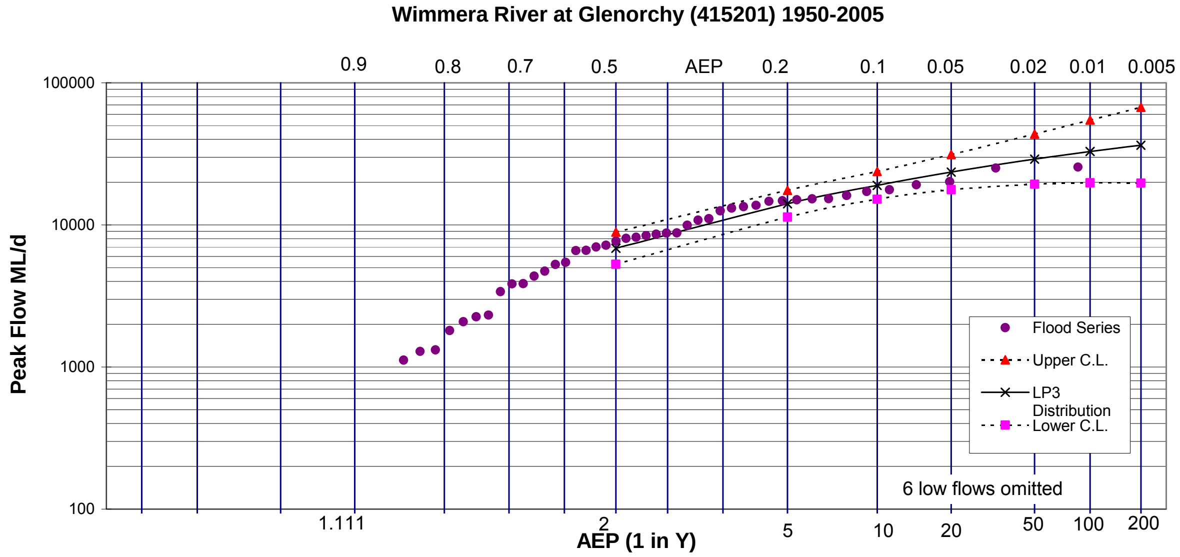

Figure 6-11 Flood frequency analysis for the Wimmera River at Glenorchy (Water Technology, 2006)

The most recent historical flood events, 1981, 1983 and 1988 have indicative AEPs ranging from 10% to 4% (10 year to 25 year ARI).

The *Horsham Flood Study* (Water Technology 2003b) undertook a flood frequency analysis for the Wimmera River at Horsham. This frequency analysis utilised streamflow records for the period 1889 to 2001. Figure 6-12 shows the flood frequency curve for the Wimmera River at Horsham (Water Technology 2003b).

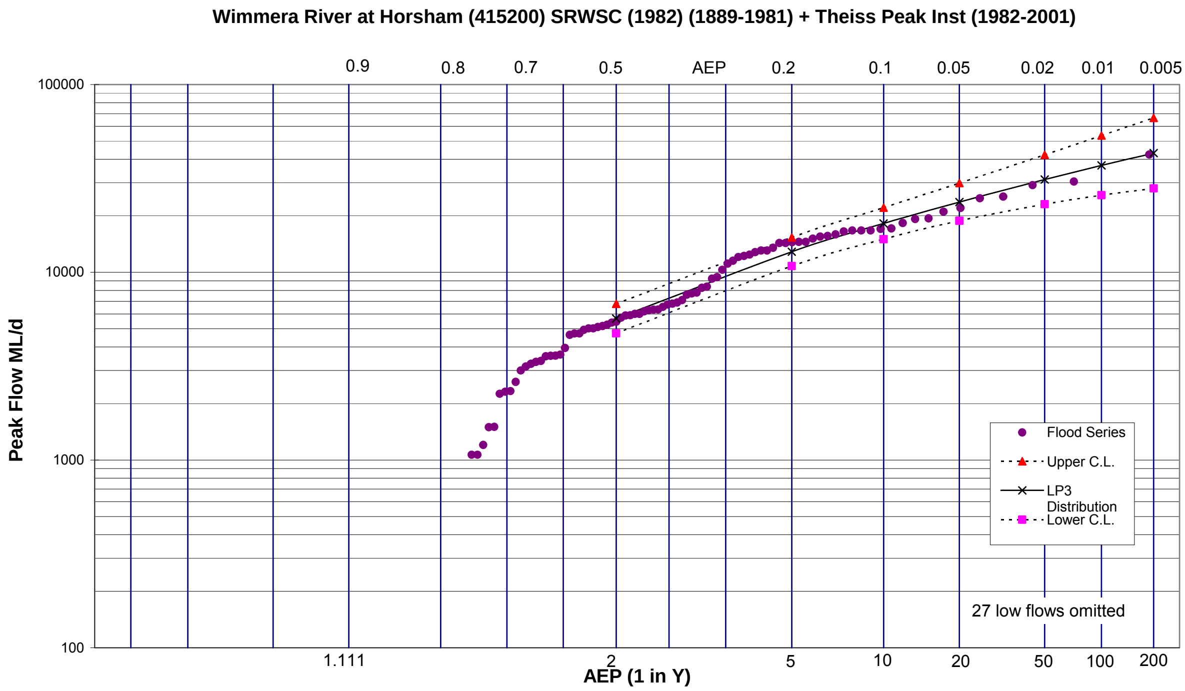

Figure 6-12 Flood frequency analysis for the Wimmera River at Horsham (Water Technology, 2003b)

6.4.3 Design rainfall

Design rainfall depths were calculated for the 5, 10, 20, 50, 100 and 200 year ARI events using the Intensity Frequency Duration (IFD) procedures outlined in *Australian Rainfall and Runoff* (IEAust 1997). The IFD parameters were provided in Table 6-4.

Table 6-4 Wimmera River catchment centroid IFD parameters

IFD Parameter	Value
1 hour duration 2 year ARI	19.2
12 hour duration 2 year ARI	3.5
72 hour duration 2 year ARI	0.9
1 hour duration 50 year ARI	40
12 hour duration 50 year ARI	6.9
72 hour duration 50 year ARI	1.8
Regional skew G	0.32
Geographic factor F2	4.36
Geographic factor F50	14.82

The design temporal patterns (IEAust 1997) for Zone 2 were used in the study for all events up to and including the 1 in 200 year ARI event. A uniform spatial rainfall pattern (i.e. same rainfall depths applied to the entire catchment) was adopted for all design events considered by this study.

Design rainfall areal reduction factors (ARF) were applied to design point rainfall depths. The ARF was determined using Siriwardena and Weinmann (1996) for catchments upstream of Glenorchy (1953 km^2) and Horsham (4066 km^2).

6.4.4 URBS routing and rainfall loss parameters

This study adopted the following routing parameters for design flood estimation:

- Upper Wimmera: $\alpha = 0.4$, $\beta = 3.0$, and m = 0.8
- Lower Wimmera: $\alpha = 0.3$, $\beta = 3.0$, and m = 0.8

The selection of design rainfall losses has a significant impact on the magnitude of the design flood estimates. The underlying assumption of the design flood estimation approach adopted by this study that is the probability (i.e. average recurrence interval) of the design peak flow provided by the URBS model is the same as the probability of the causative design rainfall event. As such, design rainfall losses were selected to ensure this assumption was maintained.

The comparison of design peak flows estimated from a URBS model to those obtained through flood frequency analysis is a common approach to ensure consistency of estimates and the maintenance of the above underlying assumption. Adopted design rainfall losses are provided in Section 6.4.5.

For the Lower Wimmera URBS model, outflows to Yarriambiack Creek are not readily simulated in the URBS model, as discussed in Section 6.2.2. The URBS model verification requires an iterative approach to resolve the Yarriambiack Creek outflows and appropriate design rainfall losses for a given design event. The approach employed was as follows:

1. Run the Lower Wimmera URBS model for the required design flood events assuming no outflow to Yarriambiack Creek
2. Run hydraulic model employing the design flood hydrographs assuming no Yarriambiack Creek outflows
3. Extract modelled Yarriambiack Creek outflows from the hydraulic model for the design flood events
4. Re-run the Lower Wimmera URBS model for the required design flood events assuming outflows to Yarriambiack Creek from the hydraulic model
5. Adjust design rainfall losses and re-run the Lower Wimmera URBS model for the required design flood events until there is reasonable agreement with flood frequency analysis estimates at Walmer
6. Re-run hydraulic model employing the design flood hydrographs from Step 5.

Section 6.4.5 provides the URBS model verification for the Upper and Lower Wimmera URBS models.

6.4.5 Design parameters verification

The rainfall loss parameters, initial loss (IL) and continuing loss (CL), were adjusted to achieve consistency between URBS design peak flows at Glenorchy (Upper catchment sub-model) and at Walmer (lower catchment sub-model) with the flood frequency estimates (refer to Section 6.4.2).

Table 6-5 and Table 6-6 display the adopted URBS design parameters, and a comparison of the URBS model design peak flow estimates with the flood frequency estimates.

Table 6-5 URBS model design peak flow verification – Upper Wimmera River

Location	Design peak flow for the Wimmera River at Glenorchy (ML/d)		
	20 Year ARI	**50 Year ARI**	**100 Year ARI**
Glenorchy Flood Study Flood frequency analysis (Water Technology 2006)	23500	29030	32830
URBS Model $\alpha = 0.4$ & $\beta = 3.0$	22980 (IL 20 mm CL 2.5 mm/h)	30070 (IL 20 mm CL 2.5 mm/h)	37580 (IL 20 mm CL 2.5 mm/h)

Table 6-6 URBS model design peak flow verification – Lower Wimmera River

Location	Design peak flow for the Wimmera River at Walmer (ML/d)		
	20 Year ARI	**50 Year ARI**	**100 Year ARI**
Horsham Flood Study Flood frequency analysis (Water Technology 2003b)	23670	31190	36980
URBS Model $\alpha = 0.3$ & $\beta = 3.0$	25310 (IL 20 mm CL 2.5 mm/h)	32570 (IL 20 mm CL 2.5 mm/h)	38710 (IL 20 mm CL 2.5 mm/h)

The comparison of design peak flows from the URBS model and the flood frequency analysis, at Glenorchy, show a good agreement, particularly for the 20 and 50 year ARI event (within 5%). A larger difference occurs for the 100 year ARI event, about 15%. However, this difference needs to view in the context of the 95% confidence limits for the flood frequency analysis shown in Figure 6-11 at the 100 year ARI event, 19960 ML/d - 51920 ML/d. The URBS model 100 year ARI design peak flow lies well within the 95% confidence limit. At Walmer, the design peak flows from the URBS model and flood frequency show good agreement.

6.5 Design flood hydrographs under current catchment conditions

Design flood hydrographs were determined for the 5, 10, 20, 50, 100 and 200 year ARI events, using model parameters outlined in Section 4.4.4, at the following locations:

- Wimmera River at Glenorchy
- Golton Creek at Western Highway
- Mount William Creek at Western Highway
- Burnt Creek at Western Highway

A range of storm durations was trialled to determine the critical storm duration.

Table 6-7 displays the URBS model design peak flows.

Table 6-7 Wimmera River – Current catchment URBS model design peak flows

Location	Design peak flow (ML/d)					
	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI
Wimmera River at Glenorchy	8726	14861	22982	30067	37584	43459
Golton Creek at Western Highway	449	588	1158	1581	2074	2540
Mount William Creek at Western Highway	2514	3439	8459	12442	17453	22032
Burnt Creek at Western Highway	1719	2255	4329	6134	8001	9158
Wimmera River at Walmer	13910	18749	25315	32573	38707	45619

Appendix C contains the design flood hydrographs for the required study area inflow points.

6.6 Design flood hydrographs under pre-European catchment conditions

The URBS model employed for the current catchment condition, as outlined in Sections 6.2 to 6.5, contained both Lake Bellfield and Lake Lonsdale storages. The pre-European catchment conditions adopted removed these storages from the URBS model structure. No other changes were made to the URBS model structure and/or parameters. Additional modifications to the URBS model to reflect changes in forested area, and rainfall losses could be explored in the URBS model. However, the evidence to support these potential revisions is not readily available. Farm dams are likely to fill early in the large rainfall event due to their relatively small capacity compared to the flood runoff volume. As the focus of this component is frequent to large flood event (5 year and greater), the impact of farm dams was discounted. The study team considers such revisions would aid further uncertainty to the estimates without enhancing their robustness.

As discussed, the URBS model provides estimates for runoff volumes into the study area. Within the study area, modifications/alternations to flood behaviour due to European settlement were assessed within the hydraulic analysis.

The revised URBS model was re-run using the parameters outlined in Section 4.4.4, with design flood hydrographs determined for the 1 in 5, 1 in 10, 1 in 20, 50, 100 and 200 year ARI events at the following locations:

- Wimmera River at Glenorchy
- Golton Creek at Western Highway
- Mount William Creek at Western Highway
- Burnt Creek at Western Highway

For the upper Wimmera (to Glenorchy), the absence of significant storages leads to no modifications of the URBS model. Hence, the pre-European design flows are the same as the current conditions. A range of storm durations was trialled to determine the critical storm duration. Table 6-8 displays the URBS model design peak flows.

Table 6-8 Wimmera River – Pre-European URBS model design peak flows

Location	Design peak flow (ML/d)					
	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI
Wimmera River at Glenorchy	8726	14861	22982	30067	37584	43459
Golton Creek at Western Highway	449	588	1158	1581	2074	2540
Mount William Creek at Western Highway	7232	9418	18230	24883	32573	39744
Burnt Creek at Western Highway	1253	1616	3076	4147	5409	6566
Wimmera River at Walmer	14342	18835	25747	32832	39398	46829

Appendix C contains the design flood hydrographs for the required study area inflow points.

Table 6-9 displays the differences between the design peak flows for the existing and pre-European catchment conditions. A positive difference reflects an increase in peak flows under the existing conditions compared with the pre-European conditions. The percentage difference is shown in the brackets.

Table 6-9 Wimmera River –URBS model design peak flows – Differences between Existing and pre-European catchments

Location	Difference in design peak flow (ML/d)					
	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI
Wimmera River at Glenorchy	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Golton Creek at Western Highway	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Mount William Creek at Western Highway	-4717 (-188%)	-5979 (-174%)	-9772 (-116%)	-12442 (-100%)	-15120 (-87%)	-17712 (-80%)
Burnt Creek at Western Highway	466 (27%)	639 (28%)	1252 (29%)	1987 (32%)	2592 (32%)	2592 (28%)
Wimmera River at Walmer	-432 (-3%)	-90 (0%)	-432 (-2%)	-260 (-1%)	-691 (-2%)	-1209 (-3%)

Figure 6-13 compares the 100 year existing and pre-European catchment conditions for Mount William Creek and the Wimmera River at Walmer.

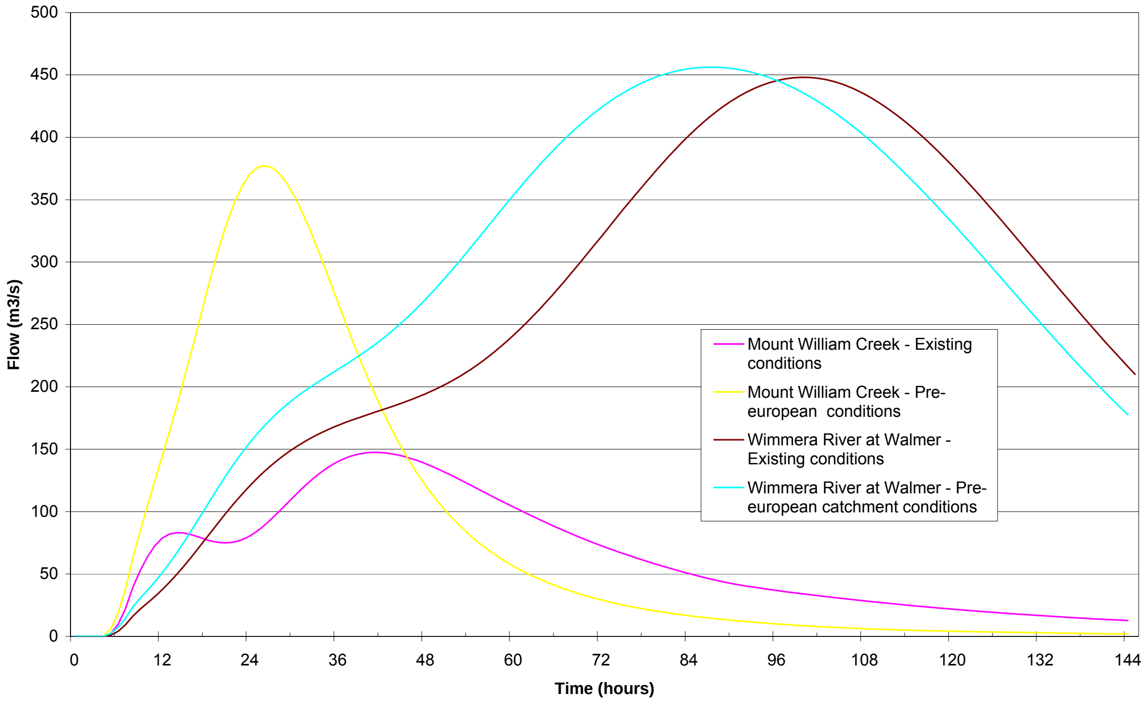

Figure 6-13 100 year design flood hydrographs under existing and pre-European catchment conditions

The removal of Lake Bellfield and Lake Lonsdale has a significant impact of the design peak flow for Mount William Creek. The design peak flows for the existing catchment conditions were found to be considerably lower than the pre-European catchment conditions. The 100 year design flood hydrographs for Mount William Creek under the pre-European conditions was considerably 'peakier' with the time to peak about 24 hours, compared with 36 hours for the existing catchment conditions. The 100 year design flood hydrograph at Walmer also peaked considerably earlier, 12 -16 hours, in the pre-European catchment conditions. However, the peak flow at Walmer is similar in both catchment conditions. This reflects the considerable floodplain storage downstream of Glenorchy. The decreases in peak flow for Burnt Creek under the pre-European catchment conditions is due to the additional contribution from the MacKenzie River at the Distribution Heads in the existing catchment conditions

6.7 Discussion

The URBS model developed by BoM (2004) provides a framework for the determination of historical and design flood hydrographs throughout the study area.

The calibration of the URBS model parameters underpins the reliability of the flood estimates. The calibration events selected were the largest events in the available streamflow record with concurrent pluviographic rainfall data. The calibration events are representative of small to frequent events with ARIs up to 50 years. The calibration to larger flood events would aid in the refinement of the model parameters. However, reconciling the URBS model design flood estimates against flood frequency estimates lends strength to the reliability of the adopted approach.

For the pre-European conditions, the major on-stream water storages in the Wimmera River catchment upstream of the study area were removed from the URBS model. As discussed, the considerable uncertainty surrounds the assessment of changes in forested area, and rainfall losses.

Considerable increases in peak flows were found to occur for Mount William Creek downstream of Lake Lonsdale under the pre-European conditions. However, similar peak flows at Walmer under the both existing and pre-European catchment conditions. The combination of tributary hydrographs (i.e. inflows are reduced from Burnt Creek under pre-European conditions given its disconnection from Distribution Heads) and the attenuation of the flows due to the available floodplain realises the similar peak flows at Walmer.

7 HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

7.1 Overview

This section details the hydraulic modelling framework development and calibration.

As discussed in Section 2.2, the complexity of the flow and flood behaviour requires a flexible hydraulic modelling framework. The adopted framework simulated flow behaviour over a full range of flows (in-channel to floodplain) with a balance against excessive simulation times. The hydraulic modelling framework comprises of the elements:

- One dimensional (1D) hydraulic model: Key waterways and anabranches
- Two – dimensional (2D) model: Broad floodplain models plus local scale detailed models
- Linked one – two dimensional (1D/2D) model: Combined the 1D model with the broad floodplain models.

Previous hydraulic modelling (SMEC 2002) applied a hydraulic modelling framework in line with the available topographic data at that time. The available survey data used by SMEC (2002) consisted of some 14 surveyed cross sections. SMEC (2002) developed a 1D hydraulic model for the Wimmera River (Faux Bridge to Dooen Swamp), Yarriambiack Creek (offtake to downstream of the Wimmera Highway Bridge), Corkers and Two Mile Creeks.

The capture of the ALS topographic data, discussed in Section 4.2.1, enabled the application of 2D and linked 1D/2D hydraulic modelling. The application of the 2D models allowed the robust simulation of flow conveyance and flood storage across the broad floodplain area, particular adjacent to the offtake. In the 2D model, the floodplain terrain was represented by a regular grid of elevations, rather waterway cross sections. This more detailed terrain representation enabled the capture of the key topographic features that influence flood behaviour. The linked 1D/2D model combined the strengths of the 1D model (in channel flows) and 2D model (floodplain flow). The simulation of near bankfull flows by the linked model allowed the identification of local changes in the channel capacity and the floodplain engagement.

The hydraulic model framework, applied in this study, provides for considerable improvement in the simulation of low-medium-high flows in comparison to the previous studies. The outcomes of the hydraulic modelling must be viewed in the light of the hydraulic models' capabilities, limitations and uncertainties. Section 7.2 discusses these aspects.

The model development for each element requires understanding of the key influences on flow behaviour and the primary outcomes required from the investigation. The application of a particular modelling element to a given reach is driven by the key flow behaviour influences. The principal input to the model development is the available topographic data. The representation of the significant topographic features underpins a robust hydraulic model. Section 7.3 details the hydraulic model development.

The comparison of the modelled water levels, flows and extents to observed data enables the calibration of the hydraulic modelling framework A robust calibration requires the comparison of modelled and observed flood behaviour across a range of flow magnitudes. Section 7.4 outlines the available observed flood data and discusses the model calibration.

7.2 Hydraulic model capabilities and uncertainties

There are numerous contributing factors to the ultimate output uncertainty in a complex hydraulic modelling exercise such as that undertaken for this study. Some of the uncertainties relate to the data inputs, whilst others are dependent on the numerical modelling processes itself. Sources of output uncertainty related to the input data for the hydraulic modelling include:

- ALS data
- Bathymetry and cross section survey
- Definition of hydraulic controls/structures
- Observed flows for model input
- Observed flows and water levels for model calibration

Sources of uncertainty related to the hydraulic modelling process include:

- Model numerical and computational schemes – these relate to the ability of the model to replicate the physics of free-surface flow in channels and over land.
- Floating point accuracy of computing resources (truncation/rounding error)
- Model schematisation and set-up (location and spacing of cross-sections, grid resolution)
- Model parameters such as computational time-steps, roughness and other energy-loss parameters (expansion/contraction coefficients and eddy viscosity for example).

As evident from the sources of uncertainty listed above, there are numerous contributing factors to the ultimate output uncertainty in the hydraulic model outputs. Additionally, there is a wide variation in the magnitude of the impact associated with each source of uncertainty. In order to identify the most significant sources of uncertainty it is possible to consider items as either first or second order magnitude, where second order items are of a significantly smaller magnitude compared to first order items and can generally be ignored. A listing of the main sources of the modelling uncertainty and their approximate magnitudes is provided in Table 7-1.

A definitive assessment of the absolute accuracy is not possible due to the combination of the contributing factors (Merwade et al 2008). The study team considers the hydraulic modelling approach employed in this study reflects best practice standard for a modelling exercise of this nature. The hydraulic modelling framework has undergone a calibration process using available observed flood information. The extent and quality of the available flood information is a constraint on the model calibration process. Further refinement of the model calibration may be possible following future flood events.

The relative accuracy between different modelling scenarios is considered to higher, and it is likely to be of the order of +/- 50 mm.

Table 7-1: Comparisons of Sources of Uncertainty

Scenario/Data/Process	Order of Accuracy	Approximate Impact on Results
ALS data and DEM	First	Change in floodplain levels/depths 0.1 m
Cross-section survey data	First	Minimal direct impact, location and spacing of sections is more critical to model outputs
Definition of hydraulic controls/structures	First	Change in floodplain levels/depths +/- 0.1 to 0.2 m
Observed flows for model input	First	Depends on available data, aim for observed/calibration accuracy +/- 10 % for flows
Observed flows and water levels for model calibration	First	Depends on available data, +/- 10 % for flows & +/- 0.15 m for observed flood levels.
Model numerical and computational schemes – these relate to the ability of the model to replicate the physics of free-surface flow in channels, wetlands and over land.	Second	N/A
Floating point accuracy of computing resources (truncation error)	Second	N/A
Model schematisation and set-up (location and spacing of cross-sections, grid resolution)	First	Difficult to quantify, aim for overall accuracy of +/- 0.1 m for levels and +/- 10 % for flows
Model parameters such as computational time-steps, surface-friction and other energy-loss parameters	First	Change in floodplain levels/depths +/- 0.1 m
Level/accuracy of model calibration	First	Depends on availability of calibration data, aim for +/- 0.1 m for levels and +/- 10 % for flows

Due to the complexity of the relationships between the input data and modelling outputs, there is no direct correlation between input and output data accuracy. Further, the error bounds on the data inputs are generally not cumulative. For example, inaccuracies in survey data inputs may be compensated for through adjustment of calibration parameters to achieve output hydraulic results that are nominally more accurate than the sum of the errors in the input data. The model development process can only address uncertainties arising from the following aspects:

- Definition of hydraulic controls/structures
- Model schematisation and set-up (location and spacing of cross-sections, grid resolution)
- Model parameters such as computational time-steps, surface-friction and other energy-loss parameters

Section 7.3 discusses the consideration of these three aspects in the model development.

The remaining aspects from Table 7-1 are constrained by the available data sources.

7.3 Model development

7.3.1 Overview

Hydraulic modelling suite, MIKE11, MIKE21 and MIKE FLOOD, developed by the Danish Hydraulic Institute (DHI) has been applied in this study. MIKE FLOOD is a state-of-the-art tool for floodplain modelling that combines the dynamic coupling of the one-dimensional MIKE 11 river model and MIKE 21 fully two-dimensional model systems. Through coupling of these two systems it is possible to accurately represent river and floodplain processes

Further details on the capabilities of the MIKE FLOOD modelling system can be found at http://www.dhisoftware.com/mikeflood.

As outlined above, a 1D hydraulic model has been constructed for the key waterways. The primary aim of the 1D model was to simulate flows up to bankfull. The 1D model development involved the definition of model branches to represent key waterways. The geometry of the modelled waterways was defined by cross sections. The location and spacing of modelled cross sections is key component in the model development. A 1D model determines a single water level at a cross section for each time step in the simulation. Section 7.3.2 discusses the 1D hydraulic model development. Figure 7-1 displays the 1D model branches.

The broad scale 2D hydraulic models were developed for the floodplain along the Wimmera River from Glenorchy to Horsham, and along Yarriambiack Creek from the Wimmera River to Warracknabeal. The primary aim of the broad scale 2D model was to simulate floodplain flow, where the channel carries only a minor proportion of the total flow. The 2D model development involves the construction of topographic grid of the floodplain. The waterway channel was represented in an indicative manner, and is informed by the 1D hydraulic model. Given the size of the study area, four broad floodplain 2D models were developed. The 2D grid resolution for the broad scale floodplain models was 25 m. Figure 7-1 displays the four broad floodplain 2D model extents.

Local scale 2D models were developed for the Wimmera River – Yarriambiack Creek offtake, and the immediate area adjacent to the Wimmera Highway Bridge across Yarriambiack Creek. The primary aim of the local scale 2D model at the offtake was to simulate flow distribution between the Wimmera River and Yarriambiack Creek for flow scenarios up to bankfull. The primary aim of the local scale 2D model at the Wimmera Highway Bridge was to simulate the local flood behaviour adjacent to the bridge. The local scale model development is similar to the broad scale development with construction of a topographic grid. However, the typical grid resolutions is 2 m to 5 m. Figure 7-1 displays the two local scale 2D model extents.

A 2D model provides water level and velocities at a grid point for each time step in the simulation. Section 7.3.3 discusses the 2D hydraulic model development at the broad and local scales.

Linked 1D-2D models enable flow across the floodplain to begin once channel flow capacity is exceeded. The primary aim of the linked model was to simulate flow scenarios where overbank inundation commences. The linked model use the 1D and broad 2D model discussed above. Section 7.3.4 discusses the linked hydraulic model development.

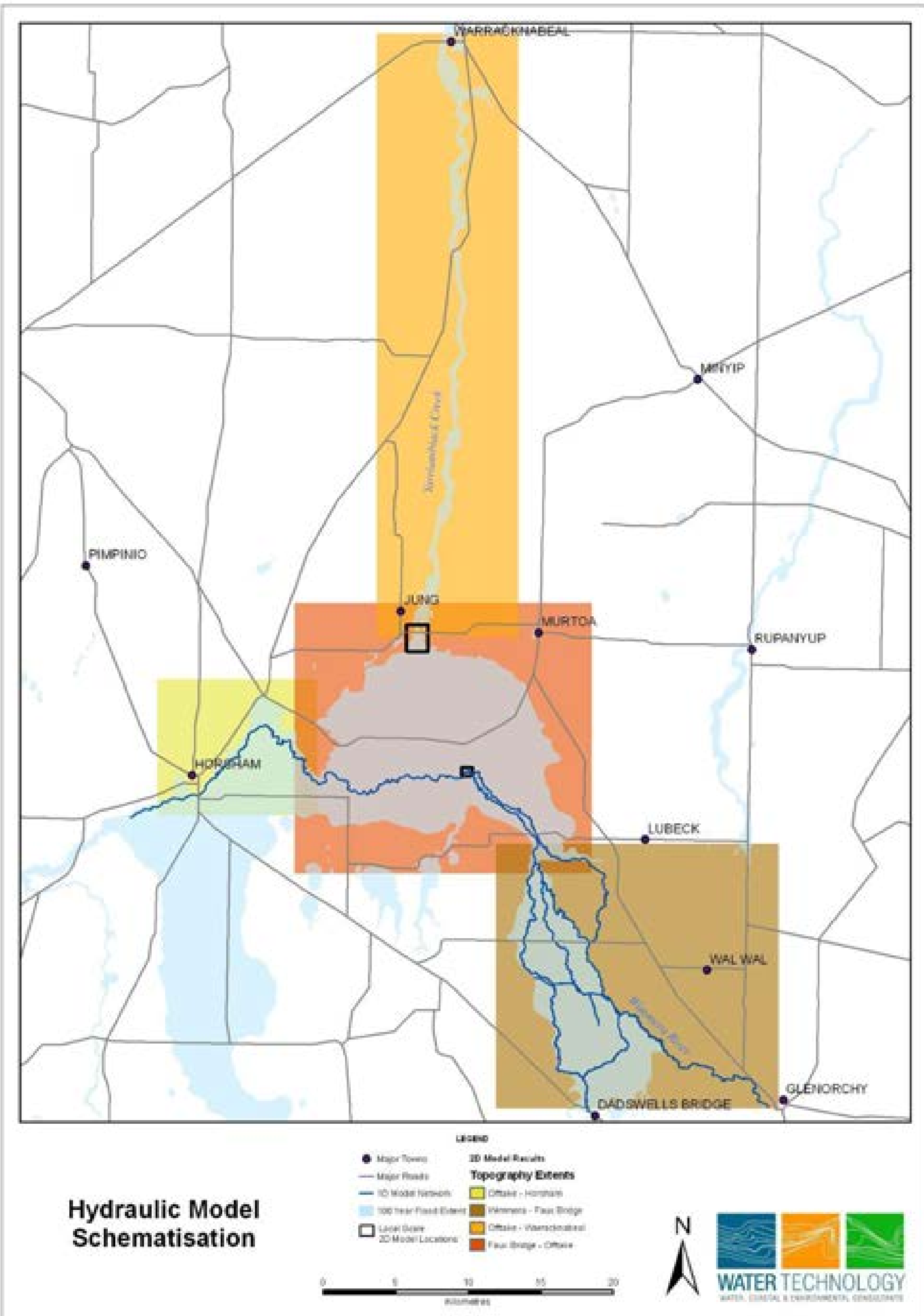

Figure 7-1 Hydraulic Model Structure

7.3.2 One dimensional model components (MIKE 11 – Low flow)

The one-dimensional model consists of the following elements.

- Branches:
  - Key anabranches and waterways included in the 1D model: Wimmera River, Mount William Creek, Station Creek and Middle Creek.
  - Other waterways, as such as Yarriambiack Creek, Two Mile Creek and Corkers Drain Creek have ill-defined cross sections, it was considered appropriate to model these waterways in the 2D models.
- Cross Sections:
  - Surveyed Wimmera River cross sections (Refer to Section 4.3 undertaken by Price Merrett): Included 45 detailed cross-sections at six environmental flow locations, and 44 indicative cross-sections. Total surveyed cross-sections - 89
  - ALS extracted cross sections: Nominal spacing between extracted 200 -300 m. Extracted cross sections located at upstream and downstream of waterway confluences, with at least one extracted cross section between the upstream and downstream limits. Total ALS extracted cross-sections – 469
  - Total cross sections in 1D model: 558
- Structures:
  - Key structures represented in the 1D model included: Huddleston's Weir, Faux' Bridge, Horsham-Lubeck Road bridge and Wimmera Highway Bridge (Yarriambiack Creek)
  - Huddleston's Weir and the flow regulation structure on the Wimmera Inlet Channel were modelled as 'control structures' within the MIKE 11 model allowing weir pool levels to be maintained during varying flows in the Wimmera River.
  - Horsham Weir was modelled as a 'weir structure' within the MIKE 11 model.
  - Glenorchy Weir was included in the MIKE11 model.
  - Yarriambiack Creek offtake was modelled in a local scale 2D model, as discussed in Section 7.4.4.1. The flow distribution (Wimmera River-Yarriambiack Creek) was obtained from the local scale 2D model. This local model 2D model included the regulator.
- Boundaries:
  - Upstream boundaries (streamflows) included: Wimmera River at Glenorchy (415201), Mount William Creek at the Western Highway, Golton Creek at the Western Highway, and Burnt Creek at Western Highway
  - Downstream (water level) boundary included: Wimmera River at Walmer (415200)
- Roughness
  - Hydraulic roughness within the 1D model is expressed as Manning's n. This study employed four estimation techniques for Manning's n within the waterway channel. The application of the four techniques was undertaken at four sites visited during the field inspection. The Manning's n values assessed

varied from 0.033 to 0.053. Appendix D details the determination of Manning's n using the four techniques.

- Pre-European waterway conditions
  - o The key waterway modifications were as follows
    - Yarriambiack Creek offtake at the Wimmera River: As discussed in Section 2.2.4, the modifications at the offtake have lowered the bed level of Yarriambiack Creek at the offtake. For the pre-European conditions, the Yarriambiack Creek bed level at the offtake was taken as 135.58 m AHD (as per SMEC 2002). This bed level was lowered by 2.25 m to 133.23m AHD (as per SMEC 2002). Section 2.2.4 outlined the modification undertaken at the offtake. Note: Section 7.3.3.2 discusses the removal of the regulator and levee adajcent to the offtake.
    - Weirs: Glenorchy, Huddleston, Yarriambiack Creek offtake weir and Horsham Weirs were removed for the pre-European waterway conditions
    - Wimmera Highway Bridge - Yarriambiack Creek: The bridge structure and approach embankments were removed for the pre-European waterway conditions. Note: Section 7.3.3.2 discusses the removal of the channel and road embankments.

  The modifications to the floodplains are discussed in Section 7.3.3.1.

7.3.3 Two dimensional model components (MIKE 21)

7.3.3.1 2D broad scale floodplain hydraulic model elements

As discussed, this study applied 2D models at the broad floodplain scale and the local scale. The broad scale floodplain 2D models consist of the following elements.

- Grid extent and resolution
  - o The study area was segmented into four broad scale 2D model areas:
    - Wimmera River: Glenorchy to Faux' Bridge;
    - Wimmera River: Faux' Bridge to Dooen Swamp including Yarriambiack Creek to downstream of Jung Weir
    - Yarriambiack Creek: Downstream of Jung Weir to Warracknabeal; and
    - Wimmera River: Dooen Swamp to Horsham.
  - o For the four 2D broad scale model areas, the ALS data was interpolated into 25 m. This grid resolution represents a trade-off between adequately describing the fine topographic features within the study area and allowing the model simulations to be completed within a practical timeframe. Each 2D model takes 12-18 hours to simulate 5-7 days.
  - o Key topographic features, such as road and channel embankments, were stamped into the 25 m model grids. This stamping ensures these key features are reflected in the 2D model topography.

- Boundaries:
  - Upstream model boundaries (streamflows) included: Wimmera River at Glenorchy (415201), Mount William Creek at the Western Highway, Golton Creek at the Western Highway, and Burnt Creek at Western Highway.
  - Inter-model boundaries: Modelled outflows from the upstream model provides the flow boundaries for the downstream models. A nominal downstream water level forms the downstream boundaries for each model area.
- Roughness
  - Hydraulic roughness within the 2D model is expressed as Manning's n. For the estimation of the floodplain Manning's n, this study assessed land use and vegetation cover. The range of Manning's n varied from 0.03 from cleared farming land to 0.20 for heavy riparian vegetation. Further discussion of Manning's n evaluation is provided in Appendix D. Refer to Figure 7-2.
- Pre-European waterway conditions
  - The key floodplain waterway modifications were as follows:
    - Yarriambiack Creek offtake at the Wimmera River: As discussed in Section 2.2.4, the modifications at the offtake have constructed levee adjacent to Yarriambiack Creek channel. For the pre-European conditions, these levees and the regulator were removed.
    - Wimmera Inlet Channel: The Wimmera Inlet Channel was removed for the pre-European waterway conditions
    - Glenorchy - Murtoa Road
    - Railway line (Murtoa to Glenorchy)
    - Taylors Lake Channel and Longerenong Road: These features were removed for the pre-European waterway conditions.
    - Jung Weir
    - Wimmera Highway Bridge - Yarriambiack Creek: The bridge structure and approach embankments were removed for the pre-European waterway conditions.
    - Riverside East Road, Heards Road, Rokeskys Road, Brown Road School Road, Horsham – Lubeck Road, Horsham Drung South Road and Glenorchy-Murtoa Road. These features were removed for the pre-European waterway conditions.
    - Horsham Flood Mitigation works: Town Levee and river widening adjacent to Horsham. These features were removed for the pre-European waterway conditions.

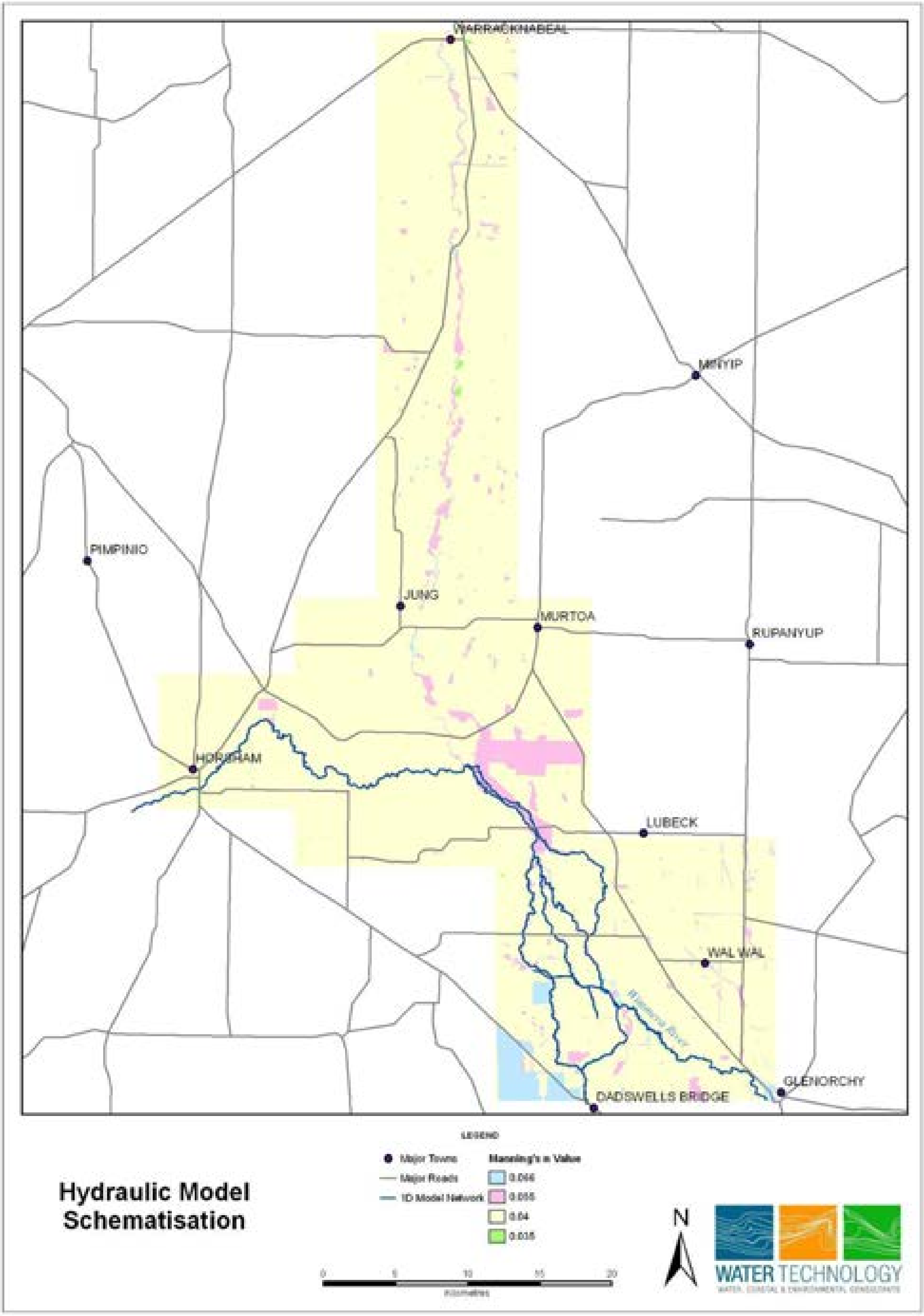

Figure 7-2 Hydraulic Model Roughness Delineation

7.3.3.2 2D local scale hydraulic model elements

The local scale 2D models consist of the following elements:

- Grid extent and resolution
  - Two local scale 2D models were developed:
    - Wimmera River at the Yarriambiack Creek offtake: A grid resolution of 0.5 m was adopted. This grid resolution enabled the simulation of the primary flow paths adjacent to the offtake, the offtake weir, and assessment of the flow distribution up to bankfull flows in the Wimmera River. (Refer to Figure 7-3).
    - Yarriambiack Creek at the Wimmera Highway: A grid resolution of 5 m was adopted. The bridge was modelled as a 1D model structure. (refer to Figure 7-4).
- Boundaries:
  - Wimmera River – Yarriambiack Creek offtake
    - Upstream flow boundary: A series of steady state flow scenarios 8.64 ML/d to 3456 ML/d (0.1 m^3/s - 40 m^3/s) were assessed.
    - Downstream water level boundary: A flow-water level relationship (rating curve) was obtained from the 1D model.
  - Yarriambiack Creek at the Western Highway
    - Upstream flow boundary: Obtained for the broad scale 2D hydraulic model.
    - Downstream water level boundary: Obtained for the broad scale 2D hydraulic model.
- Roughness
  - As per the 2D broad scale hydraulic model

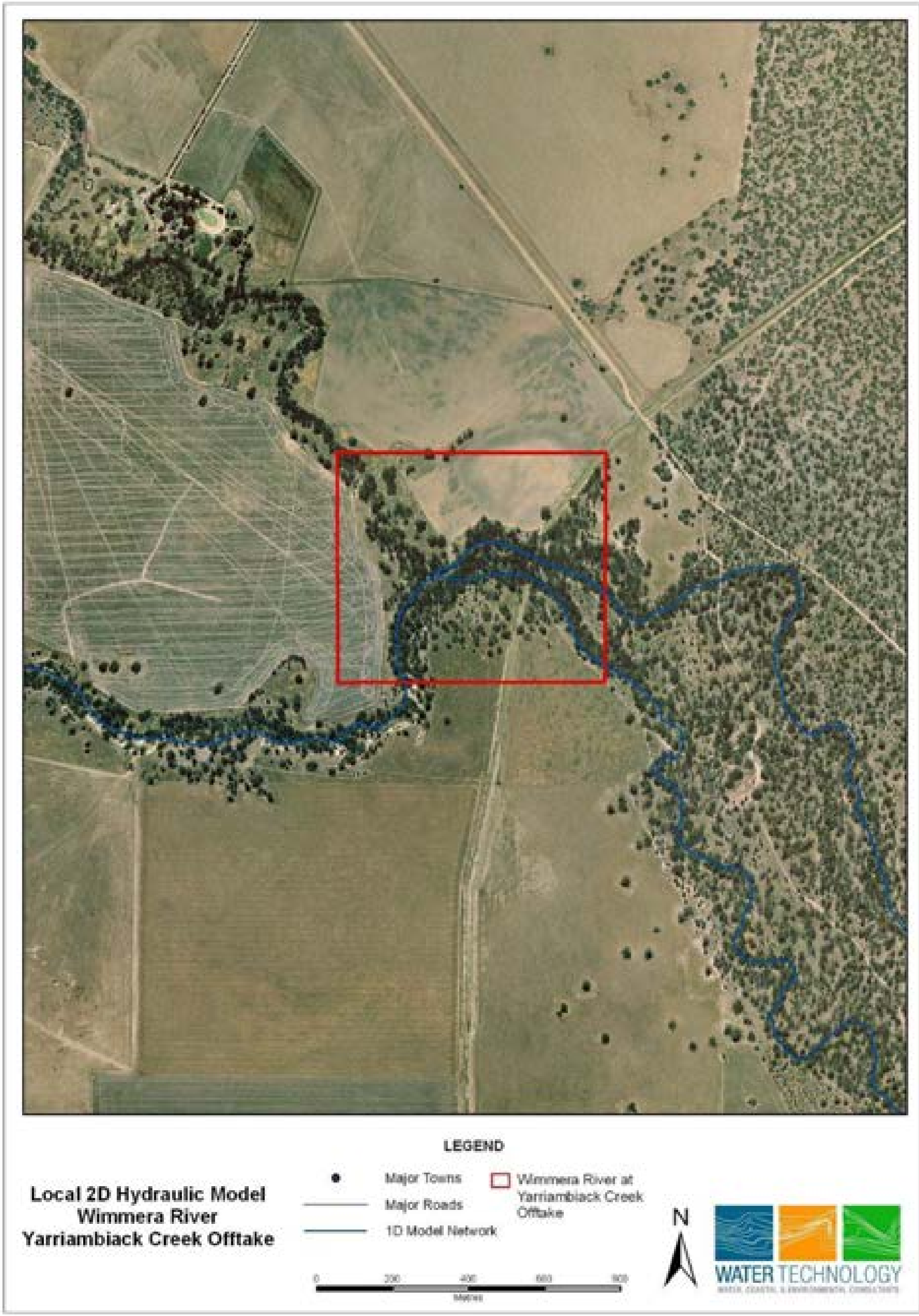

Figure 7-3 Wimmera River at the Yarriambiack Creek offtake – Local scale 2D model extent

Figure 7-4 Yarriambiack Creek at the Western Highway – Local scale 2D model extent

7.3.4 Linked 1D/2D model components (MIKE FLOOD)

The linked 1D/2D model combines the 1D model of the key waterways with the 2D broad scale floodplain hydraulic models. A dynamic link with the 2D broad scale hydraulic model occurs at each 1D model cross section. These links enables flow to enter the 2D model once the waterway channel is exceeded.

The 1D and 2D broad scale hydraulic model elements, discussed in Section 7.3.2 and 7.3.3, remain unchanged in the linked hydraulic model.

7.4 Hydraulic model calibration

7.4.1 Overview

The development of hydraulic models across a large floodplain requires a rigorous calibration process to ensure the hydraulic model accurately reproduces the observed flooding behaviour.

The calibration process consists of systematically comparing observed flooding behaviour within the study area against the hydraulic model's reproduction of that behaviour. This process generally incorporates comparisons between gauged stream flow data, observed flood levels and areas of inundation.

In order for a calibration event to be most useful it should have the following data attributes:

- Well defined inflows and outflows (boundary conditions).
- Flow and level measurements over time (temporal distribution) at discrete points of interest within and along the river such as effluent points and control structures.
- Flood extent and/or depth measurements (spatial distribution) at multiple times.
- Measures over a time period that exhibits the desired hydraulic responses in terms of flooding and drying of the system.

The historical floods used to calibrate the model were chosen based on the following criteria:

- A reasonable calibration data set of coincident flood information was available to make meaningful comparisons with the model outputs.
- Relevant flood level and extent information was available from the Flood Data Transfer Project (FDTP) for assessing model performance.

These criteria are used to assess the appropriateness of each potential calibration event.

Each component of the hydraulic modelling frameworks requires an individual calibration process, as the focus of each component varies. The 1D model calibration focuses on the model's ability to re-produce flow behaviour up to bankfull scenarios, in particular in-channel storage and travel times. The 2D model calibration assesses the broad floodplain flow extents and flow depths, plus the influence of floodplain features on flood behaviour. The linked 1D-2D model calibration aims to reflect the commencement of overbank flow.

7.4.2 1D hydraulic model calibration

7.4.2.1 Available calibration data and calibration event selection

The focus of 1D model calibration is the general flow up to bankfull flows. In particular, reasonable representation of in-channel storage and travel time along the reach. Hence, the selection of calibration events reflects a series of bankfull freshes with adequate available observed flow and water level data suitable for model calibration.

The period beginning 1 January 1981 to 31 December 1984 was selected due to the variety of flow conditions observed. The period contains two minor to moderate flood events in addition to numerous minor floods or 'freshes'. Figure 7-5 displays the streamflow time-series for the Wimmera River at Glenorchy over the January 1981 to December 1984.

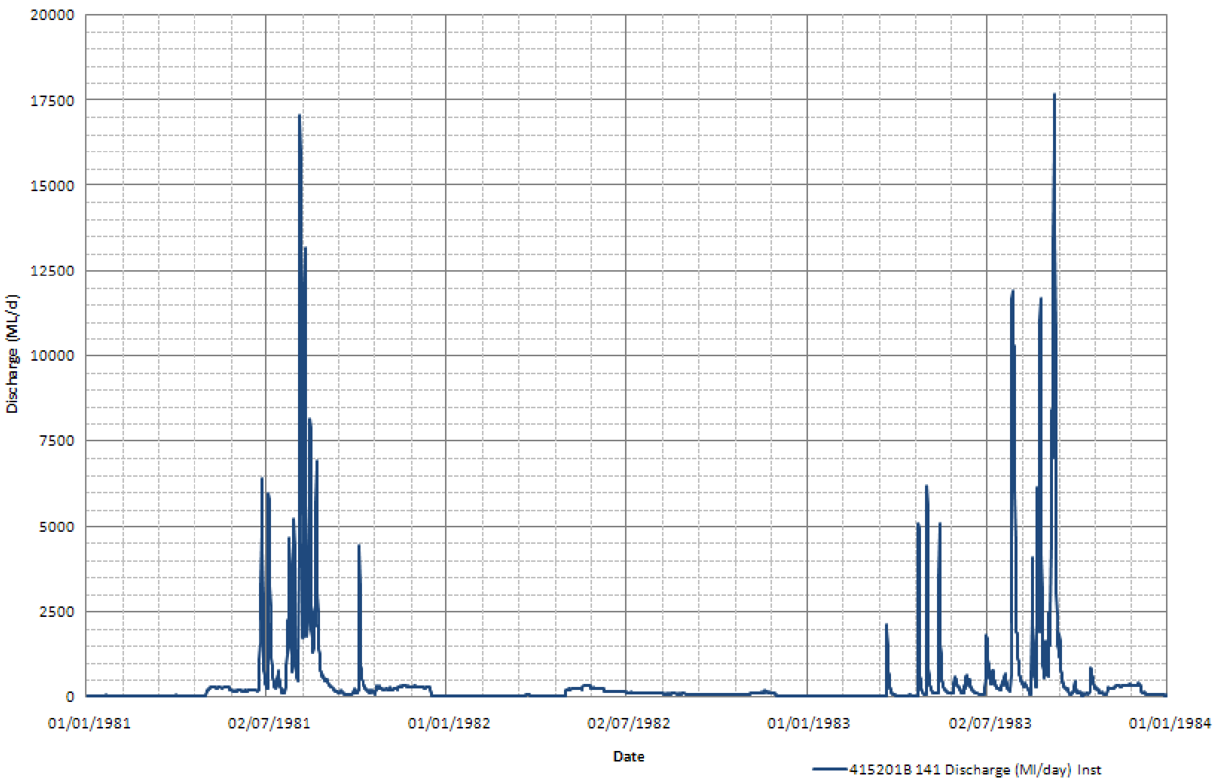

Figure 7-5 1D model calibration period - Wimmera River at Glenorchy (415201) - Observed streamflows

Within the longer calibration period, a sequence of three freshes in April-May 1983 was selected to assess the flow routing and travel times. The three freshes have peak flows of 5000- 6000 ML/d at Glenorchy. These peak flows equate to about bankfull in the Wimmera River reach from Glenorchy to Faux' Bridge. For these three freshes, observed streamflow/water levels were also available at the following gauges:

- Wimmera River at Faux' Bridge (415240)
- Wimmera River at Drung Drung (415239) (Water level only)
- Wimmera River at Walmer (415200)

Figure 7-6 displays the available streamflow time-series.

The travel time from Glenorchy to Walmer is generally about 48 hours. The reduction in the peak flow from Glenorchy to Faux' Bridge reflects the diversion of flows at Huddleston's Weir.

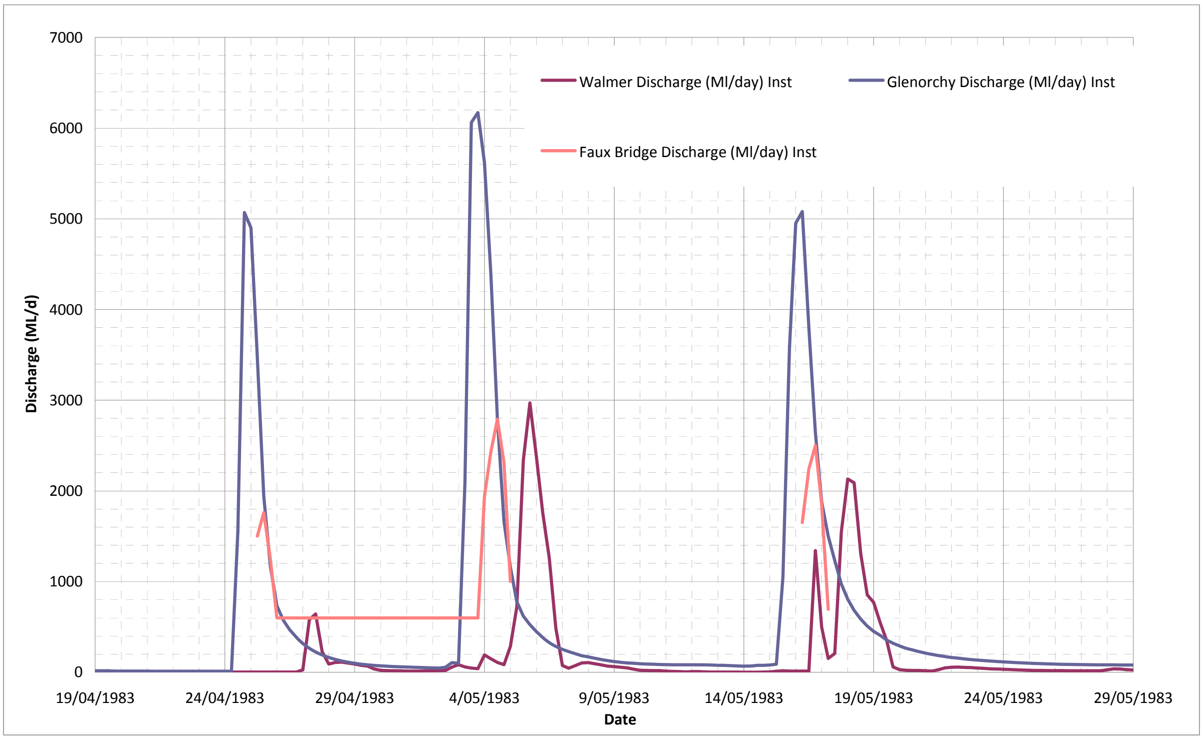

Figure 7-6 1D model calibration period – April – May 1983 - Wimmera River gauges - Observed streamflows

7.4.2.2 April-May 1983 freshes

Observed streamflows for the Wimmera River at Glenorchy and Mount William Creek at Lake Lonsdale were used as inflows to the 1D model calibration.

Comparison of observed and modelled streamflows and water levels was made at the following streamflow gauges:

- Wimmera River at Faux' Bridge (415240) (Refer to Figure 7-7 and Figure 7-8)
- Wimmera River at Drung Drung (415239) (Water level only) (Refer to Figure 7-9)
- Wimmera River at Walmer (415200) (refer to Figure 7-10)

The both water level and streamflow comparison are provided at Faux' Bridge. Only water level data is available at Drung Drung and the comparison is restricted to modelled and observed water levels. Walmer is located at the downstream limit of the 1D model. As discussed, the Walmer rating curve is employed as the downstream model boundary. Hence, the water level comparison is meaningless, and only streamflow comparison is provided.

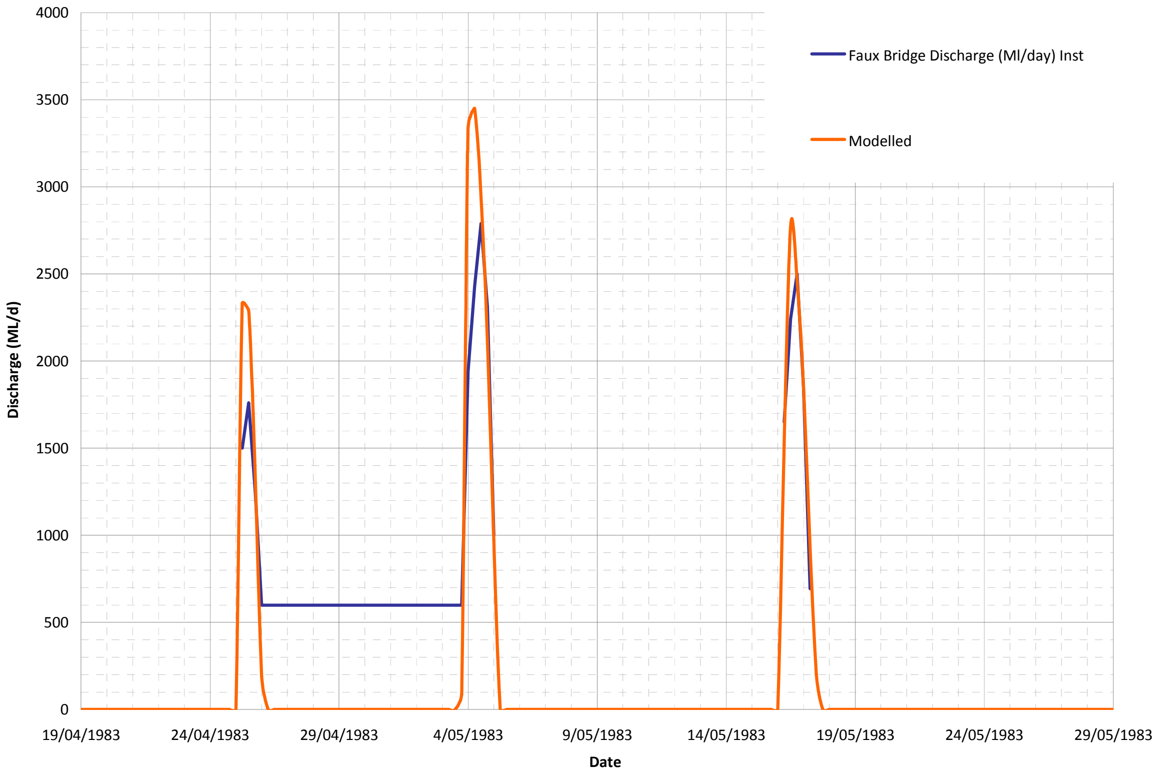

Figure 7-7 1D model calibration period – April – May 1983 - Wimmera River at Faux' Bridge - Observed and modelled streamflows

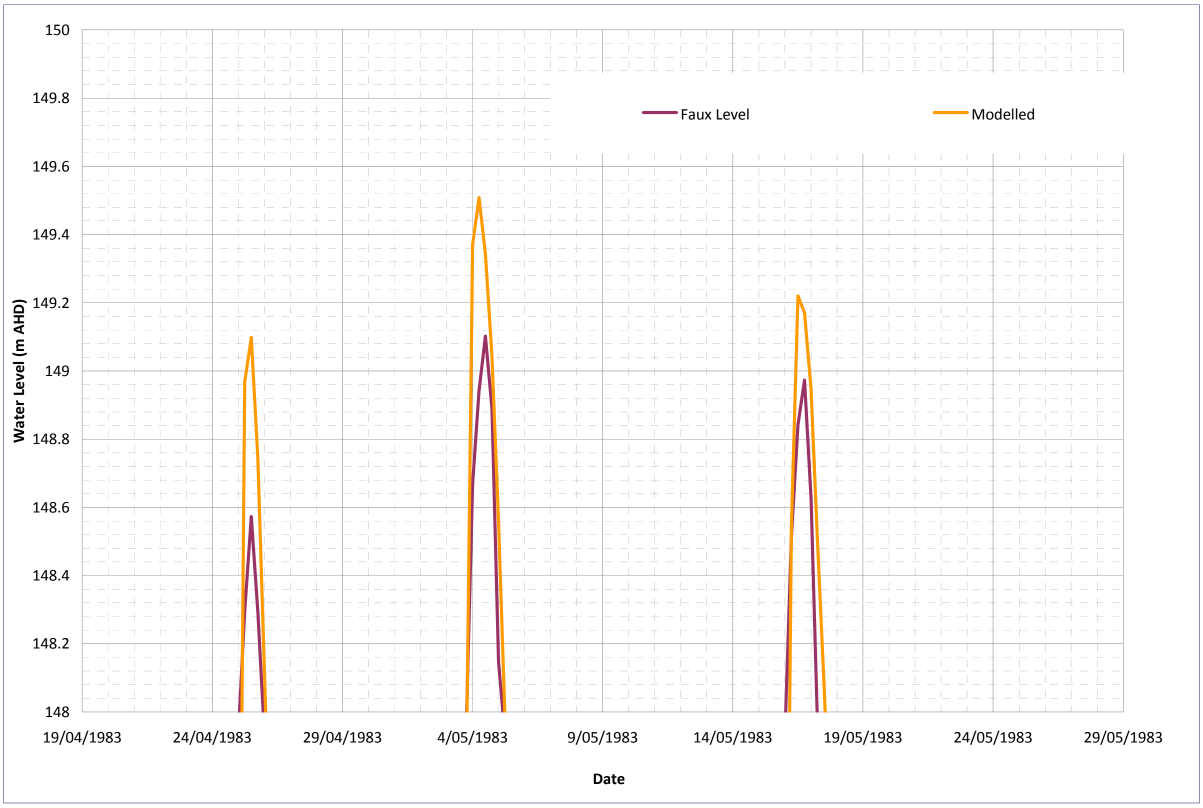

Figure 7-8 1D model calibration period – April – May 1983 - Wimmera River at Faux' Bridge - Observed and modelled water levels

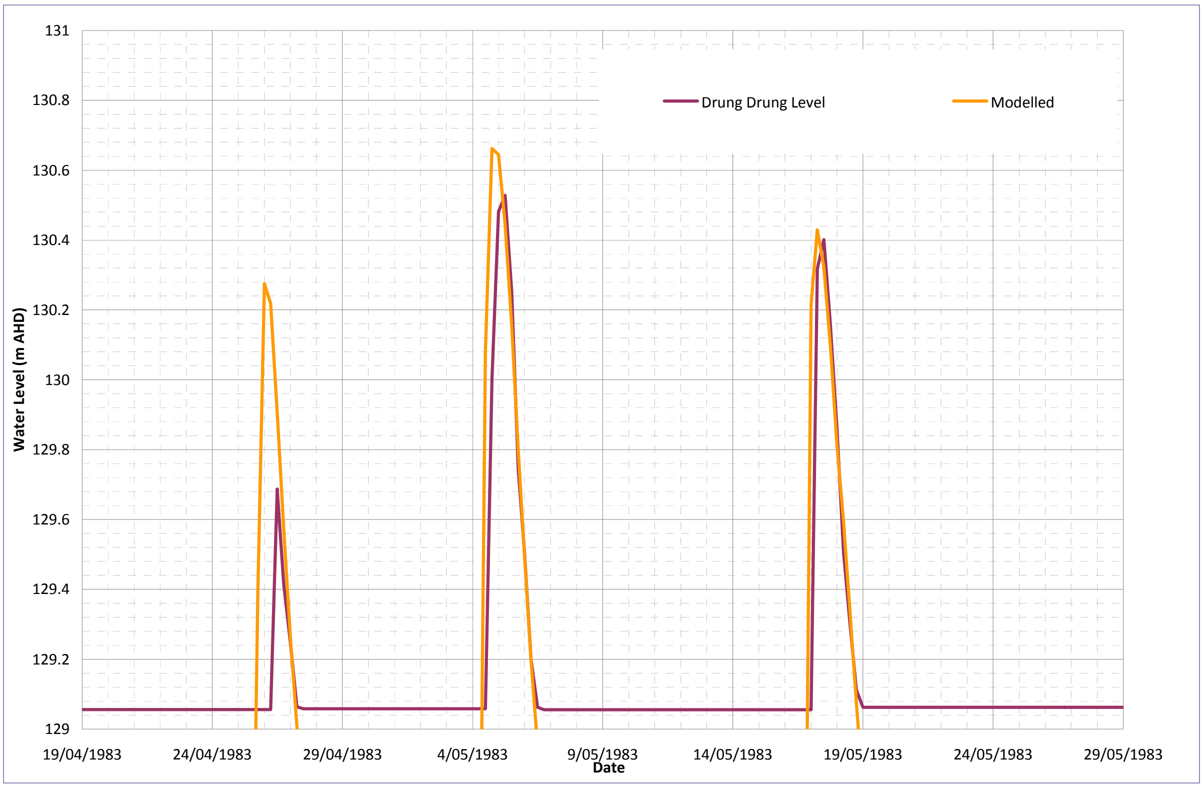

Figure 7-9 1D model calibration period – April – May 1983 - Wimmera River at Drung Drung - Observed and modelled water levels

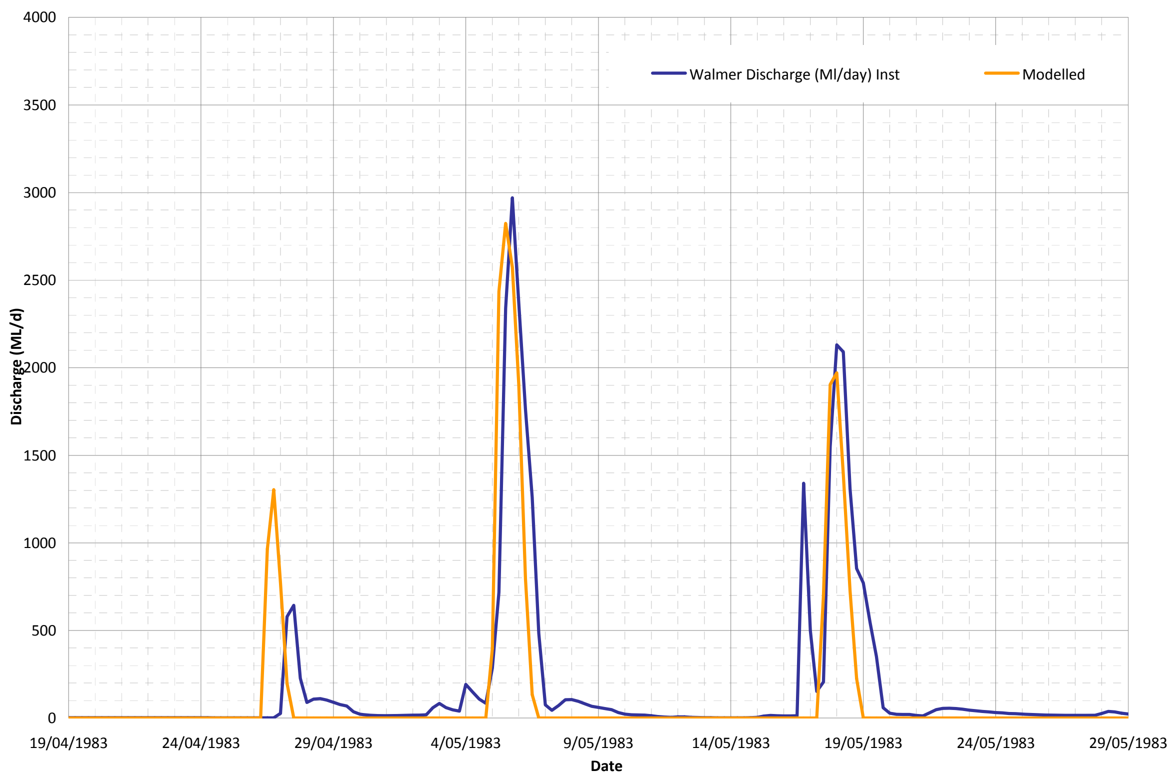

Figure 7-10 1D model calibration period – April – May 1983 - Wimmera River at Walmer - Observed and modelled streamflows

Figure 7-11 displays the modelled and observed stage–discharge curves for the Wimmera River at Faux' Bridge. The scatter in the observed data reflects the variation in rating curves applied over the period, and highlights the uncertainties in the development of rating curves. The modelled rating curve lies within the scatter of the observed data for flows greater than 2000 ML/d. This good agreement indicates the 1D model reproduces the observed flow – gauge height characteristics well for flows from 2000 to 5000 ML/d at Faux Bridge. For flows less than 2000 ML/d, the modelled gauge height under-predicts the observed gauge heights. This under-prediction may arise due to a low flow control located downstream of Faux Bridge not being represented in the 1D model cross sections. During the model construction, the identification of flow controls underpinned the siting of extracted model cross sections. However, capture of all flow controls, particularly controls operating at low flows, was not practicable. Hence, the reliability of the low flow rating is limited and should be treated as indicative.

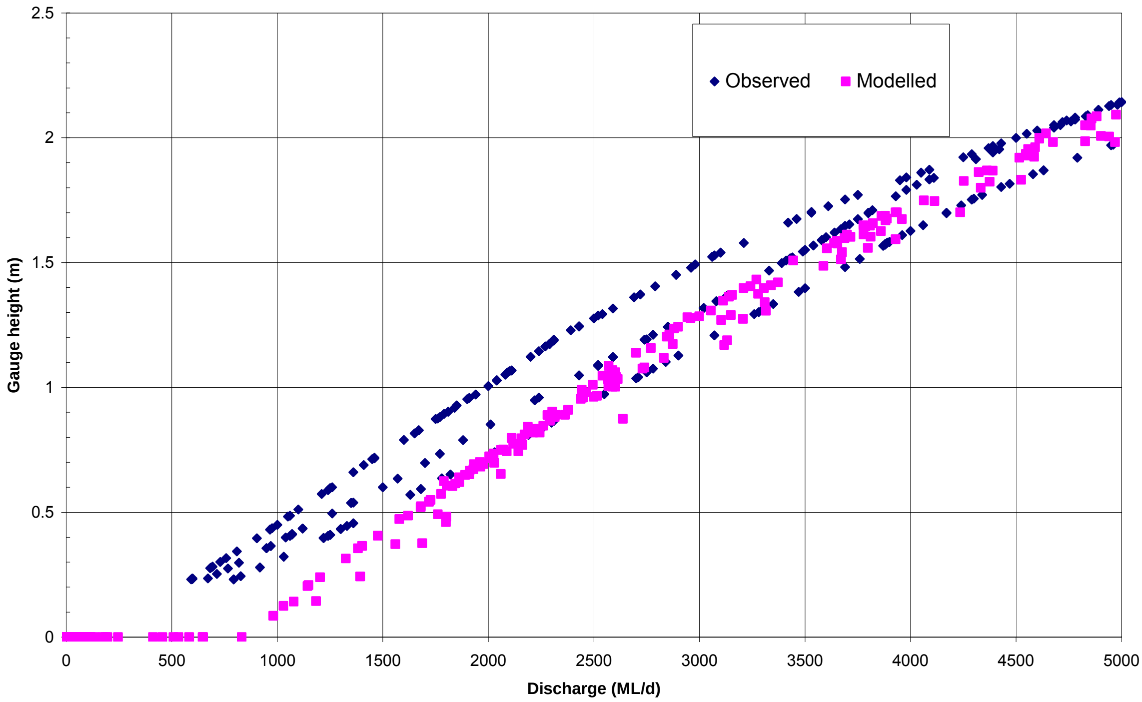

Figure 7-11 1D model calibration period – April – May 1983 - Wimmera River at Faux' Bridge - Observed and modelled stage-discharge curves

7.4.2.3 Discussion

The 1D model calibration focused on the simulation of flow behaviour for flows up to bankfull. As outlined in Section 7.2, there are numerous sources of uncertainties influencing the model ability. This section discusses these uncertainties as they related to the 1D model.

The comparison of observed and model flow behaviour targeted three freshes in April-May 1983. The availability of observed streamflow and water level data was limited to two streamflow gauges along the Wimmera River. As a result, the formal assessment of the model ability is limited to these locations. However, the timing of peak flows along Wimmera River reflects the travel time and available storage between the gauges.

The comparison of the modelled and observed streamflows revealed that the modelled peak flow is higher than the observed peak flow. This overestimation of the modelled peak flow at the gauges arises from the underestimation of diverted flow at Huddleston's Weir. However, the comparison of the modelled and observed streamflows show the timing of observed peak flows at two gauges is well preserved by the 1D model. This preservation of the timing indicates a good ability of the 1D model to simulate travel time along the Wimmera River. The reasonable simulation of the travel time indicates the 1D model schematisation and parameters (roughness) adequately reflects the available in-channel storage within the Wimmera River.

The comparison of modelled and observed stage-discharge curves at Faux' Bridge shows the water levels for low flows (up to 2000 ML/d) are underestimated. Good agreement between modelled and observed water levels occurred for flows above 2000 ML/d.

As noted, the formal assessment of the 1D model's performance is limited to available streamflow gauges.

Further assessment of the 1D model performance requires the establishment of additional streamflow gauges within the study area. Opportunistic flow gaugings, as part of environmental flow monitoring is also a valuable source of additional calibration data.

7.4.3 2D broad scale floodplain hydraulic model calibration

7.4.3.1 Available calibration data and calibration event selection

The focus of the broad floodplain 2D model calibration is the general flood behaviour during large flood events. Hence, the selection of calibration events reflects large flood events with adequate available observed flood data suitable for model calibration.

A review of the available data on historical floods in the Wimmera River and Yarriambiack Creek region identified four historical flood events suitable for the model calibration. Table 7-2 outlines the details of the selected calibration events.

Table 7-2 2D floodplain model – calibration events

Event	General description	Available observed data
August 1981	- Significant flood event causing widespread inundation of the Wimmera River floodplain between Glenorchy and Horsham - Peak flow: ▪ Glenorchy: 17100 ML/d ▪ Walmer: 24300 ML/d	Flood levels: ▪ 20 observed flood levels Streamflow data: ▪ Wimmera River at Glenorchy ▪ Wimmera River at Faux' Bridge ▪ Wimmera River at Drung Drung ▪ Wimmera River at Walmer ▪ Yarriambiack Creek at the Wimmera Highway Bridge
September 1983	- Significant flood event causing widespread inundation of the Wimmera River floodplain between Glenorchy and Horsham. - Considerable inflow from Mount William Creek	Flood levels: ▪ 17 observed flood levels Flood levels: ▪ Partial observed flood extent Streamflow data: ▪ Wimmera River at Glenorchy

Event	General description	Available observed data
	- Peak flow: ▪ Glenorchy: 17700 ML/d ▪ Walmer: 25600 ML/d ▪ Wonwondah (Burnt Creek): 1218 ML/d	▪ Wimmera River at Faux' Bridge ▪ Wimmera River at Drung Drung ▪ Wimmera River at Walmer ▪ Yarriambiack Creek at the Wimmera Highway Bridge
September 1988	- Significant contribution from Upper Wimmera River (above Glenorchy) - Peak flow: ▪ Glenorchy: 27300 ML/d ▪ Walmer: 22800 ML/d ▪ Wonwondah (Burnt Creek): 968 ML/d	Flood levels: ▪ No observed flood levels and/or extent (downstream of Glenorchy) Streamflow data: ▪ Wimmera River at Glenorchy ▪ Wimmera River at Faux' Bridge ▪ Wimmera River at Walmer
October 1996	- Small flood event, most recent flood event. - Peak flow: ▪ Glenorchy: 14800 ML/d ▪ Walmer: 19600 ML/d ▪ Wonwondah (Burnt Creek): 1546ML/d	Flood levels: ▪ No observed flood levels ▪ Observed flood extent (partial) Streamflow data: ▪ Wimmera River at Glenorchy ▪ Wimmera River at Faux' Bridge ▪ Wimmera River at Walmer

The model calibration was assessed through the comparison of observed and modelled streamflows, flood levels, and flood extents.

7.4.3.2 August 1981

Comparison of observed and modelled streamflows was made at the following streamflow gauges:

- Yarriambiack Creek at Wimmera Highway Bridge (415241). Refer to Figure 7-12.
- Wimmera River at Walmer (415200). Refer to Figure 7-13

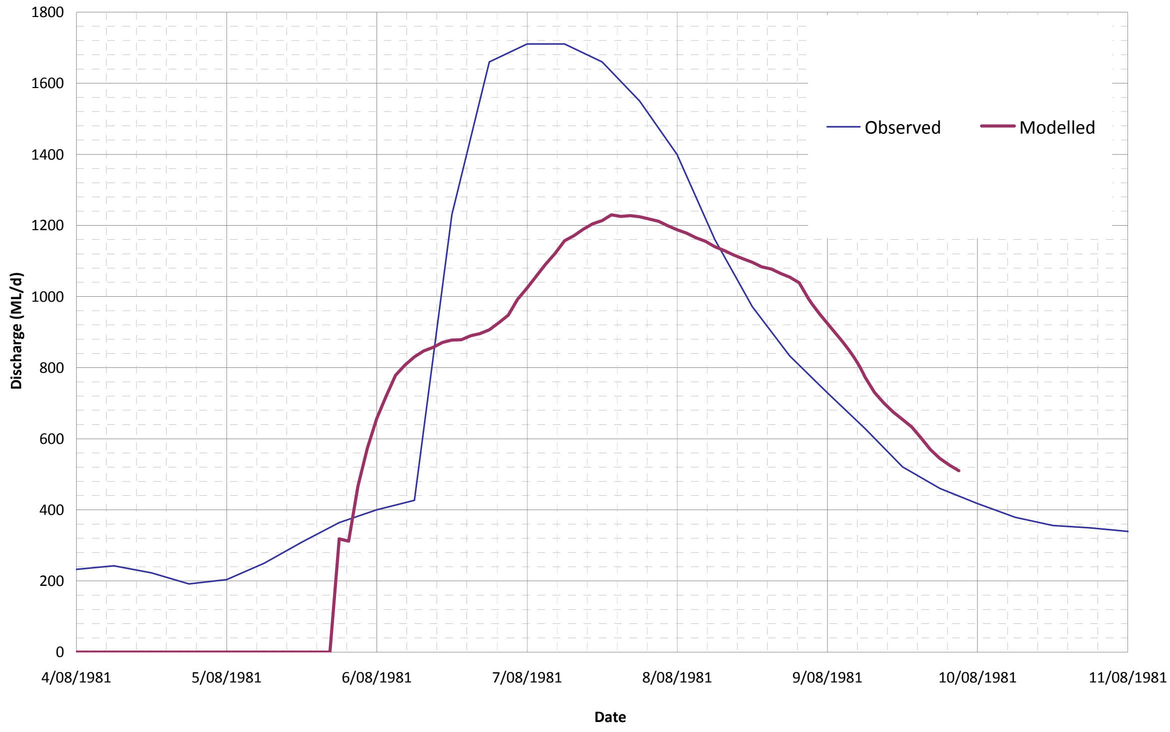

Figure 7-12 August 1981 calibration – Yarriambiack Creek at Wimmera Highway Bridge Gauge (415241)

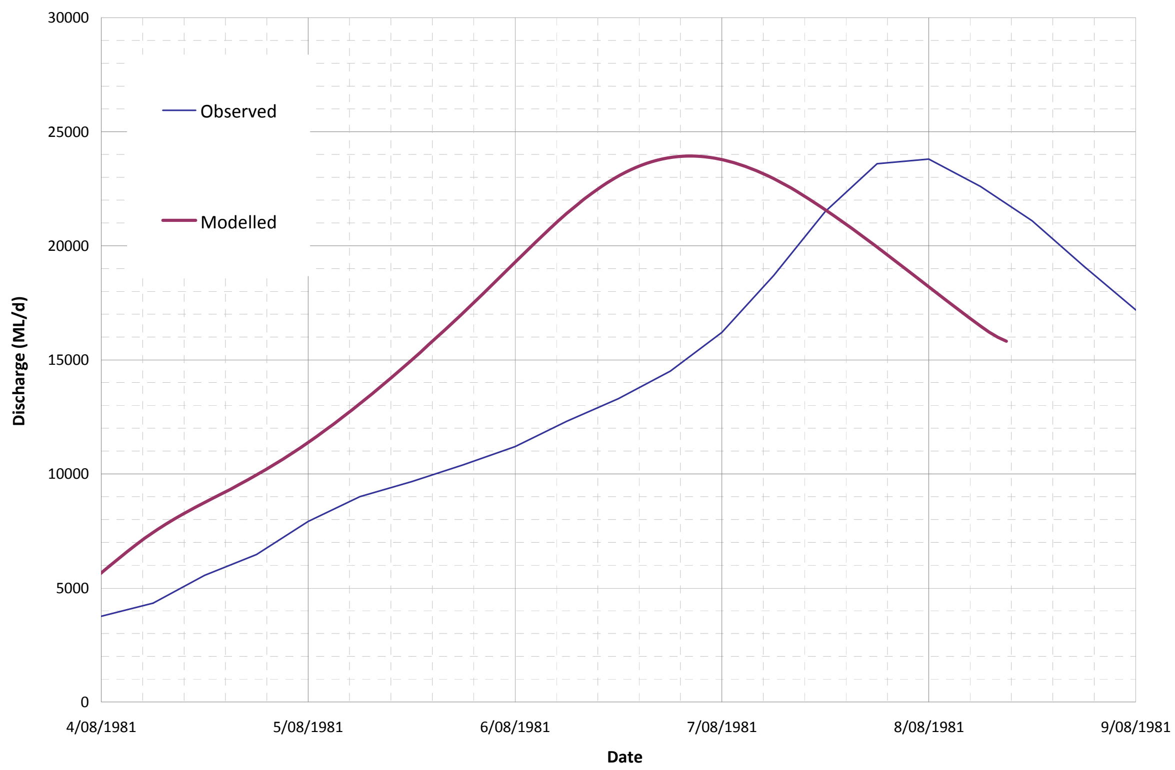

Figure 7-13 August 1981 calibration – Wimmera River at Walmer (415200)

Comparison of the modelled and observed hydrograph for Yarriambiack Creek reveals an under-estimation of the peak flow. Further, the general observed hydrograph shape is not well re-produced. Model refinements to the roughness and terrain were undertaken to improve the modelled hydrograph. The difference in the modelled peak flow (≈ 500 ML/d) equates to a difference in flood level of about 150 mm. The comparison of the modelled and observed rating curves for Yarriambiack Creek at the Wimmera Highway shows the hydraulic model reproduces well the observed rating curve. Such a comparison indicates that the hydraulic model is able to reflect the local hydraulic conditions.

The key potential contributing factors to the underestimation of the observed peak flow and poor re-production of hydrograph shape including:

- errors in the modelled (URBS) flow hydrograph used as model boundary conditions not reflecting the actual inflow hydrographs .
- representation of topographic and waterway features across the Wimmera River floodplain

The good comparison of the modelled and observed rating curves for Yarriambiack Creek at the Wimmera Highway indicates good model performance in the simulation of the relative changes in flood behaviour due to changes in waterway-floodplain conditions.

For the Wimmera River at Walmer, the observed peak flow was re-produced well, as with the general, hydrograph shape. The modelled peak flow leads the observed peak flow by some 24 hours. This earlier peaking of the modelled hydrographs was also seen with the hydrologic modelling (refer to Figure 6-6). As the hydrologic modelling (URBS) provided the flood hydrographs as input to the hydraulic analysis, it was expected that a similar early peak occurred.

The comparison of modelled and observed flood levels is detailed in Table 7-3 and Figure 7-14.

Table 7-3 August 1981 calibration event – observed and modelled flood levels

Label	Location	Observed flood level (m AHD)	Modelled flood level (m AHD)	Difference (m)	Comment
0	E 619159.85 N 5943224.19	133.44	132.94	-0.50	Located at outlet of Darlot Swamp. Observed level maybe influenced by embankment.
1	E 623494.18 N 5943044.51	133.75	133.6	-0.15	Reasonable agreement
2	E 619719.79 N 5939121.20	133.06	132.85	-0.21	Reasonable agreement
3	E 615289.72 N 5936506.06	130.32	130.33	0.01	Good agreement
4	E 626253.68 N 5936501.79	138.39	138.16	-0.23	Reasonable agreement
5	E 625924.94 N 5934167.06	138.53	138.17	-0.36	Located adjacent to Taylors Lake channel. Observed level maybe influenced by embankment.
6	E 631029.66 N 5933021.58	142.91	142.84	-0.07	Good agreement

Label	Location	Observed flood level (m AHD)	Modelled flood level (m AHD)	Difference (m)	Comment
7	E 617895.96 N 5933010.39	132.37	131.92	-0.45	Located adjacent to Horsham Drung South Road. Observed flood level may be influenced by road and/or local drainage
8	E 633170.05 N 5929669.02	145.25	145.42	0.17	Reasonable agreement
9	E 635695.32 N 5928297.85	148.07	148.66	0.59	Located on Station Creek at Ashens Bridge Road. No significant local feature influencing flood behaviour. Local modelled and observed flood extent in good agreement level No clear underlying reason for difference.
10	E 632186.14 N 5928017.18	147.05	147.15	0.10	Good agreement
11	E 630003.35 N 5924862.30	148.86	149.17	0.31	Located on Mount William Creek at Horsham Wal Wal Road. May reflect overestimate of Mount William Creek inflows.
12	E 632134.40 N 5924821.15	149.04	149.04	0.00	Good agreement
13	E 634462.74 N 5924814.28	150.82	150.94	0.12	
14	E 639519.67 N 5923918.11	154.76	154.85	0.09	
15	E 639011.78 N 5923867.30	154.00	153.90	-0.10	
16	E 636529.49 N 5920784.45	154.37	154.38	0.01	
17	E 636867.21 N 5919901.18	156.01	155.36	-0.65	Local flood level influenced by Wimmera Inlet channel. Observed flood level may be influenced by channel
18	E 639193.31 N 5917686.28	158.91	158.81	-0.10	Good agreement
19	E 642461.17 N 5916155.68	163.51	163.60	0.09	Good agreement

A reasonable comparison of observed and modelled flood levels reflects the 2D model predictive capacity. The mean flood level difference is -0.07 m with a median error of -0.03 m. Discussion of the 2D broad scale floodplain 2D hydraulic model is provided in Section 7.4.3.6.

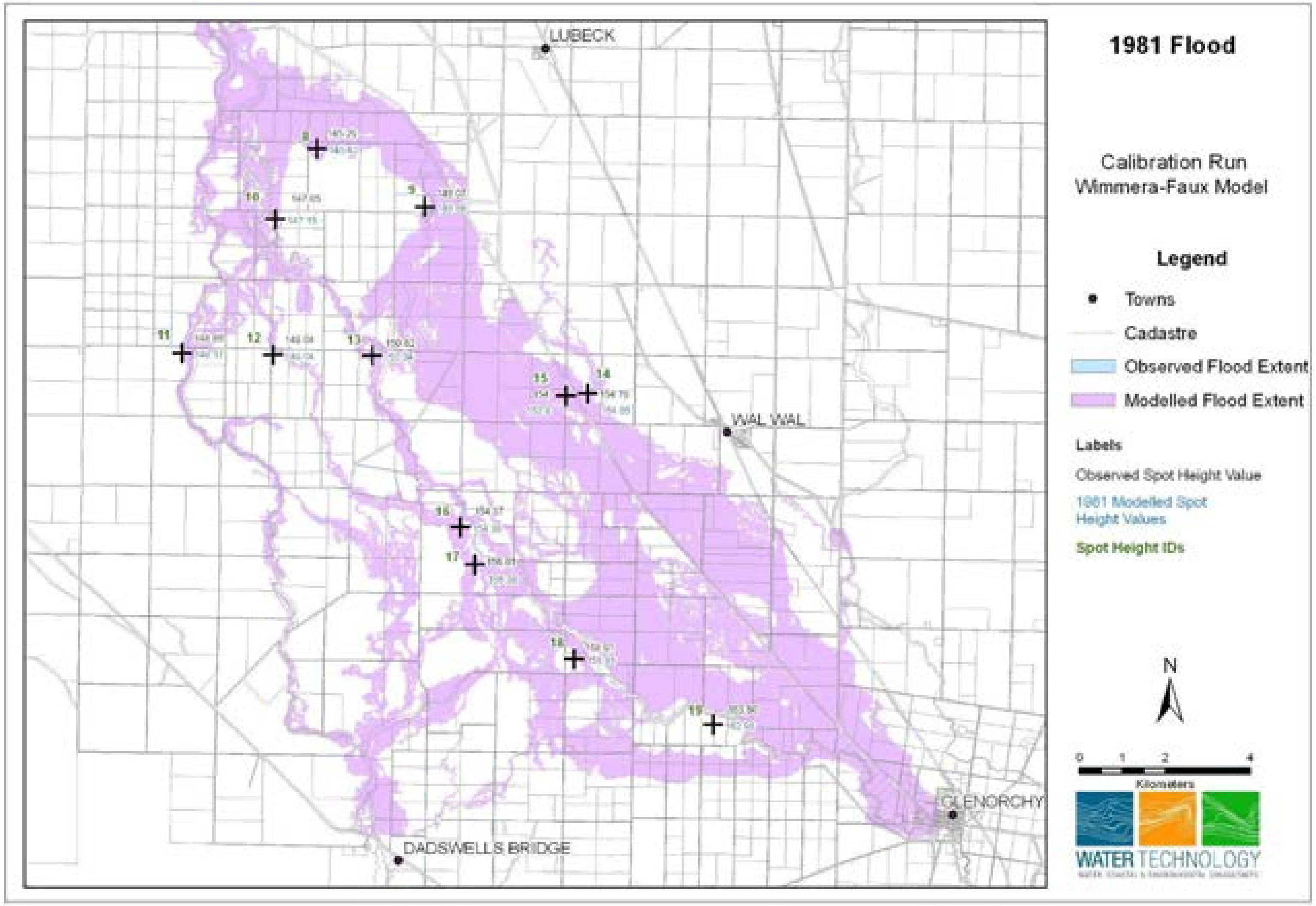

Figure 7-14 August 1981 Flood Event 2D Calibration Results –Glenorchy to Faux' Bridge

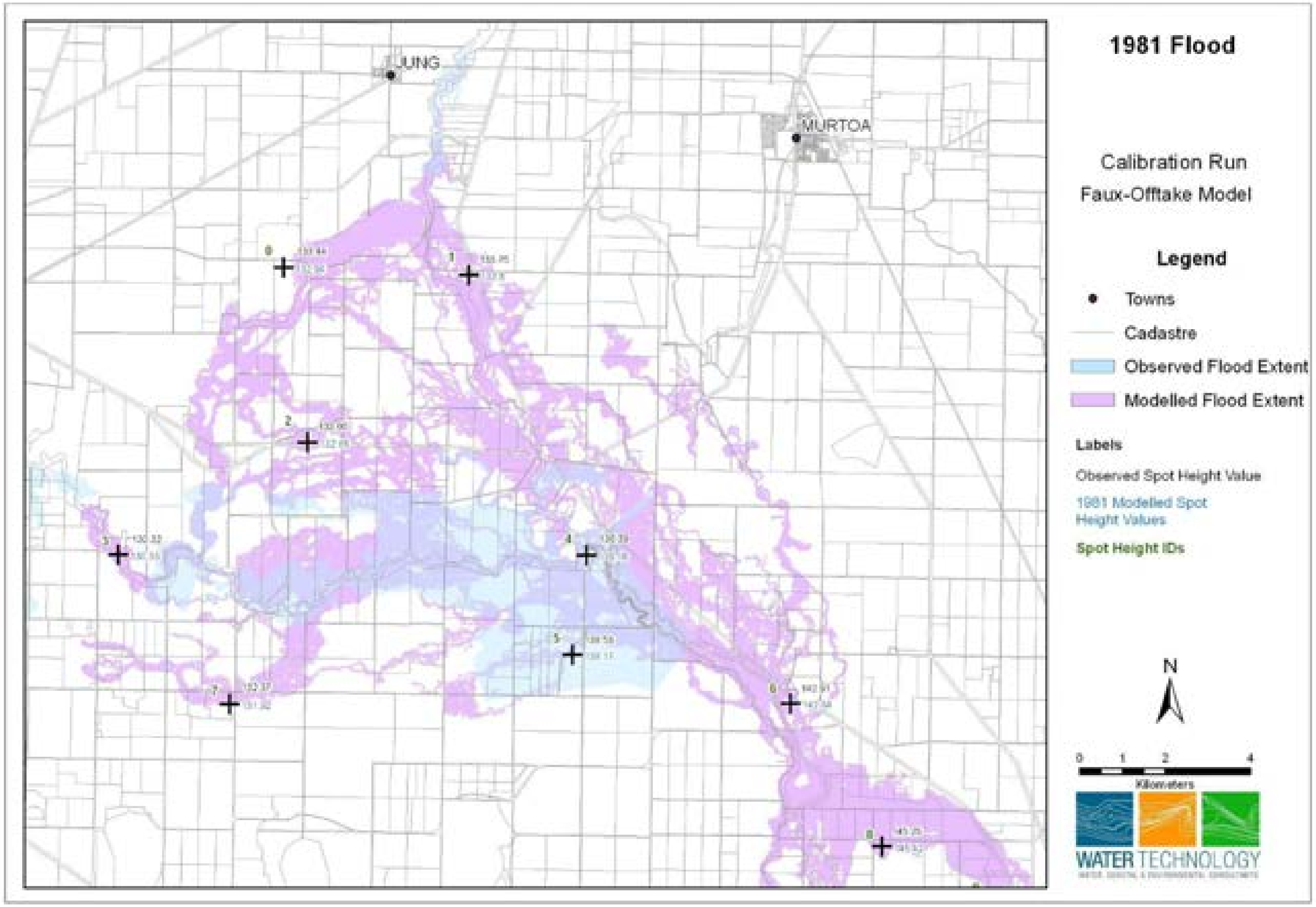

Figure 7-15 August 1981 Flood Event 2D Calibration Results –Faux' Bridge to Yarriambiack Offtake

7.4.3.3 September 1983

Comparison of observed and modelled streamflows was made at the following streamflow gauges:

- Yarriambiack Creek at Wimmera Highway Bridge (415241). Refer to Figure 7-16
- Wimmera River at Walmer (415200). Refer to Figure 7-17

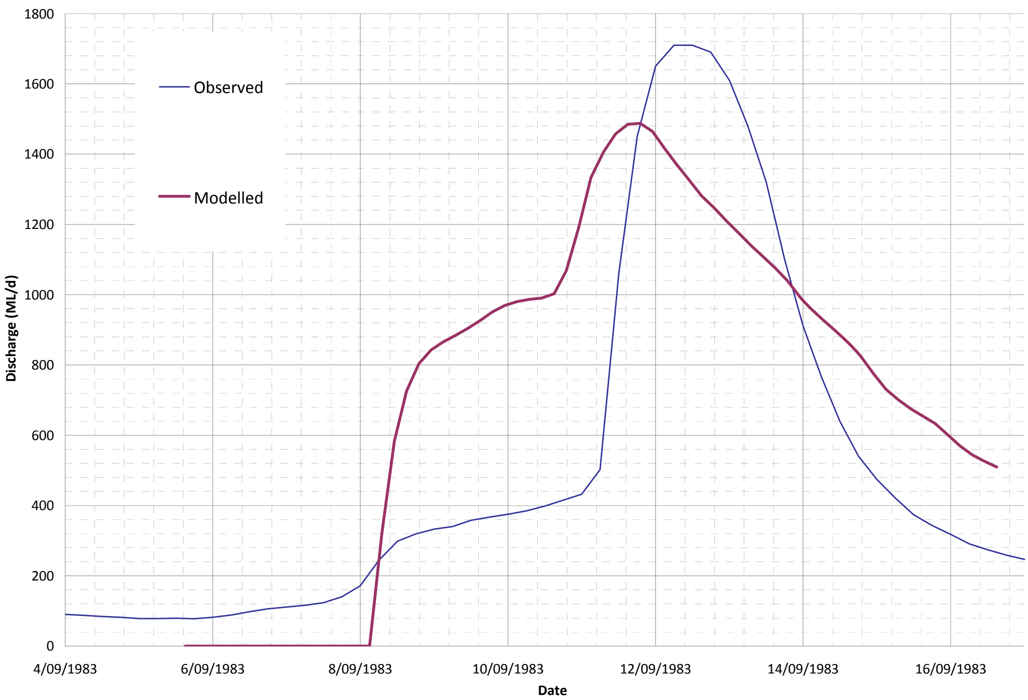

Figure 7-16 September 1983 calibration – Yarriambiack Creek at Wimmera Highway Bridge Gauge (415241)

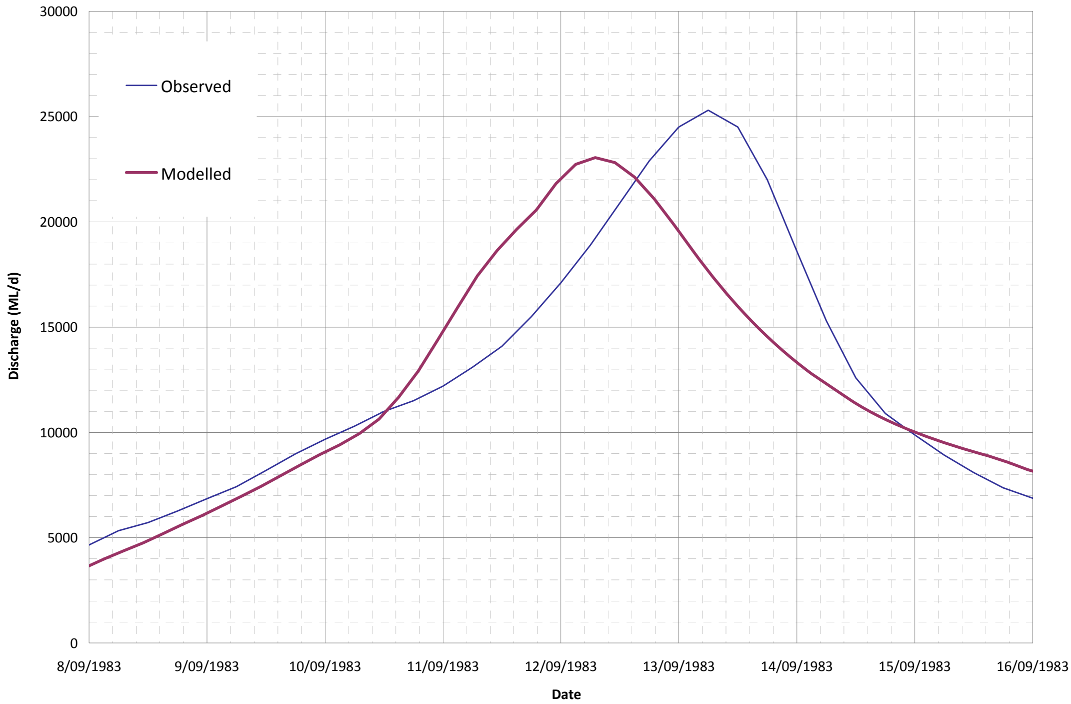

Figure 7-17 September 1983 calibration – Wimmera River at Walmer (415200)

As for the August 1981, the observed peak flow for Yarriambiack Creek at the Wimmera Highway was under-estimated. The difference in peak flow equated to a difference in flood height of around 80 to 100 mm.

The modelled flood hydrograph at Walmer peaked some 24 hours than the observed flood hydrographs. This behaviour was also reflected in the hydrologic modelling (refer to Figure 6-7). As discussed in Section 7.4.3.2, the hydrologic modelling provides the inflows to the hydraulic model. Any uncertainties in the inflows impact on the hydraulic modelling performance.

The comparison of modelled and observed flood extents, refer to Figure 7-18 and Figure 7-19, show general agreement. South of Murtoa (Figure 7-19), the observed flood extent is greater than the modelled flood extent. Contributing factors to this discrepancy may include local ponding of drainage, uncertainties in the observed flood extent, and uncertainties in the model inflows as noted above.

The comparison of modelled and observed flood levels is detailed in Table 7-4 and, Figure 7-18 and Figure 7-19.

Table 7-4 September 1983 calibration event – observed and modelled flood levels

Label (FID)	Location	Observed Flood Level (m AHD)	Modelled Flood Level (m AHD)	Difference (m)	Comment
0	E 617996.25 N 5942133.07	132.24	132.32	0.08	Good agreement
1	E 617477.94 N 5940970.41	132.16	132.2	0.04	Good agreement
2	E 617456.89 N 5939603.86	131.16	131.82	0.66	No significant local feature influencing flood behaviour. Local modelled and observed flood extent in good agreement level No clear underlying reason for difference.
3	E 618552.65 N 5939315.98	132.86	132.61	-0.25	
4	E 619841.10 N 5939298.12	133.34	132.92	-0.42	
5	E 625410.58 N 5938732.88	136.84	136.69	-0.15	Reasonable agreement
6	E 627782.61 N 5938274.46	138.19	137.29	-0.90	Local flood level influenced by Taylor's Lake Outlet. No clear underlying reason for difference.
7	E 626690.65 N 5937086.81	138.73	138.27	-0.46	
8	E 615495.14 N 5936704.42	130.43	130.47	0.04	Good agreement
9	E 626377.39 N 5936688.28	138.45	138.17	-0.28	Local flood level influenced by Taylor's Lake Outlet. No clear underlying reason for difference.
10	E 630728.21 N 5931271.89	144.27	144.3	0.03	Good agreement
11	E 634675.73 N 5930537.43	145.97	146.17	0.20	Reasonable agreement
12	E 639467.63 N 5923501.72	154.71	154.88	0.17	
13	E 636846.61 N 5923258.77	152.98	152.82	-0.16	

Label (FID)	Location	Observed Flood Level (m AHD)	Modelled Flood Level (m AHD)	Difference (m)	Comment
14	E 635829.92 N 5921220.21	154.09	153.97	-0.12	
15	E 635825.54 N 5921032.57	154.28	154.01	-0.27	Local flood level influenced by Wimmera Inlet channel. No clear underlying reason for difference.
16	E 642582.55 N 5916332.56	163.53	163.6	0.07	Good agreement

The mean flood difference is -0.10 m with a median error of -0.12 m. Excluding the observed flood levels 2 and 6, the standard deviation is 0.20 m. Discussion of the 2D broad scale floodplain 2D hydraulic model are provided in Section 7.4.3.6.

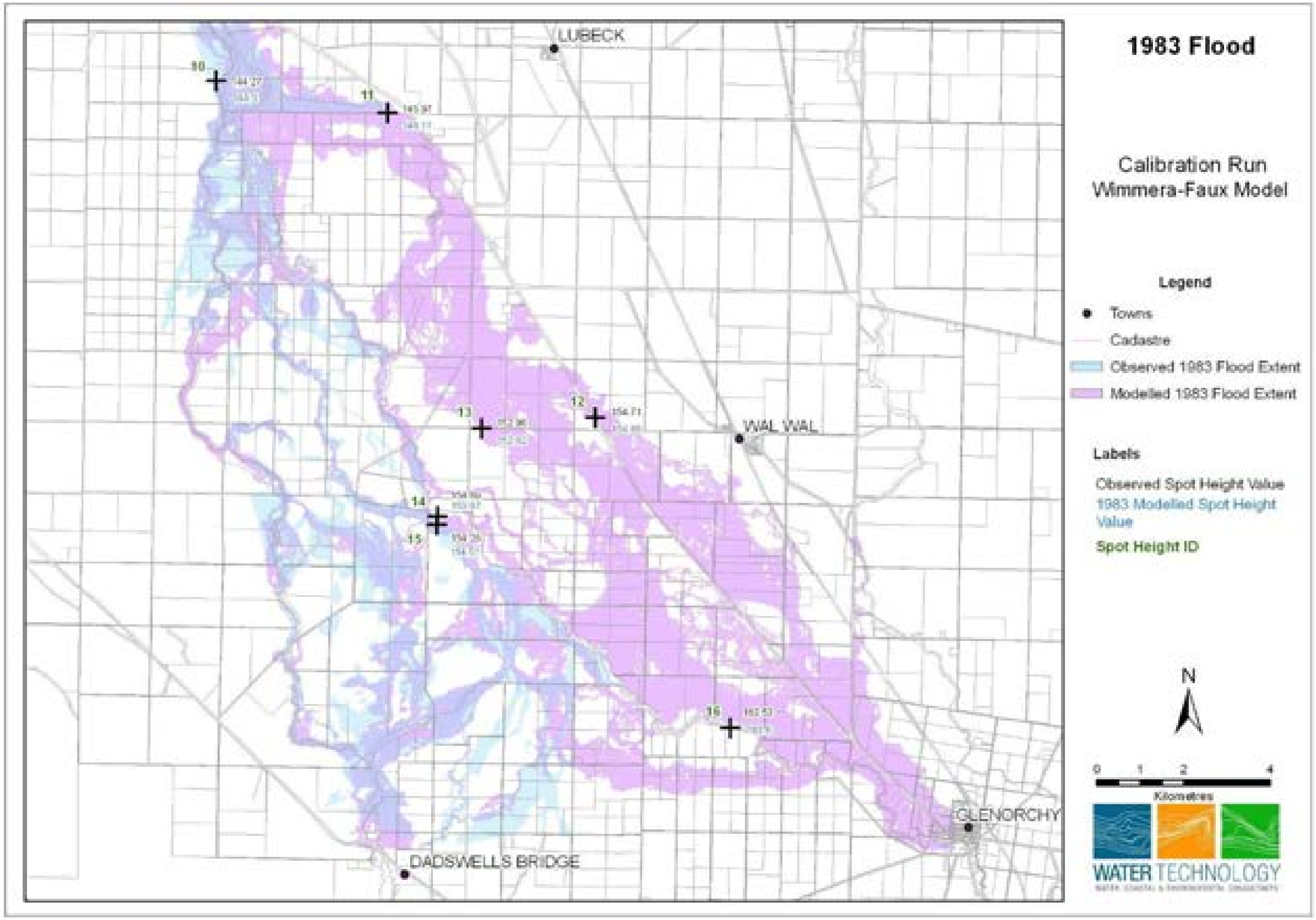

Figure 7-18 September 1983 Flood Event 2D Calibration Results –Glenorchy to Faux' Bridge

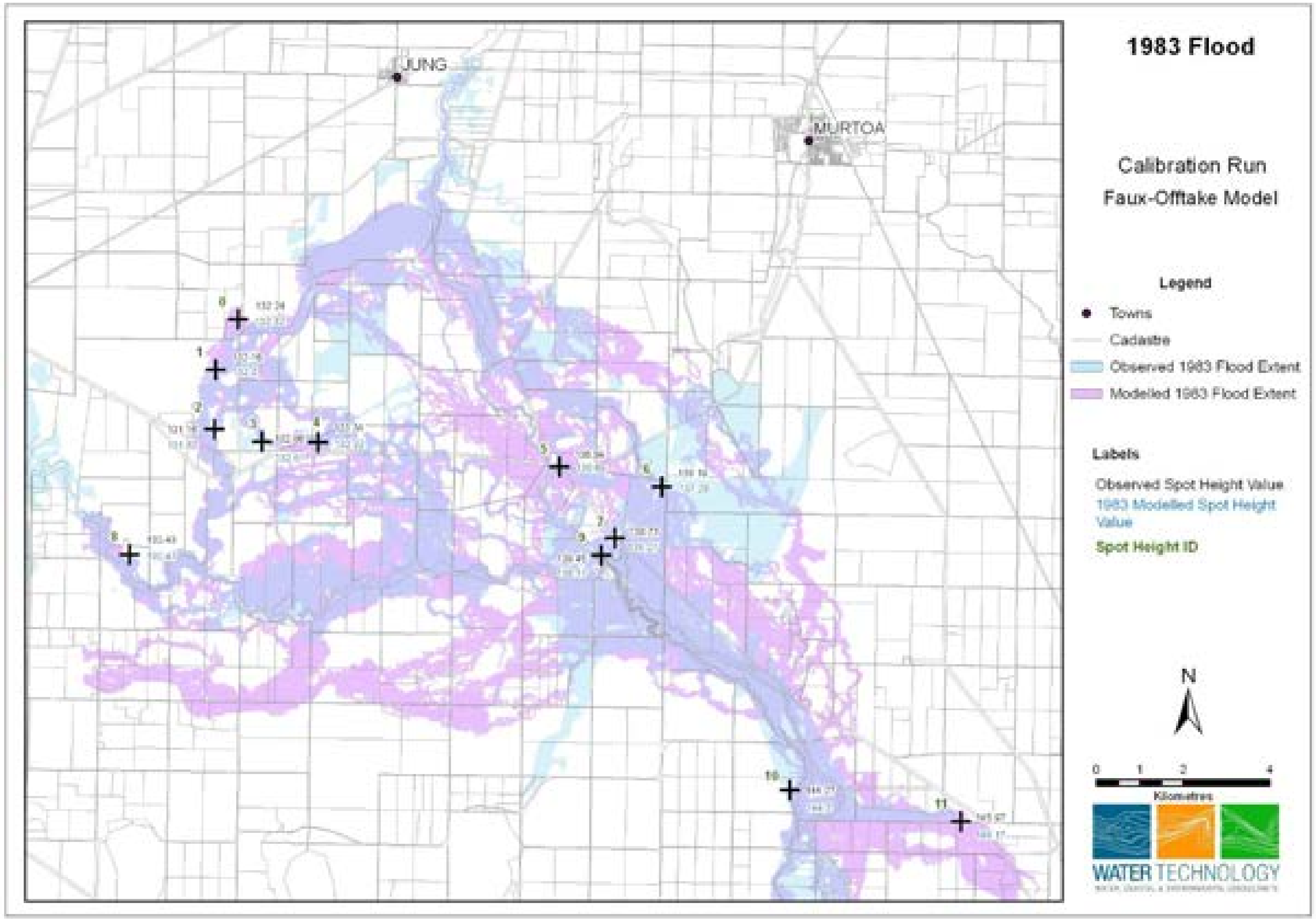

Figure 7-19 September 1983 Flood Event 2D Calibration Results –Faux' Bridge to Yarriambiack Offtake

7.4.3.4 September 1988

Comparison of observed and modelled streamflows was made at the following streamflow gauge:

- Wimmera River at Walmer (415200). Refer to Figure 7-20

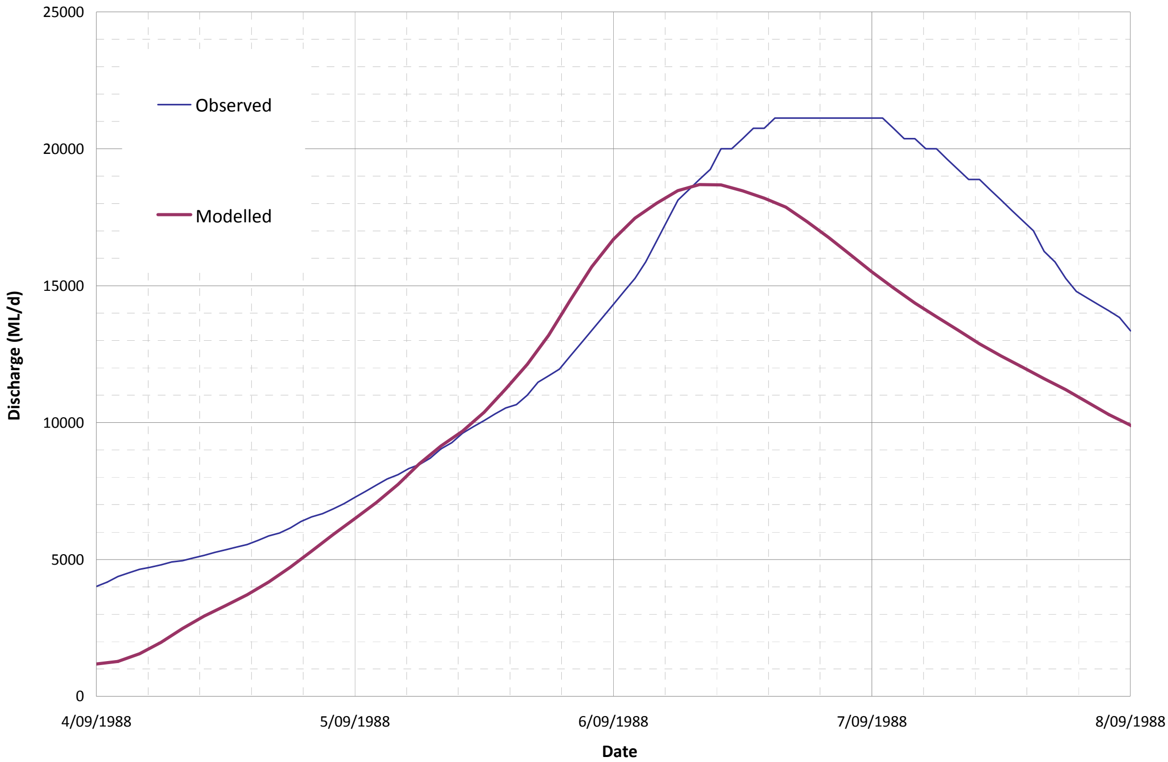

Figure 7-20 September 1988 calibration – Wimmera River at Walmer (415200)

As discussed, no other observed flood information was available for the September 1988. The modelled flood extent for the September 1988 event is shown in Figure 7-21 and Figure 7-22.

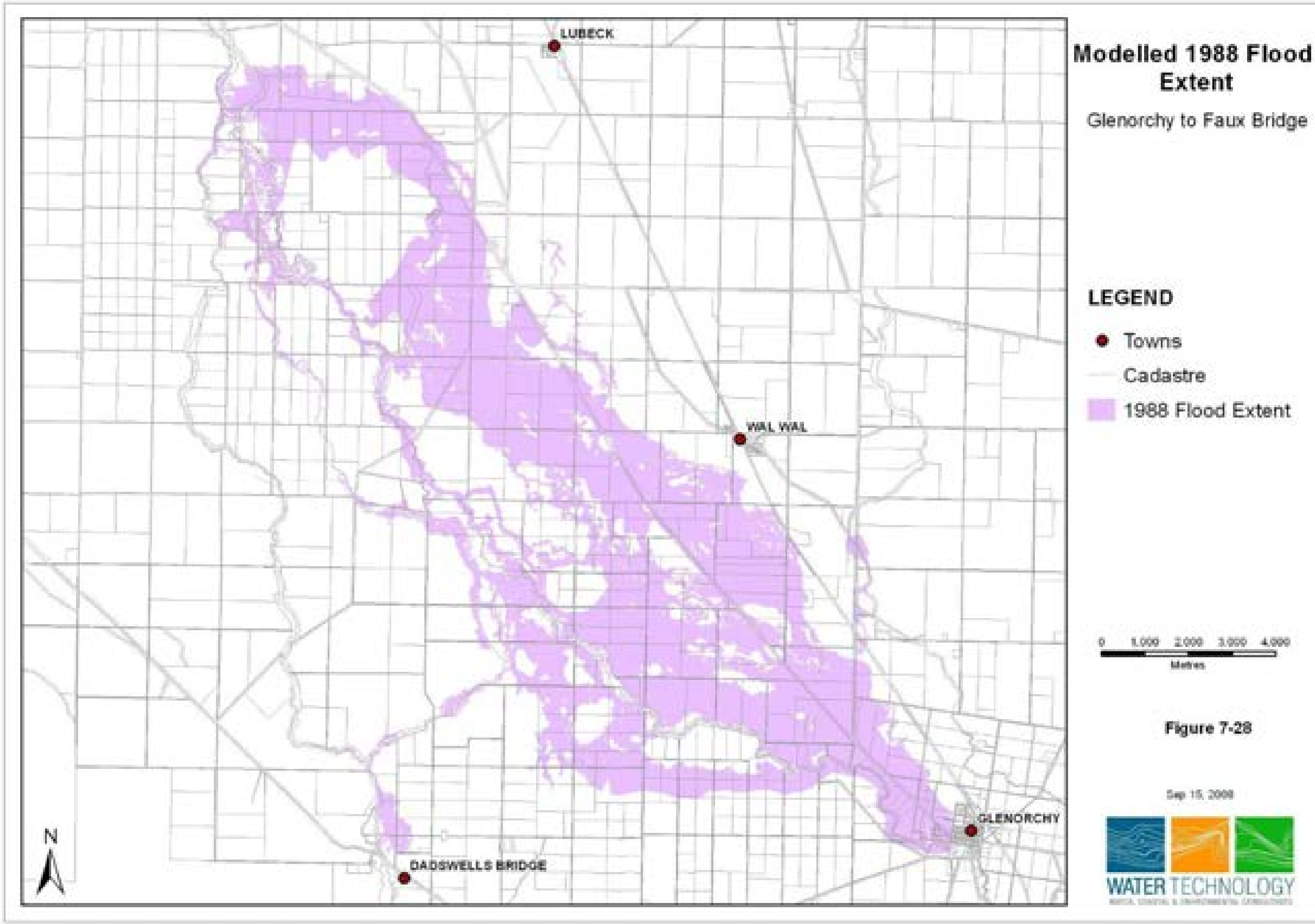

Figure 7-21 September 1988 Flood Event 2D modelled flood extents – Glenorchy to Faux' Bridge

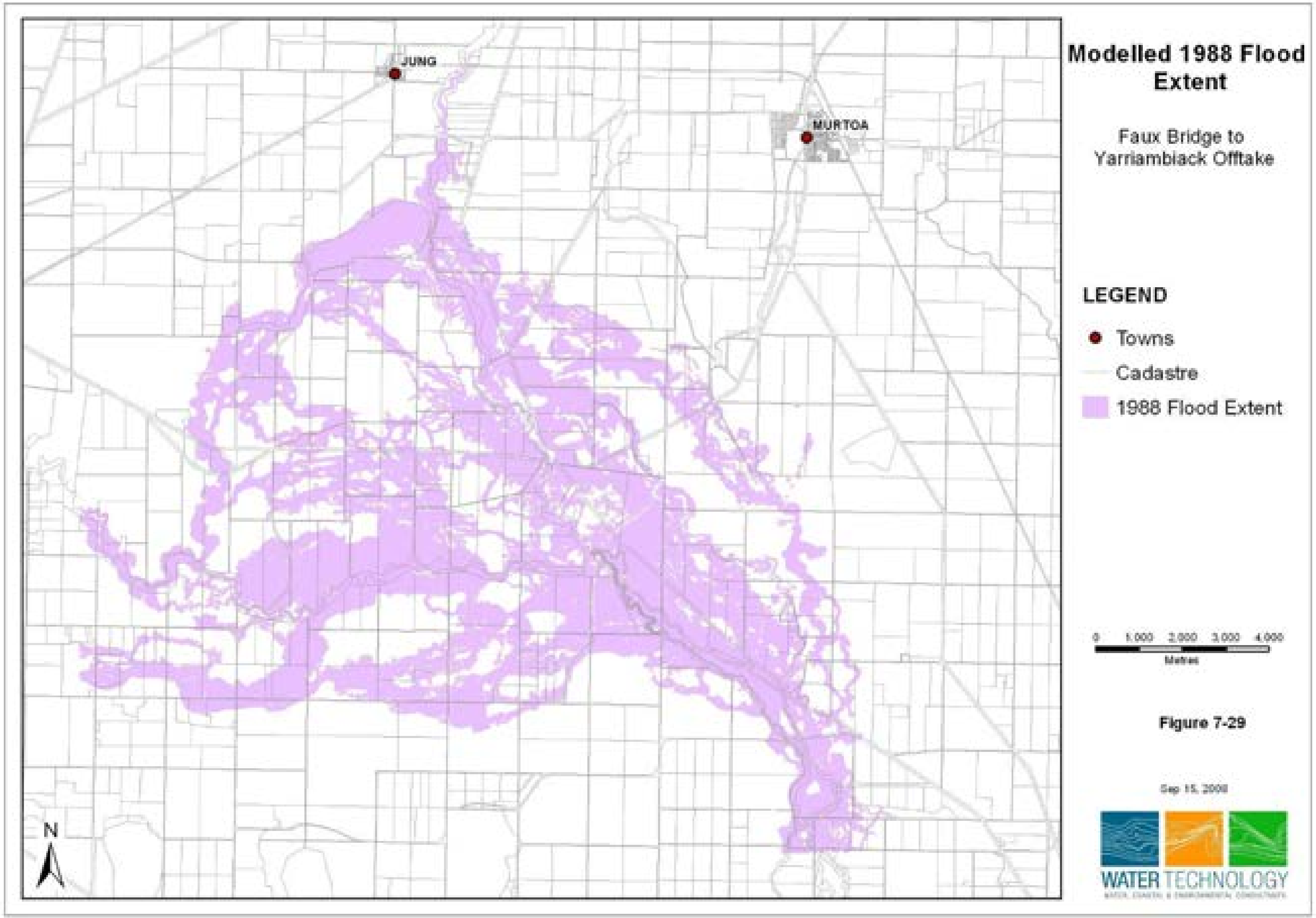

Figure 7-22 September 1988 Flood Event 2D Calibration Results – Faux' Bridge to Yarriambiack Offtake

7.4.3.5 October 1996

Comparison of observed and modelled streamflows was made at the following streamflow gauge:

- Wimmera River at Walmer (415200). Refer to Figure 7-23

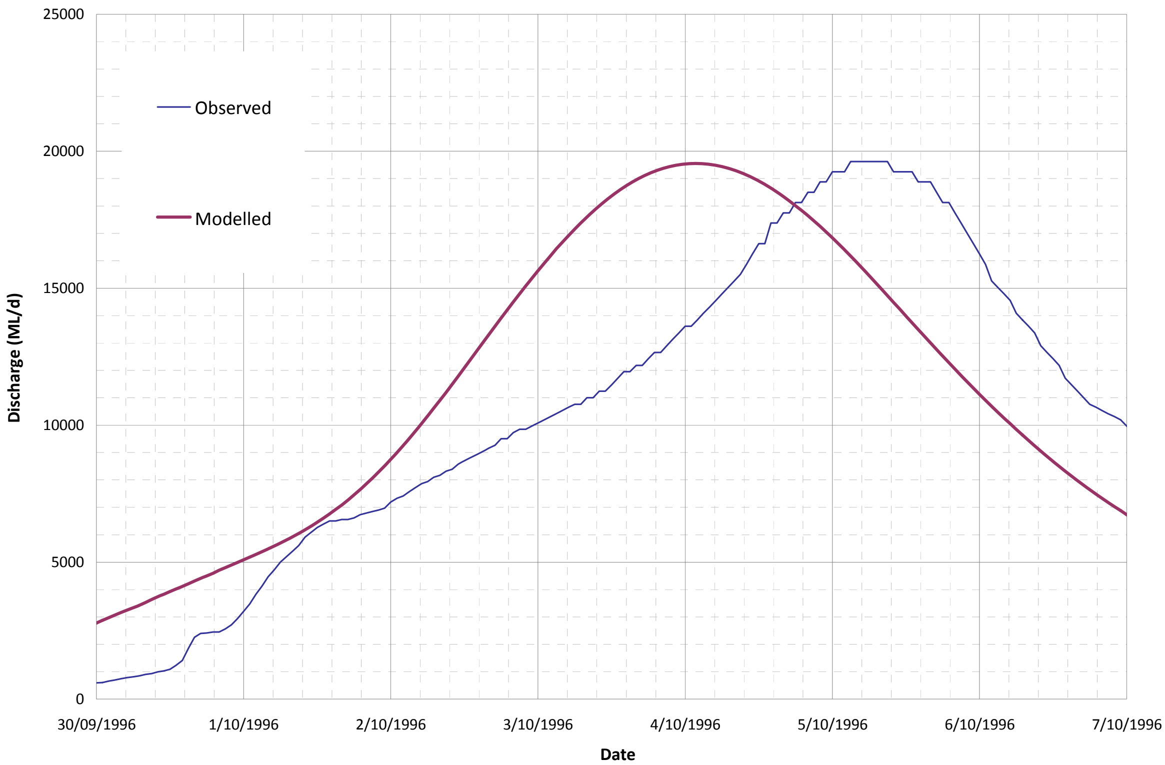

Figure 7-23 October 1996 calibration – Wimmera River at Walmer (415200)

As discussed, no observed flood levels were available for this event. However, partial observed flood extent was available. Figure 7-24 and Figure 7-25 displays a comparison of observed and modelled flood extents.

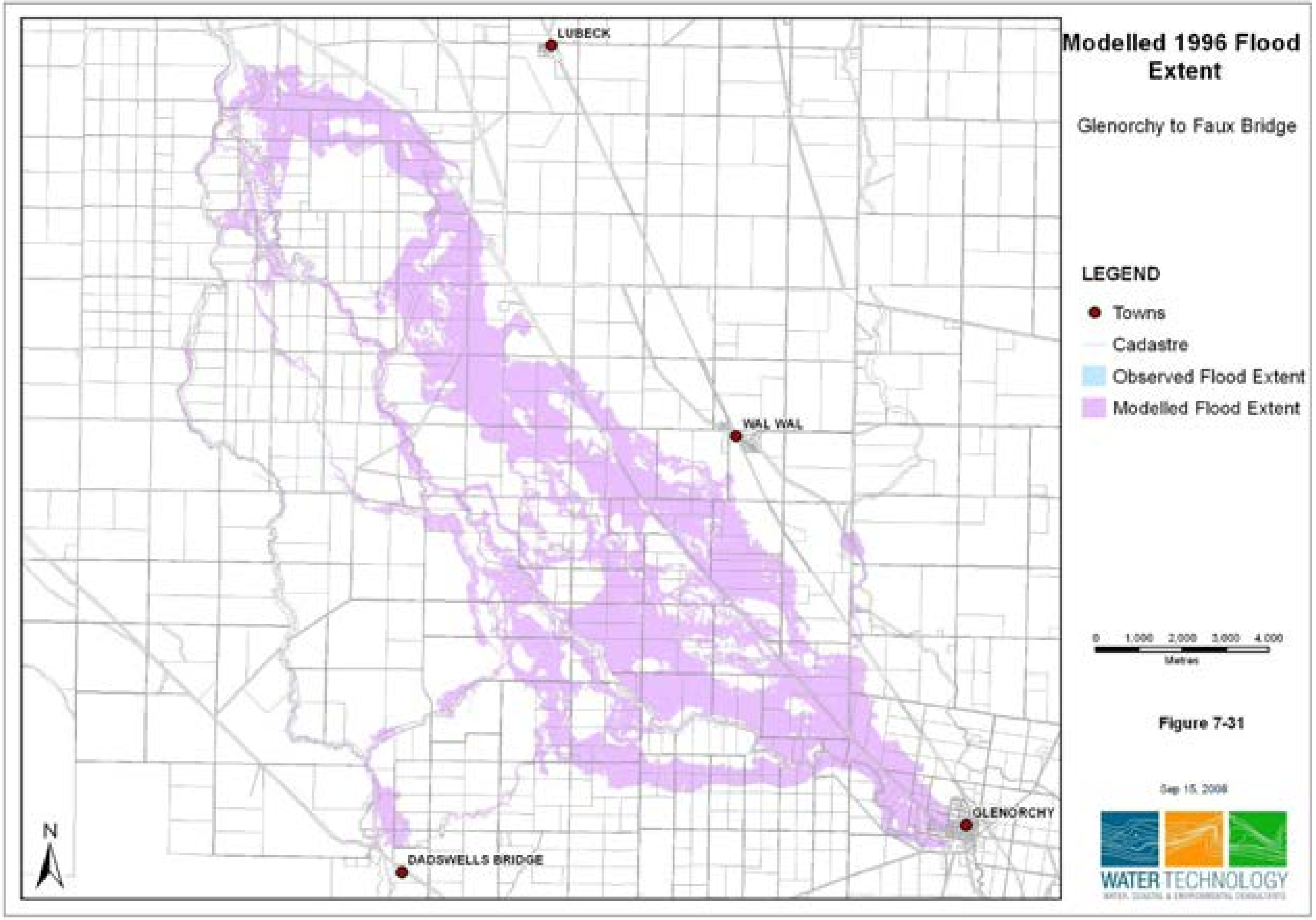

Figure 7-24 October 1996 Flood Event 2D calibration results – Glenorchy to Faux' Bridge

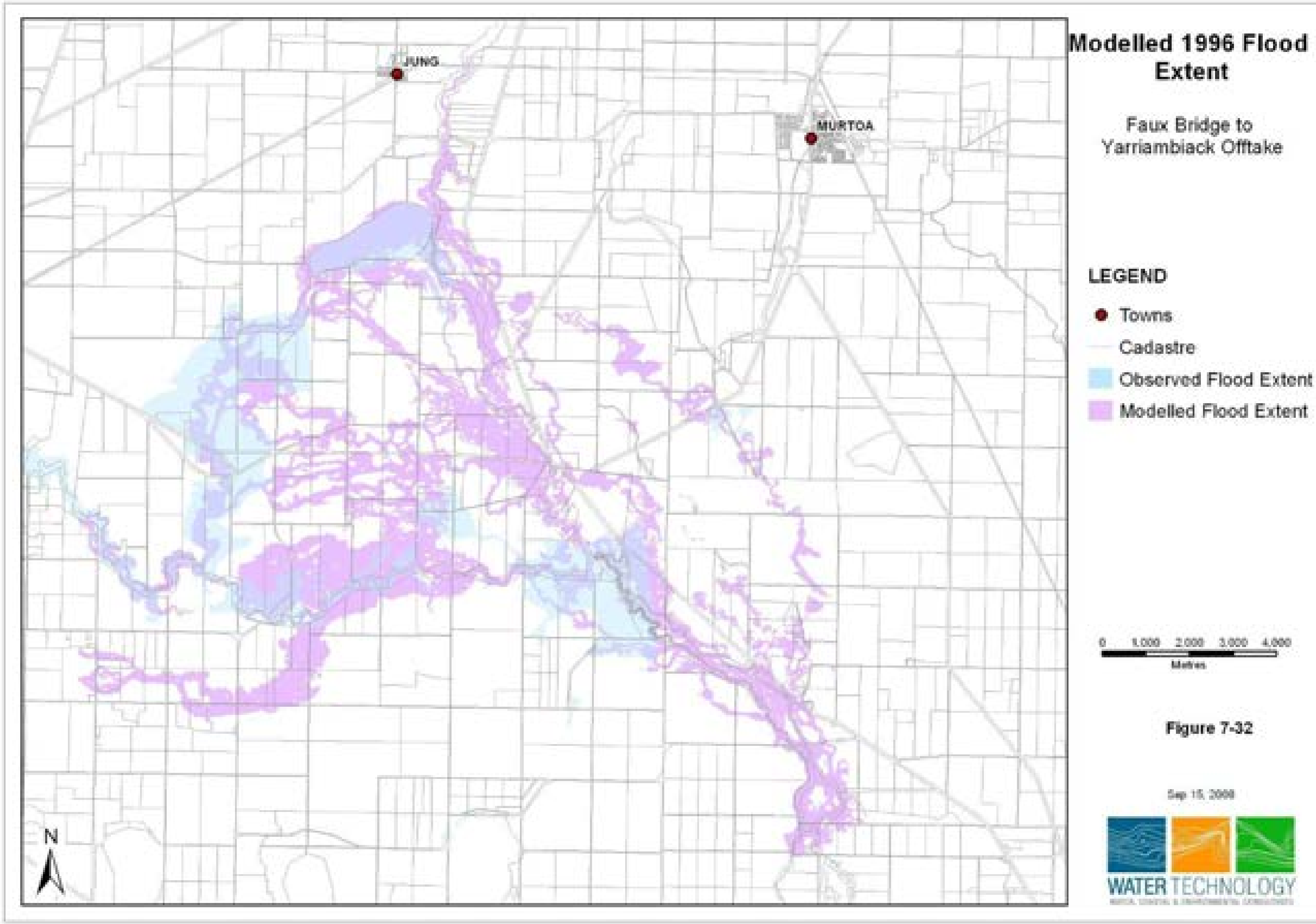

Figure 7-25 October 1996 Flood Event 2D calibration Results – Faux' Bridge to Yarriambiack Offtake

7.4.3.6 Discussion

The broad scale 2D floodplain model calibration focused on the simulation of flow and flood behaviour for large flood events. As outlined in Section 7.2, there are numerous sources of uncertainties influencing the model ability. This section discusses these uncertainties as they related to the 2D model.

The comparison of observed and modelled flow behaviour targeted four large events, August 1981, September 1983, September 1988 and October 1996. The available observed streamflow and water level data consisted of some 37 observed flood levels, observed flood extents for part of the study area, and water level and streamflow data from three gauges.

The flood events used in the model calibration have indicative AEPs ranging from 10% to 4% (10 year to 25 year ARI). The calibration events exhibited extensive floodplain flow and inundation.

The assessment of the broad scale 2D floodplain model's ability was constrained by the available observed streamflow as model inflow. The observed streamflow data for the Wimmera River at Glenorchy applied as model inflow. The other significant inflows, Mount William, Golton and Burnt Creeks were obtained from the URBS model (refer to Section 6.3). While the URBS model calibration is considered reasonable, there is likely to be significant uncertainty surrounding the modelled flows from the Mount William and Golton Creek.

The comparison of the modelled and observed streamflows revealed that the modelled peak flow was lower than the observed peak flow for Yarriambiack Creek at the Wimmera Highway. Further the general hydrograph shape was not well re-produced. As part of the model calibration process, the model schematisation and roughness were varied to improve the fit of modelled and observed hydrograph. A contributing factor to the differences may be the uncertainty surrounding the inflows to the hydraulic model from the hydrologic modelling, In particular, modelled inflows for Mount William Creek.

Peak flows and general hydrograph shape were well modelled for the Wimmera River at Walmer. As noted, the modelled hydrograph peaked some 24 hours early than the observed hydrograph. Again, uncertainty surrounding modelled Mount William Creek inflows was considered a contributing factor.

The mean differences in the modelled flood levels are -0.07 m and -0.10 m for the 1981 and 1983 flood events respectively. The median differences are a same magnitude with -0.03 m and -0.12 m for the 1981 and 1983 flood events respectively. For the August 1981 flood event, 12 of 20 modelled levels, and 10 of 17 modelled levels for the September 1983 are within +/- 0.20 m. As noted in Table 7-3 and Table 7-4, there are larger differences in modelled flood levels are some locations. These larger differences may arise from the following sources:

- Local feature influencing the adjacent flood behaviour not captured in the available topographic data and/or not represented in the model schematisation e.g. local embankment/bund.
- Errors in the measurement of the observed flood levels e.g. not at flood peak
- Errors in the specification of the model inflows from ungauged catchments.
- Flooding from local drainage rather than riverine flooding, and not captured in the hydraulic modelling framework.

The sources of uncertainty influencing the hydraulic model outputs were discussed in Section 7.2. Bearing these uncertainties in mind, the study team considers the model calibration for the broad 2D floodplain model as suitable for the purposes for assessing general flood behaviour across the Wimmera River floodplain. As noted in Section 7.2, a quantitative assessment of model performance is problematic. The comparison of modelled and observed flood behaviour supports the model's ability to simulate broad scale flood behaviour.

7.4.4 2D local scale hydraulic model calibration

7.4.4.1 Wimmera River - Yarriambiack Creek offtake model

Thiess Hydrographic Services undertook flow gauging at three locations adjacent to the offtake during an environmental water release on 24/9/2007. Furthermore, the Wimmera CMA installed five water level sensors to adjacent to the offtake tied in to Australian Height Datum. Figure 7-26 displays the location of flow gaugings (in red) and water level sensors (in orange).

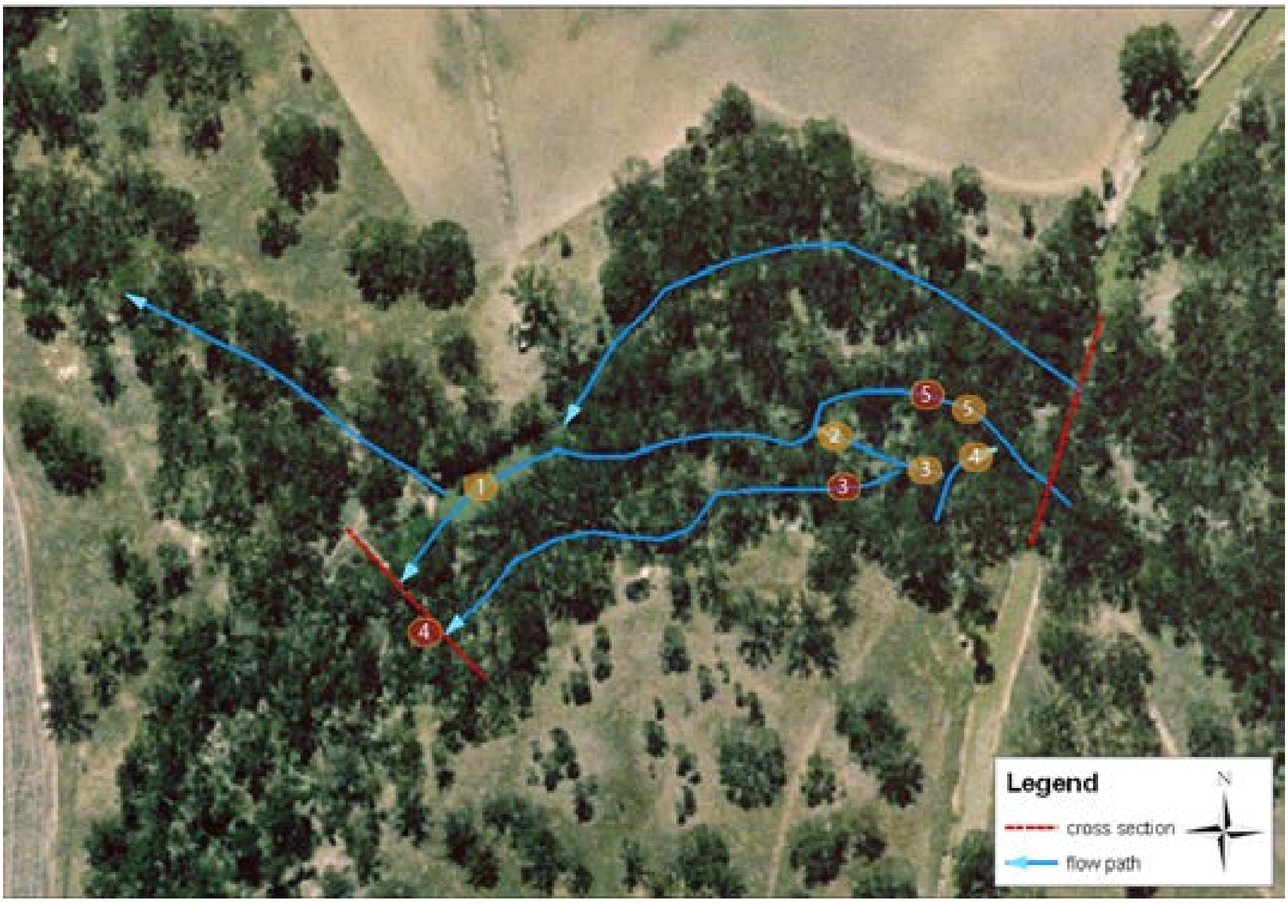

Figure 7-26 Wimmera River – Yarriambiack Creek offtake – Locations of Thiess flow gauging and Wimmera CMA pressure sensors.

The release was made from the Taylor's Lake Outlet Channel at the Wimmera River syphon. There is uncertainty surrounding the flow rate during the release. The peak flow was considered not to exceed 60 ML/d.

During the course of the model calibration modelling, model instability (errors) occurred for very low flow (less than 173 ML/d (2m^3/s). These instabilities were due to the simulation of flow scenarios with very shallow depths across a large portion of the principal flow paths. These instabilities are inherent within hydraulic models. It reflects the breakdown in the validation of the key assumptions in the hydraulic model including hydrostatic pressure and Manning's (friction/roughness) equation.

As a result, it was not possible to run the local scale 2D model hydraulic model for a flow equivalent to the September 2007 release. The model's instability persisted for flows less than 173 ML/d (2m^3/s).

The local 2D hydraulic model was run with an inflow of 173 ML/d (2 m^3/s). A general validation of model performance was undertaken through the comparison of modelled and observed water levels, refer to Table 7-5. The modelled water levels in Table 7-5 were found to be considerably higher the observed water levels. This is mainly due to the modelled flow being considerably higher than the release flows.

Table 7-5 Wimmera River – Yarriambiack Creek offtake – Local scale 2D model validation – September-October 2007

Location	Measured flow/water level	Modelled flow/water level
Sensor 1	134.34 m AHD	134.61 m AHD
Sensor 2	134.42 m AHD	134.83 m AHD
Sensor 3	134.70 m AHD	135.26 m AHD
Sensor 4	134.20 m AHD	135.10 m AHD
Sensor 5	134.54 m AHD	134.85 m AHD

As the model was unable to simulate flow of a similar magnitude to the releases, the calibration of the local 2D hydraulic model is constrained.

7.4.4.2 Yarriambiack Creek at the Wimmera Highway Bridge

The local scale 2D model for the Wimmera Highway Bridge was calibrated to the available streamflow and water level data from the gauge at the Wimmera Highway Bridge (415241). The two calibration events selected were August 1981 and September 1983, due to the availability of observed data. The aim of this calibration was to verify the simulation of flood behaviour adjacent to the bridge.

For the model calibration, the inflows to the local scale 2D model were taken as the observed flows at the Wimmera Highway. The use of observed flows removes any errors in flood levels due to errors in the model inflows. The

The peak observed flood level at Wimmera Highway (415240), for the August 1981 and September 1983 events, were 132.932 m AHD and 132.935 m AHD respectively. These compare well to the peak modelled levels of 132.95 m and 132.94 m AHD.

The comparison of modelled and observed water levels shows good agreement. This good agreement indicates the flow behaviour adjacent to the bridge is well simulated. However, it should be noted, that the observed flows at the bridge were employed as the local model inflows. As such, the calibration of the local scale 2D model does not reflect any uncertainties in the modelled hydrographs at the bridge from the broad scale 2D model (refer to Figure 7-12 and Figure 7-16). The same representation of the bridge structure was employed in both the local and broad scale hydraulic models. The calibration of the local scale model underpins the reliable simulation of the bridge structure hydraulics in the broad scale 2D model.

8 HYDRAULIC MODEL APPLICATION

8.1 Overview

This section discusses the application of the hydraulic model to the simulation of flow characteristics under various catchment and waterway scenarios.

The development and calibration of the hydraulic models, discussed in Section 7, underpins the simulation of flow behaviour characteristics (flow depths, extents and velocities) within the channel and across the floodplain.

As discussed in Section 2, hydraulic analysis was required for both low-medium (in-channel) flow scenarios and high flow (flood) events. The hydrologic analysis, discussed in Sections 5 and 6, provides the inflow hydrographs for the various flow scenarios to be considered in the hydraulic model application. In addition to the low and high flow scenarios, the hydrologic analysis provides flow scenarios for pre-European and current catchment conditions. Within the hydrologic analysis, changes to catchment conditions with European settlement considered included water resources developments (major storages and diversions).

Changes to the waterway – floodplain form within the study area, such as levees, channels, drains and diversions, were reflected in changes to the hydraulic model topography as part of the hydraulic model application.

The project brief provides the following guidance regarding the flow scenarios regimes to be simulated by the hydraulic model:

- to assess flow and flood behaviour at a range of flows (Wimmera River 0ML/day to bankfull (~ 6,000ML/day) and floods (5, 10, 20, 50, 100 and 200 year ARI) based on current and pre-European conditions (pre-1800)

For the low-medium flow regime, the project brief specifies that "a range of flows Wimmera River 0 ML/d to 6000 ML/d (bankfull)" be considered. The study team developed, in consultation with the Wimmera CMA, flow scenarios for assessment. Section 8.2 details the low-medium flow scenario assessment.

The above guidance provides a clear direction for the assessment of flood events. The derivation of required design flood hydrographs was undertaken in accordance with industry practice, as outlined in *Australian Rainfall and Runoff* (IEAust, 1997). The hydrologic analysis, Section 6, details the derivation of the design flood hydrographs. The design flood hydrograph defined peak flow, flood volume, flood duration and relative contributions at various inflow locations. Section 8.3 discusses the high flow (design flood) scenario assessment.

A key outcome of this project was improved understanding of the flow distribution between the Wimmera River and Yarriambiack Creek. Section 8.4 summaries the key project findings related to the Wimmera River – Yarriambiack Creek flow distribution, and compares this project findings with previous investigations.

8.2 Low- medium flows

8.2.1 Background

For the low – medium flow scenarios, consultations were undertaken with the Wimmera CMA to specify the following:

- Inflow locations
- Relative contributions at the specific inflow scenarios.
- Inflow hydrograph shape (peak flows, flow volumes, flow duration)

In the specification of the above inflow characteristics, the following aspects were considered:

- Hydraulic model structure and capability
- Current and pre – European streamflow regimes
- Environmental flow requirements, as outlined in SKM (2003a) and SKM (2005)
- Environmental flow delivery constraints, as outlined in SKM (2008)

These sections provide background to the above five aspects.

8.2.1.1 Hydraulic model structure and capability

Before determining the low – medium flow scenarios, the study team considers a brief discussion of the model structure and capabilities is required to set the background context.

As discussed in Section 2.4, a flexible hydraulic modelling framework was employed. This framework allowed the accurate representation of flow behaviour over the full range of flows balanced against excessive simulation times.

The robust calibration of the hydraulic modelling framework provides confidence in the modelling outputs, as discussed in Section 7. The calibration of the 1D model has focussed on the re-production of the flows up to bankfull within the entire study area. The modelled outputs have been compared to observed flows at streamflow gauge locations. Good agreement of the modelled and observed flows at the gauges underpins the model simulation of flow behaviour. However, good agreement at the gauges does not directly infer the 1D model performance at all locations away from the gauges. Flow behaviour at other locations, away from the gauges, can only be validated by observed streamflow data at a given location.

The 2D models were calibrated to four significant flood events, 1981, 1983, 1988 and 1996. The availability of observed flood data for these calibration flood events varies, with a number of observed flood levels available throughout the study area, and observed streamflows at the gauges. As for the 1D model, the calibration of the 2D model provides confidence in the model's predictive capability.

The hydraulic model provides flow behaviour, flow depth, flow velocity and flow path connectivity, at the spatial and temporal resolution outlined above for the specific modelling component.

The hydraulic analysis provides a time-series of water levels, depths, and velocities at the model resolution. For the 1D model the model resolution is the cross-section spacing, typically 150 m – 300 m, and for the 2D model at the grid resolution of 25 m. This time-series data can be subjected to a variety of hydrologic analyses, as such frequency analysis, exceedance curves, and spells analysis. Further, the hydraulic analysis provides indicative flow thresholds at which anabranches commence to flow.

8.2.1.2 *Current and pre – European streamflow regimes*

The study brief requires the consideration of the flow regimes under current and pre-European catchment conditions. As discussed in Section 2, the considerations of these two flow regimes within the hydrologic and hydraulic analyses were as follows:

- The hydrologic analysis provides the inflows to the study area (hydraulic model). The changes in catchment conditions, such as water resource development (storages and diversions), and farm dams influence the study area inflow regime. The derivation of streamflow regimes, both low – medium and high (flood) flows, requires the hydrologic analysis to consider these influences.
- The hydraulic analysis simulates flow behaviour within the study area, given an inflow regime. The hydraulic model structure is altered to reflect the topographic features in the waterways and along floodplains, such as levees, channels, and diversions. Further discussion is provided below.

For the low-medium flow scenarios, the influence of current water resources development and catchment changes have been considered by the derivation of daily flow sequences outlined in SKM (2003a). This analysis derived daily flow sequences for the period January 1990 to December 2000 (11 years) under natural and current catchment conditions. These flow sequences were employed in the development of the Bulk Entitlement assessment for the Wimmera catchment (SKM 2003c). As such, the use of these flow sequences in this study provides consistency with the Bulk Entitlement assessment. SKM (2003a) applied a rigorous approach within the limitations of the available data.

Within the hydraulic analysis, the key changes from the pre-European waterway-floodplain conditions to current conditions included levees, embankments, bridges and modifications to waterway geometry.

8.2.1.3 *Environmental flow requirements*

Environmental flow requirements, for the Wimmera River, were recommended by SKM (2002b) for the following reaches, with compliance points:

- Glenorchy to Huddleston's Weir (Reach 1): Compliance point – Glenorchy (Gauge 415201)
- Huddleston's Weir to Mount William Creek (Reach 2): Compliance point – Faux' Bridge (Gauge 415240) – currently inactive
- MacKenzie River to Lake Hindmarsh (Reach 4/5): Compliance point – Dimboola (Gauge 415243) – currently inactive

The flow requirements for Mount William Creek to MacKenzie River (Reach 3) were not provided in SKM (2003), due to unavailability of hydrological data. Only Reaches 1, 2 and 3 are of relevance to this study. SKM (2005) recommended environmental flow requirements for Mount William Creek. Also, the environmental flow requirements for Yarriambiack Creek, downstream of the offtake, were outlined in SKM (2003).

Table 8-1 displays the environmental flow requirements for Wimmera River Reaches 1 and 2 (SKM 2002b), Mount William Creek downstream of Lake Lonsdale (SKM 2005) and Yarriambiack Creek downstream of the offtake (SKM 2003).

Table 8-1 Wimmera River Environmental flow requirements – Reaches 1 and 2 (SKM 2002b), Mount William Creek downstream of Lake Lonsdale (SKM 2005) Yarriambiack Creek downstream of the off take (SKM 2003)

Reach	Season	Recommendation	Magnitude	Frequency	Duration
Wimmera River: Glenorchy to Huddleston's Weir	Summer	1.1	0 ML/d	Annual	17-30 days
		1.2	Minimum median flow 6 ML/d	Annual	Dec- May
		1.3	> 16 ML/d	3 annually	Min. 5 days
	Winter	1.4	25 ML/d Min. passing flow	Daily	July – November
		1.5	Min. 10 % inflows passed	Daily	July – November
	Annual	1.6	5,500 ML/d	Annual	Min. 5 days
Yarriambiack Creek: downstream of offtake and downstream of Wimmera Highway Bridge	Summer	6.1	0 ML/d	Annual	Max 365 (or natural)
	Winter	6.2	> 80 ML/d	Annual	Min 3 days
		6.3	> 400 ML/d	Annual	Min 1 day
Mount William Creek: Lake Lonsdale to Wimmera River	Summer		0	Annual	Max 48 days
			> 5 ML/d	3 annually	5 days
	Winter		29 ML/d	Daily	June-November
			143 ML/d	2 annually	July-October
Wimmera River : Huddleston's Weir to Mount William Creek	Summer	2.1	0 ML/d	Annual	17-30 days
		2.2	Minimum median flow 6 ML/d	Annual	Dec- May
		2.3	> 16 ML/d	3 annually	7 - 15 days
	Spring	2.4	> 164 ML/d	2-3 annually	Min. 14 days
		2.5	Minimum flow 60 ML/d	Annual	July – November
	Annual	2.6	5,500 ML/d	Annual	Min. 2 days

The above environmental flow requirements utilised a simple hydraulic analysis approach to assess flow behaviour at 4 sites within Reaches 1, 2, and 3. This study has developed a sophisticated hydraulic model, and provides the means for a review of the flow behaviour previously assessed by SKM (2002b).

The initial conditions, water levels along the river prior to the commencement of a proposed scenario influence the modelled flow behaviour. The following two conditions reflect lower and upper bounds:

- Dry bed: - no water in pools. This condition represents the lower limit after a prolonged dry spell. Initial flow in the proposed scenario would fill the pools then overflow to downstream reaches.
- Wet bed: - significant pools filled to downstream control level. This condition represents the upper limit.

8.2.1.4 Environmental flow delivery constraints

The delivery of environmental flows releases is constrained by infrastructure capacity. Limited outlet capacity is available at Lake Lonsdale, Glenorchy Weir and Huddleston's Weir to contribute towards the environmental flow requirements. Similarly, the outfall capacity from the Taylor's Lake Channel to the Wimmera River is limited.

Recent modifications to Huddleston Weir and proposed changes to the operation of Glenorchy Weir, as part of the Wimmera Mallee pipeline project, will enable additional unregulated low – medium flows to be delivered to Wimmera River below Huddleston's Weir.

SKM (2008) identified influences on environmental water delivery along the Wimmera River downstream of Glenorchy, and EarthTech (2007) undertook similar investigations along Yarriambiack and Mount William Creeks. Both studies considered water extractions, channel constrictions, vegetation obstructions and culvert crossings. Preliminary hydraulic analyses were undertaken to assess the impacts of these influences on various environmental flow recommendations.

8.2.2 Proposed low – medium flow scenarios

Taking into the account the above aspects, the study team proposed a number of low-medium flow scenarios for investigation by the hydraulic modelling framework.

Combining the hydrologic and hydraulic changes from the pre-European to current conditions, gives rise to the following two proposed scenarios:

1. Pre-European waterway and floodplain conditions simulated over the natural daily sequence from January 1990 to December 2000.
2. Current waterway and floodplain conditions simulated over the current daily sequence from January 1990 to December 2000.

Comparison of flow behaviour between the above two scenarios provides insight into the influence of water resource development. The study team suggested, as a starting point, the low-medium flow scenarios considered by this study should reflect the above environmental flow requirements. To this end, the following scenarios were suggested (the numbering of proposed scenarios continues from the previous section):

3. Steady flow 6 ML/d at Glenorchy: to provide understanding the flow path connectivity at low flows.
4. Steady flow 16 ML/d at Glenorchy: 7 days duration: to assess summer freshes and anabranch connectivity.
5. Steady flow 164 ML/d at Huddleston's Weir: 7 days duration: to gain insight for spring freshes and anabranch connectivity.

6. Steady flow 5,500 ML/d at Glenorchy: 7 days duration: to assess bank full events and anabranch connectivity.
7. Daily time-series of Glenorchy Weir 10 % passing with a minimum of 25 ML/d: Period 1990 – 2000: to assess change flow behaviour of Huddleston Weir given a potential alteration to the structure.

The study team's suggested low-medium flow scenarios are summarised in Table 8-2.

Table 8-2 Suggested low- medium flow scenarios

Scenario number	Flow specification	Purpose
1	Pre-European waterway and floodplain conditions simulated over the natural daily sequence from January 1990 to December 2000.	Assess pre-European flow behaviour
2	Current and floodplain conditions simulated over the current daily sequence from January 1990 to December 2000.	Assess current flow behaviour
3	Steady flow 6 ML/d at Glenorchy	Provide understanding the flow path connectivity at low flows
4	Steady flow 16 ML/d at Glenorchy: 7 days duration:	Assess summer freshes and anabranch connectivity.
5	Steady flow 164 ML/d at Huddleston's Weir: 7 days duration	Gain insight spring freshes and anabranch connectivity.
6	Steady flow 5,500 ML/d at Glenorchy : 7 days duration	Assess bank full event and anabranch connectivity.
7	Daily time-series of Glenorchy Weir 10 % passing with a minimum of 25 ML/d: Period 1990 – 2000	To assess change flow behaviour downstream of Huddleston's Weir given a potential alteration to the structure.

8.2.3 Agreed low-medium flow scenarios

Following consideration of the suggested flow scenarios by the Wimmera CMA, the following the low-medium flow scenarios were adopted:

- Two time-series scenarios (Scenarios 1 and 2) as outlined in Table 8-2
- Five event scenarios as follows:

Number	Flow Description	Wimmera River	Mount William Ck (below Lake Lonsdale)
3	*Summer low flow & fresh*	6 ML/day flow with 3 freshes of 16 ML/day for 5 days @ Glenorchy	0 ML/day with 3 freshes of 5 ML/day for 5 days
4	*Winter base flow and high flow*	60 ML/day with 2 high flows of 164 ML/day for 14 days @ Huddleston's weir	29 ML/day with 2 high flows of 52 Ml/day for 7 days
5	*Winter bankfull flow*	60 ML/day with 1 bankfull flow of 5500 ML/day for 2 days@ Glenorchy	29 ML/day with 1 bankfull flow of 500 ML/day for 2 days
6	*Winter very high flow*	60 ML/day with 1 very high flow of 1000 ML/day for 5 days @ Huddleston's Weir	29 ML/day with 1 very high flow of 143 ML/day for 5 days
7	*Winter extremely high flow*	60 ML/day with 1 extremely high flow of 3000 ML/day for 2 days @ Glenorchy	29 ML/day with 1 extremely high flow of 300 ML/day for 5 days

The flow events on the two waterways were assumed to coincide. For the bankfull and very high flows, the flow hydrograph shape was assumed to rise over one day to the peak and then fall back to the baseflow over one day.

8.2.4 Key hydraulic model application

8.2.4.1 Long term flow simulation

Wimmera CMA (Greg Fletcher pers. Comms.) provided daily flow sequences for the existing and pre-European catchment conditions for the following hydraulic model inflow points:

- Wimmera River at Glenorchy
- Mount William Creek between Lake Lonsdale and the Wimmera River confluence

These daily flow sequences were derived by SKM (2003a), as discussed in Section 5. The daily flows sequences extended from 1 January 1990 to 31 December 2000.

Comparisons of flow duration curves display the changes in flow behaviour due to floodplain-waterway-catchment conditions over the period January 1990 to December 2000. Figure 8-1, Figure 8-2 and Figure 8-3 show the flow duration curves for the Wimmera River at Glenorchy, Horsham Lubeck Road, and for Yarriambiack Creek at the Wimmera Highway Bridge respectively.

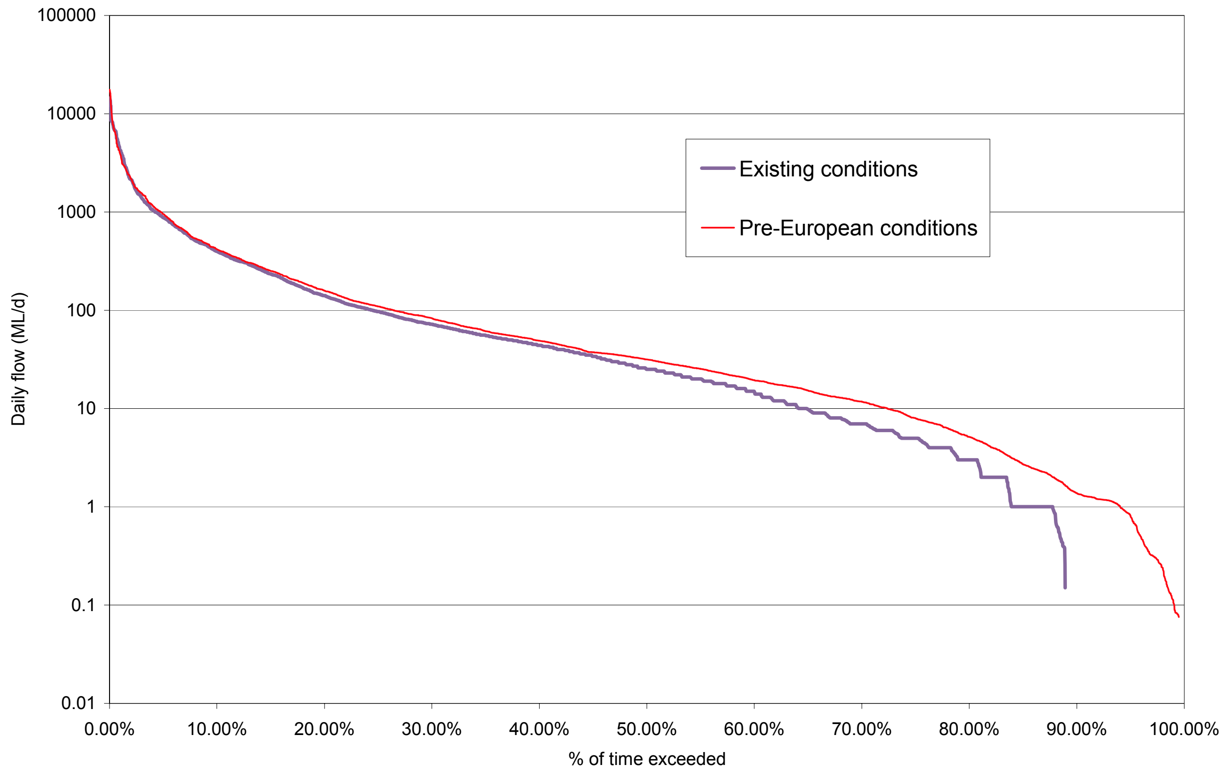

Figure 8-1 Wimmera River at Glenorchy – Flow duration curve- Existing and pre-European conditions

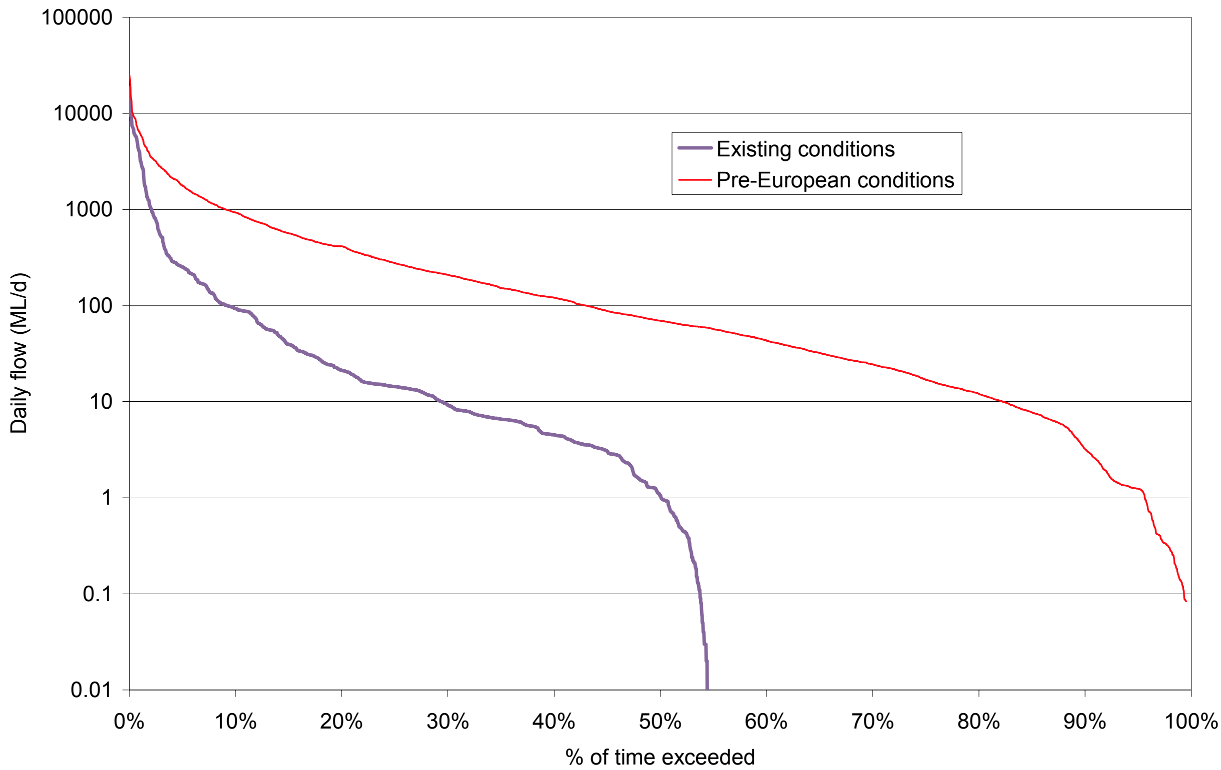

Figure 8-2 Wimmera River at Horsham Lubeck Road – Flow duration curve- Existing and pre-European conditions

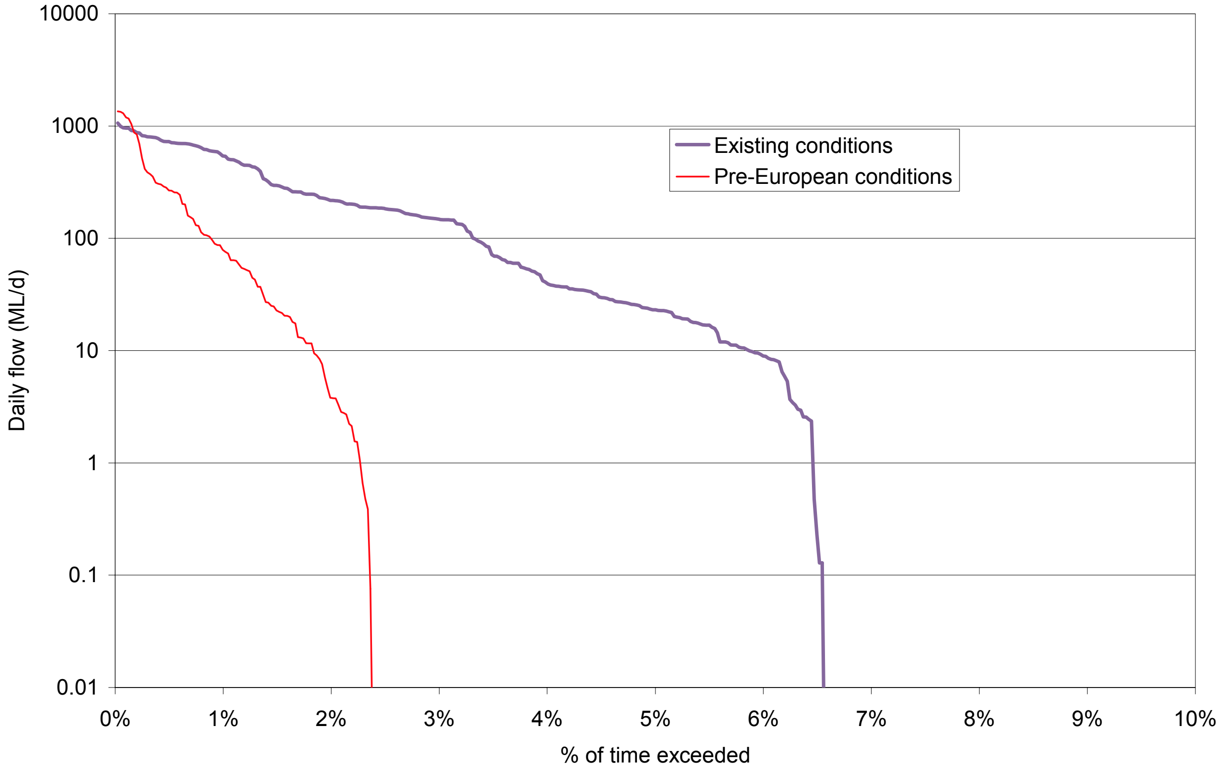

Figure 8-3 Yarriambiack Creek at the Wimmera Highway – Flow duration curve-Existing and pre-European conditions (Note difference in X axis scale)

At Glenorchy, the flow duration curves exhibited a similar shape, with the differences due to diversion and farm dams in the upper catchment (SKM 2003a). The reduced flows under the existing conditions for the Wimmera River at Horsham Lubeck Road was due to the diversion of Wimmera River flows at Huddleston's Weir. The percentage of time daily flows exceed 10 ML/d reduced from 82 % (pre-European conditions) to 29 % (existing conditions).

For Yarriambiack Creek at the Wimmera Highway, small reduction in high flows (>1000 ML/d) has occurred in the existing conditions from the pre-European conditions. However, for the remaining flow regime (< 1000 ML/d), there was an increase in the flow exceedance. The percentage of time daily flows exceed 10 ML/d increased from 2 % (pre-European conditions) to 6 % (existing conditions). This increase was due to the lowering of the offtake invert.

8.2.4.2 Environmental flows site flow behaviour assessment

As the flows are less than bankfull, the flow behaviour for summer low flows/freshes, winter baseflow/high flow and winter very high flows steady state scenarios (scenarios 3, 4 and 6) was simulated using the 1D model. The linked 1D-2D model was used to assess flow behaviour for the winter bankfull flow and winter extremely high flow scenarios (5 and 7).

For the six environmental flows sites, the water levels at each cross section under the steady state flow scenario were determined. Figure 8-4 displays the water level at the upstream cross section for Site 3 Wimmera River at Hall's Island (SKM 2002b). The water level cross section water plots for the environmental flow sites are provided in Appendix E.

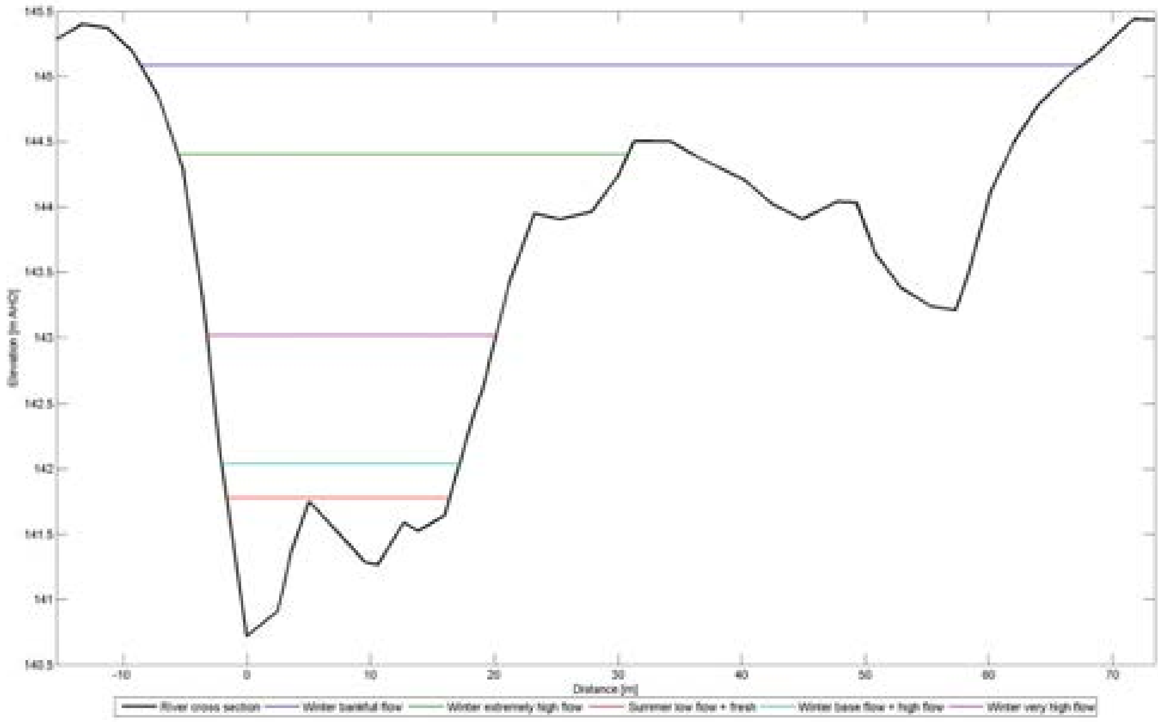

Figure 8-4 Wimmera River at Halls Island (Mount William Creek) (Environmental Flows site 3 (SKM 2002b)) upstream cross section) – Water level cross section plots

8.2.4.3 Anabranch and floodplain connectivity assessment

Through the simulation of flow behaviour for the low-medium flow scenarios, the bankfull capacity and floodplain connectivity has been assessed.

For the Wimmera River Reach, Glenorchy to Horsham-Lubeck Road, the linked 1D-2D hydraulic model was employed to simulate the winter bankfull flow and winter extremely high flow scenarios (5 & 7). Figure 8-5 and Figure 8-6, displays the floodplain inundation for the winter bankfull flow and winter extremely high flow scenarios respectively for the Glenorchy to Horsham-Lubeck Road reach.

For the hydraulic analysis, key flow characteristics for the Wimmera River (Glenorchy to Horsham-Lubeck Road) and Station Creek were assessed as shown in Table 8-3 and in Figure 8-5.

Table 8-3 Key flow characteristics – Wimmera River and Station Creek

Reach	Indicative bankfull capacity/commence to flow
Wimmera River – Glenorchy to Huddleston Weir	3200 ML/d (37 m^3/s)
Wimmera River –Huddleston Weir to Station Creek confluence	4700 ML/d (55 m^3/s)
Station Creek	Bankfull capacity: 1900 ML/d (22 m3/s) Commence to flow threshold for the Wimmera River: 2160 ML/d (25 m^3/s)
Wimmera River – Station Creek confluence to Middle Creek confluence	4700 ML/d (55 m^3/s)
Wimmera River –Middle Creek confluence to Mount William Creek confluence (Halls Island)	4700 ML/d (55 m^3/s)
Wimmera River – Horsham – Lubeck Road to Yarriambiack Creek offtake	3900 ML/d (45 m^3/s)

For Wimmera River Reach, Horsham-Lubeck Road – Dooen Swamp – Jung Weir, the two high winter flows (Scenario 5 and 7) were simulated using the linked 1D-2D hydraulic model. This simulation assessed the flow distribution for medium flows (3000- 6000 ML/d) between Wimmera River and Yarriambiack Creek. The flow distribution for low flows (less than 3000 ML/d) is discussed in Section 8.2.4.5.

In this medium flow range, Wimmera River only enters Yarriambiack Creek at the offtake. There are no overland flow breakouts from the Wimmera River. Figure 8-7 and Figure 8-8 displays the floodplain inundation for the winter bankfull flow and winter extremely high flow scenarios respectively for the Horsham-Lubeck Road – Dooen Swamp – Jung Weir reach. As seen in Figure 8-7 and Figure 8-8, flow from the Wimmera River enters Yarriambiack Creek at the offtake and continues north. Some flow fills Darlot Swamp and returns to the Wimmera River via Two Mile Creek. The remainder of the flow continues along Yarriambiack Creek and passes through the Wimmera Highway Bridge.

The two flow scenarios were also simulated for pre-European waterway-floodplain conditions using the linked 1D-2D model.

Table 8-4 displays the flow distribution under the existing and pre-European floodplain-waterway conditions for the medium flow range (3000 – 6000 ML/d) using the linked 1D-2D model.

In the winter bankfull flow scenario, the peak flow entering Yarriambiack Creek is 1198 ML/d (20% of the Wimmera River peak flow upstream of the offtake) under the existing conditions. This peak flow in Yarriambiack Creek is reduced to 677 ML/d (11% of the Wimmera River peak flow upstream of the offtake) at the Wimmera Highway. This reduced flow arises due to some flow entering and then filling Darlot Swamp. The peak flow returning to Wimmera River via Two Mile Creek is 190 ML/d. In terms of the flow volume, 25% of the Wimmera River flow volume enters Yarriambiack Creek, with 15% of the Wimmera River flow volume passing the Wimmera Highway Bridge. A small portion (1% of the Wimmera River flow volume) returns the Wimmera River via Two Mile Creek. The remainder of the flow volume is stored in Darlot Swamp.

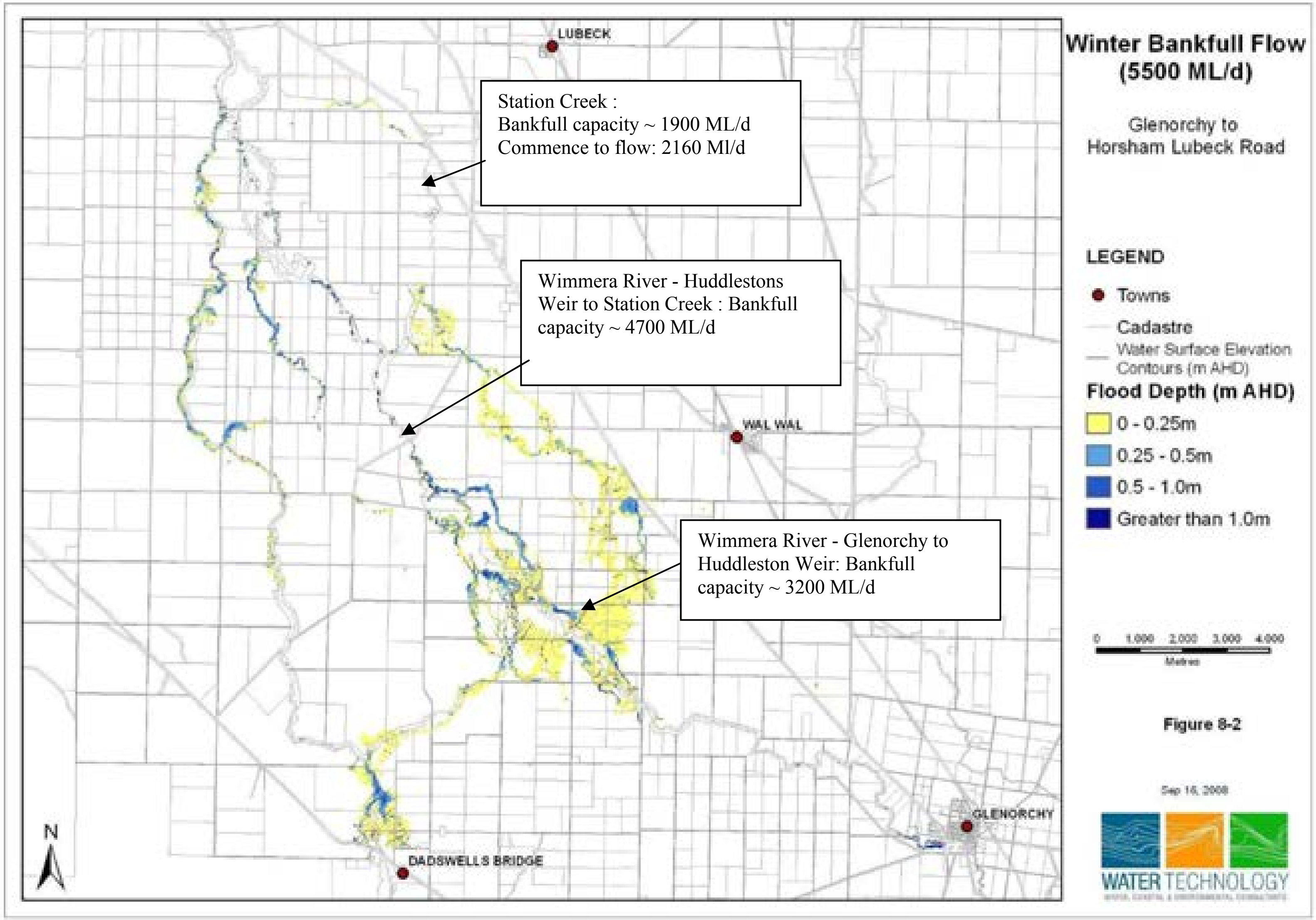

Figure 8-5 Wimmera River – Glenorchy to Horsham Lubeck Road – floodplain inundation for winter bankfull flow (5500 ML/d)

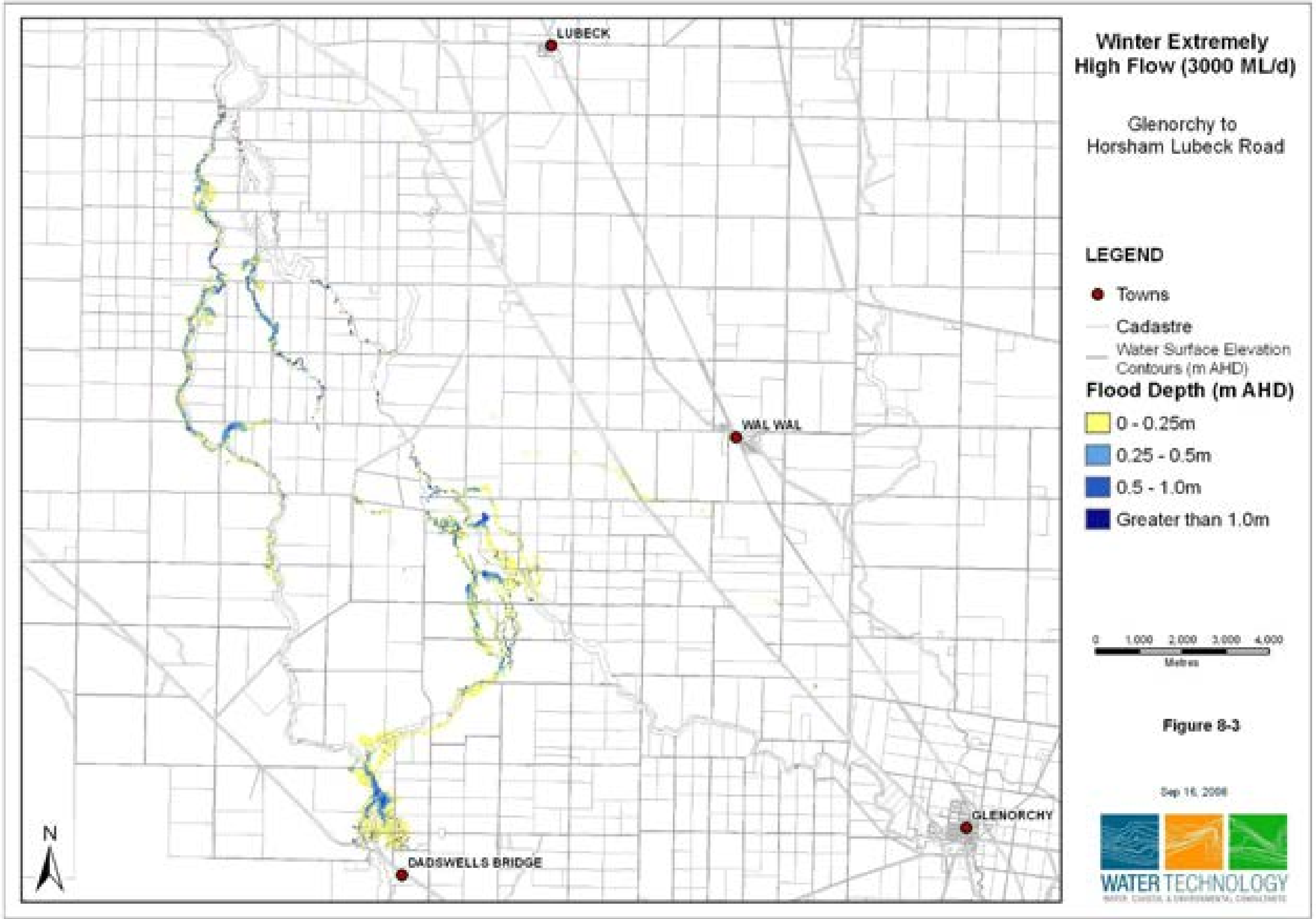

Figure 8-6 Wimmera River Glenorchy to Horsham Lubeck Road – floodplain inundation for winter extremely high flow (3000 ML/d)

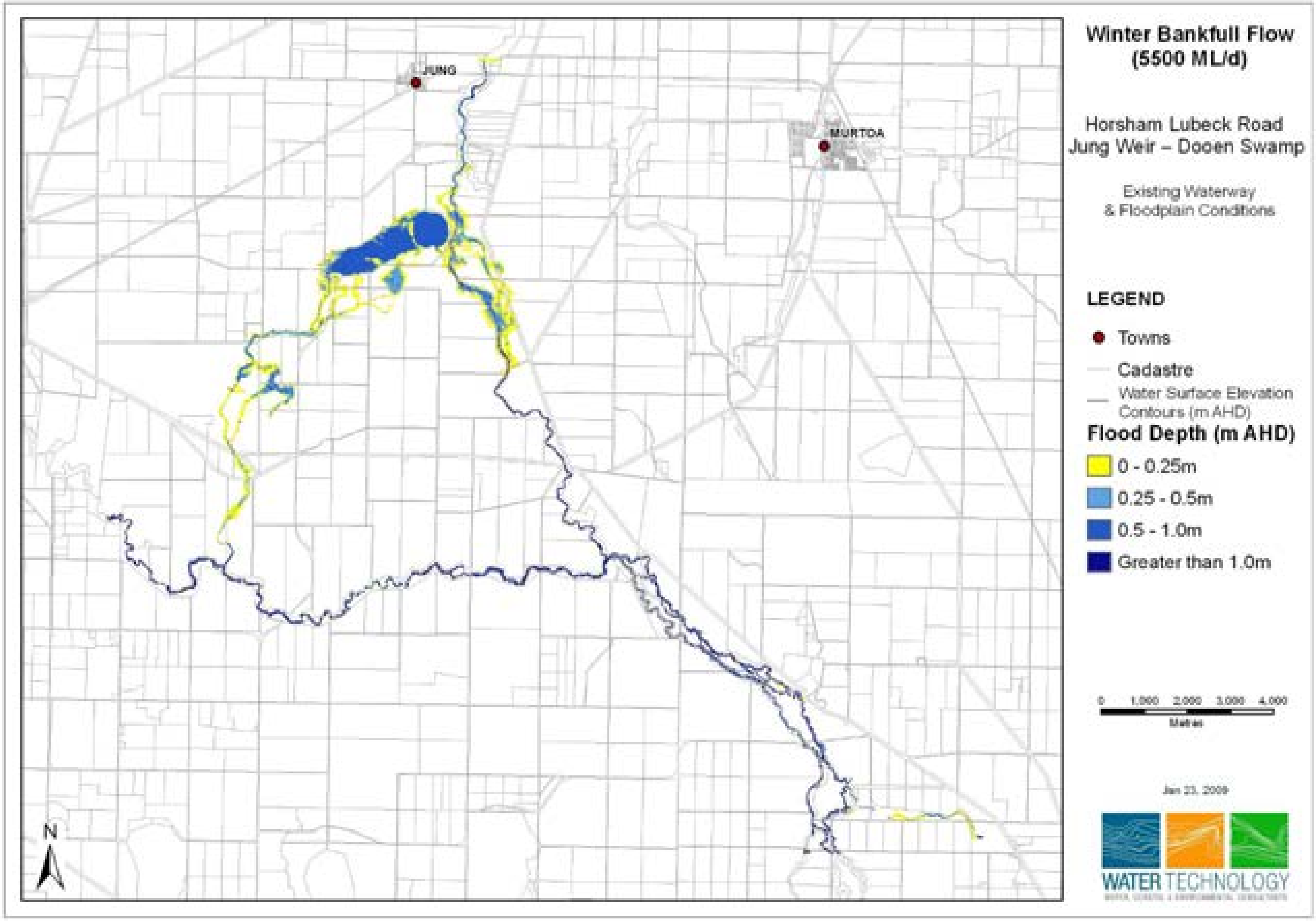

Figure 8-7 Wimmera River –Horsham Lubeck Road- Dooen Swamp – Jung Weir – floodplain inundation for winter bankfull flow (5500 ML/d)

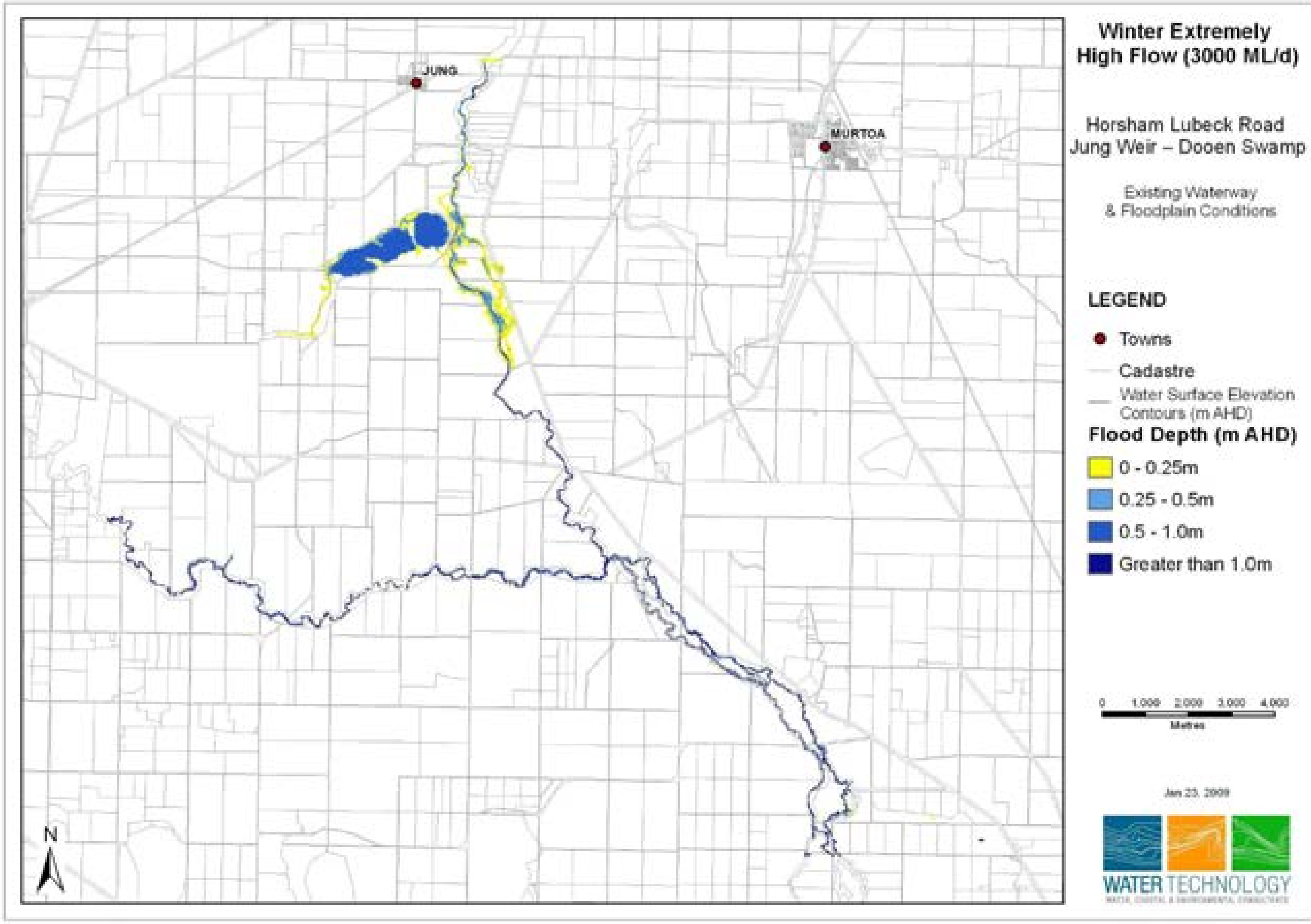

Figure 8-8 Wimmera River –Horsham Lubeck Road- Dooen Swamp – Jung Weir – floodplain inundation for winter extremely high flow (3000 ML/d)

Table 8-4 Wimmera River – Yarriambiack flow distribution – Medium flows (3000 - 6000 ML/d)

Location	Existing conditions				Pre-European waterway-floodplain conditions			
	Winter bankfull flow		Winter extremely high flow		Winter bankfull flow		Winter extremely high flow	
	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)
Wimmera River: Immediately upstream of the Yarriambiack Creek offtake	5870	18699	3115	10626	5812	19440	3250	10750
Yarriambiack Creek: Downstream of offtake	1198	4648	803	3340	78	164	0	0
Yarriambiack Creek: Wimmera Highway	677	2757	508	2231	0	0	0	0
Two Mile Creek: Longerenong Road	190	200	0	0	0	0	0	0
Wimmera River: Downstream of Two Mile Creek	5243	15798	2263	7666	5750	19280	3100	10720

Figure 8-9 displays the flow hydrographs under the existing conditions for the winter bankfull scenario.

Indicative flow travel time characteristics:

- 15 hours from offtake to Wimmera Highway
- 80 hours from offtake to Two Mile Creek at Longerenong Road via Darlot Swamp
- 15 hour Wimmera River at offtake to the Two Mile Creek confluence

For the winter bankfull flow, the peak flow in the Wimmera River upstream of the offtake is 5870 ML/d with a peak flow of 1198 ML/d (~20%) entering the Yarriambiack Creek. The peak flow at the Wimmera Highway Bridge is 677 ML/d (~12%).

This compares to the winter extremely high flow scenario where the peak flow in the Wimmera River upstream of the offtake is 3115 ML/d with a peak flow of 803 ML/d (~26%) entering the Yarriambiack Creek. The peak flow at the Wimmera Highway Bridge is 508 ML/d (~16%).

As the Wimmera River flow increases in the medium flow regime, the Wimmera Highway peak flow expressed as a percentage of the Wimmera River flow upstream of the offtake reduces.

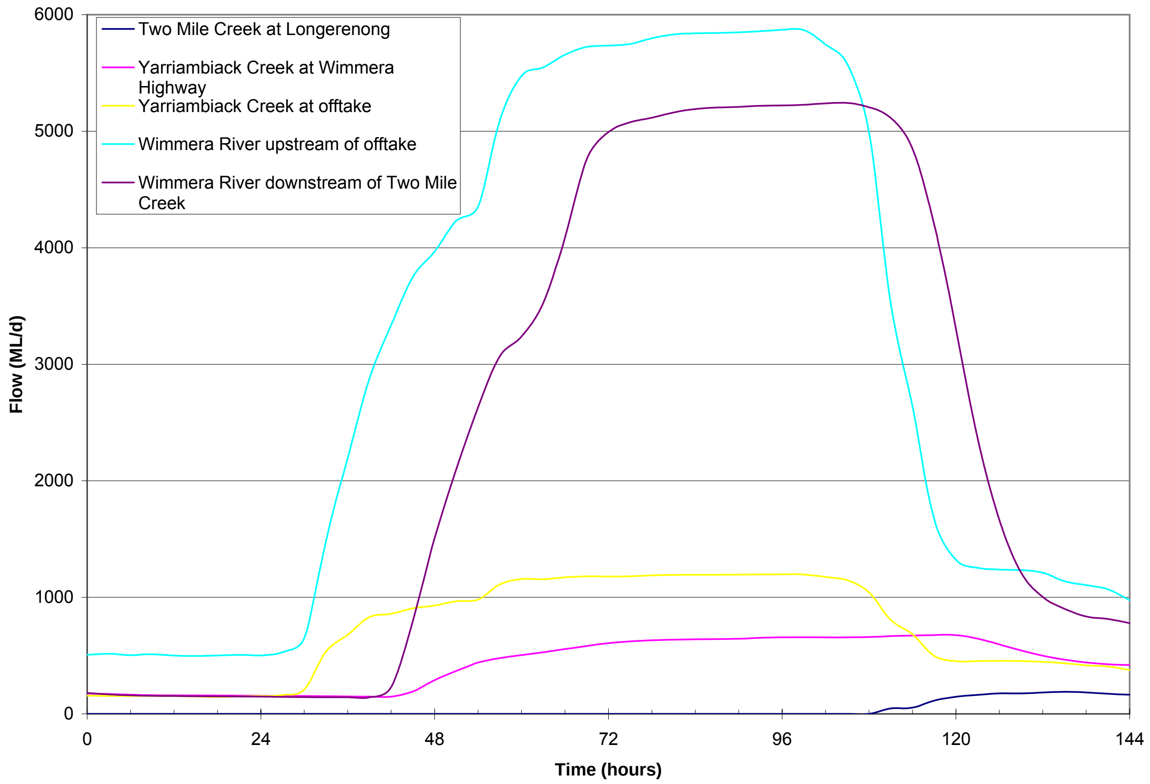

Figure 8-9 Medium flow hydrographs (Winter Bankfull)– Wimmera River – Yarriambiack Creek – Two Mile Creek – Existing conditions

Under the pre-European waterway-floodplain conditions, only a limited flow (peak flow 78 ML/d) enters Yarriambiack Creek for the winter bankfull flow scenario (Wimmera River upstream of offtake 5812 ML/d). This flow in Yarriambiack Creek fills Darlot Swamp with no flow continuing onto the Wimmera Highway. No flow enters Yarriambiack Creek for the winter extremely high flow scenario. Figure 8-10 shows the flow hydrographs under the pre-European waterway-floodplain conditions for the winter bankfull scenario. The changes in flow entering Yarriambiack Creek under the pre-European conditions is primarily due to the higher level of the Yarriambiack Creek offtake.

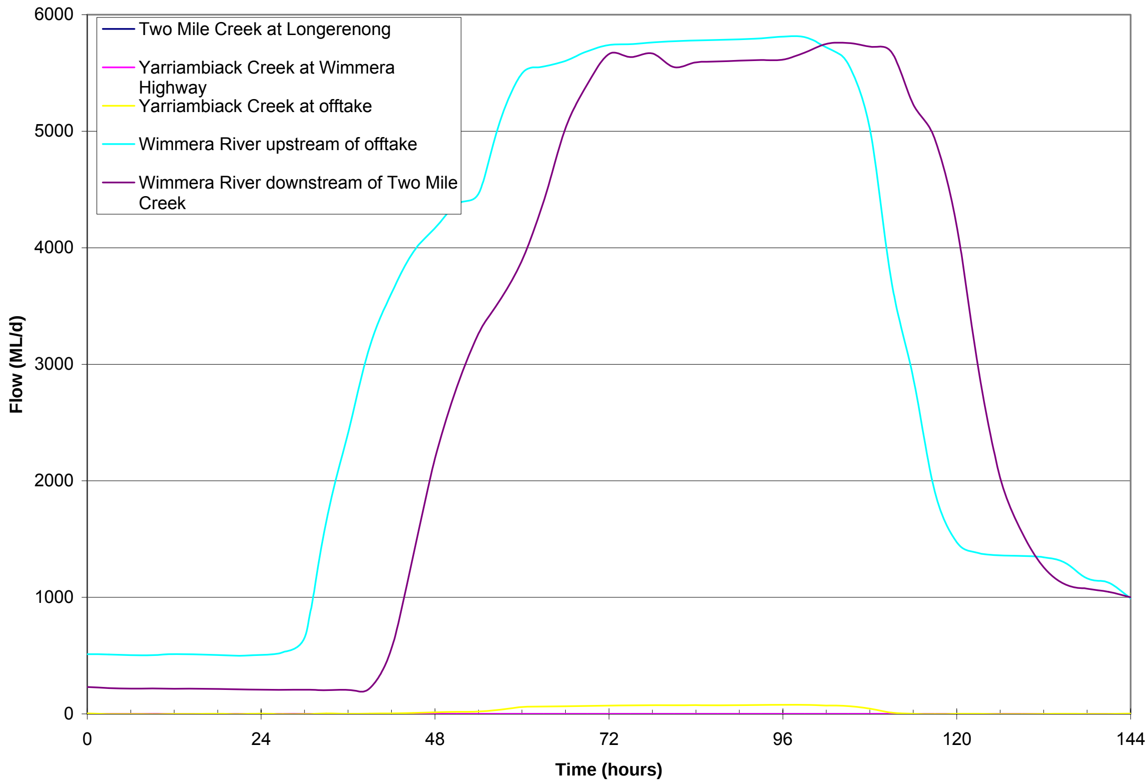

Figure 8-10 Medium flow hydrographs (Winter Bankfull)– Wimmera River – Yarriambiack Creek – Two Mile Creek – Pre-European waterway-floodplain conditions

8.2.4.4 Influences on environmental water releases

Channel Constrictions

SKM (2008) identified 12 channel constrictions on the Wimmera River between Glenorchy and Lake Hindmarsh, with four constrictions within the current study area. SKM (2008) undertook a preliminary analysis to assess channel capacity against the environmental flow recommendations, as listed in Table 8-5. The hydraulic analysis enables refinement of the previous preliminary analysis, shown in Table 8-5.

Table 8-5 Channel constrictions – revised bankfull capacities

Site	SKM (2008) Channel Capacity		Indicative refined channel capacity		Refined ability to convey flow recommendations 6000 ML/d (SKM 2003) using refined channel capacity	
	m3/s	ML/d	m3/s	ML/d	6,000	Remarks
207 (800 m Downstream of Horsham Lubeck Road	25.3	2186	162	14000	Y	Flows occur along the Mount William Creek channel. No breakouts occur to the north across Burnt Clay Road for flows up to 14,000 ML/d.
192 (1100 m downstream of Yarriambiack Creek)	28.3	2445	60	5200	N	Breakouts to the south
177 (Dooen Swamp)	53.9	4657	30	2600	N	Breakout occurs to Dooen Swamp
174 (600 m Downstream of Dooen Swamp)	20.5	1771	22	1900	N	Breakout occurs to Dooen Swamp.

As discussed in Section 8.2.4.3, the Wimmera River capacity between Glenorchy and the Horsham Lubeck Road ranges between 3200-4700 ML/d. These channel constrictions need to be considered in conjunction with the above constrictions to evaluate the potential impact to the adjacent landholders.

8.2.4.5 Wimmera River – Yarriambiack Creek offtake low flow relationship

The local scale 2D hydraulic model, discussed in Section 7.4.4.1, simulated the low flow distribution (up to 2500 ML/d) between the Wimmera River and Yarriambiack Creek. The medium flow relationship was discussed in Section 8.2.4.3.

As outlined in Section 7.4.4.1, the simulation of very low flow less than 180 ML/d, was limited due to model instability with the very shallow depths. The simulation of these very low flows was considered unreliable.

Table 8-6 and Figure 8-11 displays the estimated Wimmera River – Yarriambiack Creek flow distribution relationship for low flows under existing conditions using the local 2D model.

Table 8-6 Wimmera River – Yarriambiack Creek – Low flow (up to 2592 ML/d) flow distribution at the offtake (from local scale 2D model)

Wimmera River flow upstream of offtake (ML/d)	Yarriambiack Creek flow downstream of offtake (ML/d)	Yarriambiack Creek as percentage of the Wimmera River flow upstream of offtake (%)
173	97	56%
432	131	30%
864	188	22%
1728	302	17%
2592	415	16%

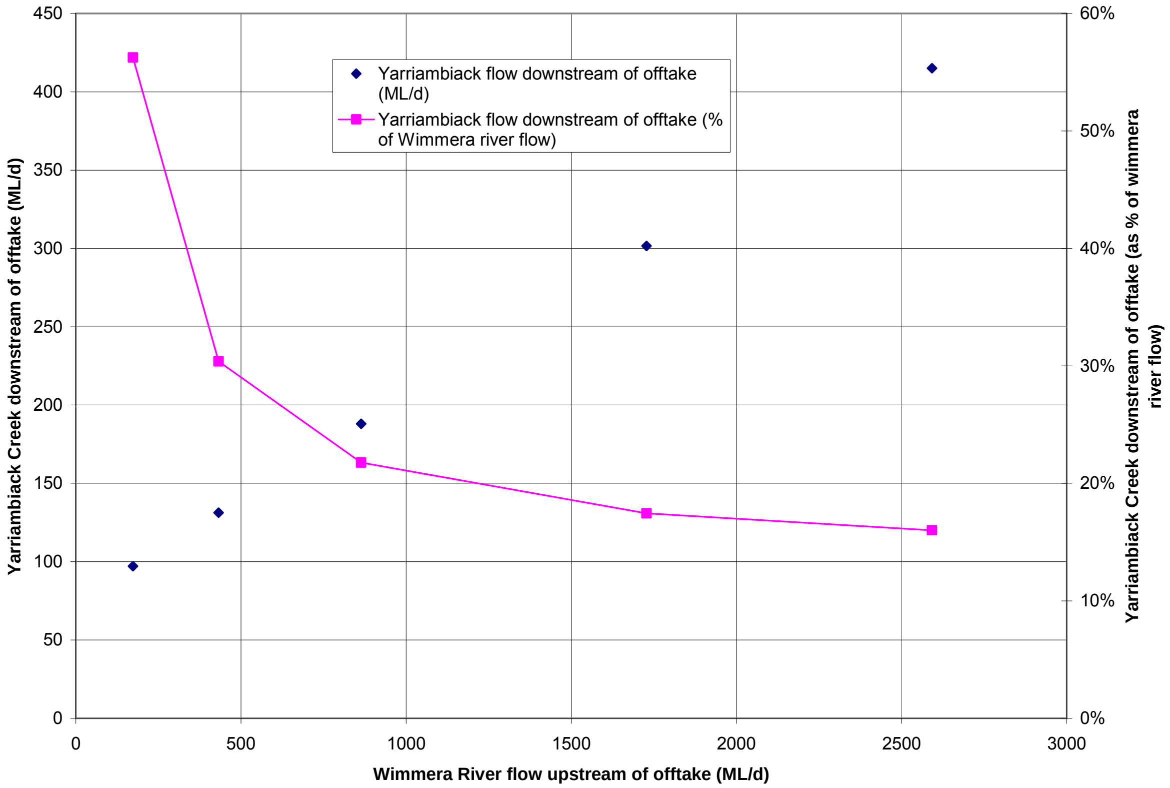

Figure 8-11 Wimmera River – Yarriambiack Creek estimated flow relationship at the offtake for flows up to 2592 ML/d (25 m^3/s) (from local scale 2D model)

As seen in Table 8-6, the percentage of the Wimmera River flows entering Yarriambiack Creek reduces with increasing Wimmera River flow. It should be noted that the use of the linked 1D-2D hydraulic model, discussed in Section 8.2.4.3, reflected a similar trend in reducing percentage of Wimmera River flows entering Yarriambiack Creek for the medium flow regime (3000-6000 ML/d).

In contrast, the 1D-2D hydraulic model for a Wimmera River flow of 3115 ML/d yielded a Yarriambiack Creek peak flow of 803 ML/d (~26%). This compares to the local 2D local model for a Wimmera flow of 2592 ML/d with Yarriambiack Creek peak flow of 415 ML/d (~16%). The difference in the flow distribution reflects the considerable uncertainty surrounding the flow distribution relationship. Further discussion of the flow distribution is provided in Section 8.4.

As highlighted above, the comparison of the two modelling approaches reflects the considerable uncertainty in the flow distribution. Verification of the modelling requires the gauging of flows adjacent to the offtake.

The study team recommends flow gauging in the Wimmera River upstream of the offtake, and along Yarriambiack Creek during a low–medium flow event. Such observed flow data could used to refine the local scale 2D model. At low flows (less than 3000 ML/d) , the assessment of flow distribution using observed streamflow data at Drung Drung and/or the Wimmera Highway is limited by the accuracy of the rating curve at both gauges. It is likely the errors in the rating curves at the gauges may exceed the flow entering Yarriambiack Creek.

8.3 High flows – design floods

8.3.1 Background

The principal aim of the high flows (design floods) hydraulic model application was simulation of flood behaviour for the 5, 10, 20, 50, 100 and 200 year ARI design flood events.

Further, the high flow hydraulic model application assessed the change in flood behaviour due to catchment, waterway and floodplain changes since European settlement. The change in flood behaviour was assessed, by the broad scale 2D floodplain hydraulic model, for the following four scenarios:

1. ***Existing waterway-floodplain-catchment conditions:*** Waterway and floodplain conditions were taken as at July 2007. Topographic survey data, discussed in Section 4, formed the basis of the hydraulic model topography. The catchment conditions similarly were taken at July 2007. Design flood hydrographs for the existing conditions (includes upstream storages) as discussed in Section 6.5, were employed as inputs to the broad scale 2D floodplain hydraulic model.
2. ***Pre-European settlement waterway-floodplain with current catchment conditions:*** Waterway and floodplain conditions were taken as the assumed conditions prior to European settlement. The pre-European waterway-floodplain conditions were developed from the existing topographic data with key modifications removed. The pre-European waterway-floodplain conditions developed by this study considered the available evidence of the modifications. However, considerable uncertainty surrounding the precise nature of waterway – floodplain modifications as the available evidence is not definitive. The catchment conditions similarly were taken at July 2007. Design flood hydrographs for the existing conditions (includes upstream storages) as discussed in Section 6.5, were employed as inputs to the broad scale 2D floodplain hydraulic model, i.e. the same flow inputs are the same as Scenario 1. The comparison of this scenario (2) with the existing conditions (Scenario 1) reveals the changes in flood behaviour due to waterway-floodplain modifications. Hence the changes reflect the flood behaviour if the waterway-floodplain modifications were reversed without any other changes across the catchment.
3. ***Pre-European settlement waterway-floodplain- catchment conditions:*** Waterway and floodplain conditions were taken as the assumed conditions prior to European settlement, as per Scenario 2. Design flood hydrographs for the pre-European catchment conditions (removes upstream storages) as discussed in Section 6.6, were employed as inputs to the broad scale 2D floodplain hydraulic model. The comparison of this Scenario 3 with the existing conditions (Scenario 1) reveals the

changes in flood behaviour due to waterway-floodplain-catchment modifications. Hence the changes reflect the flood behaviour prior to European settlement.

4. ***Existing waterway-floodplain-catchment conditions with the Wimmera Highway Bridge and approaches across Yarriambiack Creek removed:*** Waterway and floodplain conditions were taken as at July 2007 as in Scenario 1, with the Wimmera Highway Bridge and approaches removed. The catchment conditions similarly were taken at July 2007. Design flood hydrographs for the existing conditions (includes upstream storages) as discussed in Section 6.5, were employed as inputs to the broad scale 2D floodplain hydraulic model. This scenario assessed the influence of the current Wimmera Highway Bridge arrangement on flood behaviour.

8.3.2 Key 2D broad scale hydraulic model application

This section discusses the broad 2D floodplain model application to the four condition scenarios discussed above. The key flooding characteristics under the four scenarios and the changes in flood behaviour between the scenarios are discussed. In particular, the general description of flooding behaviour, based on previous investigations as outlined in Section 2.2 is assessed and refined if required. The discussion focuses on the following four reaches of the study area:

- Wimmera River – Mount William Creek: Glenorchy to Horsham-Lubeck Road (Section 8.3.2.1)
- Wimmera River – Yarriambiack Creek: Horsham Lubeck Road – Jung Weir – Dooen Swamp (Section 8.3.2.2)
- Yarriambiack Creek: Jung Weir to Warracknabeal (Section 8.3.2.3)
- Wimmera River: Dooen Swamp to Horsham (Section 8.3.2.4)

The results of the broad 2D floodplain models are presented via series of flood inundation maps. The flood inundation maps show the flood depths, flood extents and flood levels for the three scenarios across the range of design flood event magnitudes considered. The differences in flood behaviour between the three scenarios are presented as flood level differences maps. The flood difference maps show decreases and increases in flood levels for the range of design flood events.

The key flood inundation and flood level difference maps are contained in the following sections to highlight the principal characteristics. Appendix F contains a full suite of flood inundation and flood level difference maps.

8.3.2.1 Wimmera River – Mount William Creek: Glenorchy to Horsham – Lubeck Road

Scenario 1

The general flooding patterns under the existing conditions are displayed in Figure 8-12 and Figure 8-13 for the existing conditions (Scenario 1).

For the design flood events considered (5 year to 200 year ARI) considerable floodplain flow to the north occurs immediately downstream of Glenorchy. The extensive floodplain flooding reflects the limited channel of the Wimmera River at Glenorchy. The hydraulic modelling suggests the Wimmera River capacity is approximately 3200 ML/d.

Some of the northern floodplain flow re-joins the Wimmera River adjacent to Company's Bridge - Browns Road in the 5 year event. For the larger flood events (greater than 5 year) this northern floodplain flow generally continues to Station Creek, adjacent to Horsham Wal Wal Road.

To the south of the Wimmera River main channel, limited floodplain flows occurs with the flows merging with the Mount William Creek floodplain. For frequent flood events (5 & 10 year) the Mount William Creek flows, under existing conditions (Scenario 1) are confined to the creek channel, and joins the Wimmera River upstream of Huddleston's Weir. In the larger flood events (20 year and greater), floodplain flows occurs with some flow joining Middle Creek adjacent to the Wimmera Inlet channel.

Scenario 2

A key influence on floodplain behaviour on the northern floodplain is the Murtoa – Glenorchy Road. Figure 8-14 and Figure 8-15 shows the Scenario 1 – Scenario 2 flood levels difference maps for the 5 and 100 year ARI flood events. The flood difference level maps display the changes in flood levels due to the waterway-floodplain modifications as the design flows hydraulic model inputs remained the same. Increases in flood levels (positive difference shown in red, yellow and orange) reflects the existing waterway and floodplain conditions results in higher flood level than the pre-European waterway and floodplain conditions. As seen in Figure 8-14 and Figure 8-15, increased flood levels occur to the east of the current road alignment in comparison to the pre-European waterway floodplain condition. To the west of the current road alignment, there has been a decrease in flood levels. This behaviour is in line with community concerns raised during previous investigations (Water Technology, 2003), as discussed in Section 2.2.

The Wimmera Inlet Channel has a number of syphons allowing flow through the embankment. Figure 8-14 shows minimal change (less than 50 mm) in flood levels adjacent to the channel for the 5 year ARI flood event. In larger flood events, Figure 8-15 indicates some re-distribution of flood waters and hence changes in flood level occurred with the removal of the channel, as part of Scenario 2. Flood levels along Middle Creek immediately downstream of the inlet channel have increased (up to 200 mm for the 100 year ARI flood event) under the existing conditions. Correspondingly reductions in flood levels occurred along Mount William Creek immediately downstream of the inlet channel. These changes in flood levels indicate some re-distribution of flood flows under the existing conditions. This general re-distribution is line with broad knowledge discussed in Section 2.2.

Scenario 3

Under the pre-European catchment conditions (Scenario 3), the Mount William Creek inflows considerably increased due to the removal of Lake Lonsdale and Lake Bellfield. However, as there are no major storages in the Upper Wimmera (above Glenorchy) there is no change in inflows at Glenorchy under the pre-European catchment conditions assumed by this study. Further discussion of the pre-European catchment conditions design flows were provided in Section 6.6. Figure 8-16 and Figure 8-17 shows the Scenario 1 – Scenario 3 flood levels difference maps for the 5 and 100 year ARI flood events. These flood differences maps reflect changes due to the removal of waterway-floodplain modifications (as in Scenario 2) plus removal of major storages. The flood level changes along the Murtoa-Glenorchy Road are similar to the changes under Scenario 2 (refer to Figure 8-14 and Figure 8-15). Along the Mount William Creek floodplain, flood levels have reduced under the existing conditions due to the lower Mount William Creek inflows with Lake Lonsdale and Lake Bellfield.

Scenario 4

The flood behaviour in this reach is unaffected by the Wimmera Highway Bridge, and no hydraulic analysis was undertaken for Scenario 4.

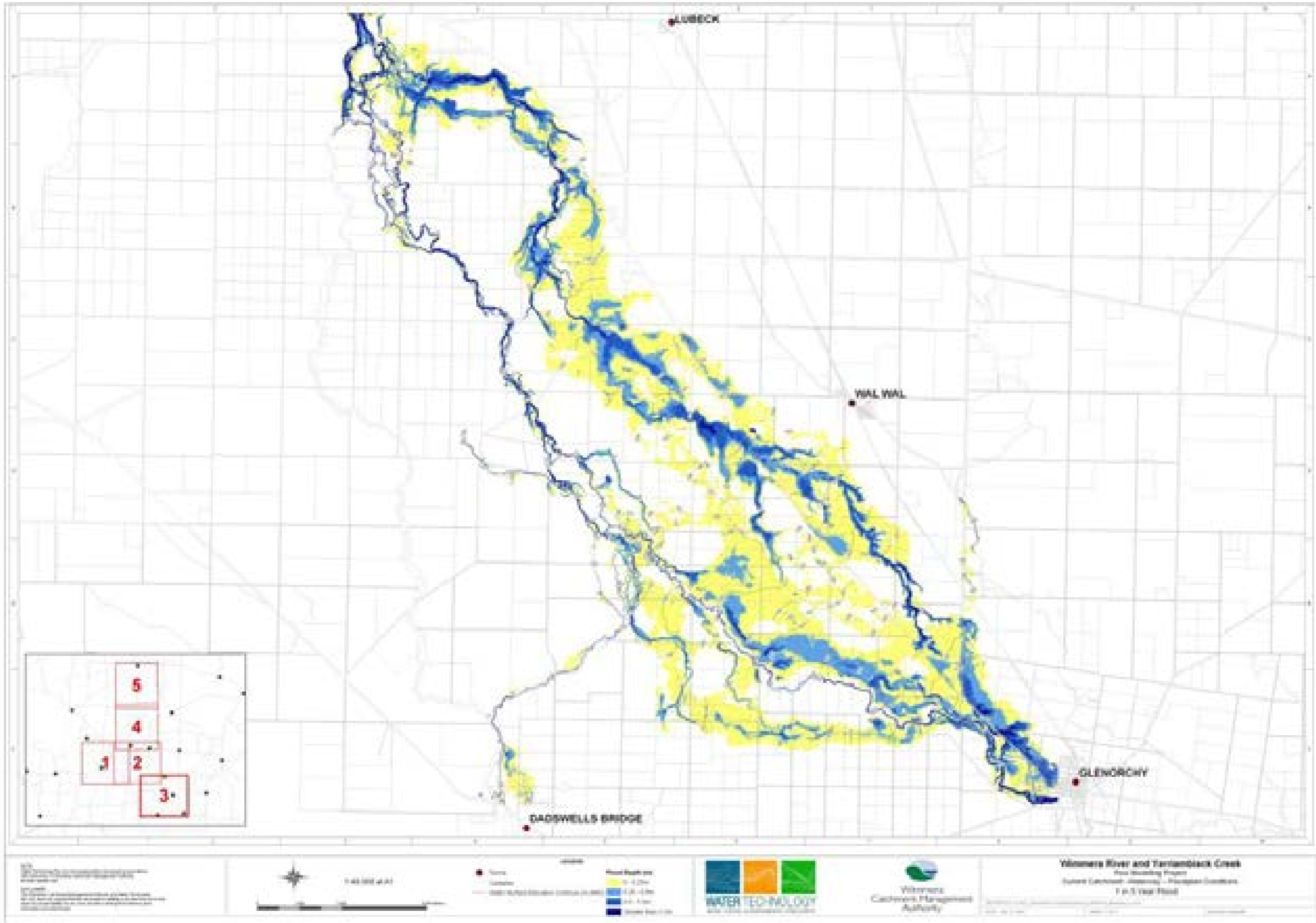

Figure 8-12 5 year ARI flood inundation maps: Glenorchy to Horsham Lubeck Road – Existing conditions (Scenario 1)

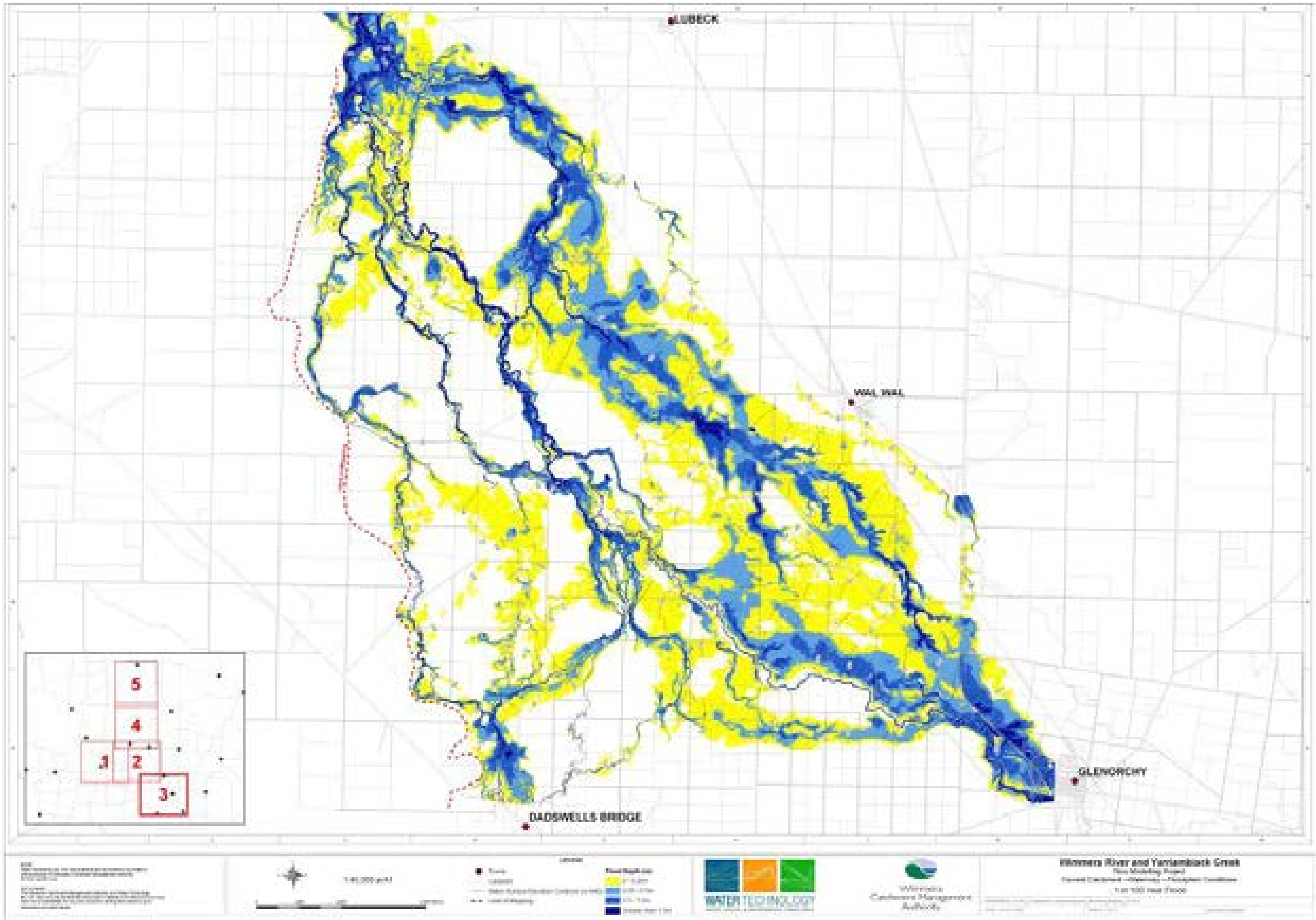

Figure 8-13 100 year ARI flood inundation maps: Glenorchy to Horsham Lubeck Road – Existing conditions (Scenario 1)

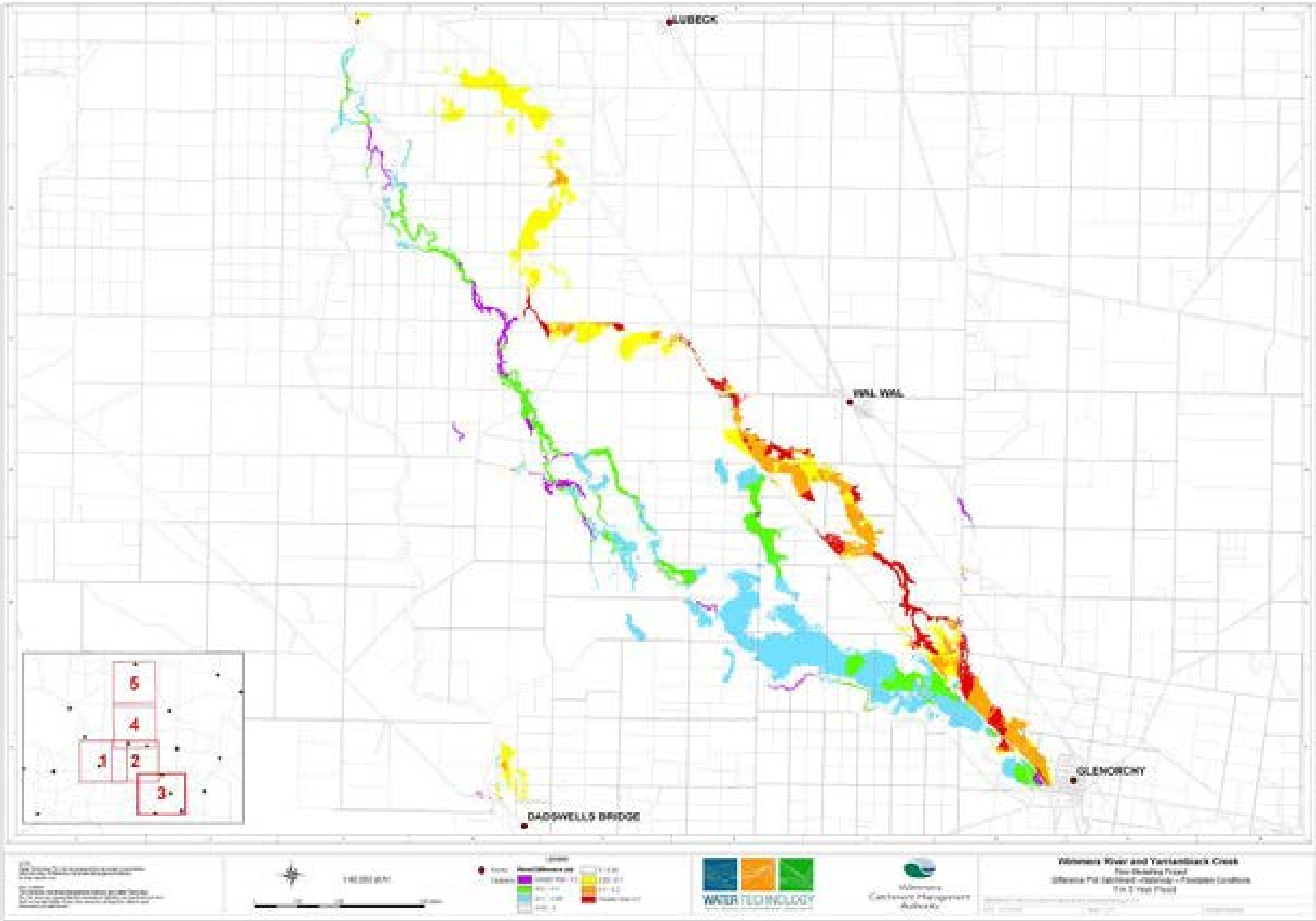

Figure 8-14 5 year ARI flood level difference map: Glenorchy to Horsham Lubeck Road: Existing conditions (Scenario 1) – Pre-European floodplain with existing catchment (Scenario 2)

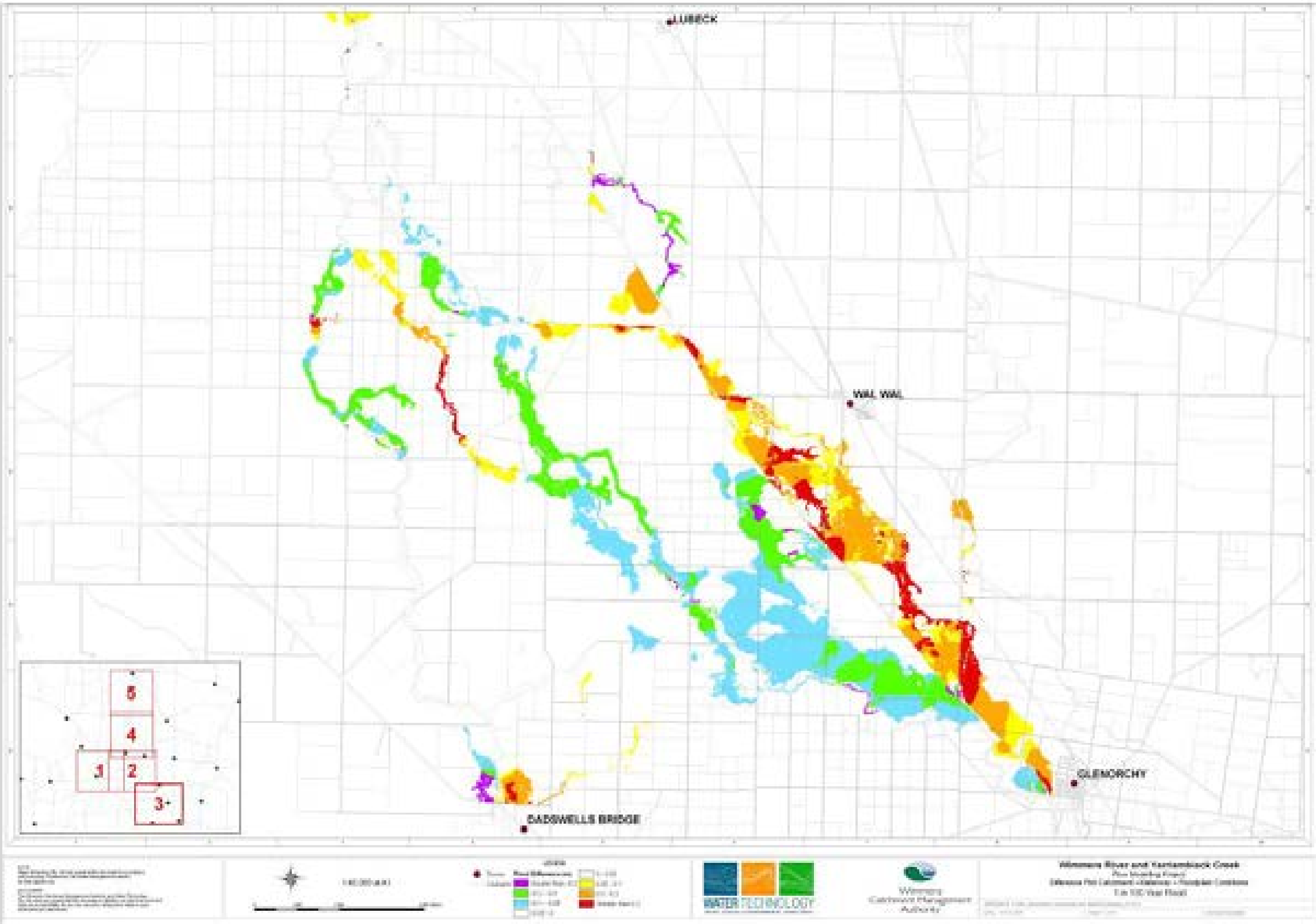

Figure 8-15 100 year ARI flood level difference map: Glenorchy to Horsham Lubeck Road: Existing conditions (Scenario 1) – Pre-European floodplain with existing catchment (Scenario 2)

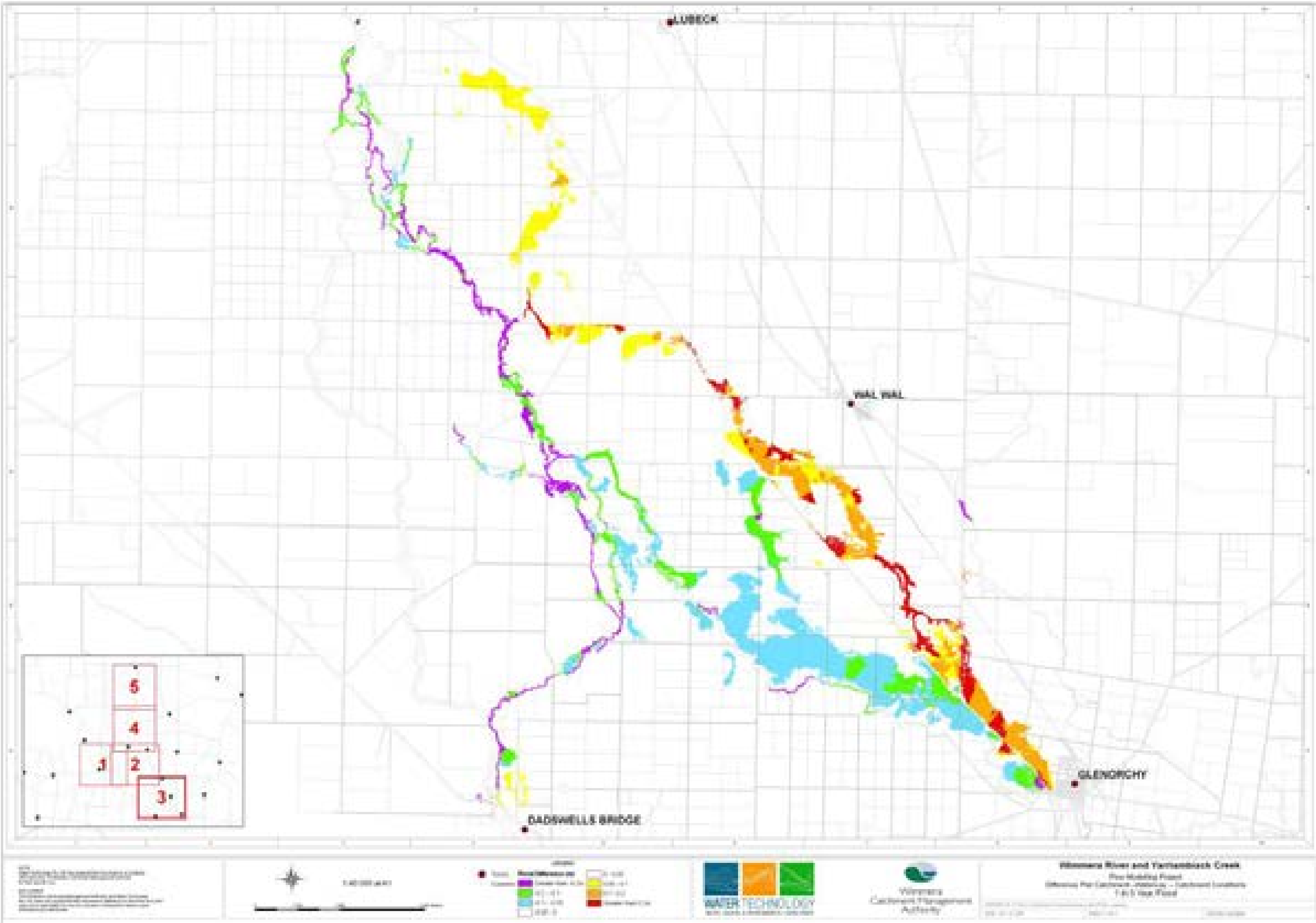

Figure 8-16 5 year ARI flood level difference map: Glenorchy to Horsham Lubeck Road: Existing conditions (Scenario 1) – Pre-European floodplain & catchment (Scenario 3)

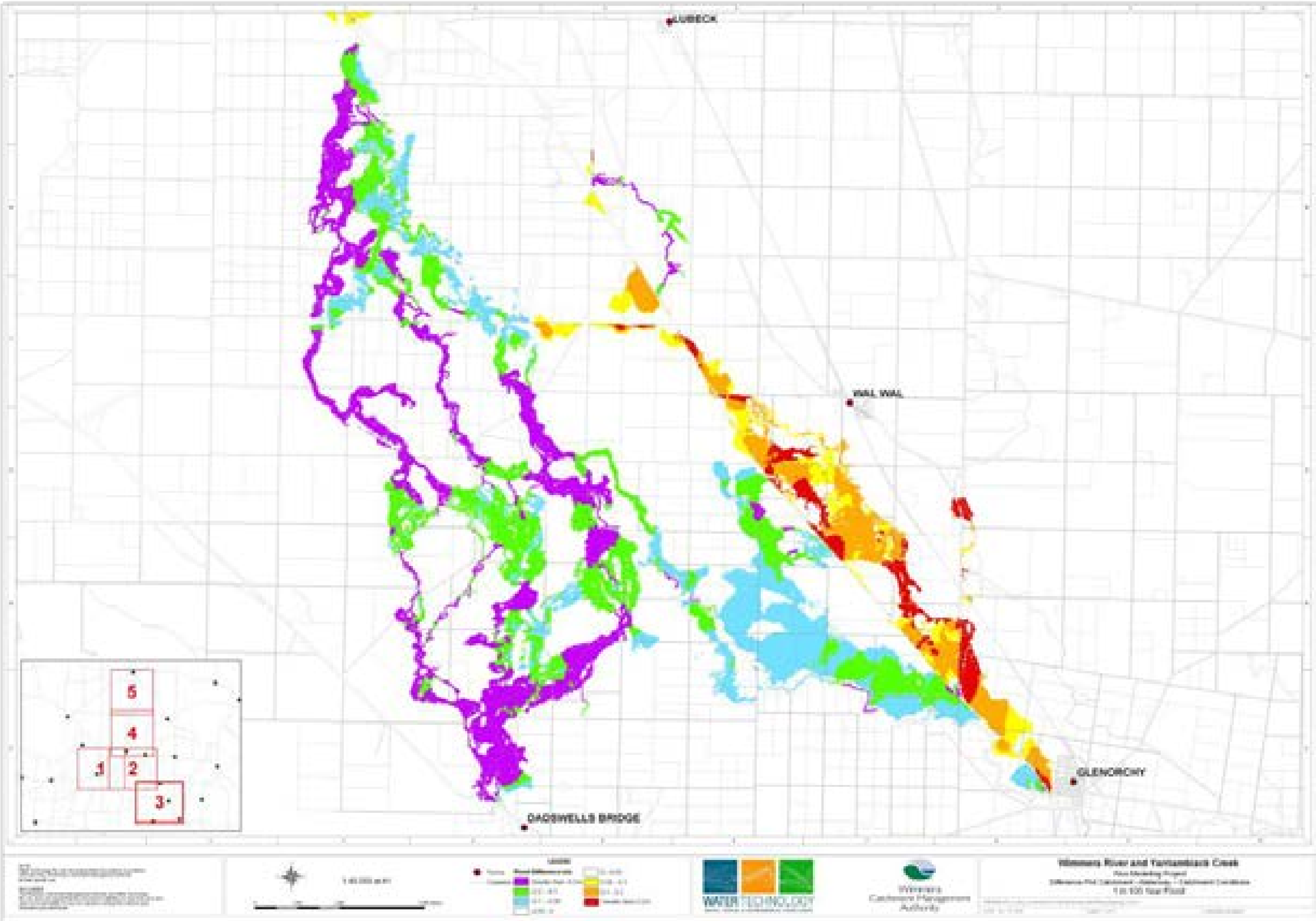

Figure 8-17 100 year ARI flood level difference map: Glenorchy to Horsham Lubeck Road: Existing conditions (Scenario 1) – Pre-European floodplain & catchment (Scenario 3)

8.3.2.2 Wimmera River – Yarriambiack Creek: Horsham Lubeck Road – upstream Jung Weir – Dooen Swamp

Scenario 1

The general flooding patterns under the existing conditions are displayed in Figure 8-18 and Figure 8-19 for the existing conditions (Scenario 1).

For the 5 and 10 year ARI flood events (flow at Horsham Lubeck Road up to ~ 16,000 ML/d), flows are generally limited to the Wimmera River channel between the Horsham – Lubeck Road and the Yarriambiack Creek offtake. During larger flows, breakouts occur over the northern bank from the Horsham – Lubeck Road to the Yarriambiack Creek offtake.

In the 5 and 10 year ARI events, flows only enter Yarriambiack Creek via the offtake. The Yarriambiack Creek flows continue north from the offtake. The capacity of the creek channel immediately south of Longerenong Road is limited to about 1800 ML/d. At this location, flow breakouts from the creek to the west. A well defined flow path continues west adjacent to Longerenong Road to join Two Mile Creek. A secondary, less well defined, overland flow path continues to the north-west.

The flow remaining in the creek channel continues towards Darlot Swamp. As the creek approaches Darlot Swamp, the creek becomes increasingly ill defined with no significant banks.

The Wimmera River breakouts across the northern bank adjacent to adjacent to Horsham – Lubeck Road continue through the Barrabool Flora and Fauna Reserve, across Burnt Clay Road and along Corkers Drain Creek. Corkers Drain Creek crosses the Taylor's Lake outlet channel at a syphon crossing and continues in a north westerly direction to join Yarriambiack Creek immediately south of Darlot Swamp. For the 50 year event and larger (flow at Horsham -Lubeck Road ~ 35,900 ML/d), shallow (up to 250 mm deep) broad floodplain flow occurs parallel to Corkers Drain Creek.

Adjacent to the offtake, breakouts over the northern bank of the Wimmera River occurs for the 20 year ARI flood event and greater. These breakouts continue north as shallow overland flow, with some flow rejoining Yarriambiack Creek adjacent to Longerenong Road.

Downstream of the Corkers Drain Creek confluence, some flows in Yarriambiack Creek enter Darlot Swamp. Once full, the Darlot Swamp overflow continues to the south along Two Mile Creek, and returns to the Wimmera River. The remainder of the flow in Yarriambiack Creek continues to the north to the Wimmera Highway.

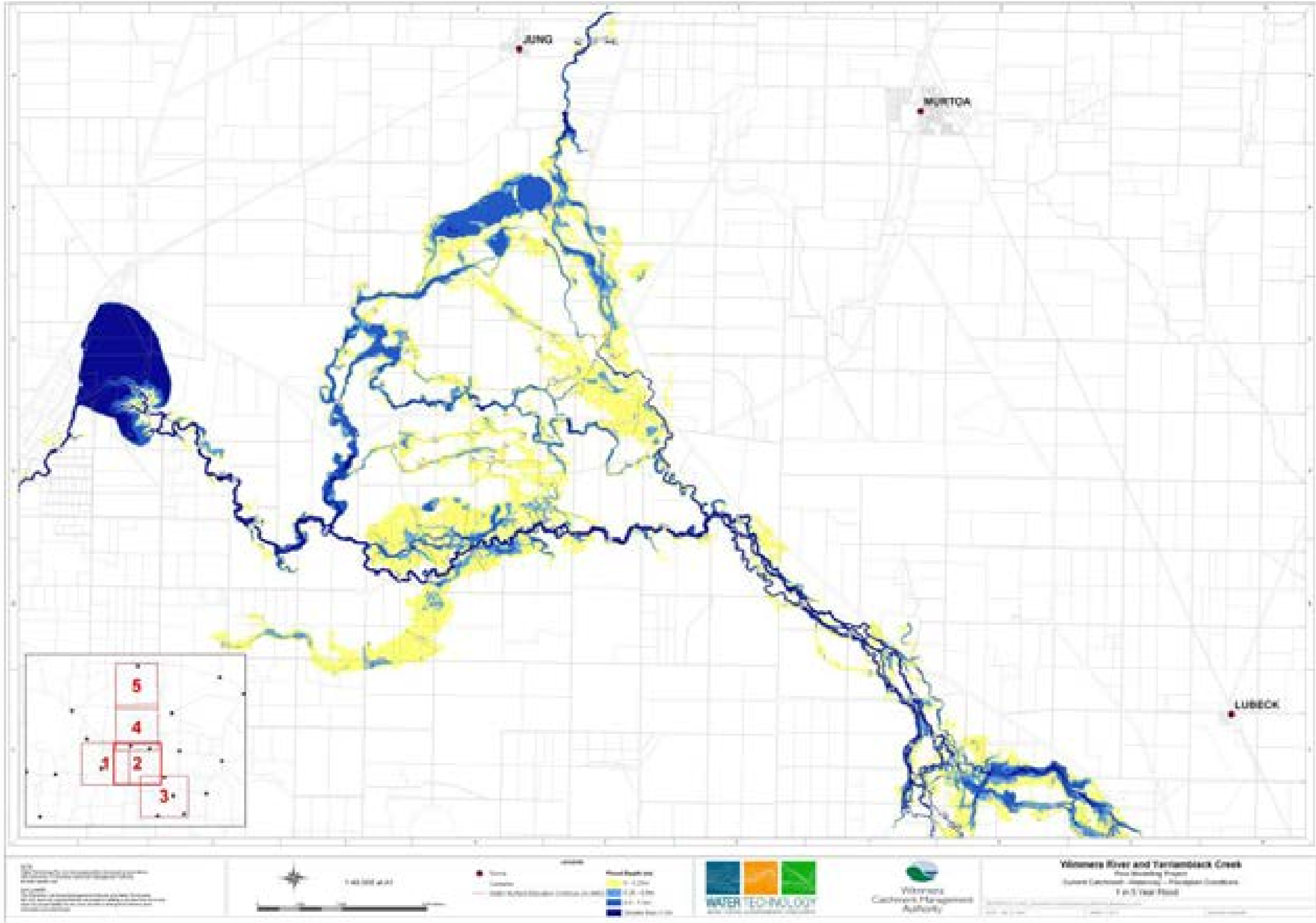

Figure 8-18 5 year ARI flood inundation maps: Horsham Lubeck Road – Dooen Swamp – Jung Weir - Existing conditions (Scenario 1)

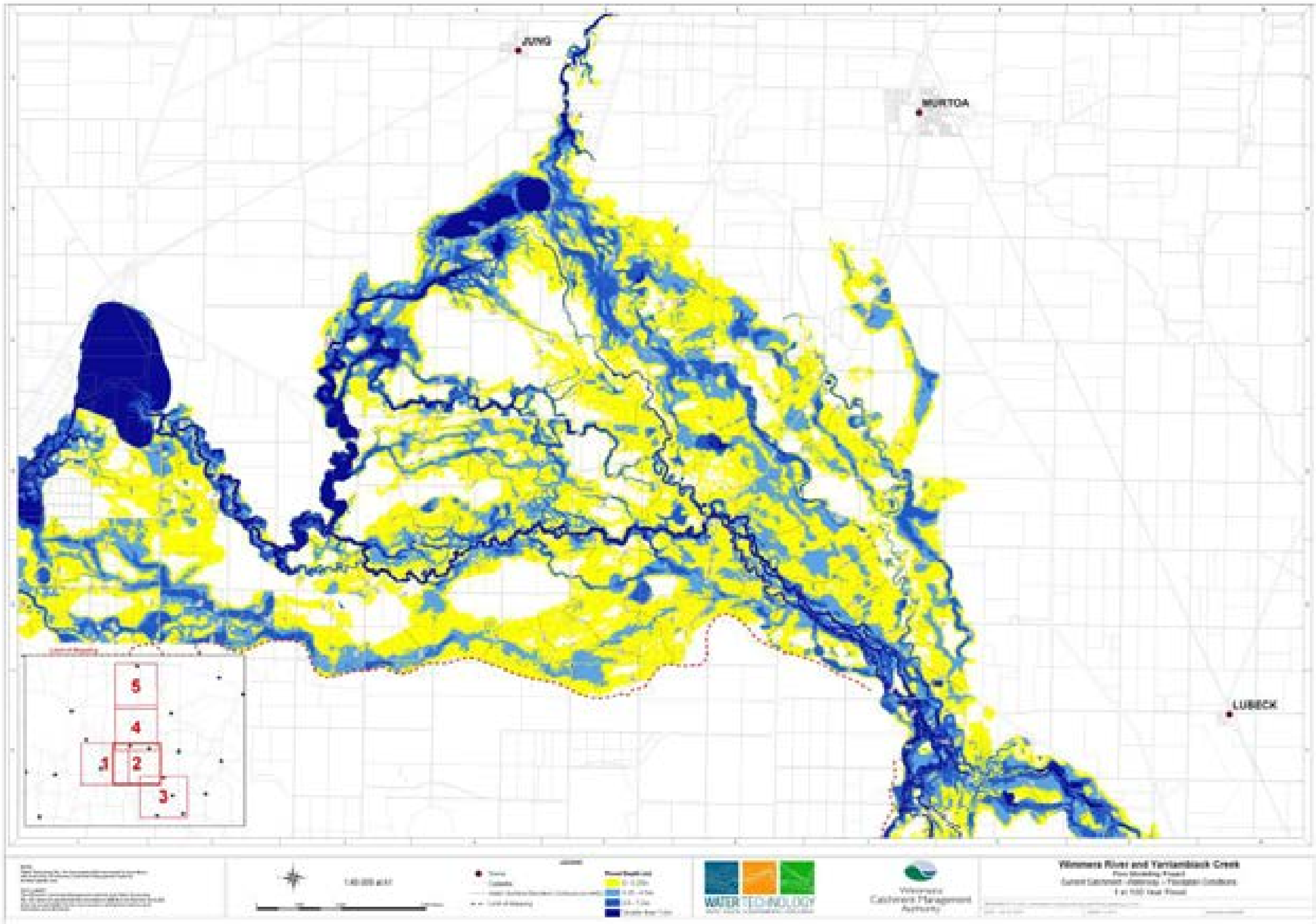

Figure 8-19 100 year ARI flood inundation maps: Horsham Lubeck Road–Dooen Swamp – Jung Weir – Existing conditions (Scenario 1)

Table 8-7 and Figure 8-20 details the nature of the flow distribution under the existing conditions (Scenario 1).

Table 8-7 Flow distribution: Horsham Lubeck Road – Dooen Swamp – Jung Weir - Existing conditions (Scenario 1) -

Location	Design flood event (ARI)					
	5 year		20 year		100 year	
	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)
Wimmera River: Horsham Lubeck Road	15,260	45,120	27,460	80,680	42,900	119,043
Yarriambiack Creek: Wimmera Highway	946	2,410	1,460	3,870	3,160	7,100
Wimmera River: Downstream of Two Mile Creek	11,120	37,400	22,640	63,000	36,300	99,000

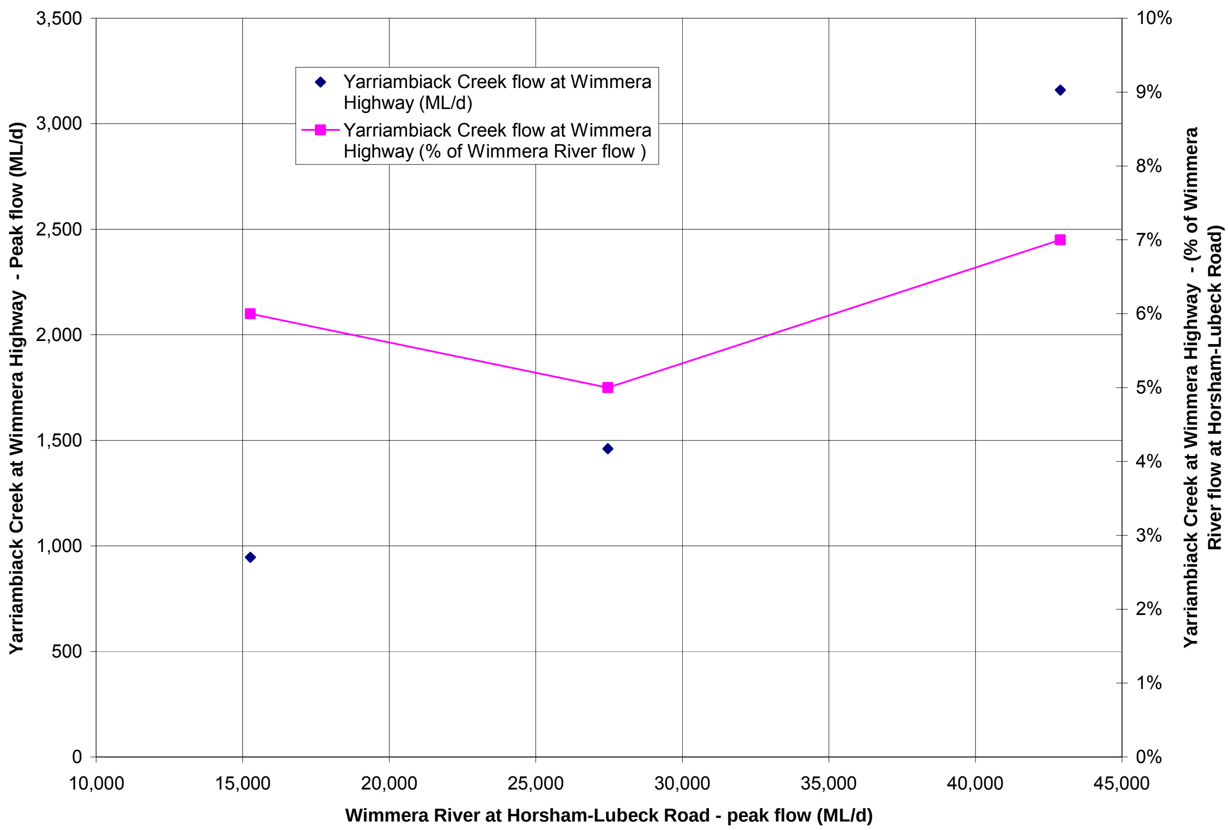

Figure 8-20 Wimmera River- Yarriambiack Creek at Wimmera Highway - flow split – high flows

Under the existing conditions, the peak flow at the Wimmera Highway expressed as a percentage of the Wimmera River peak flow at the Horsham – Lubeck Road flow varied from

5.3 % for the 20 year flood event, to 7.4 % for the 100 year event. The flow split percentage for the 5 year flood event was 6.4 %.

The reduction in peak flow for Wimmera River between Horsham - Lubeck Road and downstream of the Two Mile Creek confluence reflects the significant attenuation due to the considerable available floodplain storage in this reach. The difference in flood volume along the Wimmera River is due to effluent flows along Yarriambiack Creek and the filling of the floodplain wetlands/swamps during a flood event.

Scenario 2

As discussed in Section 2.2.4, there has been considerable modification to the waterways and floodplain within this reach. The principal modifications included the Yarriambiack Creek offtake, the Wimmera Highway crossing, Longerenong Road and the Taylor's Lake outlet channel. In Scenario 2, the post European settlement waterway-floodplain modifications were removed. Figure 8-21 and Figure 8-22 shows the Scenario 1 – Scenario 2 flood levels difference maps for the 5 and 100 year ARI flood events. The flood levels differences show differences greater than 50 mm. It is considered differences less than 50 mm lie within the reasonable limits of model accuracy.

Increases in flood levels (positive difference) reflects the existing waterway and floodplain conditions results in higher flood level than the pre-European waterway and floodplain conditions. A positive difference (yellow, orange and red) in Figure 8-21 and Figure 8-22 reflects an increase in flood levels under the existing conditions compared with the pre-European waterway and floodplain conditions. Local increases in flood levels occur along the southern side of Longerenong Road and the Taylors Lake outlet channel (for the 100 year event), and to the south of the Wimmera Highway Bridge. Further discussion of the flood level changes adjacent to the Wimmera Highway Bridge is provided below.

A negative difference (green, blue and purple) in Figure 8-21 and Figure 8-22 reflects a decrease in flood levels under the existing conditions compared with the pre-European waterway and floodplain conditions. Local decreases in flood levels occur along the northern side of Longerenong Road and the Taylors Lake outlet channel (for the 100 year event), and to the north of the Wimmera Highway Bridge. Further discussion of the flood level changes adjacent to the Wimmera Highway Bridge is provided below.

The change in flood levels adjacent to Longerenong Road and Longerenong channel (for the 100 year event only) indicates the current road/channel arrangement leads some obstruction to flood flows, and hence increased flood levels on the upstream and lower flood levels on the downstream side.

Adjacent to the offtake, this scenario raised the Yarriambiack Creek invert level and removed the regulator to represent pre-European settlement conditions. The hydraulic modelling indicated that this scenario results in local change of flood levels for the flood events considered (5 year to 200 year events). The increased invert level reduced the flow along the Yarriambiack Creek at regulator for the frequent flood events (~ 5 year event). The reduced flow and the removal of the regulator yielded some local flood level decreases (up to 200 mm)in the frequent events. For the larger flood events, the local flood levels were such that the higher invert level and the removal of the regulator had no significant impact on flood behaviour.

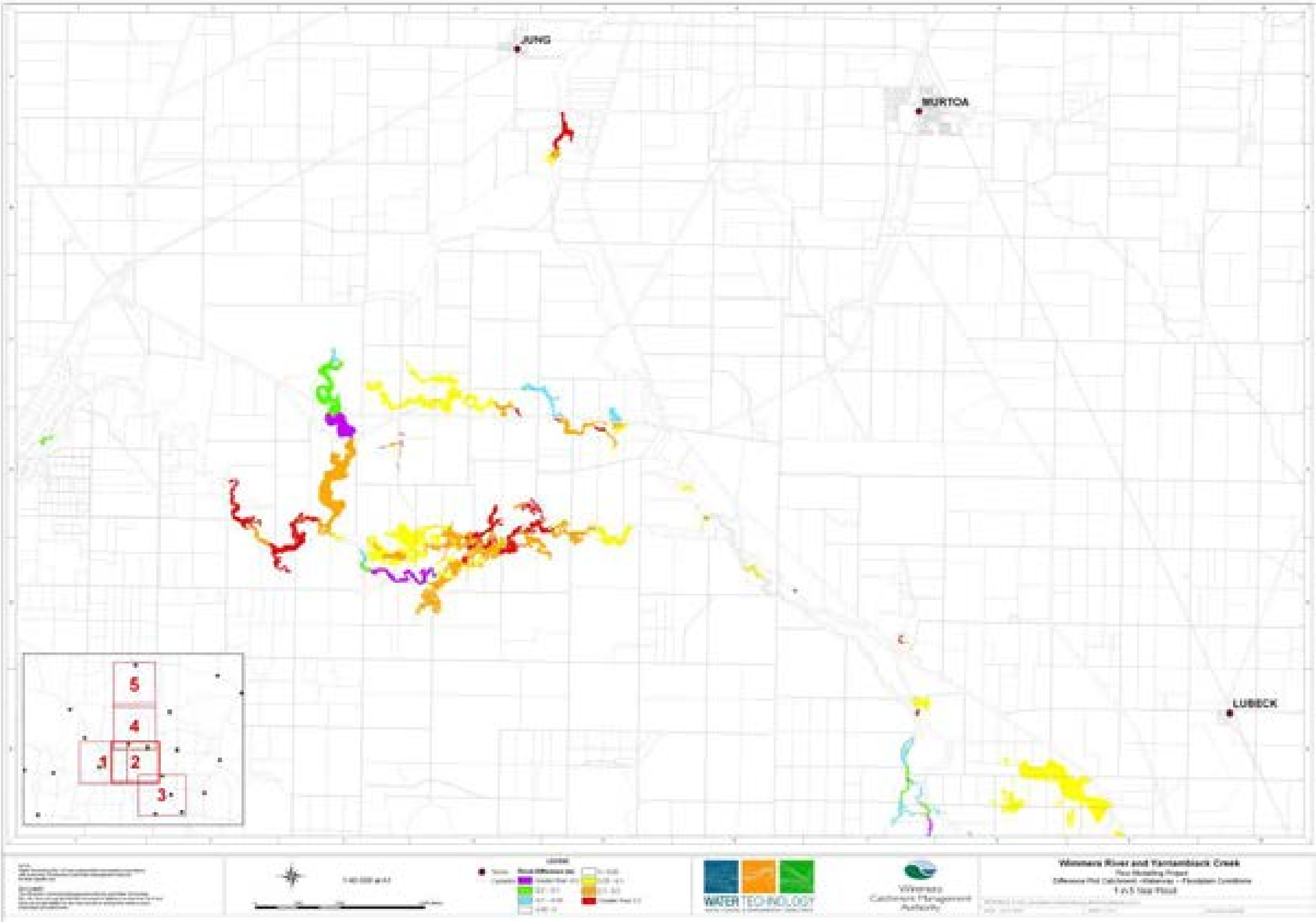

Figure 8-21 5 year ARI flood level difference map: Horsham-Lubeck Road – Dooen Swamp – Jung Weir: Existing conditions (Scenario 1) – Pre-European floodplain with existing catchment (Scenario 2)

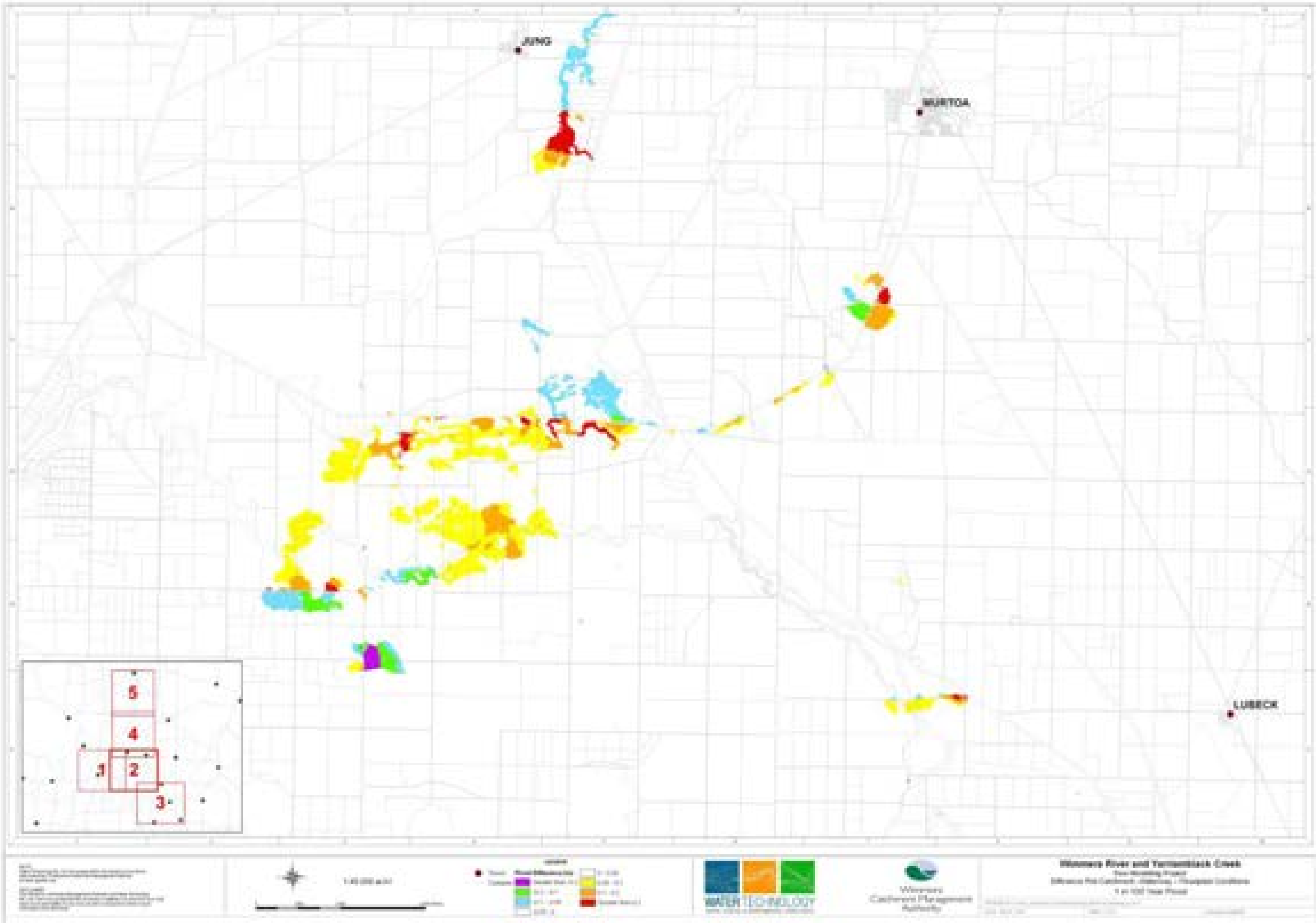

Figure 8-22 100 year ARI flood level difference map: Horsham-Lubeck Road – Dooen Swamp – Jung Weir: Existing conditions (Scenario 1) – Pre-European floodplain with existing catchment (Scenario 2)

Figure 8-23 displays the local flood levels differences adjacent to the Wimmera Highway Bridge for Scenario 2. The Wimmera Highway Bridge and its approaches obstruct the floodplain flows. This obstruction leads to increases in the 100 year flood level immediately upstream of the bridge of approximately 560 mm compared to pre-European waterway-floodplain conditions. The increased flood levels were limited to about 750 m south of the bridge. Decreased flood levels (up to 100 mm) occurred to the north of the bridge along Yarriambiack Creek. The decreased flood levels to the north of the bridge resulted from a reduction in the peak flow along Yarriambiack Creek under the existing conditions. Further discussion of the changes in peak flows and flood volume is provided below.

Under Scenario 2, all waterway and floodplain modifications since European settlement were removed. Scenario 4 provides a hydraulic assessment of the removal of the bridge and approaches only.

Table 8-8 details the nature of the flow distribution under the pre-European waterway-floodplain with the existing catchment conditions (Scenario 2). The change in peak flow and flood volume compared to the existing conditions (Scenario 1) is provided as percentage in brackets.

Table 8-8 Flow distribution: Horsham Lubeck Road – Dooen Swamp – upstream Jung Weir – Pre-European waterway-floodplain conditions with existing catchment conditions (Scenario 2)

Location	Design flood event (ARI)					
	5 year		20 year		100 year	
	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)
Wimmera River: Horsham-Lubeck Road	15,200 (0%)	45,135 (0%)	27,560 (0%)	81,400 (1%)	43,630 (2%)	121,240 (2%)
Yarriambiack Creek: Wimmera Highway	1,016 (7%)	2,540 (5%)	1,640 (12%)	4,130 (7%)	3,960 (25%)	8,160 (15%)
Wimmera River: Downstream of Two Mile Creek	11,160 (0%)	35,130 (-6%)	22,740 (0%)	64,660 (3%)	36,010 (-1%)	98,770 (0%)

As detailed in Table 8-8, increases in peak flow and flood volume occurred for Yarriambiack Creek at Wimmera Highway under the pre-European waterway-floodplain conditions with existing catchment conditions (Scenario 2), in comparison to the existing conditions. That is, the waterway-floodplain modifications have lead to reductions in peak flow and flood volumes for Yarriambiack Creek at the Wimmera Highway. These reductions were found to increase with flood magnitude, ranging from 7% for the 5 year ARI event to 25 % for the 100 year ARI event in peak flows. Under the pre-waterway-floodplains, the peak flow at the Wimmera Highway expressed as a percentage of the Wimmera River peak flow at the Horsham – Lubeck Road flow varied from 6.0 % for the 20 year ARI flood event, to 9.1 % for the 100 year ARI event. The flow split percentage for the 5 year ARI flood event was 6.7 %. The percentage flow split volumes have increased compared to existing conditions.

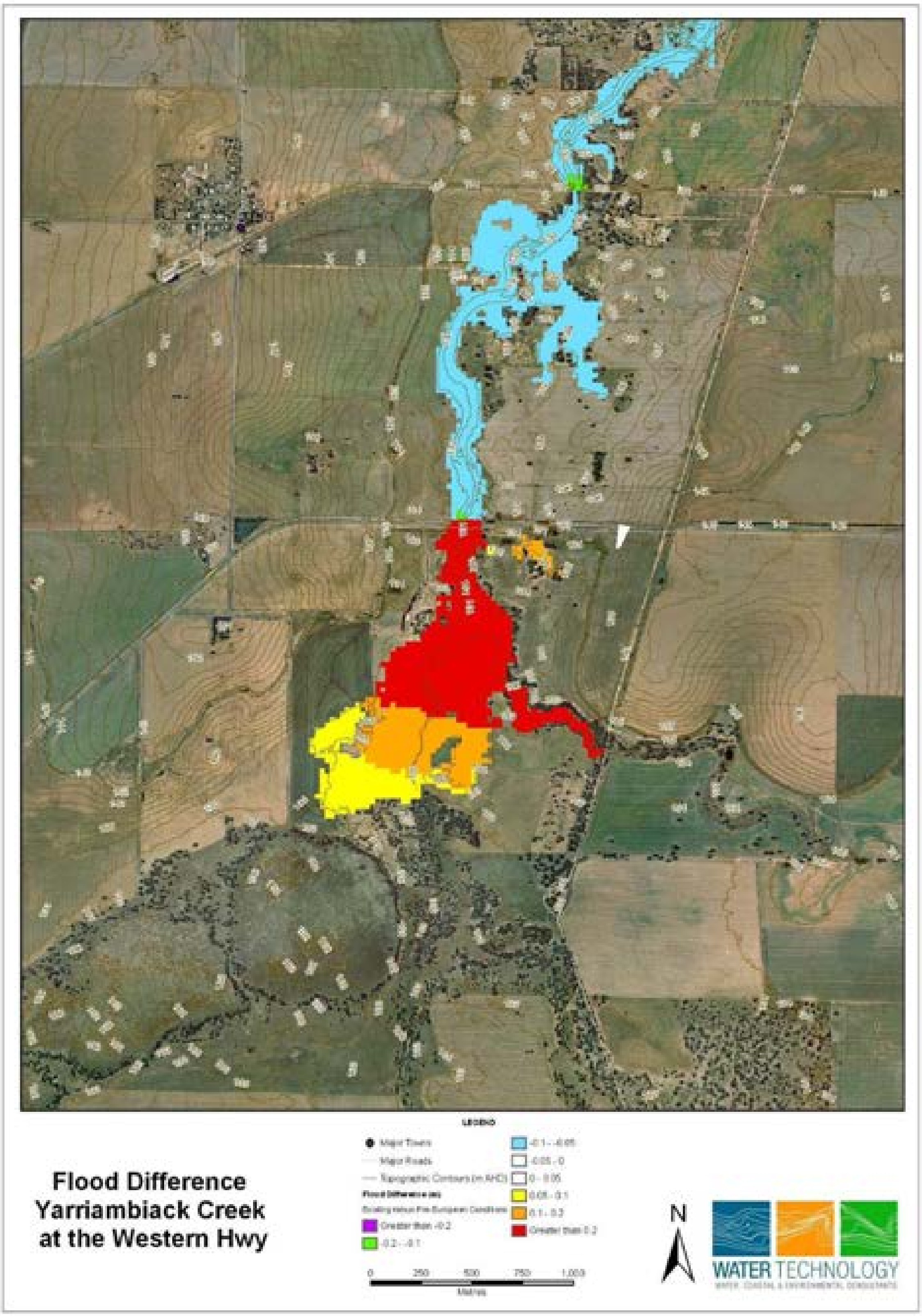

Figure 8-23 100 year ARI flood level difference map: Yarriambiack Creek at Wimmera Highway: Existing conditions (Scenario 1) – Pre-European floodplain with existing catchment (Scenario 2)

Figure 8-24 displays the flood hydrographs for Yarriambiack Creek at the Wimmera Highway under the existing and pre-European waterway-floodplain conditions.

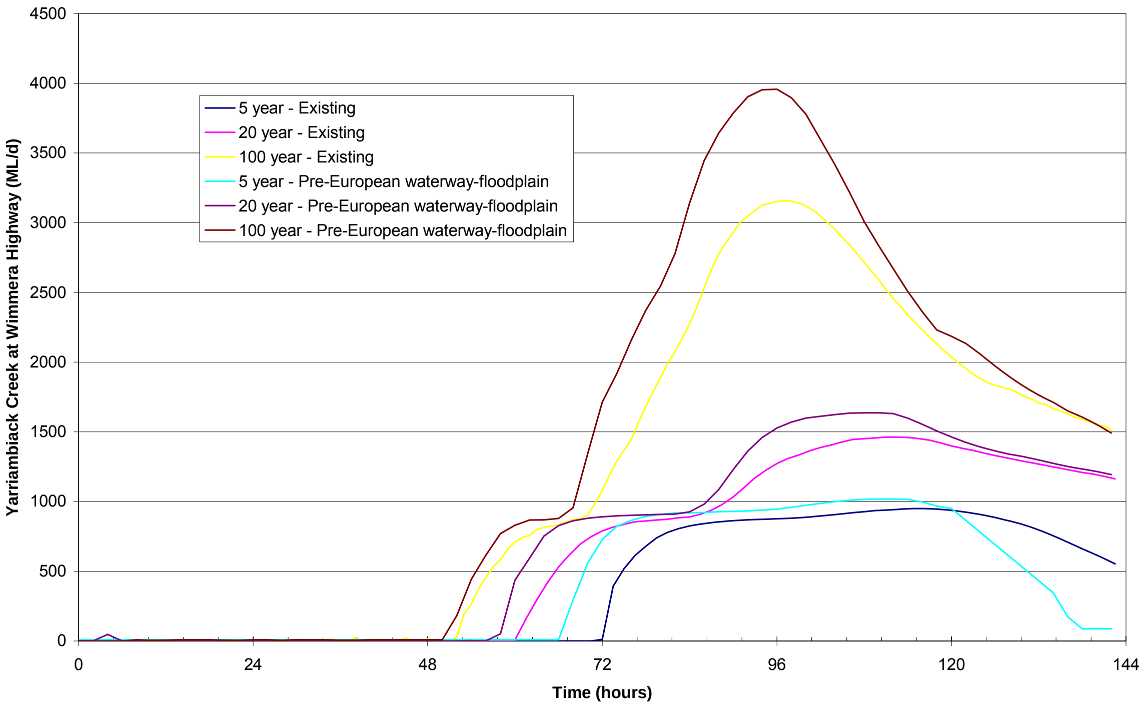

Figure 8-24 5, 20 & 100 year ARI flood hydrographs: Yarriambiack Creek at Wimmera Highway: Existing conditions (Scenario 1) & Pre-European floodplain with existing catchment (Scenario 2)

The peak flows for the Wimmera River downstream of Two Mile Creek were found to be similar to the existing conditions (Scenario 1). From these comparable peak flows, the waterway-floodplain modifications were considered to have minimal impact on flood behaviour on the Wimmera River adjacent to the Two Mile Creek confluence.

Scenario 3

In Scenario 3, the changes in the catchment conditions were assessed in addition to the waterway-floodplain modifications. Figure 8-25 and Figure 8-26 shows the Scenario 1 – Scenario 3 flood levels difference maps for the 5 and 100 year flood events. The flood levels differences show differences greater than 50 mm. It is considered differences less than 50 mm lie within the reasonable limit of model accuracy.

The changes in flood levels for Scenario 3 were similar in nature to those for Scenario 2. This reflects similar peak flows into this reach at Horsham-Lubeck Road as for Scenario 1 and 2. Table 8-9 displays the flow distribution in this reach under Scenario 3. The change in peak flow and flood volume compared to the existing conditions (Scenario 1) is provided as percentage in brackets.

Table 8-9 Flow distribution: Horsham Lubeck Road – Dooen Swamp – upstream Jung Weir – Pre-European waterway-floodplain and catchment conditions (Scenario 3)

Location	Design flood event (ARI)					
	5 year		20 year		100 year	
	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)
Wimmera River: Horsham Lubeck Road	15,970 (5%)	48,600 (8%)	28,040 (2%)	90,940 (13%)	43,480 (1%)	133,250 (12%)
Yarriambiack Creek: Wimmera Highway	990 (5%)	2,730 (13%)	1,680 (15%)	5,200 (15%)	4,060 (28%)	10,300 (45%)
Wimmera River: Downstream of Two Mile Creek	12,000 (8%)	39,800 (6%)	24,100 (6%)	76,050 (6%)	36,960 (2%)	113,190 (14%)

Table 8-9 shows a similar trend as for the Scenario 2, with peak flows and flood volumes for Yarriambiack Creek at the Wimmera Highway under Scenario 3 increased from Scenario 1. The magnitudes of the increases in peak flow flows and flood volume follow the increase in flood magnitudes. These increases reflect both the impact of waterway-floodplain conditions and catchment conditions. In contrast to Scenario 2, increases in peak flow and flood volumes under Scenario 3 occurred for the Wimmera River downstream Two Mile Creek. These increases principally highlight the role of upstream storages (Lake Lonsdale and Lake Bellfield) in attenuating flooding. The role of upstream storages on attenuating peak flows reduces with the flood magnitude.

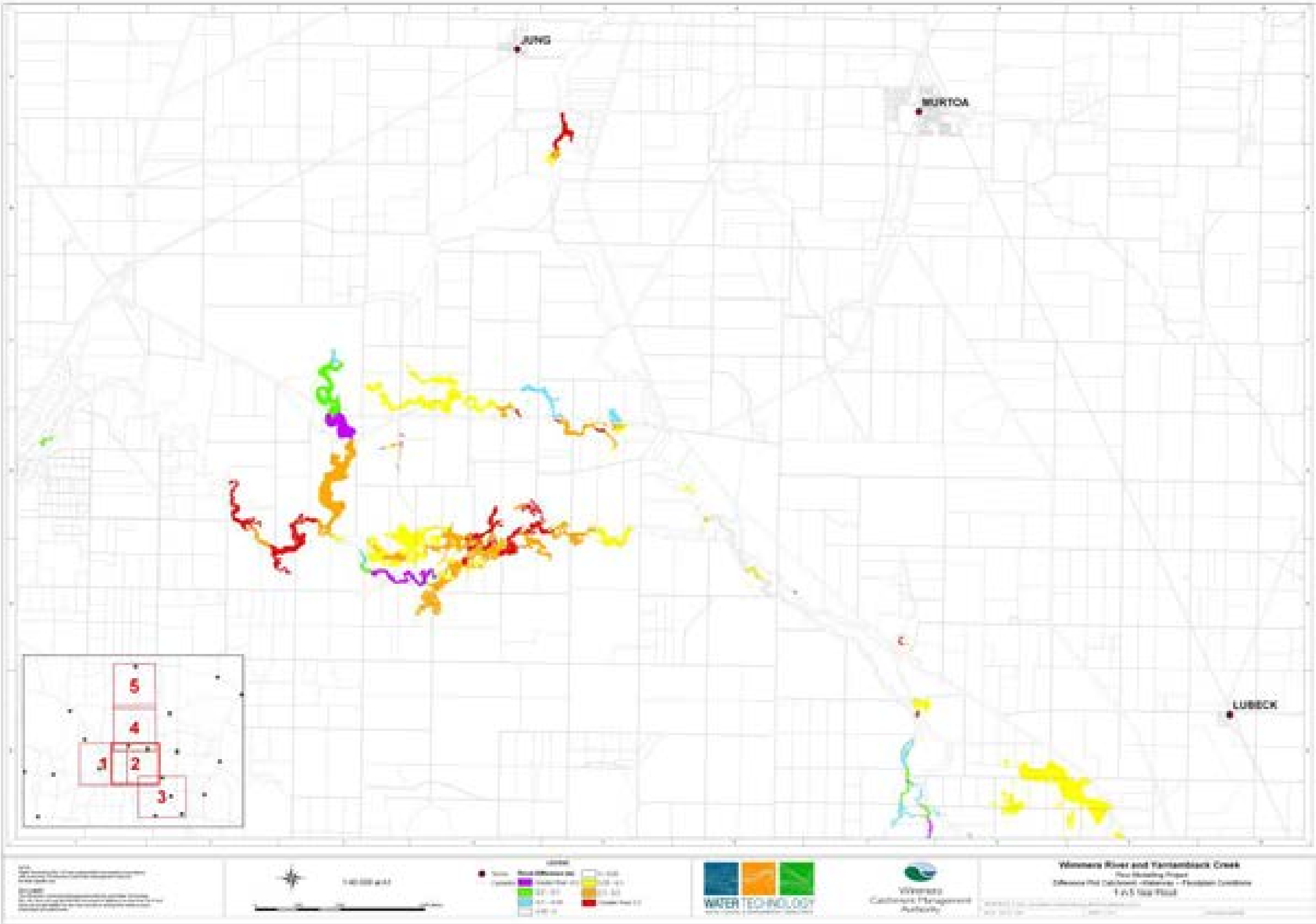

Figure 8-25 5 year ARI flood level difference map: Horsham-Lubeck Road – Dooen Swamp – upstream Jung Weir: Existing conditions (Scenario 1) – Pre-European floodplain –catchment (Scenario 3)

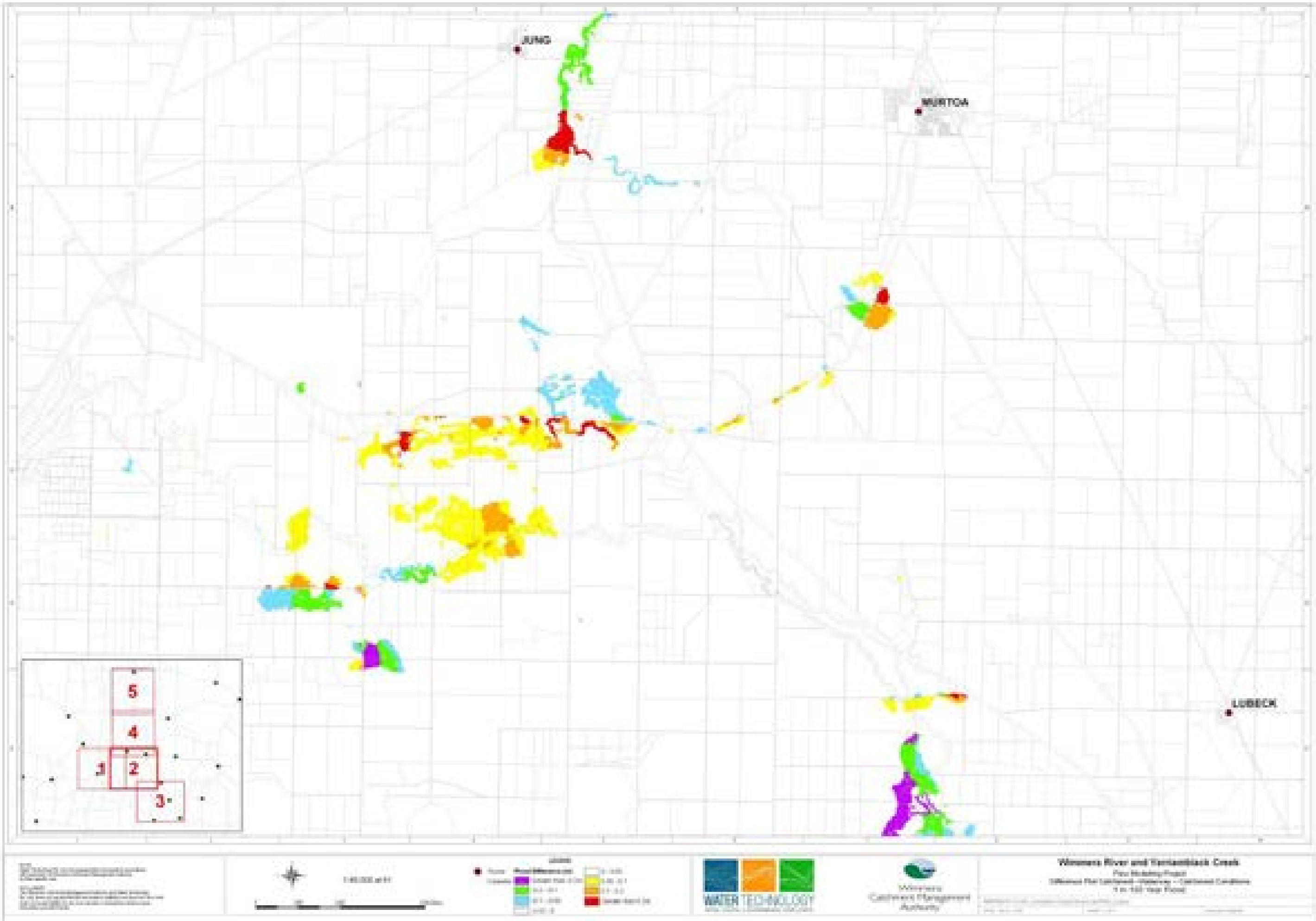

Figure 8-26 100 year ARI flood level difference map: Horsham-Lubeck Road – Dooen Swamp – upstream Jung Weir: Existing conditions (Scenario 1) – Pre-European floodplain-catchment (Scenario 3)

Scenario 4

Scenario 4 considered the removal of the Wimmera Highway Bridge and approaches. No other changes were made to the current waterway and floodplain conditions. Further, Scenario 4 considered the existing conditions as per Scenario 1 & 2. Scenario 2 identified significant reductions in flow, and hence following community consultation decided additional modelling was required to examine the bridge's impact. Limited funding necessitated the selection of 3 flood events (20, 50 and 100 year flood events only).

Figure 8-27 and Figure 8-28 shows the Scenario 1 – Scenario 4 flood levels difference maps for the 20 and 100 year flood events. The flood levels differences show differences greater than 50 mm. It is considered differences less than 50 mm lie within the reasonable limit of model accuracy.

The significant changes in flood levels for Scenario 4 occurred adjacent to the Wimmera Highway Bridge. Figure 8-29 displays the flood level differences for the 100 year flood event immediately adjacent to the Wimmera Highway.

As discussed for Scenario 2, the Wimmera Highway Bridge and its approaches obstruct the floodplain flows. This obstruction leads increases in the 100 year flood level immediately upstream of the bridge of approximately 600 mm compared to pre-European waterway-floodplain conditions. The increased flood levels were limited to about 750 m south of the bridge. Decreased flood levels (up to 100 mm) occurred to the north of the bridge along Yarriambiack Creek. The decreased flood levels to the north of the bridge resulted from a reduction in the peak flow along Yarriambiack Creek under the existing conditions. This pattern of flood level difference is in line with the Scenario 2.

Table 8-10 displays the flow distribution in this reach under Scenario 4. The change in peak flow and flood volume compared to the existing conditions (Scenario 1) is provided as percentage in brackets.

Table 8-10 Flow distribution: Horsham Lubeck Road – Dooen Swamp – upstream Jung Weir – Wimmera highway bridge removed (Scenario 4)

Location	Design flood event (ARI)					
	20 year		50 year		100 year	
	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)	Peak flow (ML/d)	Flood volume (ML)
Wimmera River: Horsham Lubeck Road	27,460 (0%)	80,680 (0%)	35,940 (0%)	102,660 (0%)	42,900 (0%)	119,043 (0%)
Yarriambiack Creek: Wimmera Highway	1,619 (11%)	4,257 (10%)	2,546 (17%)	7,129 (12%)	3,764 (19%)	8,644 (22%)
Wimmera River: Downstream of Two Mile Creek	22,557 (0%)	64,899 (3%)	30,151 (0%)	83,459 (4%)	35,861 (-1%)	103,402 (4%)

Table 8-10 shows a similar trend as for the Scenario 2, with peak flows and flood volume for Yarriambiack Creek at the Wimmera Highway under Scenario 4 increased from Scenario 1. The magnitudes of the increases in peak flow flows and flood volume follow the increase in flood magnitudes. These increases are slightly less than seen for Scenario 2. For example in the 20 year flood, the peak flow in Scenario 4 is 1,619 ML/d compared to 1,640 ML/d for Scenario 2. This indicates that the current Wimmera Highway Bridge arrangement is the key influence in the change in flow distribution since European settlement, and other modifications to waterways and floodplains play a secondary role.

For the Wimmera River downstream Two Mile Creek, only minor changes to the peak flow and flood volume were seen in Scenario 4.

The current Wimmera Highway Bridge has a significant influence on flow in Yarriambiack Creek downstream of the bridge, as discussed above. However, the bridge arrangement has no significant impact on flows in the Wimmera River downstream of Two Mile Creek, and in turn through Horsham.

Figure 8-30 shows the long profile of Yarriambiack Creek from upstream of Darlot Swamp to downstream of the Wimmera Highway Bridge. The profile indicates a fall in the invert level of Yarriambiack Creek at Darlot Swamp to the Wimmera Highway of about 1.2 m. This fall in the invert limits increases in the water level due to the current bridge arrangements to a distance of 750 m upstream of the bridge.

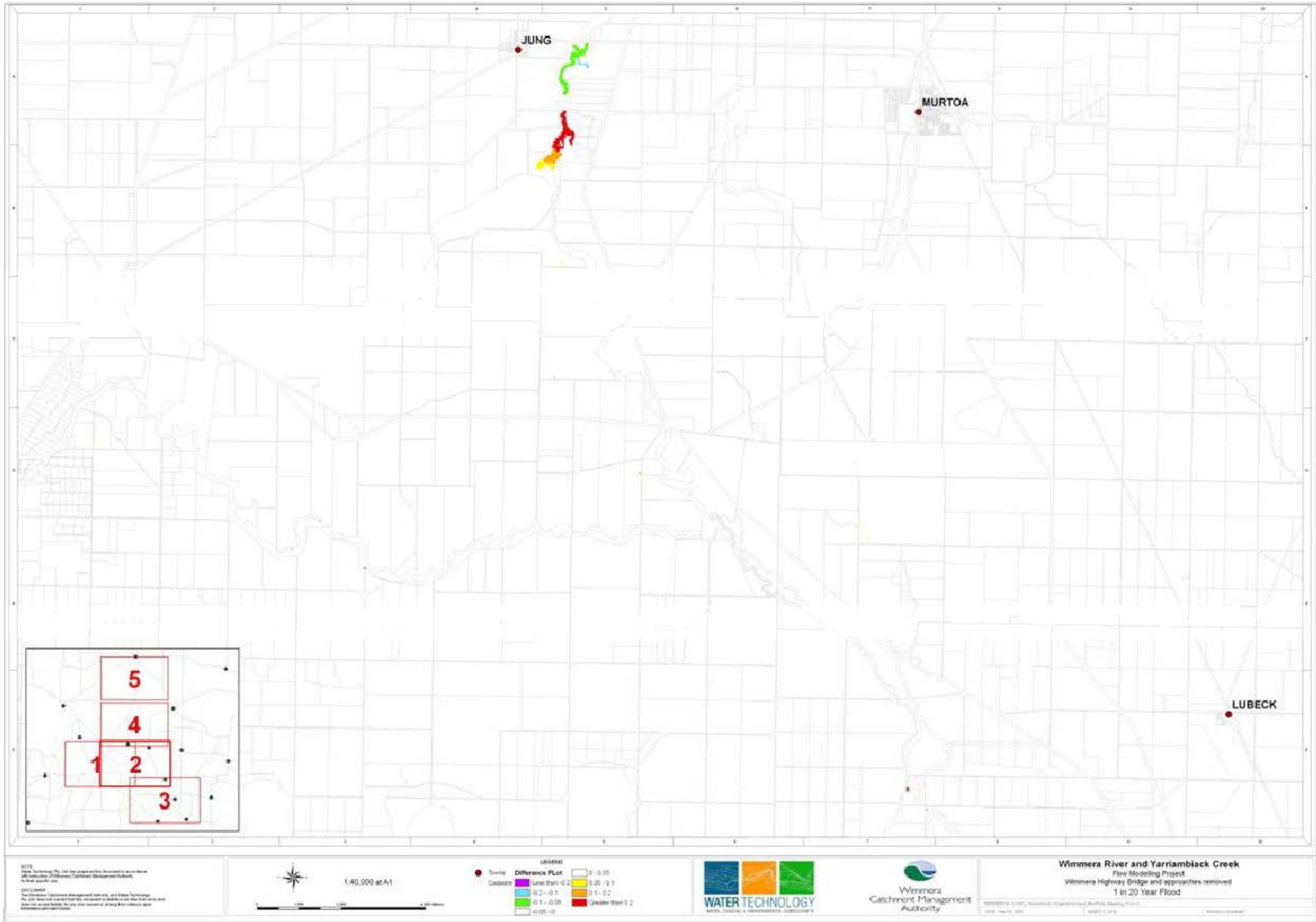

Figure 8-27 20 year ARI flood level difference map: Horsham-Lubeck Road – Dooen Swamp – upstream Jung Weir: Existing conditions (Scenario 1) – Wimmera Highway Bridge removed (Scenario 4)

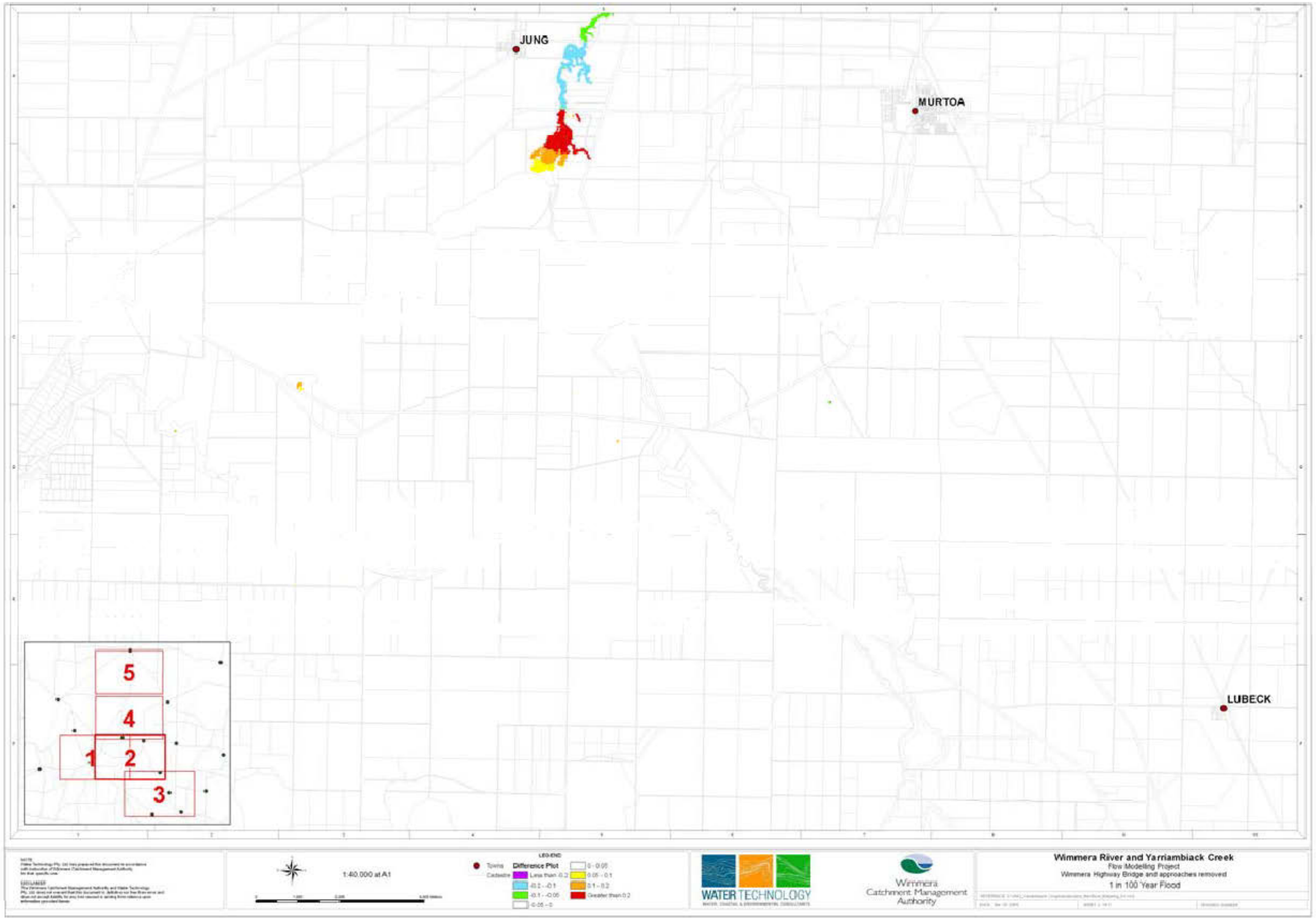

Figure 8-28 100 year ARI flood level difference map: Horsham-Lubeck Road – Dooen Swamp – upstream Jung Weir: Existing conditions (Scenario 1) – Wimmera Highway Bridge removed (Scenario 4)

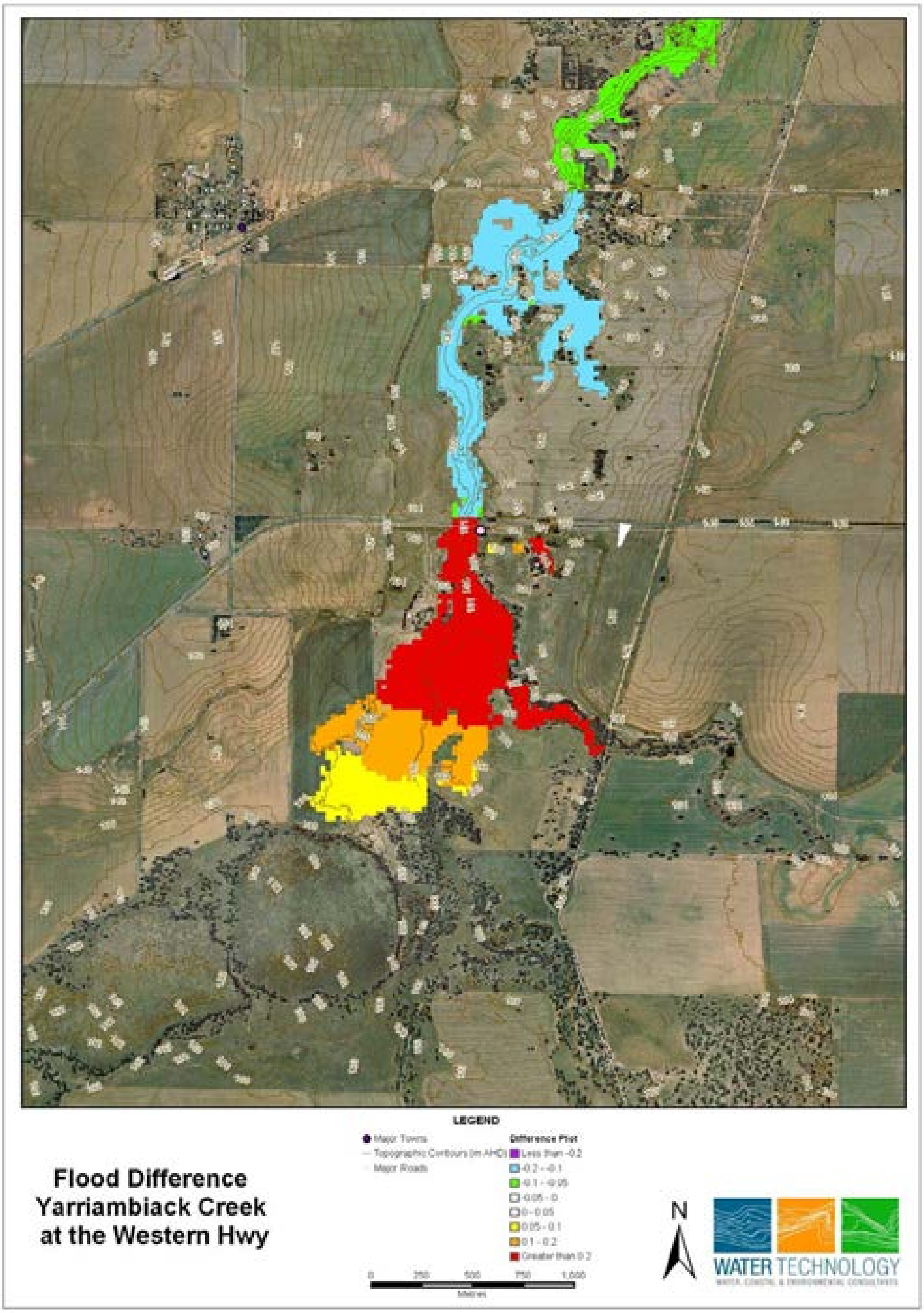

Figure 8-29 100 year ARI flood level difference map: Yarriambiack Creek at Wimmera Highway: Existing conditions (Scenario 1) – Wimmera Highway Bridge removed (Scenario 4)

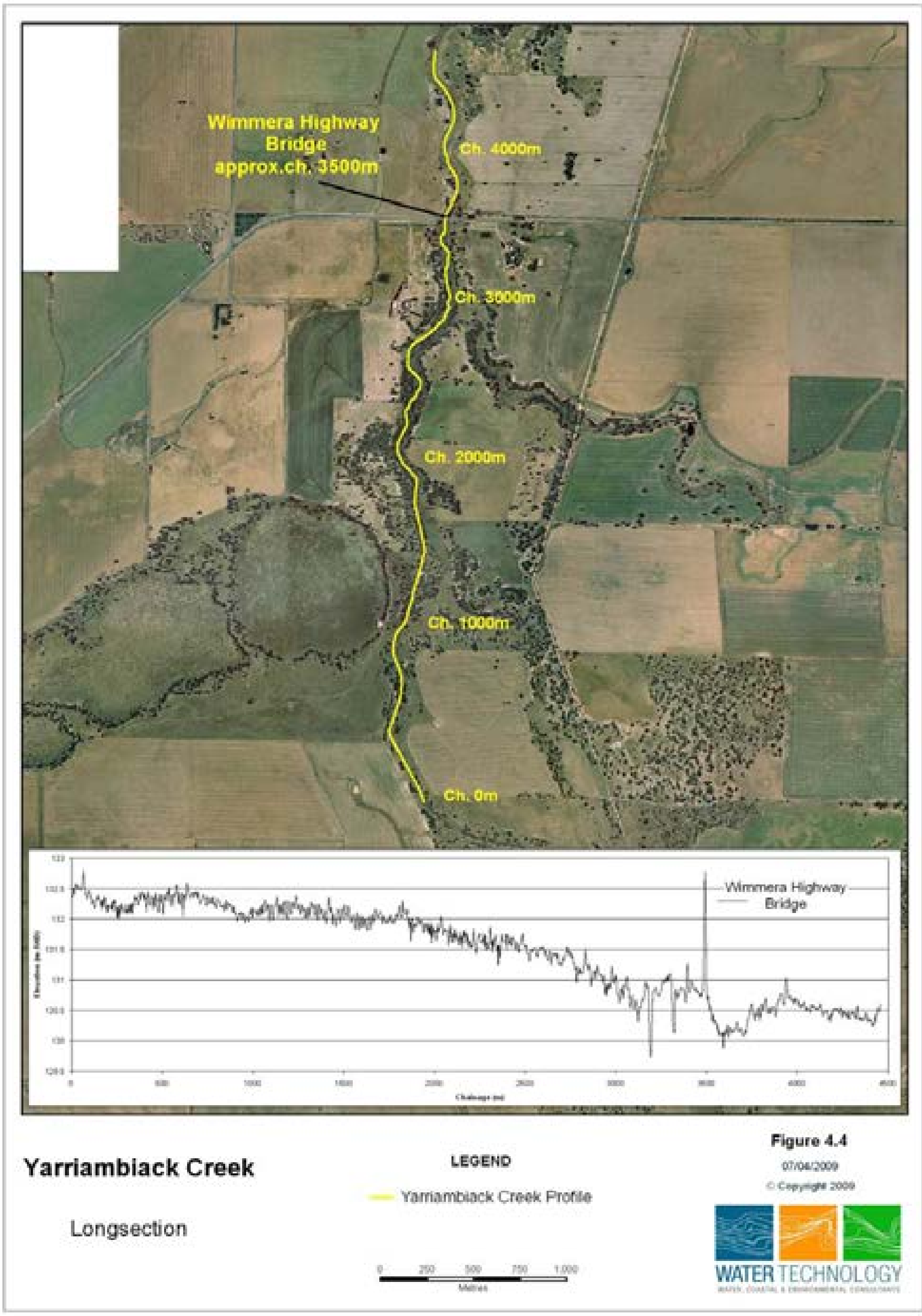

Figure 8-30 Yarriambiack Creek – long profile – Darlot Swamp to Wimmera Highway Bridge

8.3.2.3 Yarriambiack Creek: upstream Jung Weir to Warracknabeal

Scenario 1

The general flooding patterns under the existing conditions are displayed in Figure 8-31, Figure 8-32, Figure 8-33 and Figure 8-34 for the existing conditions (Scenario 1).

The flooding behaviour is characterised by inundation confined to the immediate surroundings of the creek. There are no extensive breakouts and/or floodplain areas. This characterisation is line with KBR (2004). For the design flood events considered by this study, the travel time of the peak flow from Jung Weir to Warracknabeal is about 36-40 hours.

Scenario 2

As discussed in Section 8.3.2.2, under the existing conditions (Scenario 1), there were decreases in peak flows and flood volumes entering Yarriambiack Creek, in comparison to the pre-European floodplain-waterway conditions (scenario 2). The decreased flows result in lower flood levels along Yarriambiack Creek under the existing conditions. For the 5 year ARI flood event, the decrease in flood levels are less than 50 mm, and hence are shown in Figure 8-35 and Figure 8-36. Due to the larger decreases in peak flows for the 100 year ARI event, decreases in flood levels along Yarriambiack Creek up to 100 mm occur, as seen in Figure 8-37 and Figure 8-38.

For the flow range considered, Jung Weir has no significant impact on local flood levels as the weir structure drowns out. The weir has a relatively small capacity compared to the flood volume, and fills early in flood event. As a result, Jung Weir does not significantly affect flood flows along the creek. This conclusion is in contrast to SMEC (2001), where the weir was considered to have a significant affect.

In the low-medium flow range (up to 500 ML/d), Jung Weir captured and stored flows up to the storage capcity. At these low-medium flows, the weir strucuture was not drowned out completly, and water levevls upstream of the structure would be elevated above the pre-Eurepoean conditions. The elevated water levels would be limited to the weir pool corridor, and it was considered unlikely for any siginifcant impacts on adjacent landholdings. No defintive estimate of the storage capcity was available from previous studies. An examination of the available topographic data suggested an indictive storage volume range from 75 – 150 ML. However, it should be noted this indictive storage volume range was considered relatveily small even compared to the low-medium flow range.

Scenario 3

Similar flood level differences occurred in the comparison of Scenario 3 and Scenario 1, as for Scenario 2 and Scenario 1. As for Scenario 2, the flood differences levels for the 5 year ARI flood event were less than 50 mm, and the difference maps are not shown.

Scenario 4

As discussed in Section 8.3.2.2, under the existing conditions (Scenario 1), there were decreases in peak flows and flood volumes entering Yarriambiack Creek, in comparison to the Wimmera Highway Bridge removed condition (scenario 4). The decreased flows result in lower flood levels along Yarriambiack Creek under the existing conditions. For the 5 year ARI flood event, the decrease in flood levels are less than 50 mm and flood level difference plots are provided. Due to the larger decreases in peak flows for the 100 year ARI event, decreases in flood levels along Yarriambiack Creek up to 50 mm occur, as seen in Figure 8-41 and Figure 8-42.

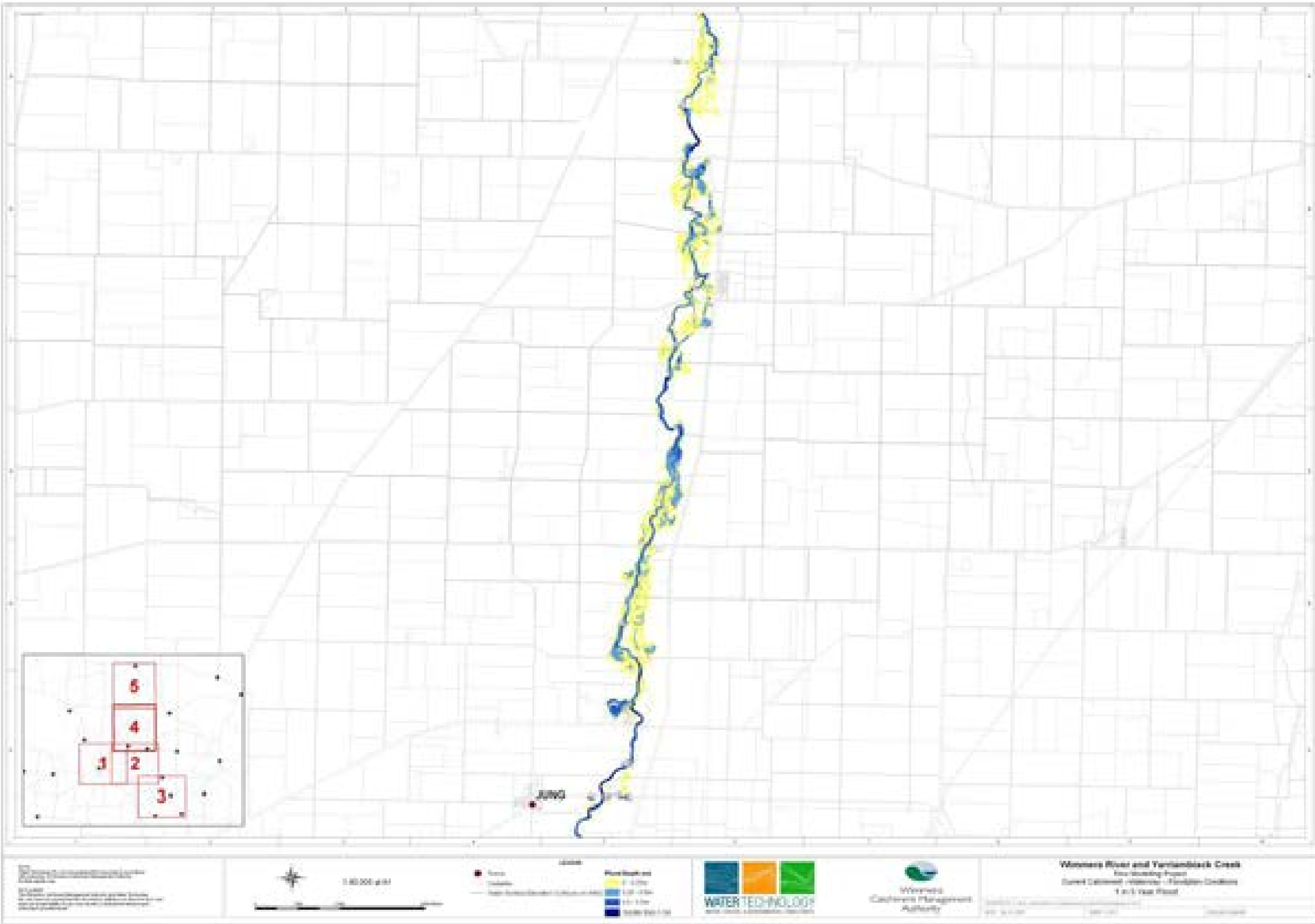

Figure 8-31 5 year ARI flood inundation maps: Yarriambiack Creek upstream Jung Weir Warracknabeal – Existing conditions (Scenario 1) (Map sheet 4)

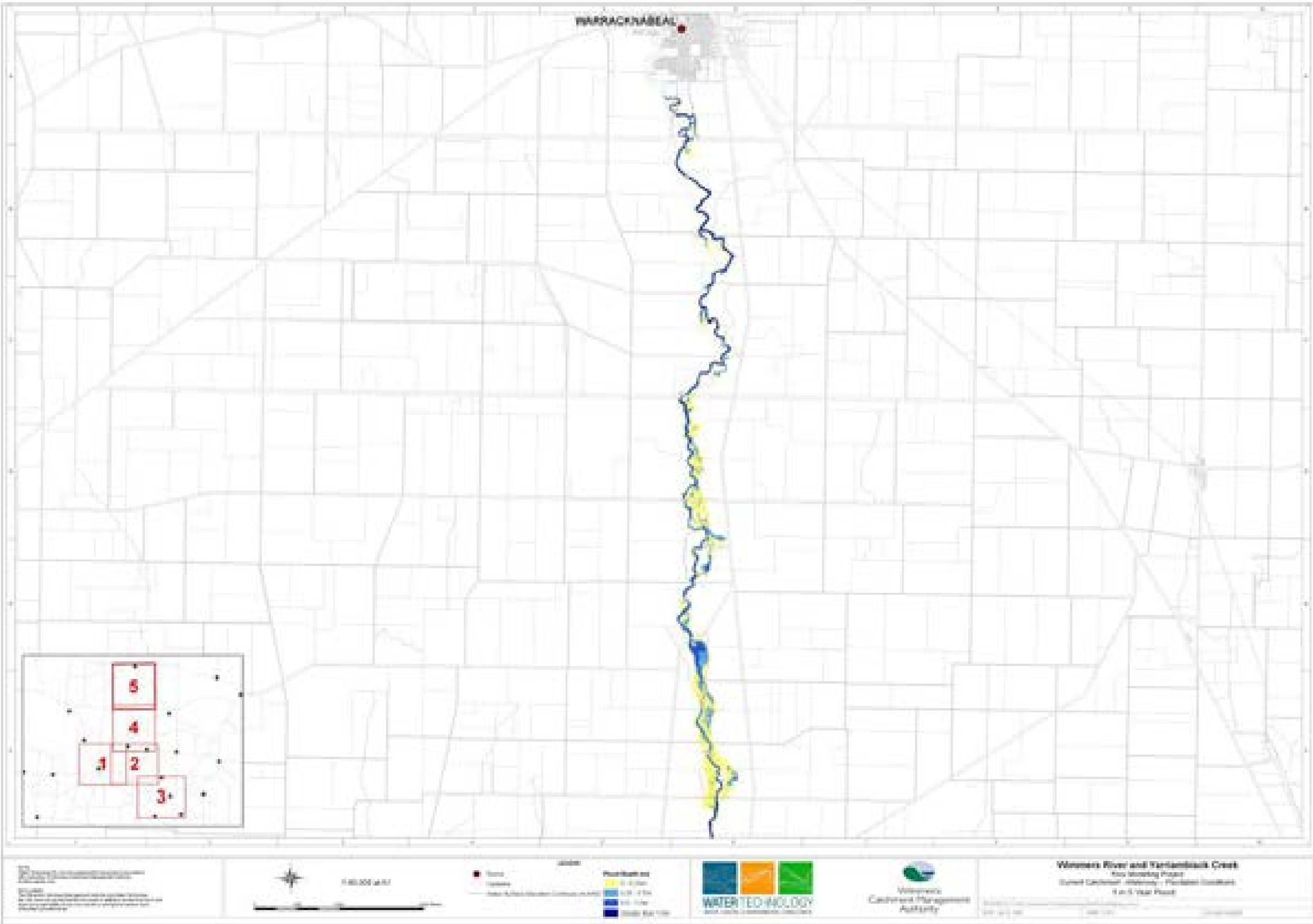

Figure 8-32 5 year ARI flood inundation maps: Yarriambiack Creek upstream Jung Weir Warracknabeal – Existing conditions (Scenario 1) (Map sheet 5)

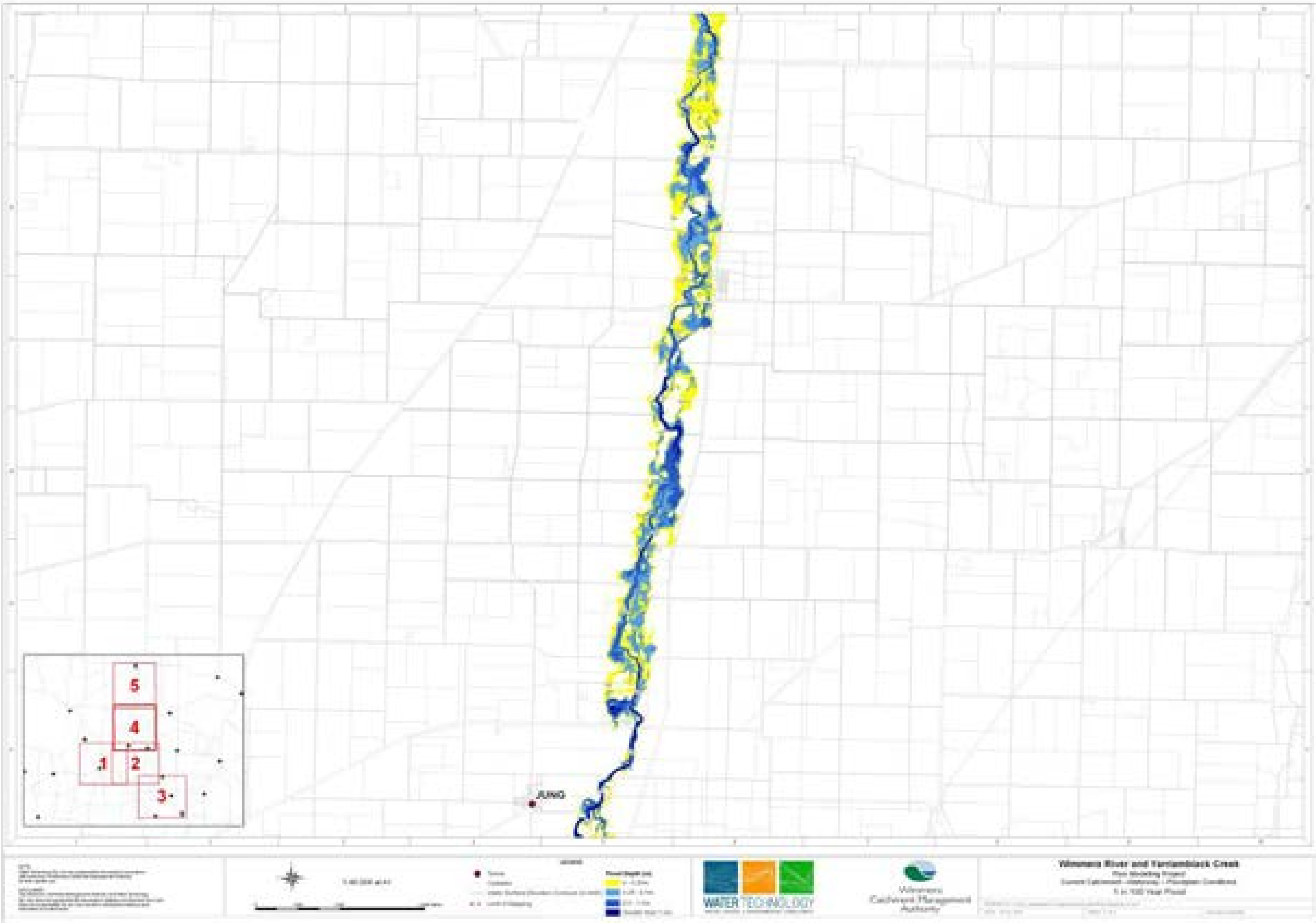

Figure 8-33 100 year ARI flood inundation maps: Yarriambiack Creek upstream Jung Weir Warracknabeal – Existing conditions (Scenario 1) (Map sheet 4)

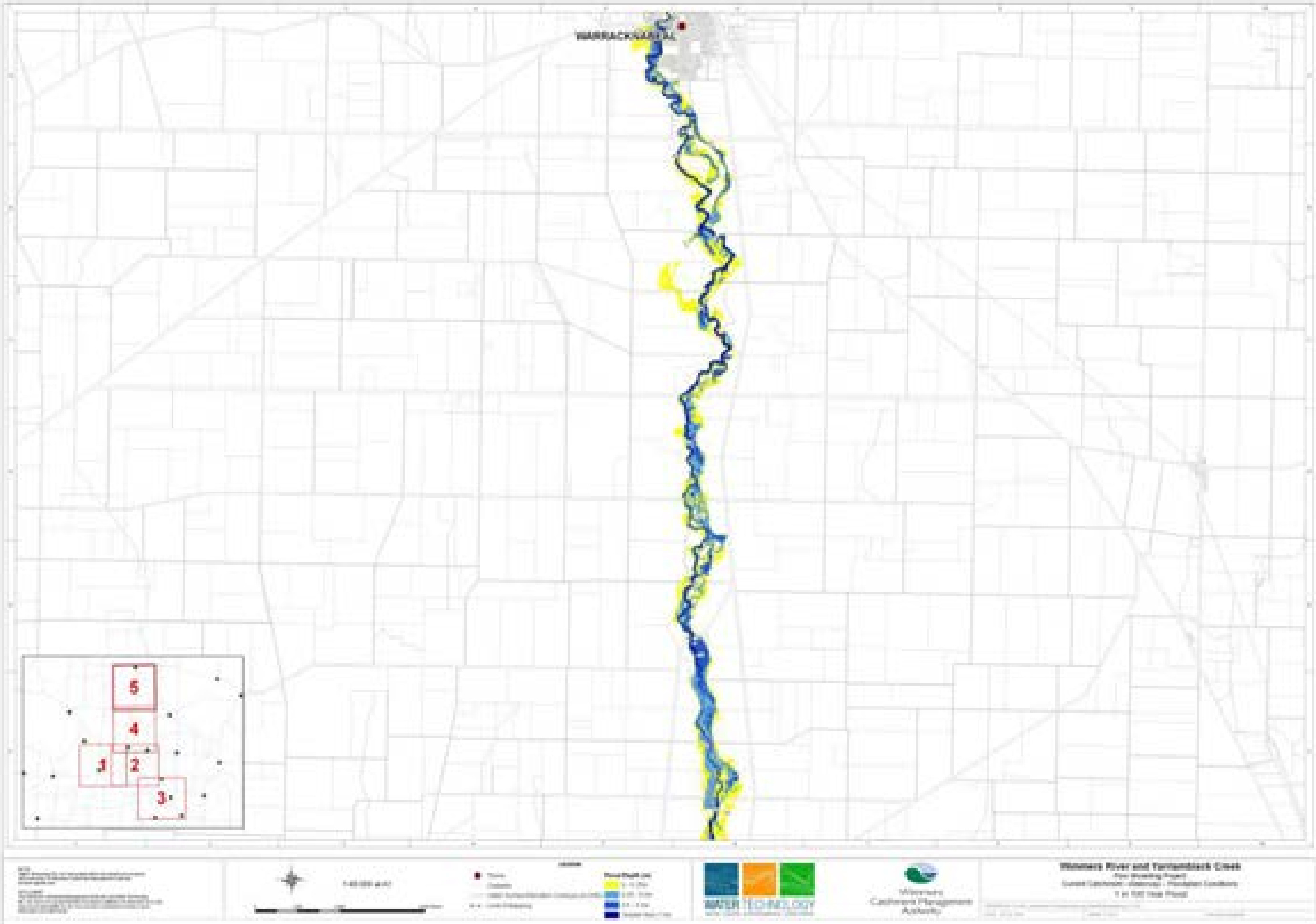

Figure 8-34 100 year ARI flood inundation maps: Yarriambiack Creek upstream Jung Weir Warracknabeal – Existing conditions (Scenario 1) (Map sheet 5)

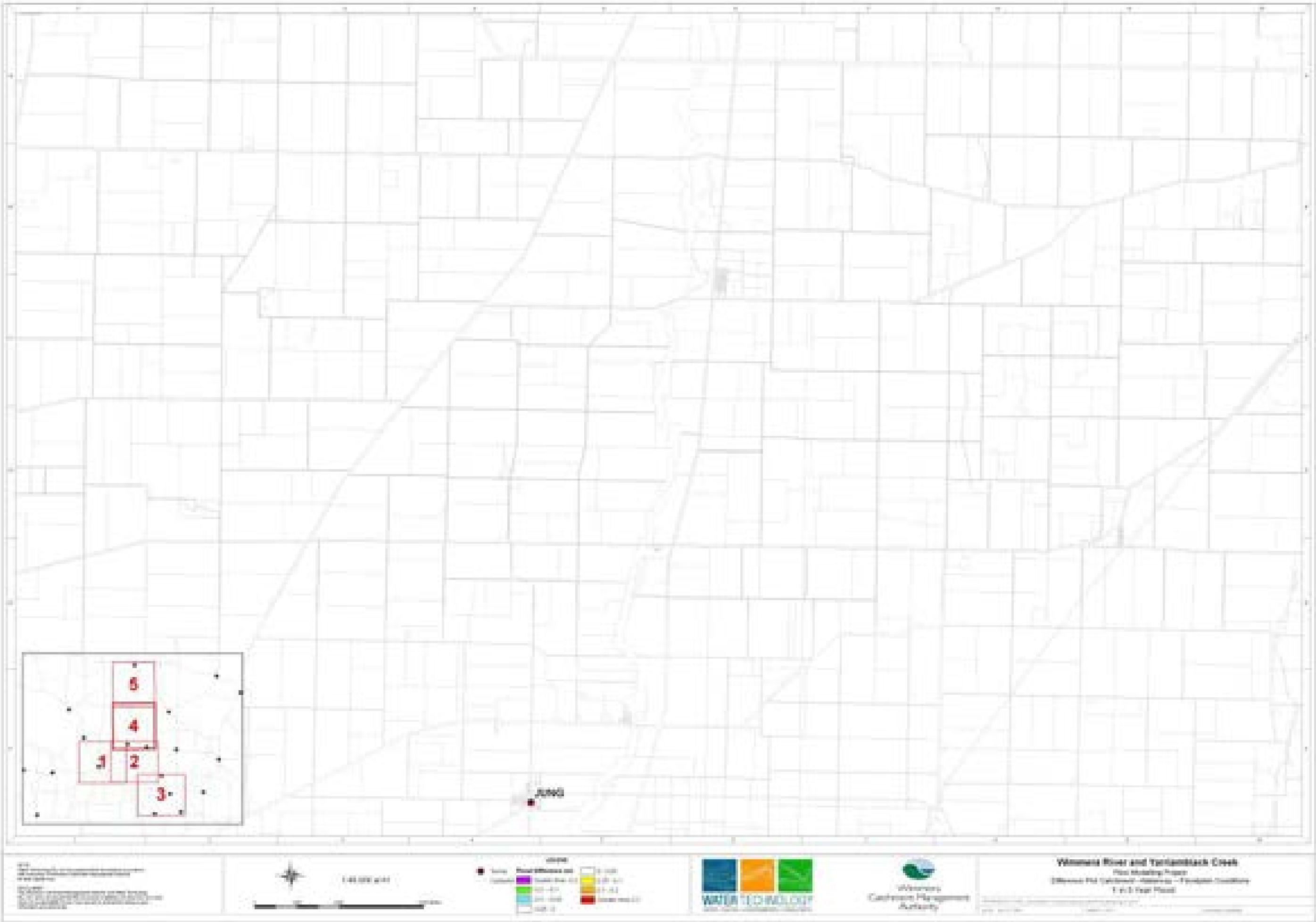

Figure 8-35 5 year ARI flood level difference map: Yarriambiack Creek upstream Jung Weir - Warracknabeal conditions (Scenario 1) – Pre-European floodplain with existing catchment conditions (Scenario 2) Map Sheet 4

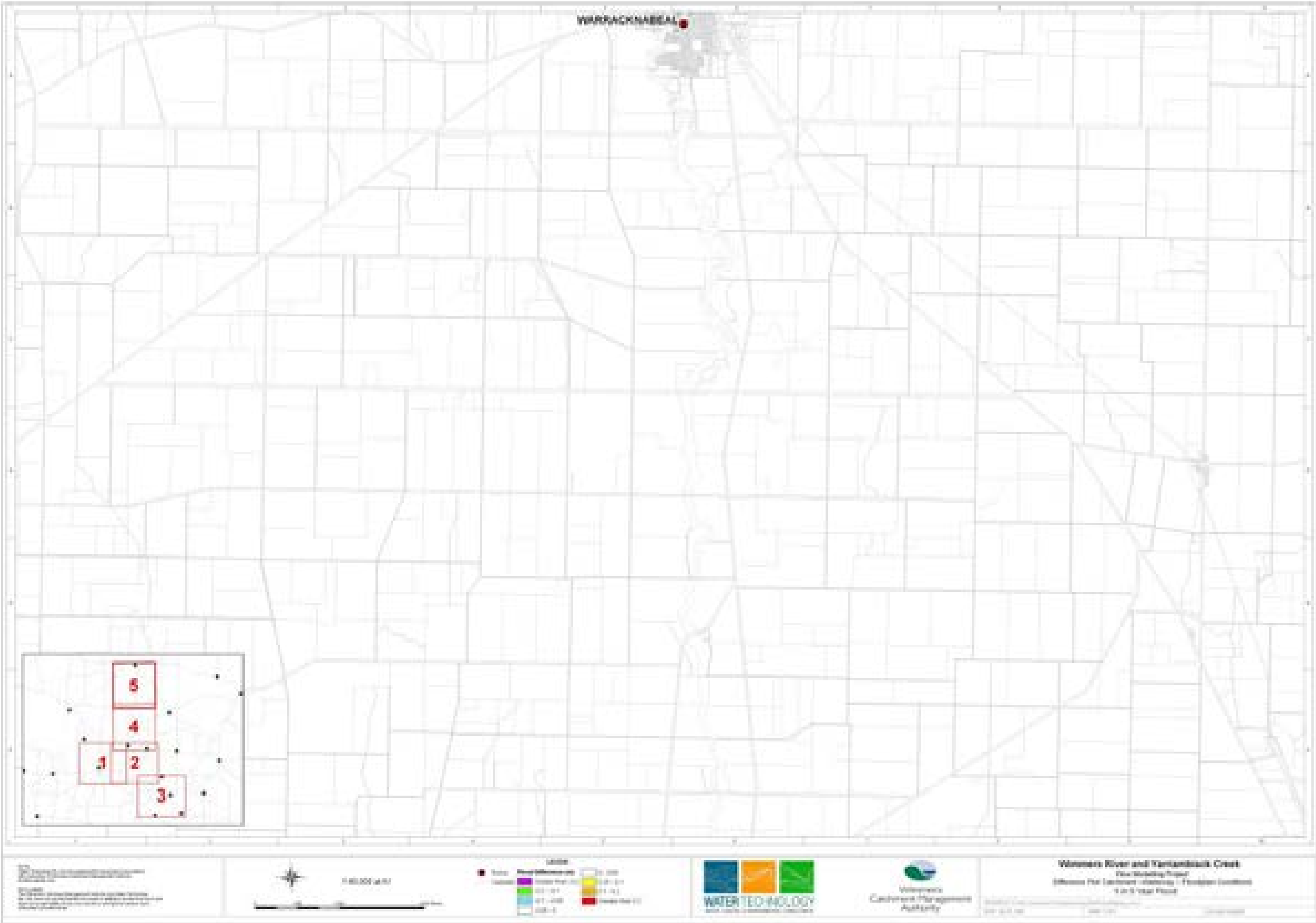

Figure 8-36 5 year ARI flood level difference map: Yarriambiack Creek upstream Jung Weir - Warracknabeal conditions (Scenario 1) – Pre-European floodplain with existing catchment conditions (Scenario 2) Map Sheet 5

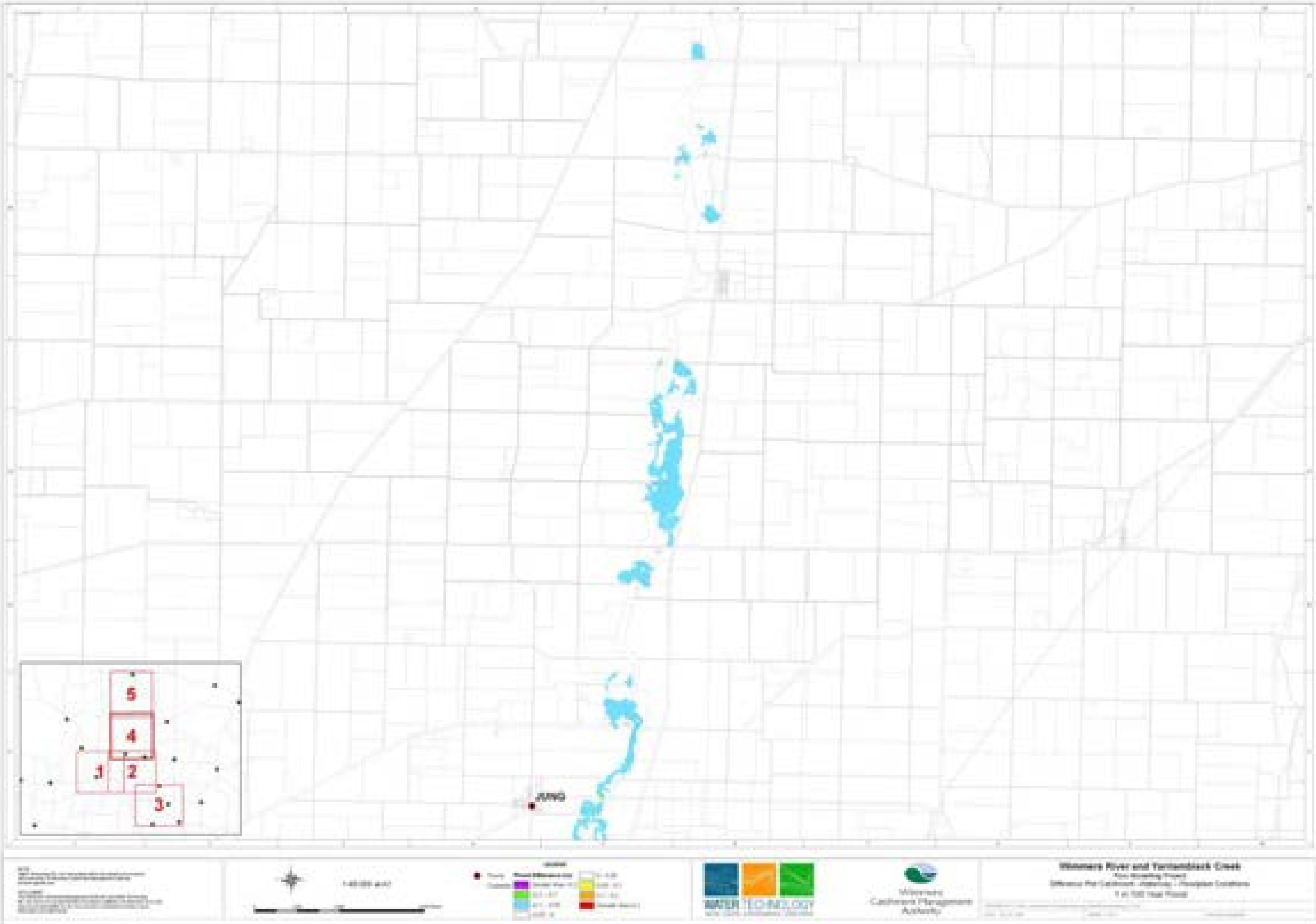

Figure 8-37 100 year ARI flood level difference map: Yarriambiack Creek upstream Jung Weir - Warracknabeal conditions (Scenario 1) – Pre-European floodplain with existing catchment conditions (Scenario 2) Map Sheet 4

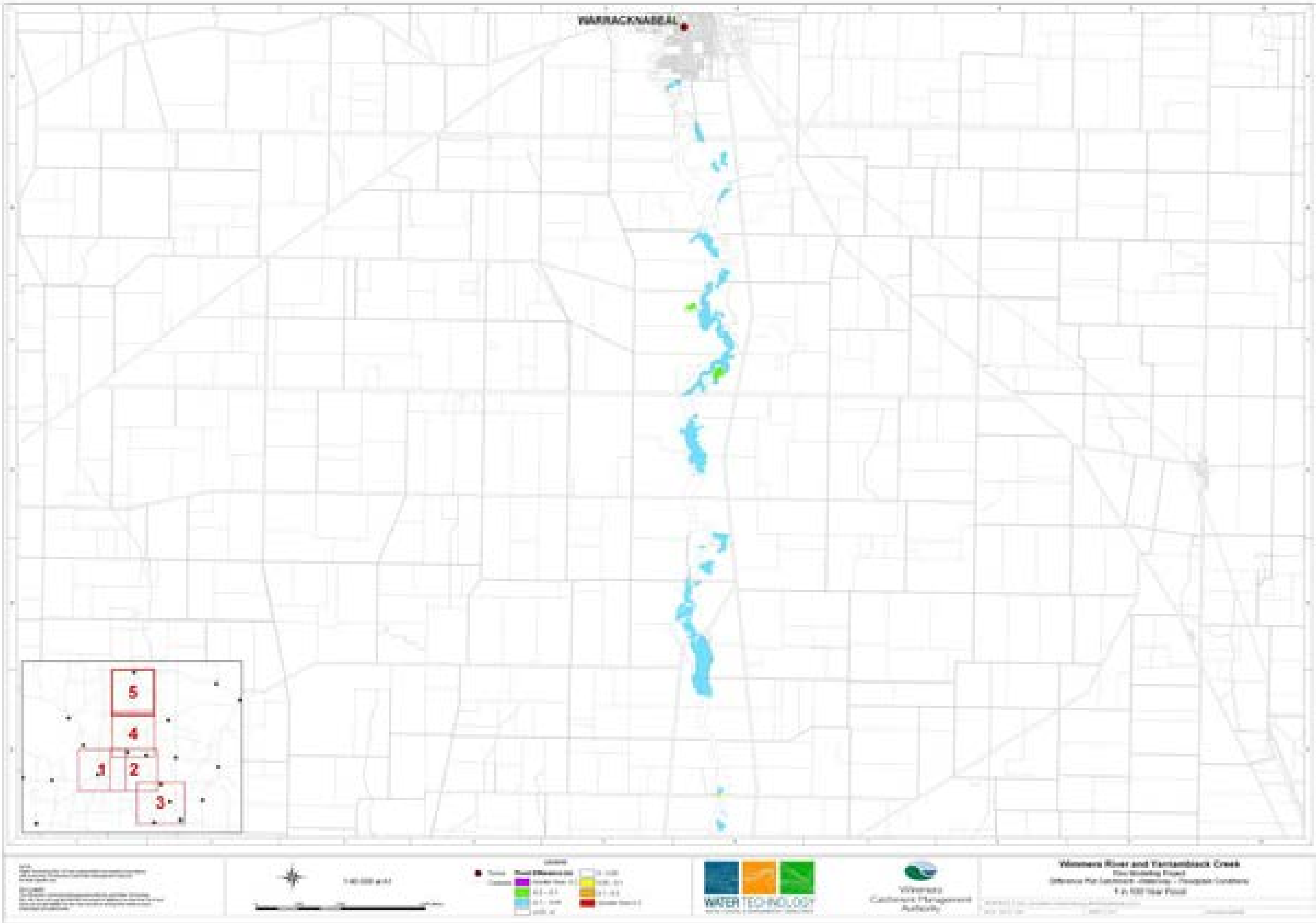

Figure 8-38 100 year ARI flood event level difference map: Yarriambiack Creek upstream Jung Weir - Warracknabeal conditions (Scenario 1) – Pre-European floodplain with existing catchment conditions (Scenario 2) Map Sheet 5

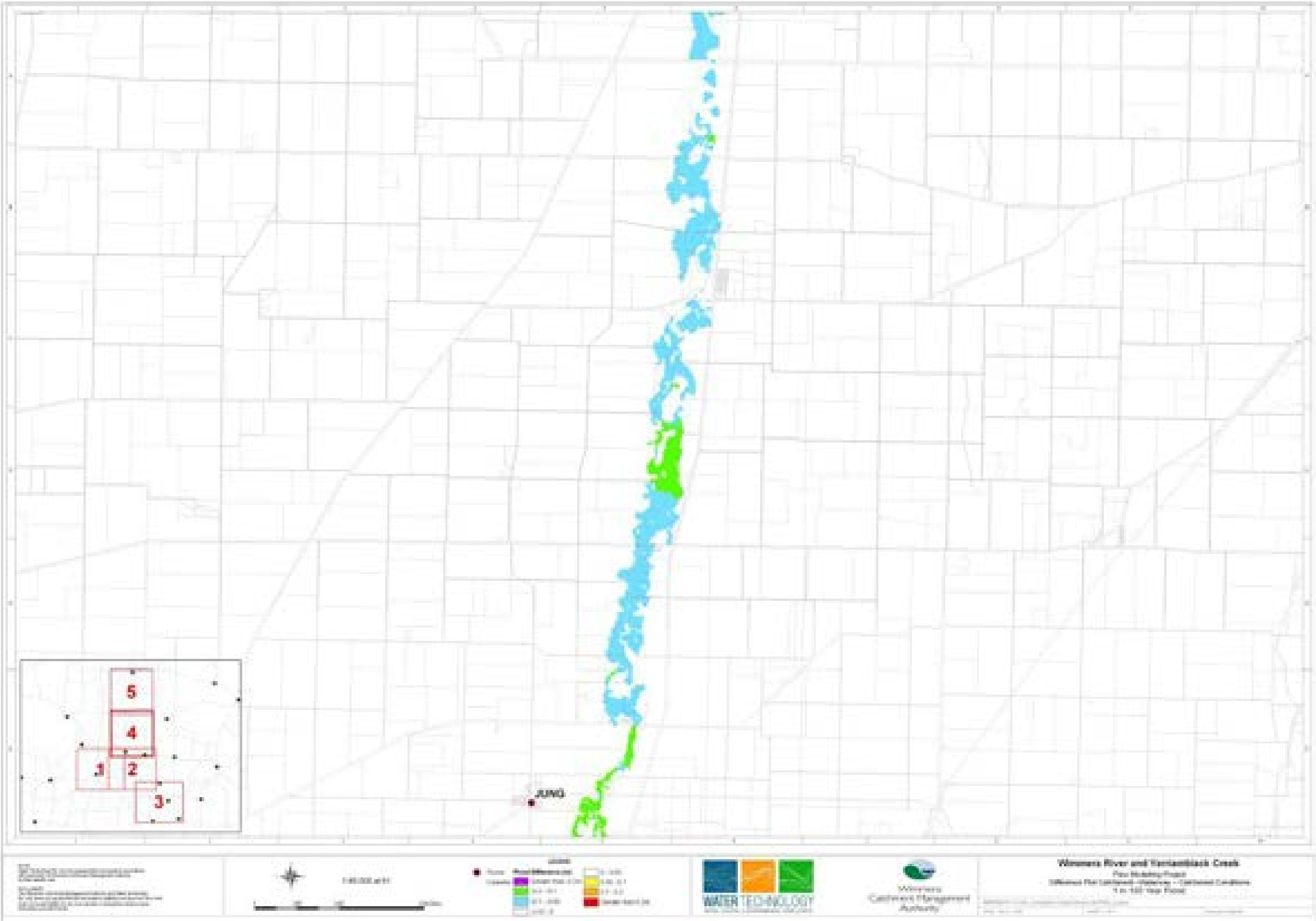

Figure 8-39 100 year ARI flood level difference map: Yarriambiack Creek upstream Jung Weir - Warracknabeal conditions (Scenario 1) – Pre-European floodplain- existing catchment conditions (Scenario 3) Map Sheet 4

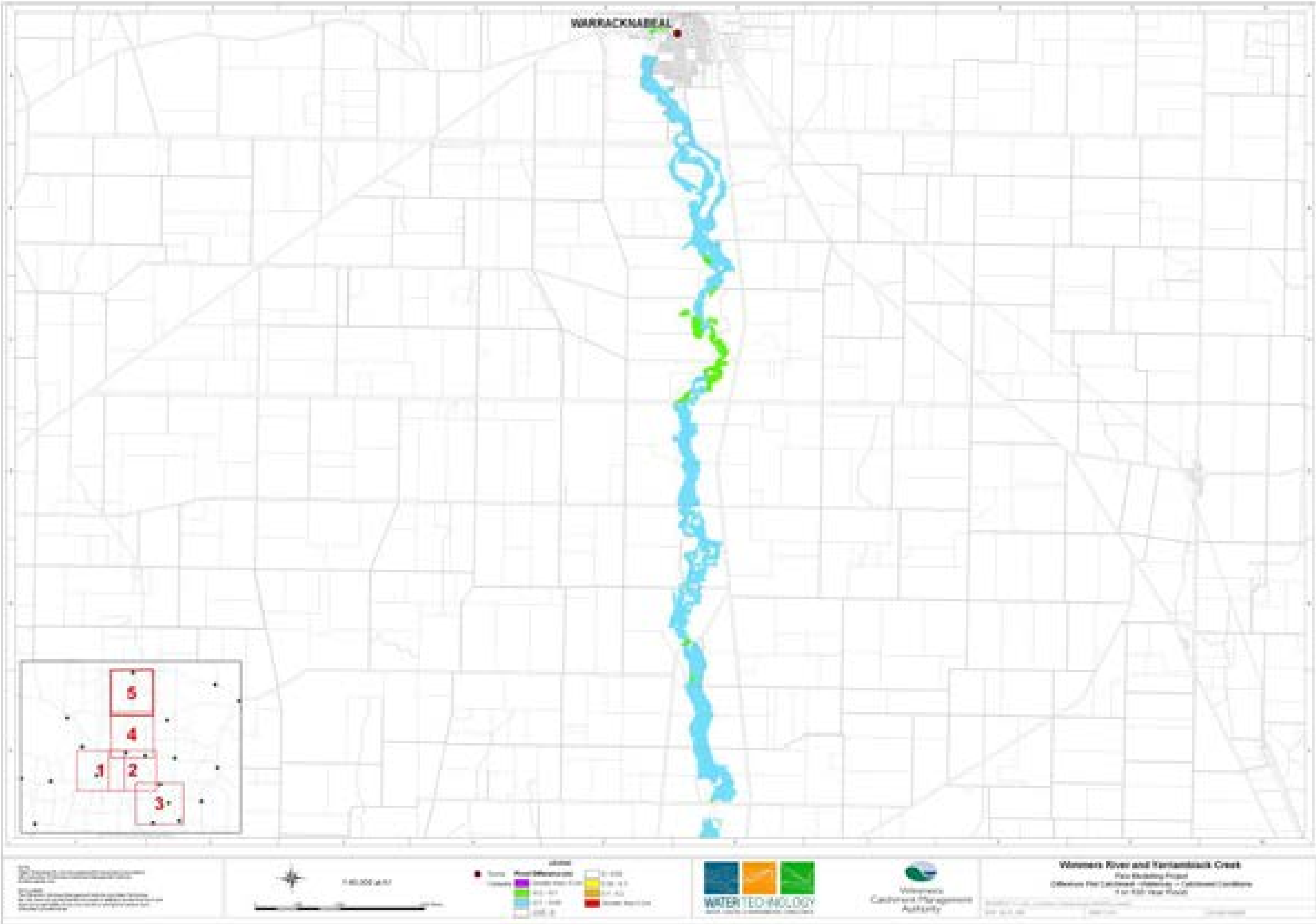

Figure 8-40 100 year ARI flood level difference map: Yarriambiack Creek upstream Jung Weir - Warracknabeal conditions (Scenario 1) – Pre-European floodplain- existing catchment conditions (Scenario 3) Map Sheet 5

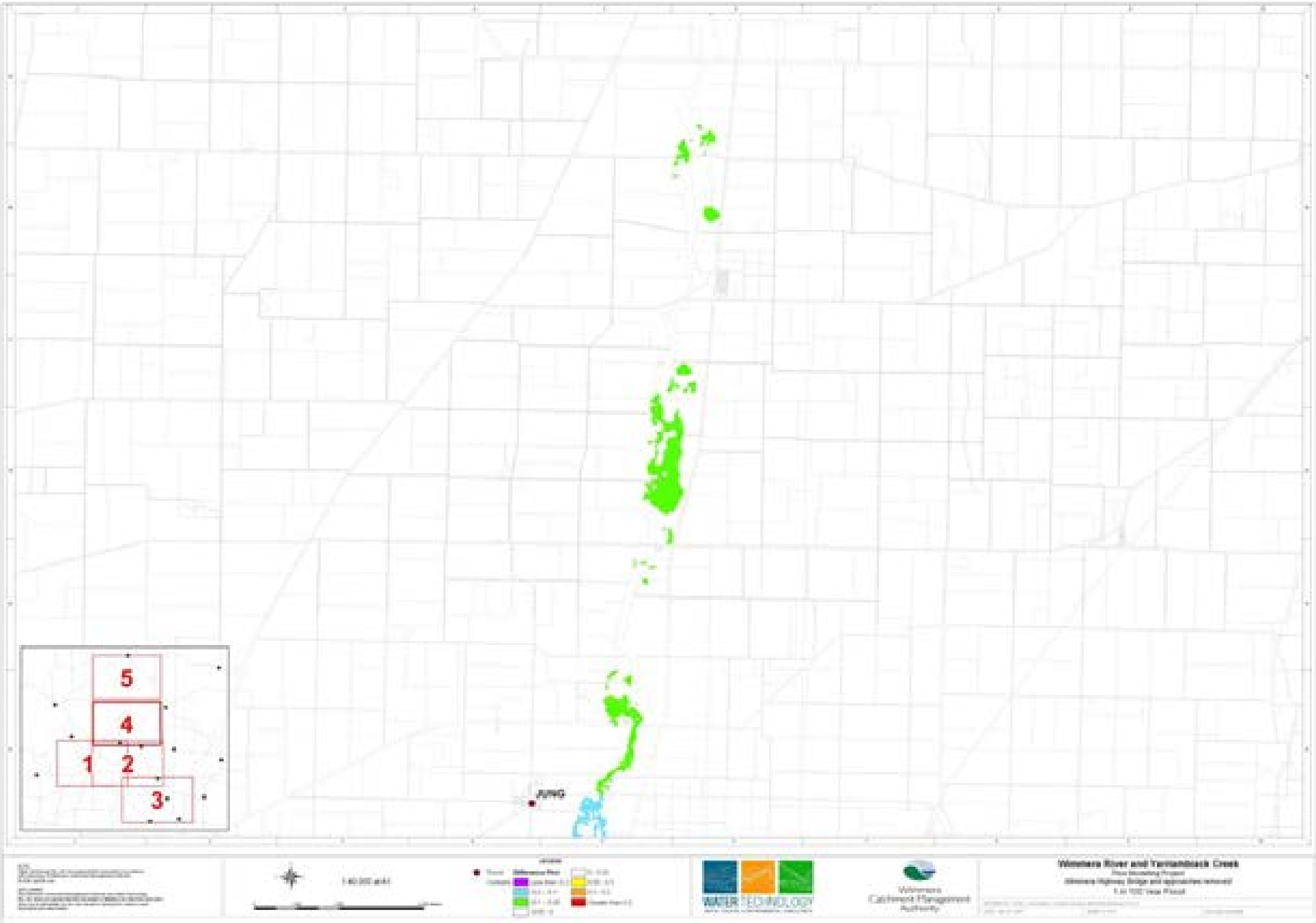

Figure 8-41 100 year ARI flood level difference map: Yarriambiack Creek upstream Jung Weir - Warracknabeal conditions (Scenario 1) – Wimmera Highway Bridge removed (Scenario 4) Map Sheet 4

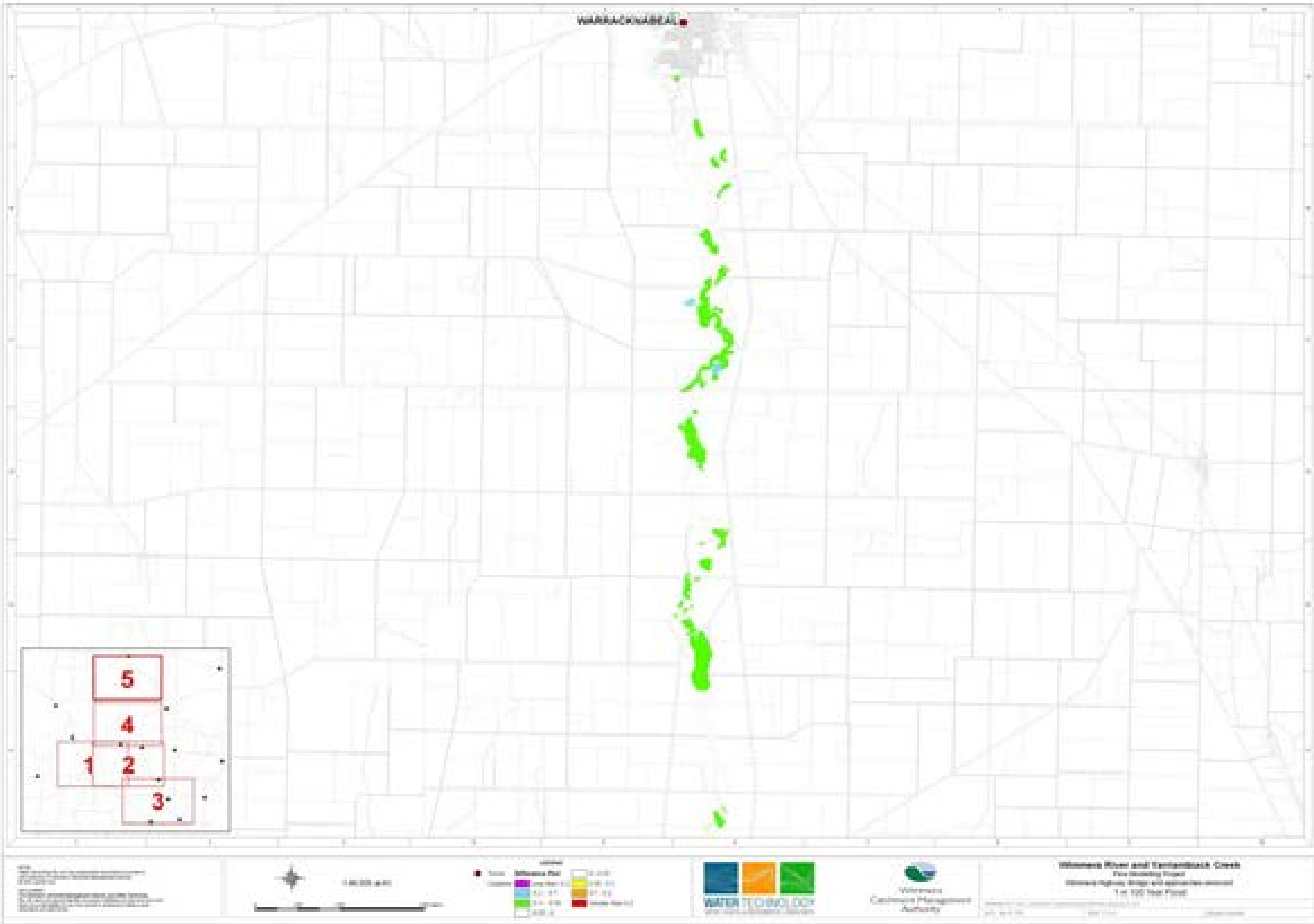

Figure 8-42 100 year ARI flood level difference map: Yarriambiack Creek upstream Jung Weir - Warracknabeal conditions (Scenario 1) – Wimmera Highway Bridge removed (Scenario 4) Map Sheet 5

8.3.2.4 *Wimmera River: Dooen Swamp to Horsham*

Scenario 1

The general flooding patterns under the existing conditions are displayed in Figure 8-43 and Figure 8-44 for the existing conditions (Scenario 1).

For the 5 year ARI event, flooding is confined to the adjacent river corridor. Dooen Swamp is filled and provides flood storage.

The 100 year ARI flood event has considerable floodplain flow. To the south of the Dooen Swamp, overland flow paths occurred adjacent to Browns, Heards and Rokeskys Roads. These breakaways leave the Wimmera River near the Two Mile Creek confluence and continue west crossing Riverside East and Cameron Roads. For the 100 year ARI flood event and larger events, the flood extent is limited by the availability of ALS data. Figure 8-44 shows the flood extent restricted to the limit of mapping. It is likely that the actual flood extents for the 100 year ARI flood event and larger events would extend beyond the limit of the detailed ALS data, particularly adjacent to Andrews Road. Future extension of the hydraulic modelling area using additional topographic data is recommended to refine the mapped flood extents (100 year ARI and greater events) adjacent to Andrews Road. These southern overland flowpaths were not included in the flood mapping undertaken by the Horsham Flood Study (Water Technology 2003b), as the flowpaths were beyond the study area.

Along the northern floodplain, overbank flooding occurred adjacent to Cameron Road, and Pryors Road and Peppertree Lane. The town levee is overtopped and outflanked adjacent to Pryors Road. This overtopping leads to flooding along Knowles, Webster, Lawrence and Culliver Streets. Further breakout occurred at Baillie and Menadue Streets, with flooding along Carr, Glancy, Rennison and Arnott Streets.

In a 50 year ARI event (~32,000 ML/d at Walmer), breakouts commence near Hamilton Street. This breakout continues to the west along Hamilton Street and McBryde Street across the Western Highway. Flooding affects Urquhart, Sloss, Madden and Firebrace Streets, and O'Callaghan's Parade. This breakout follows the Old Town anabranch. The breakout rejoins the Wimmera River via Wotonga Basin.

The flood behaviour determined by this project was in line with the findings of the Horsham Flood Study (Water Technology 2003). A spot check of 100 year ARI flood levels shows this project's flood levels are generally within 100 mm of the previous study's estimates. The use of the most recent ALS topographic data and revised hydraulic modelling provides a higher reliability in this project's flood level estimates.

Scenario 2

As discussed, extensive flood mitigation works were undertaken in the mid-late 1980's. Figure 8-45 displays the 100 year ARI flood level difference map for the existing conditions (Scenario 1) and the pre-European waterway and floodplain with current catchment conditions (Scenario 2). The impact on the mitigation works is seen by the lower flood levels under the existing waterway-floodplain conditions downstream of Dooen Swamp.

Scenario 3

No significant changes in flows for the Wimmera River downstream of Two Mile Creek were due to the pre-European catchments conditions. Hence, there were no significant changes in flood levels, and flood level difference plots are not provided.

Scenario 4

As outlined in Table 8-10, no significant changes in flows for the Wimmera River downstream of Two Mile Creek due to the removal of the Wimmera Highway Bridge (Scenario 4). Hence, there were no significant changes in flood levels, and flood level difference plots are not provided.

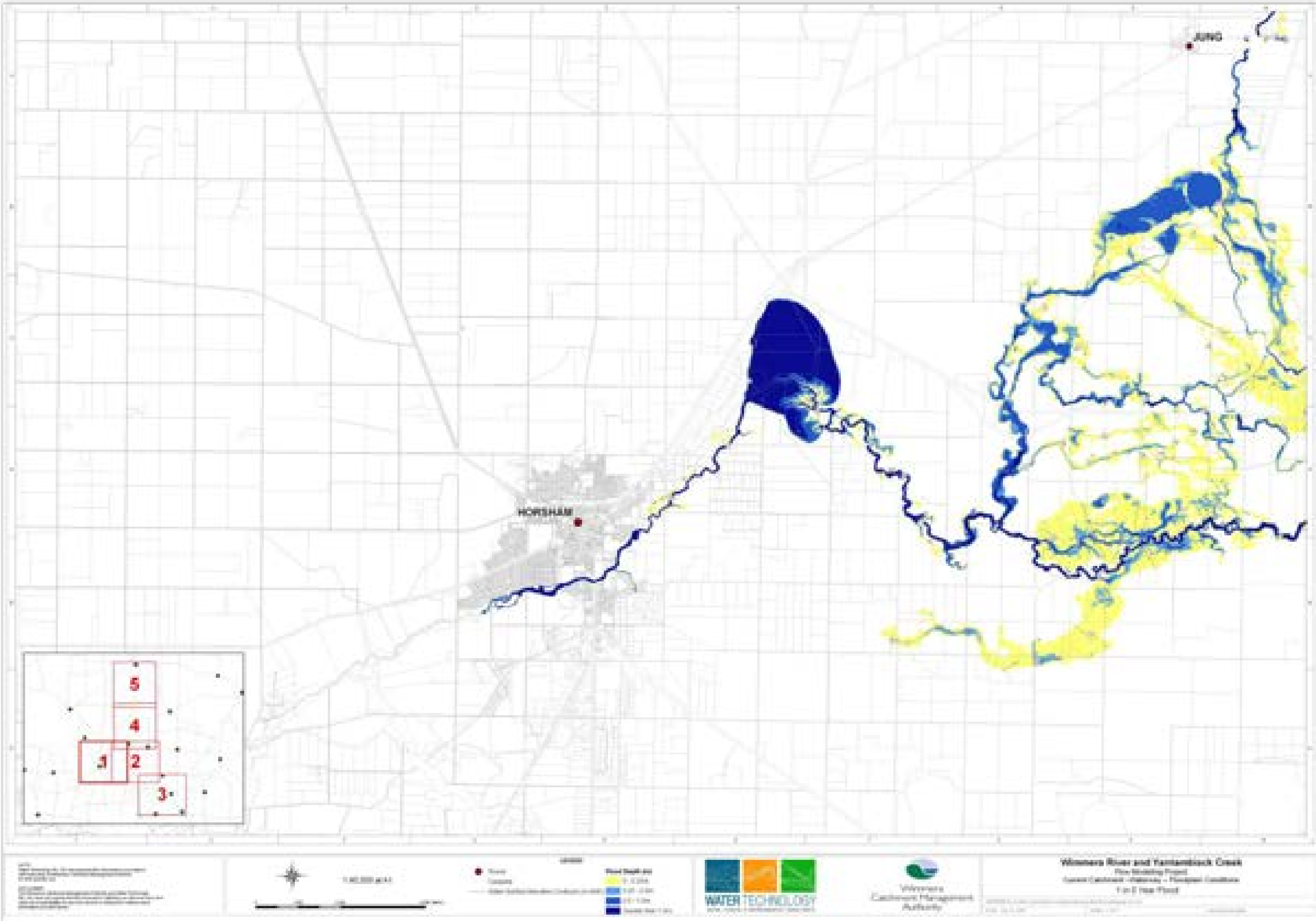

Figure 8-43 5 year ARI flood inundation maps: Wimmera River Dooen Swamp – Horsham – Existing conditions (Scenario 1) (Map sheet 1)

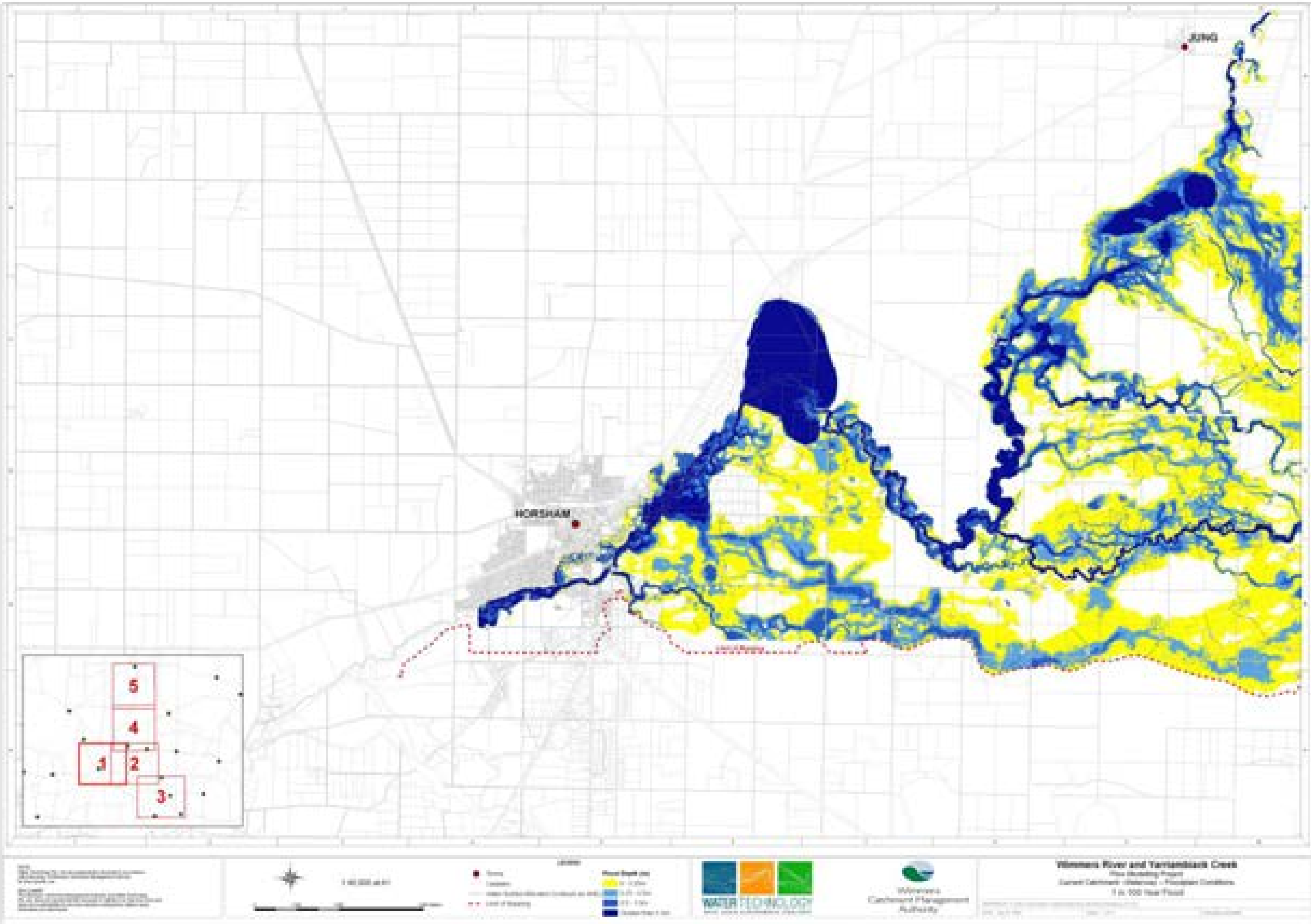

Figure 8-44 100 year ARI flood inundation maps: Wimmera River Dooen Swamp – Horsham – Existing conditions (Scenario 1) (Map sheet 1)

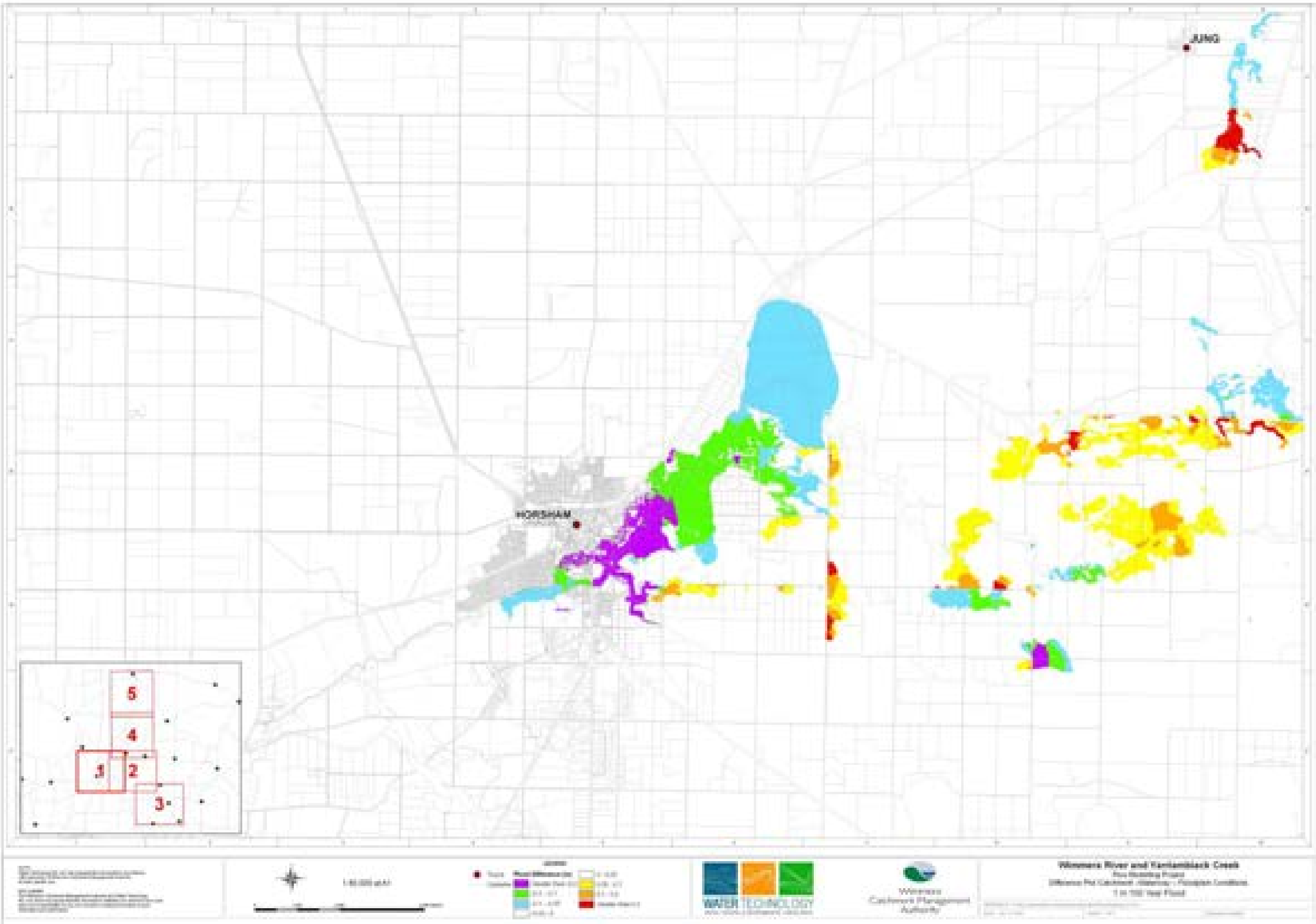

Figure 8-45 100 year ARI flood level difference map: Wimmera River Dooen Swamp – Horsham Existing conditions (Scenario 1) – Pre-European floodplain with existing catchment conditions (Scenario 2) Map Sheet 1

8.4 Wimmera River: Yarriambiack Creek flow distribution – comparison to previous investigations

8.4.1 Overview

The key requirement of this project was to improve the understanding of the flow distribution between the Wimmera River and Yarriambiack Creek. The flow distribution has been simulated across the flow regime. The low flow (Wimmera River upstream of offtake <3000 ML/d) behaviour was assessed using the local scale 2D model, the medium flow regime (3000 – 6000 ML/d) was assessed using the linked 1D/2D model, and the high flow regime (>15000 ML/d) assessed using the broad scale 2D hydraulic model.

This section summarises the findings of the low –medium –high flows hydraulic modelling. This section combines the findings from Section 8.2.4.3, 8.2.4.5 and 8.3.2.2. Further the key findings from this project were compared to the previous studies. The modelling results are presented for the existing conditions and the pre-European waterway-floodplain conditions. Also, the hydraulic impact of the Wimmera Highway Bridge arrangement across Yarriambiack Creek is discussed, with comparison made to previous studies' findings.

8.4.2 Existing conditions

For Wimmera River flows up to 16,000 ML/d, flow into Yarriambiack Creek can only enter at the offtake. In higher flows, the breakout from the Wimmera River upstream of the offtake occurs and leads to overland inflows to Yarriambiack Creek.

The flow entering Yarriambiack Creek at the offtake was obtained from the three hydraulic models for Wimmera River flows up to 16000 ML/d, i.e. Yarriambiack inflows at the offtake only. This study's modelled inflows were compared with the results from SMEC (2002). Table 8-11 displays the modelled peak flows for the Wimmera River upstream of the offtake, and for Yarriambiack Creek immediately downstream of the offtake, from this study and SMEC (2002). Figure 8-46 shows the flow entering Yarriambiack Creek as a percentage of the upstream Wimmera River flow.

Table 8-11 Wimmera River – Yarriambiack Creek flow distribution - at offtake – Existing conditions (Wimmera River < 16,000 ML/d)

Modelling approach	Wimmera River flow upstream of offtake	Yarriambiack Creek at offtake (ML/d)	
	Peak flow (ML/d)	Existing conditions Peak flow (ML/d)	Existing conditions % of Wimmera River flow upstream of offtake
2D local modelling (Section 8.2.4.5)	173	97	56%
	432	131	30%
	864	188	22%
	1728	302	17%
	2592	415	16%
1D-2D modelling (Section 8.2.4.3)	3115	803	26%
	5870	1198	20%
2D broad scale modelling (Section 8.3.2.2)	15260	2076	14%
SMEC (2002)	5103	496	10%

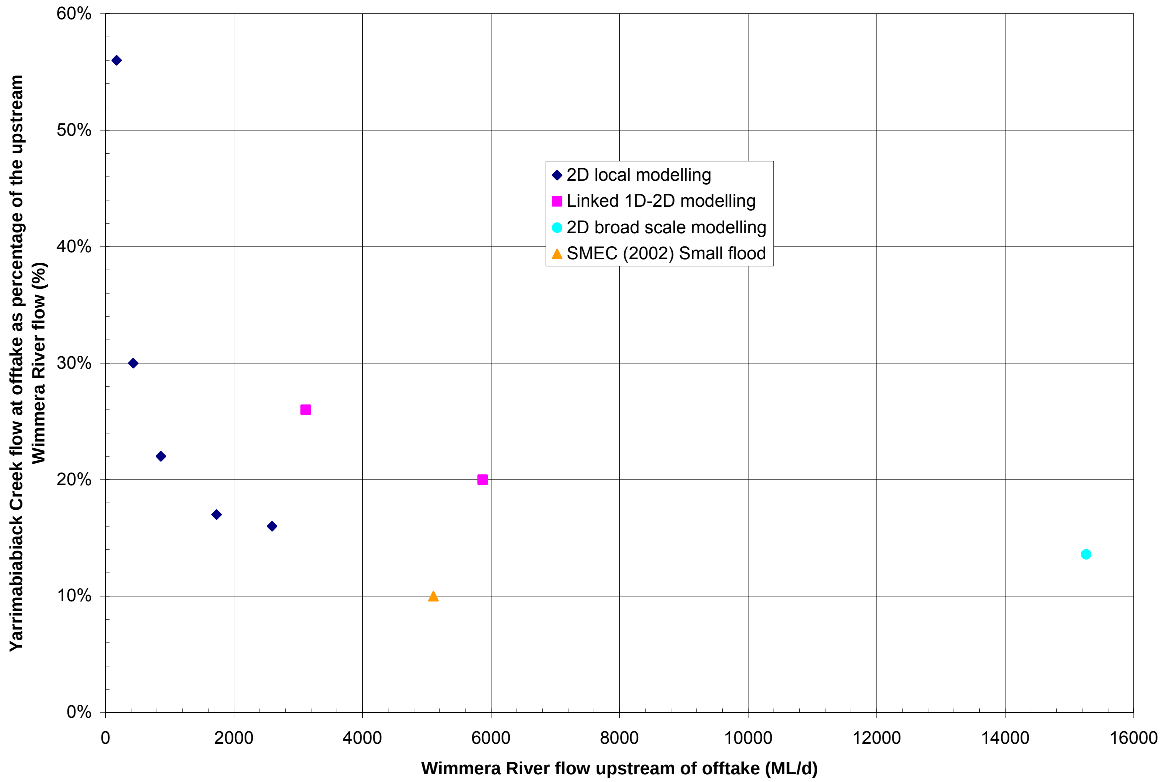

Figure 8-46 Wimmera River – Yarriambiack Creek flow distribution - at offtake – Existing conditions (Wimmera River < 16000 ML/d)

The local 2D modelling, for flows less than 3000 ML/d, shows a decreasing percentage of the Wimmera River flow entering Yarriambiack Creek as the Wimmera River flow increases. The percentage falls from 56% to 16% for the Wimmera River flow ranging from 173 ML/d to 2592 ML/d.

Figure 8-47 displays the principal flow paths operating during the low flows (< 3000 ML/d) adjacent to the Yarriambiack Creek offtake. As the flows increases the flowpath along the southern Wimmera River bank becomes active. This flow bypasses the offtake, and hence the percentage of flow entering Yarriambiack Creek reduces.

As discussed in Section 8.2.4.5, the local 2D modelling and linked 1D-2D modelling shows a differing flow distribution around 3000-6000 ML/d. The linked 1D-2D modelling yields higher flow into Yarriambiack Creek than the local 2D modelling. The differences between the approaches may arise from the different representation of the waterway geometry. Both modelling approaches were unable to be calibrated, due to lack of available observed data. The differing flow distributions highlight the complexity of the hydraulic behaviour at the offtake. Agreement of the modelling approaches does not necessarily ensure a reliable simulation of the hydraulic behaviour. Refinements to the hydraulic models require the collection of observed flow data, and then calibration of the hydraulic model to this observed data. Through a calibration process, differences between the modelling approaches may be reduced.

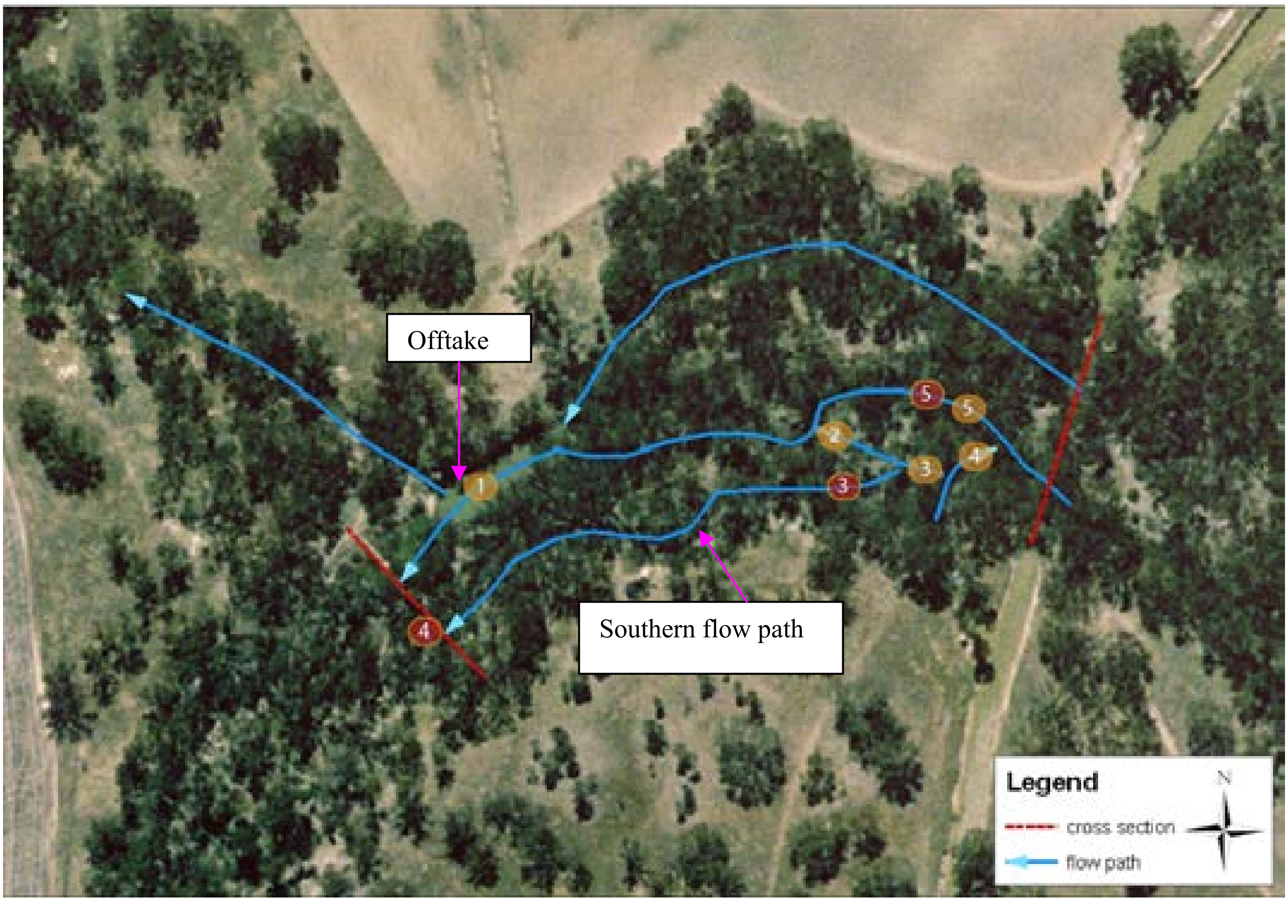

Figure 8-47 Wimmera River- Yarriambiack Creek offtake - flowpaths

SMEC (2002) considered a "small" flood event with a peak Wimmera River flow upstream of the offtake of 5103 ML/d. For this small flood event, SMEC (2002) assessed 10 % of the Wimmera River flow entered Yarriambiack Creek. The linked 1D-2D model, for a similar Wimmera River flow (5870 ML/d) yielded a flow distribution of 20 %. Again, the absence of observed flow data limits the assessment of the reliability of the linked 1D-2D model and SMEC (2002) modelling.

The local scale 2D model only considered the immediate area to the offtake. The local scale 2D model does not extent to the Wimmera Highway Bridge. Hence, modelled peak flow at Wimmera Highway was only available from the linked 1D/2D and broad scale 2D models. Table 8-12 and Figure 8-48 shows the flow distribution Wimmera River upstream of the offtake and the Yarriambiack Creek at the Wimmera Highway Bridge, from this study and SMEC (2002).

Table 8-12 Wimmera River – Yarriambiack Creek flow at Wimmera Highway – Existing conditions (Wimmera River flow 3000- 42900 ML/d).

Modelling approach	Wimmera River flow upstream of offtake	Yarriambiack Creek at Wimmera Highway (ML/d)	
	Peak flow (ML/d)	Existing conditions Peak flow (ML/d)	Existing conditions % of Wimmera river flow upstream of offtake
1D-2D modelling (Section 8.2.4.3)	3115	508	16%
	5870	677	12%
2D broad scale modelling (Section 8.3.2.2)	15260	946	6%
	27460	1460	5%
	42900	3160	7%
SMEC (2002) Small, Medium & Large floods	5103	400	8%
	16960	1409	8%
	43814	17196	39%

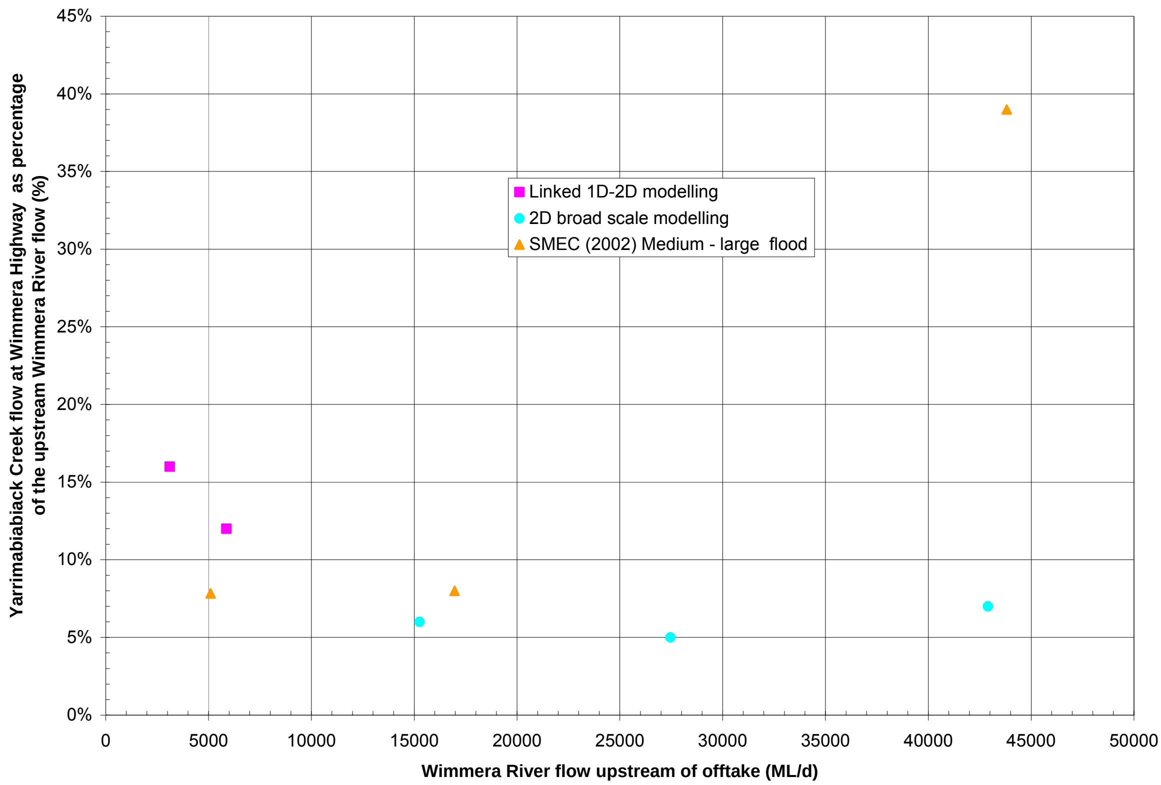

Figure 8-48 Wimmera River – Yarriambiack Creek flow distribution - at Wimmera Highway – Existing conditions (Wimmera River flow 3000 -43000 ML/d)

The broad scale 2D modelling provides a relatively constant flow distribution (as percentage of upstream Wimmera River flow) ranging from 5-7% for flows from 15260 ML/d to 42900 ML/d). A similar flow distribution, about 8%, was obtained by SMEC (2002) for a Wimmera River flow of 16960 ML/d. Further, the flow distribution obtained by this study, is line with the findings of Gippel (2006) (refer to Section 2.2.4). Gippel (2006) found using gauged flow data, for flows above 5000 ML/d at Horsham (Walmer) the peak flow at the Wimmera Highway ranged from 1.6 % to 7.5 %.

However, for the higher flow (43814 ML/d), SMEC (2002) yielded a considerably higher flow distribution of 39%.

Both the broad 2D modelling and SMEC (2002) modelling were calibrated to observed flows at the Wimmera Highway Bridge for the August 1981 and September 1983 events. As discussed, these flood events have ARIs up to 25 years. Hence the application of the models to the 100 year event required extrapolation of the models beyond the calibration events.

The broad scale 2D modelling is considered better able to capture the numerous flow paths across the floodplain, that occur during large flood event, between the Wimmera River and the Wimmera Highway, given the two dimensional nature of the modelling. SMEC (2002) employed a 1D hydraulic model with principal flowpaths including Corkers Drain Creek, Yarriambiack Creek and Two Mile Creek. The SMEC (2002) modelling did not consider the flowpath adjacent to Longerenong Road joining Yarriambiack Creek and Two Mile Creek. It is likely that the absence of this flowpath from the SMEC (2002) modelling may overestimate flows arriving at the Wimmera Highway in large flood events (say > 30,000 ML/d).

During low –medium flow events (up to 6000 ML/d), the regulator has sufficient capacity to the pass without significant back up of flows. However, the any debris blockage is likely to lead to local upstream flood level increases. This outcome is line with the findings of SMEC (2002).

As discussed in Section 8.3.2.2, this scenario considered the re-establishment of the Yarriambiack creek invert at the offtake and the removal of the regulator. The hydraulic modelling indicated that this scenario results in local change of flood levels for the flood events considered (5 year to 200 year events). The increased invert level reduced the flow along the Yarriambiack Creek at regulator for the frequent flood events (~ 5 year event). The reduced flow and the removal of the regulator yielded some local flood level decreases in the frequent events. For the larger flood events, the local flood levels were such that the higher invert level and the removal of the regulator had no significant impact on flood behaviour.

8.4.3 Pre-European waterway-floodplain conditions

As discussed in Section 7.3, the flow-flood behaviour under pre-European waterway-floodplain conditions was assessed. SMEC (2002) modelled "natural' conditions, which were taken as similar to this project's pre-European waterway-floodplain conditions.

Under the pre-European conditions, the waterway invert at the Yarriambiack Creek offtake was higher. Examination of the local 2D modelling, from the existing conditions scenario indicated that the water level at the offtake does not exceed the pre-European invert under a flow of 2592 ML/d. Hence, the pre-European waterway –floodplain conditions were not modelled using the local 2D model. The linked 1D- 2D model and the broad 2D model were employed to assess the pre-European waterway-floodplain conditions. Table 8-13 and Figure 8-49 shows the flow distribution Wimmera River upstream of the offtake and the Yarriambiack Creek at the Wimmera Highway Bridge, from this study and SMEC (2002).

Table 8-13 Wimmera River – Yarriambiack Creek flow at Wimmera Highway – Pre-European waterway-floodplain (Wimmera River flow 3000- 42900 ML/d).

Modelling approach	Wimmera River flow upstream of offtake	Yarriambiack Creek at Wimmera Highway (ML/d)	
	Peak flow (ML/d)	Pre-European waterway-floodplain Peak flow (ML/d)	Pre-European waterway-floodplain % of Wimmera river flow upstream of offtake
1D-2D modelling (Section 8.2.4.3)	3250	0	0%
	5812	78	1%
2D broad scale modelling (Section 8.3.2.2)	15200	1016	7%
	27660	1640	5%
	43630	3960	9%
SMEC (2002) Small, Medium & Large floods	5103	9	0.2%
	16960	2822	17%
	43841	19234	39%

For a medium flow in the Wimmera River (5000 – 6000 ML/d), both the linked 1D-2D model and SMEC (2002) indicated that an only minor flow (~ 80 ML/d) passes the Wimmera Highway in the pre-European conditions. In higher flows (> 15000 ML/d), the linked 1D-2D model provides a relatively constant flow distribution (5%-9%) at the Wimmera Highway. SMEC (2002) shows a considerably higher proportion of the Wimmera River flow passing the Wimmera Highway Bridge (17%-39%), particularly for a large flood event (say 42,000 ML/d). These differences in the flow distribution between this project and SMEC (2002) may arise from the use of the 2D modelling, as discussed above.

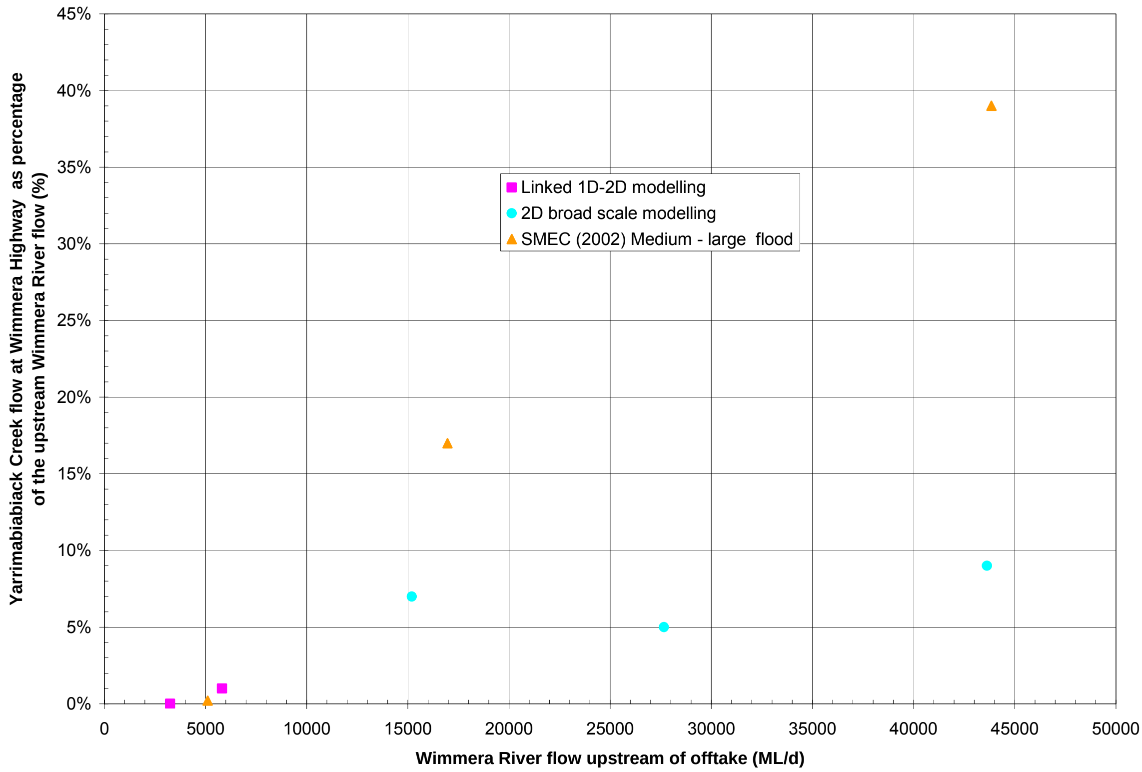

Figure 8-49 Wimmera River – Yarriambiack Creek flow distribution - at Wimmera Highway – Pre-European waterway-floodplain conditions (Wimmera River flow 3000 - 43000 ML/d)

8.4.4 Existing - Pre-European waterway-floodplain conditions comparison

The existing and pre-European waterway-floodplain conditions were assessed using the linked 1D-2D model and the broad scale 2D model. Figure 8-50 displays a comparison of peak flows at the Wimmera Highway Bridge under the first three modelled scenarios: existing (Scenario 1), pre-European waterway -floodplain conditions (Scenario 2) and pre-European catchment-waterway -floodplain conditions (Scenario 3). Discussion of Scenario 4 is provided in Section 8.4.5.

For the low-medium flows (3000-6000 ML/d), the higher peak flows occur for the existing conditions, with zero flow occurring for the pre-European conditions. This is due to the lower Yarriambiack Creek invert adjacent to the offtake.

For the high flow (> 15,000 ML/d), the pre-European waterway-floodplain condition yield the higher peak flow at the Wimmera Highway Bridge compared to the existing conditions. The magnitude of the higher peak flows increases with the Wimmera River flows.

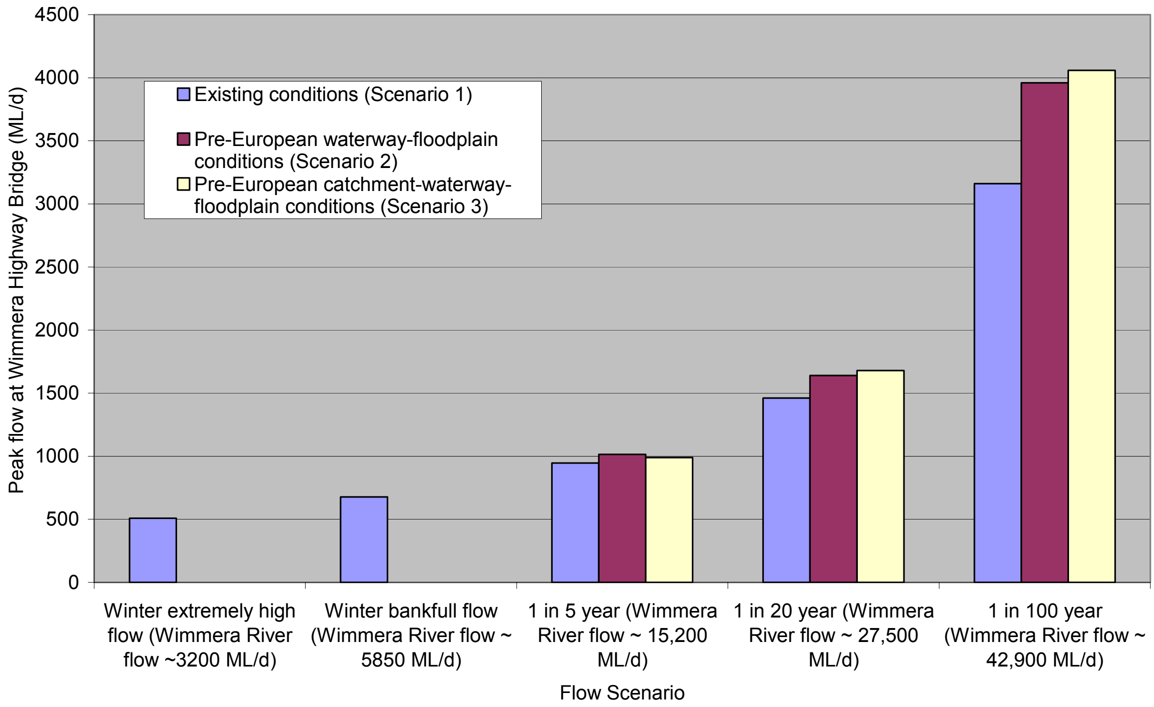

Figure 8-50 Wimmera River – Yarriambiack Creek flow distribution - at Wimmera Highway – Existing -Pre-European catchment - waterway-floodplain conditions (Wimmera River flow 3000 - 43000 ML/d)

8.4.5 Wimmera Highway Bridge

Section 8.3.2.2 provides the hydraulic assessment of the current bridge arrangements at the Wimmera Highway across Yarriambiack Creek, using the broad scale 2D model. This hydraulic assessment of the bridge was undertaken for the 20, 50 and 100 year ARI flood events.

The Wimmera Highway Bridge and its approaches obstruct the floodplain flows. This obstruction leads increases in the 100 year flood level immediately upstream of the bridge of approximately 600 mm compared to pre-European waterway-floodplain conditions. The increased flood levels were limited to about 750 m south of the bridge. Decreased flood levels (up to 100 mm) occurred to the north of the bridge along Yarriambiack Creek. The decreased flood levels to the north of the bridge resulted from a reduction in the peak flow along Yarriambiack Creek under the existing conditions.

Peak flows and flood volume for Yarriambiack Creek at the Wimmera Highway with the bridge removed increased from the existing conditions. The magnitudes of the increases in peak flow flows and flood volume followed the increase in flood magnitudes. These increases were slightly less than those seen for the pre-European waterway-floodplain conditions. For example in the 20 year, the peak flow with the bridge removed is 1,619 ML/d compared to 1,640 ML/d for pre-European waterway-floodplain conditions. This indicates that the current Wimmera Highway Bridge arrangement is the key influence in the change in flow distribution since European settlement, and other modifications to waterway and floodplain play a secondary role.

Table 8-14 compares the changes in the peak flow at Wimmera Highway under the existing conditions and with the Wimmera Highway Bridge removed from this study broad scale 2D modelling and SMEC (2002).

Table 8-14 Wimmera River – Yarriambiack Creek flow at Wimmera Highway – Pre-European waterway-floodplain (Wimmera River flow 3000- 42900 ML/d).

Modelling approach	Wimmera River flow upstream of offtake	Yarriambiack Creek at Wimmera Highway (ML/d)	
	Peak flow (ML/d)	Existing conditions Peak flow (ML/d)	Wimmera Highway Bridge removed Peak flow (ML/d)
2D broad scale modelling (Section 8.3.2.2)	27660	1460	1640
	43630	3160	3960
SMEC (2002) Small, Medium & Large floods	5103	400	398
	16960	1409	2238
	43841	17196	17058

SMEC (2002) assessed the flood behaviour with the bridge removed for the flood events ranging from 5,100 ML/d to 43,800 ML/d at Horsham Lubeck Road. The results (SMEC 2002) shows minimal impact (< 1 %) on peak flows in Yarriambiack Creek due to the bridge for small (5,100 ML/d) and large floods (43,800 ML/d). However for the medium flow (16960 ML/d) the removal of the bridge results in a considerable increase (58%) in peak flow. Whereas, this study's findings show that the removal of the bridge increases the peak flow in Yarriambiack Creek for both medium and high flow events.

For the Wimmera River downstream Two Mile Creek, only minor changes to the peak flow and flood volume were seen with the bridge removed.

The current Wimmera Highway Bridge has a significant influence on flow in Yarriambiack Creek downstream of the bridge, as discussed above. However, the bridge arrangement has no significant impact on flows in the Wimmera River downstream of Two Mile Creek, and in turn through Horsham.

8.5 Recommendations

The study team recommends flow gauging in the Wimmera River upstream of the offtake, and along Yarriambiack Creek during a low–medium flow event. Such observed flow data could used to refine the local scale 2D model. At low flows (less than 3000 ML/d) , the assessment of flow distribution using observed streamflow data at Drung Drung and/or the Wimmera Highway is limited by the accuracy of the rating curve at both gauges. It is likely the errors in the rating curves at the gauges may exceed the flow entering Yarriambiack Creek.

The hydraulic model applications to assess flood behaviour under high flow conditions were aimed at providing improved understanding for floodplain management purposes.

The existing conditions flood mapping provides flood extents, depths and velocities suitable for the delineation of flood related planning zone/overlays. The study team recommends the Wimmera CMA liaises with local authorities to prepare planning scheme amendments to enact the flood related planning zones/overlays.

Further, the existing conditions flood mapping provides flood intelligence for flood response purposes the inundation of key roads and other infrastructure can be linked to the stage heights at key flood warning gauges. This linking enables the forecasted flood heights to translate into potential flood extents. The study team recommends the Wimmera CMA liaises with local authorities to prepare revised Municipal Emergency Management Plan Flood sub-plan to reflect the flood mapping.

It is likely that the actual flood extents for the 100 year ARI flood event and larger events would extend beyond the limit of the detailed ALS data, particularly adjacent to Andrews Road (east of Horsham). Future extension of the hydraulic modelling area using additional topographic data is recommended to refine the mapped flood extents (100 year ARI and greater events) adjacent to Andrews Road. These southern overland flowpaths were not included in the flood mapping undertaken by the Horsham Flood Study (Water Technology 2003b), as the flowpaths were beyond the study area.

The study team recommends the Wimmera CMA consider future extension of the hydraulic modelling area using additional topographic data to refine the mapped flood extents (100 year ARI and greater events) adjacent to Andrews Road.

9 RECOMMENDATIONS

The following recommendations aim to enhance the modelling framework capacity over time, and to maximise the Wimmera CMA future use of the modelling framework in waterway and floodplain management application.

Streamflow and water level data collection - Yarriambiack Creek at the Wimmera Highway Bridge

Flows along Yarriambiack Creek are sourced principally from the Wimmera River during overbank flooding. The modelling framework provides insight into the flows entering Yarriambiack Creek from the Wimmera River. However, the calibration of the modelling framework was constrained by the lack of observed streamflow in Yarriambiack Creek.

The study team recommends the re-establishment of the stream flow gauge at the Wimmera Highway Bridge, and the Wimmera CMA should consult with relevant agencies to promote the gauge re-establishment. Future streamflow data from this re-established gauge is considered by the study team as a valuable input into the flow management and refined model calibration.

The study team understands the current flood warning upgrade project is installing/re-establishing gauges at the following locations:

- Wimmera River at Drung Drung (Gross Bridge) (Measuring stage only)
- Yarriambiack Creek at Wimmera Highway Bridge(Measuring stage only)

The Wimmera River channel adjacent to the Drung Drung site is subject to considerable change (Paul Fennell Wimmera CMA pers. comms). Such change in channel shape constraints the establishment of a reliable stage-flow rating curve. However, the collection of stage (water level) is seen as valuable data in refining the model calibration.

The location of Wimmera Highway Bridge adjacent to the proposed gauge provides a stable control, and enables the establishment of a reliable stage-flow rating curve, using the hydraulic model.

Streamflow and water level data collection – Mount William Creek downstream of Lake Lonsdale

The current streamflow gauge downstream of Lake Lonsdale is limited to low-medium flows. High flow data is not available at this gauge. Flows from Mount William provide a significant contribution to Wimmera River flows. The modelling framework provides insight into the contribution from Mount William Creek catchment. However, the calibration of the modelling framework was constrained by the lack of observed streamflow for high flow events.

The study team recommends the establishment of a high flow rating curve for the stream flow gauge downstream of Lake Lonsdale. Future streamflow data is considered by the study team as a valuable input into the flow management and refined model calibration.

Streamflow and water level data collection – Opportunistic environmental flows monitoring

The calibration of the 1D hydraulic model (for up to bankfull flows) was constrained by the available flow data.

The study team recommends opportunistic flow and water level gaugings during environmental flows releases be undertaken by the Wimmera CMA, and such provision could be in the implementation of VEFMAP program for the Wimmera

River. Future streamflow data from opportunistic flow gauging is considered by the study team as a valuable input into the flow management and refined model calibration.

Streamflow and water level data collection – Opportunistic flood level monitoring

The calibration of the 2D hydraulic model (for floodplain flows) was constrained by the available flood level data.

The study team recommends opportunistic flood level collection during flood events be undertaken by the Wimmera CMA, and such provision should be in the implementation of the Wimmera CMA Flood guidelines. Under the Victorian Flood Management Strategy (DNRE 1998), collection of flood data (levels and extents) is the responsibility of the CMA. Future flood level collection is considered by the study team as a valuable input into the flow management and refined model calibration.

Hydraulic model calibration refinement

The hydraulic model calibration utilised available observed streamflow and water level data for comparison to modelled streamflow and water levels. Additional streamflow and water level data enables the refinement of the hydraulic model calibration.

The study team recommends refinement of the hydraulic model calibration following the collection of observed streamflow and water levels from natural flows, environmental water releases and/or a significant overbank flood event. In particular, the availability of additional streamflow data at the Yarriambiack Creek and Wimmera Highway Bridge is seen as a critical element in the hydraulic model refinement.

Such model refinement will underpin the hydraulic model capability for use in waterway and floodplain management.

Influences on environmental water releases re-assessment

The identification of influences on environmental water releases has been identified by SKM (2008) and Earthtech (2007). These previous projects assessed the hydraulic impact of identified influences via simple hydraulic analysis. This project has undertaken a preliminary re-assessment of the hydraulic impact using the refined hydraulic modelling framework. However, a comprehensive re-assessment of the influences should ensure consistency between this study flow modelling and the understanding of the influences.

The study team recommends a thorough re-assessment of the hydraulic impact of the identified influences. Further, the study team recommends the examination of the hydraulic modelling outputs from this project to identify other potential influences, as such channel constrictions and culvert crossings.

Environmental flows – Flow requirement re-assessment

The hydraulic analysis has refined the local flow behaviour adjacent to the environmental flow sites. This refined flow behaviour may inform a revision of the environmental flow requirements.

The detailed cross sections collected in this project are suitable for use as part of VEFMAP.

The study team recommends a re-assessment of the flow behaviour at environmental flow sites using the hydraulic analysis outputs. In particular, the absence of specific environmental flow recommendations between Taylor's Lake channel and Horsham

can be underpinned by the use of the flow behaviour assessment undertaken in this study.

Environmental flows - Environmental water release management assessment

The hydraulic modelling framework provides a robust tool for the assessment of potential changes to waterway form and structures with the view to enhance environmental flow outcomes.

Earthtech (2007) and SKM (2008) identified number of environmental flow delivery constraints. This hydraulic modelling framework provides an approach to assess the change in flow behaviour due to potential works/management actions at these constraints.

The study team recommends a thorough exanimation of the hydraulic modelling outputs to inform potential management actions to enhance environmental flow outcomes.

Waterway management – works assessment

The hydraulic modelling framework provides a robust tool for the assessment of potential waterway works. The hydraulic analysis can provide insight into flow depths and flow velocities. Such insights may aid understanding of stream processes influencing erosion and deposition patterns.

The study team recommends a thorough exanimation of the hydraulic modelling outputs to inform potential waterway management actions

Floodplain management - Land use planning

The flood mapping provides a sound basis for the delineation of flood related planning zone/overlays.

The study team recommends the Wimmera CMA liaises with local authorities to prepare planning scheme amendments to enact the flood related planning zone/overlays.

Floodplain management - Flood response

The flood mapping provides a sound basis for the preparation of flood intelligence for use in flood response. **The study team recommends the Wimmera CMA liaises with local authorities to prepare revised Municipal Emergency Management Plan Flood sub-plan to reflect the flood mapping.**

Floodplain management – Hydraulic model extension adjacent to Andrews Road (east of Horsham)

The study team recommends the Wimmera CMA consider future extension of the hydraulic modelling area using additional topographic data to refine the mapped flood extents (100 year ARI and greater events) adjacent to Andrews Road.

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