Warracknabeal and Beulah Flood Study
Study Report

Report No. J404/R03 Final 1
March 2007

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EXECUTIVE SUMMARY

This report details the input data, approach and outcomes for the Warracknabeal and Beulah Flood Study.

The Warracknabeal and Beulah Flood Study has been initiated by the Wimmera Catchment Management Catchment Authority (WCMA) in conjunction with the Mallee Catchment Management Catchment Authority (MCMA) and Yarriambiack Shire Council (YSC). The study provides information on flood levels and flood risks within the townships of Warracknabeal and Beulah. The study was funded under the Natural Disaster Risk Management Studies Programme by the Australian and Victorian Governments with a contribution from the Yarriambiack Shire.

The study team was lead by Water Technology with sub-consultants, Michael Cawood and Associates, Price Merrett Consulting, MPMedia Solutions, Planning and Environmental Design and AAMHatch.

Both townships lie on Yarriambiack Creek, a distributary of the Wimmera River. The creek extends from an offtake from the Wimmera River near Longerenong and flows north for approximately 135 km, terminating at Lake Corrong, near Hopetoun. The townships have been subject to flooding on a number of occasions including 1909, 1923, 1955, 1956, 1960, 1964, 1974, 1975, 1981, and 1983.

A hydrologic analysis of Yarriambiack Creek determined design flood hydrographs for the 10, 20, 50, 100 and 200 year flood events at both Warracknabeal and Beulah. Considerable uncertainty surrounds the design flood estimates developed by this study. Rigorous calibration and/or validation of the approach was restricted by the absence of streamflow data. The absolute reliability of design estimates is unknown, however, the relativity of design estimates is considered reasonable. Table 1 displays the design peak flows at both Warracknabeal and Beulah.

Table - 1 Design peak flows at Warracknabeal and Beulah

Location	Design peak flow (m^3/s)					
	1 in 5 year	1 in 10 year	1 in 20 year	1 in 50 year	1 in 100 year	1 in 200 year
Yarriambiack Creek at Warracknabeal	13.3	14.6	20.7	31.3	41.4	43.7
Yarriambiack Creek at Beulah	9.2	10.1	13.7	21.9	29.8	31.9

Digital terrain models were developed from field and aerial survey. Using the digital terrain models, hydraulic models were established to simulate flood behaviour within the study areas. Flood behaviour was assessed for flooding originating from Yarriambiack Creek and local stormwater runoff. The hydraulic models revealed that the weir structures in both Warracknabeal and Beulah (upstream and downstream) have a key influence on flood behaviour. For Yarriambiack Creek floods, the flood extents are generally limited to creek corridor in Warracknabeal. A significant breakaway from Yarriambiack Creek, occurs for a 20 year flood event and greater, to the south of Beulah across the Henty Highway and under the Hopetoun Railway. This breakaway results in extensive inundation of agricultural land to the east of the Henty Highway. Limited Yarriambiack Creek flooding occurs in the township of Beulah. Local stormwater runoff in Warracknabeal leads to considerable ponding adjacent to the Warracknebeal Railway Station. Some minor stormwater ponding occurs in Beulah for the area bounded Bell, Phillips, Gladstone and Dingwell Streets.

Average annual flood damages for Warracknabeal and Beulah were estimated at $41,000 and $9,600 respectively. For the I in 100 year Yarriambiack Creek flood event, the following buildings were affected:

- Warracknabeal : 79 above floor and 279 below floors (Total 358)
- Beulah : 2 above floor and 50 below floor (Total 52)

Two structural mitigation options, consisting of improvements to the weir capacity, were assessed in Warracknebeal. For Beulah, four structural mitigation options were assessed. Three of the mitigation options for Beulah considered increases in the flow capacity of the upstream and downstream weirs, with the fourth option closing the railway culvert to south of the township.

The above structural mitigation options investigated were considered by the study team not to warranted further investigation. This is due to the limited reduction in flood levels and extents achieved, and the adverse flood related impacts due to flow re-direction.

Impacts due to stormwater related flooding in Beulah could be mitigated by improvements to drainage under Bell Street. For Warracknabeal, stormwater drainage improvements adjacent to the Warracknabeal Railway Station could less the stormwater related flooding impacts .

A draft planning scheme amendment has been prepared to reflect the study outcomes. The study team recommends that the Yarriambiack Shire Council adopt all aspects of the draft planning scheme amendment. Further, the study team recommends that Wimmera CMA provide the appropriate assistance to Yarriambiack Shire to enable the timely adoption of the planning scheme amendment.

The Wimmera Catchment Management Authority, in conjunction with local authorities in the Wimmera River Catchment, including Yarriambiack Shire, is undertaking a project to enhance the total flood warning system for the Wimmera Catchment. The study team recommends that the Yarriambiack Shire Council and the Wimmera Catchment Management Authority continue to actively pursue the completion of the current flood warning related project.

A Flood Sub-plan draft planning scheme amendment has been prepared to reflect the study outcomes. The study team recommends that the Yarriambiack Shire Council adopt all aspects of the revised Flood Sub-plan as an integral part of the Yarriambiack MEMP. This includes measures aimed at ‘keeping the Plan alive’ and relevant to the community.

For both Warracknabeal and Beulah, the operation of the weirs has a significant influence on local flood behaviour. The study team recommends that the Yarriambiack Shire and the Wimmera CMA develop formal operating procedures for the Warracknabeal Weir and the Beulah Upstream and downstream Weirs. The adopted operating procedures be incorporated into Flood Sub-plan as an integral part of the Yarriambiack MEMP.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The Warracknabeal and Beulah Flood Study has been initiated by the Wimmera Catchment Management Catchment Authority (WCMA) in conjunction with the Mallee Catchment Management Catchment Authority (MCMA) and Yarriambiack Shire Council (YSC). The study provides information on flood levels and flood risks within the townships of Warracknabeal and Beulah.

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Figure 1-1 displays the study areas and the contributing catchment.

The flood study involved a hydrologic analysis of Yarriambiack Creek, and a hydraulic assessment of flood behaviour in the towns and surrounding floodplain areas. The flood levels and inundation extents were mapped for a range of design events up to the 1 in 200 year flood event. Assessment of flood related damages and potential mitigation measures were also undertaken.

The structure of this report is as follows:

- Section 2 – provide a brief study background
- Section 3 – outlines the input data gathered for use in the study
- Section 4 – details the community consultation process
- Section 5 – outlines approach and outcomes from the hydrologic analysis
- Section 6 – discuss the hydraulic analysis for the existing conditions
- Section 7 – summarises the flood damage assessment
- Section 8 – outlines preliminary assessment of structural mitigation measures
- Section 9 – discusses preliminary assessment of non-structural mitigation measures
- Section 10- provides a summary of the study key conclusions

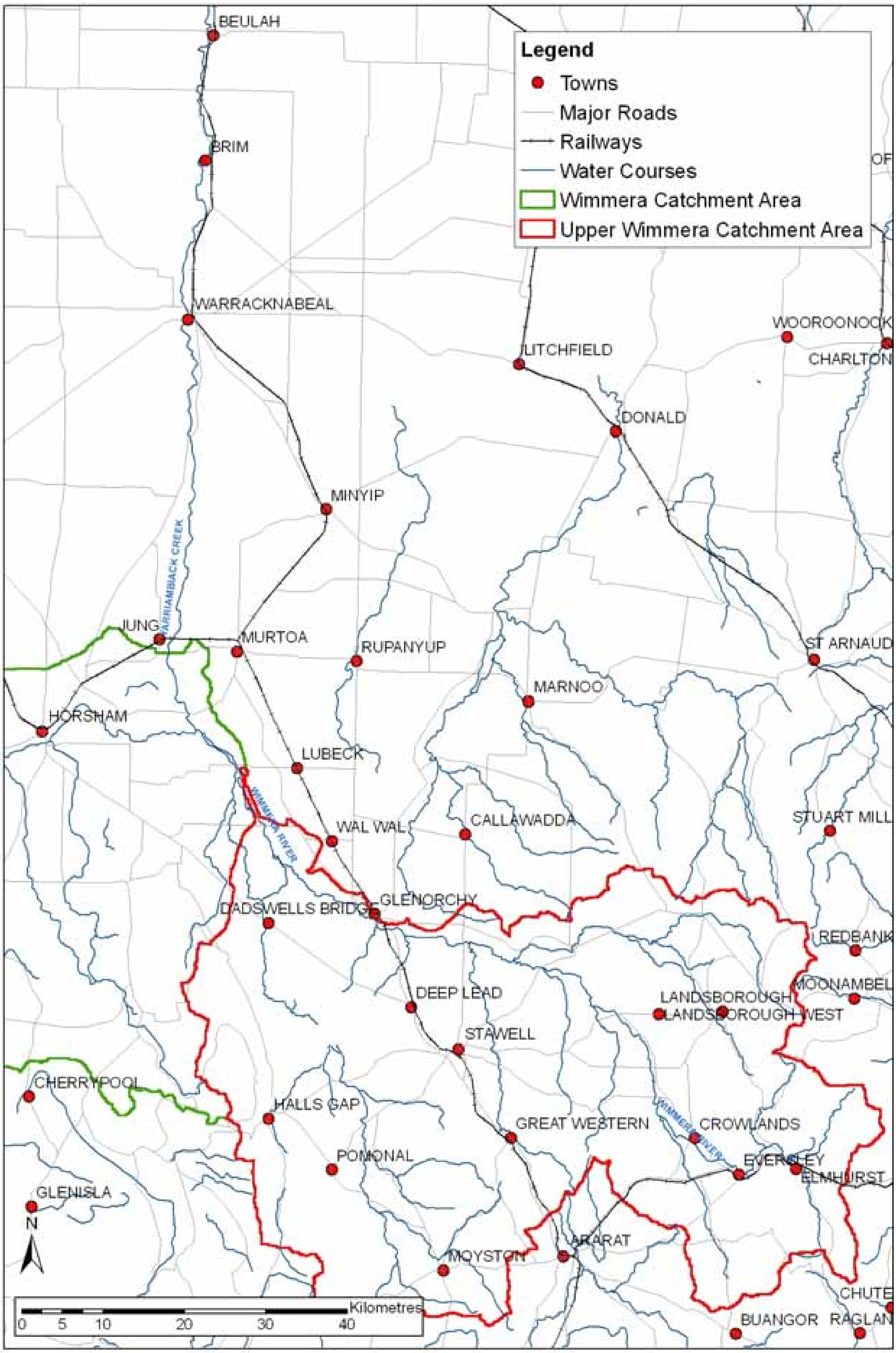

Figure 1-1 Study area and contributing catchments

2 STUDY BACKGROUND

Yarriambiack Creek is a distributary of the Wimmera River. It leaves the Wimmera River near Longerenong and flows north a distance of some 135 km via Jung, Warracknabeal, Brim and Beulah to terminate in Lake Corrong and Lake Lascelles, adjacent to Hopetoun. During very large flow events the Creek has flowed to a series of terminal wetlands further north of Hopetoun.

Under normal low flow periods approximately one third (1/3) of the Wimmera River flow enters Yarriambiack Creek. During periods of higher/flood flow events, somewhere between 5% and 15% of the Wimmera River flow enters Yarriambiack Creek (Gippel 2006).

In the upper reaches near the Wimmera River, the Yarriambiack Creek is perched as it traverses the flat alluvial Wimmera River floodplain. North of Wimmera Highway to just south of Warracknabeal the Creek flows in a broad shallow valley (approximately 1.5 km wide at the Wimmera Highway). North of Warracknabeal, the Creek channel is narrow and meanders on its own alluvial floodplain (Cooling et al 2006).

Numerous levees, channel banks, roadway embankments, culverts and regulating structures are present along or across the Creek and floodplain. Weir pools are maintained at Jung, Warracknabeal, Brim, Beulah and Lake Lascelles at Hopetoun. The Warracknabeal, Brim and Beulah weirs have been identified by WBM (2003) to the ability to readily modify the free flow of water down the Creek, particularly during moderate flows and small floods thereby influencing the extent and volume of flows downstream.

Warracknabeal and Beulah were highlighted as areas of concern in the Wimmera Floodplain Management Strategy (WCMA 2001). This strategy (WCMA 2001) recommended that a Flood Study should be carried out in order to assess and prioritise flood risks faced by Warracknabeal and Beulah.

3 AVAILABLE INFORMATION

This section outlines the range of information utilised in study including previous reports and documents as well as data, both previously available and collected specifically for this study.

3.1 Previous studies

Previous key hydrologic and/or hydraulic studies relevant to the present project and region include:

- **Bureau of Meteorology (BoM)** - Wimmera River Basin URBS Model (2004)
- **Snowy Mountains Engineering Corporation Victoria (SMEC)** – Assessment of the impact of priority structures on natural flow regimes and flooding in Yarriambiack Creek (Parts 1 and 2) (2001)
- **WBM Oceanics Australia (WBM)**– Yarriambiack Creek Flood Investigation Study (2003)
- **Kellogg Brown & Root (KBR)** – Yarriambiack Creek Management Plan (2004)
- **Sinclair Knight Merz (SKM)** – River Basin Report. Wimmera River. Lower Sub Catchment. DNRE Flood Data Transfer Project (2000)
- **Ecological Associates (EA) and Fluvial Systems** – Environmental Water Requirements of Lake Corrong and Lake Lascelles for Mallee CMA (2006)

These resources have been reviewed and drawn upon as necessary to provide background, context and verification of the current study approach and outcomes. A brief summary of the above material follows.

3.1.1 Wimmera River Basin URBS Model (BoM 2004)

The Bureau of Meteorology developed a URBS rainfall-runoff model for the Wimmera River basin to Dimboola. The purpose of the URBS model was flood forecasting. Calibration of the URBS model was undertaken with a range of model parameters developed such that the model can be used in a predictive manner with some confidence.

Of interest to this study is the URBS model ability to provide estimates of flood hydrographs for the Wimmera River at the Yarriambiack Creek offtake.

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

The WCMA in partnership with the MCMA commissioned SMEC to undertake an assessment of priority structures on Yarriambiack Creek. The final report, completed in 2001, had the following aims:

- Collate and review all readily available flow related data associated with Yarriambiack Creek
- Assess and define flood flows in the creek
- Undertake a field assessment of all structure sites
- Consult with key stakeholders
- Undertake a hydraulic assessment of all the structure sites
- Assess the impact of the structures on flooding, with particular emphasis on the nominated priority structures
- Recommend and prioritise future management options for the problem structures

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 magnitude.

A partial series flood frequency analysis was undertaken on seven years of data was available for Yarriambiack Creek at the Wimmera Highway (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.

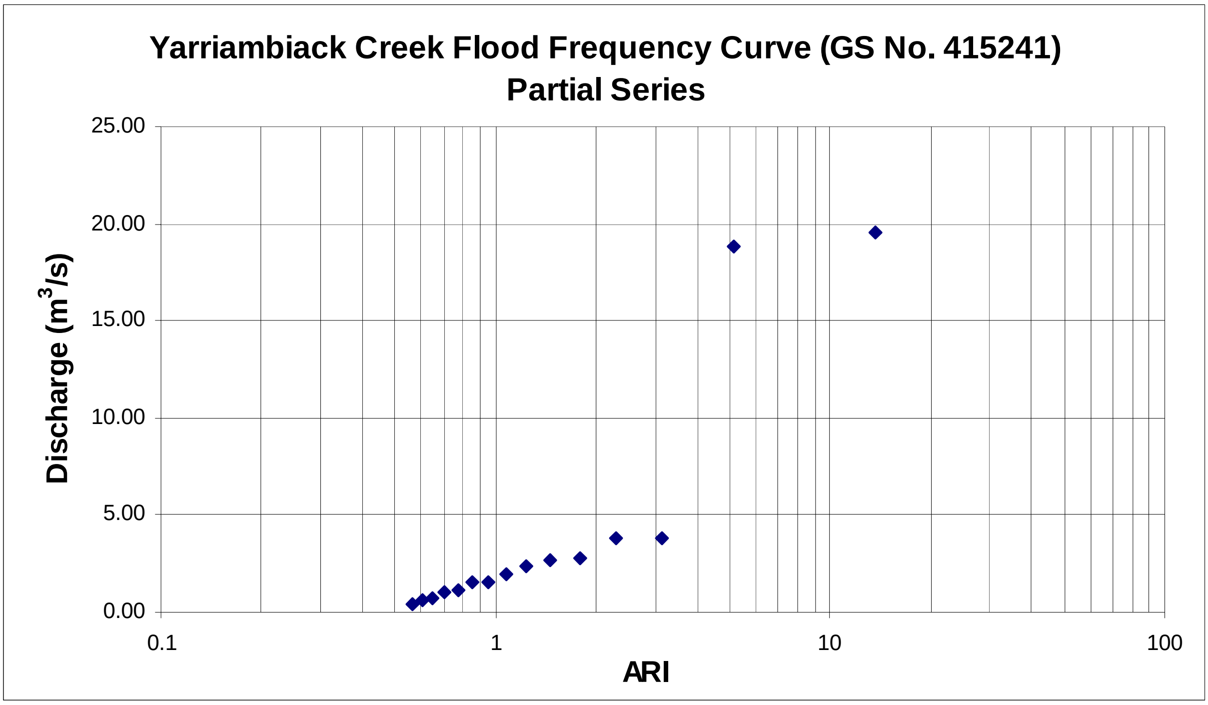

Figure 3-1 Yarriambiack Creek flood frequency analysis (415241) SMEC (2002)

SMEC (2002) states that the flood frequency curve developed from this analysis could be utilised to obtain a reasonable frequency estimate for more frequent events (up to AEP of 1 in 4) but less reliable for less frequent events.

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 m^3/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 m^3/s).
- A 50 year ARI event at Horsham corresponds to a flow of approximately 7,780 ML/d in Yarriambiack Creek (~90 m^3/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.

3.1.3 Yarriambiack Creek Flood Investigation Study (WBM 2003)

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).

3.1.4 Yarriambiack Creek Management Plan (KBR 2004)

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 flow, 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.

3.1.5 River Basin Report - Wimmera River - DNRE Flood Data Transfer Project (SKM 2000)

Flood Data Transfer (FDT) Project for the Wimmera-Mallee Catchment (SKM 2000) collated flood related information.

Due to poor quality data, low topographic relief, and the absence of detailed ground survey information the delineated 100 year ARI flood extent could not be achieved with any degree of confidence (SKM 2000). This highlights the lack of reliable data and complexity of the flooding regime in Yarriambiack Creek.

3.1.6 Ecological Associates and Fluvial Systems – Environmental Water Requirements of Lake Corrong and Lake Lascelles for Mallee CMA (2006)

Cooling et al (2006) investigated the environmental water requirements for Lake Lascelles and Corrong (Yarriambiack Creek terminal lakes). The study focused on the the following items:

- Current ecological values of the lakes
- Proposed ecological objectives for the lakes
- Threats to the maintenance and/or restoration of the lakes' ecological values
- Recommended flow regime to achieve ecological objectives

As part of the study, a hydrologic model was developed to estimate streamflow along Yarriambiack Creek from the Wimmera River to the Lakes. The details of the hydrologic model are provided in Gippel (2006). This hydrologic model was a conceptual hydrologic model based on a division of Yarriambiack Creek into seven reaches. The hydrologic behaviour of each reach was represented by a simple storage with evaporation, rainfall and downstream outflow relationships. The model was employed to determine daily streamflows over the historical period, January 1903 to June 2004.

Gippel (2006) noted that the hydrologic model was not constructed to rigorously simulate flood events, rather the focus of the model was the production of long time series for use in the water balance model of the terminal lakes. With this focus in mind, Gippel (2006) does report that "… a small to moderate could potentially take one or so week to travel from Wimmera Highway Bridge to Lake Corrong…" (Gippel 2006 p28).

Of interest to this study, was the estimated downstream reduction of flows along the Yarriambiack Creek reported in Gippel (2006). The mean daily flow reduced from 16.7 ML/d (~0.19 m3/s) at the Wimmera Highway to 8.8 ML/d at Warracknabeal and to 7.5 ML/d. This reduction was due to evaporation, seepage and attenuation of flows. Further, the maximum flow (estimated from the 1909 event) at Wimmera Highway of 2,739 ML/d decreases to 1,461 ML/d (40 % reduction) at Warracknabeal and to 691 ML/d at Beulah (52 % reduction). Gippel (2006) noted that the estimated maximum peak of 2,739 ML/d is considerably less than the 13,000 ML/d quoted by WBM (2004).

Gippel (2006) noted that the reliability of the daily streamflow sequence is unknown due to the lack of systematic streamflow gauging data.

However, it is worth noting that Gippel (2006) recommended the "Any improvements in the understanding of Yarriambiack hydrology would require action on two fronts: gauging of flows, and development of a new hydraulic model based on surveyed channel morphology…" (Gippel 2006 p. v).

This study has developed a hydraulic model based on surveyed channel morphology that could be used to improve to hydrologic understanding. Further details of the hydraulic model for Yarriambiack Creek is provided in Section 5.4.

3.2 Hydrologic data

3.2.1 Streamflow data

Numerous streamflow gauges are located within the Wimmera River/Yarriambiack Creek catchment. A subset of the available streamflow gauges were utilised in this hydrologic analysis and are outlined in Table 3-1.

Table 3-1: Details of Streamflow Gauge

Station Number	Station name	Period of record
415201	Wimmera River at Glenorchy	May 1975 - July 2005
415240	Wimmera River at Faux Bridge	August 1978 - December 1987
415241	Yarriambiack Creek at Wimmera Hwy	January 1978 to December 1986

Figure 3-2 shows the location of the above streamflow gauges.

Limited estimated peak flows were available from SMEC (2002) as follows:

- Warracknabeal Weir – September 1983: 1,114 ML/d (12.9 m3/s)
- Beulah Weir - August 1981: 1,180 ML/d (13.6 m3/s)

A peak flow estimate of 13,000 ML/d (150 m3/s) at Railway Bridge on Yarriambiack Creek (1.5 km downstream of the Wimmera Highway) for the 1909 event was contained in the Horsham Floodplain Management Study (SRWSC 1982).

The basis of the above peak flow estimates is unclear and accordingly the reliability is considered low.

3.2.2 Rainfall data

A number of daily and pluviographic rainfall stations are located within or to adjacent to the Wimmera River catchment.

Figure 3-2 shows the location of the both the pluviographic and daily rainfall stations.

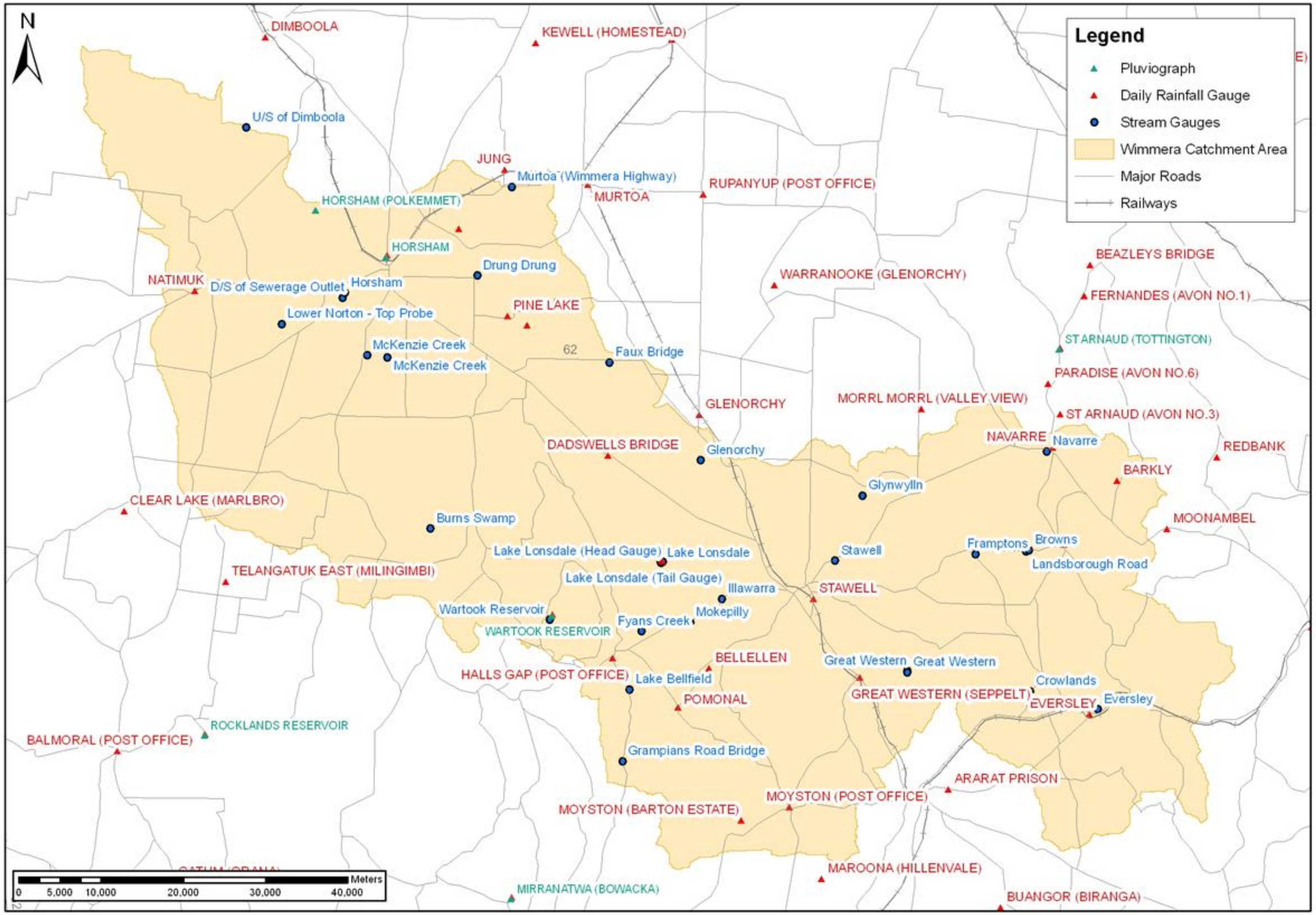

Figure 3-2 Streamflow and rainfall gauges

3.3 Topographic data

3.3.1 Overview

There have been three major sources of topographic information gathered during the course of the investigation, these being:

- Aerial Photogrammetry
- Aerial Laser Survey (ALS)
- Field Survey

Following the collection and processing of the topographic information, a detailed Digital Terrain Model (DTM) was developed as the basis for the establishment of a hydraulic model of the study areas. The sources of the topographic information are discussed in more detail below.

3.3.2 Aerial survey

Aerial Photogrammetry

Aerial photogrammetry was undertaken specifically for the Beulah study area. The aerial photogrammetry was undertaken by AAM Hatch Pty Ltd. Figure 3-3 illustrates the extent of the photogrammetry.

The nominated accuracy for this survey was a standard error (68% confidence level or 1 sigma) of 0.15m in both the horizontal and vertical planes.

Aerial Laser Survey

The WCMA undertook extensive Aerial Laser Survey (ALS) for the authority's entire in 2005. At the time of the ALS capture, the Warracknabeal Flood Study was earmarked for commencement in 2006. In response, high resolution data capture was undertaken for Warracknabeal study area. The ALS data employed for the Warracknabeal study area has a nominated accuracy (standard error) of 0.15 m in the vertical planes. The available ALS data for the Yarriambiack Creek corridor within WCMA's area has a nominated accuracy (standard error) of 0.5m in the vertical planes. Figure 3-4 shows the ALS data extent for Warracknabeal.

As Beulah lay outside the WCMA's area, the ALS captured in 2005 did not cover the Beulah study area. At the commencement of this study, aerial photogrammetry for the Beulah study area was undertaken, as discussed above. During the study of the study, the WCMA advised additional ALS data had become available for the Beulah study area. This additional ALS data was sourced from Grampians Wimmera Mallee Water as part of the Wimmera Mallee Pipelining Project.

Figure 3-3 illustrates the ALS data extent for the Beulah study area. The ALS data employed in this study for Beulah has a nominated accuracy (standard error) of 0.15m in both the horizontal and vertical planes.

3.3.3 Field Survey

Field survey was conducted by Price Merrett Consulting to provide aerial photo control, waterway cross-section and culvert/bridge structure details.

For Warracknabeal, a number of historical cross sections and the available ALS data was considered adequate to define the waterway geometry. Hence, no cross section survey were required at Warracknabeal.

The absence of the available cross section required the survey of 5 cross sections for the Yarriambiack Creek in Beulah.

For both townships, a number of bridges and culvert and weir structures were survey including the following:

Beulah

- Weir Pool Upstream Inlet structure
- Weir Pool Downstream outlet structure
- Birchip Rainbow Road Culverts
- Railway Bridge and culvert to the south of Beulah
- Culverts under Railway Line adjacent to grain bunkers

Warracknabeal

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

The extent location and extent of the field survey is illustrated in Figure 3-3 and Figure 3-4 for Beulah and Warracknabeal respectively.

3.3.4 Digital elevation model

Using the topographic survey discussed in Section, Digital Elevation Models (DEM) of both the Warracknabeal and Beulah study areas were constructed. A grid size of 5m were employed in both Warracknabeal and Beulah.

Further details on the use of the DEM in the hydraulic analysis is provided in Section 6.

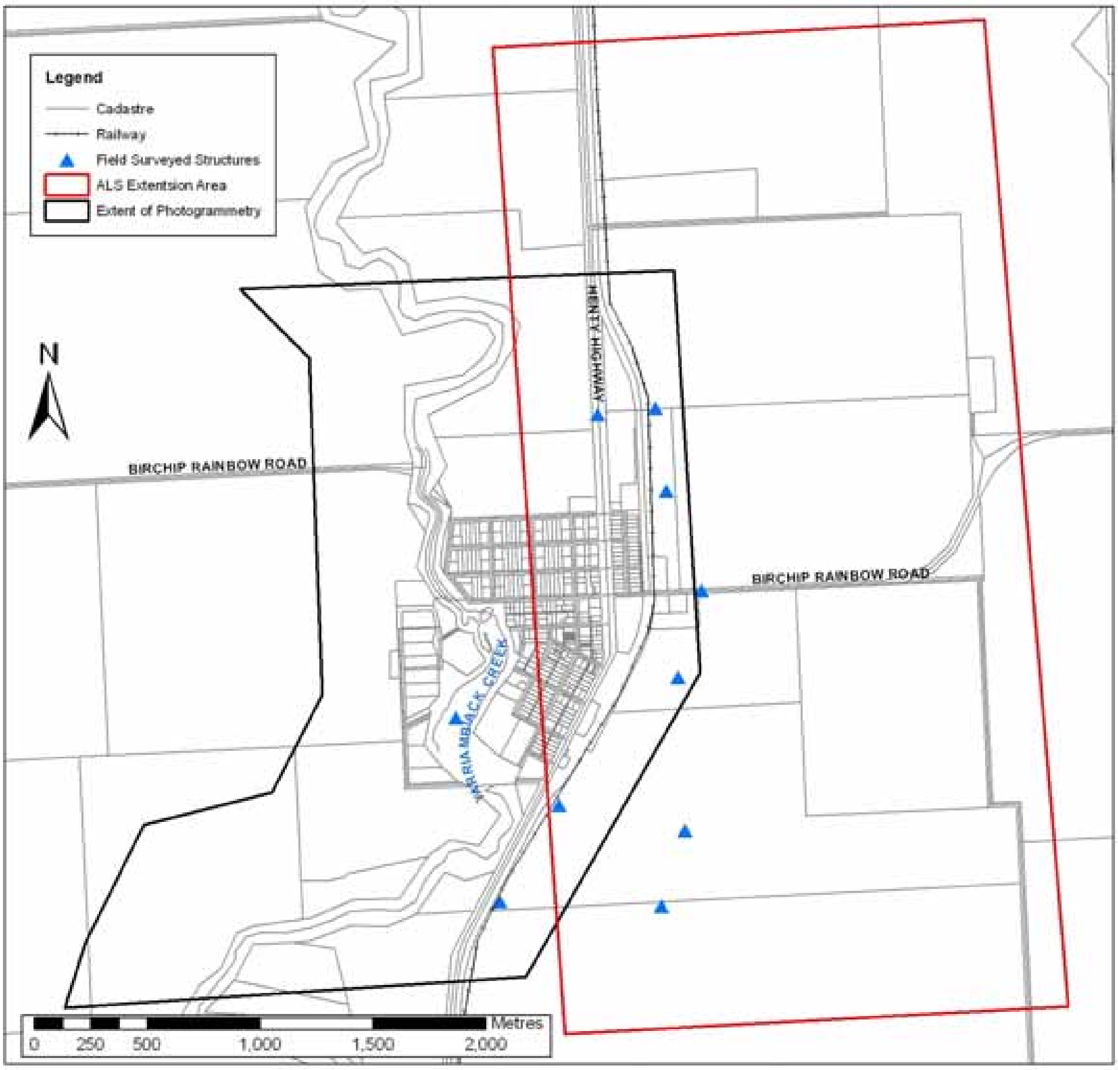

Figure 3-3 Beulah study area: Topographic survey elements

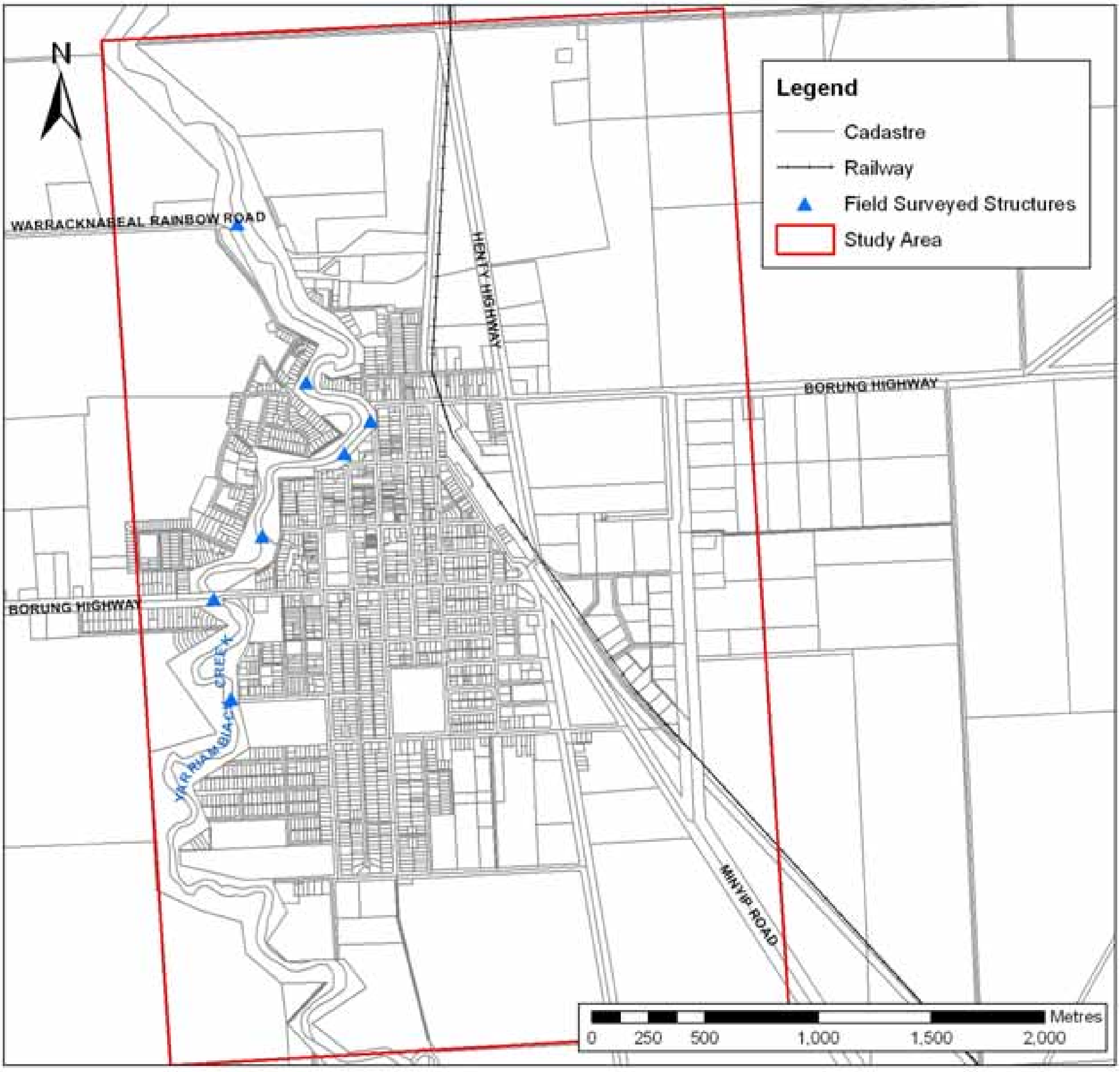

Figure 3-4 Warracknabeal study area: Topographic survey elements

4 COMMUNITY CONSULTATION

4.1 Overview

A key ingredient in the development of a widely accepted study outcomes was the active engagement of the community in the study. The communications strategy adopted by this study was aimed at the community developing a “sense of ownership” of the final study outcomes.

In an effort to engender this “sense of ownership” the consultation process proposed was based on relationships with landholders within the study area. These relationships were developed over the course of the study through community information sessions and on-going communication of study progress.

To provide regular input to the study from the community, a three stage community process has been undertaken. The aims of three stages are as follows:

- First stage community consultation:- re-establish the linkages with the community made during the Glenorchy – Horsham flood Scoping Study 2002-2003; and to raise awareness of the study and identify community concerns.
- Second stage community consultation:- to seek community feedback/input regarding draft flood study report and potential mitigation options.
- Third stage community consultation:- to seek community feedback/input regarding draft floodplain management plan, flood warning and response options.

4.2 Stage 1 community consultation

4.2.1 Aims and elements

The aim of the first stage community consultation is awareness of the study commencement and to begin the development of linkages with key community members.

The first stage community consultation consisted of the following three elements:

- Press releases and public notices
- Information brochure and questionnaire
- Community information sessions

Sections 4.2.2 to 4.2.4 detail the above three elements with a summary of the key flooding related concerns raised by the community outlined in Section 4.2.5.

4.2.2 Press releases and public notices

The study team in conjunction with WCMA drafted a press release. The press release was aimed at raising public awareness of the study, and informing the community about the information brochure, questionnaire and community information sessions. The press release was supplied to the Warracknabeal Herald and Hopetoun Courier and was incorporated into articles. Brief news stories were also run on 3WM and ABC Local Radio.

A public notice outlining the study objective and scope, and the location and timing of the community information sessions was placed in the Warracknabeal Herald and Hopetoun Courier Horsham Times.

4.2.3 Information brochure and questionnaire

In consultation with WCMA, the study team developed an information brochure and questionnaire. The purpose of the information brochure and questionnaire was three fold:

- Raise awareness of the study's objectives and scope within the community
- Provide opportunity for the community to express their knowledge of past flooding and present flood related concerns.

The information brochure was a double-sided colour A3 page folded into thirds. The brochure outlined the objectives and scope of the study, and identified opportunities for the community to be involved in the study. Photographs included in the brochure showing the various flood events were obtained from the WCMA.

The questionnaire consisted was part of the brochure which was to be cut out and returned. The questionnaire contained 10 questions. The questions were aimed at seeking local community flood knowledge and their present flood related concerns.

The information brochure and questionnaire were delivered to approximately 1500 (1260 in Warracknabeal and 240 in Beulah) residences located within the study area.

A total of 14 questionnaire responses have been received. This represents approximately a 1 % response rate. The low response rate is due to the lack of flooding in recent years and the current drought.

A summary of the community responses to the questionnaire is provided in Section 4.2.5.

4.2.4 Community information sessions

The community information sessions were held:

- Beulah: Business & Information Centre 77 Phillips Street Beulah Friday June 2, 10am-noon
- Warracknabeal: Yarriambiack Shire Offices Function Room 34 Lyle Street, Warracknabeal Friday June 2, 1.30-3.30pm

The sessions were conducted in an informal manner with a short introduction presented by Clare Mintern (WCMA) and a study overview presented by Steve Muncaster (Water Technology).

A number of discussions were conducted with small groups of residents by the study team and WCMA during the course of the information sessions. Three landholders indicated a desire to meet on site at later time. These three site visits were undertaken with landholders in mid June.

A total of 10 residents attended the community information session in Warracknabeal with 14 residents attending the Beulah information session.

4.2.5 Summary of questionnaire responses and concerns

A strong comment raised at the community information sessions and in the responses that was *"why is money being spent worrying about flooding… it does not flood"*. One comment indicated " 1909 flood never will occur again due to Bellfield and other floods". This comment reflects the lack of flood events, particularly over past ten years with no flow in the creek occurring. Given the current drought, this comment can be understood. Further, comments were made about low flows and the maintenance of water levels in the weir pools.

There were general comments regarding the maintenance and operation of the outlet weir structures at Warracknabeal and Beulah. Concerns were raised about the Yarriambiack Shire Council maintenance routine on clearing debris adjacent to the weir structures. Also comments made that council should actively maintain drains and gutters. The Warracknabeal weir outlet structure is yet to be tested in flood event. The operation of the Beulah upstream weir inlet structure was seen as potentially causing adverse flooding impacts.

The issue of debris being caught in the weir structures during a flood event was a constant concern to residents. Some residents/landholders suggested “cleaning up” the creek to remove possible debris.

The participation in the community information sessions showed the “passion” in community about Yarriambiack Creek. This passion highlights the place Yarriambiack Creek holds in the community.

Comments were received that actions/outcomes should be addressed and not “swept under the carpet” or the “buck passed on”.

Table 4-1 outlines the various aspects of flooding and the community concerns as raised by responses to the questionnaire and/or at the community information sessions.

Table 4-1 Summary of community responses

Brochure question	Concerns/responses
Past floods (Questionnaire question No. 1)	• Events in 1956, 1981 and 1996. • "Never" • Minor events in 1970s and 1980s
Main flooding issue (Questionnaire question No. 2)	• Bridges and banks across creek • Debris in the creek • "If we had some water in the creek it might be an issue" • Stormwater drainage, Council maintenance of drains • Schoolyard drainage • Operation of weirs to limit flooding impacts
Nature of flooding (Question No. 3)	• Shallow to moderate flood depth • Ponded / slow flowing
Damage or disruption (Question No. 4)	• Landed flooded (10 responses) • One response indicated residence flooded due to stormwater • Disruption access cut adjacent to school yard • Crop/pasture damage (5 responses)
Flooding situation – improving or worsening (Question No. 5)	• Improving/ not changing due to no rain (9 responses) • Worsening – stormwater drainage/blocked pipe (1 response)
Knowledge of flood marks (Question No. 6 & 7)	• 3 responses provided flood marks
Undertaken works to protect your property (Question No. 8)	• No- 6 responses • Yes – 4 responses if what works ? - small channel - maintain adjacent drains - low level bank - tree and Lucerne planting
Flooding warning sources (Question No. 9)	• Neighbours (5 responses) • Radio (5 responses) • Shire (1 response)
Other comments	• As discussed above

4.3 Stage 2 community consultation

4.3.1 Aims and elements

The aim of the second stage consultation was to gain community feedback on the draft flood study report and potential mitigation options. The second stage community consultation consisted of the following three elements:

- Press releases and public notices
- Community information sessions

Sections 4.3.2 to 4.3.3 detail the above three elements.

4.3.2 Press releases and public notices

The study team in conjunction with Wimmera CMA drafted a press release and public notice. The press release and public notice were aimed at raising public awareness of the community information sessions. The press release and public notices was supplied to the Warracknabeal Herald and Hopetoun Courier. Brief news stories were also run on 3WM and ABC Local Radio.

Community members who provided their contact details at the Stage 1 community information sessions were sent a posted invitation to the Stage 2 community information sessions.

4.3.3 Community information sessions

The community information sessions were held:

- Beulah: Business & Information Centre 77 Phillips Street Beulah Tuesday 25 July 2006, 7 pm – 9pm
- Warracknabeal: Yarriambiack Shire Offices Function Room 34 Lyle Street, Warracknabeal Wednesday 26 July, 7 pm -9 pm

The sessions were conducted in an informal manner with a short introduction presented by Clare Mintern (WCMA) and study progress presented by Steve Muncaster (Water Technology).

A number of discussions were conducted with small groups of residents by the study team and WCMA during the course of the information sessions.

4.4 Stage 3 community consultation

4.4.1 Aims and elements

The aim of the third stage consultation was to gain community feedback on the draft mitigation measures. The third stage community consultation consisted of the following three elements:

- Press releases and public notices
- Community information sessions/Individual residents meetings

Sections 4.4.2 to 4.4.3 detail the above two elements.

4.4.2 Press releases and public notices

The study team in conjunction with Wimmera CMA drafted a press release and public notice. The press release and public notice were aimed at raising public awareness of the Beulah community information session. The press release was supplied to the Warracknabeal Herald and Hopetoun Courier and was incorporated into articles. Brief news stories were also run on 3WM and ABC Local Radio.

Community members who provided their contact details at the Stage 1 and 2 community information sessions were sent a posted invitation to the Stage 3 community information session.

4.4.3 Community information sessions/individual resident meetings

A community information session was held in Beulah on Friday 19 October 4 pm -5.30 pm. Only one community member attended the session.

In Warracknabeal, a series of individual meetings were conducted with key community members in lieu of a community information session.

5 HYDROLOGIC ANALYSIS

5.1 Overview

Design flood hydrographs were required for the 1 in 10, 1 in 20, 1 in 50, 1 in 100 and 1 in 200 year floods and the Probable Maximum Flood (PMF) at the following locations:

- Yarriambiack Creek at Warracknabeal
- Yarriambiack Creek at Beulah

As discussed, Yarriambiack Creek is a distributary of the Wimmera River. Significant flows along Yarriambiack Creek result from breakouts from the Wimmera River during flood events. There is a limited local catchment with only a minor contribution to significant along Yarriambiack Creek. However, local rainfall event may result in overland flow from the Yarriambiack Creek.

Given the primary importance of the Wimmera River to flows in Yarriambiack Creek, the determination of design flood hydrographs were undertaken using the following three step process:

- Upper Wimmera Catchment: Develop design flood hydrographs for the upper Wimmera catchment to the Wimmera River/Yarriambiack Creek offtake with a hydrologic model
- Wimmera River/Yarriambiack Creek offtake: Determine the flow split of the design flood hydrographs at Wimmera River/Yarriambiack Creek offtake with a coarse two dimensional (2D) hydraulic model. Design flood hydrographs estimated for Yarriambiack Creek at the Wimmera Highway Bridge.
- Yarriambiack Creek - Wimmera Highway Bridge to Warracknabeal and Beulah: Route the design flood hydrographs at the Wimmera Highway Bridge along Yarriambiack Creek to Warracknabeal and Beulah via a one dimensional (1D) hydraulic model.

The catchment hydrologic model, URBS, was the principal tool employed to estimate design flood hydrographs for the upper Wimmera River. 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 URBS model employed by this study was developed by BoM (2004). The URBS model parameters were determined through calibration of the modelled flood hydrographs to recorded flood hydrographs.

The URBS model design hydrographs, at Wimmera River/Yarriambiack Creek offtake, are input to a 2D hydraulic model, MIKE21. The 2D hydraulic model was used to develop a coarse approximation of the flow split between the Wimmera River and Yarriambiack Creek for large flood events.

The 1D hydraulic model, MIKE11, was used to route the design hydrographs generated by 2D hydraulic model at the Wimmera Highway Bridge down Yarriambiack Creek to Warracknabeal and Beulah.

The underlying assumption for this analysis that is the recurrence interval of a flood event in the upper Wimmera River catchment is maintained along Yarriambiack Creek i.e. a 1 in 100 year in the upper Wimmera River results in a 1 in 100 year flood at Warracknabeal and Beulah. The lack of available streamflow data limits the verification of this assumption. The study team considers the adoption of this assumption as reasonable, given the absence of adequate streamflow data to development and adoption of alternative relationships between the frequency of Wimmera River and Yarriambiack Creek flood events. The study team acknowledges considerable uncertainty surrounds the design flood estimates for Yarriambiack Creek.

The following sections detail the input data, methodology and outputs for each of three components of the hydrologic analysis.

5.2 Upper Wimmera River Catchment

5.2.1 Overview

The hydrologic model, URBS, is a networked conceptual runoff and streamflow routing model that calculates flood hydrographs from rainfall and other channel inputs. The model is based on catchment geometry and topographic data.

The URBS model employed by this study was developed by Bureau of Meteorology (BoM 2004). This model was developed as part of the flood warning system for the Wimmera River to Dimboola.

This section details the URBS model structure, calibration and application to estimate design flood hydrographs for the upper Wimmera River catchment.

5.2.2 Upper Wimmera River URBS model structure

The URBS model, , was developed by available BoM (2004) for use for the entire Wimmera River catchment excluding the Yarriambiack Creek distributary. Several minor modifications were made to the model structure to enable the outputs (flood hydrographs) required for this study.

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. There are 53 sub-catchments upstream of the streamflow gauge on the Wimmera River at Faux Bridge. Figure 5-1 shows the URBS model catchment sub-division.

5.2.3 Upper Wimmera River URBS model 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. For this analysis, the URBS model was calibrated to recorded streamflow for the Wimmera River at Glenorchy and Faux Bridge.

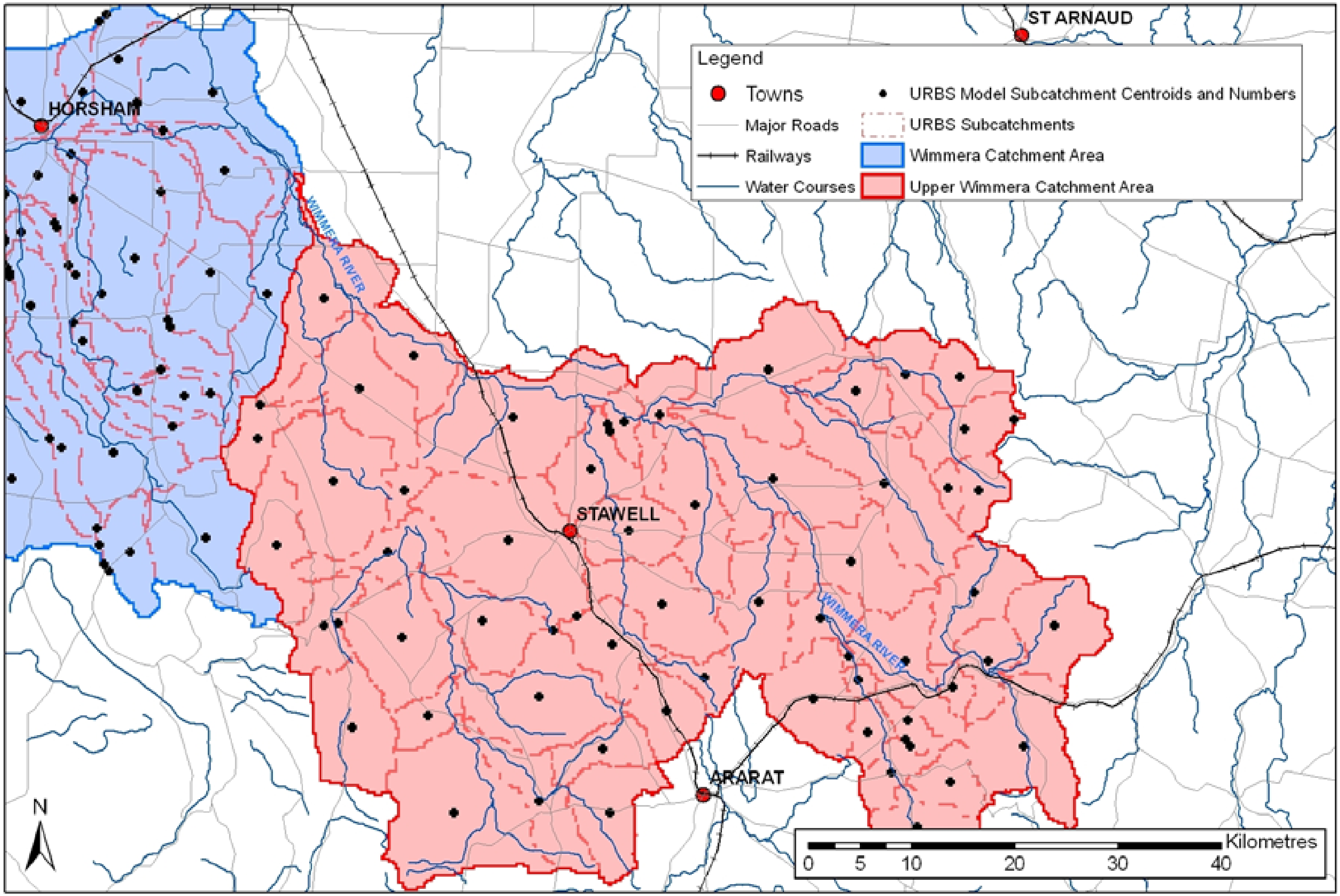

Figure 5-1 URBS Model Structure – Catchment Subdivision

The selection of suitable flood events for model calibration was dependent on the availability of concurrent streamflow and pluviographic records. Two flood events selected for calibration: August 1981; and September 1983. The details of the selected calibration flood events are given in Table 5-1.

Table 5-1: URBS model calibration event

Event	Event Start & Finish Date	Glenorchy (415201)			Faux Bridge (415240)		
		Recorded Peak flow (m^3/s)	Date and Time of Peak	Qualitative Estimate of flood magnitude	Recorded Peak flow (m^3/s)	Date and Time of Peak	Qualitative Estimate of flood magnitude
August 1981	02/08/1981 08/08/1981	198	04/08/81 14:00	Moderate	184	05/08/81 15:00	Moderate
September 1983	03/09/1983 24/09/1983	206	09/09/83 11:00	Moderate	217	10/09/83 07:00	Moderate

As outlined, 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 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 combination of α and β 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.

A summary of calibration results are provided in Table 5-2.

Table 5-2 URBS model calibration

Event	Routing parameters		Rainfall loss parameters		Wimmera River at Glenorchy		Wimmera River at Faux Bridge	
	α	B	IL (mm)	CL (mm/hr)	Recorded peak flow (m^3/s)	Modelled peak flow (m^3/s)	Recorded peak flow (m^3/s)	Modelled peak flow (m^3/s)
August 1981	0.55	3.5	10	2.3	198	198	185	188
September 1983	0.55	3.5	20	2.2	205	205	217	212

5.2.4 Upper Wimmera River URBS model verification

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 a flood frequency analysis. This section discusses the following aspects of the verification:

- Flood frequency analysis for the Wimmera River at Glenorchy
- Design rainfall depths, spatial and temporal patterns
- URBS routing parameters
- Design rainfall losses determination

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 5-2 shows the flood frequency analyses for the Wimmera River at Glenorchy.

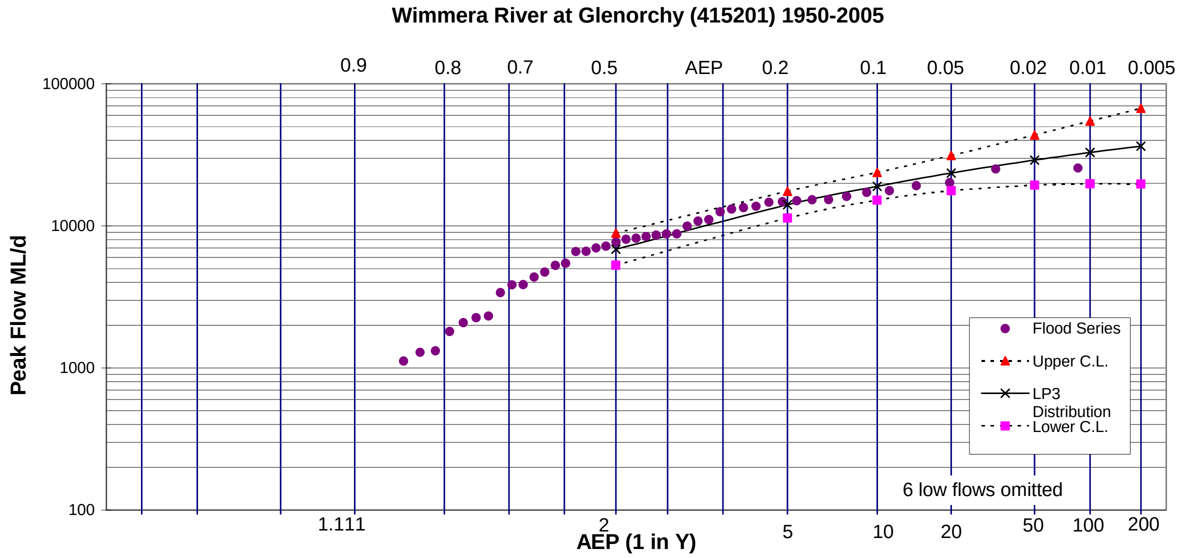

Figure 5-2 Flood frequency analysis for the Wimmera River at Glenorchy (Water Technology, 2006)

Design rainfall depths were calculated for the 1 in 5, 1 in 10, 1 in 20, 50, 100 and 200 year events using the IFD procedures outlined in ARR87. The IFD parameters were provided in Table 5-3.

Table 5-3 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 ARR87 design temporal patterns for Zone 2 were used in the study for all events up to and including the 1 in 200 year 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.

As discussed in Section 5.2.3, this study adopted α of 0.55, β of 3.5, and m of 0.8 as the routing parameters for design flood estimation.

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.

Table 5-4 displays the URBS model parameter found to provide consistent peak flows estimates as the flood frequency analysis at Glenorchy.

Table 5-4 Upper Wimmera River – Adopted URBS design parameters

Routing parameters		Rainfall loss parameters	
α	β	IL (mm)	CL (mm/hr)
0.55	3.5	10	2.3

5.2.5 Upper Wimmera River design flood hydrographs

Design flood hydrographs were determined for the 1 in 5, 1in 10, 1 in 20, 50, 100 and 200 year ARI events at Faux Bridge using model parameters outlined in Section 5.2.4. A range of storm durations was trialled to determine the critical storm duration.

Table 5-5 displays the URBS model design peak flows and critical storm durations for Wimmera River at Faux Bridge. The 30 and 36 hour storm durations were found to be critical for the 1 in 5 and 1 in 10 year events respectively. The 72 hour storm duration was found to be critical for 1 in 20, 1 in 50, 1 in 100 and 1 in 200 year events.

Table 5-5 Upper Wimmera River - URBS model design peak flows

Location	Design peak flow (m^3/s)					
	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI	200 Year ARI
Wimmera River at Glenorchy	164	221	270	337	380	421
Wimmera River at Faux Bridge	207	290	358	454	513	524

Appendix A contains the design flood hydrographs for Wimmera River at Faux Bridge.

5.2.6 Discussion

The Upper Wimmera URBS model was calibrated to historical flood hydrographs for the Wimmera River at Glenorchy and Faux Bridge. Further, the URBS model parameters were verified for use in the design flood estimation by obtaining consistent design flood estimates from the URBS model and flood frequency analysis. The study team considered the calibration and verification of the upper Wimmera River URBS model provides a robust approach to design flood estimation for the Wimmera River to the Yarriambiack Creek offtake.

The URBS model routing parameters, α and β, adopted by this study were 0.55 and 3.5 respectively. BoM (2004) reported a range of 0.30 – 0.45 for α and 2.0 -3.0 for β. The study team acknowledges that the adopted parameters lie outside the BoM (2004) range. Given the calibration approach employed, as discussed above, the study team considers the adopted parameters as suitable for this study's purposes.

5.3 Wimmera River - Yarriambiack Creek Offtake

5.3.1 Overview

As described in Section 5.1, a three step process has been employed to evaluate the required design flood hydrographs. This section discusses the second component, the hydraulic modelling of the Wimmera River/Yarriambiack Creek offtake.

Considerable anthropogenic modifications to the natural flow behaviour have occurred in the vicinity of the offtake, as discussed by SMEC (2002), KBR (20004), SKM (2003) and Cooling et al (2006). Coooling et al (2006) contains a detailed description of the current flow behaviour at the offtake.

The flow behaviour at the offtake during significant flood event in the Upper Wimmera, and consequently in Yarriambiack Creek, is the primary focus of this study. As a result, the development of the hydraulic model for the offtake has focused on the simulation of flood flow behaviour. Given this focus, the study team cautions against the use of this model to investigate the offtake flow behaviour during low flow periods.

5.3.2 Offtake hydraulic model structure

A hydraulic model of the Yarriambiack Creek offtake and surrounding floodplain area was established to assist in assessing flood behaviour. The two-dimensional model, MIKE 21, was applied for this analysis. The model was developed with a grid size of 25m, providing a coarse estimate of the flood flow distribution and behaviour. Figure 5-3 displays the complex topography at the offtake.

The URBS model design hydrographs from Section 5.2 are input to the two dimensional hydraulic model.

5.3.3 Offtake hydraulic model calibration

To calibrate the offtake hydraulic model requires observed flood hydrographs at the upstream end on the Wimmera River (model inflow) and at the downstream end on Yarriambiack Creek (model outflow). As outlined in Section 3.2.1, streamflow data is available at the upstream end, for the Wimmera River at Faux Bridge, and the downstream end, for the Yarriambiack Creek at the Wimmera Highway Bridge. The concurrent period of streamflow data at the two gauges is August 1978 to December 1986. During this period, significant flood events occurred in August 1981 and September 1983.

The September 1983 event was selected as the calibration event for the offtake model. The hydraulic roughness and model topography was adjusted in an effort to achieve reasonable consistency between observed and modelled flows at the Wimmera Highway Bridge. Table 5-6 provides the results of the initial calibration runs.

Table 5-6 2D Offtake model calibration results

Event	Wimmera River at Faux Bridge Observed peak flow **m^3/s**	Yarriambiack Creek at Wimmera Highway Observed peak flow **m^3/s**	Yarriambiack Creek at Wimmera Highway Modelled peak flow **m^3/s**
September 1983	**217**	**19.9**	**12.6**

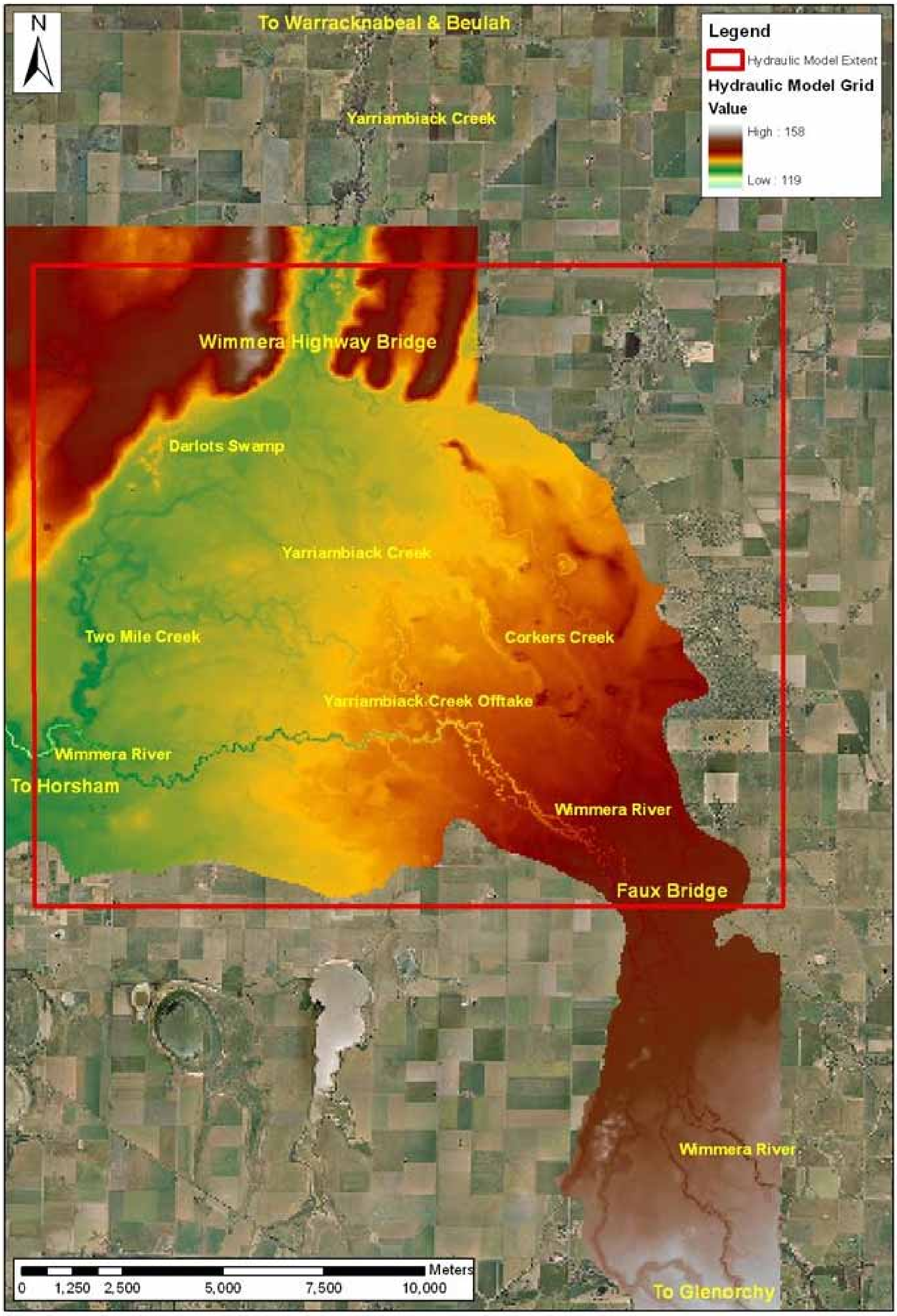

Figure 5-3 2D Hydraulic model structure

Figure 5-4 shows the modelled and observed September 1983 flood hydrographs for the Yarriambiack Creek at the Wimmera Highway Bridge.

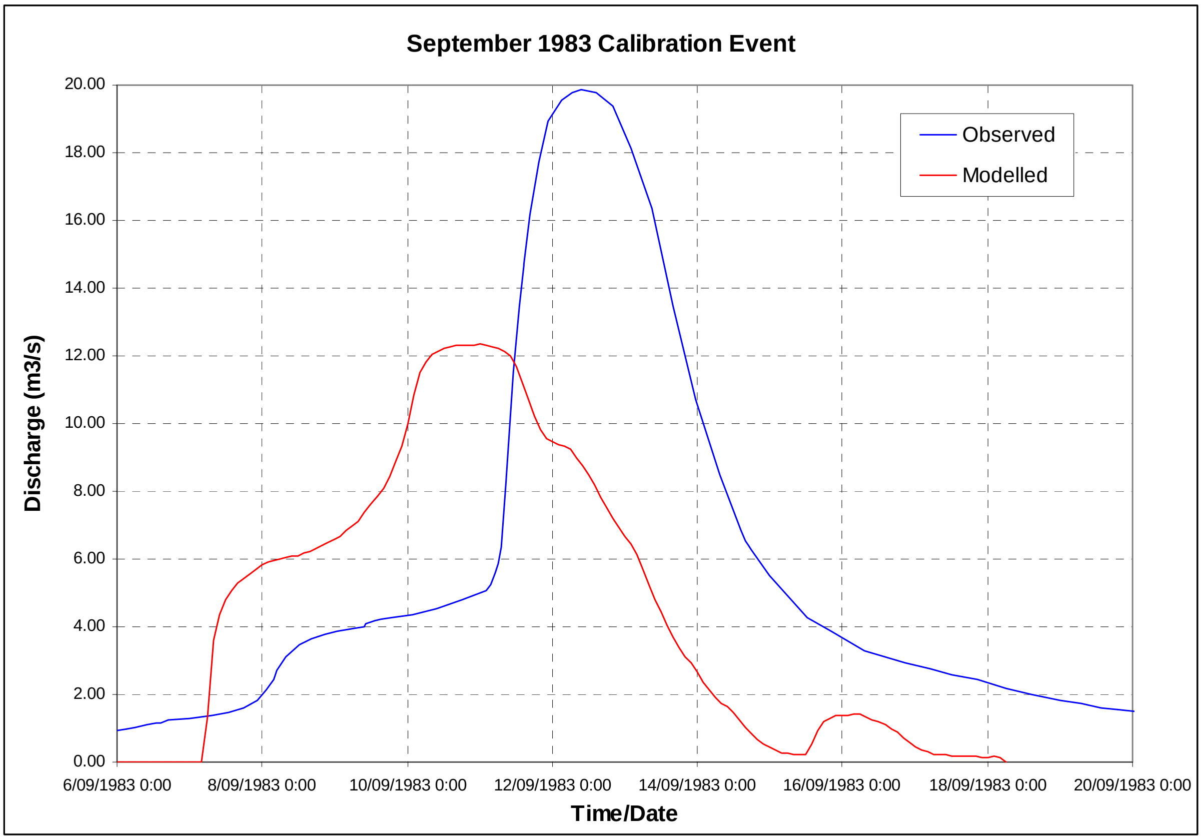

Figure 5-4 Offtake hydraulic model – September 1983 calibration event flood hydrographs

The disparity between modelled and observed peak flow for the 1983 event is due to the coarse grid representation of various creeks' channels. Whilst the coarse grid model will approximate the hydraulic behaviour of large flood flows well, smaller flood flows are less well represented due to their flow distributions being controlled primarily by creeks' channels.

5.3.4 Design flood hydrographs at the Wimmera Highway Bridge

Table 5-6 shows that the September 1983 calibration event is underestimated by the offtake hydraulic model. The study team considers, in the absence of other information, to scale the design events according to the ratio of peak modelled to peak observed flow for the September 1983 event (19.9/12.6 = 1.58) is appropriate to determine the design flood hydrographs at the Wimmera Highway.

Table 5-7 outlines the design flood peak flow based on the scaling results and Figure 5-5 displays the design flood hydrograph at the Wimmera Highway Bridge.

Table 5-7 Design peak flow – Yarriambiack Creek at the Wimmera Highway

Design Event ARI (years)	Wimmera River at Faux Bridge Peak flow m³/s	Yarriambiack Creek at Wimmera Highway Modelled peak flow m³/s	Yarriambiack Creek at Wimmera Highway Scaled adopted peak flow m³/s	Flow Split Yarriambiack Creek /Wimmera River (%)
5	**207**	**12.3**	**19.4**	**9.4**
10	**290**	**13.7**	**21.6**	**7.4**
20	**358**	**20.0**	**31.6**	**8.8**
50	**454**	**28.3**	**44.8**	**9.8**
100	**513**	**36.8**	**58.1**	**11.3**
200	**524**	**38.1**	**60.2**	**11.4**

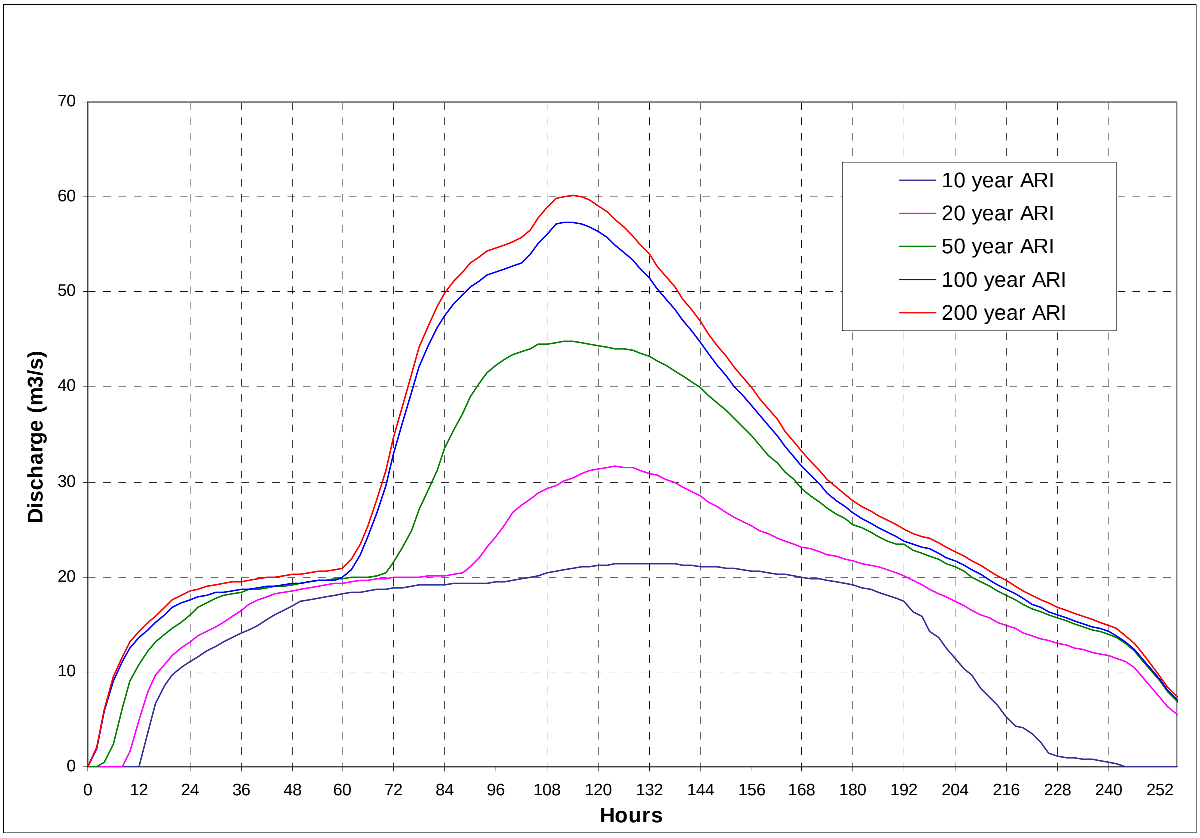

Figure 5-5 Yarriambiack Creek design hydrographs at Wimmera Highway Bridge

5.3.5 Discussion

As discussed in Section 3.1, SMEC (2002) describes a partial series flood frequency analysis that was undertaken on seven years of data. Further SMEC (2002) states that the flood frequency curve developed could be utilised to obtain a reasonable frequency estimate for more frequent events (up to ARI of 1 in 4) but less reliable for less frequent events. Through this analysis, the September1983 event has an approximate return interval of just under 10 years which is consistent with the return interval suggested by SMEC (2002).

The flow split between Yarriambiack Creek and the Wimmera River, provided in Table 5-7, shows a range of 7.4% to 11.4 %. A generally increasing trend with flow magnitude occurred. The range of the flow split is agrees with SKM (2002). Gippel (2006), using the recorded flow at Wimmera Highway (July 1978 to October 1986) found an increasing trend of flow split with flow magnitude.

The study team acknowledges the application of the scaling factor (1.58) to the modelled Yarriambiack Creek hydrographs is an attempt to combat the limitations of the 2D model. However, the study team considers the application of the scaling factor is acceptable given the absence of alterative rigorous approaches.

It should be noted that the study team recommends a full hydraulic investigation of the offtake system should be undertaken. The study team suggest that a fully linked 1D-2D hydraulic model is needed to fully define and understand the flood behaviour.

The study team considers significant uncertainty surrounds the derivation of the design flood hydrographs for Yarriambiack Creek at the Wimmera Highway.

5.4 Yarriambiack Creek – Wimmera Highway to Warracknabeal and Beulah

5.4.1 Overview

As described in Section 5.1, a three step process has been employed to evaluate the required design flood hydrographs. This section discusses the third component, the hydraulic modelling of the Yarriambiack Creek from the Wimmera Highway to Warracknabeal and Beulah.

5.4.2 Creek hydraulic model structure

The flood hydrographs developed by the offtake hydraulic model are routed to Warracknabeal along Yarriambiack Creek via a one-dimensional (1D) hydraulic model. The 1D model was developed employed DHI's Mike11 software package

This 1D creek hydraulic model was established utilising floodplain cross sections extracted from a digital terrain model based on the ALS data, discussed in Section 3.3.1. As the ALS data is only available to just downstream of Warracknabeal, the 1D model developed is limited to Yarriambiack Creek from the Wimmera Highway to Warracknabeal. Further discussion of the determination of flood hydrographs is discussed in Section 5.4.5.

Figure 5-6 illustrates the creek hydraulic model structure showing indicative cross section locations.

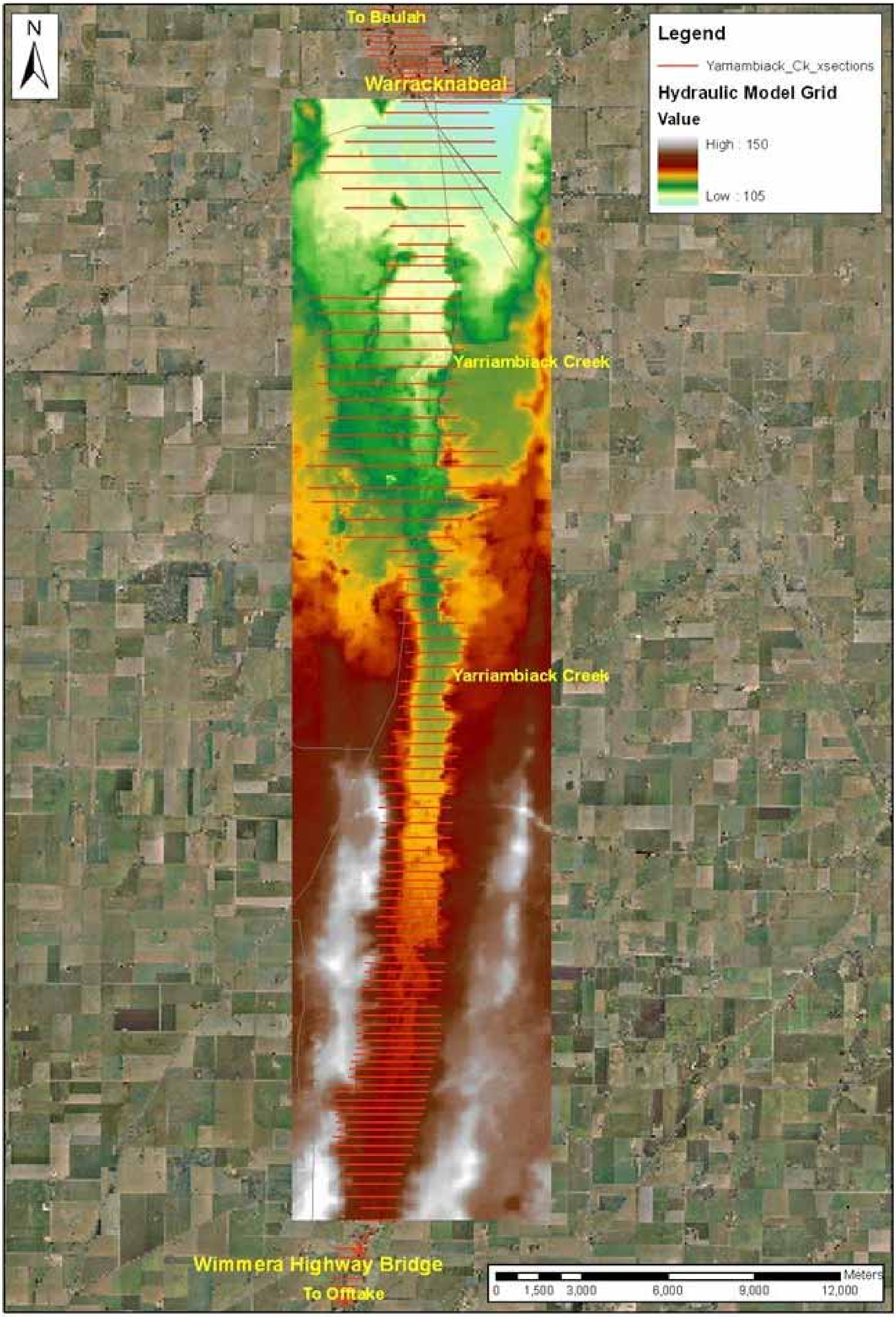

Figure 5-6 Yarriambiack Creek 1D hydraulic model structure

5.4.3 Creek hydraulic model calibration

Due to the intermittent nature of streamflow in Yarriambiack Creek, significant infiltration can occur between the Wimmera Highway, Warracknabeal and Beulah. This infiltration reduces the flood volume as the flood move north along Yarriambiack Creek. To account for the infiltration loss, the constant seepage allowance was applied along the length (Wimmera Highway to Warracknabeal) of the creek model.

As discussed in Section 3.2.1, an estimate of the peak flow upstream of the Warracknabeal Weir for September 1983 is available. For the September 1983 event, the creek hydraulic model was calibrated against this estimated peak flow. A seepage allowance of 3.2 mm/h was found to result in a reasonable comparison of modelled and estimated peak flows.

5.4.4 Design flood hydrographs for Yarriambiack Creek at Warracknabeal

The scaled design flood hydrographs at the Wimmera Highway Bridge, as determined in Section 5.3.4, were applied as input to the creek model. Using the creek model structure and seepage determined above, design flood hydrographs for Yarriambiack Creek at Warracknabeal were evaluated. Table 5-8 displays the design peak flows and Figure 5-7 shows the design flood hydrographs.

Table 5-8 Yarriambiack Creek at Warracknabeal: Design peak flows

Design Event ARI (years)	Yarriambiack Creek at Wimmera Highway Scaled adopted peak flow m^3/s	Yarriambiack Creek at Warracknabeal Adopted peak flow m^3/s
5	**19.4**	**13.3**
10	**21.6**	**14.7**
20	**31.6**	**20.7**
50	**44.8**	**31.3**
100	**58.1**	**41.4**
200	**60.2**	**43.7**

The estimated peak flow at Warracknabeal for the September 1983 was 1,114 ML/d (12.9 m^3/s). Using the design peak flows from Table 5-8 the September 1983, has an approximate recurrence interval of 5 years. This recurrence interval appears to low given the historical absence of the floods with similar magnitude. Further discussion of the reliability of the design flood estimates at Warracknabeal is provided in Section 5.4.6.

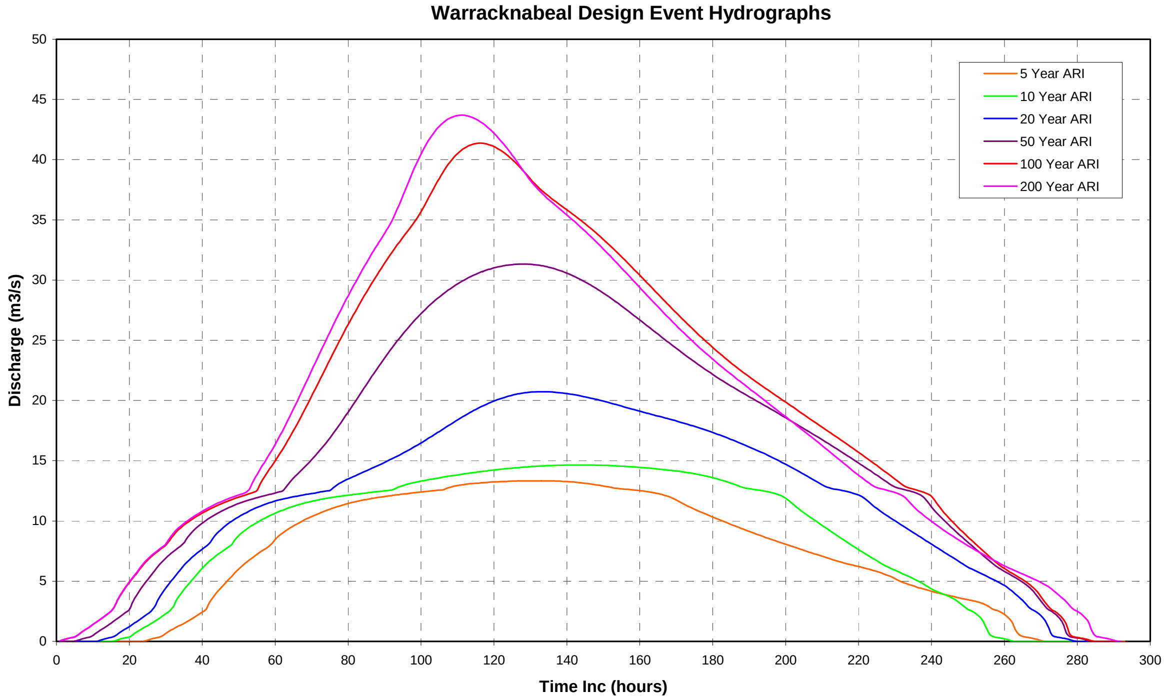

Figure 5-7 Yarriambiack Creek Design Flood Hydrographs at Warracknabeal

5.4.5 Design flood hydrographs for Yarriambiack Creek at Beulah

Given the absence of topographic data for the Yarriambiack Creek reach from Warracknabeal to Beulah, the creek model was unable to directly provide design flood estimates at Beulah. An alternative approach, as outlined below, was adopted.

The creek model yielded design peak flow estimates at Warracknabeal from the design flood hydrograph at the Wimmera Highway Bridge. The reach length from the Wimmera Highway to Warracknabeal is approximately 56.3 km km and the reach length from Warracknabeal to Beulah is approximately 48.4 km (Cooling et al 2006). As the reach lengths are comparative and the nature of the creek similar, an assumption was made that the associated infiltration and attenuation of the flood hydrographs from the Wimmera Highway to Warracknabeal would be similar for the reach Warracknabeal to Beulah.

The design flood hydrographs at Beulah were then determined by scaling the Warracknabeal design flood hydrographs with the ratios of the peak flows at Wimmera Highway and Warracknabeal. Table 5-9 displays the design peak flows and Figure 5-8 shows the design flood hydrographs for Yarriambiack Creek at Beulah.

Table 5-9 Yarriambiack Creek at Beulah: Design peak flows

Design Event ARI (years)	Yarriambiack Creek at Beulah Adopted peak flow m^3/s
5	**9.2**
10	**10.1**
20	**13.7**
50	**21.9**
100	**29.8**
200	**31.9**

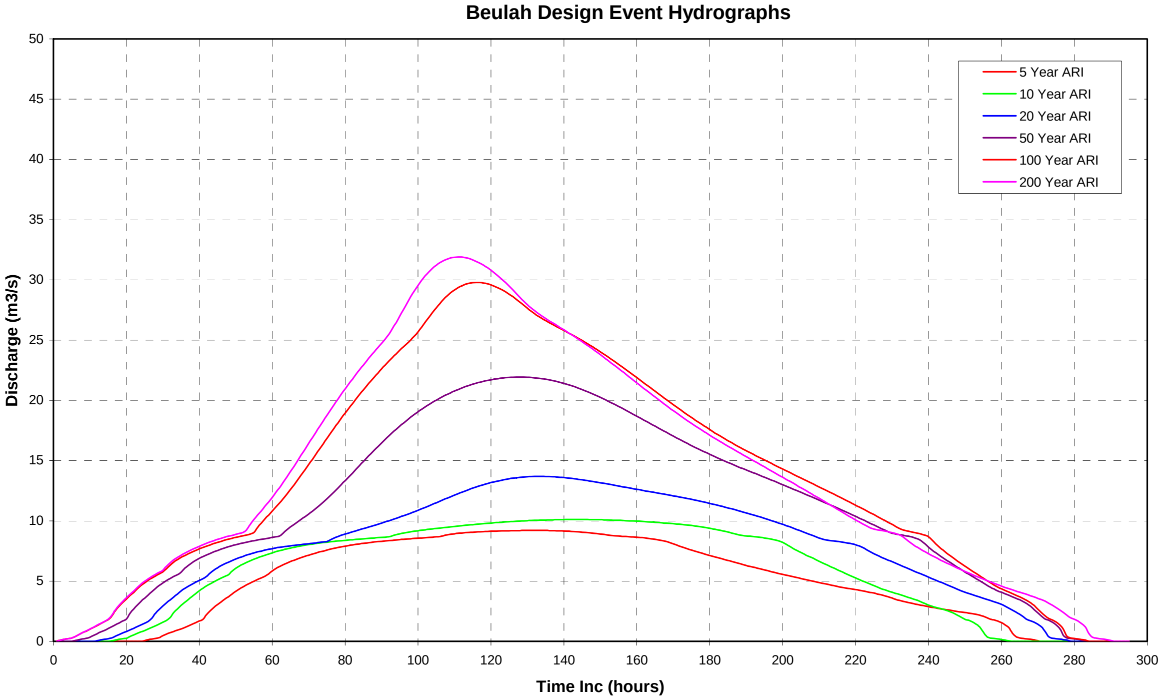

Figure 5-8 Yarriambiack Creek Design Flood Hydrographs at Beulah

As discussed in Section 3.2.1, the peak flow estimate for the August 1981 flood event was 1,180 ML/d (13.6 m^3/s). Using the design peak estimates from Table 5-9, has an approximate recurrence of 20 years. Further discussion of the reliability of the design flood estimates at Beulah is provided in Section 5.4.6.

5.4.6 Discussion

The hydrologic analysis for this study was required to estimate design flood hydrographs for Yarriambiack Creek at both Warracknabeal and Beulah. As detailed in Sections 5.2, 5.3 and 5.4, the hydrologic analysis employed a three-component approach to the estimation of the required design flood hydrograph. The lack of available streamflow data along Yarriambiack Creek has limited the opportunity to calibrate each component and the entire analysis approach. Some general comments on the reliability of the design flood hydrograph provided by this study follow.

As noted by Gippel (2006), SKM (2000) and WBM (2004) quote the Warracknabeal Flood Study as assigning the ARIs of 25 year and 280 year to 1981 and 1909 flood events respectively. However, the basis of the determination of these ARIs is unknown. The study team has been unable to access the previous Warracknabeal Flood Study Report.

Using the findings of this study, the 25 year ARI event at Warracknabeal is estimated at about 23 m^3/s. To the knowledge of the study team, no peak flow estimate at Warracknabeal is available for the 1981event. Hence, it is not possible to assess the ARI of the 1981 event flood event at Warracknabeal. However, as noted in Section 5.4.5, the estimated peak flow for the 1981 event at Beulah (1,180 ML/d or 13.6 m^3/s) has an approximate ARI of 20 years.

An estimate of 13,000 ML/d (150 m^3/s) at the Railway Line across Yarriambiack Creek (downstream of the Wimmera highway Bridge) was provided by the Horsham floodplain management Study (SRWSC 1982). Using this study's findings, outlined in Section 5.3.4, the estimated 1909 peak flow has an ARI well in an excess of 200 years.

Gippel (2006) constructed a conceptual hydrologic model to route daily flows along Yarriambiack Creek. The study team acknowledges the purpose of the Gippel (2006) model, and understands direct comparison of the results from Gippel (2006) and this study must be viewed the purpose of the two investigations in mind.

The study team considers informative a comparison of the attenuation of flows along Yarriambiack Creek. Gippel (2006) found a reduction in maximum peak flow from the Wimmera Highway to Warracknebeal of 38%, and from Warracknabeal to Beulah of 52 %. This compares to this study's respective reductions of 34 % and 33 %. The similarity of the reductions for this study is due to the scaling approach adopted given the lack of the topographic data for the creek hydraulic model.

Gippel (2006) found a reduction in mean daily flows, due to evaporation and filling of channel and flood plain storage, of 47 % from the Wimmera Highway to Warracknebeal, Using this study's 20 year design flood hydrographs, the reduction in flood volume from the Wimmera Highway to Warracknebeal was 33 %, and from Warracknabeal to Beulah of 34 %.

The travel time of the peak flows from the Wimmera Highway to Warracknabeal was found to reduce with flood magnitude. For the 20 year flood event, the peak flow travel time from the Wimmera Highway to Warracknabeal was 36 hours, compared to 28 hours for the 100 year flood event. This decrease in travel time with increasing flood magnitude is in line with the comments contained in Gippel (2006).

As highlighted throughout this hydrologic analysis, the study team acknowledges considerable uncertainty surrounding the design flood estimates developed by this study. Rigorous calibration and/or validation of the approach is restricted by the absence of streamflow data. The study team considers, while the absolute reliability of design estimates is unknown, the relativity of design estimates is considered reasonable.

The study team strongly supports the recommendations of Gippel (2006) that improvement in the understanding of Yarriambiack Creek hydrology requires systematic gauging of streamflow.

6 EXISTING CONDITIONS HYDRAULIC ANALYSIS

6.1 Overview

The hydraulic analysis determined flood behaviour at Warracknabeal and Beulah under the existing waterway and floodplain conditions. The flood behaviour was assessed for flood events originating from both Yarriambiack Creek (creek flooding) and local catchment rainfall (stormwater flooding).

The flood behaviour, due to creek flooding, was assessed for the 10, 20, 50, 100, and 200 year flood events plus an indicative probable maximum flood (PMF). The design flood hydrographs for Yarriambiack Creek, outlined in Section 5.4, were utilised as inflows to Warracknabeal and Beulah study areas respectively.

The flooding behaviour, due to stormwater flooding, was only assessed for the 100 year flood event from the local catchments.

The linked one dimensional and two-dimensional unsteady hydraulic model, MIKEFLOOD, was the principal tool for the hydraulic analysis. MIKEFLOOD is a state of the art tool for floodplain modelling that has been formed by the dynamic coupling of DHI's well proven MIKE 11 river modelling and MIKE 21 fully two-dimensional modelling systems. Through this coupling it is possible to extend the capability of the 2D MIKE 21 model to include:

- A comprehensive range of hydraulic structure (including weirs, culverts, bridges, etc);
- ability to accurately model sub-grid scale channels;
- ability to accurately model dam break or levee failures.

For this present study, a two-dimensional (2D) MIKE 21 model has been set up to model the overall floodplain flows. A coupled one dimensional (1D) MIKE 11 model has been utilised to explicitly model waterway (bridge and/or culvert) crossings within the study area.

This section details the input data, methodology and outputs for the existing conditions hydraulic analysis. Section 6.2 outlines the hydraulic analysis for flooding originating from Yarriambiack Creek with Section 6.3 discusses the stormwater flooding due to the local catchment rainfall.

6.2 Yarriambiack Creek

6.2.1 Model Structure

Warracknabeal

The basis of the two dimensional model is the topographic grid which is based on the aerial photogrammetry and field survey. A 5m grid has been employed in Warracknabeal and is illustrated in Figure 6-1.

The bridge crossings at Jamouneau Street and Borung Highway were modelled as MIKE 11 structures and dynamically coupled with the two dimensional model. Head loss through the bridges could therefore be modelled explicitly within the model. It was assumed that the pedestrian bridges would provide minimal head loss and were therefore neglected. The weir at the Rainbow Road Bridge was modelled as an open cell section based on the terrestrial survey data.

Beulah

Similarly, a 5m grid was employed in Beulah, based on the DTM discussed in Section 3.3.4. Figure 6-2 displays the hydraulic model topographic for Beulah.

For Beulah the following two MIKE 11 structures were dynamically linked to the MIKE21 two dimensional domain:

- Weir Gates downstream – a set of 5 x 900mm culverts
- Culverts under Birchip Rainbow Road – a set of 4 x 1200mm

6.2.2 Design Flood Modelling

Design flood levels and inundation extent were determined using the MIKEFLOOD model for the 20, 50, 100, 200 year and PMF events. The design inflow hydrographs for Yarriambiack Creek as determined by the hydrologic analysis were used as model inflow boundary conditions.

Table 6-1 and Table 6-2 display the peak design flood levels just at the Warracknabeal Weir and the Rainbow Road Crossing in Beulah respectively.

Table 6-1 Predicted Design Flood Levels in Yarriambiack Creek at Warracknabeal Weir Flood Gauge

Design flood event ARI (years)	Depth (m)	Surface elevation (m AHD)
10	2.41	108.22
20	2.67	108.47
50	2.86	108.66
100	2.90	108.70
200	2.92	108.72

Table 6-2 Predicted Design Flood Levels in Yarriambiack Creek at Rainbow Road (Beulah) Flood Gauge

Design flood event ARI (years)	Depth (m)	Surface elevation (m AHD)
10	1.07	85.86
20	1.11	85.90
50	1.15	85.95
100	1.20	86.00
200	1.21	86.02

Flood inundation maps for Warracknabeal and Beulah are collated in the flood map atlas.

6.2.3 Discussion

As discussed in Section 6.2.2, the flood behaviour in Warracknabeal is predominately controlled by the weir at Rainbow Road. Flood inundation is generally limited to the creek corridor for the events considered by this study. Minor breakouts from the creek occur in the 20 year ARI event adjacent to the weir on the western bank. This breakout leads to minor backwater flooding alongside Craig Avenue. Further, minor breakouts area occur near the corner of Symes and Craig Avenues. The 50 year ARI event experiences more minor breakouts along the length of the creek with considerably more backflow experienced from the western side of the weir pool Subsequent breakouts are experienced for the 100y ARI on the eastern side of Herron island allowing water into the main section of town.

Formal calibration of the hydraulic model for Warracknabeal is limited by the absence of systematic concurrent streamflow and flood level information. The study team undertook board validation of the modelled design flood extents through community consultation and a comparison to flood photos. General community agreement with the modelled design flood extents was achieved.

In Beulah, for the range of flood events considered by this study, limited flooding occurs in the residential areas. In the 50 year ARI event and greater events, a minor breakouts at the Rainbow Road. This breakouts continues east along Bell Street then turn to north near Phillips Street, and flows to the stormwater storage at Lascelles Street. Further, a breakout from the weir pool occurs between Gladstone and Lalor Street. This breakout flows to the north east towards Gladstone Street.

The hydraulic analysis confirms the community perception that the upstream and downstream weir structures in Beulah control the flood behaviour.

Further, the hydraulic analysis showed for the 10 year flood a break out to the south of township, across the Henty highway and under the railway. This breakouts inundates agricultural land to the east of the Henty highway and continues flowing to the north across the Birchip – Rainbow Road. Given the nature of the terrain, north of the Birchup Road and east of the Henty Highway, the breakout flows would return to Yarriambiack Creek adjacent to the current grain bunkers. However, due to the absence of culverts under the railway, the breakout flow is contained to the east of the railway.

As for Warracknabeal, in Beulah the potential formal calibration of the hydraulic model is limited. The study team, again, undertook board validation of the modelled design flood extents through community consultation and a comparison to flood photos. General community agreement with the modelled design flood extents was achieved.

The study team acknowledges considerable uncertainty surrounds the reliability of the flood extents for both Warracknabeal and Beulah.

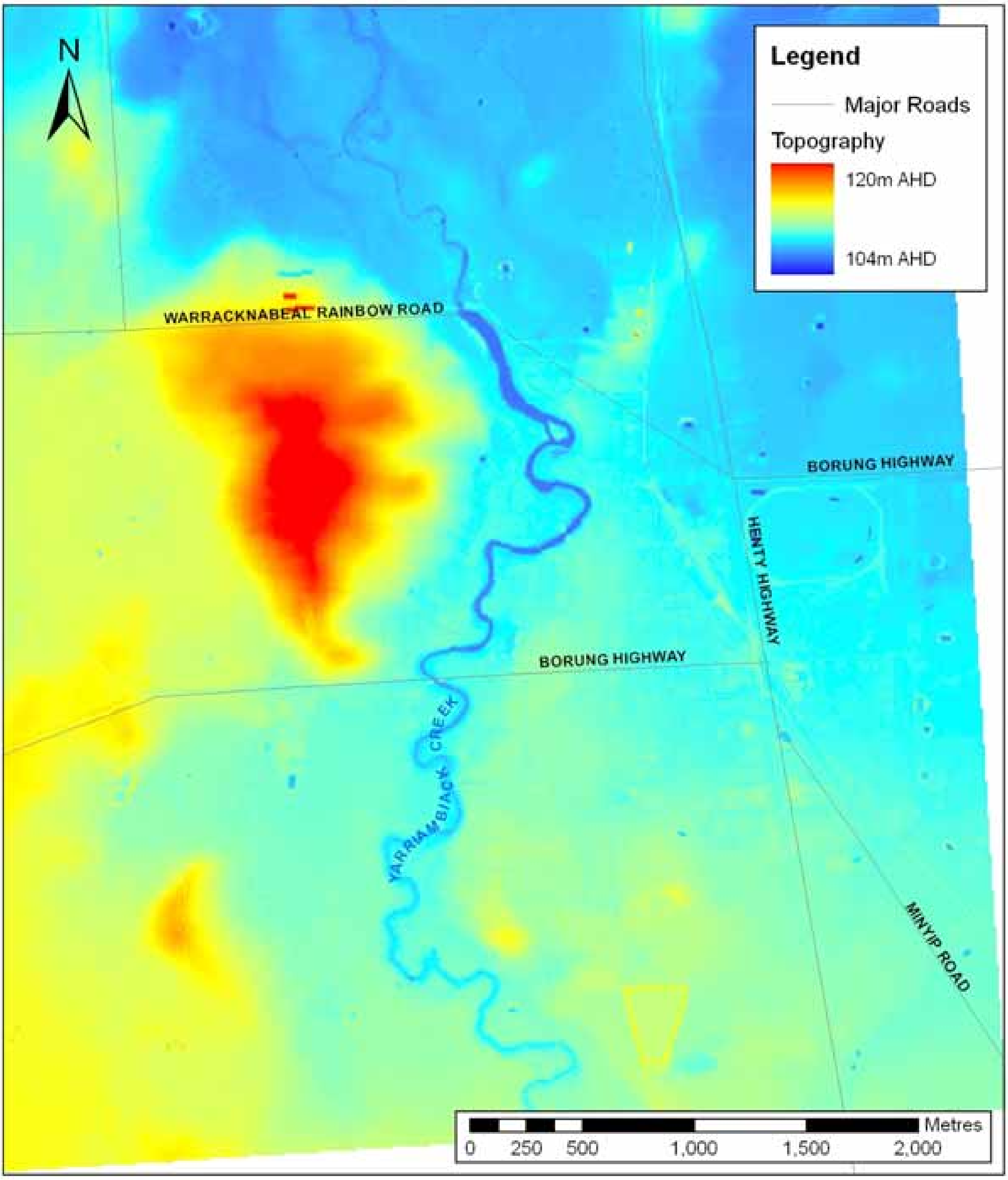

Figure 6-1 Warracknabeal - Hydraulic Model Topographic Grid

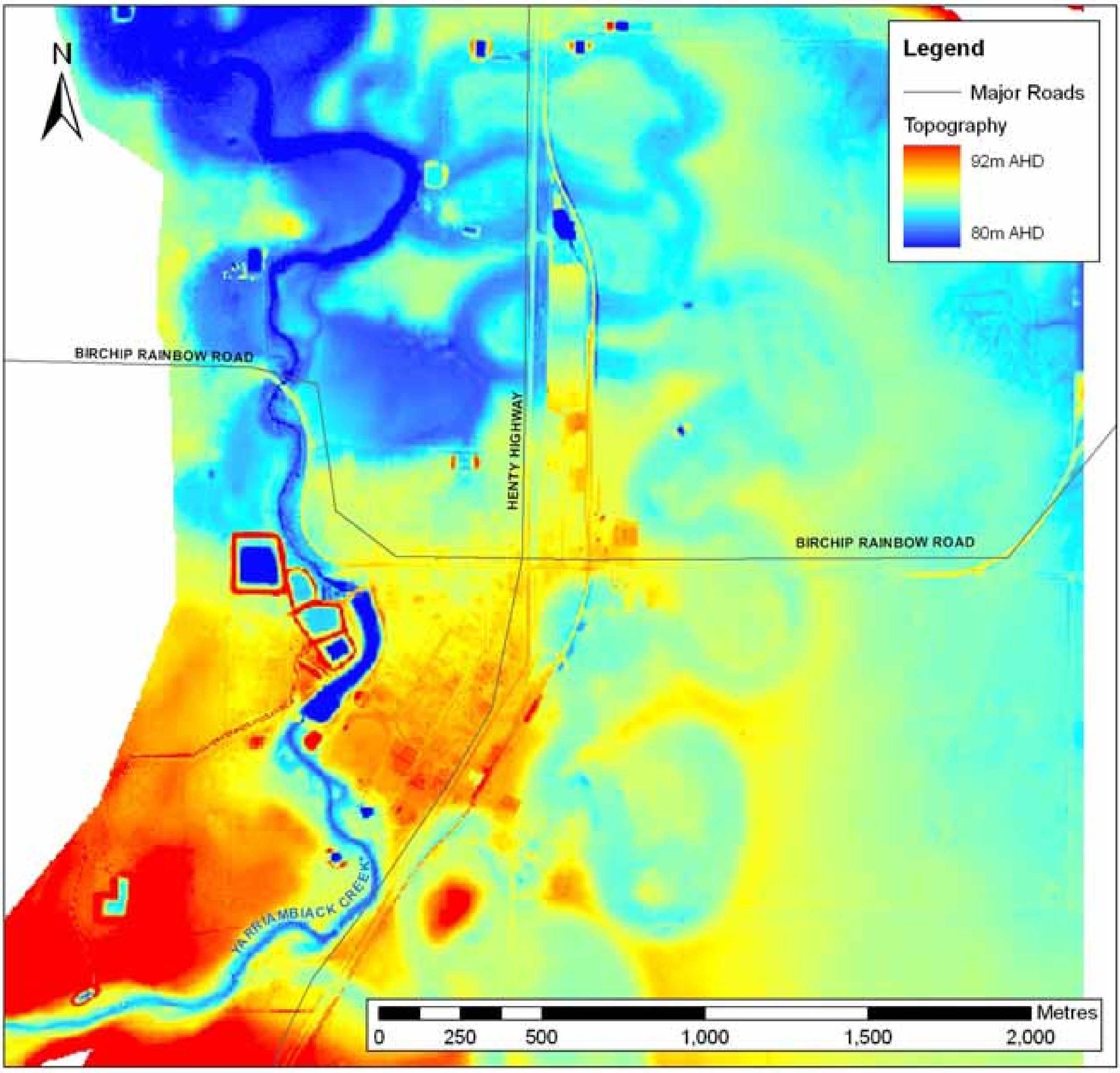

Figure 6-2 Beulah - Hydraulic Model Topographic Grid

6.3 Stormwater flooding

6.3.1 Background

Through the consultation phase of this study, local stormwater flooding was put forward as a significant flooding risk. To simulate these conditions, the hydraulic analysis was modified to enable the analysis of local rainfall stormwater flooding. The Wimmera CMA requested the study team assess the flood behaviour for the 100 year local flooding event.

6.3.2 Model structure

Warracknabeal

Discussions with community members and Yarriambiack Shire Council officers suggested that runoff from the local catchment to the south east (Whitton Swamp) contributed to stormwater flooding in Warracknabeal.

A hydraulic analysis, using MIKEFLOOD, was undertaken for the entire Whitton Swamp catchment. A preliminary hydraulic analysis revealed limited runoff enters the township along the Henty Highway from the Whitton Swamp catchment. The significant proportion of the Whitton Swamp catchment runoff flows overland on the eastern side of the Henty Highway towards the racecourse.

Beulah

Discussions with Yarriambiack Shire Council officers suggested that local flooding in Beulah arises from runoff generated within the township i.e. no contributing from the surrounding land.

Using the DEM, as discussed in Section , a hydraulic model (MIKEFLOOD) based on 5 m grid was developed.

6.3.3 Design rainfall determination

The design rainfall depths were obtained for Warracknabeal and Beulah respectively from the application of the IFD procedures in Australian Rainfall and Runoff (IEAust 1999).Table 6-3 displays the IFD parameters applied.

Table 6-3 Design Rainfall parameters

Geographic Coordinates		***Log Normal Intensities***	
36.272	142.383	1 hour 2 year	17.9768
Geographical Factors		12 hour 2 year	3.0002
Skew	0.1612	72 hour 2 year	0.7884
F2	4.3924	1 hour 50 year	39.1663
F50	14.8911	12 hour 50 year	6.2802
		72 hour 50 year	1.5904

The design temporal patterns for Zone 2, outlined in Australian Rainfall and Runoff (IEAust 1999), were applied.

The net design rainfall was determined by applying an initial loss of 15 mm and continuing loss of 3 mm/hour. For a range of storm durations, Table 6-4 displays the net design rainfall depths (i.e after rainfall losses).

Table 6-4 Design 100 year local rainfall excess

Storm duration (hours)	Rainfall excess (mm)
	Warracknabeal/Beulah
3	49
4.5	52
6	50
9	51
12	56
18	47
24	44
36	27

The application of the above rainfall losses results in the 12 hour storm duration yielding the greatest rainfall excess. As a result, the 12 hour storm duration was adopted for the stormwater flooding analysis for both Warracknabeal and Beulah.

6.3.4 Stormwater drainage infrastructure

Warracknabeal

A plan showing the nature of drainage infrastructure (pipes) was obtained from Yarriambiack Shire Council. As the pipe network primarily contained relatively small pipe diameters, the pipe network was not included in the hydraulic model.

A pump station, located at Anzac Park (Scott and Gardiner Streets), drains the adjacent area to Yarriambiack Creek via a pipe along Gardiner Street. The pump station was considered of sufficient capacity to include in the hydraulic model. Limited information was available for the pump station and pump capacity was estimated at $0.7m^3/s$.

Culverts located under the railway line and the Henty Highway adjacent to the Railway Station and Kelsall Street, were included in the hydraulic model. The inclusion of these culverts enabled the overland flows from the township into the showgrounds/racecourse area.

Beulah

Limited underground drainage infrastructure has been constructed in Beulah. Given the limited nature of the drainage infrastructure, for this study, the drainage infrastructure has not been incorporated into the hydraulic analysis.

6.3.5 Design local flooding modelling

The rainfall excess from the 100 year 12 hour design storm was applied as direct rainfall in the MIKEFLOOD model for both Warracknabeal and Beulah.

The use of the MIKEFLOOD model in this manner allows the determination of overland flowpaths and ponding areas arising from local runoff.

The 100 year flood extents, depths, elevations were mapped, and are provided in the accompanying flood map atlas.

6.3.6 Discussion

Warracknabeal

The local flooding analysis revealed significant ponding of stormwater runoff along Tarrant Street adjacent to the Warracknabeal Railway Station. This ponding affects properties in the area bounded by Tarrant, Woolcock, and Molyneaux Streets. Insufficient drainage across the railway in this area contributes to this ponding.

Further ponding occurs in the residential area bounded by Woolcock, Thomas, Franklin and Molyneaux Streets. The flat nature of this area hampers the capacity of drainage infrastructure.

To the west of Yarriambiack Creek, overland runoff from the area adjacent to the Hospital, collects to an overland flow path beginning near the corner of Watson and Gould Streets. This overland flowpath continues in north east direction, near Woobine Street, across Tobruk Avenue, along Coral and Calaredon Avenues. Again, the flat nature of this area hampers the capacity of drainage infrastructure.

The study team recommends the Yarriambiack Shire consider investigate potential measure to reduce the local flooding impacts, particularly adjacent to the Railway Station.

Beulah

Some limited ponding occurs in the area bounded by Bell, Phillips, Gladstone and Dingwell Streets. This ponding appears to resulted from the raised road crest along Bell Street. Improved drainage under Bell Street is likely to reduce the ponding extent. From Bell Street, a small overland flow path continues north to the stormwater drainage dam located at Lascelles Street.

Further, limited ponding occurs in the area bounded by Tavernor, Phillips, Lalor and Deakin Streets.

The study team recommends the Yarriambiack Shire consider investigate potential measures to improve drainage under Bell Street.

7 FLOOD DAMAGE ASSESSMENT

7.1 Overview

A flood damages assessment has been undertaken for the study area under existing conditions. The flood assessment determined the monetary flood damages for design flood hydrographs as determined by the hydrologic and hydraulic models. The AAD was also determined as part of the flood damage assessment.

Damages from flooding can be sub-divided into a number of categories. Figure 7-1 shows the various categories commonly used in flood damage assessments.

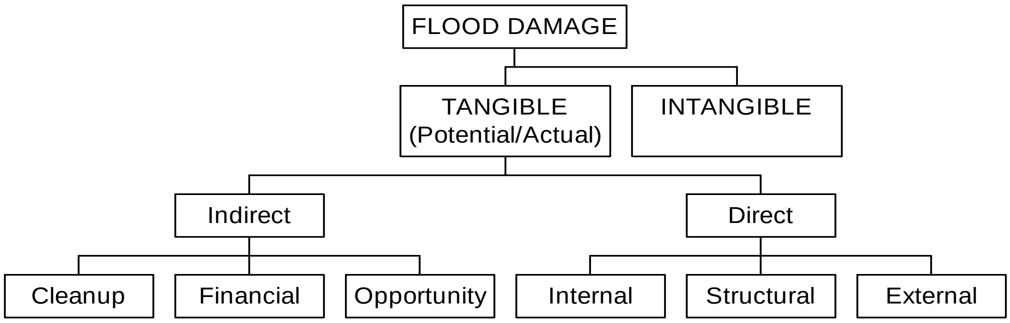

Figure 7-1 Flood Damage Categories

Tangible flood damages are those to which a monetary value can be assigned and include property damages, business losses and recovery costs. Intangible flood damages are those to which a monetary value cannot be assigned and include anxiety, inconvenience and disruption of social activities. Both are a function of flood magnitude. This flood damages assessment focuses on the tangible flood damages. Intangible damages are important but have not been directly accounted for in this flood damage assessment.

Tangible damages can be sub-divided into direct and indirect damages. Direct damages are those financial costs caused by the physical contact of flood waters and include damage to property, roads and infrastructure.

Property damages can be sub-divided into internal and external damages. Internal damages include damage to carpets, furniture and electrical goods. External damages include damages to building structures, vehicles and in rural areas, crops, fencing and machinery.

Tangible direct damages are further defined as either potential or actual damages. Potential damages are the maximum damages that could occur for a given flood event. In determining potential damages, it is assumed that no actions are taken (whether months or hours) prior to or during the flood to reduce damage by, for example, lifting or shifting items to flood free locations, shifting motor vehicles or sandbagging. Actual damages are the expected damages for a given flood event, allowing for some degree of community flood damage control. The actual damage is calculated as a proportion of the potential damage, based on the community's flood preparedness, a function of community awareness and the lead-time of flood warnings.

Indirect damages are those additional financial costs generally incurred after the flood during clean-up and include the cost of temporary accommodation, loss of wages, loss of production for commercial and industrial establishments and the opportunity loss caused by the closure or limited operation of business and public facilities. Indirect damages are often extremely hard to estimate.

The remainder of this section details the input data required and the methodology adopted for this flood damage assessment.

7.2 Available Information

This section outlines the range of information utilised within the flood risk assessment including property and floor level data, infrastructure data and flood data.

7.2.1 Property and Floor Level Data

The following property data were collected for 54 buildings in Beulah and 701 buildings in Warracknabeal:

- Building location:- property address (Street Number and Street Address) and ground coordinates.
- Building type:- urban and rural residential, commercial, industrial and public
- Property damage or value class:- intended to represent dwellings of respectively poor, normal or excellent value. Reflects value of contents value, construction quality.
- Ground and floor levels: ground and floor level data including location (i.e. coordinates)

A standard medium value class was adopted for all residential and commercial properties in Violet Town for the flood damage assessment.

7.2.2 Infrastructure Data

For this study, as detailed in the report '*Rapid Appraisal Method (RAM) for Floodplain Management*' (NRE, 2000), total damage to infrastructure was based on the length of road infrastructure inundated. NRE (2000) considers this assumption reasonable, as much of the service infrastructure follows the paths of road reserves and the quantity of other infrastructure might be expected to be broadly a function of the length of road. Damage to bridges is also incorporated into the NRE (2000) infrastructure damage cost estimates.

Road were identified using the cadastral information supplied by Yarriambiack Shire Council and by inspection of aerial photos.

7.2.3 Flood Data

The hydraulic analysis provides a regular grid of flood elevations and flood depths for both Warracknabeal and Beulah study areas. By overlaying the flood elevations and depths onto the property data, a flood level can be assigned to each flood affected building, similarly lengths of road inundated can easily be calculated. The 10, 20, 50, 100 and 200 year ARI design floods were assessed in this study, with a 5 year ARI flood assumed to result in no significant flood damage cost.

7.3 Approach

The flood damage assessment was based on the RAM (NRE, 2000) and current best practice. The Bureau of Transport Economics report '*Economic Costs of Natural Disasters in Australia*' (BTE, 2001), provides an excellent source of information regarding methodology and cost estimates for flood damage assessments.

The flood damage assessment first estimated costs associated with direct flood damage (e.g. structural building, contents, external property, and infrastructure damage), then considered the costs associated with indirect flood impacts (e.g. emergency services, clean-up costs, alternative accommodation costs).

7.3.1 Direct Flood Damage

Property Damage

For each property in the study area it was first decided if the building was inundated above floor level or below floor level by querying the design flood depths and the floor level from the property survey. Adjusted ANUFLOOD (Smith & Greenway, 1992) stage-damage curves were then applied to each property for above floor flooding and an adjusted stage-damage curve from report '*Floodplain Management in Australia'* (DPIE, 1992), was used for properties with below floor flooding.

The ANUFLOOD stage-damage curves were factored up by 60% to bring them up to a 1999 flood damage cost level as recommended by the RAM (NRE, 2000). The ANUFLOOD stage-damage curves were further adjusted by a Building Price Index (BPI) ratio up to 2004 and by Consumer Price Index (CPI) ratio to June 2005 (BPI was not available for 2005), to bring them all up to a June 2005 flood damage cost level. There are a total of three residential ANUFLOOD stage-damage curves (small, medium and large houses) and fifteen commercial ANUFLOOD stage-damage curves (small, medium and large buildings of value class from one to five).

In this study, properties that contain buildings have been designated either residential medium value or commercial medium value. Essentially, all non-residential properties are designated as commercial, irrespective of their use, so that shops, Council premises and light industry etc. are assigned the same flood-depth to damage curve. The medium value residential damage curves have been adopted for residential properties and the medium value class two commercial damage curves have been adopted for commercial properties. The survey team used to collect this data were experienced in these types of surveys and categorised the majority of the buildings as medium quality. It is recognised that this approach is an approximation, but is considered appropriate given the lack of individual and detailed building size, age, use, value and quality information.

The DPIE stage-damage curve for external damages was factored up using a ratio of the 2004 and 1992 BPI, and a ratio of the June 2005 and 2004 CPI to bring the curve up to a June 2005 flood damage cost level. Note that there is no distinction between residential and commercial external damages. It was found that many of the properties inundated below floor level were only partly inundated. The flood damage cost was reduced by the ratio of the flooded area and the property area.

The stage-damage curves used in this study are displayed in Figure 7-2.

The stage-damage curves were applied to each inundated property and the costs summed to calculate the total direct potential flood damage cost.

The total direct potential flood damage cost is the cost that would be incurred if no mitigation measures are taken prior to or during a flood. In reality communities generally have some degree of warning, and particularly if a community has had previous flood experience, may reduce the effect of the flood significantly. Measures such as evacuation, doorstep sandbagging or the removal of valuable items to a safe level above flood waters have the potential to reduce the flood damage cost. Warracknabeal and Beulah residents are considered an inexperienced community. Further, recent dry conditions along Yarrianbiack Creek (no flow since 1996) community awareness of flooding has reduced. A potential to actual direct flood damage reduction factor from RAM (NRE, 2000) of 0.7 was adopted. This conservatively assumes that the community has no flood experience and have greater than 12 hours warning time, as shown in Figure 7-3.

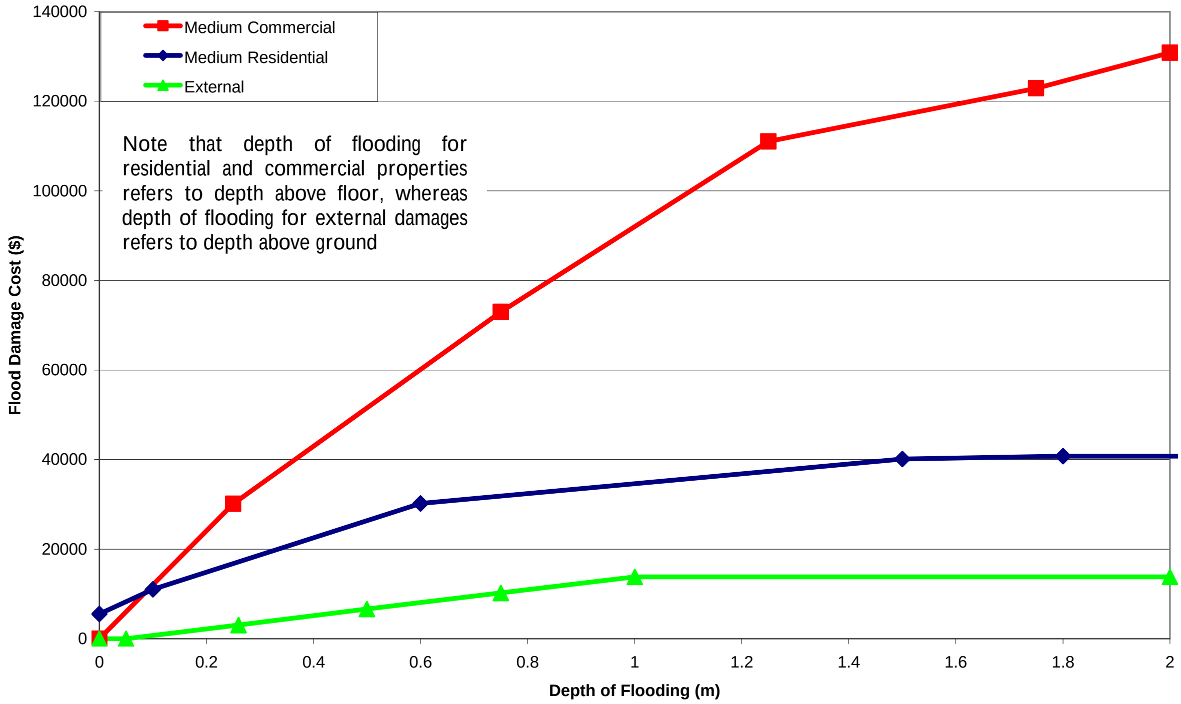

Figure 7-2 Adopted Stage-Damage Curves for Residential, Commercial and External Flooding

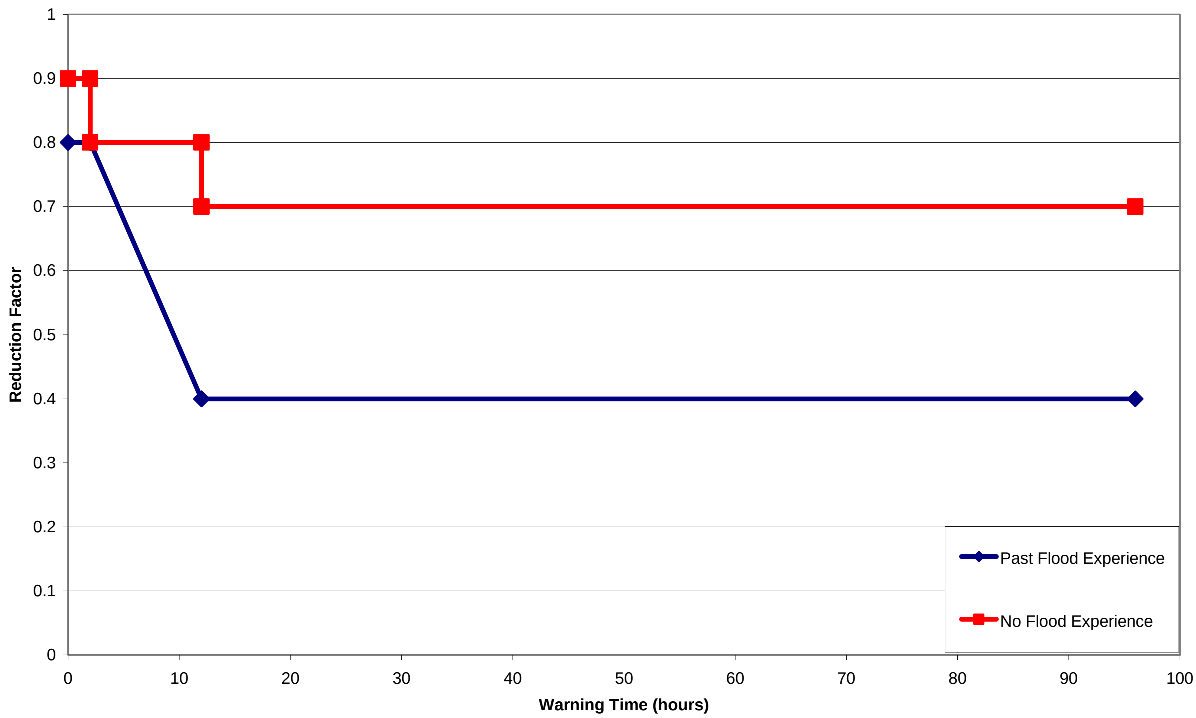

Figure 7-3 Reduction Factor Curves for Potential to Actual Direct Damage Ratio

Infrastructure Damage

Damage to infrastructure includes street and road repairs (including restoration of weakened subgrades), bridge repairs, telephone and telecommunications facilities, electrical connections, water supply and sewerage infrastructure and resulting higher maintenance costs.

For this study, as detailed in the RAM (NRE, 2000), total damage to infrastructure was based on the length of road infrastructure inundated. NRE (2000) considers this assumption reasonable, as much of the service infrastructure follows the paths of road reserves and the quantity of other infrastructure might be expected to be broadly a function of the length of road. Damage to bridges is also incorporated into the NRE (2000) infrastructure damage cost estimates by an approximation of damage to bridges per km of road inundated.

While it is appreciated that using the length of road inundated as the primary measure of total damage to infrastructure is a coarse approximation, it is considered reasonable, as it is the best estimate that we have due to lack of data and as it is only a small portion of the total damage cost.

Roads are subdivided into three categories in NRE (2000) – highway, sealed road and unsealed road. Roads inundated were identified as sealed roads from cadastral information supplied by Yarriambiack Shire Council and by inspection of aerial photos.

The length of road inundated for the design flood events was calculated. The RAM (NRE, 2000) estimates of $10,000 per km for initial road repairs, $5,000 per km for road accelerated deterioration and $3,500 per km of road for bridge repairs were adjusted by a Consumer Price Index (CPI) ratio for 1999 to June 2005, to bring them all up to a June 2005 flood damage cost level. The adopted flood damage rates for infrastructure are shown in Table 7-1. The length of inundated road for each design flood event was then multiplied by the adopted flood damage rates.

Table 7-1 Adopted Infrastructure Flood Damage Rates

Infrastructure	Flood Damage Rates (per km of road inundated)
Initial Road Repairs	**$12,147**
Accelerated Road Deterioration	**$6,073**
Bridge Repairs and Maintenance	**$4,251**
Total	**$22,471**

Estimates adopted from BTE (2001) and adjusted to a June 2005 cost level by a ratio of CPI.

7.3.2 Agricultural damages

The hydraulic analysis for Beulah showed extensive flooding occurs on agricultural land to the east of the Henty Highway. Predominantly this land is under dry land board acre farming. NRE (2000) damage estimates for a range of crops based on the timing of the flooding and the flooding duration.

Lengthy, greater than a week, inundation is likely adjacent to Beulah given the nature of the flood behaviour. NRE (2000) provides a range of damage estimates, depending on the timing of flooding, from $55 in May to $217 in December per hectare for dry land board acre crops. Historically flooding along Yarriambiack Creek as predominantly occurred in August through to October. This study adopts the October damage estimate of $171 per hectare.

Further, NRE (2000) provides a clean cost estimate for board acre crop in low velocity flood events of $10 per hectare.

This study applies a $181 per hectare to estimate agricultural damages.

7.3.3 Indirect Flood Damage

Indirect flood damages are damages incurred as a consequence of a flood but are not due to the direct impact of the flood itself (e.g. emergency services, clean-up costs, alternative accommodation, lost business opportunity, etc.). Indirect damages are extremely hard to estimate and are often calculated by assuming they equal 30% of the total actual direct flood damage cost (including damage to properties and infrastructure), as in the RAM (NRE, 2000), however it is recommended that this be revised to best suit population density. BTE (2001) suggests adopting a more rigorous approach, and provide estimates on the cost of post flood clean-up, relocation and emergency response actions. BTE (2001) suggest that post flood residential clean-up may cost approximately $330 for materials and approximately 160 hours in labour (an average weekly wage of $1,008 for May 2005 was adopted from the Bureau of Statistics website). The total commercial clean-up was estimated as $2,400 for inundated properties (BTE, 2001). It was assumed that for external damages (below floor flooding) that the indirect damage cost was equal to one weeks labour. BTE (2001) estimates the cost of residential relocation per property as $53 per house for relocation of household goods and $26 per person per night for alternative accommodation (assuming an average of 2.6 people per household from Bureau of Statistics, and a requirement of seven nights accommodation). BTE (2001) also suggest that volunteer emergency response costs be considered and that estimates of volunteer hours be made. It has been assumed for this study that for the 100, 50 and 20 year ARI design flood events that 50, 40 and 30 volunteers respectively worked for fifteen hours (assuming average weekly wage above). The BTE (2001) cost estimates were based on figures from 1999, they were adjusted by a ratio of CPI for 1999 to June 2005.

To put all these figures into perspective, when applying the above indirect flood damage estimates to each design event it works out that the total indirect flood damage cost is approximately 43% of the total actual direct flood damage cost for the 100 year ARI event and approximately 37% for the 20 year ARI event. This is perhaps higher than the recommended 30% as suggested in the RAM (NRE, 2000). The above indirect flood damage rates are deemed to provide a good estimate of indirect flood damage costs. The BTE (2001) estimates are adopted in this study.

Table 7-2 Adopted Indirect Flood Damage Rates

Indirect Flood Damage Item	Flood Damage Rates
Residential Clean-up Costs	
- **Materials**	**$401 per household (1)**
- **Labour**	**$4,032 per household (1,2)**
Commercial Clean-up Costs	
- **Total**	**$2,915 per building (1)**
Below Floor Flooding Clean-up Costs	
- **Total**	**$1,008 per property (3)**
Residential Relocation Costs	
- **Relocation of household items**	**$64 per household (1)**
- **Alternative accommodation**	**$575 per household (1,4)**
Emergency Response Costs	
- **100 year ARI**	**$18,902 (5)**
- **50 year ARI**	**$15,122 (5)**
- **20 year ARI**	**$11,341 (5)**

1 Estimate adopted from BTE (2001) and adjusted to a June 2005 cost level by a ratio of CPI.

2 Residential labour cost based on 160 hours of labour and an average weekly wage of $1,008.

3 Below floor flooding cost based on one weeks labour and an average weekly wage of $1,008.

4 Alternative accommodation cost assumes an average of 2.6 people per household at $32 per night for 7 nights.

5. Emergency response costs assume that for the 100, 50 and 20 year ARI event that 50, 40 and 30 volunteers respectively worked for 15 hours each at an average weekly wage of $1,008.

7.3.4 Total Flood Damage

The total flood damage cost was calculated as the sum of the direct actual property flood damage cost the direct infrastructure flood damage cost and the indirect flood damage cost.

The Average Annual Damage (AAD) was also calculated. The AAD is a measure of the flood damage per year averaged over an extended period. It is calculated by the area under the flood frequency and total flood damage curve. It assumes that no flood damage is incurred at the 5 year ARI flood event, and considers floods up to the 200 year ARI event. The flood damage assessment was conducted for the 10, 20, 50, 100, and 200 year ARI flood events as requested in the project brief.

7.4 Summary

The methodology, as described in Section 7.3, was adopted for this flood risk assessment. The results are summarised in Table 7-3 and Table 7-4 for Warracknabeal and Beulah respectively.

Table 7-3 Warracknabeal Flood Damage Assessment Costs for Existing Conditions

Design flood events ARI (years)	100yr	50yr	20yr	10yr
Properties Flooded Above Floor (total)	79	34	3	0
Properties Flooded Above Floor (residential)	71	29	3	0
Properties Flooded Above Floor (commercial)	8	5	0	0
Properties Flooded Below Floor	279	161	63	4
Total Properties Flooded	**358**	**195**	**66**	**4**
Direct Potential External Damage Cost	$777,986	$333,316	$122,786	$2,589
Direct Potential Residential Damage Cost	$1,093,422	$429,849	$47,631	$0
Direct Potential Commercial Damage Cost	$758,594	$549,660	$0	$0
Total Direct Potential Damage Cost	**$2,630,002**	**$1,312,824**	**$170,417**	**$2,589**
Total Actual Damage Cost	**$1,446,501**	**$722,053**	**$93,729**	**$1,424**
Infrastructure Damage Cost	**$186,936**	**$118,369**	**$52,928**	**$8,098**
Indirect Clean Up Cost	$508,512	$221,218	$42,842	$372
Indirect Residential Relocation Cost	$45,380	$18,535	$1,917	$0
Indirect Emergency Response Cost	$18,902	$15,122	$11,341	$7,561
Total Indirect Cost	**$572,793**	**$254,875**	**$56,100**	**$7,933**
Total Cost	**$2,206,230**	**$1,095,297**	**$202,757**	**$17,455**

The AAD was calculated for Beulah to be approximately **$41,000** per year.

Table 7-4 Beulah Flood Damage Assessment Costs for Existing Conditions

Design flood event (ARI years)	200yr	100yr	50yr	20yr	10yr
Properties Flooded Above Floor (total)	2	2	2	0	0
Properties Flooded Above Floor (residential)	1	1	1	0	0
Properties Flooded Above Floor (commercial)	1	1	1	0	0
Properties Flooded Below Floor	50	50	34	6	3
Total Properties Flooded	**52**	**52**	**36**	**6**	**3**
Direct Potential External Damage Cost	$133,299	$118,478	$60,414	$14,901	$3,099
Direct Potential Residential Damage Cost	$18,393	$17,929	$14,957	$0	$0
Direct Potential Commercial Damage Cost	$10,898	$10,108	$5,304	$0	$0
Total Direct Potential Damage Cost	**$162,589**	**$146,516**	**$80,675**	**$14,901**	**$3,099**
Total Actual Damage Cost	**$89,424**	**$80,584**	**$44,371**	**$8,196**	**$1,705**
Infrastructure Damage Cost	**$86,791**	**$84,323**	**$60,355**	**$17,646**	**$1,646**
Argiculturcal Damages	**$59,429**	**$57,977**	**$50,783**	**$25,599**	**$693**
Indirect Clean Up Cost	$36,065	$34,203	$23,017	$2,624	$392
Indirect Residential Relocation Cost	$639	$639	$639	$0	$0
Indirect Emergency Response Cost	$18,902	$18,902	$15,122	$11,341	$7,561
Total Indirect Cost	**$55,606**	**$53,744**	**$38,778**	**$13,965**	**$7,953**
Total Cost	**$291,250**	**$276,628**	**$194,287**	**$65,407**	**$11,997**

The AAD was calculated for Beulah to be approximately **$9,600** per year.

8 STRUCTURAL MITIGATION MEASURE ASSESSMENT

8.1 Overview

Mitigation measures provide a means to reduce the existing flood risk (AAD). Mitigation measures can reduce existing flood risk by lowering the likelihood of flooding and/or lowering the flood damages (consequences) for a given flood depth. Mitigation measures can be broken into:

- Structural – Physical barriers or works designed to prevent flooding up to a specific design flood standard. Structural measures aim to reduce existing flood risk flood by lowering flood likelihood at a given locations. Structural works include levees, floodways waterway works, improvements to hydraulic structures.
- Non-structural- Management and planning arrangements between relevant authorities designed to reduce related flood damages. Non-structural measures aim to reduce existing flood risk flood by lowering flood damage. Non-structural measures include land use planning, flood warning and flood response

This section deals only with structural mitigation measures. Non-structural measures are discussed in Section 9.

This section provides a preliminary assessment of the potential structural mitigation options identified during the course of this study. The assessment has been undertaken through the use of the hydraulic model and subsequent improved understanding of the flood behaviour in both Warracknabeal and Beulah. This preliminary assessment is aimed at providing a board assessment of the feasibility for a range of mitigation measures.

Structural mitigation options were selected for analysis in the hydraulic model based on discussions with Wimmera CMA and Yarriambiack Shire. These options were considered likely to provide the greatest reduction in flood risk and consequence. The analysis of these options does not equate to an endorsement of these options but rather provides a basis from which a future comprehensive floodplain management study could be undertaken considering a greater range of mitigation options available.

8.2 Potential structural mitigation measures for Warracknabeal

The key structure influencing flood behaviour in Warracknabeal is the undershot weir at the Rainbow Road. During previous flood events, this structure consisted of culverts with a number of stop boards located at the culverts' entrance. A gated undershot weir was constructed in 2000. Unfortunately, since the construction of the undershot weir no large flows have occurred to test the effectiveness of this structure during an event. As the key control on flood behaviour, the two identified structural mitigation options centred on increasing flow capacity of the undershot weir.

8.2.1 Option 1 Warracknabeal Weir Enlargement

Currently the undershot weir consists of two 2.5m wide culvert cells with a upstream sluice gate operated manually. This option 1 increases capacity of the undershot weir by providing an additional two 2.5 m wide culverts. The impact of this option on flood behaviour was assessed for the 100 year flood event by the hydraulic model.

Figure 8-1 displays differences in the flood levels for the 100 year flood event due to this option.

8.2.2 Option 2 Rainbow Road culverts

This option increases the flow capacity at the weir by providing culverts under the Rainbow Road to the west of the Yarriambiack Creek. For this option, a 5 m wide culvert was incorporated into the hydraulic model. The initial breakout from the weir pool is experienced on this western bank of Yarriambiack Creek. The impact of this option on flood behaviour was assessed for the 100 year flood event by the hydraulic model. Figure 8-2 displays differences in the flood levels for the 100 year flood event due to this option.

8.2.3 Discussion

As the Warracknabeal Weir is the significant control on flood behaviour, the mitigation options that any increase flow conveyance reduces flood levels and extents. The doubling of conveyance through the weir gates reduced the general surface elevation level by an average of up to 100mm throughout the flooding extent. By the provision of culverts on the western side of the weir pool (Option 2), reductions in flood levels of up to 200mm were experienced.

The study team considers the structural mitigation options investigated by this study do not warranted further investigation. This is due to the limited reduction in flood levels and extents achieved, and the adverse flood related impact due to flow re-direction.

The main point that can be drawn from these mitigation runs is the importance of the operation of the weir gates upon the flooding levels experienced upstream of this point.

The study team recommends that the Yarriambiack Shire and the Wimmera CMA develop formal operating procedures for Warracknabeal Weirs. The adopted operating procedures be incorporated into Flood Sub-plan as an integral part of the Yarriambiack MEMP.

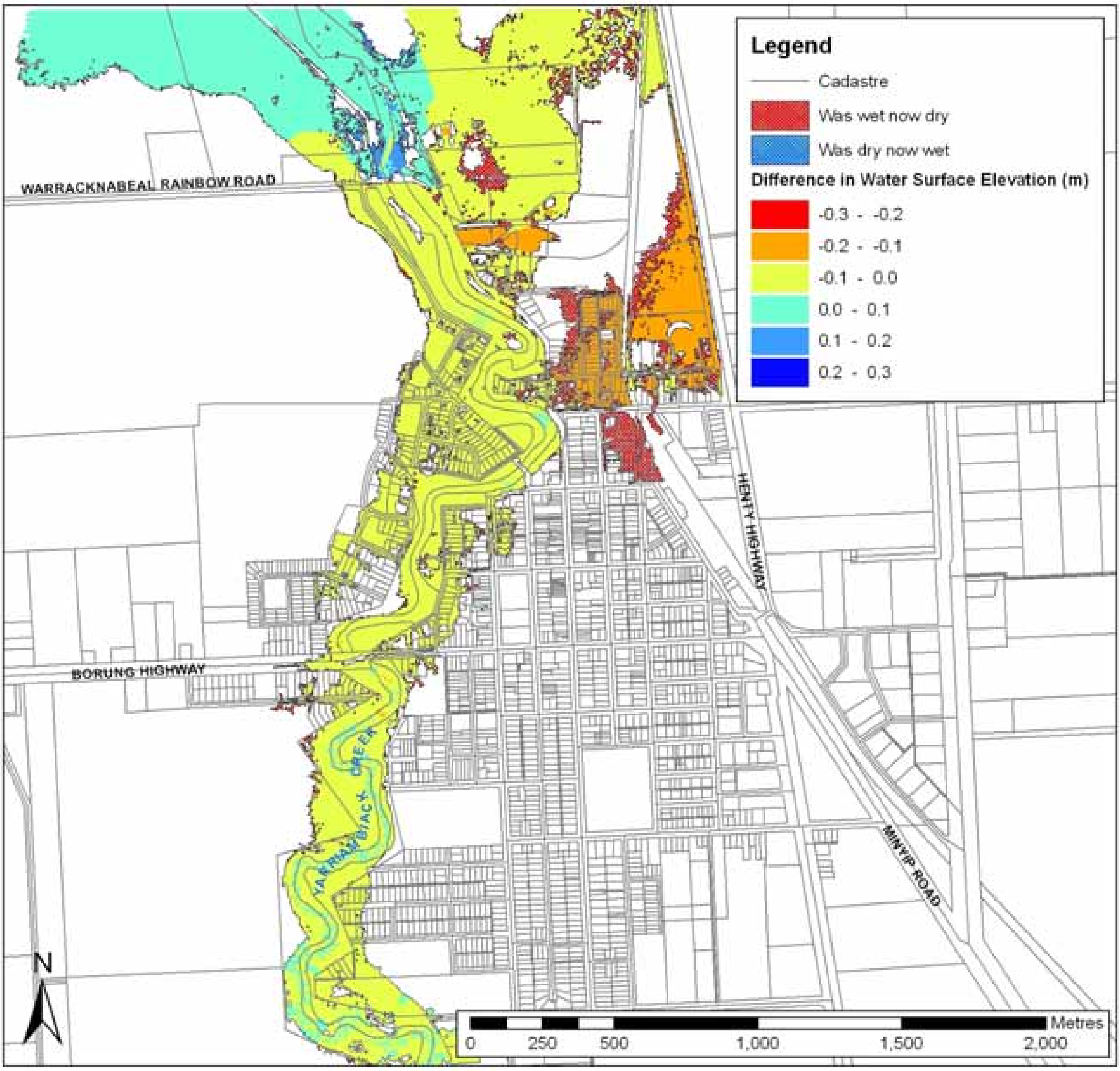

Figure 8-1 Warracknabeal – Mitigation Option 1 – 100 year flood level difference plot

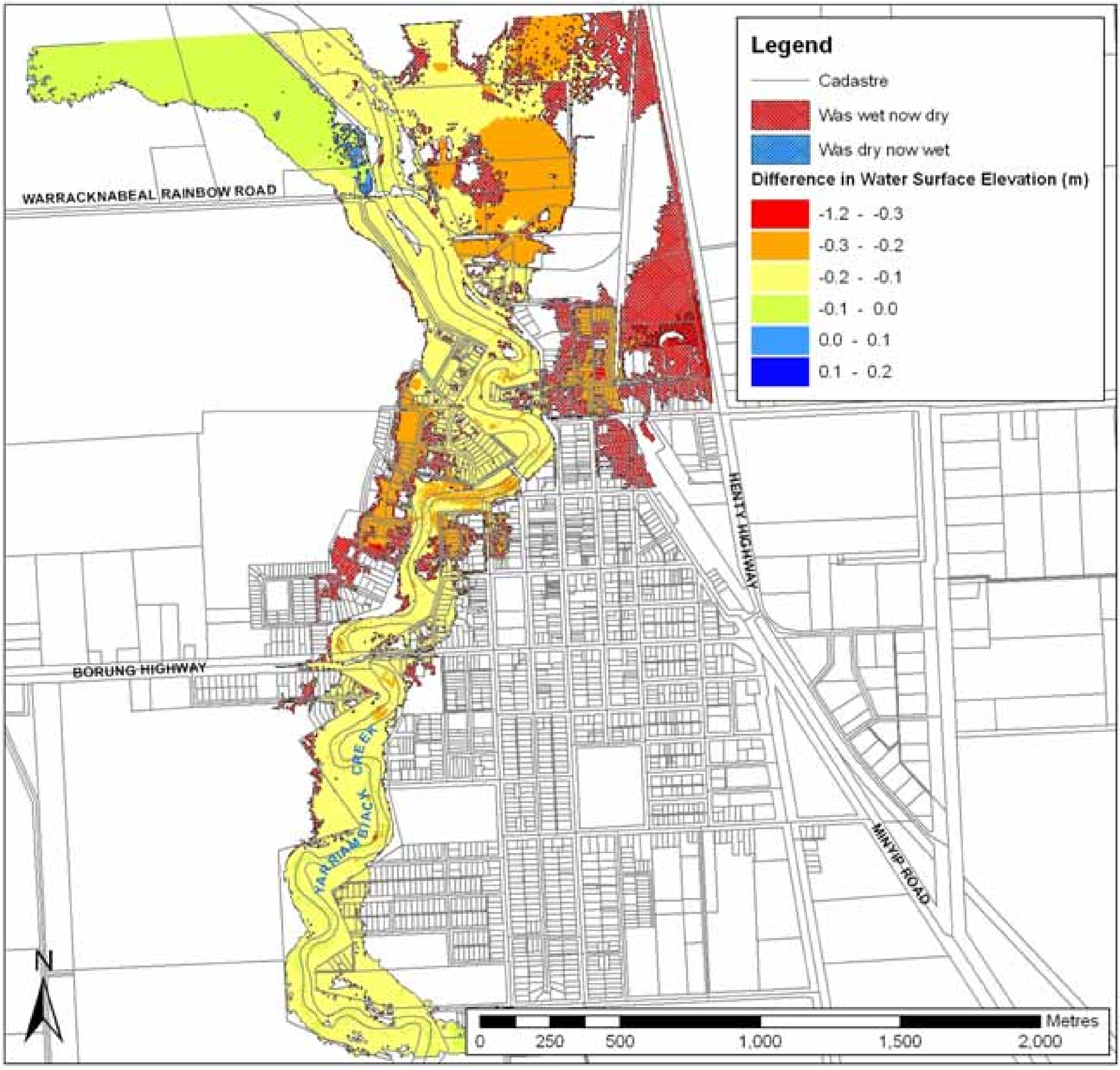

Figure 8-2 Warracknabeal – Mitigation Option 2 – 100 year flood level difference plot

8.3 Potential structural mitigation measures for Beulah

Flood behaviour in Beulah along Yarriambiack Creek primarily influenced by upstream and downstream weir structures. Floodplain flow to the east of Henty Highway is controlled by the set of culverts under the railway track to the south to the township. The potential structural mitigation measures explored investigate the influences of these structures.

8.3.1 Option 1 Upstream Weir Enlargement

The upstream weir consists of a single 5 m wide culvert with an manually operated sluice gate controlling flows. This option 1 increases capacity of the undershot weir by providing an additional two 2.5 m wide culverts. The impact of this option on flood behaviour was assessed for the 100 year flood event by the hydraulic model. Figure 8-3 displays differences in the flood levels for the 100 year flood event due to this option.

8.3.2 Option 2 Henty Highway/Railway culverts to the north of Beulah

This option aims to improve the return overland flow to the Yarriambiack Creek from the eastern side of the railway line. The option consists of a two 2.5 m wide culverts under the railway and Henty Highway north of the bunkers. The impact of this option on flood behaviour was assessed for the 100 year flood event by the hydraulic model. Figure 8-4 displays differences in the flood levels for the 100 year flood event due to this option.

8.3.3 Option 3 Railway culverts to the south of Beulah

Breakouts from Yarriambiack Creek cross the Henty Highway to the south of Beulah. These breakout flows continue through two culverts/bridges under the railway line and inundate land to the east of the railway. The option 3 investigates the impacts on flood behaviour by preventing this inundation to the east of railway by closing the culverts/bridges under the railway line to the south of town. The impact of this option on flood behaviour was assessed for the 100 year flood event by the hydraulic model. Figure 8-5 displays differences in the flood levels for the 100 year flood event due to this option.

8.3.4 Option 4 Upstream Weir and Downstream Weir Enlargement

The option 1 investigated the enlargement of the upstream weir structure. This option follows on from option 1 and assesses the flood behaviour with the downstream weir structure enlarged as well. The upstream weir consists of a single 5 m wide culvert and the downstream weir consists of five 0.9 m pipe culverts. Both structures have an manually operated sluice gate controlling flows. This option increases capacity of the upstream undershot weir by providing an additional two 2.5 m wide culverts and increases the downstream undershot weir by providing an additional five 0.9 m pipe two 2.5 m wide culverts. The impact of this option on flood behaviour was assessed for the 100 year flood event by the hydraulic model. Figure 8-6 displays differences in the flood levels for the 100 year flood event due to this option.

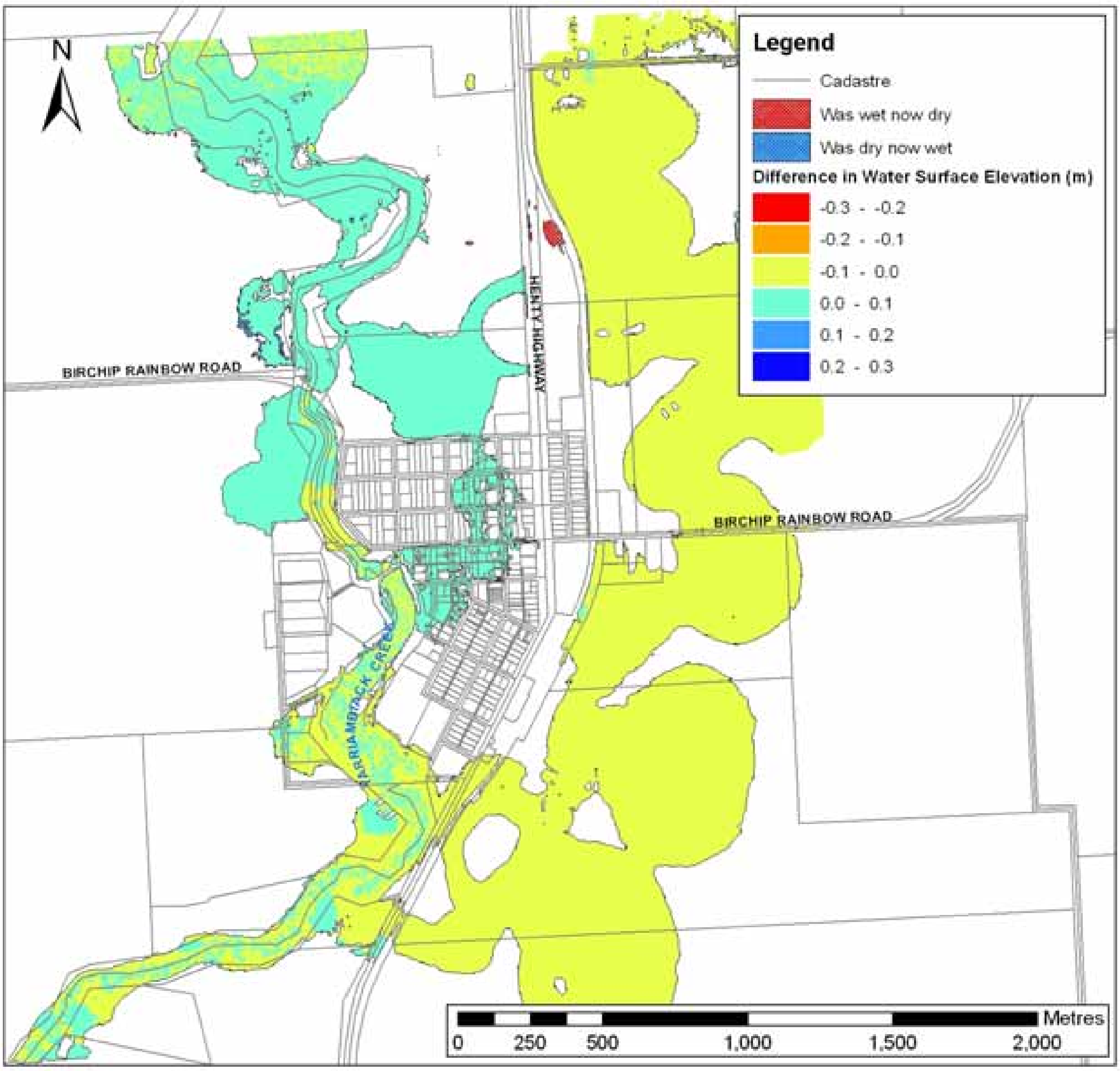

Figure 8-3 Beulah – Mitigation Option 1 – 100 year flood level difference plot

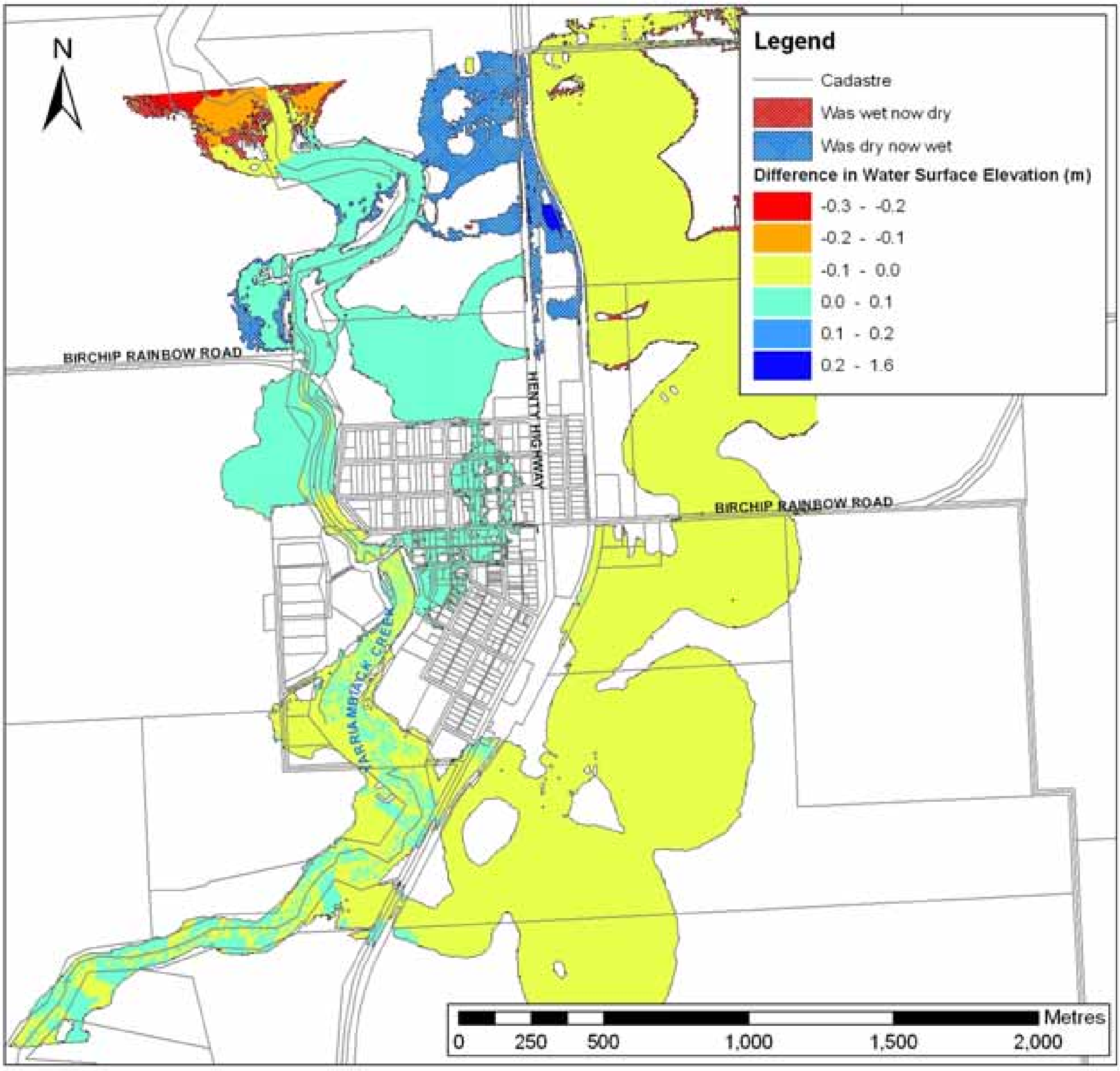

Figure 8-4 Beulah – Mitigation Option 2 – 100 year flood level difference plot

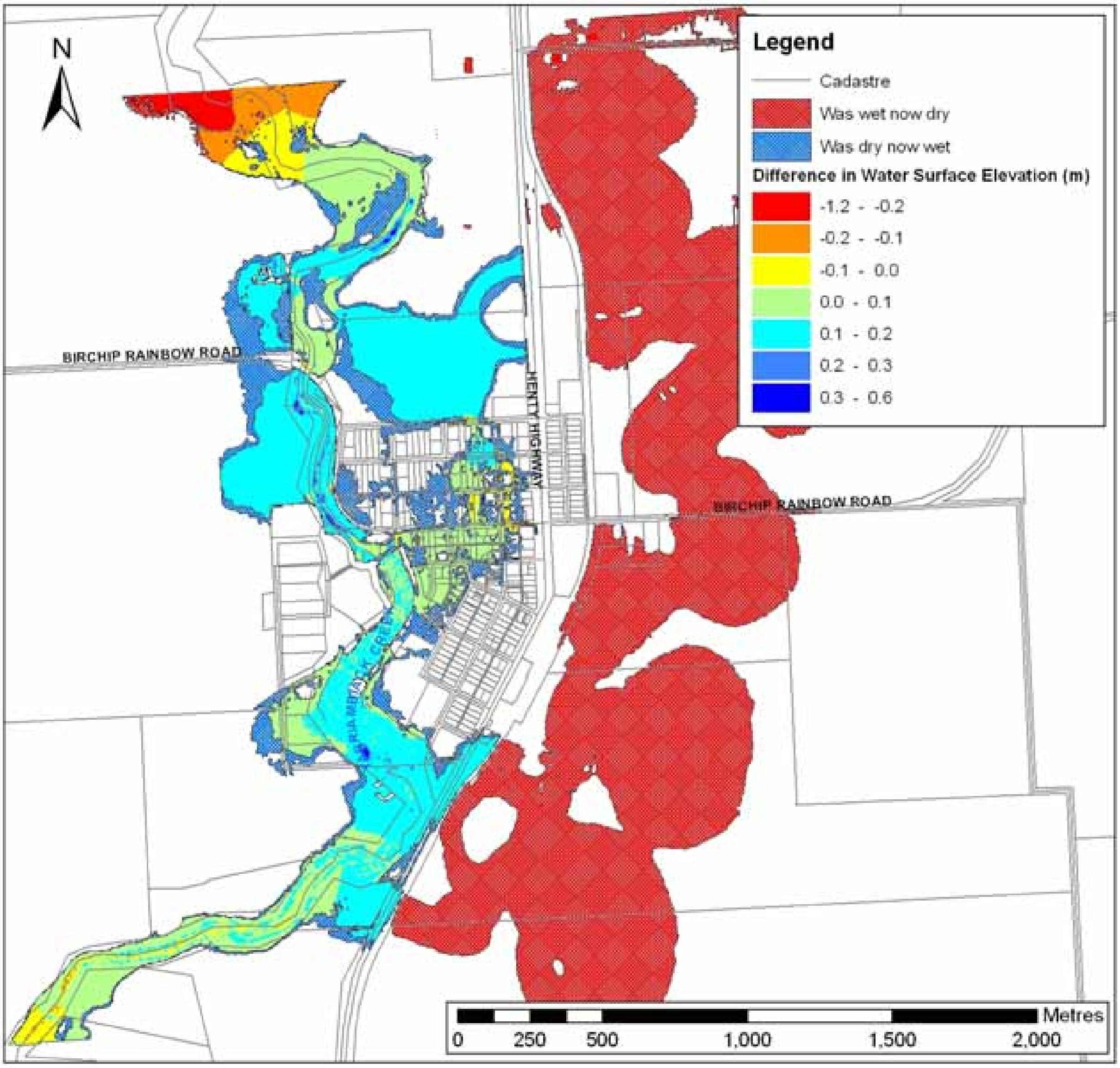

Figure 8-5 Beulah – Mitigation Option 3 – 100 year flood level difference plot

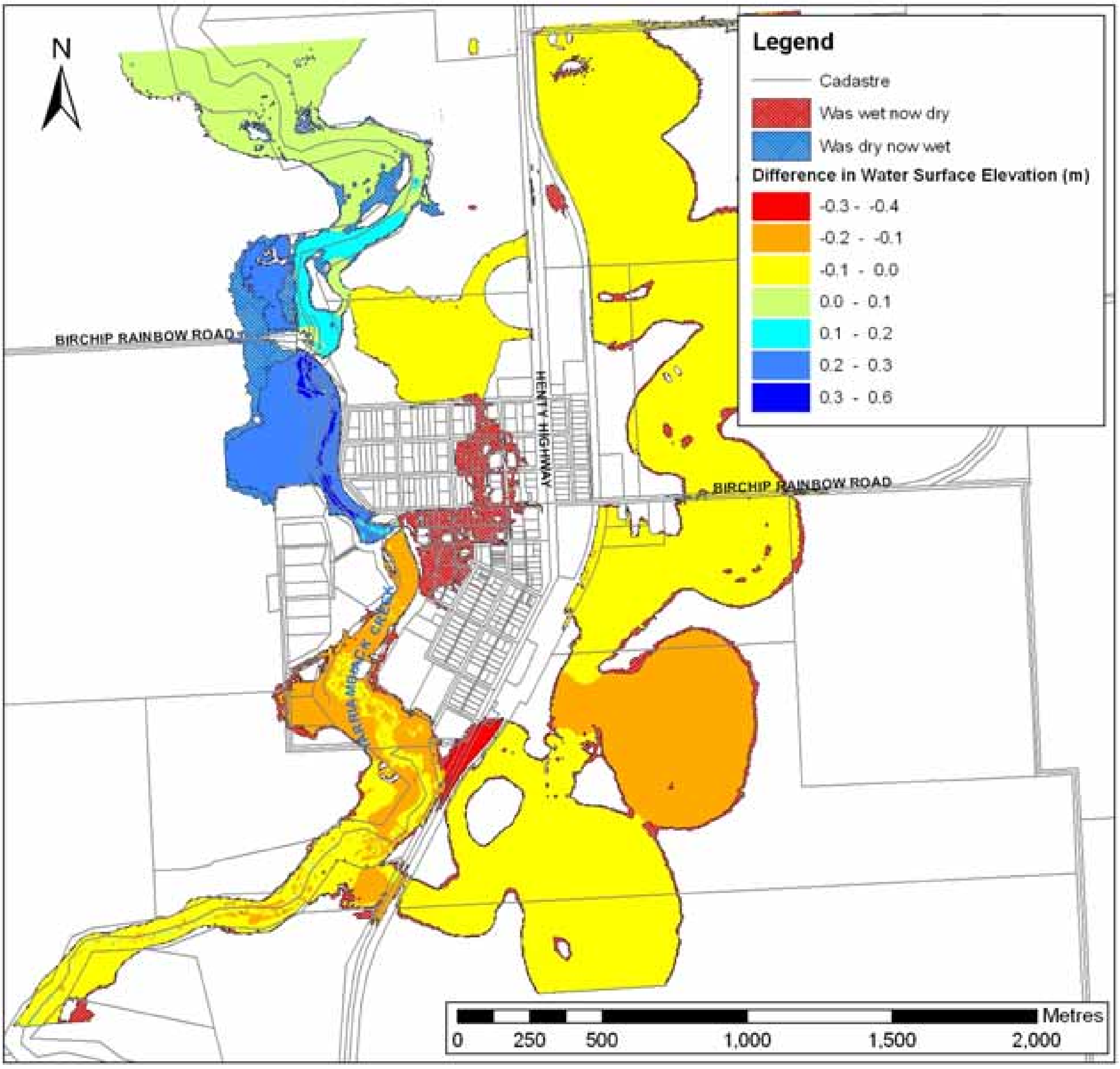

Figure 8-6 Beulah – Mitigation Option 4 – 100 year flood level difference plot

8.3.5 Discussion

Option 1, enlarging the upstream structure, leads to the downstream weir becoming the dominant flow control, setting the level for the weir pool and hence controlling the increased flooding through the town centre. This township flooding is caused through a slightly lower section of the weir pool allowing minor overtopping. Downstream of the weir, the capacity of the culverts crossing the Rainbow-Birchip Road controls flood levels. Some minor flooding is experienced behind the downstream weir and flood flows directed down Gladstone street.

Option 2 explores the significance of returning the secondary flow path to the east of town back to the Yarriambiack Creek, via a set of culverts under the Henty Highway to the north of the Railway Bunkers. Reduction in flood levels up to 100 mm occur the east of the Henty Highway.

Option 3 prevents the flooding of agricultural land to the east of the Henty Highway. However, the re-direction of this break out flow along Yarriambiack Creek leads to increases in flood levels and extents adjacent to the creek corridor. Flood levels for the 100 year event increase up to 100 mm through the residential area along Gladstone and Deakin Streets.

Option 4 prevents inundation through the township of Beulah by cut off the breakouts from the weir pool and just downstream of the weir. Small increases in flood levels and extents occur to the east of the Henty Highway. The increased flow capacity through the weirs reduces the flow attenuation of the weirs. This leads to an increase flood levels downstream of the Rainbow Road.

The study team considers the structural mitigation options investigated by this study do not warranted further investigation. This is due to the limited reduction in flood levels and extents achieved, and the adverse flood related impact due to flow re-direction.

The hydraulic analysis for the existing conditions and for the mitigated measures investigated highlight the influence of the both upstream and downstream weir structures on flood behaviour.

The study team recommends that the Yarriambiack Shire and the Wimmera CMA develop formal operating procedures for the Beulah Upstream and downstream Weirs. The adopted operating procedures be incorporated into Flood Sub-plan as an integral part of the Yarriambiack MEMP.

9 NON-STRUCTURAL MITIGATION MEASURES ASSESSMENT

9.1 Overview

This section discusses a range of non-structural mitigation measures for Warracknabeal and Beulah. As discussed in Section 8.1, non-structural mitigation measures include land use planning, flood warning and flood response.

9.2 Revised flood related provisions and overlays delineation

The current Yarriambiack Shire planning scheme applies Land Subject to Inundation Overlay (LSIO) in both Warracknabeal and Beulah. The LSIO extent is based on the 1 in 100 year ARI flood extent estimated from historical flood information (SKM 2000).

The existing conditions hydraulic analysis, discussed in Section 6, provides a basis the hydraulic basis for a revision of the flood related planning overlays.

In addition to LSIO, the Victorian Planning Provisions (VPP) enable the delineation of the Floodway Overlay (FO). The FO is intended to delineate land subject to higher flood risk. The study team utilised guidelines provided by DNRE (1998b) to investigate possible delineation of FO. The guidelines provide three approaches to the delineation of FO as follows:

- Flood frequency
- Flood depth
- Flood hazard

For **flood frequency**, Appendix A1 of the advisory notes suggest areas which flood frequently and for which the consequences of flooding are moderate or high, should generally be regarded as floodway. The 10 year ARI flood extent was considered an appropriate floodway delineation option for both Warracknabeal and Beulah.

Flood hazard combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 9-1 for delineating the floodway based on flood hazard. The flood hazard for the 1 in 100 year ARI event was considered for this study. Figure 9-1 displays the flood hazard criteria for floodway delineation.

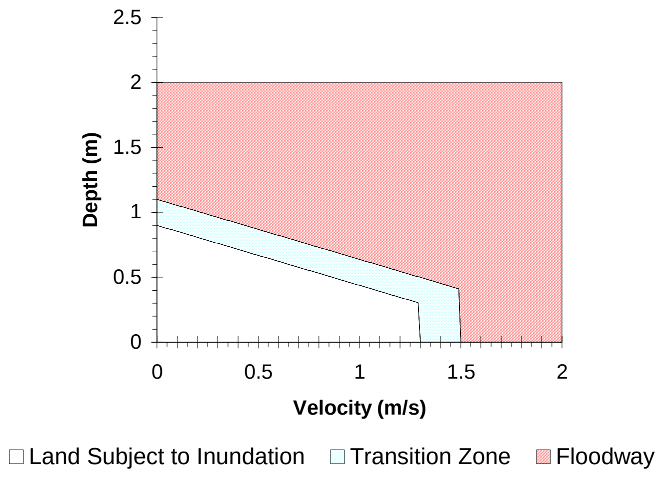

Figure 9-1 Floodway overlay flood hazard criteria

For **flood depth**, regions with a flood depth in the 1 in 100 year ARI event greater than 0.5 m were considered as FO based on the flood depth delineation option.

Figure 9-2 and Figure 9-3 displays possible FO delineation options for consideration by the Wimmera CMA and Yarriambiack Shire. Figure 9-4and Figure 9-5 shows the draft LSIO based on the 1 in 100 year ARI flood extent.

Planning and Environmental Design has prepared a draft amendment for the Yarriambiack Shire planning scheme to enable the revised delineation of the flood related overlays determined by this study. Further, this draft amendment has revised the related provisions. The revised provisions aim to provide a clear and consistent basis of the assessment of development across the Wimmera CMA.

The study team recommends that the Yarriambiack Shire Council adopt all aspects of the draft planning scheme amendment. Further, the study team recommends that Wimmera CMA provide the appropriate assistance to Yarriambiack Shire to enable the timely adoption of the planning scheme amendment.

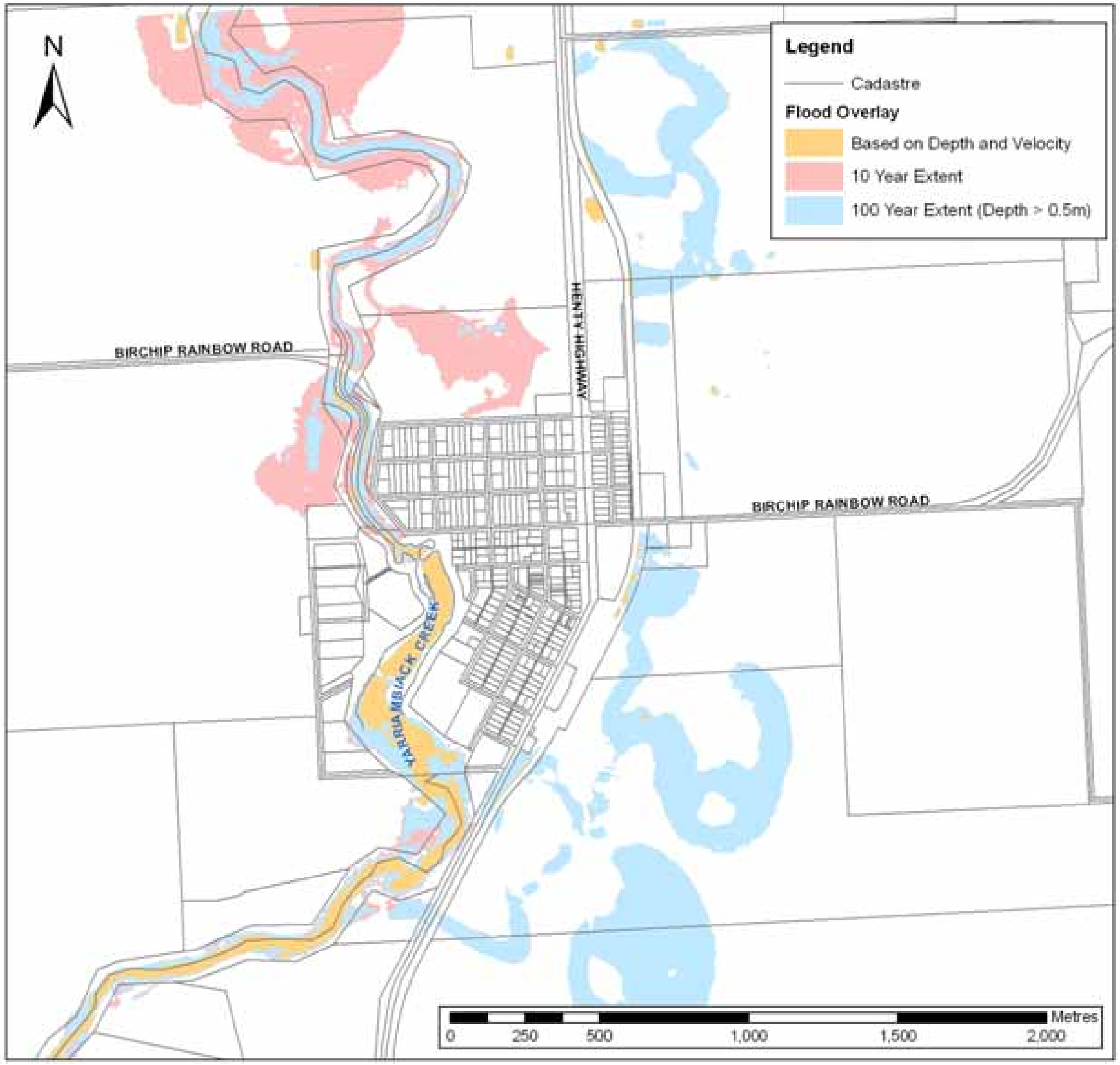

Figure 9-2 Beulah - FO delineation options

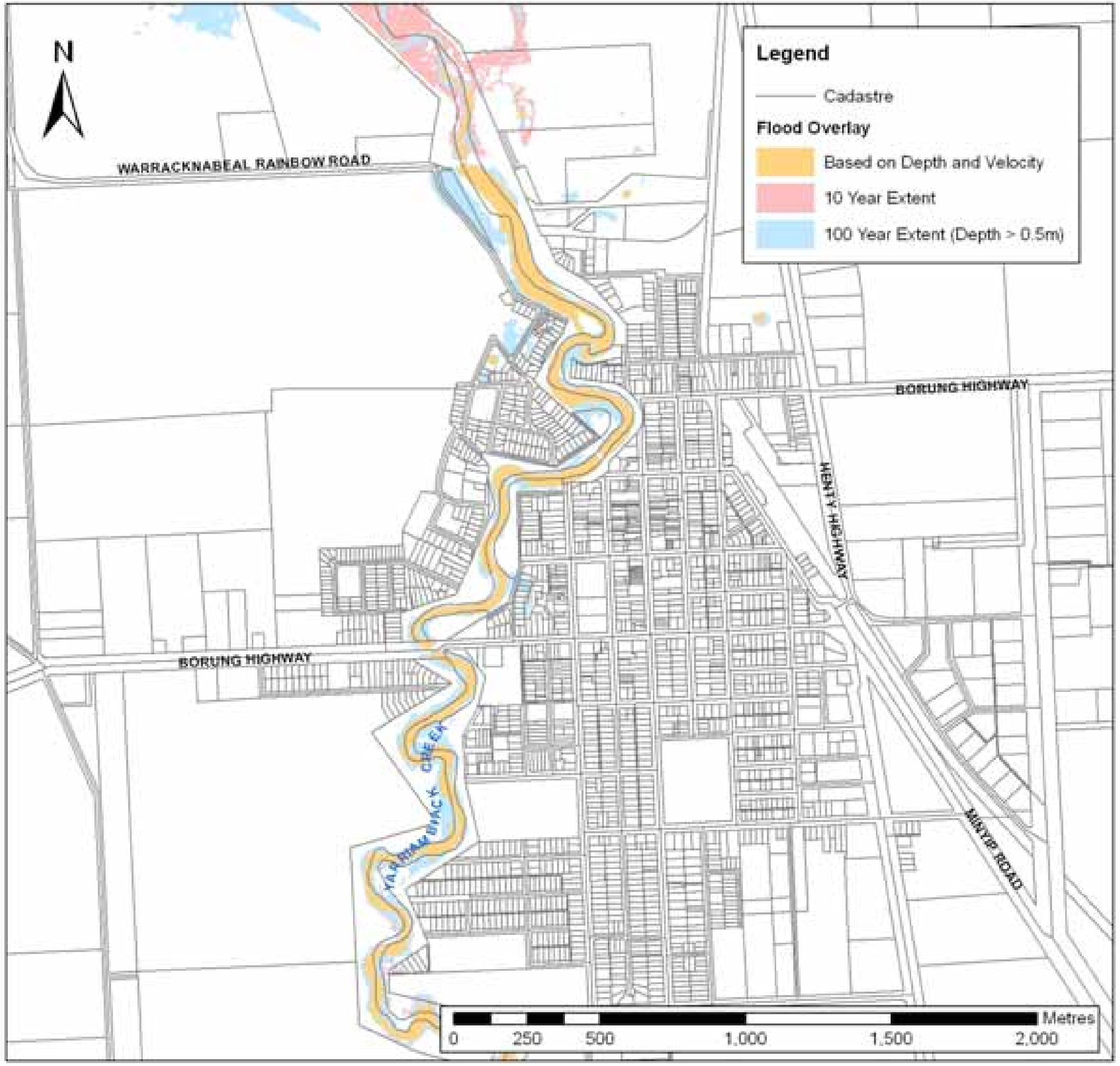

Figure 9-3 Warracknabeal - FO delineation options

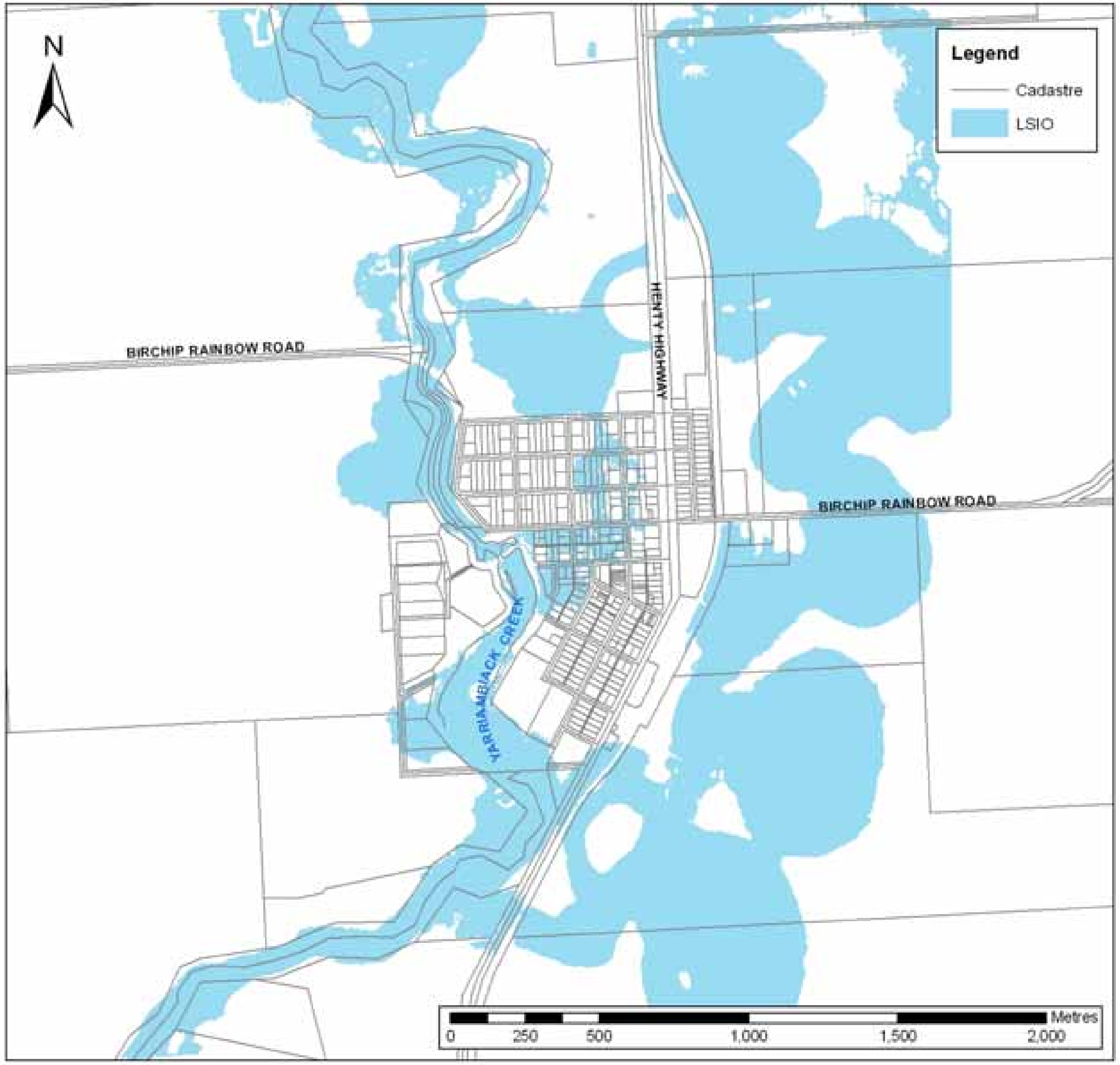

Figure 9-4 Beulah – Draft LSIO delineation

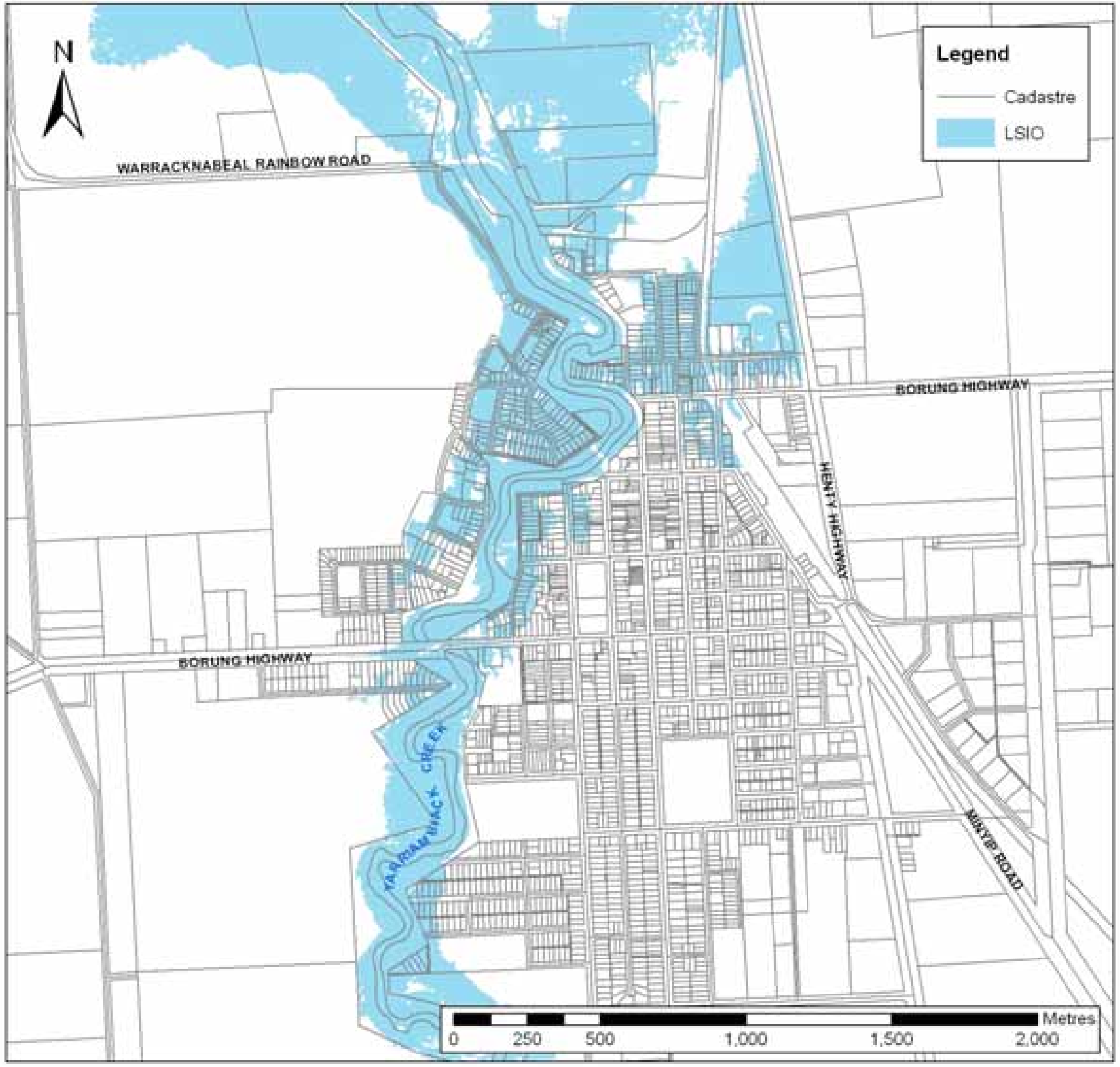

Figure 9-5 Warracknabeal – Draft LSIO delineation

9.3 Flood forecasting and warning

VFWCC (2005) identified flood warning system development priorities throughout Victoria and ranked the Wimmera River catchment second on a list of ten priority catchments.

The study team understands the Wimmera Catchment Management Authority, in conjunction with local authorities in the Wimmera River Catchment, including Yarriambiack Shire, is undertaking a project to address a number of the concerns raised in VFWCC (2005) for the Wimmera Catchment.

The study team recommends that the Yarriambiack Shire Council and the Wimmera Catchment Management Authority continue to actively pursue the completion of the current flood warning related project.

9.4 Flood response

Flood response for Warracknabeal and Beulah is outlined in the Yarriambiack Shire Municipal Emergency Management Plan (MEMP) and the accompanying Flood sub-plan.

A revised Yarriambiack Shire sub-plan has developed by Michael Cawood and Associates, and includes relevant information on local flood behaviour and intelligence from the existing conditions hydraulic analysis.

The study team recommends that the Yarriambiack Shire Council adopt all aspects of the revised Flood Sub-plan as an integral part of the Yarriambiack MEMP. This includes measures aimed at 'keeping the Plan alive' and relevant to the community.

10 STUDY CONCLUSIONS AND RECOMMENDATIONS

This section summaries the conclusions and recommendations arising from this study.

Hydrologic analysis

The study team acknowledges considerable uncertainty surrounding the design flood estimates developed by this study. Rigorous calibration and/or validation of the approach is restricted by the absence of streamflow data. The study team considers, while the absolute reliability of design estimates is unknown, the relativity of design estimates is considered reasonable.

The study team strongly supports the recommendations of Gippel (2006) that improvement in the understanding of Yarriambiack Creek hydrology requires systematic gauging of streamflow along Yarriambiack Creek.

Hydraulic analysis

Formal calibration of the hydraulic model has been limited, given the lack of reliable concurrent streamflow and flood level information. The study team undertook board validation of the modelled design flood extents through community consultation and a comparison to flood photos. General community agreement with the modelled design flood extents was achieved.

The study team acknowledges considerable uncertainty surrounds the reliability of the flood extents for both Warracknabeal and Beulah.

Stormwater drainage

The study team recommends the Yarriambiack Shire consider investigate potential measures to improve drainage under Bell Street, Beulah.

The study team recommends the Yarriambiack Shire consider investigate potential measure to reduce the local flooding impacts, particularly adjacent to the Warracknabeal Railway Station.

Structural mitigation measures

The study team considers the structural mitigation options investigated by this study do not warranted further investigation. This is due to the limited reduction in flood levels and extents achieved, and the adverse flood related impact due to flow re-direction.

Land use planning

The study team recommends that the Yarriambiack Shire Council adopt all aspects of the draft planning scheme amendment. Further, the study team recommends that Wimmera CMA provide the appropriate assistance to Yarriambiack Shire to enable the timely adoption of the planning scheme amendment.

Flood Warning

The study team recommends that the Yarriambiack Shire Council and the Wimmera Catchment Management Authority continue to actively pursue the completion of the current flood warning related project.

Flood Response

The study team recommends that the Yarriambiack Shire Council adopt all aspects of the revised Flood Sub-plan as an integral part of the Yarriambiack MEMP. This includes measures aimed at 'keeping the Plan alive' and relevant to the community.

The study team recommends that the Yarriambiack Shire and the Wimmera CMA develop formal operating procedures for the Beulah upstream and downstream Weirs. The adopted operating procedures be incorporated into Flood Sub-plan as an integral part of the Yarriambiack MEMP.

The study team recommends that the Yarriambiack Shire and the Wimmera CMA develop formal operating procedures for the Warracknabeal Weir. The adopted operating procedures be incorporated into Flood Sub-plan as an integral part of the Yarriambiack MEMP.

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APPENDIX A UPPER WIMMERA DESIGN FLOOD HYDROGRAPHS

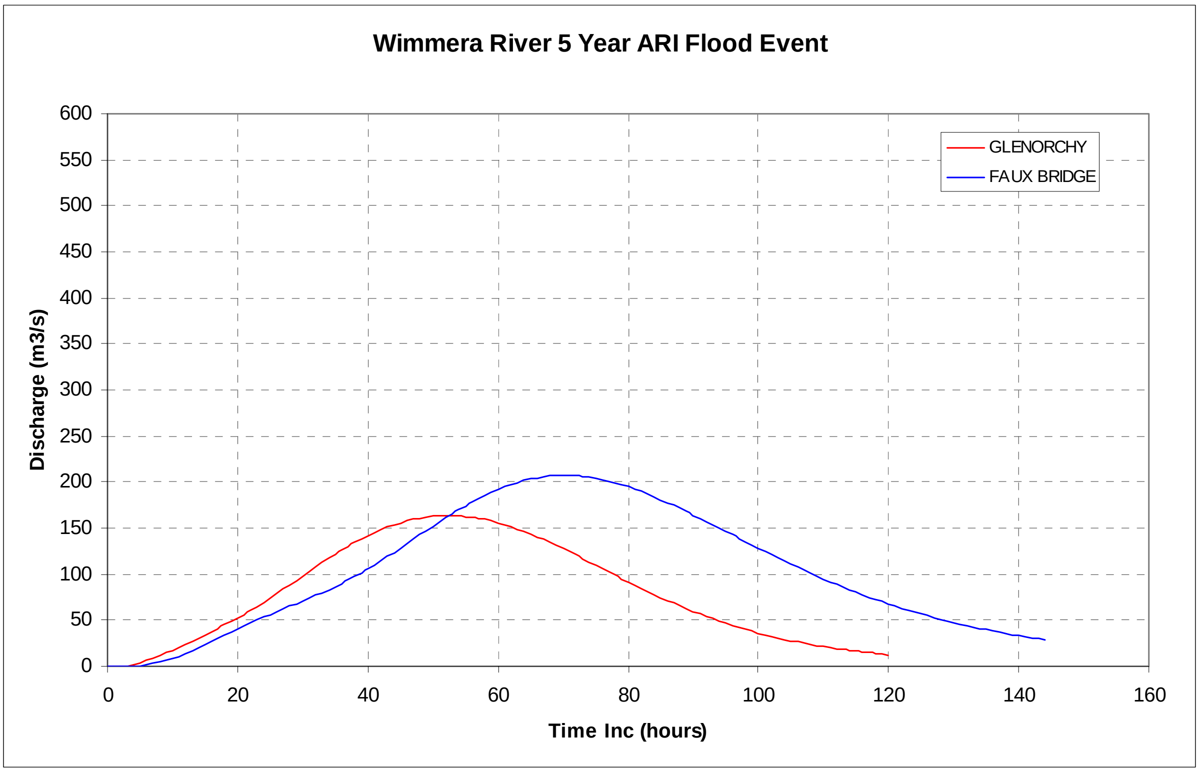

Figure A -1 5 year ARI Design flood hydrographs for the Wimmera River at Glenorchy and Faux Bridge

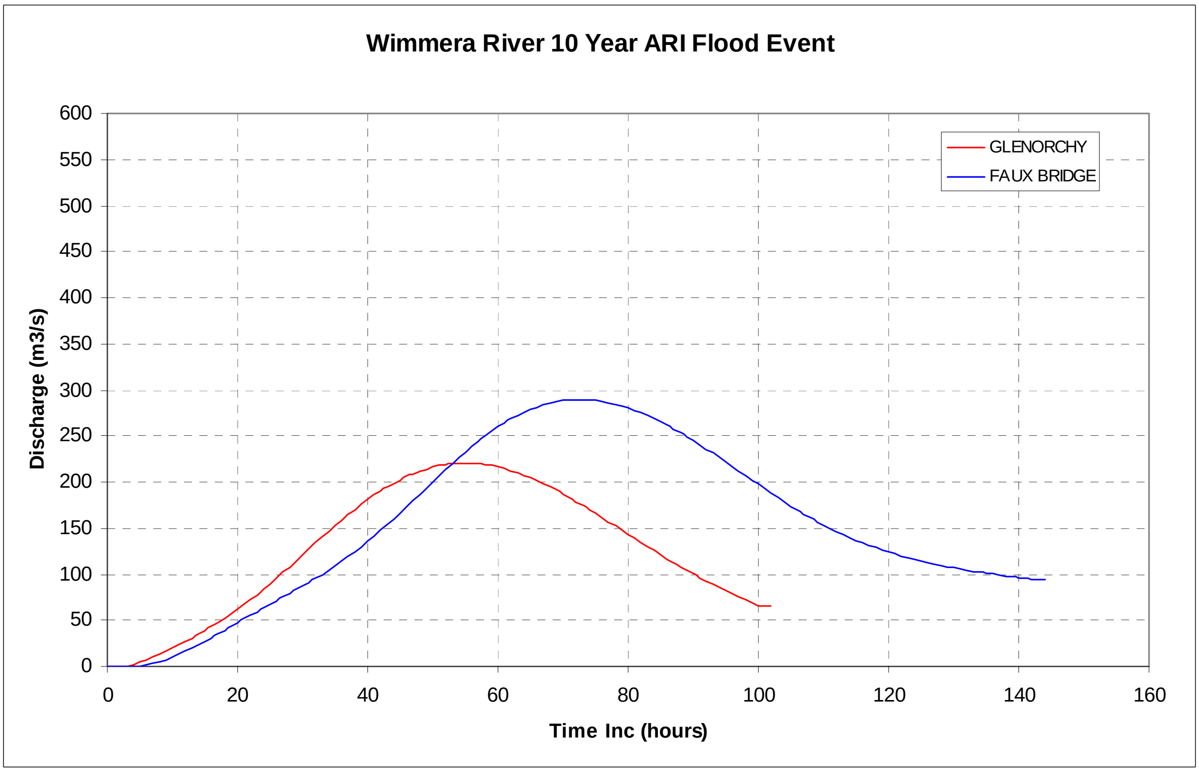

Figure A -2 10 Year ARI Design flood hydrographs for the Wimmera River at Glenorchy and Faux Bridge

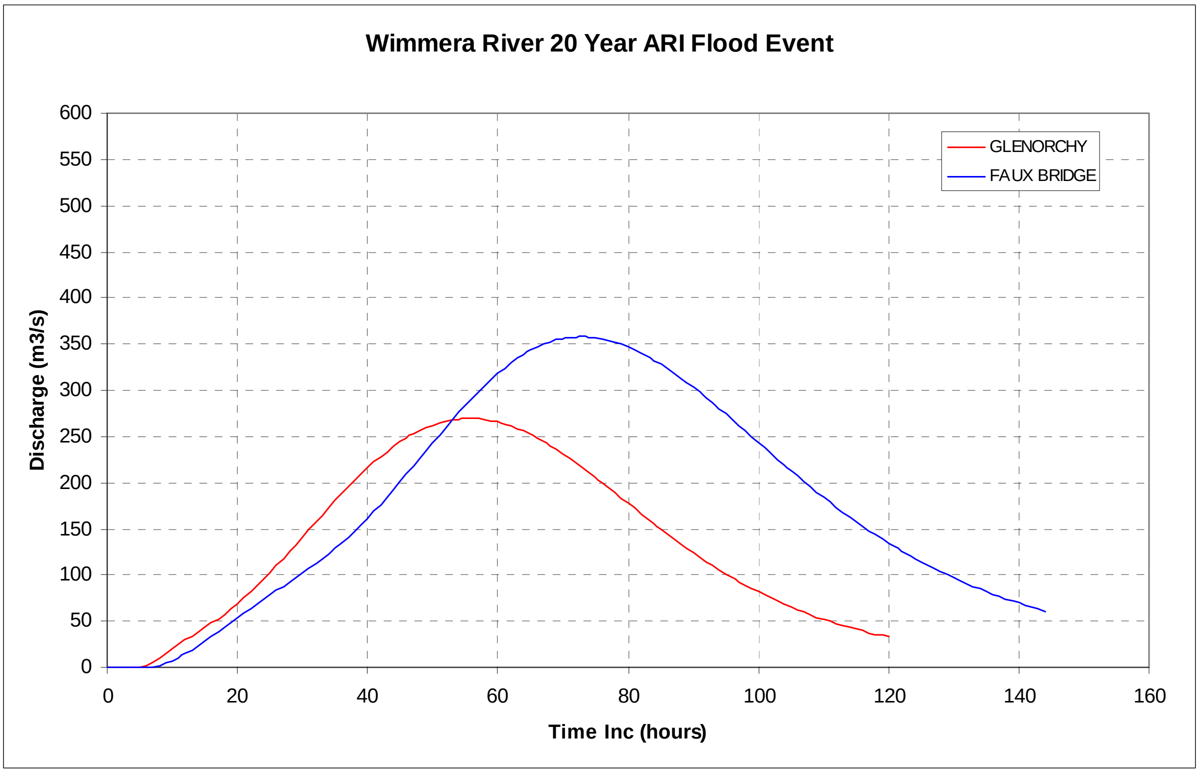

Figure A -3 20 Year ARI Design flood hydrographs for the Wimmera River at Glenorchy and Faux Bridge

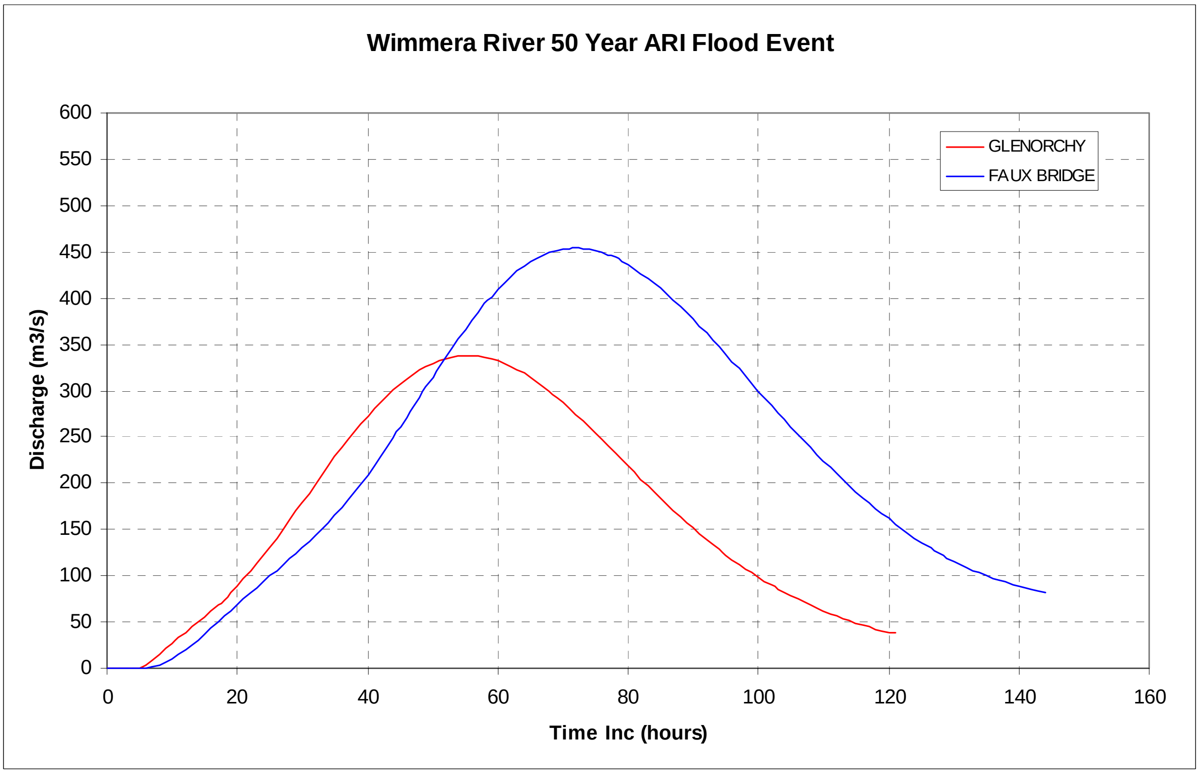

Figure A -4 50 Year ARI Design flood hydrographs for the Wimmera River at Glenorchy and Faux Bridge

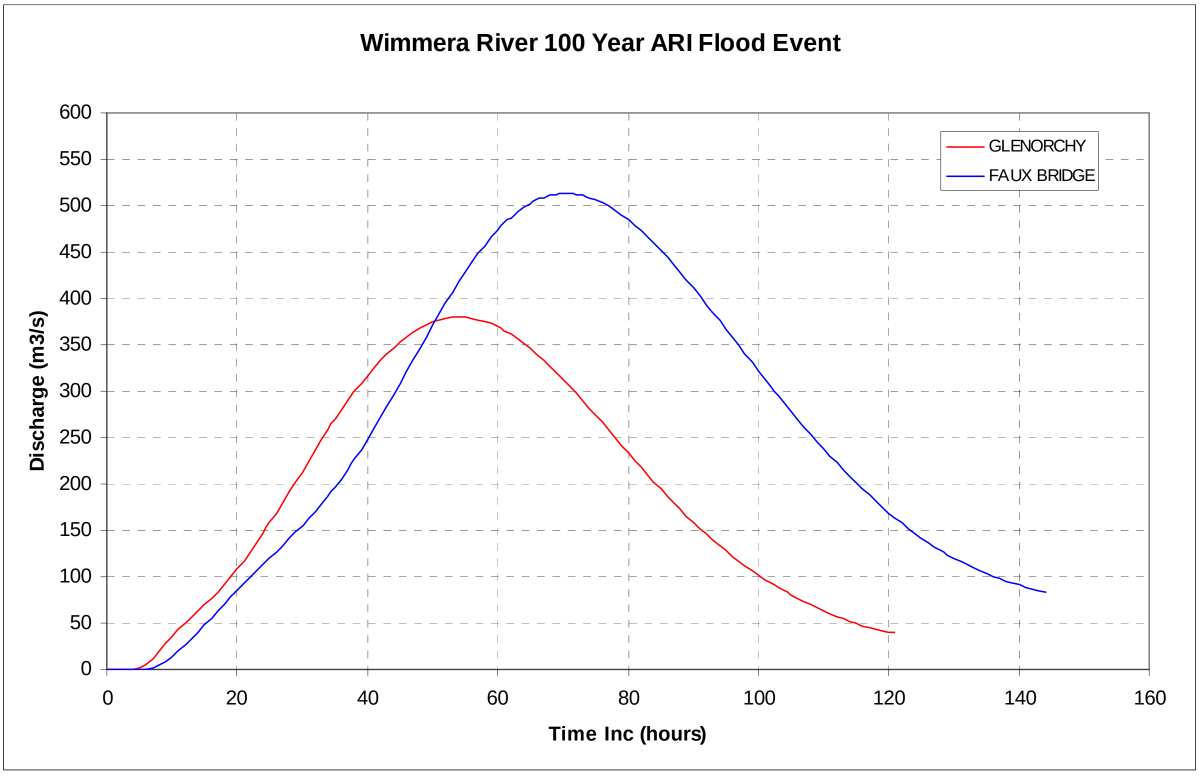

Figure A -5 100 Year ARI Design flood hydrographs for the Wimmera River at Glenorchy and Faux Bridge

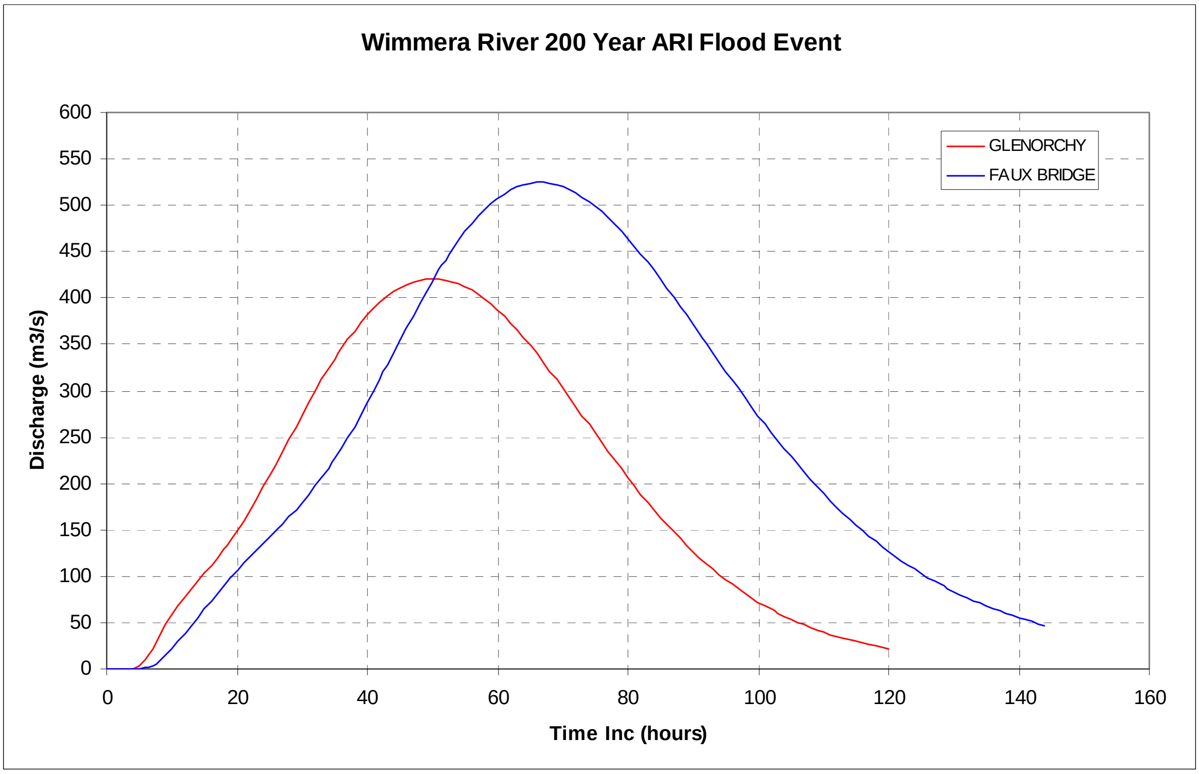

Figure A -6 200 Year ARI Design flood hydrographs for the Wimmera River at Glenorchy and Faux Bridge