A part of BMT in Energy and Environment

Upper Wimmera Flood Investigation Final Report

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Date: 30 June 2014

Upper Wimmera Flood Investigation Final Report

Prepared for:	Wimmera Catchment Management Authority
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies) In association with Michael Cawood and Associates

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BMT WBM Pty Ltd Level 5, 99 King Street Melbourne Vic 3000 Australia PO Box 604 Collins Street West Vic 8007 Tel: +61 3 8620 6100 Fax: +61 3 8620 6105 ABN 54 010 830 421 www.bmtwbm.com.au	**Document:**	R.M8460.009.01.Final.docx
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	Project Manager:	Joel Leister
	Author:	Joel Leister and Dexter Reynolds
	Client:	Wimmera Catchment Management Authority
	Client Contact:	Abdul Aziz
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Synopsis:	**This report documents the tasks undertaken as part of the Upper Wimmera Flood Investigation.**	

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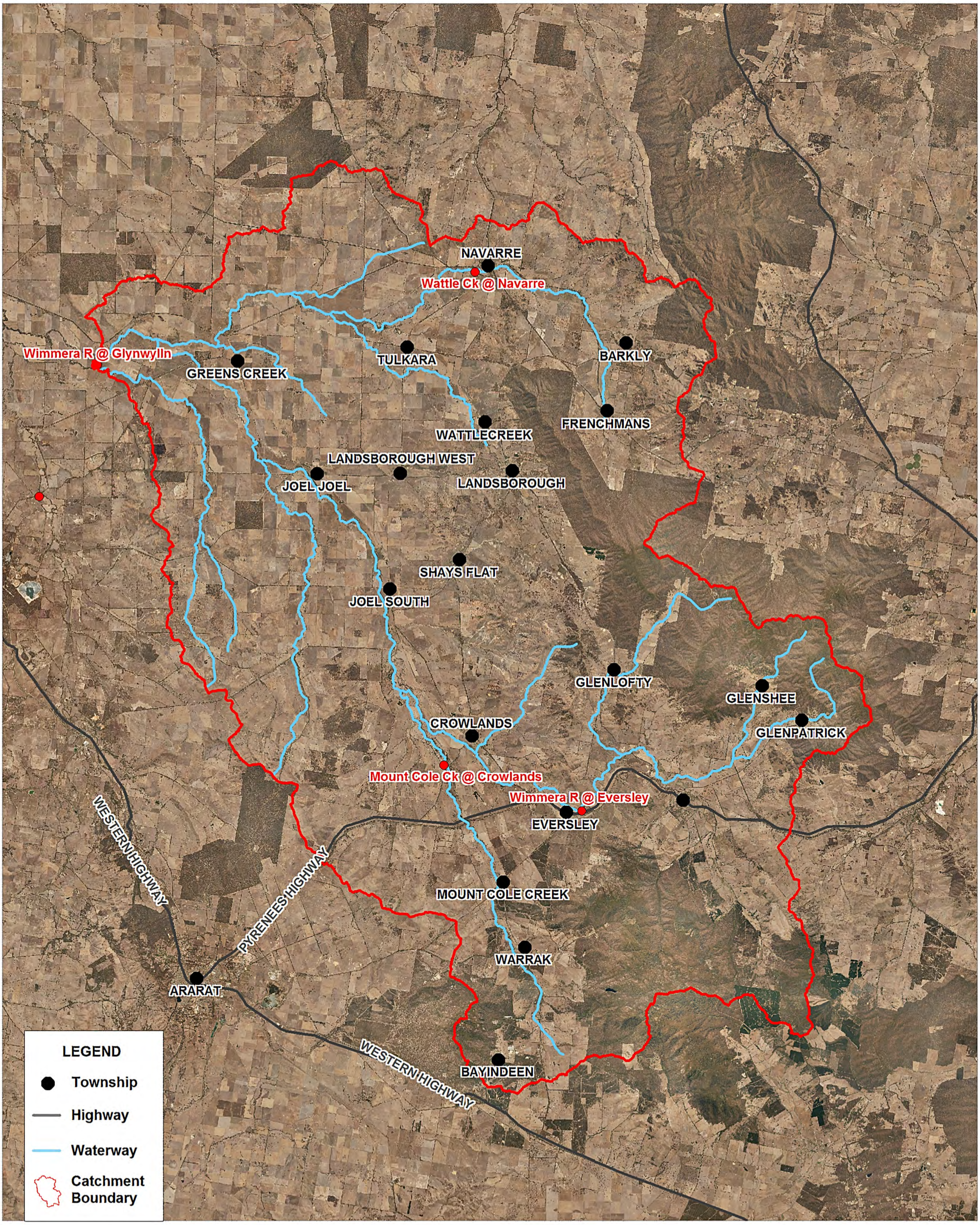
Executive Summary

This Executive Summary outlines the objectives, methodology and key outcomes of the Upper Wimmera Flood Investigation. Detailed reporting and mapping undertaken as part of the Upper Wimmera Flood Investigation are contained within the main report.

Study Background

Following the widespread flooding across Victoria in September 2010 and January 2011 the Minister for Water on the 19th September 2011 announced funding for the Upper Wimmera Flood Investigation. The Wimmera Catchment Management Authority (Wimmera CMA), in partnership with the Department of Environment and Primary Industries (DEPI), Northern Grampians Shire Council (NGSC), Pyrenees Shire Council (PSC) and, Ararat Rural City Council (ARCC) have commissioned this investigation.

The Upper Wimmera Catchment has an area of 1,500 km2 and is located in Central West Victoria. The catchment includes a number of waterways, namely, the Wimmera River and a number of its tributaries, including Mount Cole Creek, Wattle Creek (also known as Heifer Station Creek), Howard Creek and Seven Mile Creek. The majority of the catchment is used for agricultural purposes, predominately grazing. There are several townships within the catchment including Navarre, Landsborough, Elmhurst, Eversley, Crowlands, Joel Joel, Greens Creek and Campbells Bridge (Figure 1). The catchment was subject to flooding on three separate occasions between September 2010 and January 2011, which emphasised the need for improved understanding of the flood behaviour. The WCMA engaged BMT WBM Pty Ltd (BMT WBM) to undertake the flood investigation of the catchment.



Title:

Upper Wimmera Flood Study
Study Catchment

Figure: 1

Rev: A

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Key Objectives

The key objectives of this study are to:

- Review available data and historic flood information;
- Engage with the community and stakeholders in order to understand their experiences of flooding and desired outcomes - data collected from the community will be potentially used as inputs (rainfall) and model outputs and verification (flood behaviour matching event observations);
- Determination and documentation of flood levels, extents, velocities and depths (and thus flood risk) for a range of flood events;
- A review of Ararat Rural City Council, Northern Grampians Shire Council and the Pyrenees Shire Council Planning Scheme's current Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO) overlay in the existing planning scheme. Prepare draft documentation for recommended (if any) amendments for council review;
- Preparation of digital and hard copy floodplain maps for design 1% AEP and other flood events, showing both floodplain and floodway extents, suitable for incorporation into municipal planning schemes should council deem appropriate;
- Assessment of flood damages;
- Identification and assessment of structural and non-structural mitigation measures to alleviate intolerable flooding risk;
- Costing and assessment of preferred structural mitigation measures;
- Preparation of flood intelligence and consequence information, including maps, for various flood frequency return periods;
- Review and update Northern Grampians Shire Council and the Pyrenees Shire Council Flood Response under the Municipal Emergency Management Plan;
- Delivery of all flood related data and outputs including fully attributed Victorian Flood Database (VFD) compliant datasets;
- Transparently reporting the outcome of the study together with the process followed and the findings;
- Engage the community in all stages of the flood investigation to ensure that most appropriate outcomes are achieved; and
- Recommend improvements to the existing flood warning network to reduce the impact upon potentially flooded persons and properties.

Data Collection

As part of the Upper Wimmera Flood Investigation, datasets and information were obtained from a variety of organisations. The datasets obtained included:

- **Topographic Data** – Including LiDAR and Permanent Survey Marks.
- **GIS Data** – Including: aerial photography, flood overlays, historical flood extents, cadastral information, planning zones and other government zones.

- **Infrastructure Data** – Including: drainage network details and floodplain control structure details.
- **Rainfall and Streamflow Data** – Including: daily rainfall, pluviograph, stream stage and stream flow records.
- **Historic Flood Levels** – Including: surveyed flood levels and surveyed floor levels.

In addition to collecting data from external sources, site inspections and community surveys were also undertaken as part of the Upper Wimmera Flood Investigation.

Stakeholder Engagement

Community consultation was undertaken throughout the development of the Upper Wimmera Flood Investigation. The consultation included a series of public meetings and through community surveys.

The WCMA formed a Steering Committee for the project which consisted of key stakeholders from WCMA, DEPI, Council, VicSES and the local community. The steering committee provided governance and management of the Investigation and ensured that issues important to the Upper Wimmera community were properly considered. Throughout the study, regular meetings were with the Steering Committee at which the interim reports and presentations were discussed and issues were resolved.

Flood Model Development

The fully calibrated flood model developed for the Upper Wimmera Flood Investigation, to define flood behaviour within the study area and assess mitigation options, incorporates both hydrologic and hydraulic modelling techniques. Flood frequency analyses was undertaken using the FLIKE package to determine the magnitude of predicted peak discharges for a given level of risk or probability. Hydrologic modelling was undertaken using the RORB hydrologic modelling package to determine the rainfall-runoff characteristics of the catchment.

The catchment flows derived from the hydrologic modelling were then used as input flow boundaries for the TUFLOW hydraulic model. The TUFLOW hydraulic model was used to generate the required flood mapping and define the flooding characteristics of the study area.

The flood model was calibrated to the January 2011 flood event and validated against the September 2010 flood event. To assess the impacts of flooding on the Upper Wimmera, the flood model was run for the following Annual Exceedance Probability (AEP) events: 20%, 10%, 5%, 2%, 1% and 0.5% along with the Probable Maximum Flood (PMF) event.

Hydrologic Modelling

Flood Frequency Analysis

Flood frequency analysis (FFA) has been undertaken using the methods outlined in the draft version of Australian Rainfall and Runoff (ARR) Book IV Peak Flow Estimation. FFA of the four gauges within the catchment has been undertaken using the FLIKE software. The results of the FFA for the Glynwylln gauge provided peak flow estimates for a given AEP event for the Wimmera River. The resulting peak flows verses return period at Glynwylln gauge are shown in Table 1-1.

Table 1-1 Wimmera River at Glynwylln: Flood Frequency Analysis Results

AEP	Expected Quantile (m^3/s)	90% Quantile Probability Limits	
20%	153	118	201
10%	247	183	353
5%	364	254	606
2%	559	352	1168
1%	743	424	1879

Hydrologic Modelling

The purpose of the hydrologic modelling was to characterise the catchment's runoff response to rainfall. This modelling produces time-series of discharge data (i.e. hydrographs) and was undertaken using the RORB hydrologic modelling software. The RORB model covered the entire Wimmera River catchment to downstream Glynwylln Gauge; an area of approximately 1,465 km^2.

To establish a degree of confidence that the hydrologic modelling was suitably representing the runoff behaviour of the catchment, model calibration and validation was undertaken at the four stream gauges within the catchment. The RORB model was calibrated against two flood events and summary statistics were reviewed to assess the fit of the model. The model was then validated against a further two flood events using the calibrated parameters. The RORB model was then used to derive flow hydrographs to provide inputs into the TUFLOW hydraulic model for the required flood events.

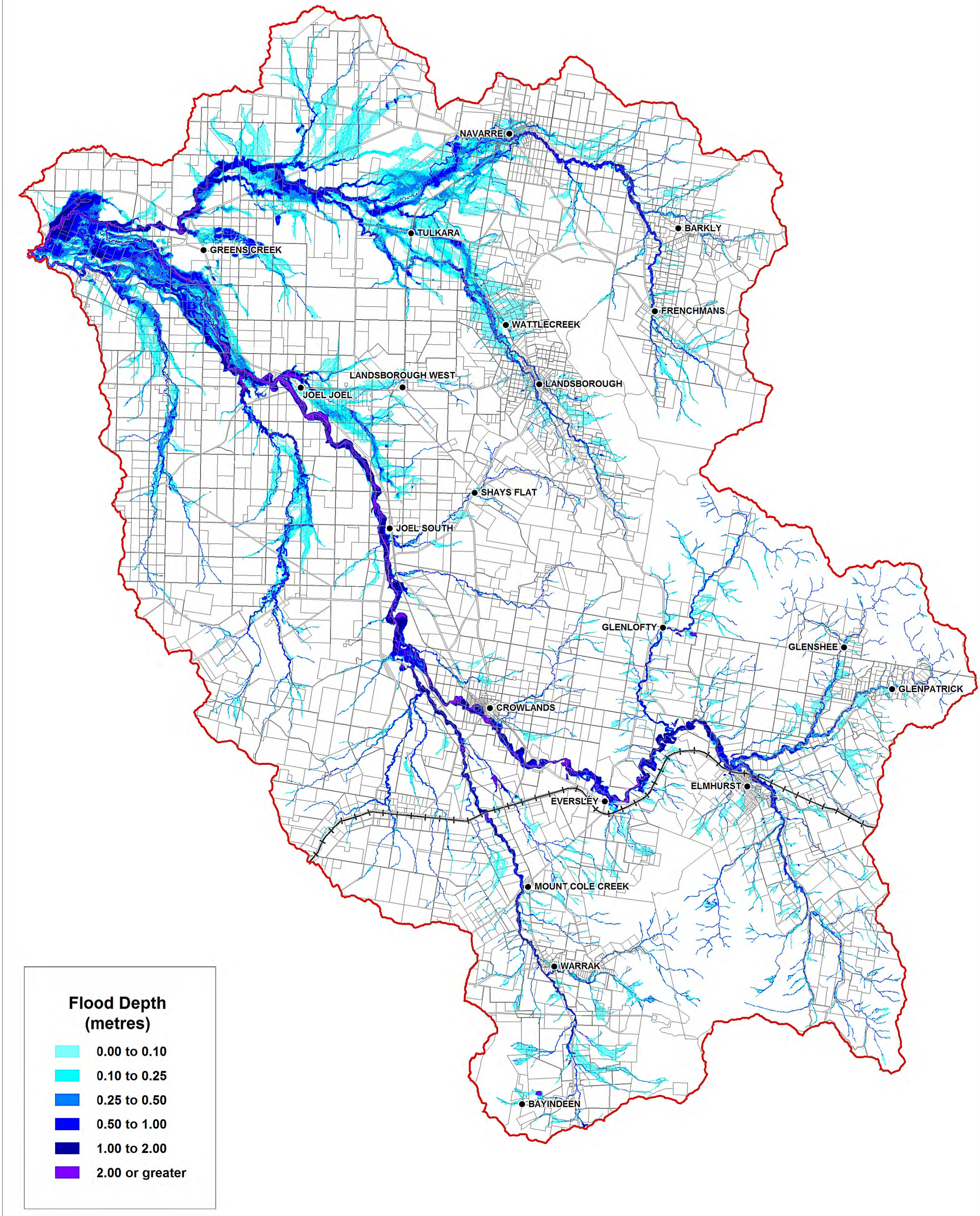
Hydraulic Modelling

In order to produce flood extents, depths, velocities and other hydraulic properties for the study area a 1D/2D linked hydraulic model was developed using TUFLOW. The floodplain was represented in the 2D domain with drainage and hydraulic structures modelled as 1D elements as required. The townships of Navarre and Landsborough were modelled at a higher resolution than the surrounding floodplain by incorporating a fine grid 2D domain into the model. The model covers the entire Upper Wimmera catchment.

The Upper Wimmera TUFLOW model underwent a calibration process to fit the model to the observed data. The TUFLOW model was calibrated to the September 2010 flood event and validated against the January 2011 flood event. The hydraulic model was successfully calibrated to the September 2010 and validated to the January 2011 flood events. The results demonstrated that the flood model has been effectively calibrated and is suitable for undertaking modelling of existing conditions and flood mitigation scenarios.

Existing Conditions Flood Mapping and Results

The flood model was run for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP design flood events (existing conditions) along with the PMF event. For each of these design flood events a suite of flood mapping outputs was generated including: flood depth, flood level, flood velocity, flood hazard and flood affected properties and buildings. Existing conditions peak flood depth for the 1% AEP event is presented in Figure 2.



Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Depths - Catchment

Figure: **2**

Rev: **A**

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Existing Conditions Flood Damages Assessment

The existing conditions flood damages were assessed using a combination of the Rapid Appraisal Method (RAM) and ANUFLOOD methods, both widely adopted throughout Victoria. The ANUFLOOD method was adopted to estimate potential building damages while the RAM method was used to estimate potential agricultural and infrastructure damages.

Flood damages assessments enable floodplain managers and decision makers to gain an understanding of the monetary magnitude of assets under threat from flooding. The information determined in the damages assessment is also used to inform the selection of mitigation measures via a benefit cost analysis. The results of the flood modelling indicated that during the 1% AEP event, only 3 properties experience above floor flooding, as shown in Table 1-2. The existing conditions Average Annual Damages for the Upper Wimmera catchment were calculated to be $2,926,300. However, agricultural damage and road infrastructure damage account for 77% and 22% of the total damage respectively.

Table 1-2 Properties flooded and above floor flooding against AEP event

Event AEP	No of Properties Inundated	No. of properties with Above Floor Flooding
PMF	53	37
0.5%	33	7
1%	20	3
2%	12	2
5%	7	0
10%	3	0
20%	2	0

Flood Management Options Assessment

Through consultation with the community, emergency management authorities and other stakeholders, an understanding of the major factors that influence flood risk in the Upper Wimmera were identified. This understanding was further enhanced through computer flood modelling and mapping undertaken as part of the investigation. These factors relate to the physical characteristics of the floodplain that contribute to flood risk in the Upper Wimmera and the factors that hamper the community's ability to manage the impact of flooding. The major factors are:

- The locations of many of the towns, including Navarre and Landsborough, are on the banks of multiple waterways subject to flooding;
- Limited road access through the majority of the Upper Wimmera catchment during times of flood;
- The steep upper catchment resulting in fast flood responses from heavy rainfall. Flooding is generally fast flowing but confined to recognised flow paths

- The flat lower catchment results in widespread flooding (flood extents are wide), floodwaters are generally slower in velocity and more likely to simply ‘pond’ on the floodplain.
- The limited rain and streamflow gauges within the catchment limit the ability for the community and emergency services to respond to a flood event. Flood warning is designed more for the towns downstream on the Wimmera River, rather than the Upper Wimmera Catchment. Flood warning in the upper reaches of any catchment is challenging due to the rapid response of the upper catchment.

In order to address and manage these factors that contribute to the flood risk in the Upper Wimmera, a comprehensive flood management options assessment was undertaken, including both structural and non-structural management options.

Management Option Screening

The screening was undertaken by the Technical Working Group. The Technical Working Group screened all management options collated as part of this investigation based on the knowledge of the members and the results of the flood modelling and analysis completed by BMT. The screening considered the feasibility of each potential management option in terms of;

- The option’s likelihood of delivering the required flood alleviation to the communities of the Upper Wimmera; and
- The economic, social and environmental costs.

In total 27 structural and eight non-structural management options were screened resulting in three structural and six non-structural management options were recommended for further assessment.

Structural Management Options Assessment

The three management schemes that were assessed were:

- **Scheme 1: Removal of Vegetation** – The creek alignments through Navarre and Landsborough are heavily vegetated and this scheme was used to determine the impact on flood levels through the removal of this vegetation.
- **Scheme 2: Town Levee around Navarre** - The design of a levee(s) to prevent flow from entering the Navarre for all flood events up to and including the 100 year ARI flood event.
- **Scheme 3: Whole of Catchment Access** - The design of upgraded roads to ensure safe road access between townships during all flood events up to and including the 100 year ARI flood event.

Hydraulic modelling of the range of design events; that is the 20%, 10%, 5%, 2%, 1% and 0.5% AEP and the PMF events; were used to undertake flood impact and damages assessments. Additionally, a benefit-cost ratio, which is an economic assessment based on preliminary cost estimates, was undertaken.

The resulting reductions in flood risk and Average Annual Damages (AAD) for the four schemes assessed was similar. As a result, the benefit-cost ratios were most heavily influenced by the cost of each scheme, as shown in Table 1-3.

Table 1-3 Structural Management Scheme Benefit-Cost Ratios

Structural Management Scheme	AAD	Capital Cost	Total Scheme Cost	BCR
Existing	$2,914,700			
Scheme 1	$2,912,500	$850,000	$1,165,000	0.03
Scheme 2	$2,912,200	$1,500,000	$2,067,000	0.02
Scheme 3	$2,821,500	$37,320,000	$51,443,000	0.03

Recommended Structural Management Scheme

All three modelled structural mitigation schemes provide minimal reductions to the Annual Average Damages and consequently result in very low Benefit-Cost Ratios. This is not unexpected due to the majority of the flood damages being incurred through damages to agricultural land and roads, and the schemes one and two having very little (if any) difference to these values. Whilst there is a noticeable reduction in the damages for Scheme 3, it comes at a significant capital cost; hence the BCR is still very low.

Consequently, there is no preferred structural mitigation scheme recommended by the Steering Committee for the Upper Wimmera Catchment. However, mitigation works should still be considered for protection of individual properties where deemed appropriate. A series of non-structural mitigation works will also be implemented across the catchment, including recommendations for improving the flood warning system and amendments to the planning scheme overlays.

Recommended Non-Structural Management Options

A number of non-structural management options identified during options screening were recommended for implementation in the Upper Wimmera Flood Investigation. These were:

- Declaration of flood levels;
- Amendments to planning schemes, including Planning Overlays;
- Flood response plan, including flood intelligence and consequence information.
- Flood warning system; and
- Community education.

List of Abbreviations, Acronyms & Glossary

1D/2D Model	1D hydraulic models rely on cross-sections taken at select location as representative of the floodplain or controls. A 2D model is (typically) a grid built from a DEM which allows for better representation of floodplains and allows superior modelling of complex flow patterns.
AEP	Annual Exceedance Probability – The % probability of an event occurring within any one year, as it is a probability it is possible to have two (or more) events that exceed this level within the space of a single year.
AEMI	Australian Emergency Management Institute
AHD	Australian Height Datum – The datum to which all vertical control mapping would be referred Australia wide. The datum (zero level) is set at the mean sea level around Australia.
ARCC	Ararat Rural City Council
ARI	Average Recurrence Interval – The probable recurrence interval of any event occurring, i.e. 100 year event is probable only to occur once every 100 years. The inverse of ARI is AEP, i.e. 50 year ARI = 2% AEP and is therefore possible to have two (or more) 100 year ARI storm events within the space of any 100 year period.
AWS	Automatic Weather Station
BoM	Bureau of Meteorology
CMA	Catchment Management Authority
Critical Duration	The design event that results in the peak discharge for any given AEP
DEM	Digital Elevation Model – Three dimensional computer representation of terrain
DEPI	Department of Environment and Primary Industries
DoTARS	Department of Transport and Regional Services
DSE	Department of Sustainability and Environment (now known as Department of Environment and Primary Industries)
EA	Emergency Alert
EMA	Emergency Management Australia
EMMV	Emergency Management Manual Victoria
ERTS	Event Report Radio Telemetry System
FFA	Flood Frequency Analysis, whereby historic data is used to determine design flood estimations.
FFWS	Flash Flood Warning System
FI	Fraction Imperviousness – The fraction of the catchment that is impervious, that is, land which does not allow infiltration of water

FLIKE	A software package for performing the FFA, includes many standard statistical distributions
FO	Flood Overlay
IC	Incident Controller
ICC	Incident Control Centre
LGA	Local Government Area
LiDAR	Light Detection and Ranging – Ground survey taken from an aeroplane typically using a laser. Using the laser pulse properties the ranging and reflectivity is used to determine properties of the laser strike, soil type/tree/building/road/etc. It is usual to filter non-ground strikes (trees/buildings/etc) from the LiDAR before it is used to generate a DEM.
LSIO	Land Subject to Inundation Overlay
Manning's n	Hydraulic roughness due to ground conditions, typically averaged over an area of relative homogeneity, e.g. it's harder for water to flow through an area of heavy brush and trees than maintained grass.
MEMPC	Municipal Emergency Management Planning Committee
MERO	Municipal Emergency Resource Officer
MFEP	Municipal Flood Emergency Plan
NGSC	Northern Grampians Shire Council
OESC	Office of the Emergency Services Commissioner
PMF	Probable Maximum Flood – the flood resulting from the PMP (see below).
PMP	Probable Maximum Precipitation – Largest probable rainfall event. These typically have an ARI beyond 1,000,000 years, or alternatively a 0.000001% AEP.
PSC	Pyrenees Shire Council
PSM	Permanent Survey Mark
QA	Quality Assure
RDO	Regional Duty Officer
RORB	A node and link runoff and routing hydrologic modelling program
TFWS	Total Flood Warning System
TUFLOW	A 1D and 2D hydraulic modelling package developed by BMT WBM and is the most widely used 1D/2D flood modelling software in Australia.
VFD	Victorian Flood Database
VICPOL	Victoria Police
VICSES	Victoria State Emergency Service

Contents

List of Figures

List of Tables

1 Introduction

1.1 Study Background

Following the widespread flooding across Victoria in September 2010 and January 2011 the Minister for Water on the 19th September 2011 announced funding for the Upper Wimmera Flood Investigation. Funding for the investigation was made available through the Victorian Coalition Government's Flood Warning Network - Repair and Improvement initiative and the Australian Government's Natural Disaster Resilience Grants Scheme. The Wimmera Catchment Management Authority (Wimmera CMA), in partnership with the Department of Sustainability (DSE), Northern Grampians Shire Council (NGSC), Pyrenees Shire Council (PSC) and, Ararat Rural City Council (ARCC) have commissioned this investigation.

The Wimmera Catchment Management Authority (Wimmera CMA) has engaged BMT WBM Pty Ltd (BMT WBM) to undertake a flood investigation for the Upper Wimmera River catchment. This investigation is due to frequent flooding in the townships of Navarre and Landsborough.

In order to ensure that the best outcomes for the communities of the Upper Wimmera, the work undertaken by BMT WBM will be overseen and guided by the Steering Committee and Technical Working Group, which have been established for the Upper Wimmera Flood Investigation. Moreover, specialist technical reviewer(s) appointed by DSE are commissioned to review and advise on key components of the flood investigation to ensure the best outcomes for the community.

This report documents the final hydrologic and hydraulic modelling and calibration that has been undertaken as part of the Upper Wimmera Flood Investigation. Based on the results of this modelling a number of outcomes have been achieved including; a flood damages assessment; a flood mitigation assessment; and suggested flood management systems. These have been documented and included in this final report..

1.2 Previous Reports

Several previous flood reports and documents have been made available that detail and document the known flooding history of the Upper Wimmera. These reports and documents include:

- Flood Data Transfer Project - Shire of Northern Grampians (DNRE 2000);
- Flood Data Transfer Project - Shire of Pyrenees (DNRE 2000);
- Wimmera Region Flood Report - January 2011 (WCMA 2011); and
- 2011 Flood Impact Summary (NGSC 2011);

Whilst the flood data transfer project provides some detailed background information into the available flood data of the Upper Wimmera system, the more recent reports related to the December 2010 and January 2011 flood events are the more relevant to the current study.

1.3 Catchment Description

The Upper Wimmera Catchment has an area of 1,500 km^2 and is located in Central West Victoria (refer to Figure 1-1). The catchment includes a number of waterways, namely, the Wimmera River and a number of its tributaries, including Mount Cole Creek, Wattle Creek (also known as Heifer Station Creek), Howard Creek and Seven Mile Creek. The majority of the catchment is used for agricultural purposes, predominately grazing. There are several townships within the catchment including Navarre, Landsborough, Elmhurst, Eversley, Crowlands, Joel Joel, Greens Creek and Campbells Bridge (refer to Figure 1-2).

The catchment originates in the mountainous areas of The Great Dividing Range and the Pyrenees. From there the Wimmera River and its tributaries flow in a generally westerly direction towards Glenorchy. The upper part of the catchment is relatively steep with numerous well defined flowpaths. However, as the River and its tributaries flow into the lower portion of the upper catchment, the topography flattens to form a wide and relatively undefined floodplain.

The main waterway in the catchment is the Wimmera River, which originates south of Elmhurst in the Mount Cole State Forest. The River flows in a generally westerly direction past the townships of Elmhurst, Eversley before it's confluence with Mount Cole Creek, just downstream of Crowlands. From this confluence, the River flows in a generally northerly direction through Joel Joel before its confluence with Wattle Creek, approximately halfway between the towns of Glynwylln and Greens Creek. However, due to the relatively flat nature of the floodplain in these localities, cross catchment flows between the creek systems occurs well before the confluences.

The Wimmera River eventually discharges into Lake Hindmarsh after flowing through a number of towns, including Glenorchy, Horsham and Dimboola. However, this study focuses on the catchment upstream of Glynwylln. Whilst the focus of the study comprises all areas and townships upstream of the Glynwylln gauge, particular interest concerns the two largest population centres of Navarre and Landsborough.

The town of Navarre is located towards the North of the study catchment, approximately 35 kilometres North East of Stawell in the Northern Grampians Shire Council. The town is situated on the bank of Wattle Creek (refer to Figure 1-2), one of the main tributaries of the Wimmera River.

The town of Landsborough is located towards the centre of the study catchment, approximately 33 kilometres East of Stawell in the Pyrenees Shire Council. The town is situated on the banks of Howards Creek (refer to Figure 1-2), a tributary of Wattle Creek

1.4 Study Area

The Upper Wimmera study area is detailed in Figure 1-2. The study area extends from the upper extent of the Wimmera catchment to the Glynwylln gauge on the Wimmera River. The study area will be modelled in detail using dynamically linked 1D/2D hydraulic models to simulate the flood behaviour within the study area. Flow inputs into the hydraulic model will be from a hydrologic model of the Upper Wimmera River Catchment. The extent of the study area ensures that the interactions between the various creek systems are included in the hydraulic model, and removes “boundary effects” influencing the modelled flood behaviour in the townships subject to frequent flooding.

1.5 Historical Flooding

During the flood events in Western Victoria during 2010 and 2011, townships in the Upper Wimmera catchment were inundated on three separate occasions; during September and December 2010; and the large flooding in January 2011, the magnitude of which was influenced by the antecedent conditions from the preceeding large events. Another significant event occurred in December 2011 as a result of an extremely intense, yet localised, storm in the vicinity of Joel Joel.

As advised by the Wimmera CMA (Water Technology 2011), the January 2011 flood event is considered to be the largest flood event to have occurred within the Upper Wimmera River catchment, and is well beyond what locals have seen in their lifetimes. During the January 2011 event, heavy rainfall (144 millimetres across two days in the Pyrenees (as captured by the Bureau of Meteorology) combined with an already wet catchment to result in significant flooding in all the waterways in the Upper Wimmera Catchment. The flood event damaged the stream gauges at Glynwylln and Eversley with flood levels peaking well above historic levels. The townships of Navarre, Landsborough, Elmhurst, Eversley, Crowlands, Joel Joel, Greens Creek and Campbells Bridge all experienced significant flooding.

1.6 Key Objectives

The key objectives of this study are to:

(1) Review available data and historic flood information;

(2) Engage with the community and stakeholders in order to understand their experiences of flooding and desired outcomes - data collected from the community will be potentially used as inputs (rainfall) and model outputs and verification (flood behaviour matching event observations);

(3) Determination and documentation of flood levels, extents, velocities and depths (and thus flood risk) for a range of flood events;

(4) A review of Ararat Rural City Council, Northern Grampians Shire Council and the Pyrenees Shire Council Planning Scheme's current Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO) overlay in the existing planning scheme. Prepare draft documentation for recommended (if any) amendments for council review;

(5) Preparation of digital and hard copy floodplain maps for design 1% AEP and other flood events, showing both floodplain and floodway extents, suitable for incorporation into municipal planning schemes should council deem appropriate;

(6) Assessment of flood damages;

(7) Identification and assessment of structural and non-structural mitigation measures to alleviate intolerable flooding risk;

(8) Costing and assessment of preferred structural mitigation measures;

(9) Preparation of flood intelligence and consequence information, including maps, for various flood frequency return periods;

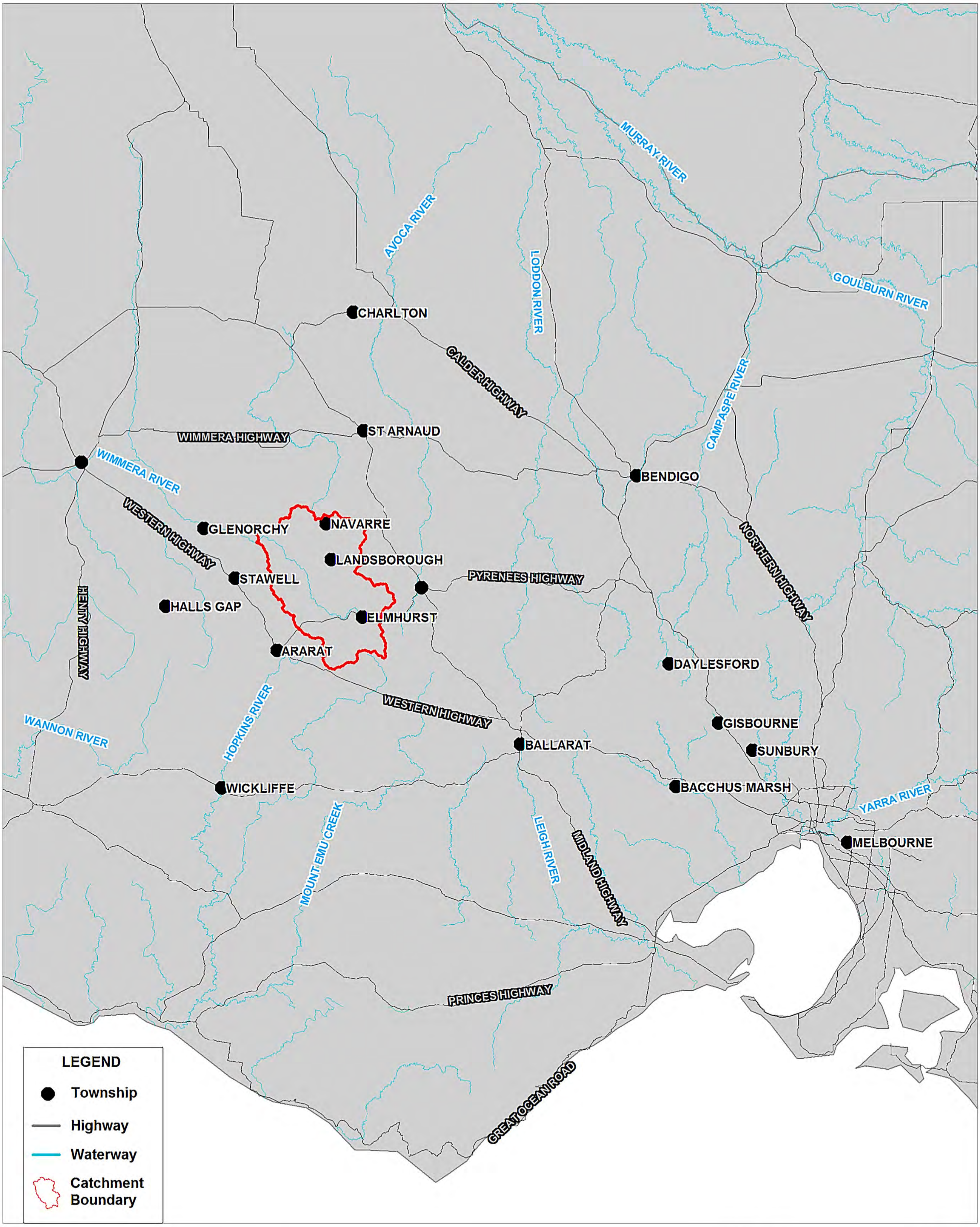
(10) Review and update Northern Grampians Shire Council and the Pyrenees Shire Council Flood Response under the Municipal Emergency Management Plan;

(11) Delivery of all flood related data and outputs including fully attributed Victorian Flood Database (VFD) compliant datasets;

(12) Transparently reporting the outcome of the study together with the process followed and the findings;

(13) Engage the community in all stages of the flood investigation to ensure that most appropriate outcomes are achieved; and

(14) Recommend improvements to the existing flood warning network to reduce the impact upon potentially flooded persons and properties.



Title:
Upper Wimmera Flood Study
Catchment Locality

Figure: 1-1

Rev: A

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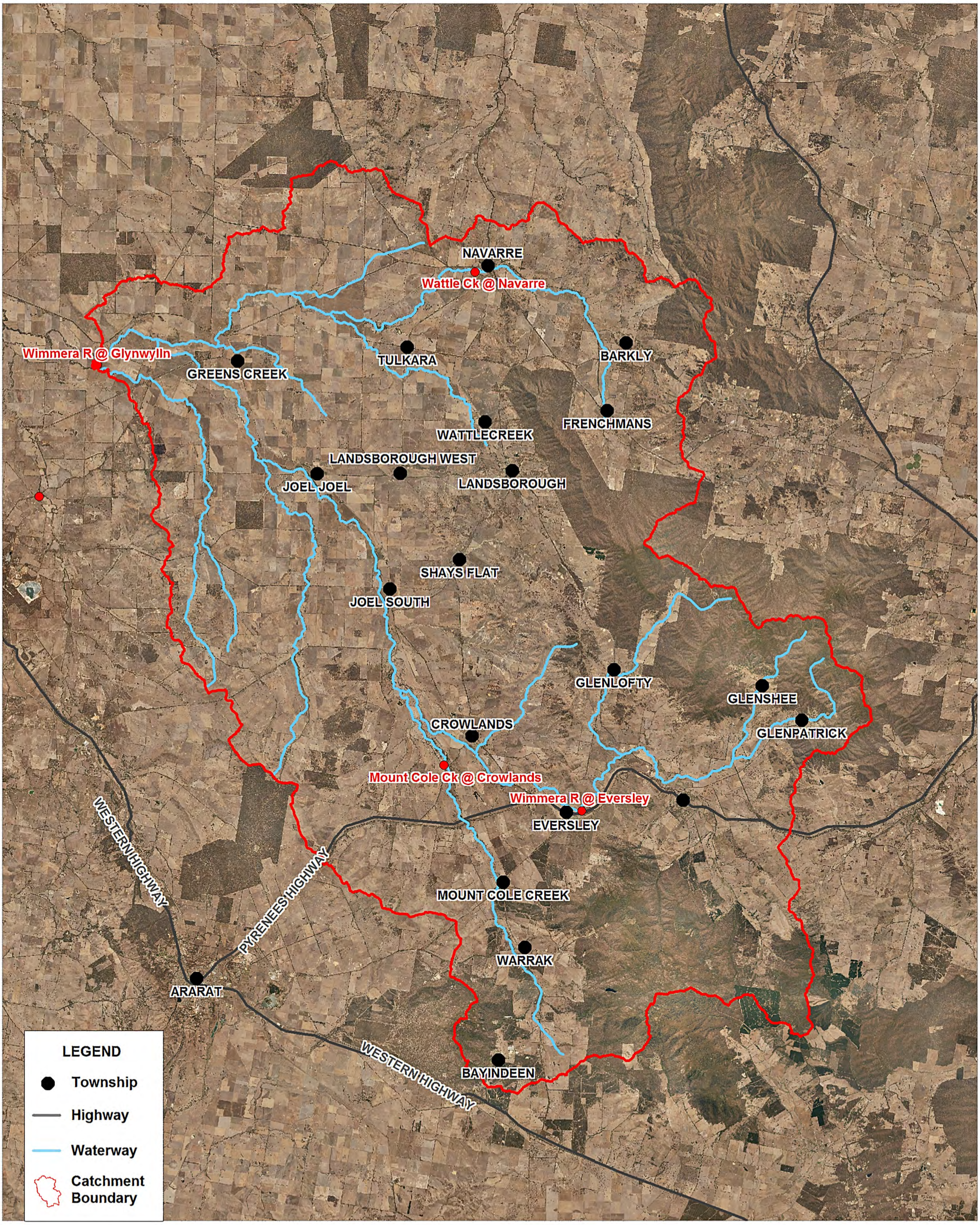

Title:

Upper Wimmera Flood Study
Study Catchment

Figure: 1-2

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2 Data Collation

This section documents the data that was collated by BMT WBM for the Upper Wimmera Flood Investigation. BMT WBM sourced data from a number of agencies, including:

- Wimmera Catchment Management Authority (Wimmera CMA).
- Ararat Rural City Council (Ararat RCC).
- Northern Grampians Shire Council (Northern Grampians SC).
- Pyrenees Shire Council (Pyrenees SC).
- Department of Sustainability and Environment (DSE).
- VicRoads; and
- VicTrack.

2.1 Topographic Data

Topographic data, including airborne ground survey (LiDAR) and ground contours, are used to generate the Digital Elevation Model (DEM) which forms the basis of both the hydrologic and hydraulic modelling components of the study. A number of data sets were provided, and these were cross-interrogated to determine if any discrepancies exist in any one data set that may lead to issues in the modelling.

Wimmera CMA:

- 1m contours;
- Thinned LiDAR (quoted vertical accuracy 0.5m);
- Thinned LiDAR (quoted vertical accuracy 0.1m);
- 10m gridded DEM.

Pyrenees SC:

- Unfiltered LiDAR covering PSC portion of the catchment and some minor overlap with neighbouring Local Government Areas (LGA);
- LiDAR covering the townships of Navarre, Landsborough, Elmhurst and Mount Cole Creek.

DSE:

- Permanent Survey Marks (PSM) within the catchment supplied by DSE (13/02/12) with a vertical accuracy of 1 mm.

The provided LiDAR data sets have been checked to ensure they are suitable for use in the Upper Wimmera Flood Investigation. BMT WBM's previous interim report (BMT WBM, 2012a) details the data verification process that has been undertaken to ensure the accuracy and suitability of the provided topographic information.

2.2 Aerial Photography

Aerial Photography of the catchment is an important tool for verifying catchment particulars such as land use, building footprints and other structures. During the hydrologic modelling stage it was used, along with the planning scheme overlays, to estimate the fraction imperviousness of the catchment. Similarly, when developing the hydraulic model it was used to aid in the assignment of roughness to the catchment and any blockages caused by buildings. Finally, aerial photography during a flood event was used to verify the model results by comparing relative extents and breakaway flows.

Wimmera CMA:

- Four (4) geo-referenced tiles covering the entire catchment;
- Two (2) geo-referenced tiles of Navarre (14/01/11) and the Upper Wimmera (15/01/11) following the January 2011 flood event; and
- 112 non-tile non-geo-referenced photographs of Landsborough and Navarre during/following the January 2011 flood event were provided.

2.3 Planning Scheme Information

The planning scheme layers are used in conjunction with the aerial photography and on-ground photography to define the current land use of the catchment. The planning scheme layers are used in both the hydrologic and hydraulic model to define factors such as fraction impervious and Manning's 'n' value (ground roughness).

Northern Grampians SC:

- Supplied the entire NGSC LGA portion of the catchment and some of neighbouring LGAs.

Pyrenees SC:

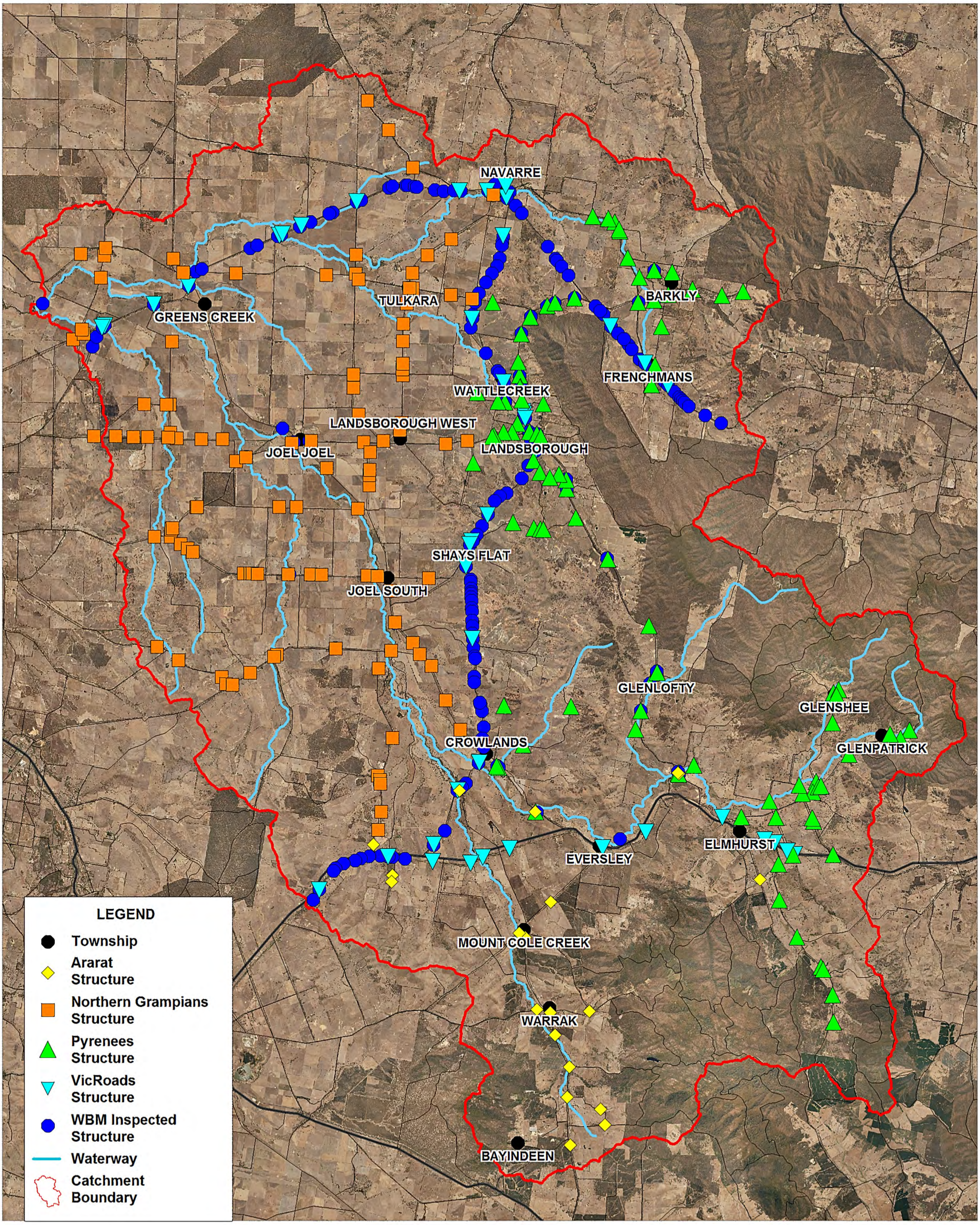
- Supplied the entire PSC LGA portion of the catchment and some of neighbouring LGAs.

Ararat RCC:

- Supplied the entire ARCC LGA portion of the catchment and some of neighbouring LGAs.

2.4 Drainage Assets (Culverts and Bridges)

Culvert and bridge information is typically only used during the hydraulic modelling component of the flood investigation. It is important to incorporate any assets in the hydraulic model using as accurate information as possible. Locating the asset in the wrong location may disconnect it from the main flow channel. Whilst applying incorrect attributes (width/height/inverts/weirs/drops/etc) may result in incorrect flows passing through the structure. This may result in either elevated or depressed flooding upstream and over the road and elevated or depressed water levels downstream depending on which attributes are incorrect.



Title:

Upper Wimmera Flood Study Structure Locations

Figure: **2-1**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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BMT WBM:

- Following the inception meeting a number (144) of structures were measured and documented along Highways C221 and B160. Where safe access was possible, the structure's width and height was measured and the structure photographed.
- Following the first community consultation meeting a number (41) of structures were measured and documented throughout the catchment with a focus on bridges opposed to smaller drainage culverts. Where safe access was possible, the structure's width and height was measured and the structure photographed.

Northern Grampians SC:

- NGSC has supplied information on bridges and major culverts in GIS format and accompanying spreadsheet database. The two data sets are comprehensive for culverts containing information on culvert dimensions and length, but do not detail inverts.
- Bridge information supplied typically contains details of the number of piers and the existence of any hydraulic controls (weirs/drop structures). BMT WBM staff visited Northern Grampians SC Offices and made copies of available bridge plans.

Pyrenees SC:

- PSC has supplied information on the location of bridges and major culverts in GIS format with limited information contained. The provided information is insufficient for the purposes of hydraulic modelling, but aided in identifying structures that were subsequently field measured by BMT WBM staff.
- BMT WBM staff visited Pyrenees SC Offices and made copies of available bridge plans..

Ararat RCC:

- ARCC has supplied information on bridges in GIS format. Bridge information supplied typically contains details of the number of spans and the length of the bridge.
- No information has been provided regarding the location or any other data of culverts within the ARCC LGA.

VicRoads:

- VicRoads has supplied information on the location of bridges and major culverts in GIS format. The information contained includes type of structure, number of barrels/spans, widths, heights and heights. Inverts are not included.

VicTrack:

- VicTrack has supplied original drawings as well as structure survey reports for their assets. The information contained includes type of structure, number of barrels/spans, widths, heights as well as a photograph of each structure. Inverts are not included.

2.5 Gauge Data

Gauge data can be used for all stages of the investigation. Historic data can be used to calibrate or verify the hydrologic model if enough other collaborative data sources exists e.g. 6 minute rainfall on a gauge with instantaneous flow. It can be used in a similar manner to verify hydraulic models where gauges have instantaneous flow or gauge height. Where out of bank flooding occurs the instantaneous flow will typically be incorrect unless it has been allowed for in the gauge rating curve, however the gauge height can be used and matched to the flood surface generated in the hydraulic modelling outputs. Finally gauging tables can be used in flood warning as trigger heights to initiate mobilisation of resources, evacuation and other flood intelligence (which roads are impassable, etc).

The hydrographers at Theiss Services were contacted by BMT WBM to determine that quality of the data captured during the recent flood events in the Upper Wimmera which had flows that exceeded the then current rating curve (September 2010, December 2010 and January 2011). Rebekah Webb (Senior Hydrographer at Theiss Services) advised the data collated by BMT WBM (and detailed below) as part of this study was the best data currently available. Subsequently, Theiss Services advised that all four gauges in the Upper Wimmera were to be re-rated and that these would be supplied to BMT WBM.

Following the re-rating undertaken by Thiess Services, updated gauge records were provided to BMT WBM. A significant difference between the previously suppled data and updated data was noted, particularly with respect to the January 2011 event. For the purposes of the hydrologic assessment only the revised gauge data supplied by Theiss Services was used, superseded data from the Victorian Data Warehouse was not used.

Wimmera CMA:

- Stream gauge station heights for a number of stations during the January 2011 events
- Stream gauge station heights for a number of stations during the September 2010 events
- Stream gauge flow/height readings for a number of older historic flood events between 1909 and 1996
- Pluviograph data for the Eversley pluviograph site (data covers the September 2010, December 2010 and January 2011 flood events)

Bureau of Meterorology:

- Daily Rainfall (for the months of September 2010, December 2010 and January 2011)
  - Raglan (89107)
  - Pyrenees (79101)
  - Eversley (79014)
  - Avoca (Post Office) (81000)
  - Moonambel (79031)

  - Barkly (79002)
  - Redbank (79039)
  - Navarre (79037)
  - Navarre (Avon No.3) (79086)
  - Moorl Morrl (Valley View) (79032)
  - Stawell Aerodrome (79105)
  - Buangor (Craigie) (89109)
- Pluviographs (for the period 1st September 2010 to 31 January 2011)
  - Navarre (Avon No.3) (79086)
  - Ararat Prison (89085)

Victoria Data Warehouse:

- Rainfall
  - Wattle Creek @ Navarre (13/09/1993 to 15/11/2011)
  - Wimmera River @ Eversley (4/11/1992 to 8/11/2011)
- Instantaneous Flow (ML/Day) and Station Height (m)
  - Mount Cole Creek @ Crowlands (30/04/1985 to 9/11/2011)
  - Wattle Creek @ Navarre (04/03/1976 to 15/11/2011)
  - Wimmera River @ Eversley (22/03/1963 to 08/11/2011)
  - Wimmera River @ Glynwylln (31/05/1956 to 15/11/2011)

Thiess Services:

- Instantaneous Flow (ML/Day)
  - Mount Cole Creek @ Crowlands (29/04/1985 to 08/05/2012)
  - Wattle Creek @ Navarre (03/03/1976 to 14/05/2012)
  - Wimmera River @ Eversley (22/05/1973 to 07/05/2012)
  - Wimmera River @ Glynwylln (30/05/1956 to 14/05/2012)
- Mean Daily Flow (ML/Day)
  - Mount Cole Creek @ Crowlands (30/04/1985 to 28/03/2012)
  - Wattle Creek @ Navarre (04/03/1976 to 13/05/2012)
  - Wimmera River @ Eversley (21/10/1902 to 29/12/1933 and 23/03/1963 to 06/05/2012)
  - Wimmera River @ Glynwylln (09/06/1946 to 13/05/2012)

2.6 Historic Flooding

It is understood that there has been a number of sizable rainfall events in the Upper Wimmera catchment in recent memory. These include the December 1988, August 1999, September 2010 December 2010, January 2011 and December 2011 events. The information detailed in this section is in addition to the reports presented in Section 1.2

Wimmera CMA:

- December 2011 flood event
  - Survey marks
  - Ground photos
- January 2011 flood event
  - Two (2) geo-referenced aerial photographs of Navarre (14/01/11) and the Upper Wimmera (15/01/11).
  - 112 non-tile aerial photographs of Landsborough and Navarre during/following flood event
  - Survey marks
  - Ground photos of Navarre
  - Damage map - houses flooded above floor
- September 2010 flood event
  - Survey marks
  - Stream gauging
  - Ground photos of Navarre & Landsborough
- Other historic flood events
  - Survey marks
  - Stream gauging

The information provided will assist in the calibration and verification of the hydraulic model. Data largely exists around townships (understandably) with little information available outside Navarre or Landsborough. Aerial photography of two events exists and it may be possible to extract rough flood extents outside of the two major townships for the January 2011 event. Gauge heights exist for the four locations in the catchments for the January 2011 and September 2010 flood events.

3 Hydrologic Modelling

The flood response of a catchment can be characterised by undertaking rainfall-runoff (hydrological) modelling, and by analysing the peak discharge through Flood Frequency Analysis (FFA). These have both been undertaken as part of the hydrological modelling for the Upper Wimmera Flood Investigation.

Flood Frequency Analysis involves the use of historic flow conditions at a river gauging site to aid the prediction of probable future flow rates. This is achieved by the analysis and fitting of a number statistical distributions to the gauged streamflow data. Once a statistical distribution has been fitted to the streamflow data, estimates of the rarity of flood events can be made in terms of probability, that is, an estimate of the return period of an event can be made. Given the longer streamflow record at Glynwylln and Eversley, estimates of rarer events at this site contain smaller uncertainty bounds than the river gauges at Navarre and Crowlands which have significantly shorter period of instantaneous flow records.

Rainfall-runoff modelling, or hydrological modelling, of the Wimmera River Catchment to Glynwylln was undertaken with the RORB hydrological modelling package. The output from the RORB model will provide inputs for the TUFLOW hydraulic model. Hydrological models of the Upper Wimmera catchment have previously been developed as part of flood studies and flow modelling studies focussed on sites along the mid and lower reaches of the Wimmera River. Consequently, these models lacked the required definition in the upper catchment, and therefore, a new RORB model was developed to meet the requirements of this study.

This chapter is presented in the following format:

- Flood Frequency Analysis
- Hydrological modelling
    - RORB model development
    - Calibration and Validation of the RORB model
    - Design event modelling

3.1 Flood Frequency Analysis

3.1.1 Introduction

Flood frequency analysis (FFA) has been undertaken using the methods outlined in the draft version of Australian Rainfall and Runoff (ARR) Book IV Estimation of design peak discharges (Kuczera and Franks, 2006). FFA of the Navarre, Crowlands, Eversley and Glynwylln gauges has been undertaken using the FLIKE FFA software (Kuczera, 1999). This package provides a Bayesian framework for comprehensive at-site flood frequency estimation that allows the inclusion of ungauged historical events.

3.1.1.1 Background on Approach

The ARR technical committee recommends that Bayesian methods are used in preference to the methods outlined in previous versions of ARR. Specifically published on the ARR website, the following Practice Advice is given:

- Log Pearson 3 (LP3) is no longer specifically recommended - the user should select the distribution which best fits the data. In many locations research has found the best fit is either the Generalised Extreme Value (GEV) or LP3, but other distributions are not precluded.
- The log space moment fitting technique recommended in ARR87 is no longer recommended as other techniques have been shown to be more efficient. The preferred technique uses Bayesian methods as described in the draft flood frequency chapter mentioned above.

The approach taken here is consistent with the advice published on the ARR website and repeated above.

3.1.2 Data

Streamflow data was available at four locations in the study catchment as shown in Figure 1-2, namely:

- Wattle Creek at Navarre (415238);
- Mount Cole Creek at Crowlands (415245);
- Wimmera River at Eversley (415207); and
- Wimmera River at Glynwylln (415206)

The instantaneous flow record lengths for each of these gauges varied between 27 years (Mount Cole Creek at Crowlands) to 56 years (Wimmera River at Glynwylln). In addition, the gauges at Eversley and Glynwylln had recorded average daily flows which extend the stream gauging record (refer to section 3.1.2.5). The length of record for instantaneous maximum flows for each of the gauging sites within the catchment is listed in Table 3-1.

Table 3-1 Stream Flow Gauges in the Upper Wimmera Catchment

Station	Name	Start Year – Month Continuous Recording	End Year – Month Continuous Recording
415206	Wimmera River at Glynwylln (Figure 3-4)	1956 – May	Active
415207	Wimmera River at Eversley (Figure 3-3)	1963 - March	Active
415238	Wattle Creek at Navarre (Figure 3-1)	1976 - March	Active
415245	Mount Cole Creek at Crowlands (Figure 3-2)	1985 – May	Active

Figure 3-1 Wattle Creek at Navarre Stream Gauge

Figure 3-2 Mount Cole Creek at Crowlands Stream Gauge

Figure 3-3 Wimmera River at Eversley Stream Gauge

Figure 3-4 Wimmera River at Glynwylln Stream Gauge

3.1.2.1 Water Year

For the purposes of the FFA a water year was used starting 1st of October to 30th September the following calendar year. This timeframe was reached from analysis of the monthly aggregated historic peak flows for each year over all four gauges. This water year ensures that the largest event of each year is independent of the largest events of the preceding and following years

3.1.2.2 Gauged Data Error

Not all of the four streamflow gauges have continuous records covering the three most recent significant events; September 2010, December 2010 and January 2011. During the January 2011 event the Wattle Creek at Navarre gauge was not operational. Following the flood a maximum height and flow was estimated from debris marks. The data from the other streamflow gauges was screened to ensure that it was suitable for calibration. The screening process raised some concerns about the Eversley and Crowlands streamflow gauges during the January 2011 event, as detailed below

As the RORB model is calibrated against gauged flows and the flow data is used in the FFA, the accuracy of the rating curves used to translate the recorded station levels into flows can significantly influence the reliability of the calibration and FFA. During the January 2011 event, all three gauges recorded water levels that exceeded the highest gauged flows and the Eversley and Crowlands stream gauges recorded water levels that exceeded the highest values on the published rating curves, as presented in Table 3-2; the gauged height refers to the maximum height at which hydrographers have undertaken measurements at the gauge site during a flood event so as to determine the flow rate. Review of the gauge data indicates that the Wattle Creek at Navarre gauge was inoperable during the January 2011 flood event (no gauge data is available). As above, peak flow was estimated, however due to uncertainty inherent in the method of estimation it was determined that it would be inappropriate to use for calibration purposes.

Table 3-2 Stream Gauge Rating Curve Heights

Name	Maximum Gauged Height	Published Maximum Rating Curve Height	January 2011 Recorded Height	Exceeded Gauged Height	Exceeded Rating Curve
Wimmera River at Glynwylln	7.6	8.9	8.8	Yes	No
Wimmera River at Eversley	3.5	4.1	5.84	Yes	Yes
Wattle Creek at Navarre	4.8	4.8	-*	-*	-*
Mount Cole Creek at Crowlands	2.3	2.5	3.45	Yes	Yes

*Navarre gauge was not functioning correctly during the January 2011 event

The gauging stations at Wimmera River at Eversley (Figure 3-3) and Wimmera River at Glynwylln (Figure 3-4) suffered damage during the January 2011 flood event that required repair works following the flood event. However, both of these gauges continued to record water levels.

Following conversations with Thiess Services, BMT WBM was advised that that all four gauges in the Upper Wimmera catchment were to be re-rated based on the recent flood events. The re-rating was to include physical gauging undertaken during the recent flood events. The updated data was provided by Thiess Services to BMT WBM. It was noted that significant differences in flow between the previously sourced data and the updated data exist, particularly in the larger events including January 2011. The updated data was used for the FFA and calibration presented in this report.

Further as part of the hydraulic modelling process a rating analysis will be undertaken at each of the gauge locations. The rating curves will be compared to the hydraulic modelling results, particularly at high station levels with significant out of bank flows where it has not been possible to obtain manual streamflow gauging.

3.1.2.3 Censored Data

During the period of record there were a number of low flow years during drought periods. During these years there was effectively no flood flow. As recommend in Australian Rainfall and Runoff (ARR) Book IV Peak Flow Estimation (Kuczera and Franks, 2006), low flows were censored from the dataset to ensure that these low flows did not unduly affect the fit of the flood frequency curve.

To determine mean daily discharge values below which to censor data, flow duration curves were prepared for each of the four gauges being analysed and these are presented in Figure 3-5 to Figure 3-8 for each of four gauges. The updated mean daily flow as provided by Thiess Services was used for censoring data. Only the mean daily flows that were equalled or exceeded 5% of the time on the flow duration curve were used in the FFA, these flow values are presented in Table 3-3.

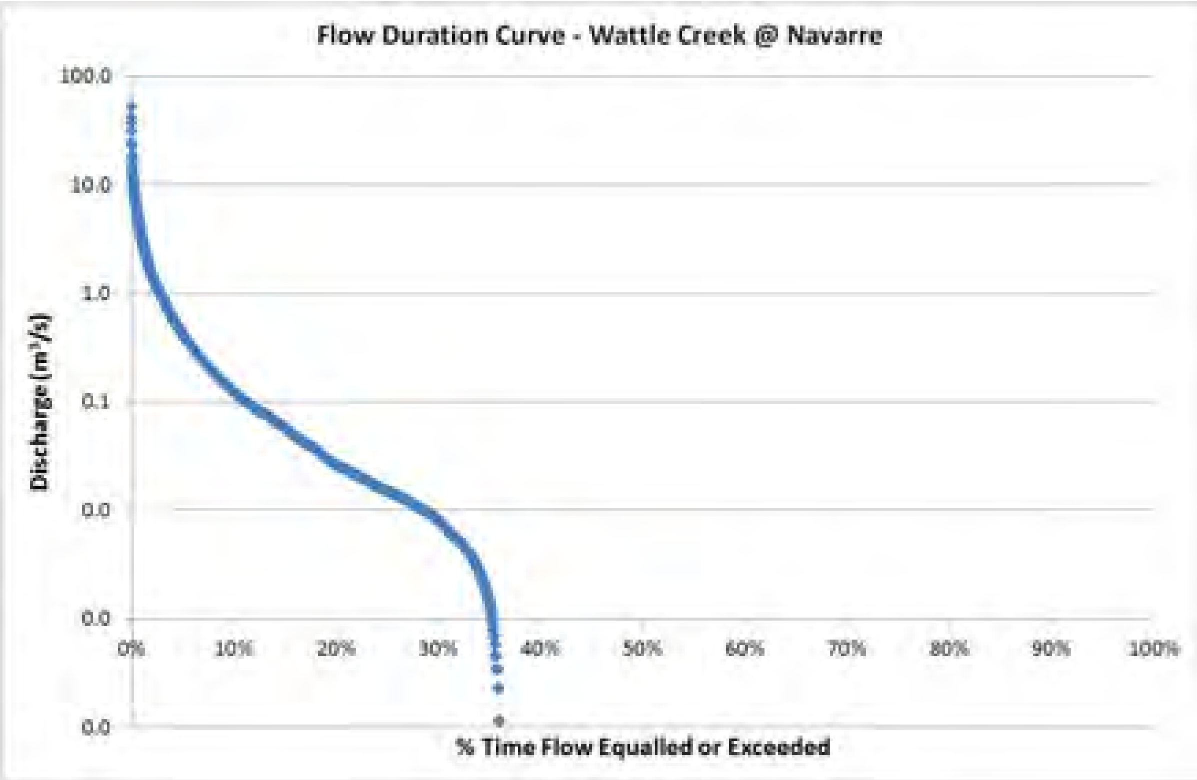


Figure 3-5 Flow Duration Curve - Wattle Creek at Navarre

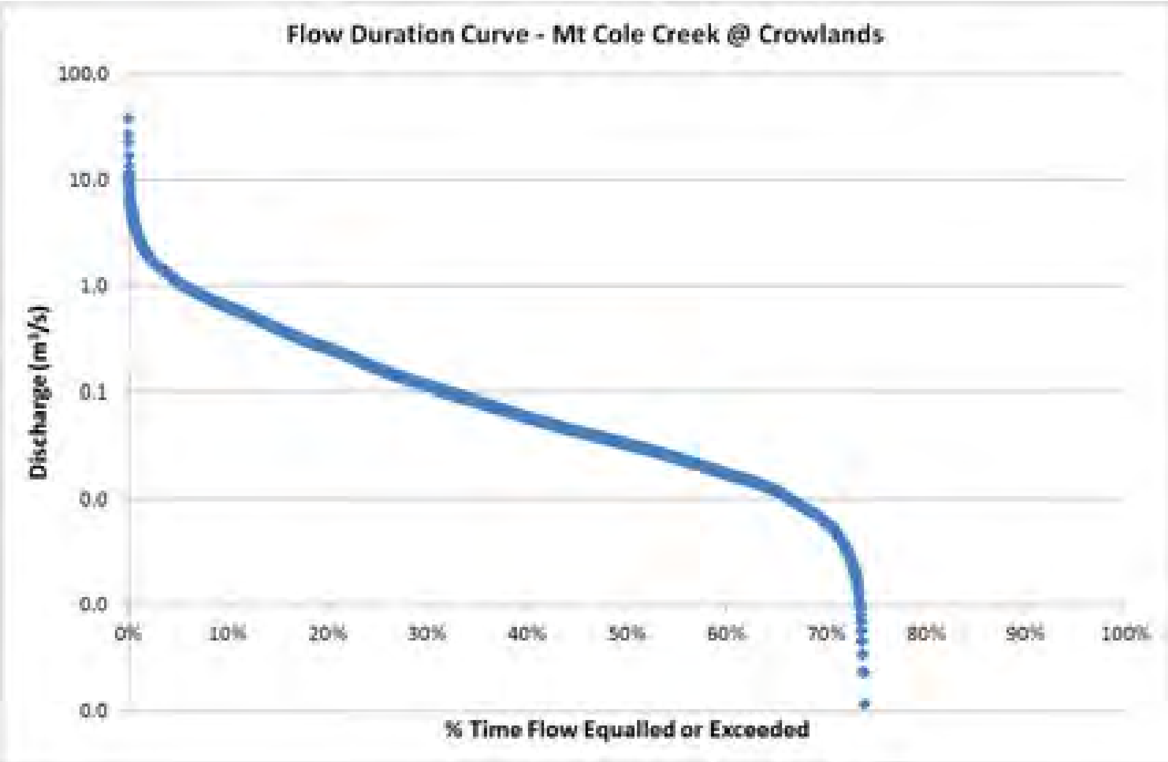


Figure 3-6 Flow Duration Curve - Mount Cole Creek at Crowlands

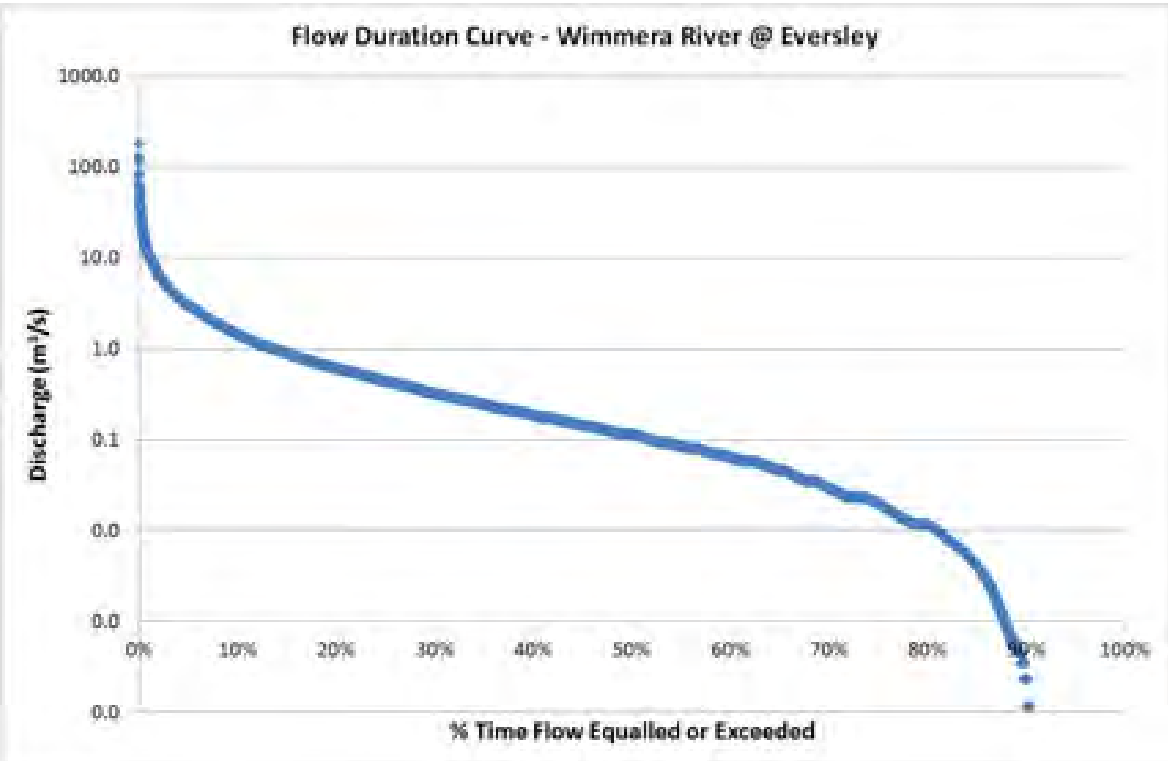


Figure 3-7 Flow Duration Curve - Wimmera River at Eversley

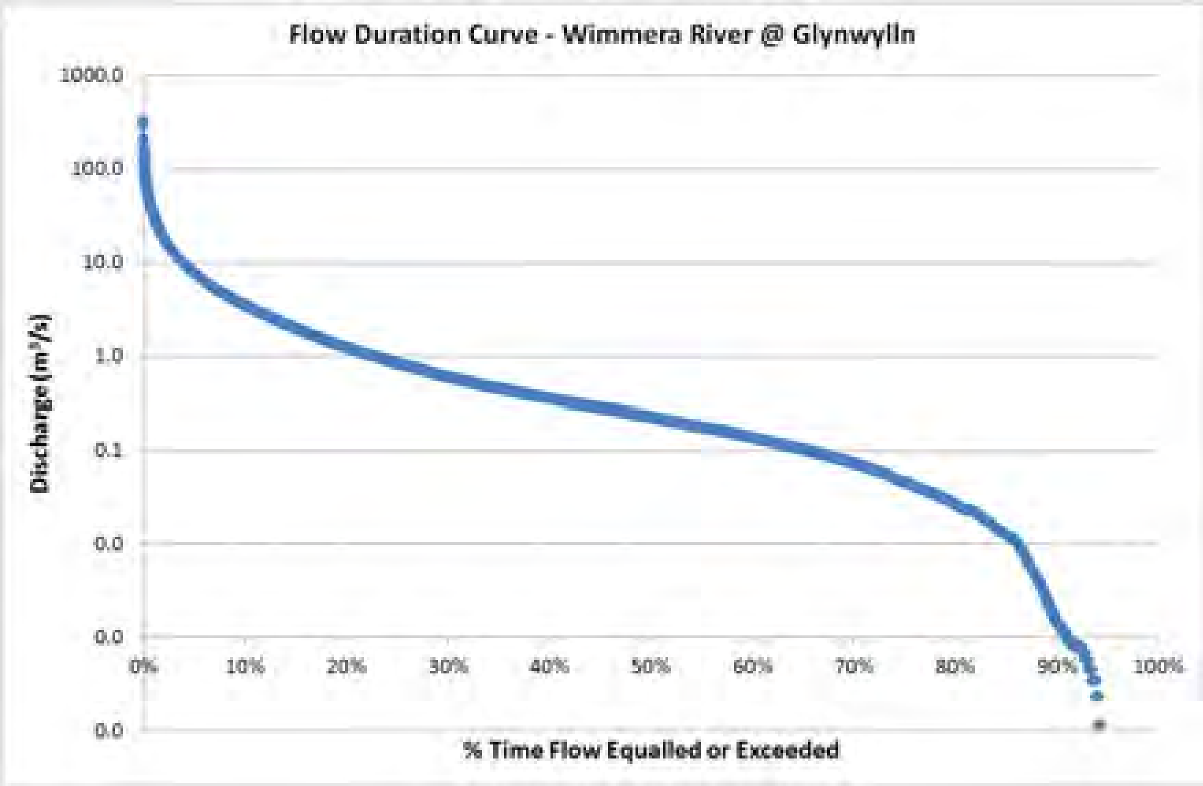


Figure 3-8 Flow Duration Curve - Wimmera River at Glynwylln

Table 3-3 Censored Data Values

Gauge Site	Flow Rate equalled or exceeds 5% of the time
Wattle Creek at Navarre	0.42 m^3/s
Mount Cole Creek at Crowlands	1.09 m^3/s
Wimmera River at Eversley	2.94 m^3/s
Wimmera River at Glynwylln	7.74 m^3/s

3.1.2.4 Historic Data

There was no historic data, other than that from the stream gauges, included in the flood frequency analysis. Whilst large flood events are known to have occurred in the catchment prior to the commencement of stream gauging, the available information indicates that these historic events were smaller than the more recent events that have been captured in the stream gauge record.

As discussed previously in Section 3.1.2.2, the Wattle Creek at Navarre stream gauge was inoperable during the January 2011 flood event. This flood event is considered to be the largest flood event to have occurred at this location in living memory. Although flow data is not available for this event to be included in the Flood Frequency Analysis, the FLIKE software package has a feature that can include anecdotal information in the FFA to account for large events (like 'the biggest in living memory') that do not have reliable data. This feature of FLIKE was used to include the January 2011 flood event for the Wattle Creek at Navarre FFA.

3.1.2.5 Extending Instantaneous Flow Record

Where mean daily flows records exist that exceed the instantaneous record (Wimmera River at Glynwylln and Eversley) these were used to extend the instantaneous record. This was achieved by plotting the mean daily flow against the instantaneous flow record where they overlap. These are illustrated in Figure 3-9 and Figure 3-10 for Eversley and Glynwylln respectively. From the plotted data a line was fitted that represents the best fit for the available overlap of data. For the Eversley gauge an R^2 value (a coefficient of determining the variability in a data set from predicted to observed, a value of 1 indicates a perfect fit) of 0.89 was noted, the Glynwylln gauge indicated a similar level of fit with an R^2 value of 0.93.

From this a relationship was derived and then applied to the historic mean daily flow record to estimate the peak flow on the day. The estimated peak flow was used in the FFA to extend the record in years where instantaneous flow data was not collected. The derived relationship was only applied where instantaneous flow records were unavailable.

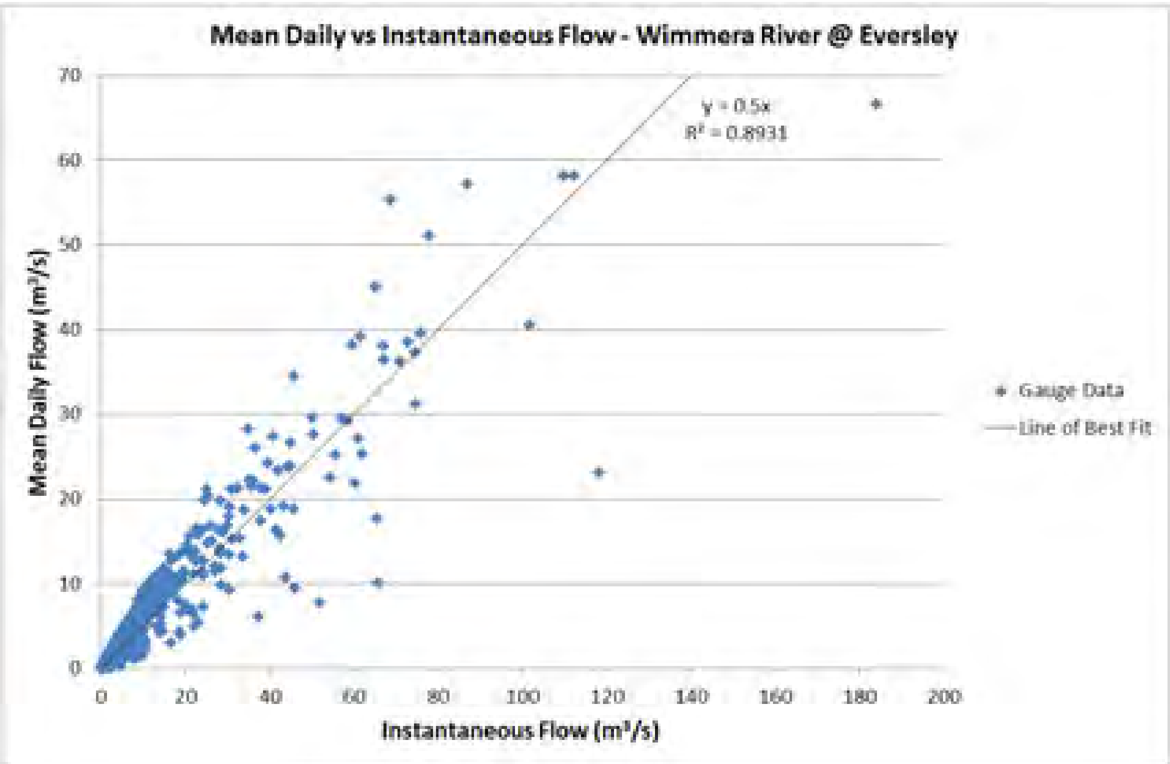


Figure 3-9 Mean Daily vs Instantaneous Flow - Wimmera River at Eversley

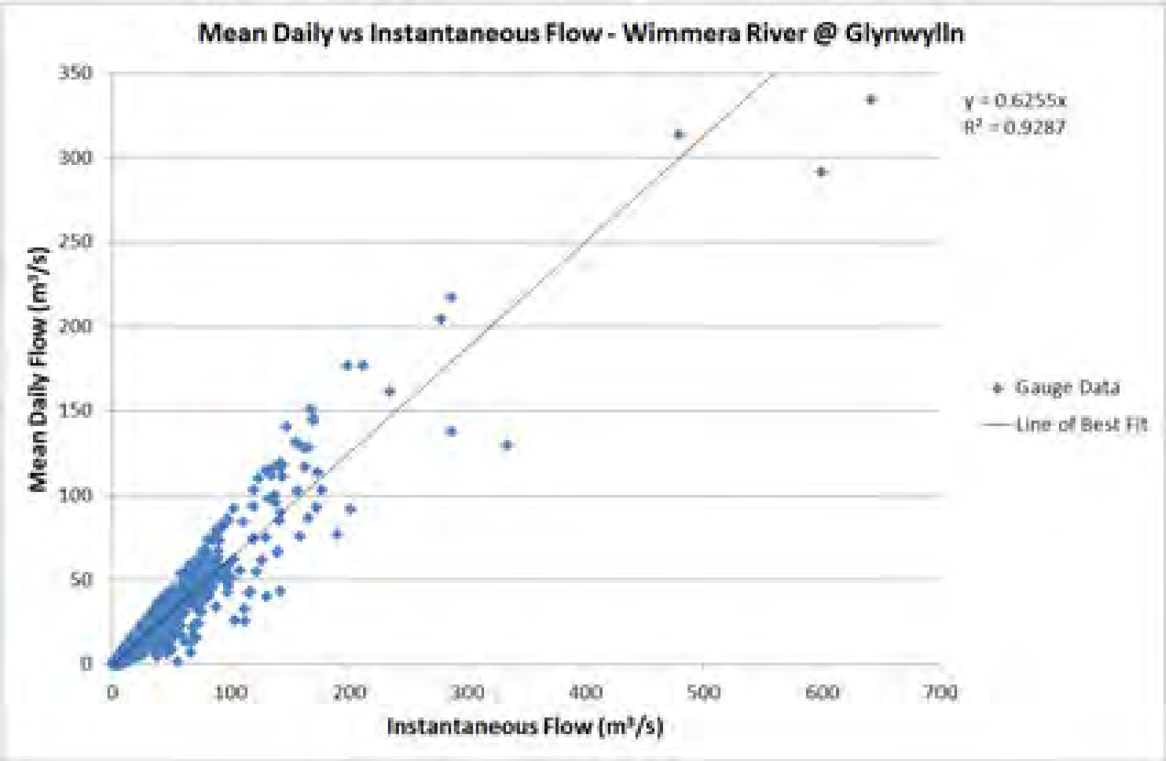


Figure 3-10 Flow Duration Curve - Wimmera River at Glynwylln

3.1.3 Flood Frequency Analysis

The FFA was undertaken using the FLIKE software program which uses a Bayesian inference framework. The software uses global search to determine the most probable values of the parameters and calculates a second-order approximation of the posterior distribution. Confidence limits are then calculated together with flood quantiles and expected probability flood distributions. FLIKE has the capability to use 5 flood probability models or extreme value distributions, namely:

- Log Normal;
- Log Pearson Type III;
- Gumbel;
- Generalised Extreme Value; and
- Generalised Pareto.

As there is no theoretical basis to select one flood probability model or distribution over another all 5 flood models were investigated.

3.1.3.1 Annual Maximum Data

The annual maximum data for each of the gauging stations are listed in Table 3-4 to Table 3-7. For the purposes of the FFA a water year was used starting 1st of October to 30th September the following calendar year. Using the water year as opposed to a calendar year increases the likelihood that the maximum event of a given year is independent of the maximum event of the preceding and following year. BMT WBM have checked all events to ensure independence across the September – October divide. The data was modified within FLIKE to take account of the censored flows and the historic information as discussed above. The results were then investigated and the most appropriate distribution selected.

Table 3-4 Annual Maximum Series: Wattle Creek at Navarre

Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)
1	2010	92	19	1989	19
2	1993	65	20	1978	19
3	1999	62	21	1986	13
4	1981	61	22	2008	12
5	1988	59	23	2000	10
6	1983	51	24	1982	10
7	1996	44	25	1977	8
8	1979	42	26	2003	7
9	1992	40	27	1985	6
10	1980	34	28	1998	5
11	1990	33	29	2009	5
12	2011*	33	30	2001	5
13	1991	31	31	2004	2
14	1997	30	32	2007	0
15	1987	29	33	2002	0
16	1995	28	34	2005	0
17	1994	25	35	2006	0
18	1984	22			

* The gauge recording for January 2011 is considered erroneous as the January 2011 is acknowledged as the largest flood event at this location in living memory. Refer to discussion in subsequent section of this report.

Table 3-5 Annual Maximum Series: Mount Cole Creek at Crowlands

Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)
1	2011	93	14	1995	11
2	2010	50	15	1991	7
3	1987	39	16	1986	7
4	1988	37	17	2009	6
5	1990	21	18	1999	5
6	1992	20	19	2001	4

Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)
7	1993	16	20	1994	3
8	1989	16	21	2000	3
9	2005	13	22	1998	3
10	2007	13	23	2004	3
11	1996	12	24	2003	2
12	1997	12	25	2002	1
13	2008	12	26	2006	0

Table 3-6 Annual Maximum Series: Wimmera River at Eversley

Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)
1	2011	396	28	1908	52	55	1919	19
2	1910	264	29	1997	50	56	1927	18
3	1909	234	30	1964	49	57	1991	17
4	2010	225	31	1980	46	58	1972	17
5	1974	184	32	1975	44	59	1978	16
6	1912	173	33	1907	44	60	1971	16
7	1923	158	34	1984	44	61	2000	11
8	1920	115	35	1973	43	62	1928	11
9	1983	112	36	1979	42	63	1985	10
10	1996	110	37	1904	41	64	1966	10
11	1918	91	38	1986	40	65	1994	10
12	1903	88	39	1982	38	66	2008	10
13	1988	87	40	1932	37	67	1998	9
14	1976	78	41	1922	35	68	2005	8
15	1992	76	42	1925	35	69	1970	8
16	1993	74	43	1999	33	70	2009	7
17	1968	74	44	1990	32	71	2001	7
18	1924	72	45	1913	31	72	1967	6
19	1965	70	46	1933	30	73	1977	6
20	1981	67	47	1987	30	74	2003	6
21	1911	65	48	1989	28	75	2007	3
22	1917	65	49	1926	28	76	1914	2
23	1921	65	50	1969	26	77	2002	2
24	1931	65	51	1930	25	78	2004	1
25	1916	63	52	1905	25	79	2006	0

Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)
26	1915	63	53	1929	21			
27	1906	52	54	1995	19			

Table 3-7 Annual Maximum Series: Wimmera River at Glynwylln

Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)	Rank	Water Year Ending	Discharge (m^3/s)
1	2011	641	23	1999	103	45	1972	26
2	2010	479	24	1984	97	46	1969	24
3	1988	286	25	1971	97	47	1961	24
4	1981	278	26	1975	91	48	1948	23
5	1973	235	27	1964	89	49	1949	21
6	1983	212	28	1958	88	50	1966	20
7	1974	199	29	1987	79	51	1985	18
8	1956	187	30	1995	77	52	1977	17
9	1992	174	31	1952	72	53	1998	17
10	1996	170	32	1991	70	54	2001	15
11	1997	170	33	1951	69	55	2005	14
12	1976	168	34	1989	67	56	2000	13
13	1955	161	35	1986	65	57	2003	11
14	1993	155	36	1982	60	58	1962	11
15	1960	147	37	1950	56	59	2004	11
16	1965	144	38	2009	54	60	1967	11
17	1980	142	39	1994	41	61	2007	10
18	1979	134	40	1957	41	62	2008	10
19	1990	119	41	1959	39	63	1970	9
20	1968	111	42	1978	37	64	2002	3
21	1954	110	43	1947	36	65	2006	2
22	1953	106	44	1963	32			

3.1.3.2 Results - Wattle Creek at Navarre

The FFA was undertaken for Wattle Creek at Navarre using the annual maximum data listed in Table 3-4 and censoring flows less than the 5% exceedance flow. In addition, the recorded January 2011 event was excluded from the annual series due to its incorrect recording of the peak flow. However, as the January 2011 flood event is considered the largest flood to have occurred at this gauge location, it has been included by using a feature in FLIKE that allows for the inclusion of historical floods that do not have details regarding the discharge. The inclusion of this event does not require an estimate of the size of the discharge during the event but rather a qualitative description, ie: it was the biggest flood during the record length. In the case of the Wattle Creek at Navarre gauge, the January 2011 event was included as the largest event to have occurred in the 35 year of stream gauging records.

Inspection of the results presented in Figure 3-11 to Figure 3-15 indicates that acceptable fits are provided by all distributions with the exception of the Log-Normal (Figure 3-11) distribution; distributions are considered acceptable if the 90% confidence limits encompass gauged data (labelled the Gauged Flows in Figure 3-11 to Figure 3-15).

Given the relatively short gauging period at Navarre of 35 years there is considerable uncertainty in the estimate of rarer events (those with longer return periods) regardless of distributions. The Log Pearson Type III distribution (Figure 3-12) indicates this greater uncertainty for the rarer events better than the other distributions such as Gumbel which suggests tighter confidence limits than seems feasible considering the limited data set.

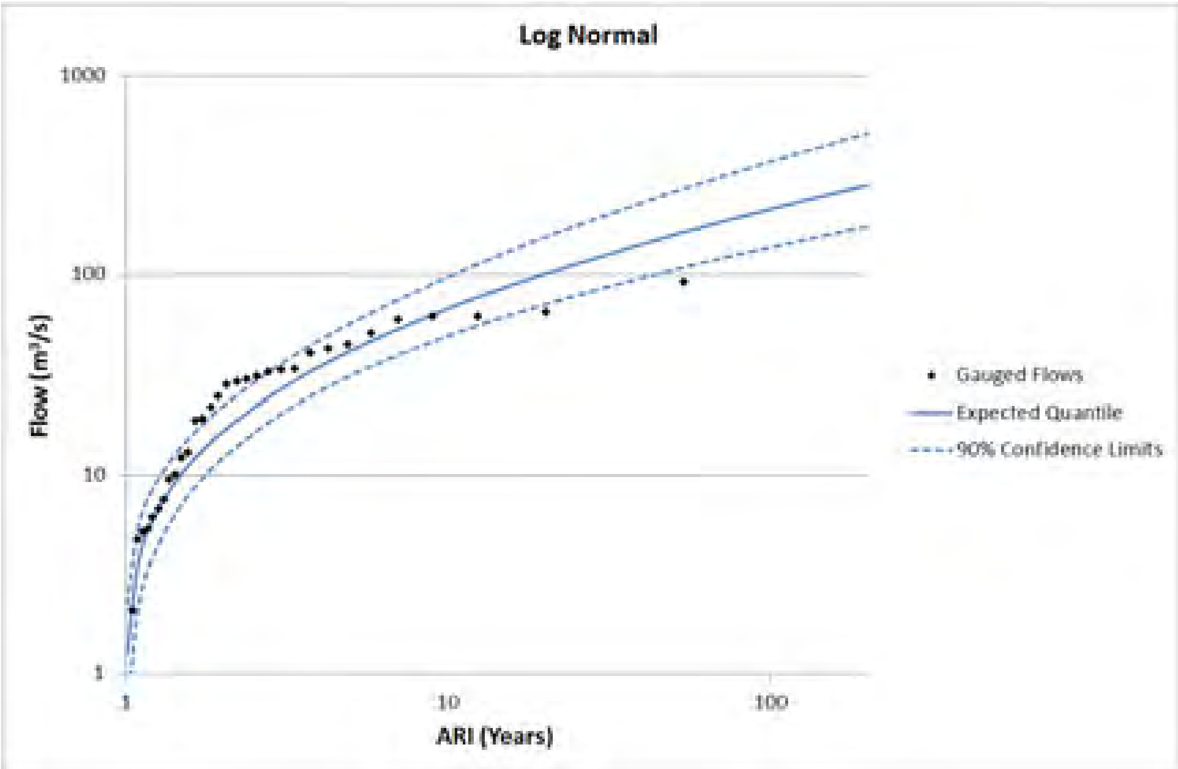


Figure 3-11 FFA Results: Wattle Creek at Navarre - Log Normal Fitting

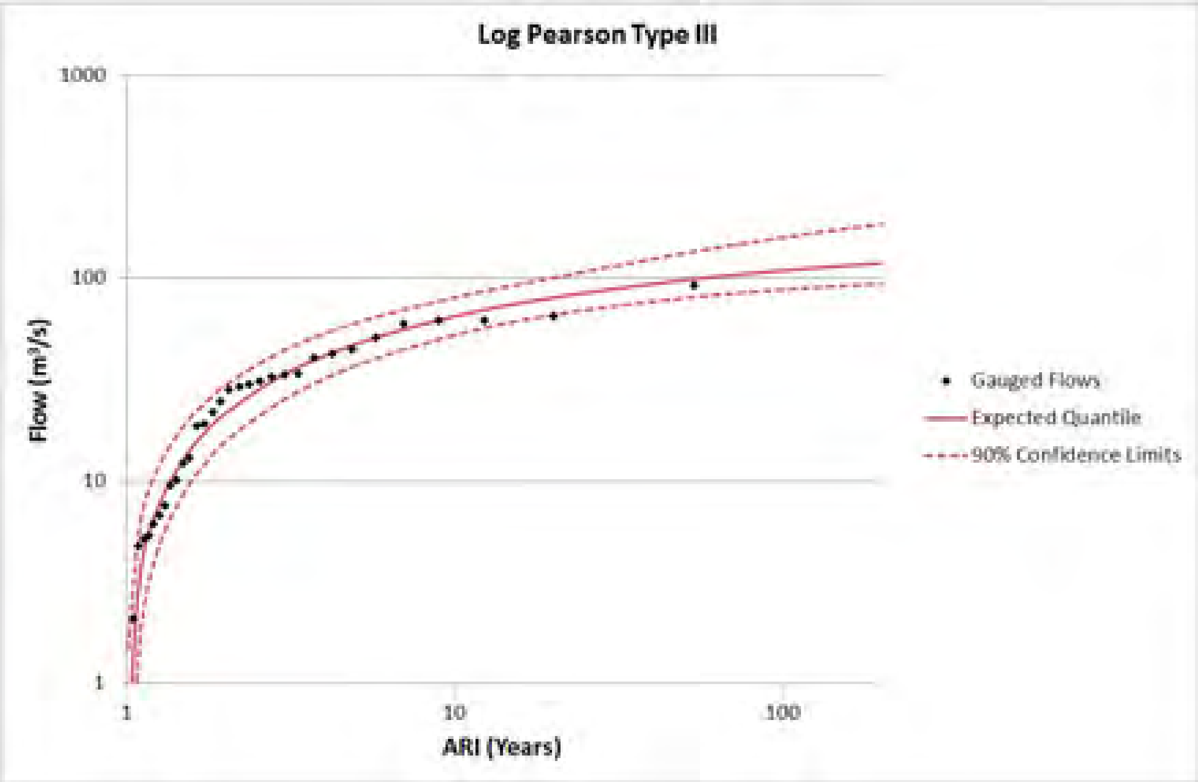


Figure 3-12 FFA Results: Wattle Creek at Navarre - LP3 Fitting

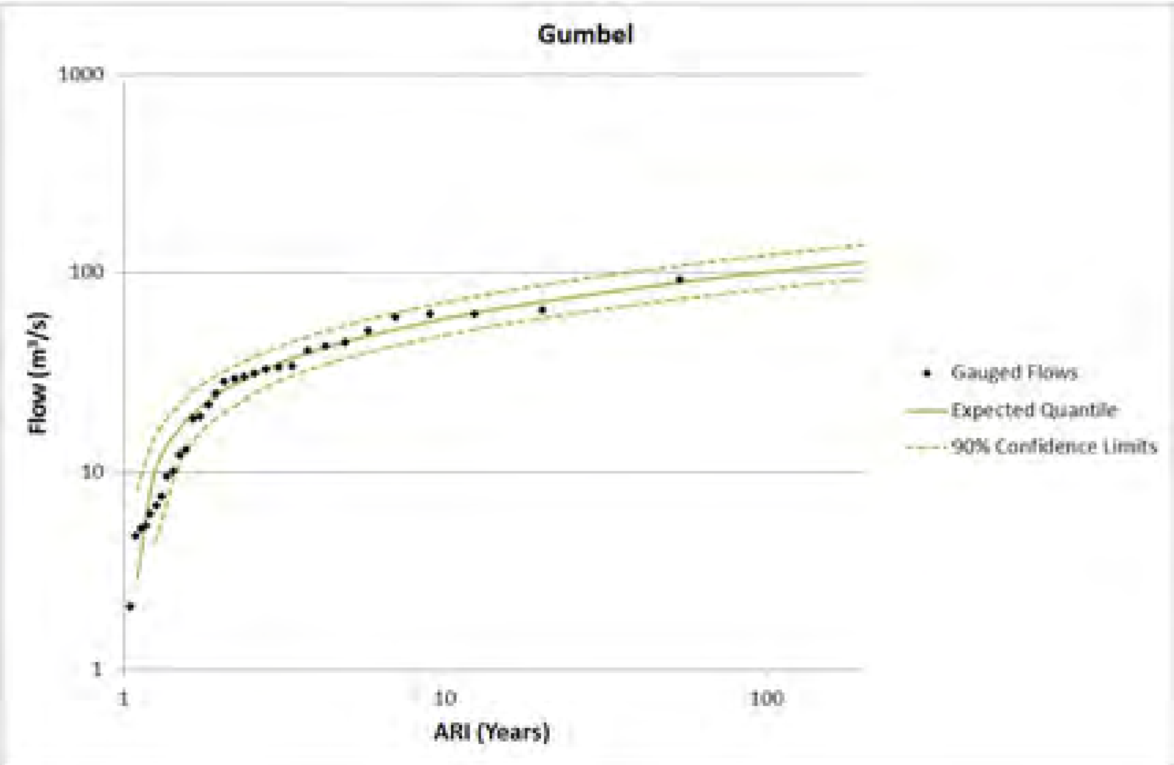


Figure 3-13 FFA Results: Wattle Creek at Navarre - Gumbel Fitting

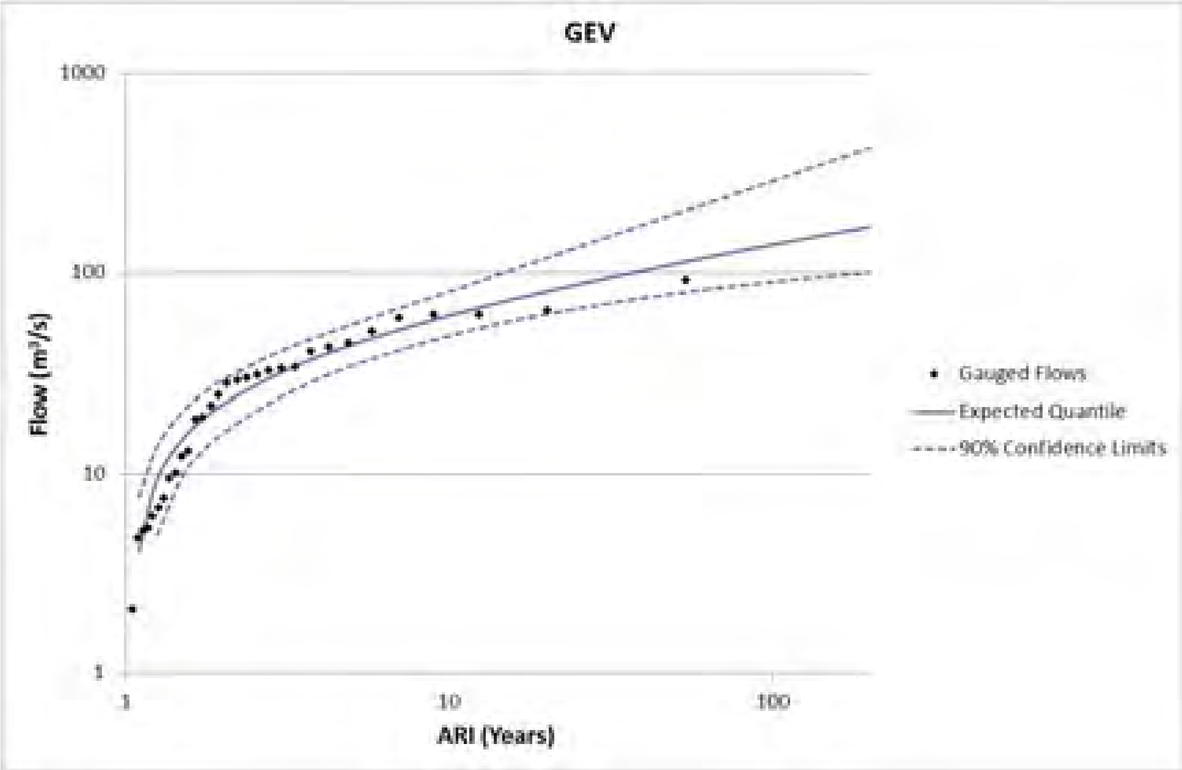


Figure 3-14 FFA Results: Wattle Creek at Navarre - GEV Fitting

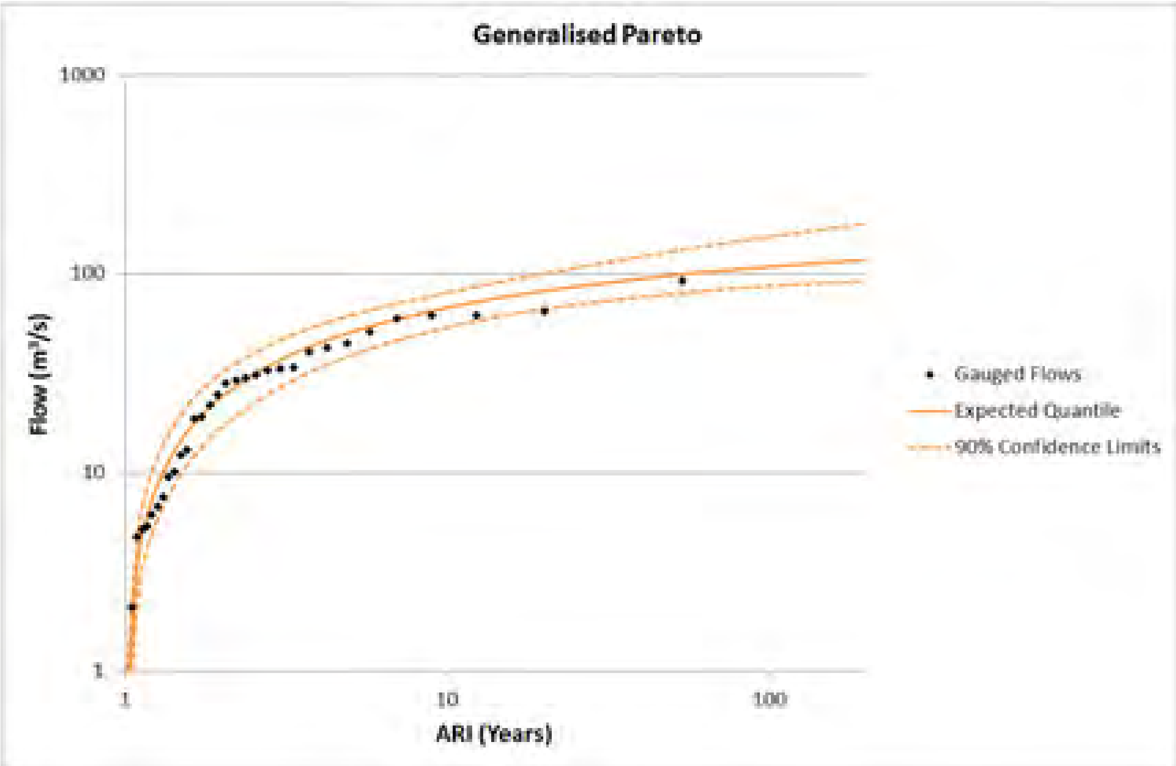


Figure 3-15 FFA Results: Wattle Creek at Navarre - Generalised Pareto Fitting

The Log Pearson Type III distribution provides an acceptable fit to the data. The results for the Log Pearson Type III distribution are shown in Table 3-8. This table lists the 1% AEP peak discharge as 109 m^3/s.

Table 3-8 Wattle Creek at Navarre: Flood Frequency Analysis Results

AEP	Expected Quantile (m^3/s)	90% Quantile Probability Limits	
20%	47	37	60
10%	65	52	80
5%	80	66	101
2%	98	80	132
1%	109	88	159

3.1.3.3 Results - Mount Cole Creek at Crowlands

The FFA was undertaken for Mount Cole Creek at Crowlands using the annual maximum data listed in Table 3-5 and censoring flows less than the 5% exceedance flow.

Inspection of the results presented in Figure 3-16 to Figure 3-20 indicates that acceptable fits are provided by all distributions with the exception of only the Gumbel distribution (Figure 3-18).

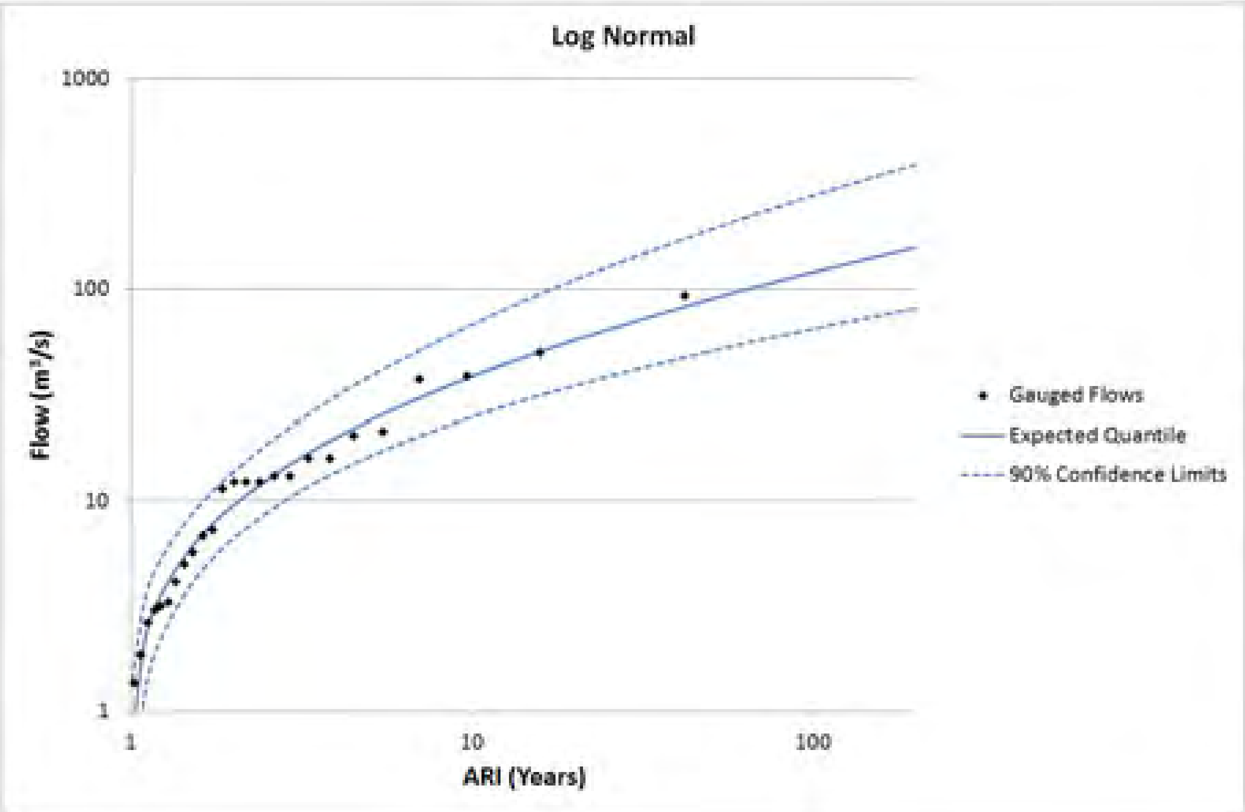


Figure 3-16FFA Results: Mount Cole Creek at Crowlands - Log Normal Fitting

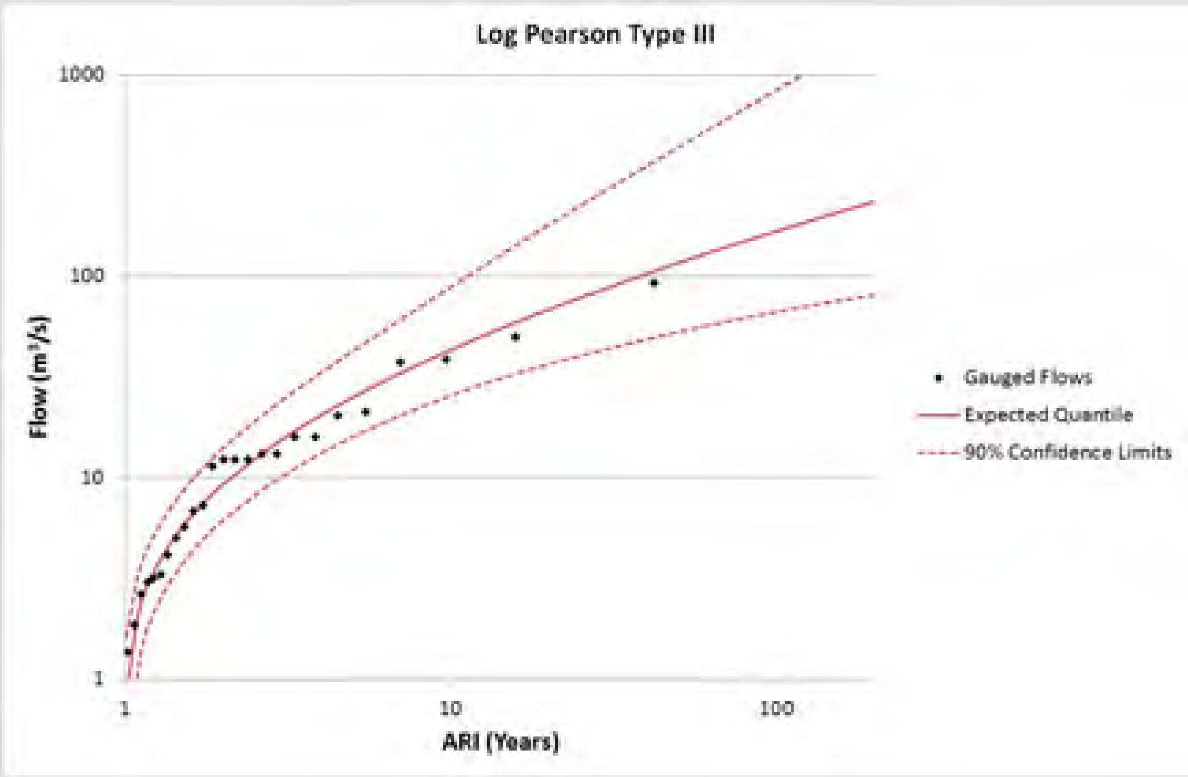


Figure 3-17 FFA Results: Mount Cole Creek at Crowlands - LP3 Fitting

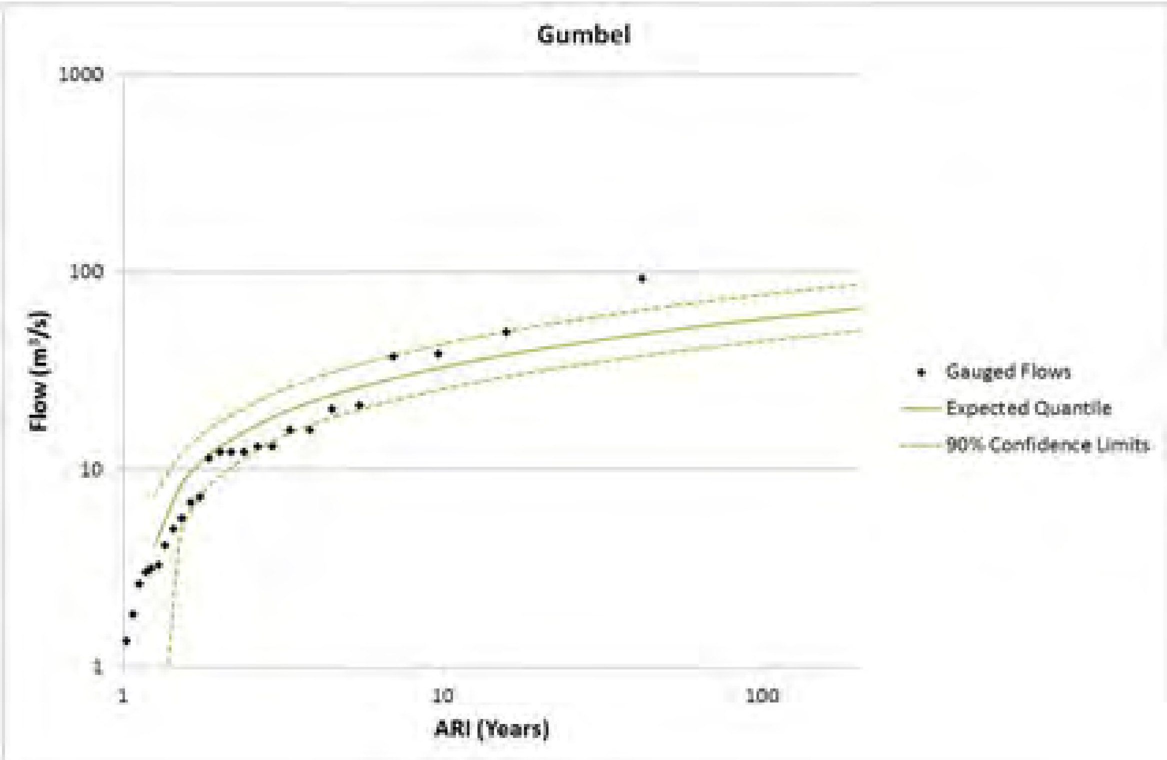


Figure 3-18 FFA Results: Mount Cole Creek at Crowlands - Gumbel Fitting

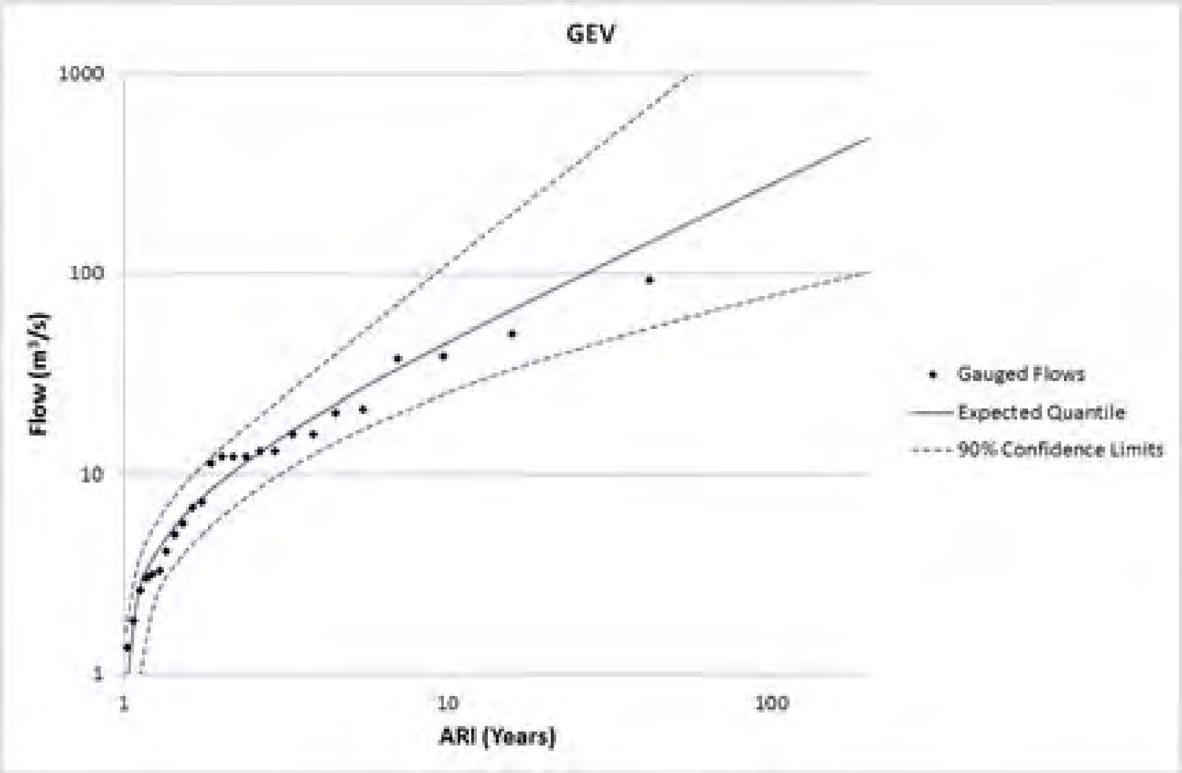


Figure 3-19 FFA Results: Mount Cole Creek at Crowlands - GEV Fitting

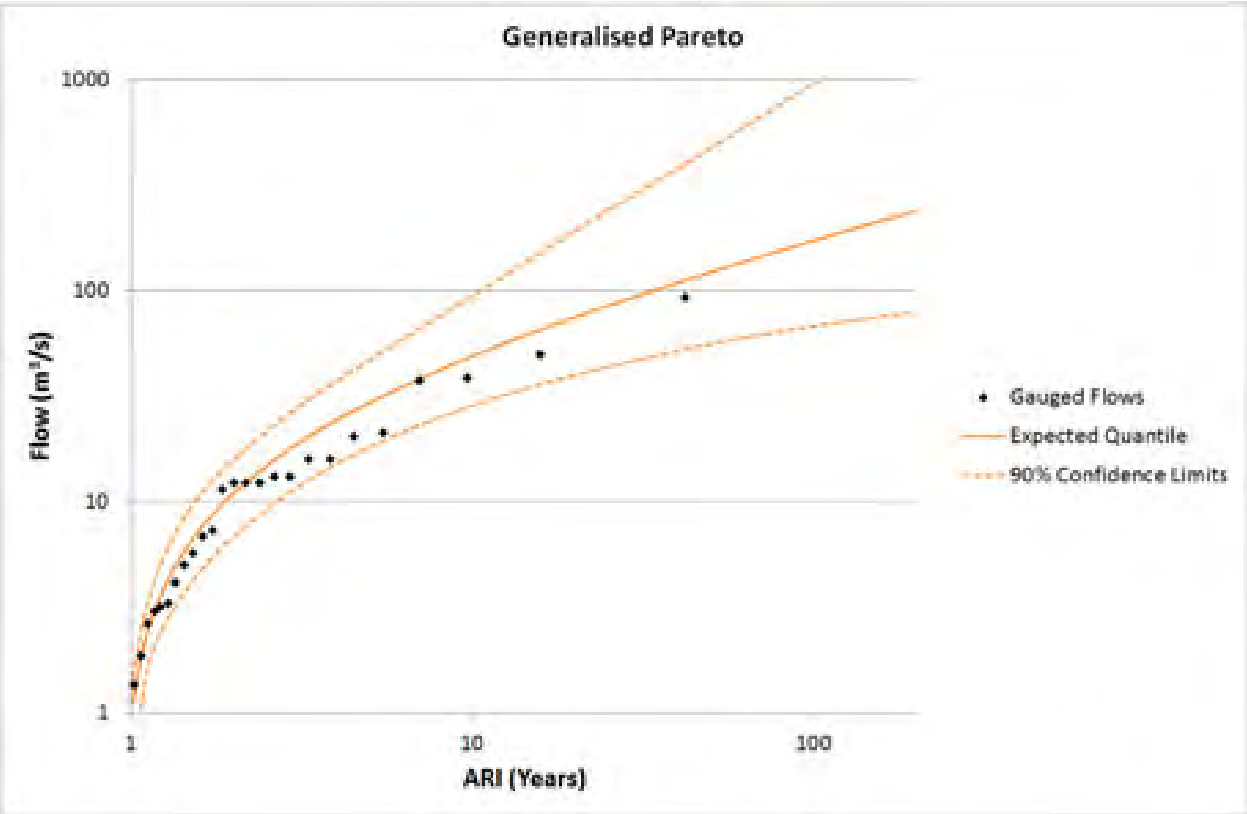


Figure 3-20FFA Results: Mount Cole Creek at Crowlands - Generalised Pareto Fitting

Whilst the Log Normal (Figure 3-16), Log Pearson Type III (Figure 3-17), GEV (Figure 3-19) and Generalised Pareto (Figure 3-20) distributions provide acceptable fits, the Log Pearson Type III is preferred as the fit to the rarer events is better. The results for the Log Pearson Type III distribution are shown in Table 3-9. This table lists the 1% AEP peak discharge as 167 m^3/s.

Table 3-9 Mount Cole Creek at Crowlands: Flood Frequency Analysis Results

AEP	Expected Quantile (m^3/s)	90% Quantile Probability Limits	
20%	25	16	42
10%	43	26	88
5%	68	37	180
2%	116	53	437
1%	167	66	840

3.1.3.4 Results - Wimmera River at Eversley

The FFA was undertaken for the Wimmera River at Eversley using the annual maximum data listed in Table 3-6 and censoring flows less than the 5% exceedance flow.

Inspection of the results presented in Figure 3-21 to Figure 3-25 indicates that acceptable fits are provided by all distributions with the exception of the Gumbel (Figure 3-23) distribution.

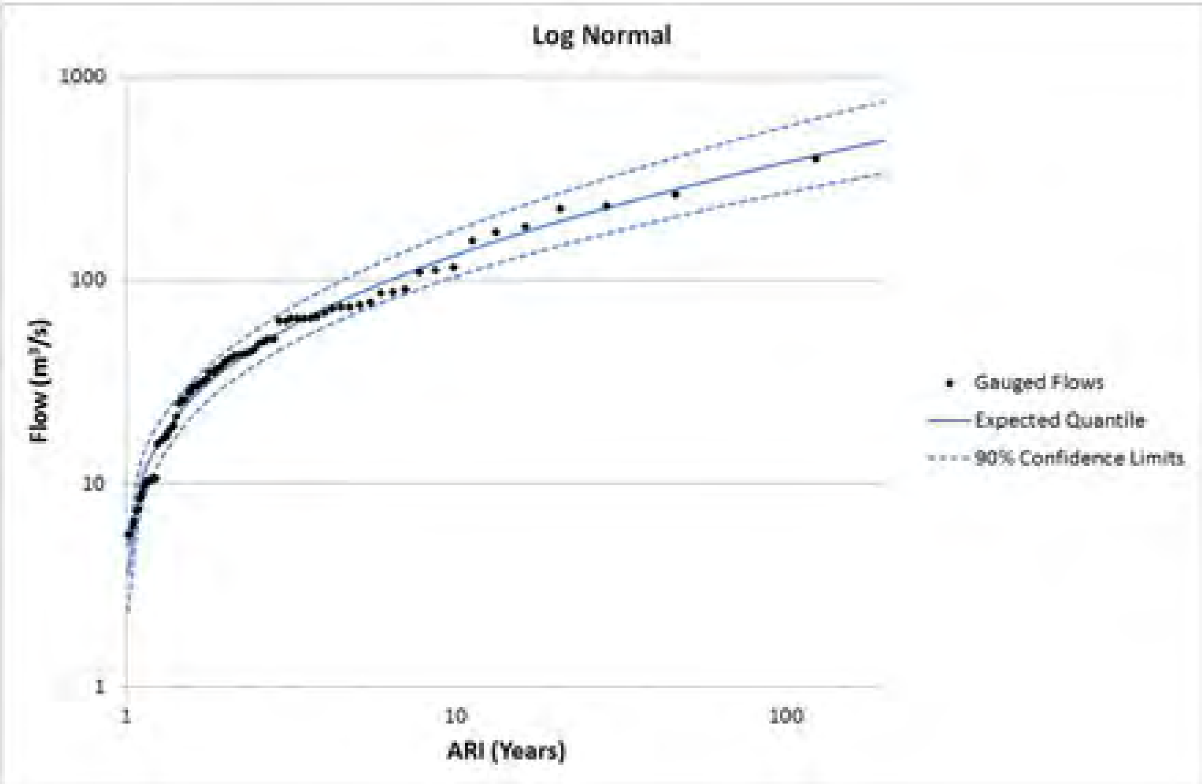


Figure 3-21 FFA Results: Wimmera River at Eversley - Log Normal Fitting

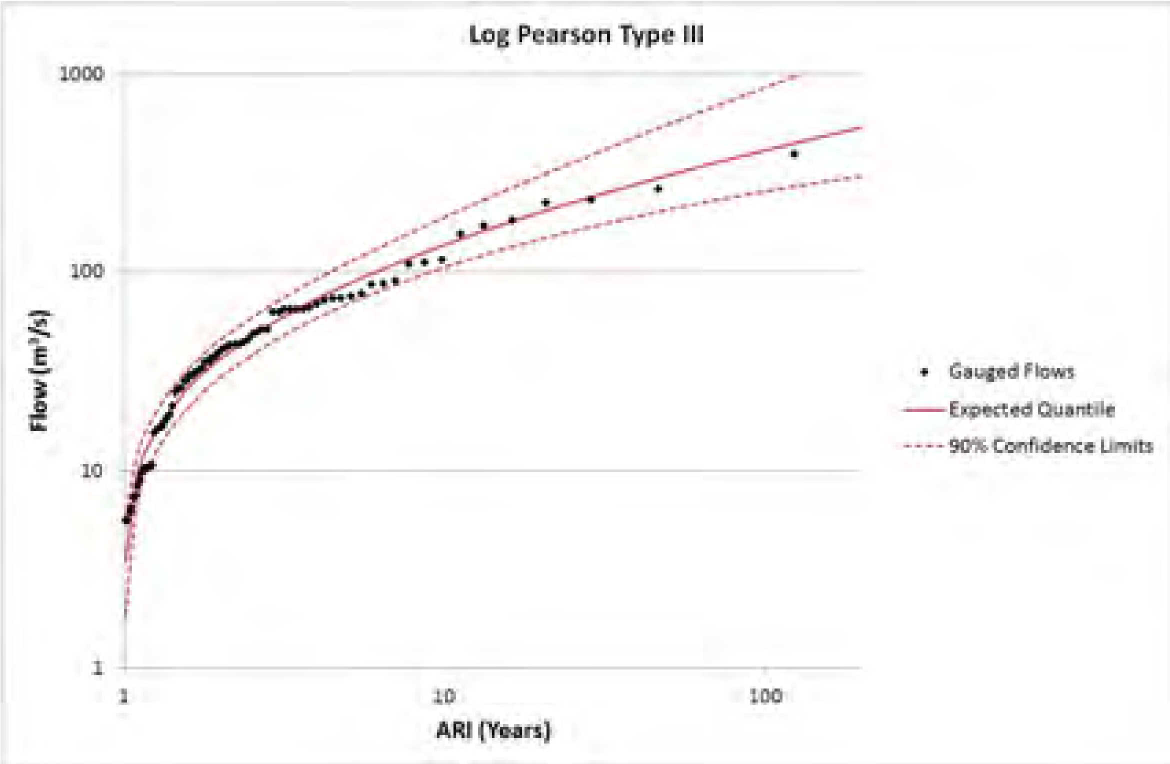


Figure 3-22 FFA Results: Wimmera River at Eversley - LP3 Fitting

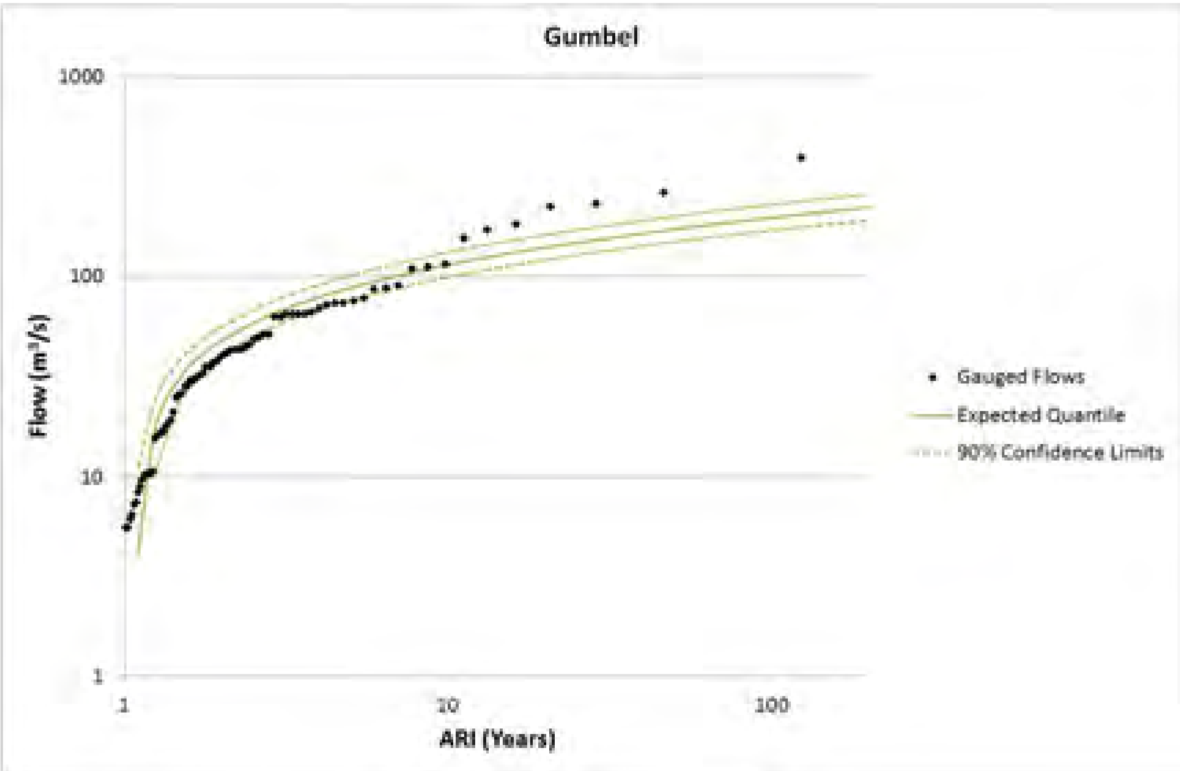


Figure 3-23 FFA Results: Wimmera River at Eversley - Gumbel Fitting

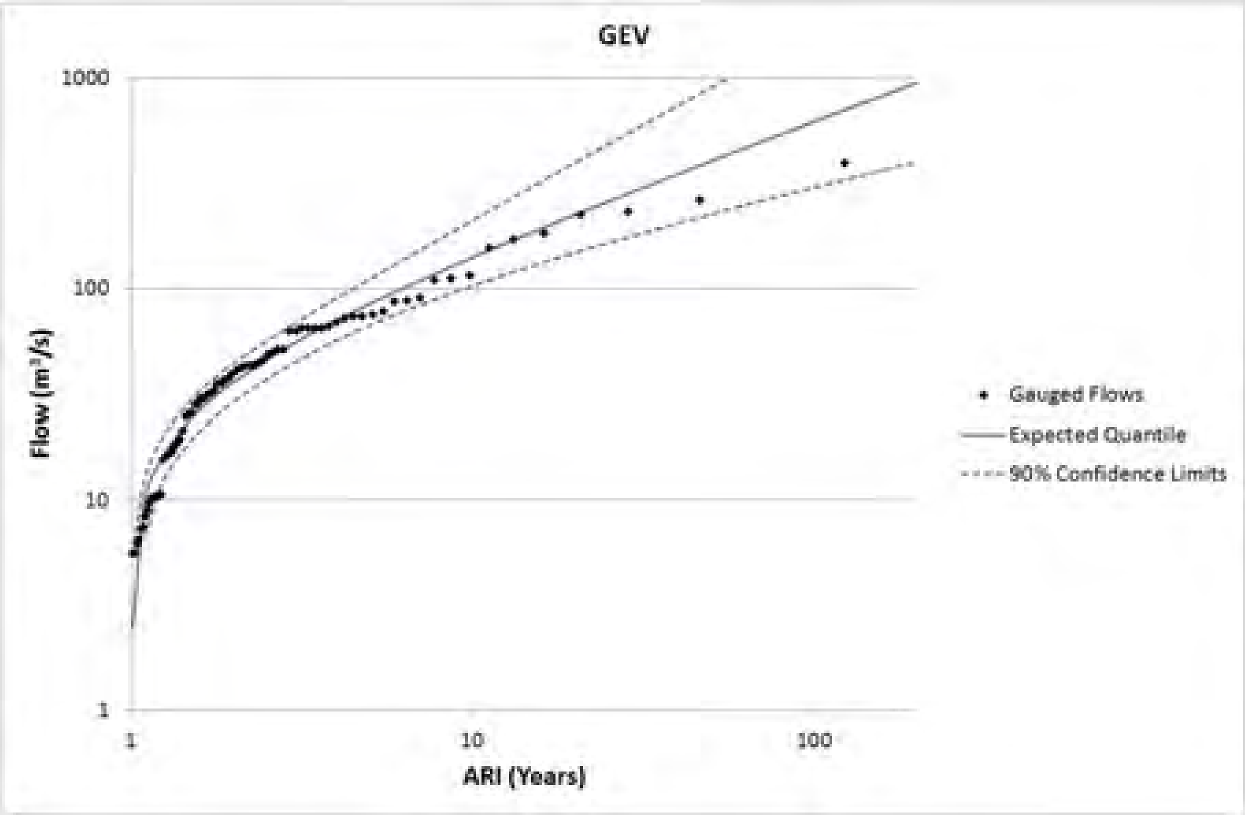


Figure 3-24 FFA Results: Wimmera River at Eversley - GEV Fitting

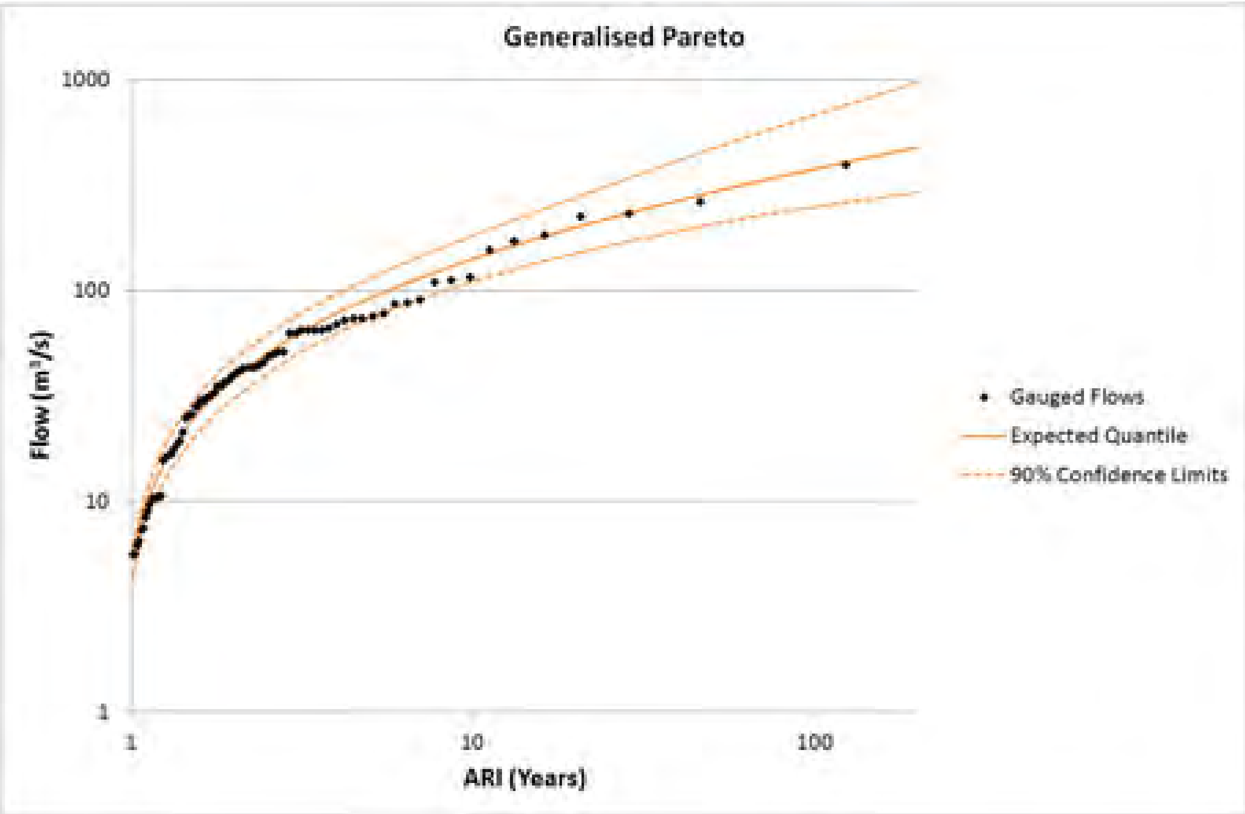


Figure 3-25 FFA Results: Wimmera River at Eversley - Generalised Pareto Fitting

Whilst the Log Normal (Figure 3-21), Log Pearson Type III (Figure 3-22) and Generalised Pareto (Figure 3-25) distributions provide acceptable fits, the Log Pearson Type III is preferred as the fit to the rarer events is better. The results for the Log Pearson Type III distribution are shown in Table 3-10. This table lists the 1% AEP peak discharge as 412 m^3/s.

Table 3-10 Wimmera River at Eversley: Flood Frequency Analysis Results

AEP	Expected Quantile (m^3/s)	90% Quantile Probability Limits	
20%	87	69	111
10%	137	105	189
5%	201	147	307
2%	309	207	560
1%	412	255	856

3.1.3.5 Results - Wimmera River at Glynwylln

The FFA was undertaken for the Wimmera River at Glynwylln using the annual maximum data listed in Table 3-7 and censoring flows less than the 5% exceedance flow.

Inspection of the results presented in Figure 3-26 to Figure 3-30 indicates that acceptable fits are provided by all distributions with the exception of the GEV (Figure 3-29) and Gumbel (Figure 3-28) distributions.

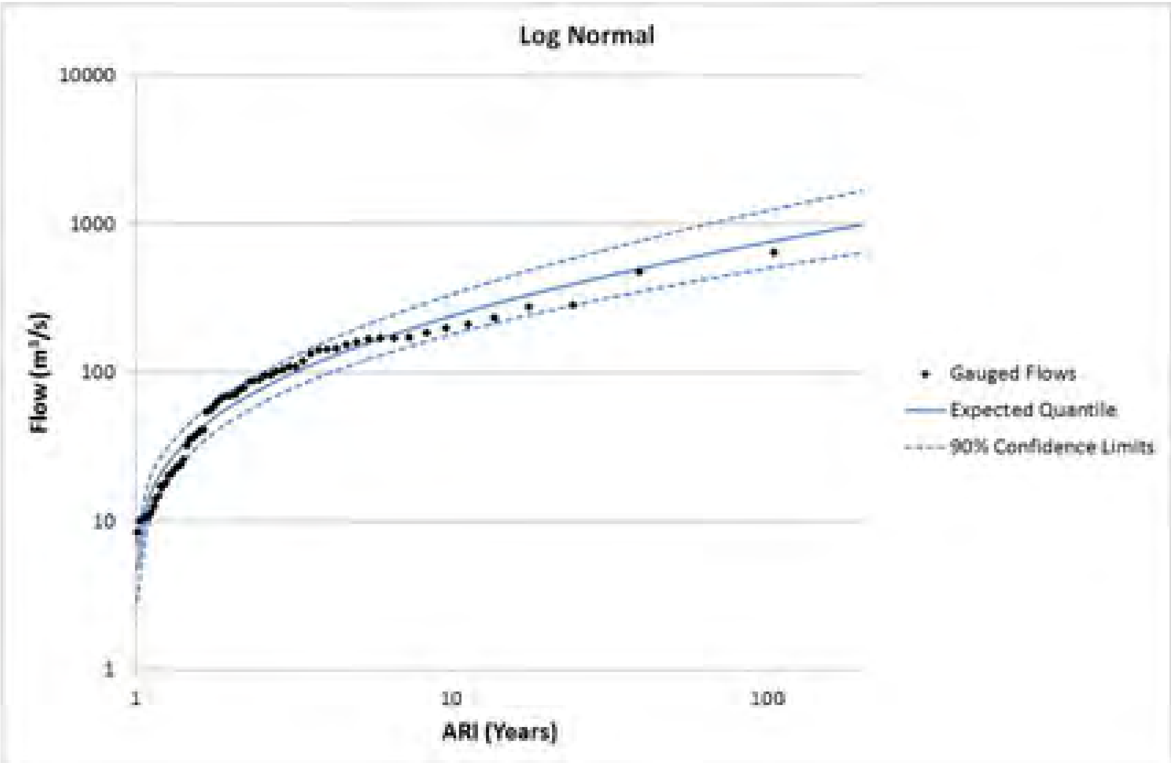


Figure 3-26 FFA Results: Wimmera River at Glynwylln - Log Normal Fitting

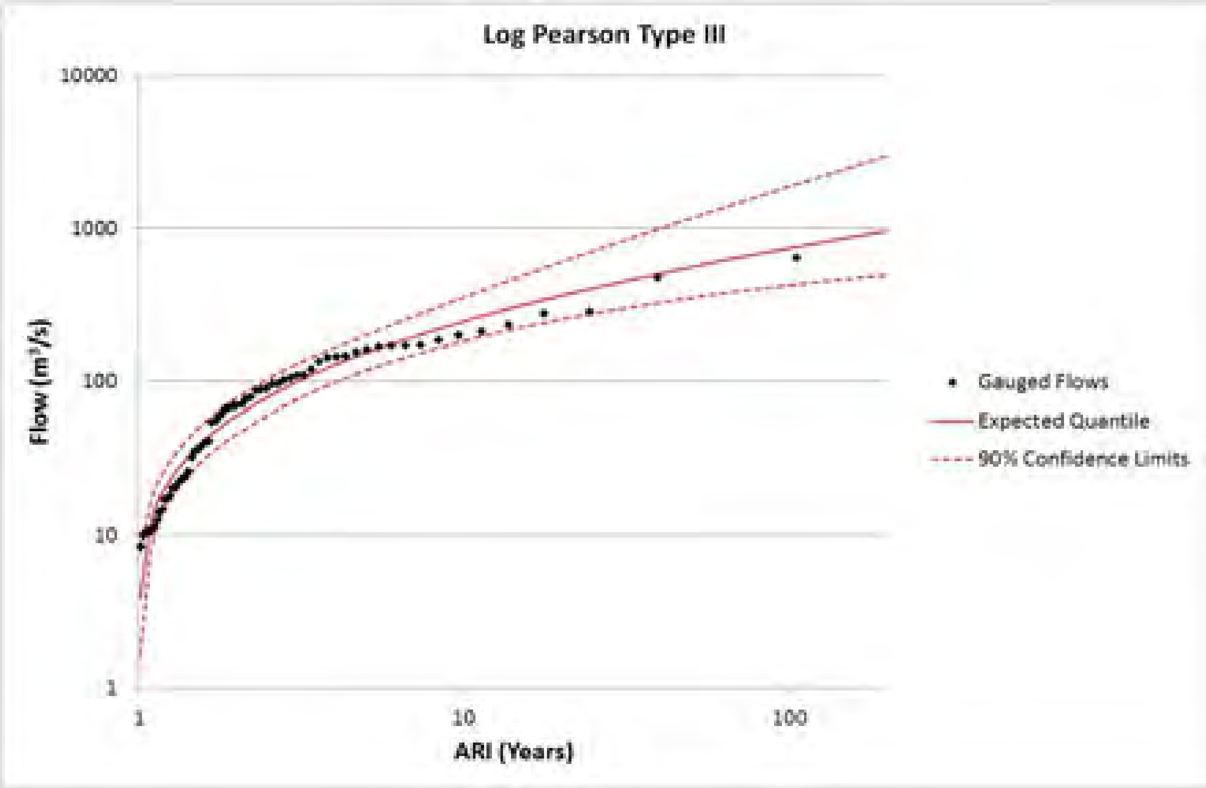


Figure 3-27 FFA Results: Wimmera River at Glynwylln - LP3 Fitting

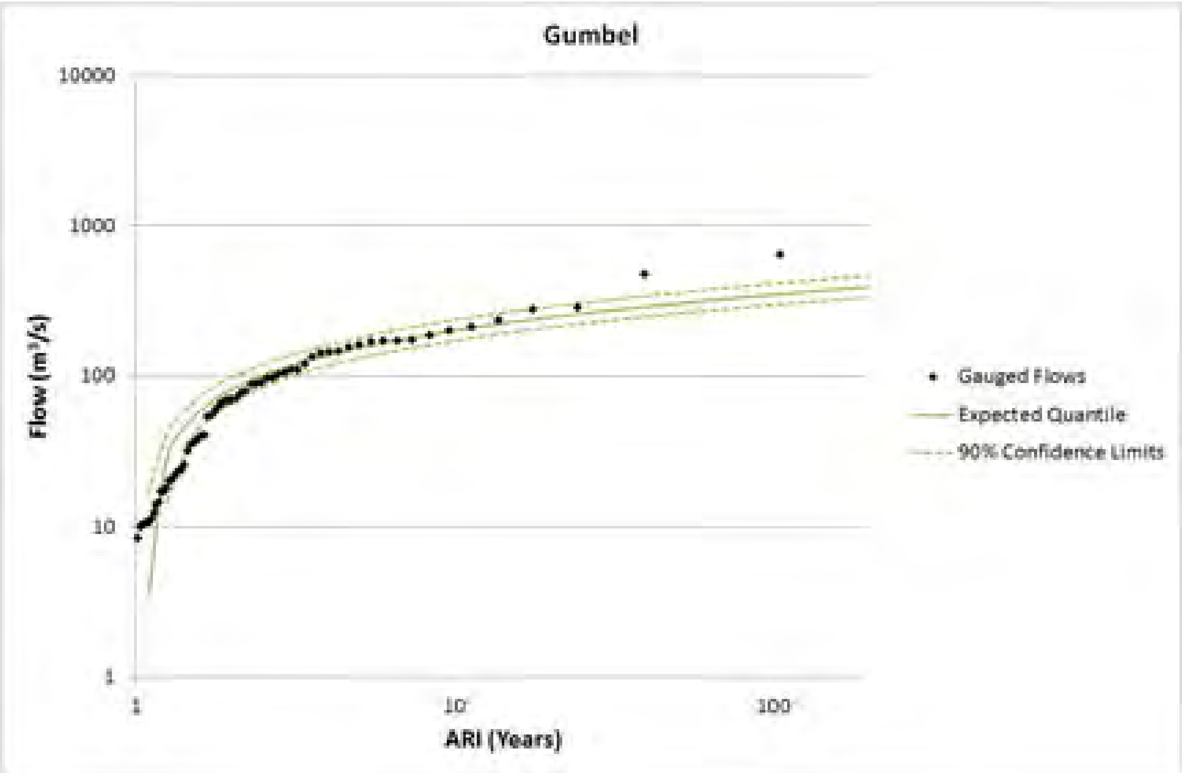


Figure 3-28 FFA Results: Wimmera River at Glynwylln - Gumbel Fitting

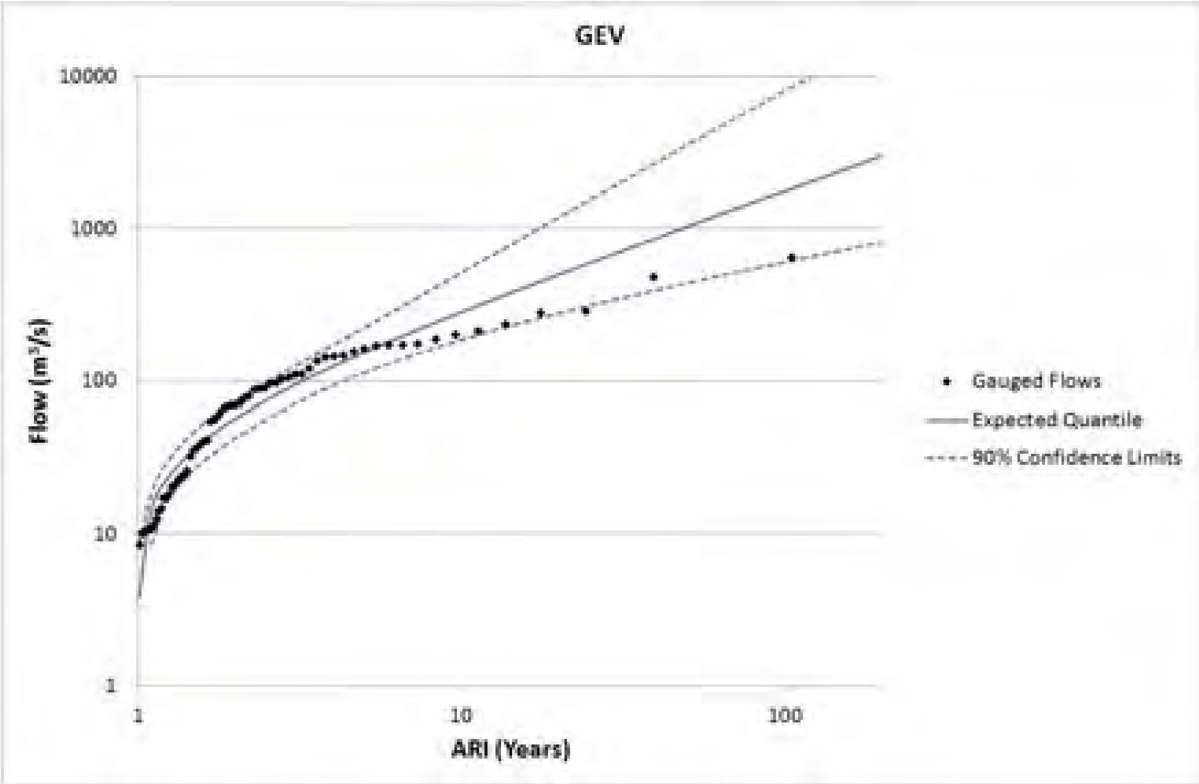


Figure 3-29 FFA Results: Wimmera River at Glynwylln - GEV Fitting

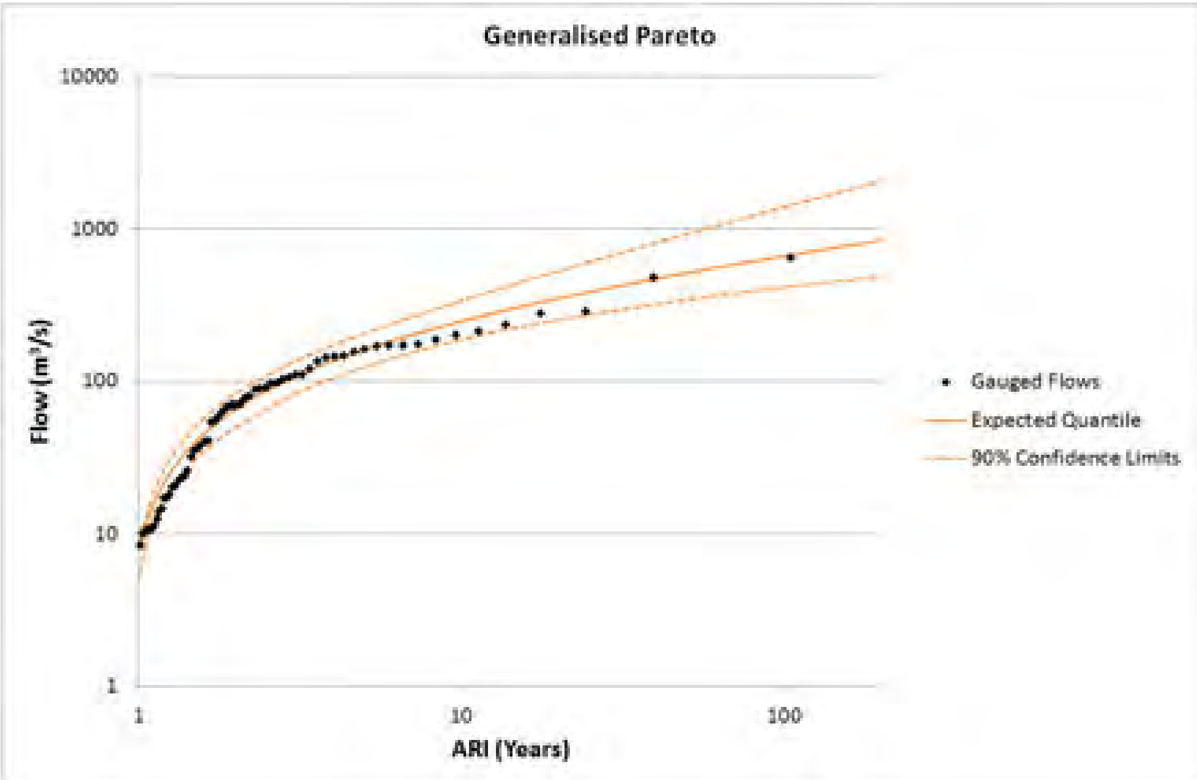


Figure 3-30 FFA Results: Wimmera River at Glynwylln - Generalised Pareto Fitting

Whilst the Log Normal (Figure 3-26), Log Pearson Type III (Figure 3-27) and Generalised Pareto (Figure 3-30) distributions provide acceptable fits, the Log Pearson Type III is preferred as the fit to the rarer events is better. The results for the Log Pearson Type III distribution are shown in Table 3-11. This table lists the 1% AEP peak discharge as 743 m^3/s.

These results indicated that the January 2011 event was approximately between the 1% and 2% AEP flood event.

Table 3-11 Wimmera River at Glynwylln: Flood Frequency Analysis Results

AEP	Expected Quantile (m^3/s)	90% Quantile Probability Limits	
20%	153	118	201
10%	247	183	353
5%	364	254	606
2%	559	352	1168
1%	743	424	1879

3.1.4 Discussion

The results from the analysis for the Wimmera River at Glynwylln (refer to Table 3-11) table lists the 1% AEP peak discharge as 743 m^3/s.

The gauging record at Glynwylln is of sufficient length (56 years, plus an additional 10 years of mean daily flow records) to enable the flood frequency analysis to be undertaken. The Australian Rainfall and Runoff (ARR) Book IV Peak Flow Estimation (Kuczera and Franks, 2006) no longer prescribes limits on the minimum AEP that can be derived from the flood frequency analysis. The current recommendation is that the limits of extrapolation should be guided by consideration of the confidence limits, however, the 1% AEP flood event is the largest event that should be estimated by frequency analysis.

Whilst the analysis of the gauging record at Glynwylln indicates that the January 2011 flood event is approximately between the 1% and 2% AEP flood events, the event discharge of 641 m^3/s also falls within the 90% confidence limits of both the 2% and 1% AEP flood events. This indicates a level of uncertainty in the estimates of peak discharge for rare events at this location.

3.2 RORB Model

Rainfall runoff modelling is a method utilised to estimate the amount of runoff produced by a catchment for a given rainfall event, taking into account the hydrologic characteristics of that catchment.

RORB simulates the linkages between sub-catchments as reach storages with the storage discharge relationship defined by the following equation;

S = 3600kQm

where 'S' represents the storage (m3), 'Q' is the discharge (m3/s), 'm' is a dimensionless exponent and 'k' is non-dimensional empirical coefficient. 'k' is defined by the product of the catchment value

'k_c' and the individual reach k_i. Both m and k_c are defined as calibration parameters within the RORB storage-discharge equation.

3.2.1 Model Description

The RORB model incorporates an area of approximately 1,465 square kilometres. To ensure accurate representation of the hydrological response of the overall catchment, the model was divided into 129 individual sub-catchments. Conceptual reaches (approximate overland flow paths) were defined and three recorded hydrograph locations (Mount Cole Creek at Crowlands and the Wimmera River at Glynwylln and Eversley) were included for calibration purposes. Additional streamflow records exist at the Navarre gauge on Wattle Creek, but this gauge did not record the January 2011 event, and therefore, was not used for the calibration of the RORB model (refer to Section 3.3 for more details). Whilst there were formal storages identified in the catchment (farm dams, etc), it was determined that none of these are large enough to affect the total runoff from the catchment during large storm events. Consequently, there were no storages included in the hydrologic model.

3.2.2 Sub-Catchment Definition

The catchment and sub-catchment boundaries were initially determined using the software package CatchmentSIM, based on the Wimmera CMA LiDAR elevation dataset. The catchment breakup was then refined to ensure that consistency in sub-catchment size and shape was achieved as best as the catchment topology would allow with a final total of 129 individual sub-catchments. The sub-catchment breakdown is shown in Figure 3-31.

3.2.3 Reach Types

The Upper Wimmera catchment is predominately a rural catchment with some areas of state park and rural townships. There are no extended sections of engineered channel in the catchment. As such throughout the RORB model Reach Type 1, which is applicable for natural channels, was used.

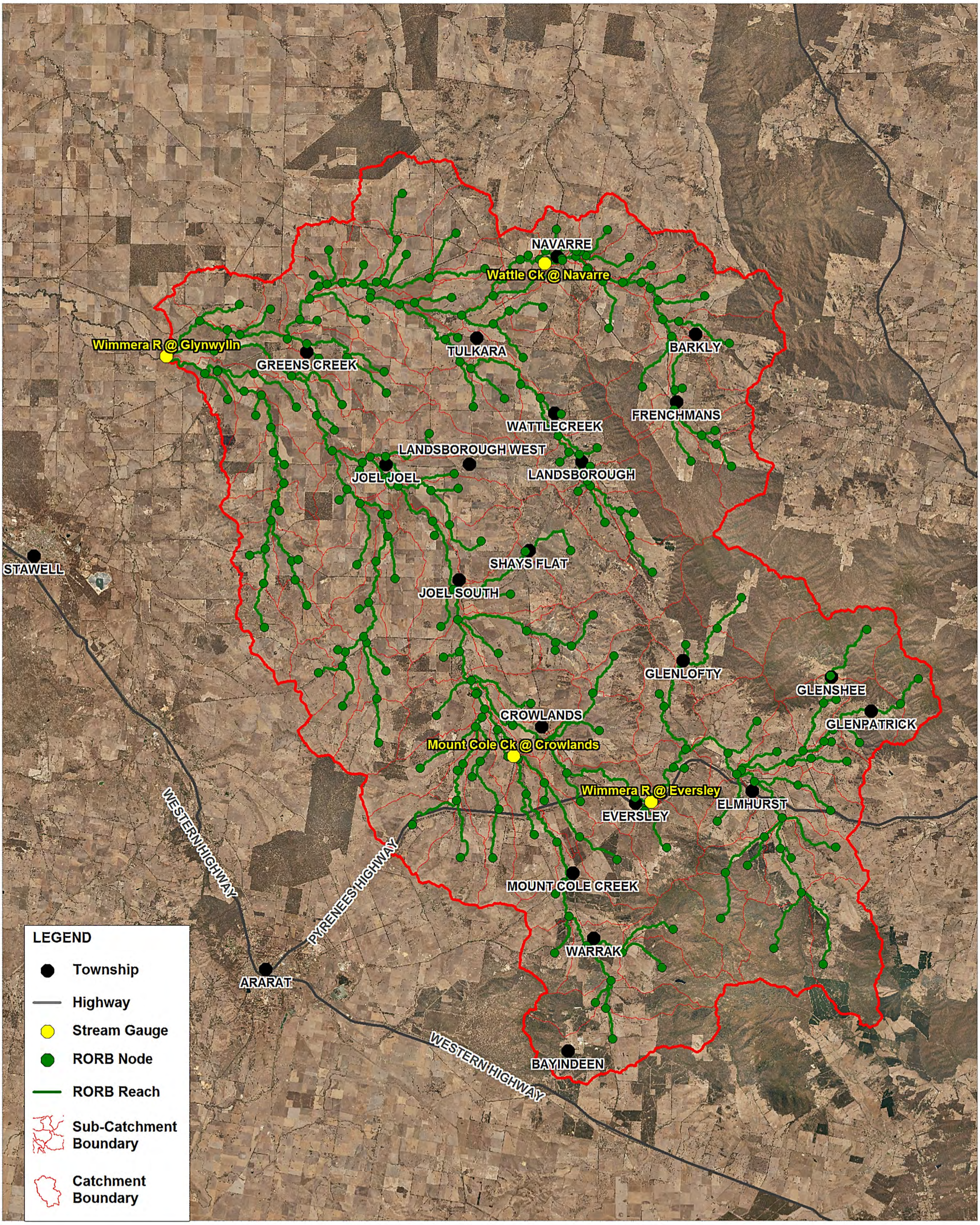
Reach alignments are shown in Figure 3-31.

3.2.4 Fraction Impervious

Whilst the Upper Wimmera catchment is predominately a rural catchment, a number of fraction impervious values were adopted for this study for other areas such as areas of state park and rural townships. The adopted values are shown in Table 3-12. These values are based on standard industry values recommended by Melbourne Water (Melbourne Water Flood Mapping Guidelines and Technical Specifications 2010) for fraction impervious and from inspection of aerial photography.

Table 3-12 Fraction Impervious Values

Land Use Type	Fraction Impervious
Farm Zone	0.05
Low Density Residential	0.2
Public Conservation	0
Public Park & Recreation	0.1
Service and Utilities	0.5
Schools	0.7
Hospitals	0.7
Railway	0.7
Local Government Facilities	0.6
Public Building	0.7
Rural Conservation	0.05
Major Roads	0.7
Secondary Roads	0.6
Rural Living	0.2
Township	0.55



Title:

Upper Wimmera Flood Study
RORB Model Layout

Figure: 3-31

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 5 10km

Approx. Scale

Wimmera Catchment Management Authority | Ararat Rural City | Northern Grampians Shire | Australian Government | State Government Victoria | BMT WBM

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3.3 Calibration and Validation

To establish that the hydrologic modelling is suitably representing runoff behaviour of the catchment, and in turn providing reasonable inputs for the hydraulic modelling process, model calibration and validation to actual flood events is undertaken; the model is first calibrated to two events and then validated against another event whilst only varying the loss parameters. The calibration and validation process is described in detail below. The calibration and validation results were assessed visually, combined with comparisons of peak flow and total volume at each gauge in combination with the Nash-Sutcliffe Efficiency (NSE) value.

3.3.1 Calibration and Validation Process

The hydrologic modelling calibration process involves the following steps:

(1) Collect, collate and verify relevant data including streamflow hydrographs, rainfall pluviographs and daily rainfall totals.

(2) Choose the historical storm events to be used in the calibration and validation process based on the available data and the nature of the event.

(3) Create the storm event inputs to be used in the calibration and validation process.

(4) Apply the calibration storm event to the RORB model and optimise the model parameters to achieve model calibration.

(5) Validate the model parameters against an alternate storm event.

(6) Following the completion of the hydraulic model, assess the accuracy of the hydrologic model calibration and re-calibrate if required.

The following sections detail these processes and outline the assumptions used in the hydrologic calibration and validation process.

3.3.2 Stream Gauge Information

The same four gauges used in the FFA will be used in the RORB calibration; Mount Cole Creek at Crowlands, Wattle Creek at Navarre and the Wimmera River at Eversley and Glynwylln. Not all of the four streamflow gauges have continuous records covering the three most recent significant events; September 2010, December 2010 and January 2011. During the January 2011 event the Wattle Creek at Navarre gauge was not operational.

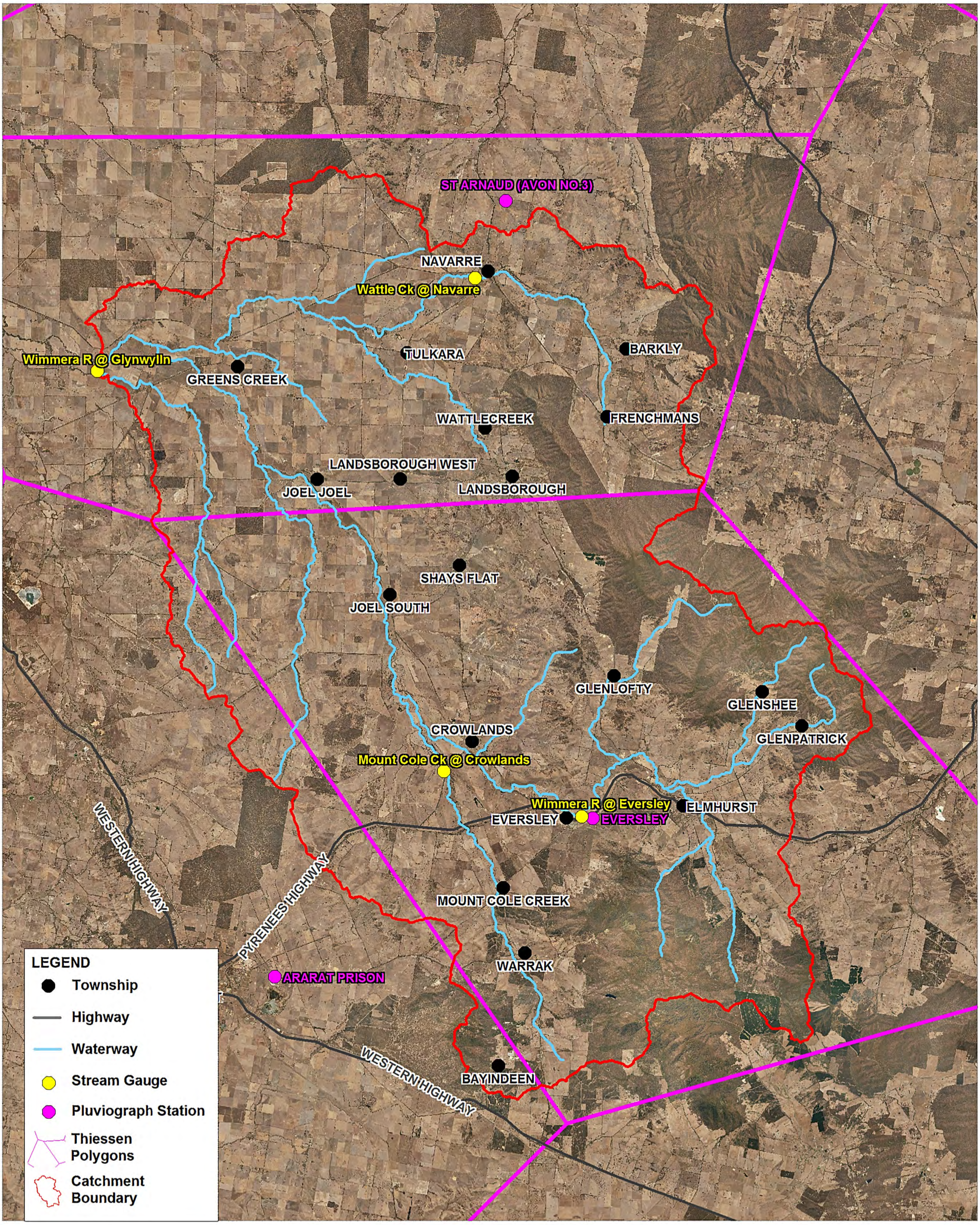
3.3.3 Rainfall Selection and Distribution

There are three pluviograph stations as shown in Figure 3-32 and 11 daily rainfall stations located in and around the study catchment, as shown in Figure 3-32.

For both the calibration and validation events modelled, the pluviograph and daily rainfall data was filtered to remove the stations that were inactive during a specific event. The data recorded at each station was then checked to ensure that there were no errors in the recorded data, and then validated against surrounding stations to check for consistency in the rainfall patterns. A summary of the three storm events is provided in Section 3.3.4.

The relevant pluviographs that covered the event were then input into the RORB model as hyetographs, and distributed across the sub-catchments by Thiessen Polygons. The temporal rainfall information in these hyetographs was used to temporarily disaggregate the daily rainfalls.

The recorded rainfall at the daily rainfall stations was summed across the duration of the storm event and applied as total rainfall depth inputs into the RORB model. The total rainfall depths were also distributed across the sub-catchments using Thiessen Polygons.



Title:

Upper Wimmera Flood Study
Stream Gauge and Pluviograph Stations

Figure: **3-32**

Rev: **A**

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Approx. Scale

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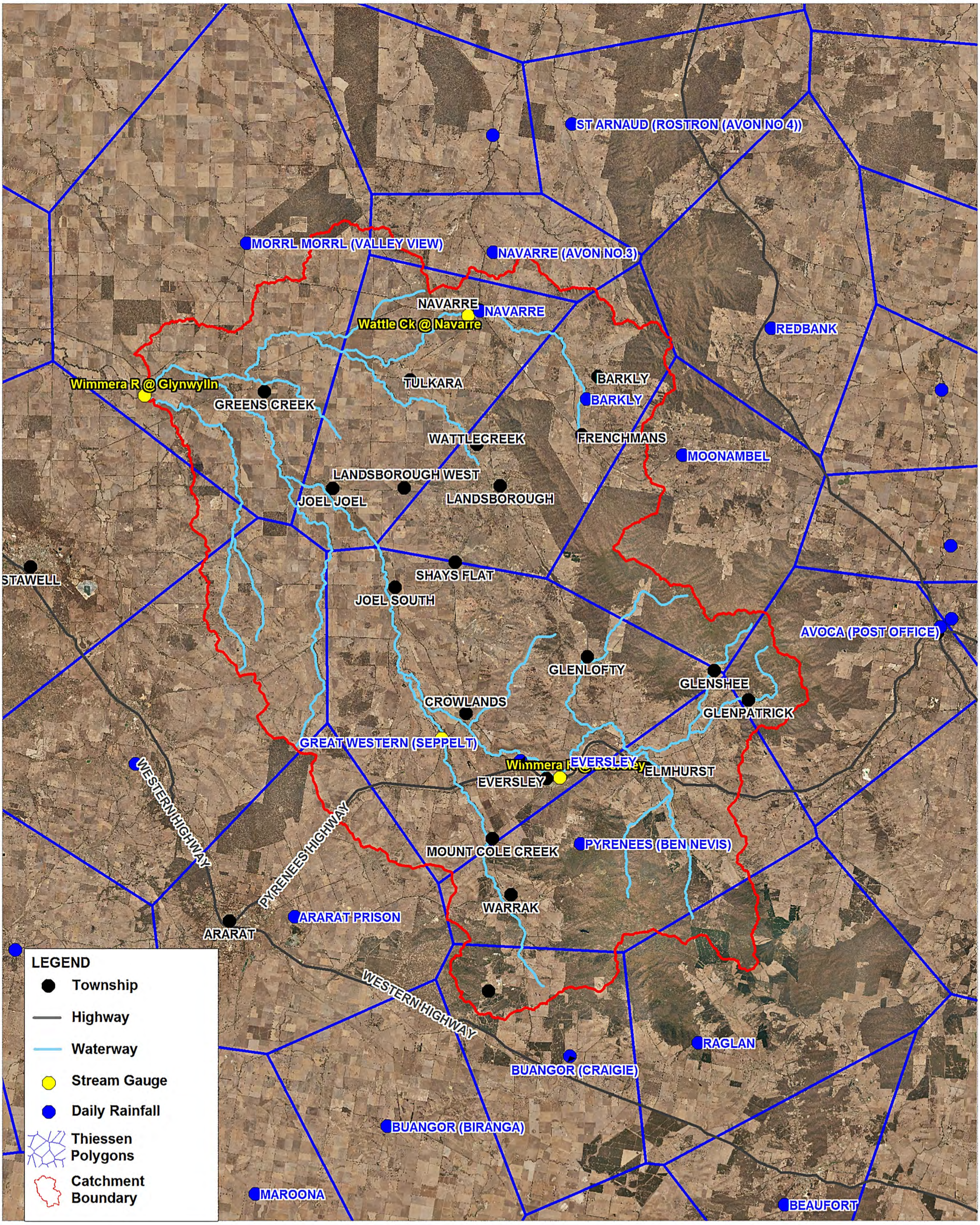


Title:

Upper Wimmera Flood Study
Stream Gauge and Rainfall Stations

Figure: 3-33

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 5 10km
Approx. Scale

Wimmera Catchment Management Authority
Ararat Rural City
Northern Grampians Shire
Pyrenees Shire
Australian Government
State Government Victoria
BMT WBM

Filepath : T:\M8460.MT.WimmeraUpperFloodStudy\MapInfo\Drawings\R.M8460.009.01.Final\UW_Final_Fig3-33_RainfallGauges_RevA.WOR

3.3.4 Calibration and Validation Event Selection

The selection of the calibration and validation events was based on the following criteria:

- the availability of rainfall and streamflow data;
- the requirements for calibration of the hydraulic model, e.g., the availability of recorded flood levels across the floodplain
- a preference to test the hydrologic (and hydraulic) model on floods of different magnitudes;
- expectations in the community that a particular event, e.g. largest in living memory, will be modelled

Both rainfall and streamflow data at a resolution commensurate with hydrological response of the study catchment are required to calibrate a hydrological model. The hydrological response of the Upper Wimmera River catchment is of the order of 1 - 2 days. It is therefore necessary to have data at a sub-daily scale to adequately model the catchment's response.

As discussed in Section 1.5 there is a long history of flood events in the Upper Wimmera River catchment which have impacted upon the township of Navarre and Landsborough. Unfortunately the amount of data captured for historical events is less available than the information available for the more recent events which has limited the events that can be used in the calibration and validation process.

As described in the above section there are four stream gauges located within the study catchment, all of which are used in the RORB model calibration process, and all of which are used in the validation process. Table 3-1 lists the dates where streamflow data is available.

During the investigation of historical flooding and the flood frequency analysis process (Section 3.1), it was established that the largest flood events to have occurred since 1956 in chronological order are:

- September 2010;
- December 2010; and
- January 2011.

In addition to the above events, a significant rainfall event occurred in December 2011. This event was characterised by a localised yet extremely intense rainfall event in and around the township of Joel Joel. The magnitude of the this rainfall event was not adequately captured in the surrounding rainfall and pluviograph gauges to enable a calibration or verification of this event to be undertaken

A brief summary of the hydrologic data available for these events is provided in the following section.

3.3.4.1 Calibration and Validation Event Selection Summary

This section provides a summary of the calibration and validation flood events. As shown in Table 3-7, the January 2011 flood was the largest flood event recorded at the Glynwylln gauge on the Wimmera River.

As the January 2011 event was the largest event recorded at three of the four gauges (the Navarre gauge was not operational at the time of the event), and has all pluviograph stations in operation, it was deemed the preferred event to use for calibration. The September 2010 event was the second largest event of the three events of recent history, and was used as the second calibration event. For the September event only one pluviograph, but all stream gauges were operational. The December 2010 event, the smallest of the events, was selected as the verification event. For December 2010 two pluviograph and all streamflow gauges were operational.

Table 3-13 Calibration and Validation Rainfall Event Rainfall Summary

Data Station		September 2010	December 2010	January 2011
Pluviograph Gauge	Navarre (Avon No.3)	**N**	Y	Y
	Ararat Prison	**N**	**N**	Y
	Eversley	Y	Y	Y
Streamflow Gauge	Wimmera River at Glynwylln	Y	Y	Y
	Wimmera River at Eversley	Y	Y	Y
	Wattle Creek at Navarre	Y	Y	**N**
	Mount Cole Creek at Crowlands	Y	Y	Y

3.3.5 Calibration Parameters

The RORB parameters that are available for calibration are; k_c, *m,* and initial loss (*IL*) (RORB automatically adjusts continuing loss (*CL*) to maintain the water balance). The approach adopted to calibrate the RORB model was to use the RORB spatially variable routing parameters based on the best calibration fit for each gauge.

The RORB program provides the facility to manually adjust the calibration parameters until an acceptable fit is found. RORB also provided a number of summary statistics including difference in observed and calculated hydrograph volumes, differences in peak flow and differences in the time to peak. In addition, the Nash-Sutcliffe Efficiency (NSE) was also calculated. This is a statistical measure to evaluate a model's performance against observed data.

The NSE is a measure of how much of the residuals (the difference between the calculated and observed) variance is explained by the model. A value of 1 indicates a perfect fit to the model data whereas a value of zero indicates simply modelling the average value would perform equally well. A value of less than 0 indicates poor model performance. NSE is defined as;

$$NSE = 1 - \frac{var(Res)}{var(hyd)} \qquad \text{Equation 1}$$

where *var(Res)* is the variance of the model residuals or the difference between the observed and calculated flows, and *var(hyd)* is the variance of the observed hydrograph.

3.3.6 January 2011 Calibration Results

An automated batching program was developed by BMT WBM to test various RORB model parameters. This process was run for 5000 scenarios with various values of k_c, and *IL* within defined bounds for each variable. For each individual scenario, each parameter was selected at random between the pre-defined lower and upper limits. The NSE value, along with the volume and peak flow error, was reported for each simulation. The scenarios that resulted in the best fits according to peak flow, volume and NSE value were then visually inspected to determine the best fit to the available data. Additional manual refinement of these RORB model parameters was undertaken to further improve the fit to the observed data. The best fit for the calibration parameters are listed in Table 3-14 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 3-34.

Table 3-14 Calibrated Parameters and Values for January 2011

Station	k_c	*m*	*IL* (mm)	CL* (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mount Cole Creek at Crowlands	23.24	0.80	45	15.53	0.48	0.7%	0.0%
Wimmera River at Eversley	22.94	0.80	45	4.1	0.63	1.4%	0.0%
Wimmera River at Glynwylln	30.55	0.80	60	2.48	0.82	-0.6%	0.0%

* The continuing loss (CL) is determined by RORB to maintain the water balance during the calibration run

The calibration resulted in a reasonable fit for the gauge at Glynwylln. Glynwylln is considered to be the most important gauging location for flooding in the Upper Wimmera catchment and accordingly more weight was given to fitting at this station. It is the most important gauge for two reasons:

- although the water levels for the January 2011 event exceeded the highest physical gauging of the site, the level was still within the published limit of the rating curve; and
- the gauge is located near the catchment outlet and therefore indicates the overall catchment response to the calibration.

Both the modelled total volume and peak flow are within 1% of the observed record. The timing is generally reasonable, however, the peak occurring roughly 7 hours apart is not ideal. The overall hydrograph shape matches reasonably well, as indicated by the NSE value of 0.82.

The fit at Crowlands is fair, however, the model indicates a slower catchment response than the observed record, with the timing of the two peaks out by approximately 6 hours. Further, the catchment response to the initial response is not captured due to the losses (particularly the high CL) required to maintain the volume and peak flow of the gauge.

Although a reasonable correlation of peak flows has been achieved, the water levels recorded at this gauge exceeded the highest physical gauging undertaken. Therefore the flows derived from the recorded water levels have a higher degree of uncertainty compared with the Glynwylln gauge flows, and so the calibration parameters adopted for the Crowlands catchment also have a higher degree of uncertainty.

The calibration at Eversley is relatively good. Both the initial catchment response and subsequent larger peak are well represented, however as with the other gauges the timing of the peak is out with the larger peak occurring 4 hours after the observed record.

Whilst some variation in the calibration loss parameters is expected due to different antecedent conditions within the catchment (previous flooding in September and December 2010 affected the various creek systems in the catchment to varying degrees), the range of loss values required to achieve an acceptable calibration at each interstation area may indicate an issue with the underlying data. Whilst the loss parameters for Eversley and Glynwylln are relatively consistent with each other, the losses required for Crowlands are high by comparison.

As noted previously, there is a level of uncertainty regarding the accuracy of stream gauges and the temporal distributions of the rainfall within the catchment. A significant error in the estimate of the flow, combined with poor spatial and temporal representation of the rainfall, could lead to the range of loss parameters (displayed in Table 3-14) for each interstation area.

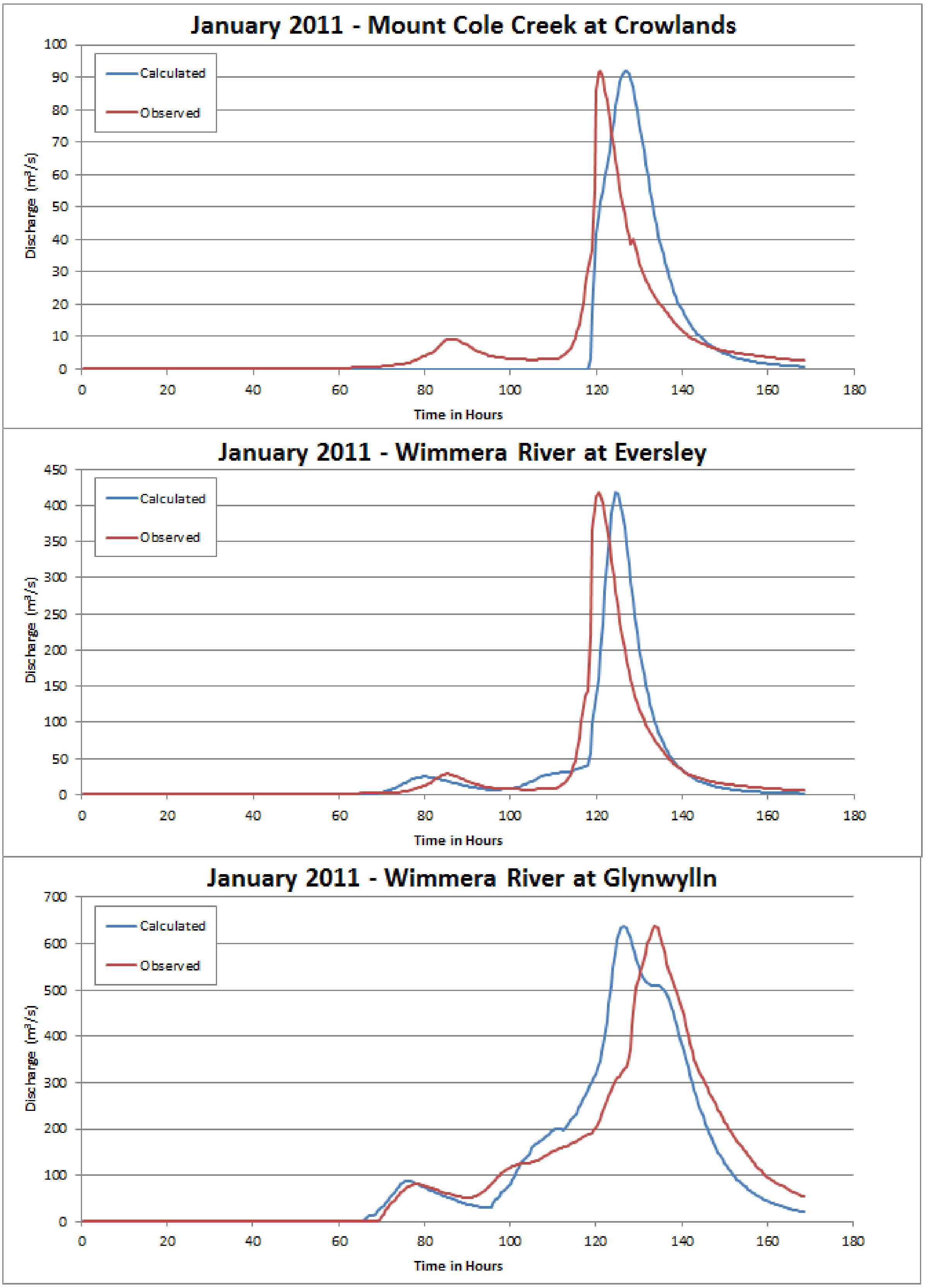


Figure 3-34 Calibrated Hydrograph Comparison for January 2011

3.3.7 September 2010 Calibration Results

The same approach to calibration documented above for the January 2011 event was undertaken for the September 2010 event. The best fit for the calibration parameters are listed in Table 3-15 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 3-35.

Table 3-15 Calibrated Parameters and Values for September 2010

Station	k_c	m	IL (mm)	CL* (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Wattle Creek at Navarre	25.12	0.8	10	1.33	0.92	0.5%	0.0%
Mount Cole Creek at Crowlands	29.2	0.8	20	1.92	0.95	0.2%	0.1%
Wimmera River at Eversley	27.6	0.8	10	1.29	0.82	0.4%	0.0%
Wimmera River at Glynwylln	30.02	0.8	20	1.82	0.78	-0.4%	0.0%

* The continuing loss (CL) is determined by RORB to maintain the water balance during the calibration run

Initial calibration of the event at the Glynwylln gauge resulted in significant difference in the timing of the observed gauge data, to the extent that the peak was occurring approximately 14 hours prior to the observed record. Although the timing of the hydrograph was not being reproduced, the comparison of peak flow and volume was acceptable. The RORB manual (Laurenson et al, 2005) notes that sometimes in catchments whose lower reaches are relatively flat, the shape of the hydrograph can be re-produced but not the timing. Consequently, it was necessary to insert a translation into the RORB model to enable the timing of the calculated hydrograph to match that of the observed hydrograph.

With the time-shifted hydrograph the calibration resulted in a reasonable fit for the gauge at Glynwylln. Glynwylln is considered to be the most important gauging location for flooding in the Upper Wimmera catchment and accordingly more weight was given to fitting at this station.

Both the modelled total volume and peak flow are within 1% of the observed record. The timing is generally reasonable, however the peak rises quicker than the observed record and recedes slower. The overall hydrograph shape matches reasonably well, as indicated by the NSE value of 0.78.

The calibration of Navarre is generally very good with the timing, peak flow, volume all being similar to the observed record.

The fit at Crowlands is good, with the initial rise and falling limb well represented. Both volume and peak flow are within 1% and the timing of the peak matches well as shown with an NSE of 0.95 is reveals the strength of the calibration.

The calibration at Eversley is relatively good. The catchment doesn't respond or recede quite as quickly as the observed record, however the general shape and height produced by the hydrologic model are reasonable comparable to the observed record. The timing of the peak in the hydrologic modelled was found to occur approximately 5 hours after the peak was recorded in the observed record.

Unlike the calibration of the January 2011 event which required high losses for the Crowlands gauge, the initial and continuing losses used in the calibration of the September 2010 event for all four gauges are consistent across the catchment and are within the expected bounds for an event of this magnitude.

As noted previously, there is a level of uncertainty regarding the accuracy of stream gauges and the temporal distributions of the rainfall within the catchment. A significant error in the estimate of the flow, combined with poor spatial and temporal representation of the rainfall, could lead to the range of loss parameters (displayed in Table 3-16) for each interstation area. This is particularly true for the September 2010 event where only a single pluviograph record was operational during the event.

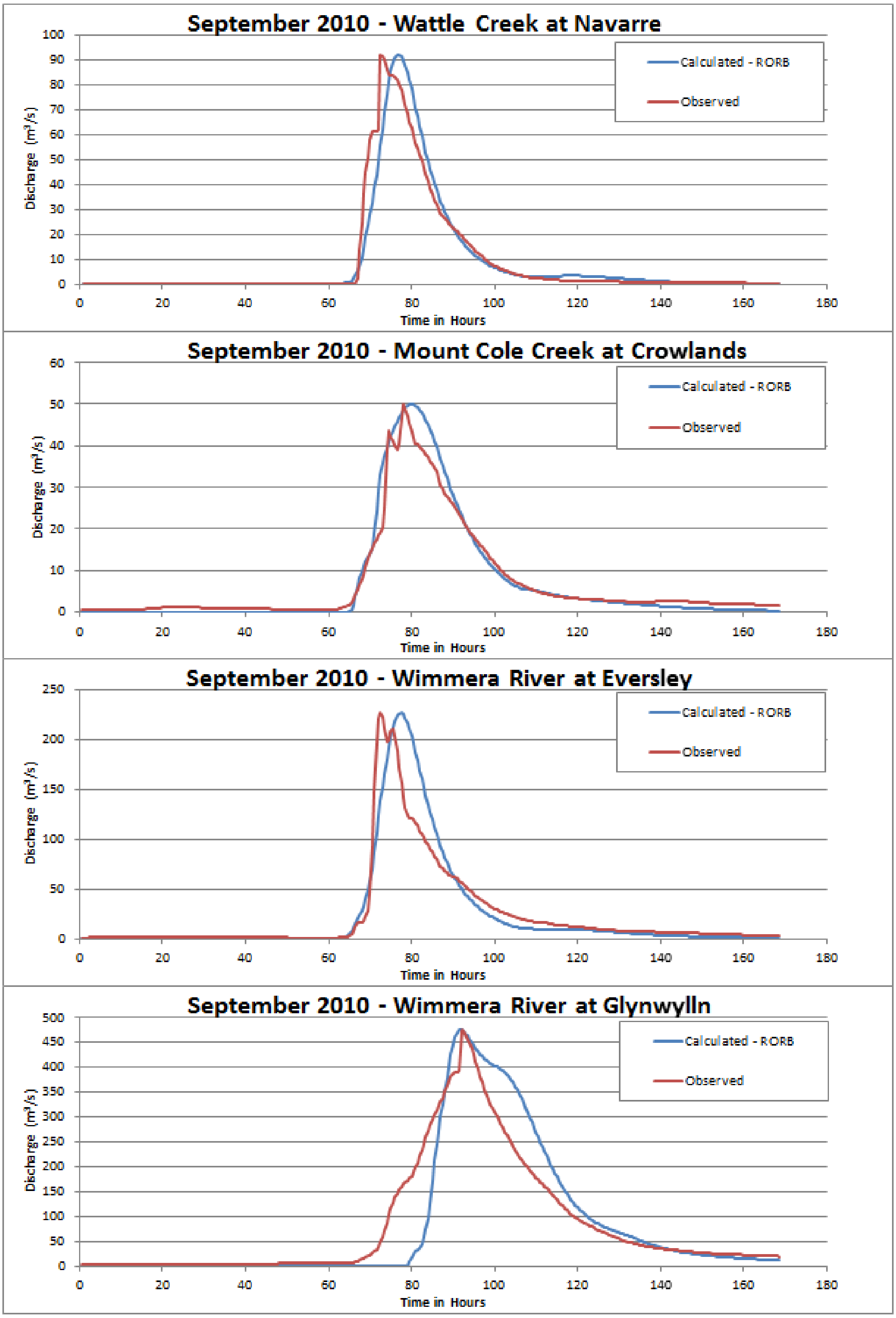


Figure 3-35 Calibrated Hydrograph Comparison for September 2010

3.3.8 Validation Results

The k_c and m parameters used for the calibration of both the September 2010 and January 2011 events were found to be largely similar. Due to general close agreement in the k_c values between the January 2011 and September 2010 calibrations, it was decided to take the average k_c between methods to use for the validation. The reasoning being that a set of parameters between the two calibration events could be used for both events without unduly reducing the calibration results. For the Navarre gauge the parameters used to calibrate the September 2010 event were used (as the gauging record at Navarre during January 2011 is incomplete).

To validate the December 2010 event, the RORB model of the Upper Wimmera was run with the rainfall described in Section 3.3.4.1 for this event. As outlined above, the rainfall was spatially distributed across the catchment using the two available hyetographs.

The calibration parameters outlined in Table 3-16 were input to RORB and the initial loss (IL) and continual loss (CL) adjusted to achieve the best fit. The resulting hydrographs, together with observed hydrographs, are shown in Figure 3-36.

Table 3-16 Validation Parameters and Values for December 2010

Station	k_c	*m*	*IL* (mm)	CL* (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Wattle Creek at Navarre	25.12	0.8	25.0	8.30	0.35	1.4%	0.9%
Mount Cole Creek at Crowlands	26.22	0.8	30.0	15.06	-0.02	0.8%	24.9%
Wimmera River at Eversley	25.27	0.8	20.0	8.57	-4.19	0.3%	184.7%
Wimmera River at Glynwylln	30.29	0.8	13.0	10.89	0.45	-0.4%	5.6%

The FFA for the Glynwylln gauge estimates that the December 2010 event has an AEP of approximately 33%. It is therefore possible that the k_c and m parameters are not as well suited to smaller, more frequent flood events.

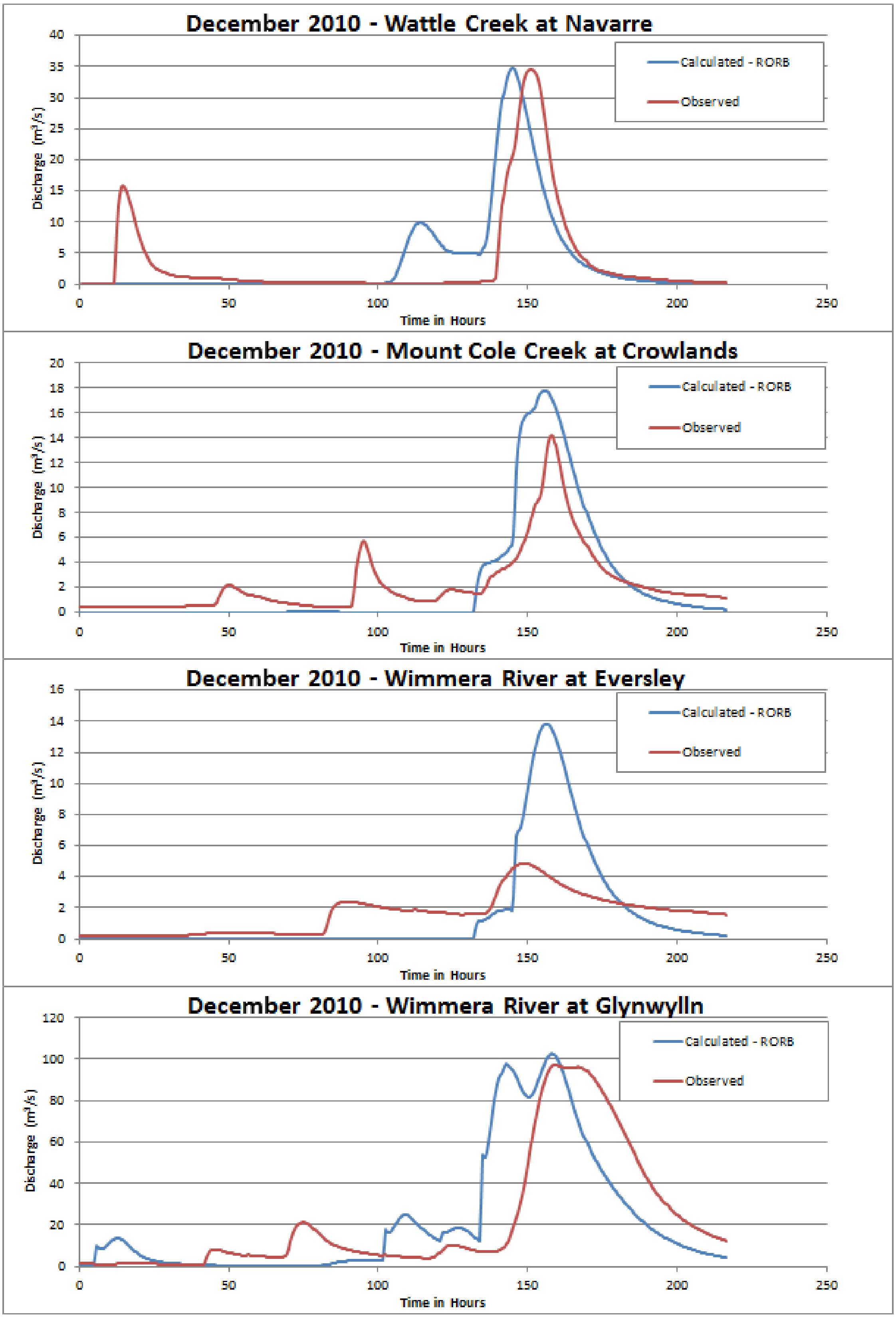


Figure 3-36 Validated Hydrograph Comparison for December 2010

3.3.9 Calibration / Validation Conclusions

The RORB model of Upper Wimmera catchment has been calibrated to the September 2010 and January 2011 flood event and validated against the December 2010 flood event. The adopted calibration parameters were applied to the validation event.

There are a number of issues with the available data which has created uncertainty and limited the ability to accurately represent the catchment response in the RORB model. These issues include;

- Suspect flow data at the Crowlands gauge during the September 2010 and December 2011 events;
- Odd behaviour of the Glynwylln gauge at the peak of the September 2010 event.

As noted previously, that whilst the Glynwylln and Eversley gauges recorded flows with a magnitude between the 1% and 2% AEP events, the Crowlands gauge recorded flows with a magnitude between the 2% and 5% AEP. Such variability is not uncommon, particularly on large catchments, and is normally a result of variability of rainfall over a catchment. However, the RORB model required larger rainfall losses within the catchment of the Crowlands (compared with the remainder of the catchment) so as to approximate the recorded flows at the Crowlands gauge. Such significant variation in rainfall losses across a generally homogeneous catchment is less common and indicates that there may be a discrepancy within the rating curve for larger flood events.

As part of the hydraulic modelling process a rating analysis can be undertaken at the Crowlands gauge by outputting the modelled flow rate and height. The updated rating curves determined by Thiess Services from field measurements will be compared to the hydraulic modelling results. Where it has not been possible to obtain manual streamflow gauging, particularly at high station levels with significant out of bank flows, significant differences may exist between the two rating curves.

Additionally, the results of the validation to the December 2010 flood event showed a poorer fit to to the observed data when compared to the calibration events. As discussed in the previous section, the December 2010, although significant in parts of the catchment, was determined to be a relatively frequent event at the Glynwylln gauge (AEP of approximately 33%).

The technical steering committee accepted the calibrated hydrologic model due to its ability to accurately represent the rare flood events (1% AEP) as these results will have significant influence on the planning and emergency management outputs of the study. It was noted that more frequent events (~20% AEP) may be over-estimated in the design event modelling.

3.4 Design Event Modelling

The design event modelling utilises the parameter set derived through the calibration of the hydrologic model to determine the flows for a series of events with a specific AEP (eg: the 1% AEP event).

3.4.1 Global Parameters

The RORB model parameters for design event modelling are summarised in Table 3-17. The interstation areas are the same as those used in the calibration process. The parameters *m* and k_c are adopted from the calibration process.

The loss model adopted was the "initial loss/continuing loss" model. The loss values were taken from the range of loss values determined during the calibration events. These losses were then adjusted until the peak 1% AEP discharge matched the estimated 1% AEP from the Flood Frequency Analysis (Section 3.1) at Glynwylln

Table 3-17 RORB Parameters

RORB Parameter	Multiple Parameter RORB Model	
	Inter-Station Area	Value
Catchment Area	1,465 km^2	
Initial Loss	Catchment Outlet	25
Continuing Loss	Catchment Outlet	Varies, see section 3.4.5
k_c	Wattle Creek at Navarre	25.12
	Mount Cole Creek at Crowlands	26.22
	Wimmera River at Eversley	25.27
	Wimmera River at Glynwylln	30.29
	Catchment Outlet	30.29
m	Mount Cole Creek at Crowlands	0.8
	Wimmera River at Eversley	0.8
	Wimmera River at Glynwylln	0.8
	Catchment Outlet	0.8
Fraction Impervious	Varies, as per land use (Table 3-12)	
Reach Types	Type 1	

3.4.2 Design Event Probabilities

Hydrological analysis was undertaken for the 20%, 10%, 5%, 3%, 1% and 0.5% Annual Exceedance Probability (AEP) design storm events. Hydrological analysis was also undertaken for the Probable Maximum Precipitation (PMP) storm event.

3.4.3 Increase Rainfall Intensity – Climate Change

Increase rainfall intensity sensitivity analysis requires that the base case design rainfall intensities be increased by a factor of 32%. The Rainfall Intensity for the catchment was increased by 32% by adjusting the IFD intensity parameters. The geographic factors, F2 & F50, were adjusted in accordance with Equations A(3.1) and A(3.2) in ARR Volume 1 Book II Section 1. For the purposes of increasing rainfall intensity the skew coefficient is not modified. A summary of the IFD parameters used for the rainfall sensitivity modelling calculation are contained in Table 3-18.

3.4.4 Design Rainfall

In order to define the design rainfall for AEP events, Intensity Frequency Duration (IFD) parameters for the Upper Wimmera catchment were generated by the Bureau of Meteorology (http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml accessed 12/04/2012) using a method based on the maps from Volume 2 of Australia Rainfall and Runoff (AR&R) - A Guide to Flood Estimation. These IFD parameters are an input to RORB, and are used to generate design rainfall intensities and depths using standard AR&R procedures. Storm data was sourced from the Bureau of Meteorology, which are based on Figures 1.8 to 6.8 and 7d to 9 of Australian Rainfall and Runoff (AR&R) Volume 2. The adopted values for the catchments are presented in Table 3-18.

Table 3-18 IFD Parameters

IFD Parameter		Adopted Value	Climate Change
Rainfall Intensity (mm/hr)	50% AEP, 1 Hour Duration	18.97	25.04
	50% AEP, 12 Hour Duration	3.47	4.58
	50% AEP, 72 Hour Duration	0.97	1.28
	2% AEP, 1 Hour Duration	40.73	53.76
	2% AEP, 12 Hour Duration	6.95	9.17
	2% AEP, 72 Hour Duration	1.83	2.42
Skew Coefficient		0.3	0.3
Geographical Factor F2		4.35	4.47
Geographical Factor F50		14.85	16.59
Zone		2	2

3.4.4.1 Temporal Patterns

RORB's filtered temporal patterns function was used to derive the design storm events. Aerial Reduction Factors (ARF) were applied using the reductions as per Australian Rainfall and Runoff 1987 Book II – Design rainfall and considerations Figures 1.6. The resulting design storms were run through the RORB model of the catchments, and the results summarised to determine the critical durations.

3.4.4.2 Calculation of PMP

The probable maximum precipitation (PMP) was derived using the Generalised Southeast Australia Method (GSAM) (BoM 2006). Having a catchment area of 1,465 km^2 and being located in Victoria within the GSAM Inland Zone (Figure 1.1 (BoM 2006)) the durations limits are from the 24 hour event to the 72 hour event. Table 3-19 provides a summary of the final PMP estimate of rainfall depth across the catchment. The PMP storms modelled in RORB were spatially and temporally distributed in accordance with the GSAM method.

Table 3-19 GSAM Estimate of PMP Rainfall Depth

	Duration			
	24hr	36hr	48hr	72hr
Final PMP Estimate (mm)	510	570	610	640

3.4.5 Design Event Losses

The initial loss and continuing losses were adjusted for each design event probability such that the peak design flow is similar to the peak flow determined in the FFA. The adjustment of loss parameters was undertaken solely to enable the peak design flows determined by the hydrologic model to correlate to the design flows at Glynwylln determined by the flood frequency analysis.

From the investigation it was found that an IL of 25 mm with variable CL dependant on the event probability was the most appropriate method. For the PMP the parameters for the 0.2% AEP were adopted. Table 3-20 summaries the losses used for each design AEP to correlate the peak flow to the adopted FFA results.

Table 3-20 RORB Design Event – Model Losses

AEP	Multiple Parameter	
	IL	CL
20%	25	1.5
10%	25	1.5
5%	25	2
2%	25	2.5
1%	25	2.5
0.5%	25	2.25
0.2%	25	2
PMP	25	2

3.4.6 Critical Event Derivation

For each design AEP, the peak discharge at various locations within the catchment may be generated by storm events of different durations. Therefore, consideration of peak discharges for a range of durations is important. For example, a 24 hour duration event may result in the peak discharge in the upper portion of a catchment, while a 72 hour duration event could result in the peak discharge at the bottom of a catchment. Alternatively, the peak flood level may be more related to volume than discharge, and a high volume event may be more appropriate for consideration. Accordingly, to assess the peak discharges and volumes over the catchment, a variety of storm durations for each AEP were modelled. A summary of the critical duration is presented in Table 3-21.

Table 3-21 RORB Design Event – Critical Duration

AEP	Navarre	Eversley	Crowlands	Glynwylln
20%	18h	18h	18h	18h
10%	18h	18h	18h	18h
5%	72h	72h	72h	72h
2%	72h	72h	72h	72h
1%	9h	72h	72h	72h
0.5%	9h	12h	12h	72h
0.2%	9h	12h	12h	18h
PMP	24h	24h	24h	24h

3.4.7 Peak Flows

Peak flows for each design event probability modelled were extracted from the hydrologic model at the four gauge locations and the outlet, and are presented in Table 3-22. Hydrographs of the 72 hour AEP events are shown in Figure 3-37.

Table 3-22 RORB Design Peak Flow Values

	Peak Flow (m^3/s)							
AEP	20%	10%	5%	2%	1%	0.5%	0.2%	PMF
Wattle Creek at Navarre	27	42	57	84	113	153	216	1043
Mount Cole Creek at Crowlands	23	37	47	73	99	137	195	1102
Wimmera River at Eversley	57	89	121	180	249	330	463	2335
Wimmera River at Glynwylln	156	249	351	551	748	959	1290	8231
Catchment Outlet	166	265	371	585	798	1024	1375	8732

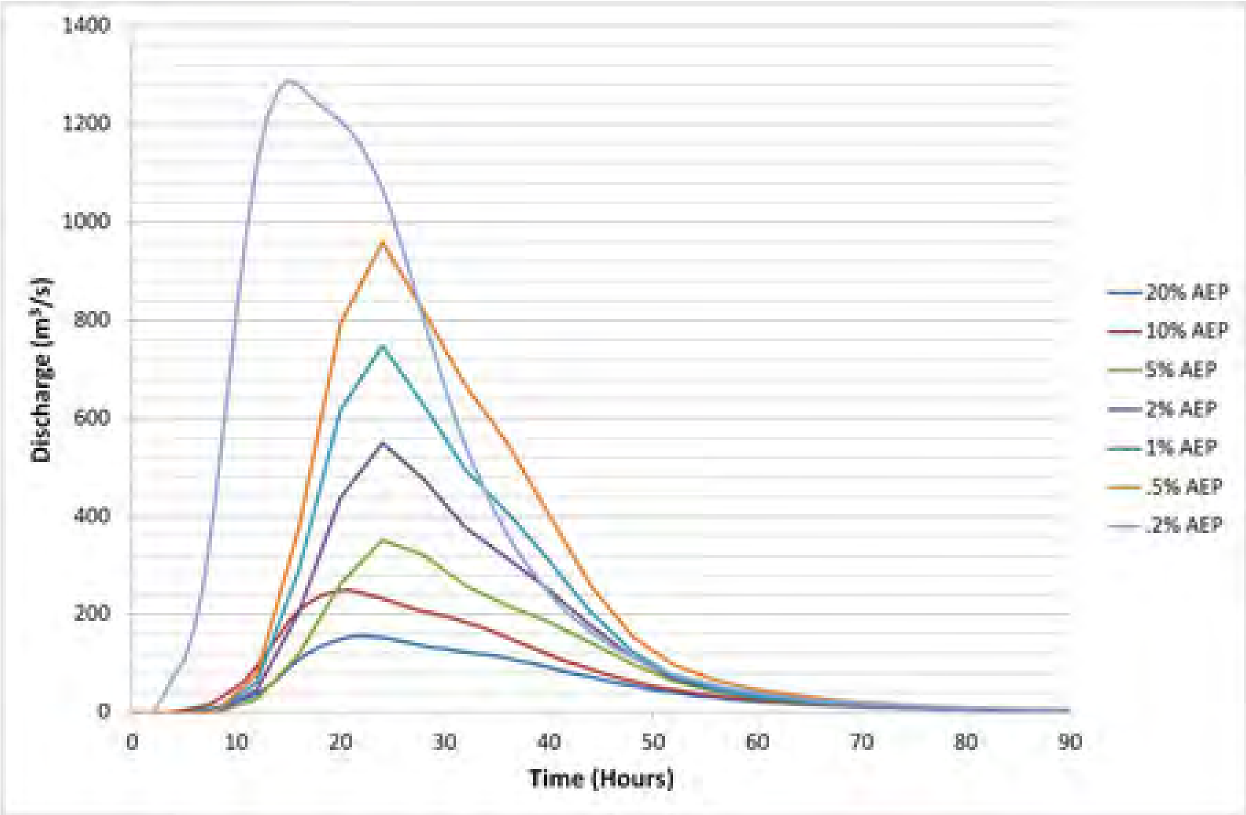


Figure 3-37 72 Hour Design Hydrographs

3.5 Summary

BMT WBM has successfully calibrated the RORB hydrologic model to the September 2010 and January 2011 flood event and verified the calibration against the December 2010 flood event. The results from the calibration in combination with the results of the Flood Frequency Analysis were used to guide the development of the design flow.

The adopted RORB parameters for each interstation area are summarised in Table 3-23. Note that initial loss is held constant whilst continual losses (CL) vary depending on the AEP of the event.

Table 3-23 Adopted RORB design parameters

Station	kc	m	IL (mm)	CL AEP	CL (mm/h)
Wattle Creek at Navarre	25.12	0.80	25	20%	1.50
				10%	1.50
Mount Cole Creek at Crowlands	26.22	0.80		5%	2.00
				2%	2.50
Wimmera River at Eversley	25.27	0.80		1%	2.50
				0.50%	2.25
Wimmera River at Glynwylln	30.29	0.80		0.20%	2.00
				PMF	2.00

A comparison of the peak flows determined through the design event modelling and those adopted from the Flood Frequency Analysis are shown in Table 3-24 (Wimmera River at Glynwylln). The RORB and Flood Frequency Analysis flows match at Glynwylln as would be expected given the losses were adjusted to achieve such a match.

Table 3-24 Wimmera River at Glynwylln: Comparison of FFA and Design Flow

AEP	Adopted FFA Peak Flow (m3/s)	RORB Model	
		Peak Design Flow (m3/s)	% Difference to FFA
20%	153	156	-2%
10%	247	249	-1%
5%	364	351	4%
2%	559	551	2%
1%	743	748	-1%

4 Hydraulic Modelling

TUFLOW, a fully 2D hydraulic modelling package with the ability to dynamically nest 1D elements was adopted for this study. In addition to the main 2D domain that covers the entire catchment the TUFLOW model contains two nested fine mesh 2D domains allowing flooding behaviour to be more accurately represented within the townships of Landsborough and Navarre. 1D pipe elements have been used to model major road culverts.

4.1 Model Description

The 2D model domain extends from the catchment outlet approximately 600 metres downstream of the Glynwylln stream gauge, near the confluence of the Wimmera River and Seven Mile Creek, up to and including the upper catchments, covering an area of approximately 1500 square kilometres of the Upper Wimmera catchment and floodplain, as shown in Figure 4-1. The model extent allows for the flood behaviour within the study area, from the upper catchment to the Glynwylln stream gauge, to be accurately represented without the influence of boundary effects. The downstream extent of the model also coincides just downstream of a major hydraulic control in the form of a bottleneck in the regional terrain.

The geometry of the 2D model was established by constructing three domains populated by uniform grids of square elements. One of the key considerations in establishing a 2D hydraulic model relates to the selection of an appropriate grid element size. Element size affects the resolution, or degree of accuracy, of the representation of the physical properties of the study area as well as the size of the computer model and its resulting run times. Selecting a very small grid element size will result in both higher resolution and longer model run times.

In adopting the element size for the Upper Wimmera model, the above issues were considered in conjunction with the final objectives of the study. Given the size of the study area, it would be infeasible to model the whole study area with a grid element size small enough to appropriately represent the flooding behaviour within the Navarre and Landsborough townships due to time and data size restrictions. As a result a grid size element size of 15 metres was adopted for the broader catchment. To ensure accurate representation of flooding within the townships, two nested fine mesh domains with a grid element size of 5 metres was adopted for each township. The areas enclosed by the three model domain are shown in Figure 4-1. The selection of these grid element sizes allows for the more complex flow behaviour within the township to be modelled appropriately while allowing run times to be kept to an acceptable length.

Each square grid element contains information on ground topography, sampled from the DEM and surface resistance to flow (Manning's 'n' value) at 7.5 metre spacing within the 15 metre domain and at 2.5 metre spacing within the 5 metre domain.

The 1D networks are dynamically linked to the 2D model domain. Hence, a free exchange of water between the 1D road culverts and the linked floodplains can occur.

4.2 Model Development

The following sections provide an overview of methodology and assumptions used to establish the key elements of the hydraulic model.

4.2.1 Topography

For the development of the DEM to be used in the hydraulic model two LiDAR data sets were used. For the greater catchment and flood plains the 2005 thinned LiDAR strikes were converted into a 5 m regularly spaced grid. This was sampled internally by TUFLOW every 7.5 m as described above.

Additional LiDAR information from the WCMA Flood Plains LiDAR – Stage 2 which had been commissioned by DSE for the townships of Navarre and Landsborough was provided to BMT WBM. This LiDAR set was provided in 1 m grid format and was subsequently converted to a 2 m grid as an input to TUFLOW. The accuracy of this LiDAR was quoted as ±0.1 m. This is superior to the ±0.5 m quoted for the 2005 LiDAR data. Typically for the greater floodplain the 2005 LiDAR was used but in the critical areas around the two main townships the newer data was used. Where the WCMA Flood Plains LiDAR covers the general floodplain it was used in preference to the 2005 thinned LiDAR.

4.2.2 Surface Roughness

The roughness layer, or Manning's 'n' layer, was based on areas of different land-use type determined from aerial photography and site inspections. The adopted Manning's 'n' coefficients are summarised in Table 4-1 and the layer is shown in Figure 4-2. The values used are based on standard texts such as *Open Channel Hydraulics* (Chow 1959) and were validated during the calibration and validation process (Refer to Section 4.3).

As the majority of the Upper Wimmera floodplain area is broad acre cropping or grazing the hydraulic model is sensitive to the adopted roughness for this land use type. Given that there can be a large seasonal variation in the roughness characteristics of the crops, i.e. before and after harvest, sensitivity testing was undertaken to determine whether a low coefficient value, 'after harvest' or a high coefficient value 'before harvest' would result in higher flood levels resulting in a conservative flood levels. The value adopted of 0.04 represents the crops after harvest.

Table 4-1 2D Domain Manning's 'n' Coefficients

Land Use	Manning's 'n'
Roads	0.025
Roads including heavily vegetated road reserve	0.04
Railway	0.04
Residential - urban	0.20
Residential - rural	0.10
Commercial and industrial	0.30
Residential - urban	0.06

Land Use	Manning's 'n'
Building footprints	2.00
Unmaintained grass/crops	0.04
Maintained grass/sports ovals	0.03
Waterway or Parks with little brush/bush	0.035
Waterway or Parks with moderate brush/bush	0.06
Waterway or Parks with heavy brush/bush	0.08
Waterway or Parks with very heavy brush/bush	0.12
Vineyards or plantation	0.08

4.2.3 Hydraulic Structures

Throughout the Upper Wimmera catchment there are a number of hydraulic structures and controls. Notably these are largely limited to culverts and bridges under roads. As noted previously the Upper Wimmera catchment does not contain any large engineered storages other than defacto-storages from road and rail embankments. The catchment does not have any large weirs, viaducts, spillways or other large hydraulic structures associated along the Wimmera River further downstream in the catchment.

However, a number of large road and rail bridges exist throughout the catchment along with a significant number of smaller bridges and road culverts that drain the smaller creeks and local depressions. Two approaches have been adopted for this study to model these hydraulic structures.

For small single span bridges with regular bases as well as for circular and box culverts the preferred approach for this investigation was the use of 1D elements inserted and dynamically linked to the 2D domain.

For large or for bridges with irregular shaped bases the modelling approach adopted for this study was to model the structure in the 2D domain using TUFLOW's layered flow constriction. The layered flow constriction allows for typical bridge characteristics such as bridge deck height and thickness as well as any blockages associated with guard or hand rails to be incorporated directly in the 2D domain. From these structures the losses are assigned to the grid cells, additional losses associated with piers can be incorporated where appropriate on an individual basis.

TUFLOW has a number of modelling options available for both the 2D and 1D domains that allow for structure geometry and associated losses to be included. The loss values adopted for this study are based on standard values from sources including the *TUFLOW User Manual* (BMT WBM, 2010) and *Waterway Design: A Guides to the Hydraulic Design of Bridges, Culverts and Floodways* (Austroads 1994) and were confirmed during the calibration and validation process (Refer to Section 4.3).

4.2.4 Boundary Conditions

The TUFLOW model has been developed to use inflow boundaries obtained from the RORB hydrologic modelling stages of the flood model development as described in Section 3.2. There are three main types of boundaries used in the Upper Wimmera hydraulic model, 2D-2D linking, external and internal flow boundaries as shown in Figure 4-1.

As the 2D model extends from the top of the catchment the only external boundary is the one that allows water to leave the model at the outlet. This boundary is located approximately 650 metres downstream of the Glynwylln gauging station and after the natural contraction in the terrain. For this boundary a head versus flow (stage-discharge) relationship was deemed the most appropriate. The head versus flow relationship is generated by TUFLOW based on the topography and the catchment slope at the outlet. The location of the downstream boundary is far enough downstream to ensure that there are no boundary effects within the study area.

The internal inflow boundaries are used to input “excess rainfall”, that is, the rainfall after the initial and continuous losses have been removed. The rainfall excess is taken from the output of the RORB hydrologic model. The RORB output flow boundaries used for the hydraulic model input are the “downstream sub-catchment hydrographs”. These are the flows leaving each subcatchments. These flows include some routing within the RORB model to account for the time for the rainfall excess to reach the main stream channels but do not account for the routing time from the main channel to the subcatchment outlet. This routing time is accounted for within the hydraulic model. These rainfall excess flows have been applied to the hydraulic model as flow versus time boundaries applied to the 2D model domain. The internal inflow boundaries have been model as source over area boundaries that allow for the excess rainfall to be distributed over a specified area allowing for greater definition in flood behaviour. The areas which flows are distributed are typically over a 10 meters buffered area from the centreline of the creek or channel (for a total buffered width of 20 meters).

In addition to the internal and external boundaries the 2D hydraulic model includes a number of 2D-2D boundaries. These boundaries are included to allow water to flow freely between the main broader floodplain grid and the two fine mesh grids used to increase the resolution of the Landsborough and Navarre townships. To ensure that there were no boundary effects caused by the linking of the domains the boundaries were located ample distance from any points of interest (roads or properties).

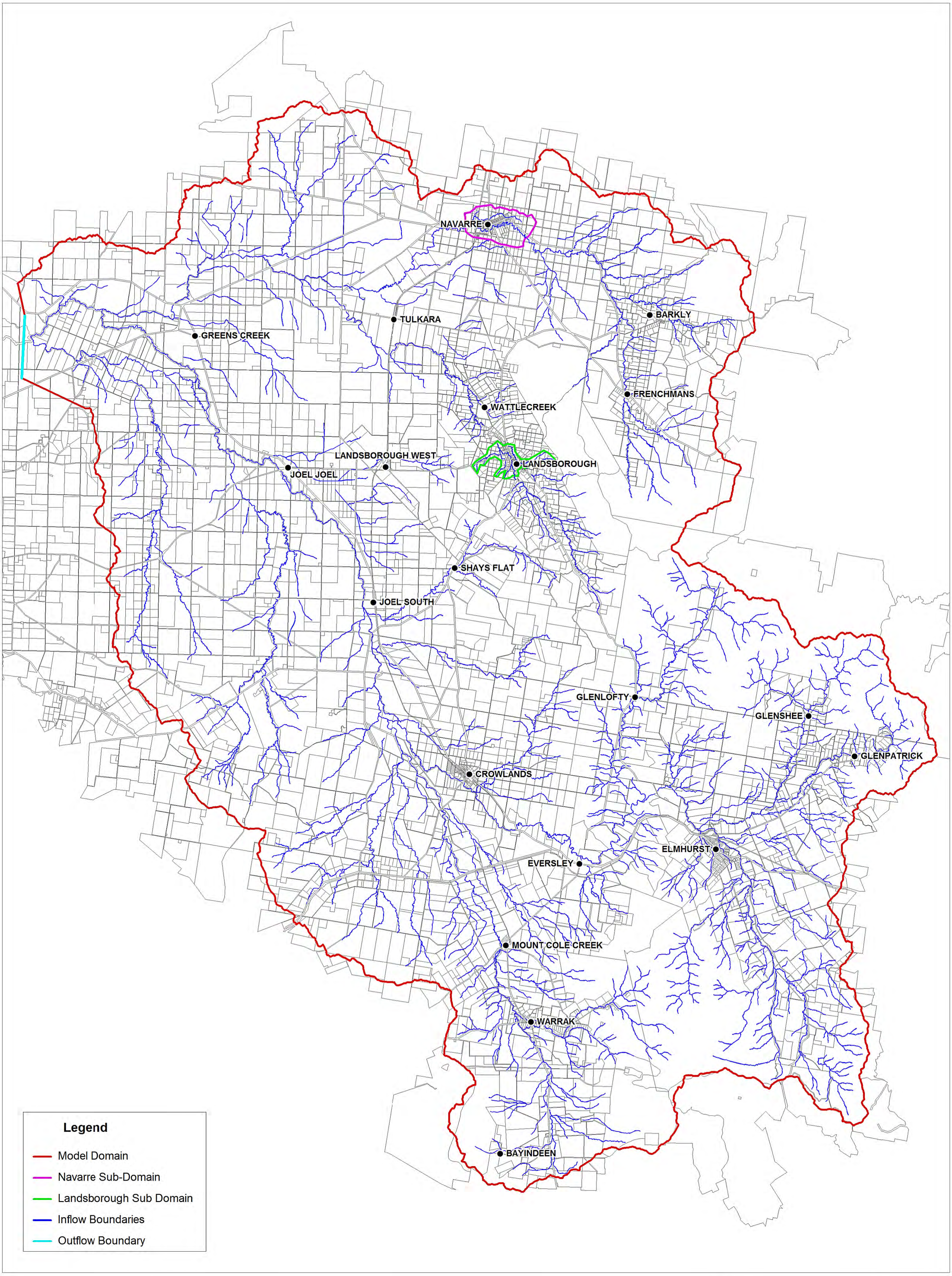
4.2.5 Upper Wimmera Township Fine Mesh Domain

Given the high social and economic sensitivity of the Navarre and Landsborough Townships in comparison to rural parts of the floodplain, a fine mesh domain with a grid element size of five metres has been established to improve the definition of flood behaviour within these two townships.

The two fine mesh domains are embedded in the larger coarser grid floodplain domain and dynamically linked such that flood water can flow between domains freely. Further, to ensure that there were no boundary effects caused by the linking, the extents of the fine mesh domains extend beyond sensitive areas such as roads or residential properties.

The Navarre township fine mesh domain extends upstream east of Supple Road, with the downstream boundaries beyond Tulkara-Railway Road to the west and Baines Road to the south. The extent of the domain is such that both creeks north and south of the town are incorporated within the fine mesh to ensure they are well defined in this sensitive area.

Similarly, the Landsborough township fine mesh domain extent covers the entire town. The downstream domain extends just downstream of Peacocks Road to the north-west, and upstream the domain extends to the south-west beyond Ararat-Arnaud Road. This domain incorporates the junction of the two creeks, Malakoff and Native-Youth Creeks that surround the town.



Title:

Upper Wimmera Flood Investigation
TUFLOW Model Setup

Figure: **4-1**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 3.75 7.5km
Approx. Scale

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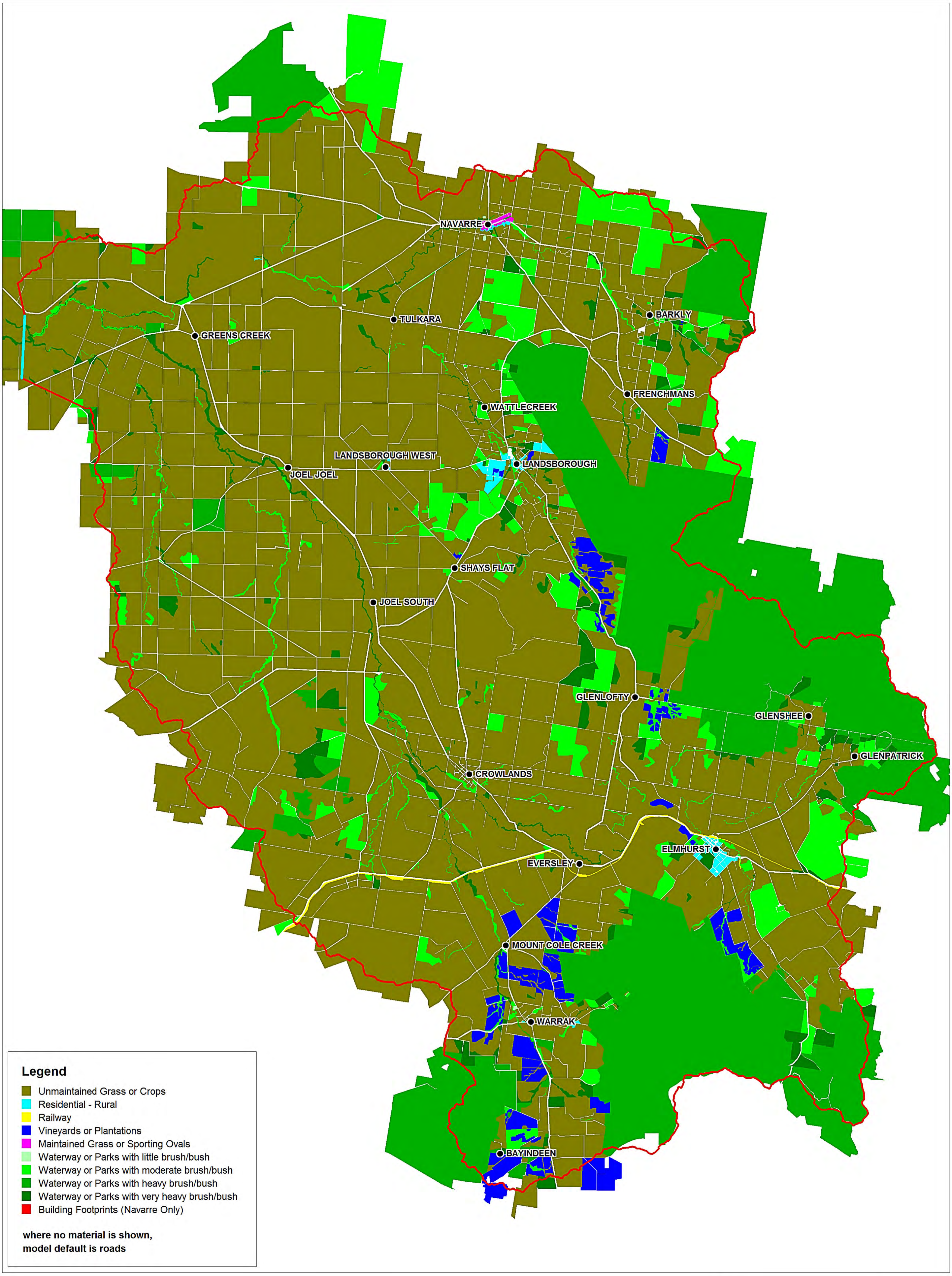

Title:

Upper Wimmera Flood Investigation
Manning's 'n' distribution

Figure: **4-2**

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4.3 Model Calibration and Validation

To establish a degree of confidence that the hydraulic model is suitably representing the characteristics of the study area and correctly translating the flows derived from the hydrologic modelling process into flooding behaviour, model calibration and validation is undertaken. Calibrated inflows, as discussed in Section 3.3, are applied to the model. Model parameters are then adjusted using reasonable values, until the model suitably replicates the recorded flood data at the stream gauges, flood marks, and anecdotal flood behaviour evidence.

The Upper Wimmera TUFLOW model underwent a calibration process to fit the model to the observed data. The TUFLOW model was calibrated against the September 2010 flood event and validated against the January 2011 flood event. The TUFLOW model was calibrated by varying the model parameters within acceptable tolerances. Summary statistics were reviewed in addition to an assessment of model fit to ensure the best fit was obtained.

4.3.1 Calibration and Validation Process

The hydraulic modelling calibration process involves the following steps:

(1) Collect, collate and verify relevant data including stream height recordings, flood marks and anecdotal evidence.

(2) Choose the historical storm events to be used in the calibration and validation process based on the available data and the nature of the event.

(3) Create the storm event inputs developed in the hydrologic modelling process to be used in the calibration and validation process.

(4) Apply the September 2010 calibration storm event to the TUFLOW model and optimise the model parameters to achieve model calibration.

(5) Validate the model parameters against the January 2011 storm event.

The following sections provide an overview of the above mentioned processes as well as outline the assumptions made during the hydraulic model calibration and validation process and present the calibration and validation results.

4.3.2 Calibration and Validation Data

During the September 2010 and January 2011 flood events, in addition to the flood data automatically recorded at the stream gauges, further data was gathered resulting in the following data being available for use in the hydraulic model calibration and validation process.

- The stage hydrograph recorded at the four gauges.
- Peak flood level marks, surveyed around Navarre for the January 2011 flood event.
- Estimated anecdotal flood depths around Navarre for the January 2011 flood event.
- Peak flood level marks, surveyed around Navarre and near the Glynwylln gauge for the September 2010 flood event.
- Peak flood extent marks, surveyed around Landsborough for the September 2010 flood event.

- Aerial photography taken during the January flood events. The photography was not taken until after at the time of flood peaks it does provide an indication of peak flood extent.
- Anecdotal evidence of flood behaviour and heights which has been provided by the community.

4.3.3 Event Selection

Following the completion of the hydrologic model calibration process, three historic storm event inputs were available to be used to calibrate the hydraulic model. Of these three events the two largest are the January 2011 and the September 2010 flood events which also have the two highest stage levels recorded at the Glynwylln stream gauge in recent records. As outlined in the previous section these two events are also the events with the largest amount of flood level data captured during and after the events.

Furthermore these two events occurred recently so they also represent the flood behaviour of the floodplain in its current state and having occurred recently, there is a large amount of reliable anecdotal evidence of flood behaviour which has been provided by the community that can be used to check the hydraulic model in areas of habitation such as Navarre, Landsborough, Elmhust and the other townships where there is no recoded data available.

For these reasons, the September 2010 and the January 2011 flood events were chosen as the hydraulic model calibration and validation events respectively. The September 2010 event was selected as the calibration event as it has the larger data set of the two to calibrate the hydraulic model. Whilst a rarer event, the January 2011 was used as the verification event as there are only three quality controlled surveyed data points to use for calibration purposes, along with a number of anecdotal accounts. Due to the size of the event and lack of supporting flood marks the December 2010 event was not used for either hydraulic calibration or verification.

4.3.4 September 2010 Calibration Event – Hydraulic Model Setup, Assumptions and Results

The September 2010 flood event occurred during an unseasonably wet spring. The event preceded two further large flood events within the catchment; the December 2010 and January 2011 storm events.

Whilst the initial routing of flows is performed in the RORB hydrologic model, the majority of the routing is performed in the hydraulic model. This routing is primarily influenced by the streams sinuosity, terrain slope and the hydraulic manning's roughness selected. As there is greater ability to spatially vary roughness, and therefore velocity, in the hydraulic model then the hydrologic model it is possible to more precisely mimic the observed record. However the hydrologic inputs ultimately control the limit to the accuracy by controlling the broad timing and the total inflow volumes into the model.

The primary variable during the calibration process was the manning's n roughness parameter. These parameters were varied within typical bounds for each identified material until a suitable match with the observed record was reached. In addition to varying manning's n, the location, number of and type of inflow boundaries were trialled to ensure that flows were applied appropriately and able to mimic the observed record.

Both the hydraulic TUFLOW and hydrologic RORB model flow results from the calibration event were compared in Figure 4-3 to the observed September 2010 records. The flow rate predicted by TUFLOW at the Glynwylln stream gauge shows a very good fit with respect to the observed record. The rising limb matches very well with the observed record; however the falling limb recedes slightly faster than the observed records.

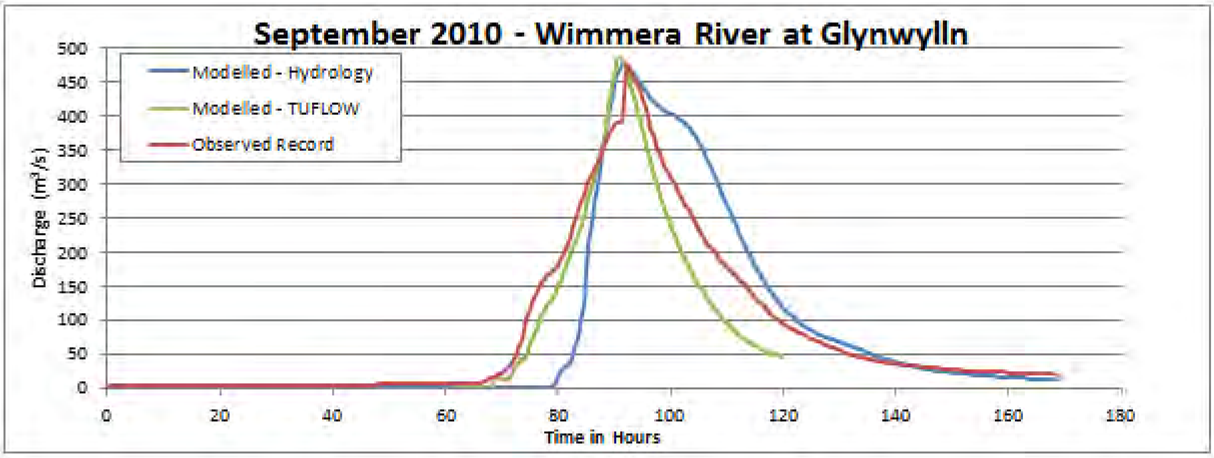


Figure 4-3 September 2010 Calibration Event Flow Rate Comparison

Figure 4-5 and Table 4-2 present the level comparisons between the hydraulic model and the observed record at the stream gauges. Table 4-2 shows very good match between the modelled levels at all of the gauge, and with the exception of Navarre, all were within 100mm of the observed records.

Table 4-2 September 2010 Calibration Level Comparison

Stream Gauge	Recorded Gauge Depth (m)	Modelled Depth (m)	Difference (m)
Wimmera River at Glynwylln	8.31	8.30	-0.01
Wimmera River at Eversley	6.34	6.27	-0.07
Wattle Creek at Navarre	4.64	4.51	-0.13
Mount Cole Creek at Crowlands	2.64	2.66	0.02

The model results for the Navarre and Glynwylln gauges show very good match with the observed record, matching the rising and falling limbs as well as peak level. These are shown in Figure 4-5. The model results at the Crowlands and Eversley gauges replicate the rising limbs and peak flood levels; however both have water levels that drain faster than the observed record, particularly the Eversley gauge which has a very long extended falling limb.

Following the September 2010 flood event a number of locations within the catchment were surveyed. The recordings in and around Landsborough were measured from handheld units that did not record sufficient vertical accuracy for calibration/verification purposes (all elevation have been rounded to the nearest metre). The points throughout Landsborough have been taken to be accurate measures of the flood water extent and have been used as such for the purposes of the hydraulic model calibration.

Figure 4-6 presents the flood level difference between the modelled and observed flood height in and around Navarre. The flood levels modelled were found to typically be slightly elevated compared to the observed record. The exception was the mark to the north of town which was found to be slightly below the observed record.

The model results in and around the Glynwylln stream gauge was found to be very good, as shown in Figure 4-8. Of the five flood marks, three were within ±0.20m, with two within ±0.05m. This matches well with the estimated difference at the gauge itself of -0.01m. The remaining two markers show levels significantly higher than the nearby observed flood height measurements, stream gauge and modelled heights. These are assumed to be either erroneous or the result of local upwelling caused by a tree or other sub-grid element that is not replicated within the hydraulic model.

A graphical summary of the 13 surveyed flood marks is shown below in Figure 4-4. The flood marks from in and around Landsborough have been excluded from this analysis. The distribution shows that the majority of points are within the ±0.2m calibration tolerance, whilst the remainder are normally distributed between over and under-estimating the peak flood level. The distribution of the differences between the surveyed flood marks and the observed flood marks indicate that the error is of a random nature, rather than a systematic error within the model.

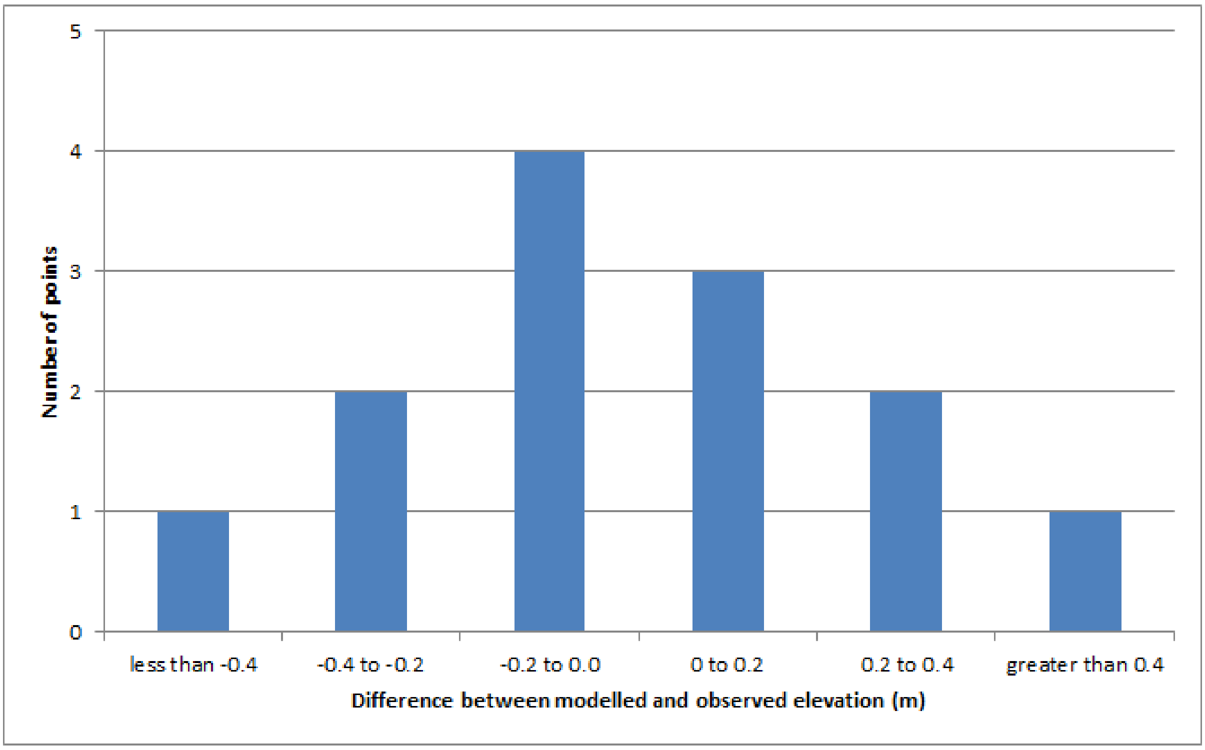


Figure 4-4 Distribution of Surveyed Flood Marks

As mentioned above, there is no vertically accurate survey marks recorded in and around the township of Landsborough. The recorded flood extent marks are shown in Figure 4-7. Of the eight marks, 4 were found to be exactly on the modelled extent, a further 2 were within 1 model grid cell (5m) indicating very close match. The remaining two markers were substantially higher up the banks than the modelled results. Inspection of the topography in the area suggest that to match the mark approximately 10m out would require water levels to be raised approximately 0.1m. The flood mark the furthest from the modelled flood extent (approximately 20m) would require raising water levels locally by 0.3m.

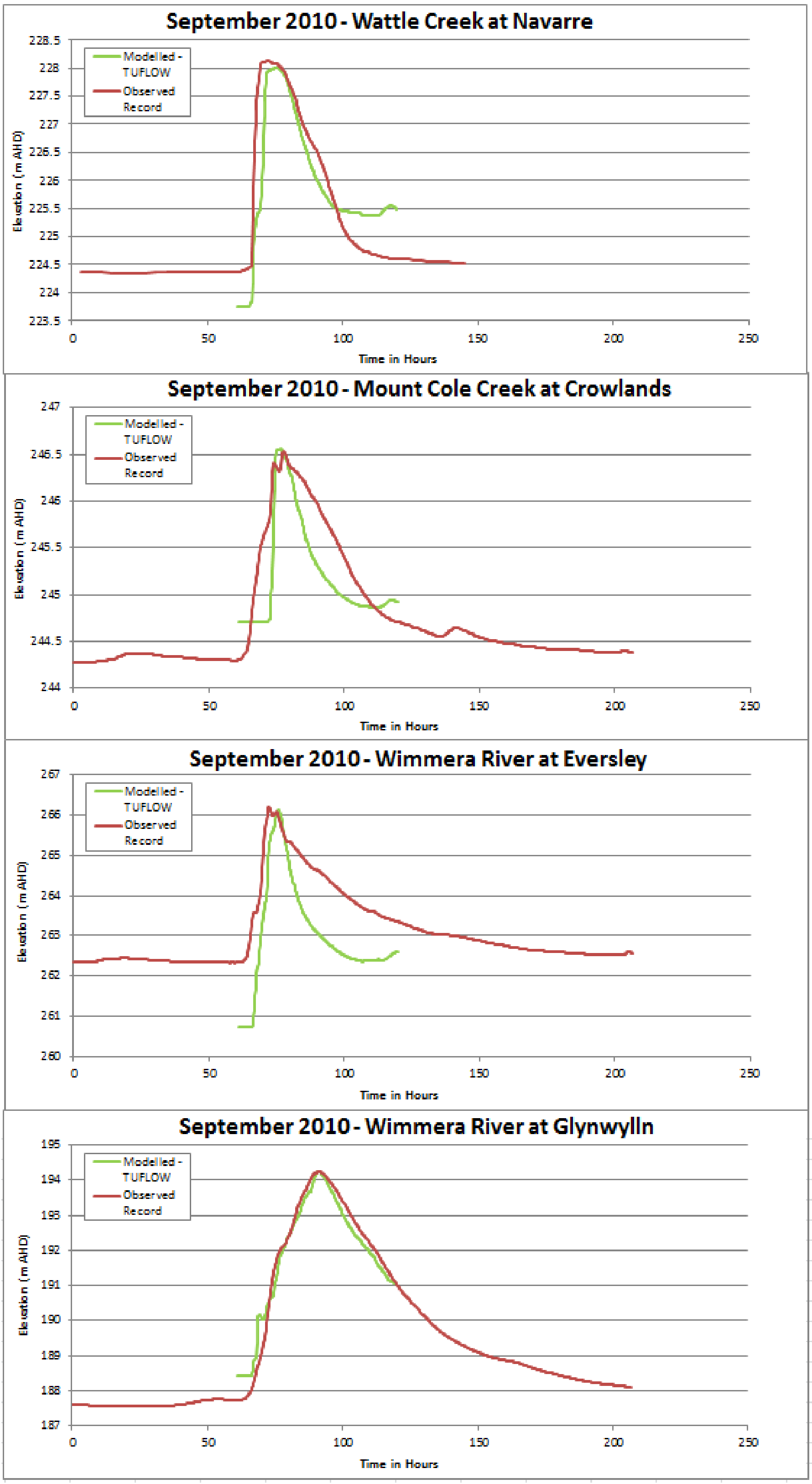
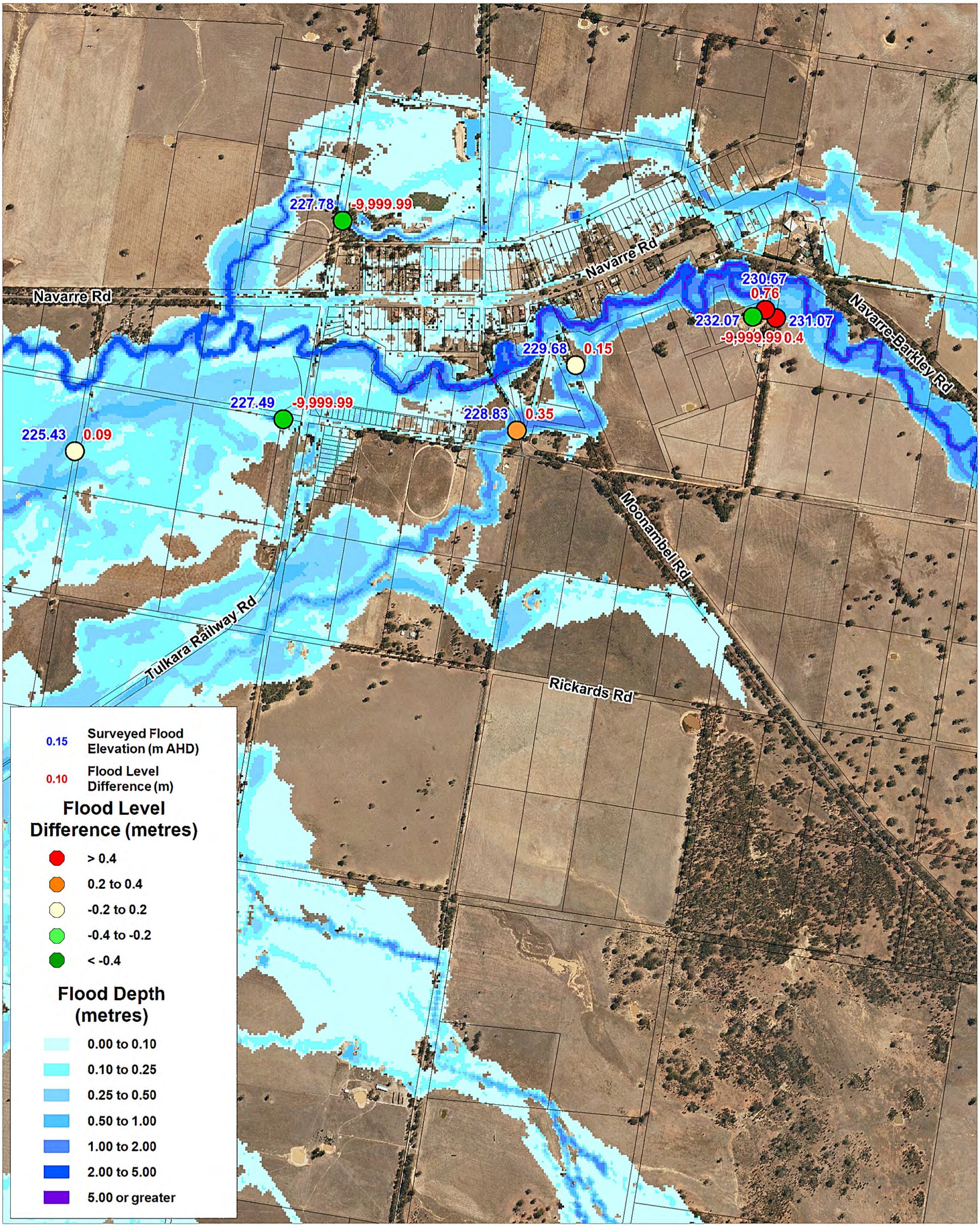


Figure 4-5 Calibration 2010 Validation Event Flow Comparison



Title:

Upper Wimmera Flood Investigation
September 2010 Calibration - Navarre

Figure: **4-6**

Rev: **A**

N

0 250 500m
Approx. Scale

Wimmera Catchment Management Authority · Ararat Rural City · Northern Grampians Shire · Pyrenees Shire · Australian Government · State Government Victoria · BMT WBM

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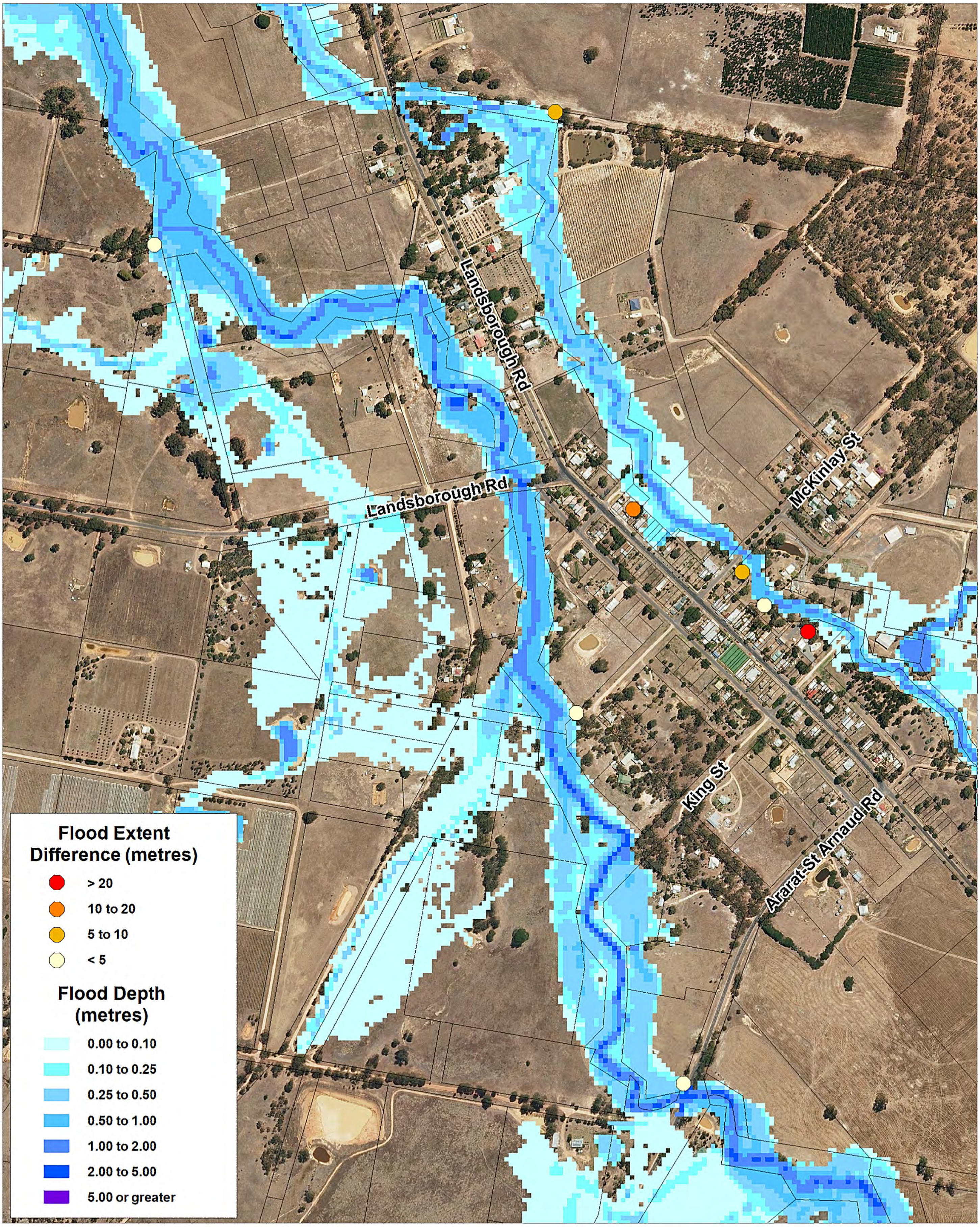

Title:

Upper Wimmera Flood Investigation
September 2010 Calibration - Landsborough

Figure: 4-7

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Approx. Scale

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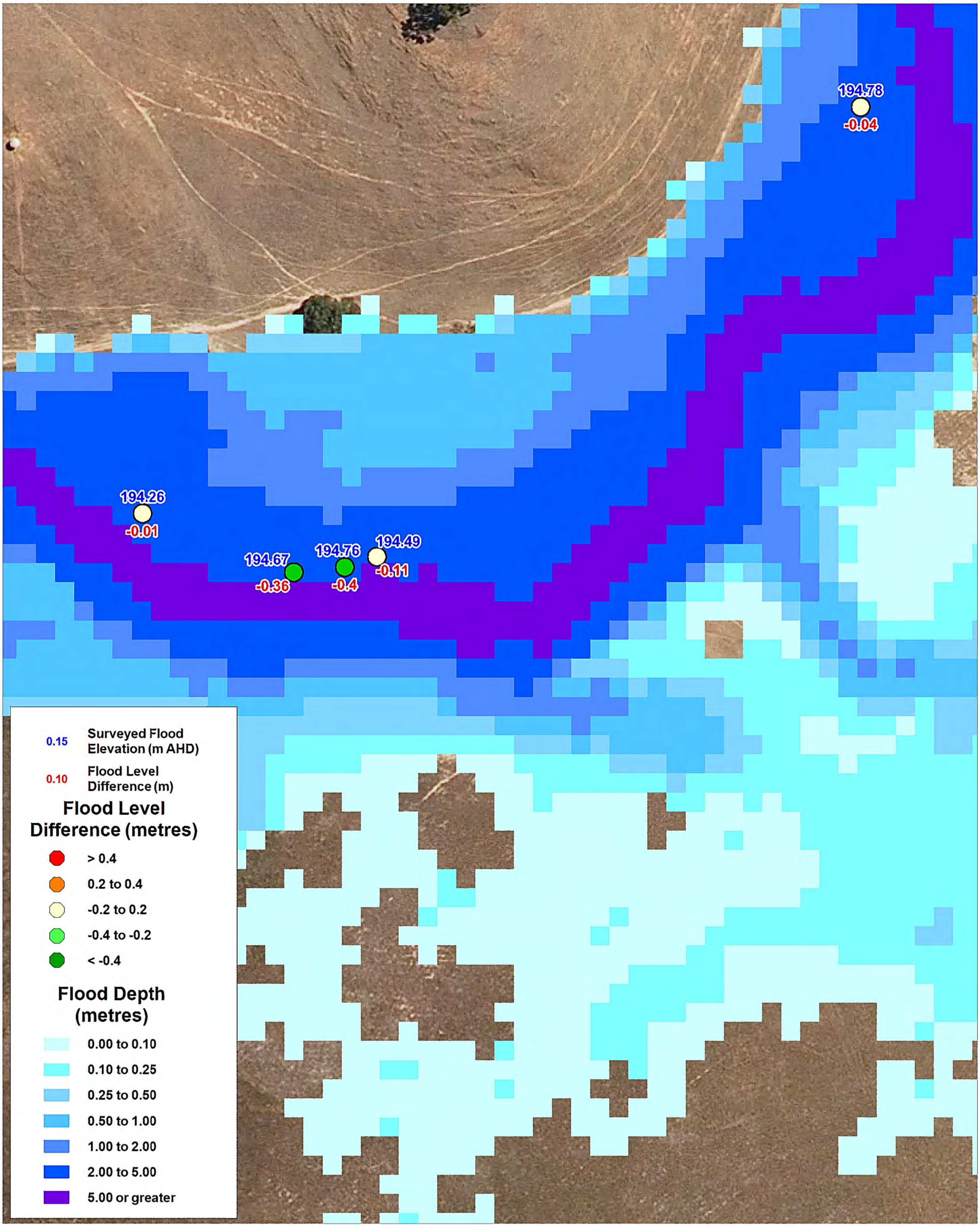

Title:
Upper Wimmera Flood Investigation September 2010 Calibration - Glynwylln

Figure: 4-8

Rev: A

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Approx. Scale

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4.3.5 Verification Event – Hydraulic Model Setup, Assumptions and Results

To validate the TUFLOW hydraulic model the January 2011 event was run through the model using exactly the same model schematisation as used in the calibration of the September 2010 event presented above.

The January 2011 flood event occurred during the hot summer months, however was preceded by a period of high rainfall during the winter and spring of 2010 including two major flood events which occurring during the September and December of 2010.

As can be seen in Figure 4-9 the flow rates for across the Glynwylln gauge during the January 2011 event is presented along with both the modelled hydrologic flows and the modelled hydraulic flows reported by TUFLOW. Compared to the September 2010 calibration event the January 2011 validation event shows a similarly good match. The rising limb matches very well with the observed record, however the falling limb recedes slightly faster than the observed records. As was found with the January 2011 calibration event, the hydraulic model was found to better match the shape and timing of the observed records than the hydrologic RORB model due to the hydraulic model being able to control the routing of the catchment by spatially varying the catchment roughness.

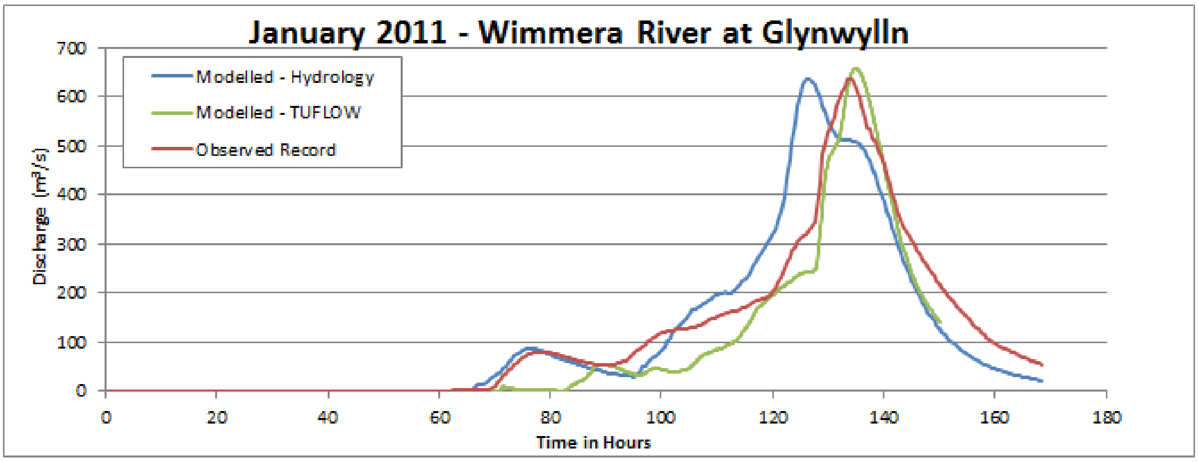


Figure 4-9 January 2011 Verification Flow Rate Comparison

Inspection of Figure 4-10 and Table 4-3 show a reasonable match is observed when the peak modelled water levels are compared to the observed record. Figure 4-10 compares the observed depth to the modelled height.

Table 4-3 January 2011 Verification Level Comparison

Stream Gauge	Observed Depth (m)	Modelled Depth (m)	Difference (m)
Wimmera River at Glynwylln	8.80	9.13	0.33
Wimmera River at Eversley	7.44	8.02	0.58
Wattle Creek at Navarre	4.77*	4.52	-0.25
Mount Cole Creek at Crowlands	3.45	2.97	-0.48

*Due to gauge failure the depth at the Navarre gauge was estimated by Thiess Services from debris marks following the event

As with the stream flow at Glynwylln, generally there is a reasonable fit between the observed record and the modelled results. The peak water level in the model is slightly elevated, with the general timing of the rising limb of the main peak comparable. The initial peak however is not replicated; this is likely a result of the initial wetting of the model filling any non-formalised storages and depressions in the terrain. Formalised storages such as farm dams and the like were filled prior to simulation. Non-formalised storages include road embankments, railway lines, local depressions in the DEM, etc. Due to the filling of these non-formalised storages and depressions, little of the initial flow was found to be reaching the modelled gauges.

Similarly the Crowlands gauge shows a reasonable match to the observed record with the general timing (if not height) of the main peak well simulated. As with the Glynwylln gauge the initial rise is not observed with the water in the model filling the depressions in the terrain.

The Eversley stream gauge height was the gauge the hydraulic model was least able to be replicate. Setting aside peak height due to aforementioned uncertainty, the modelled flow rose later than the observed yet at a much faster rate, also it was observed that the flood waters would recede at much faster rate than the observed. This gives the catchment a ‘peakier’ nature than the observed records indicate. A number of sensitivity tests were run by varying the manning’s roughness in the catchment and also distributing the flow to a greater number of locations to increase the routing. However a significantly better fit to the observed record was not obtained.

In addition to the stream gauge data, a number of locations throughout Navarre were surveyed following the January 2011 event. Further anecdotal reports were received from the community during the consultation meetings held in the towns of Navarre, Landsborough and Elmhurst.

For the Navarre Township only the three flood marks were surveyed by a trained survey team (Figure 4-11). All three points flood heights were found to be slightly underestimated by the model. However, two points were found to be within ±0.15m, with a larger difference between the observed and modelled results for the remaining point.

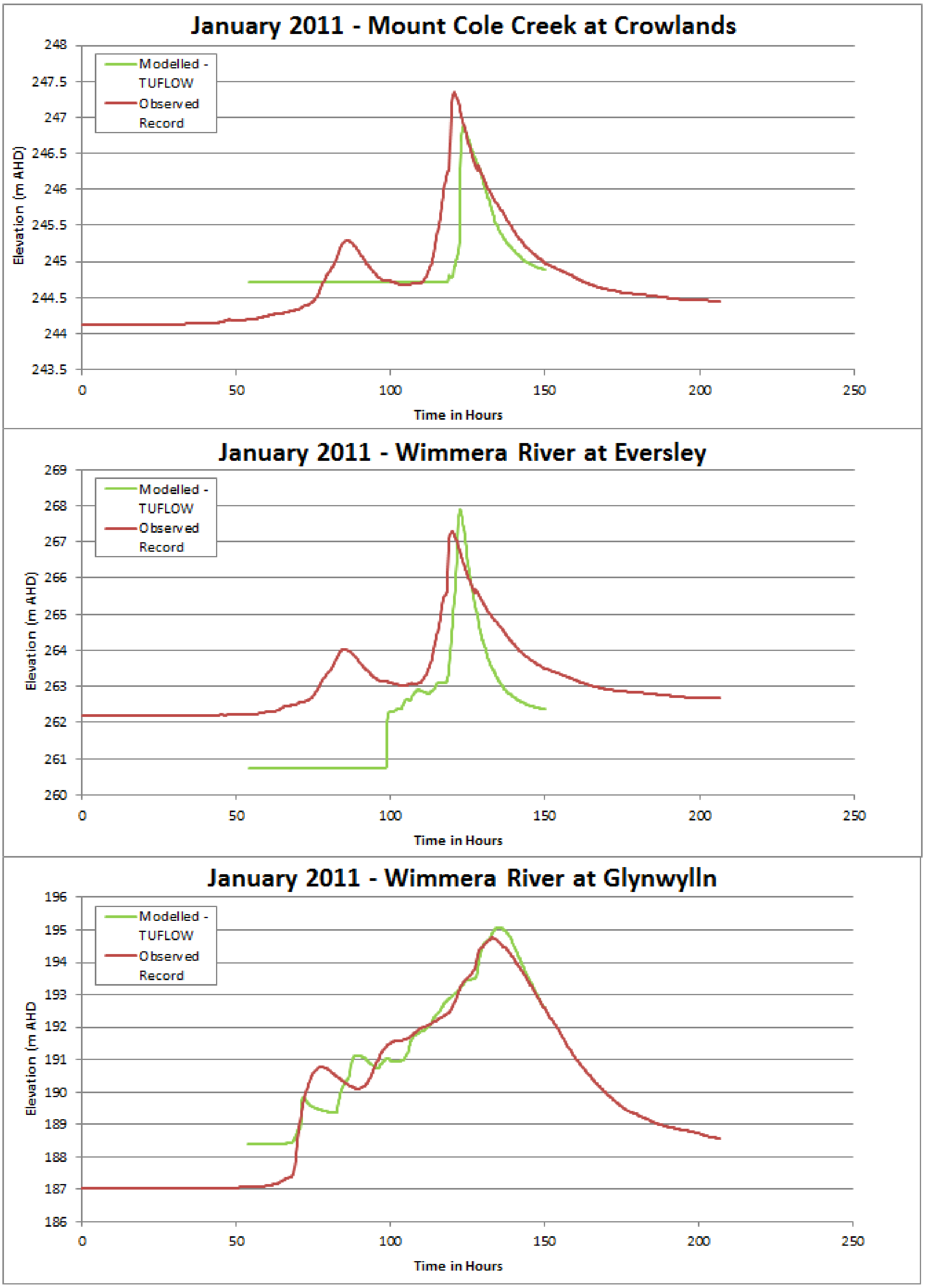
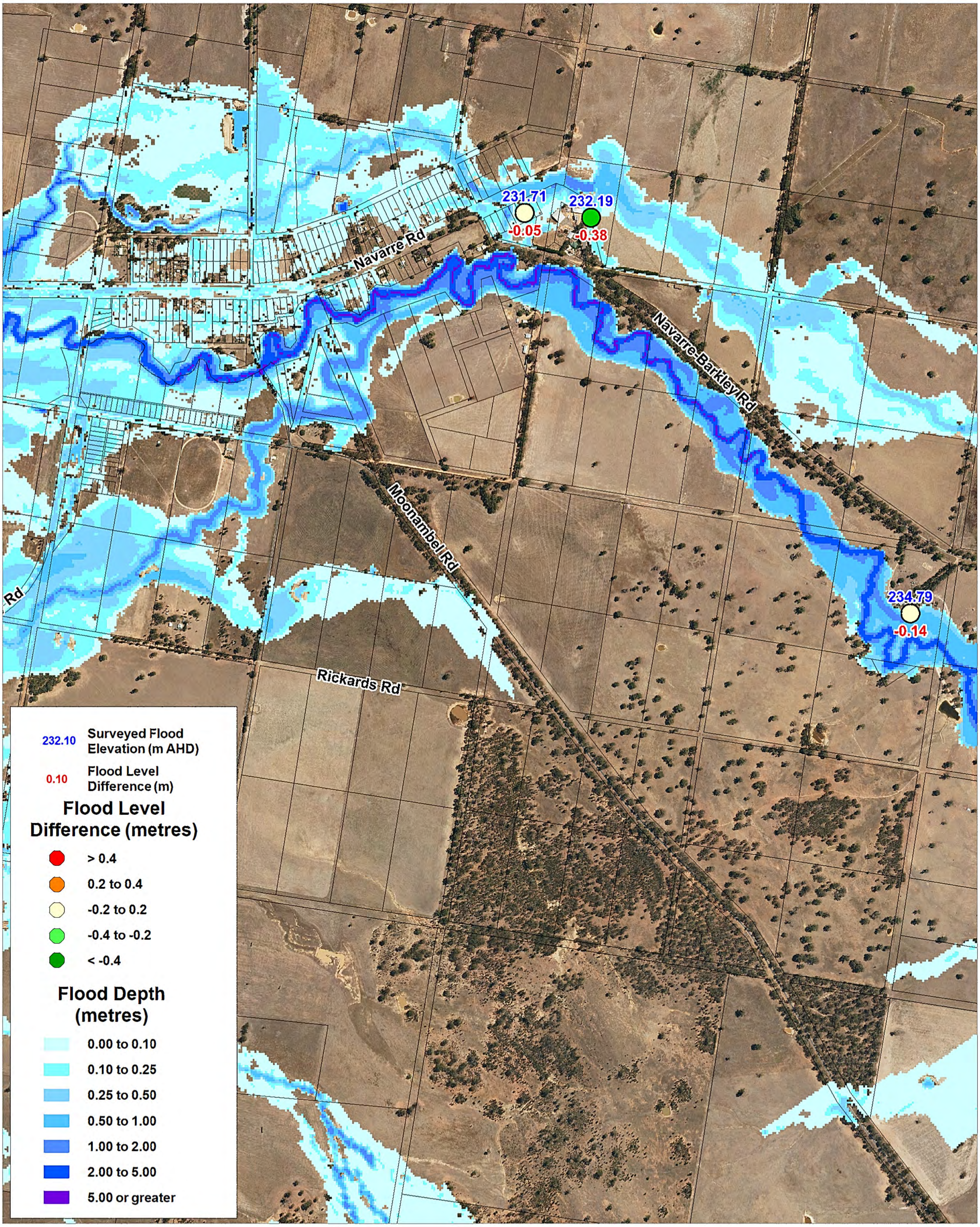


Figure 4-10 January 2011 Verification Event Level Comparison



Title:

Upper Wimmera Flood Investigation
January 2011 Verification - Surveyed - Navarre

Figure: **4-11**

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Approx. Scale

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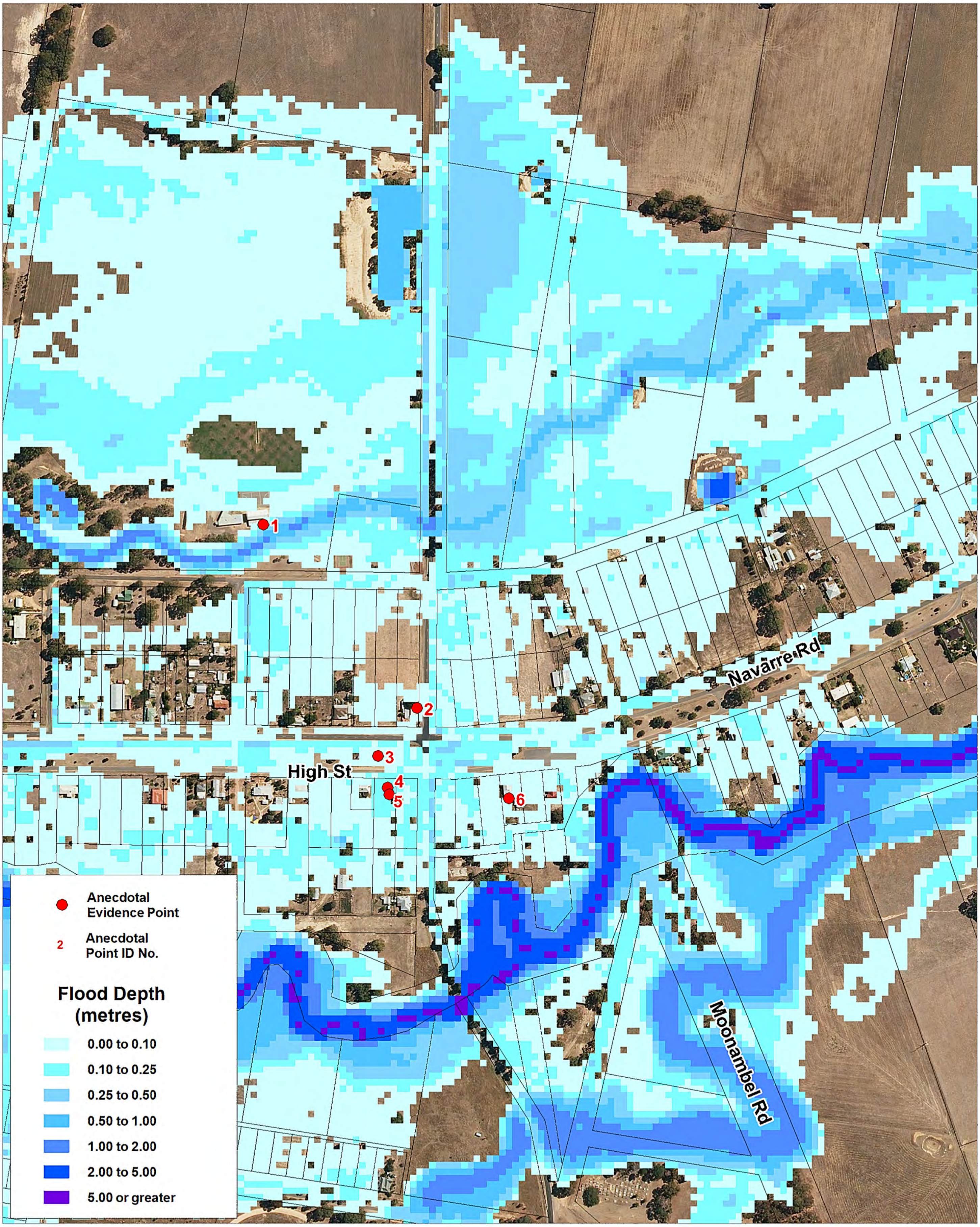
In addition to the three surveyed flood marks in and around Navarre, a number of flood marks were measured by Wimmera CMA staff, local government representatives and resident locals. These additional flood marks are presented in Figure 4-12 and Table 4-2. Further complicating the reliability of many of the anecdotal flood marks was the delay between the storm and the day of recording. Due to the delay, many of the marks had been cleaned or painted over and as such were based on the recollections and estimations of the community which may potentially underestimate or exaggerate the true flood level.

Flood levels to the north of town (point 1 located at the sports oval) was found to closely match the resident's recollection. Further in the town and to the south the model tended to underestimate the flood levels. The exception is the flood mark on the eastern edge of the church which was within 3cm. The flood levels in the town are generally shallow and the modelled results are highly dependent on the DEM, and the filtering around buildings may be a cause of the discrepancy between the modelled and observed flood marks. This is especially important when comparing flood depths as the filtering routines may have influenced the DEM ground levels in and around the building footprints.



Title:	Figure:	Rev:
Upper Wimmera Flood Investigation **January 2011 Verification - Anecdotal - Navarre**	**4-12**	**A**

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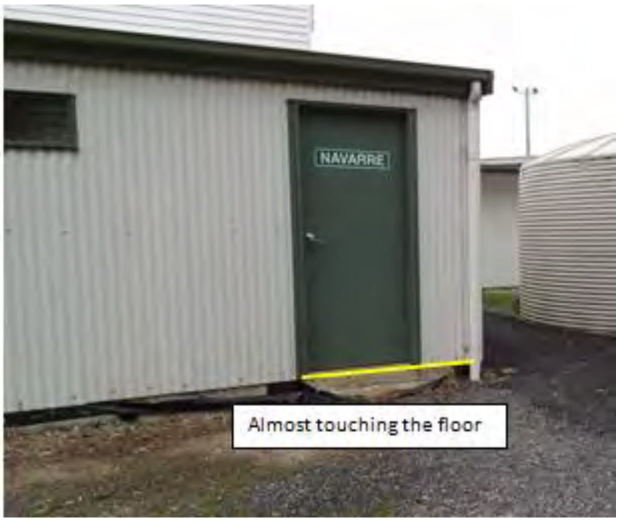
Table 4-4 January 2011 Verification – Anecdotal Flood Level Comparison

Point ID No.	Photo	Estimated Depth (m)	Modelled Depth (m)	Difference (m)
1		0.15	0.17	0.02
2		0.15	0.00	-0.15

Point ID No.	Photo	Estimated Depth (m)	Modelled Depth (m)	Difference (m)
3		0.35	0.05	-0.30
4		0.18	0.15	-0.03
5		0.35	0.23	-0.12

Point ID No.	Photo	Estimated Depth (m)	Modelled Depth (m)	Difference (m)
6		0.3	0.04	-0.27

4.3.6 Calibration Sensitivity Analysis

As part of the calibration process of the hydraulic model a number of parameters were varied. These primarily involved varying the mannings' n within typical ranges for the general pastoral land which comprises the majority land use within the catchment. The ranges varied from 0.04 to 0.06 for relatively short and un- cropped pastoral land respectively. Due to reports of blocked and damaged structures such as culverts and bridges during the calibration events a sensitivity analysis was undertaken whereby all bridge and culvert structures were blocked by 20%.

The difference between the peak modelled flood level and the recorded gauge levels is presented in Table 4-5 and Table 4-6 for the September 2010 calibration and January 2011 verification events respectively. As mentioned above, the September 2010 event was selected as the calibration event and the best calibration was achieved with a manning's n of 0.04 for the pastoral land.

When this was applied to the January 2011 verification event the worst comparison was achieved of the three manning's n. The best 'calibration' of the verification event was achieved with a manning's n of 0.06. This suggests that the January event occurred during a time of greater grass growth in the catchment following the wet months preceding the event (September and December 2010).

Under the 20% blockage of all structures within the catchment sensitivity scenario there was negligible increase in flood levels at the four gauges. Table 4-5 and Table 4-6 illustrate the flood level impact resulting from the blockages. Due to the relatively minimal capacity of the majority of the structures compared to the flows the blockages result in relatively minor changes to the determined flood levels.

Table 4-5 September 2010 Sensitivity Analysis Comparison

	Manning's n = 0.04	Manning's n = 0.05	Manning's n = 0.06	Manning's n = 0.04 & 20% Blockage
Wimmera River at Glynwylln	-0.01	-0.11	-0.19	-0.01
Wimmera River at Eversley	-0.08	-0.12	-0.14	-0.08
Wattle Creek at Navarre	-0.13	-0.11	-0.10	-0.13
Mount Cole Creek at Crowlands	0.02	0.00	-0.01	0.02

Table 4-6 January 2011 Sensitivity Analysis Comparison

	Manning's n = 0.04	Manning's n = 0.05	Manning's n = 0.06	Manning's n = 0.04 & 20% Blockage
Wimmera River at Glynwylln	0.33	0.27	0.21	0.33
Wimmera River at Eversley	0.57	0.53	0.49	0.57
Wattle Creek at Navarre	-0.24	-0.22	-0.21	-0.24
Mount Cole Creek at Crowlands	-0.49	-0.50	-0.50	-0.49

4.3.7 Calibration and Validation Summary

Given the limitations to the amount of calibration/verification data that was available, particularly in the January 2011 event, good agreement has been achieved between the recorded and modelled water levels in the September 2010 calibration event. This agreement was confirmed in the January 2011 validation event where acceptable agreement has been achieved between the recorded and modelled water levels.

The initial calibration and validation results (an earlier iteration than presented in this report) were also presented to the Technical Working Group and Steering Committee, and to a series of Public Meetings held in Navarre, Landsborough and Elmhurst. The feedback from these sessions and a number of surveys that were completed indicated that modelling was achieving an accurate representation of the both the September 2010 and January 2011 flood events as they recalled where feedback suggested that good agreement was achieved with the anecdotal evidence provided. Copies of the received resident's surveys will be included as part of the final study report.

In conclusion the flood model has been successfully calibrated against the September 2010 flood event and validated against the January 2011 flood event. As a result, the model setup and the parameters and assumptions used are appropriate for use in the design event and mitigation modelling required for the completion of the Upper Wimmera Flood Investigation.

4.4 Design Event Modelling

Design events are hypothetical floods representing a probabilistic estimate based on a probability analysis of flood and rainfall data. It is important to note that this does imply that the design rainfall will always results in the design flood event at any time that the estimated flood would occur. There are other factors such as catchment roughness and soil moisture content that contribute to defining a design event.

The design events modelled for the catchment are the 20%, 10%, 5%, 2%, 1% and 0.5% annual exceedance probability (AEP), i.e. the 5, 10, 20, 50, 100 and 200 year average recurrence interval (ARI), design events. In addition the probable maximum flood (PMF) event, based on the probable maximum precipitation (PMP) rainfall event is to be modelled.

The above mentioned design events will be used to undertake existing conditions flood mapping and damages assessments for the Upper Wimmera study area along with being used to formulate the components Upper Wimmera Flood and Drainage Management Plan.

Climate change sensitivity testing for the Upper Wimmera study area will also been undertaken for rainfall intensity increases of 10% and 20% for the 1% AEP flood event. Refer to Section 3.4.3 for further details on climate change sensitivity.

At this stage only the 1% AEP design event has been modelled using the calibrated hydraulic model (as described previously) and the results presented in Section 6.

5 Modelling Quality Assurance

To ensure that results and outcomes that have established as part of the Upper Wimmera Flood Investigation and can be used for any future assessments or works to be undertaken within the Upper Wimmera floodplain, an extensive Quality Assurance (QA) program has been undertaken. This includes independent internal review of all modelling and reporting outputs, and in some instances, external review of the presented results and reporting.

A comprehensive independent internal review was undertaken on the Upper Wimmera flood model for both the hydrologic and hydraulic modelling components, an overview of which is provided below.

5.1 Hydrologic (RORB) Model Review

The independent hydrologic (RORB) model review included, but is not limited to, the following checks:

- The methodology of the model development and calibration and validation process was checked for suitability and agreed upon.
- The catchment definition, sub-catchment breakup, reach alignments and reach types were appropriate for the catchment characteristics.
- That the RORB model was developed correctly to ensure that input data, both catchment characteristics and rainfall was appropriately represented in the model.
- A review of the model calibration and validation output results, including a review of the adopted parameters for design event modelling.

5.2 Hydraulic (TUFLOW) Model Review

The independent hydraulic (TUFLOW) model review included, but is not limited to, the following checks:

- The methodology of the model development and calibration and validation process was checked for suitability and agreed upon.
- That the TUFLOW model was developed correctly to ensure that input data appropriately represented in the model.
- That the topography, surface roughness and hydraulic structures were appropriately represented with the hydraulic model.
- The boundary conditions were correctly modelled ensuring that flow is entering and leaving the model appropriately and not influencing the model results, i.e. imposing boundary effects within the study area.

That the volume and conservation of mass errors present within the TUFLOW model were within acceptable limits as to not influence results.

6 Flood Mapping and Results

This section provides a brief overview of the floodplain mapping process used in Upper Wimmera Flood Investigation and presents a selection of the existing conditions mapping outputs.

TUFLOW produces a geo-referenced data set defining peak water levels, depth, velocities and hazard throughout the model domain at the corners of its computational cells. This data is imported into GIS to generate a digital model of the flood properties and produce the required flood mapping outputs.

Ultimately the existing conditions peak flood depth will be mapped for the 20%, 10%, 5%, 2%, 1% and 0.5% AEP and PMF events. For this draft report only the 1% AEP event has been reported.

6.1 Flood Depth Mapping and Description

Flooding within the Upper Wimmera floodplain is very extensive, spanning the entire width of the floodplain in larger events, many of which are over 1km in width. The township of Navarre, Landsborough, Elmhurst amongst others are also impacted upon due to their close proximity to the creeks and rivers throughout the catchment. Flood depth throughout the catchment is presented in Figure 6-1.

In the 1% AEP there is widespread inundation of the town of Navarre, shown in Figure 6-2, due to the flood waters. Flooding from the northern creek Youngs Creek overtops the banks and spreads southwards into the town. Similarly flood waters from Wattle Creek overtop the banks spilling into the township inundating most of the properties south of Navarre Road. North of Navarre Road flooding is less widespread causing inundation of numerous properties with the potential to inundate many existing dwellings.

During the 1% AEP flooding in and around Landsborough, shown in Figure 6-3, is largely contained within the banks of the two creeks that enclose the town centre. Generally the towns properties appears well protected from the 1% AEP flood extent with few dwellings inundated. A number of roads leading into the town are overtopped potentially isolating the town till flood waters recede.

6.2 Flood Hazard Mapping

Existing conditions peak flood hazard is mapped for the 1% AEP event. The 1% AEP flood hazard is shown in Figure 6-5 through Figure 6-8.

Hazard mapping was undertaken using a methodology prescribed in this study that is designed to determine if it is safe for people and vehicles to move about during a flood event. Hazard is defined in terms of the depth and velocity-depth product as follows:

- Low Hazard – depth less than 400 mm and/or velocity x depth less than 0.4 m^2/s;
- Moderate Hazard - depth less than 800 mm and/or velocity x depth less than 0.8 m^2/s; and
- High Hazard - depth greater than 800 mm and/or velocity x depth greater than 0.8 m^2/s.

Due to the relatively flat nature of the study area and the broadness of the floodplain there exists a mixture of flood hazard within the catchment. Generally the areas of broad floodplain are categorised as low hazard. Whilst the flooding is extensive in many areas it is generally shallow. Areas of high hazard are usually confined to the waterways. The hazard in waterways is usually due to the depth of the water rather than the velocity. However, where roads cross a waterway, there is usually higher velocity (due to constriction of the waterway) and therefore higher hazard results from the overtopping flood waters.

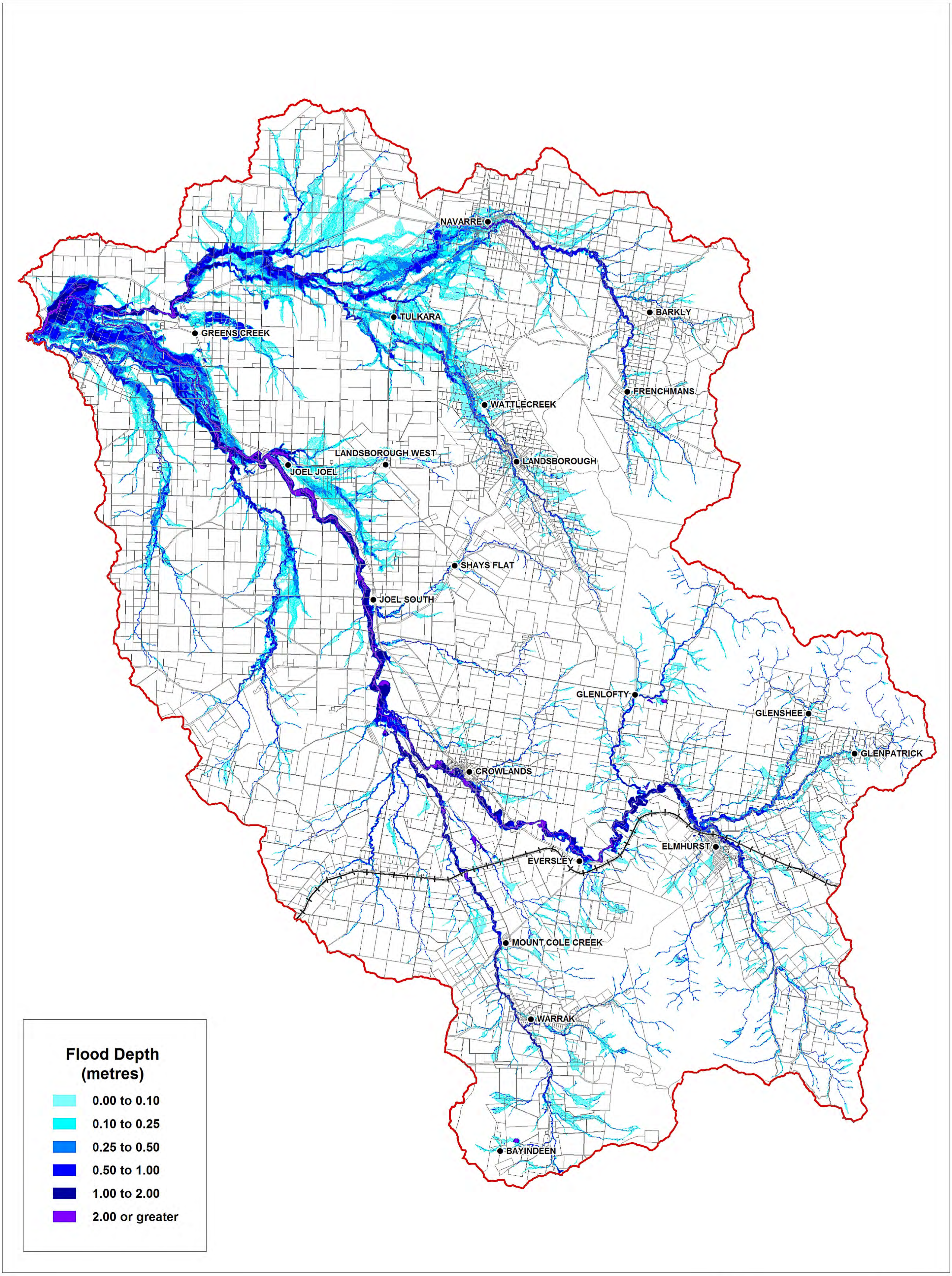
In the township of Navarre there is extensive flooding, however the hazard outside of main creeks is low. Both the depth and velocity of flood waters in the town is low and consequently the flood hazard is also low during the 1% AEP flood event.

Floodwaters pose little hazard to the townships of Landsborough or Elmhurst. Moderate and high hazard floodwaters are generally confined to the creek systems near the towns. However, road crossings into and out of the town at the creeks show high levels of hazard and therefore the towns may experience isolation due to the hazards along the roads until floodwaters recede.

6.3 Flood Velocity Mapping

Existing conditions flood velocity is mapped for the 1% AEP event at peak flood level. The flood velocity mapping for this study is designed to depict both the magnitude and direction of the flow velocities. The 1% AEP flood hazard is shown in Figure 6-9 through Figure 6-12.

Flood velocity mapping is useful in determining the areas of flood risk, identifying flowpaths and identifying the direction of flow.



Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Depths - Catchment

Figure: **6-1**

Rev: **A**

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Approx. Scale

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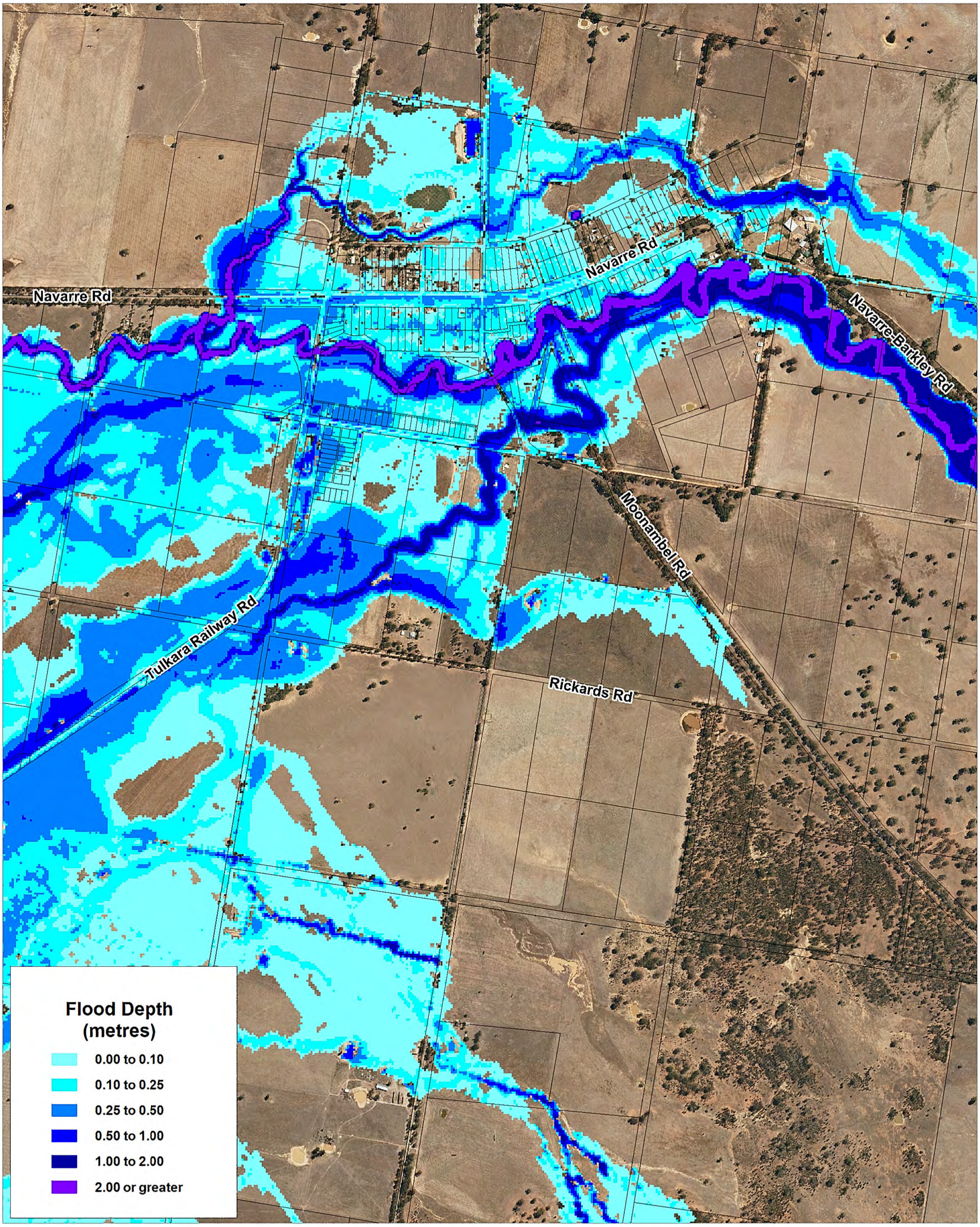

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Depths - Navarre

Figure: **6-2**

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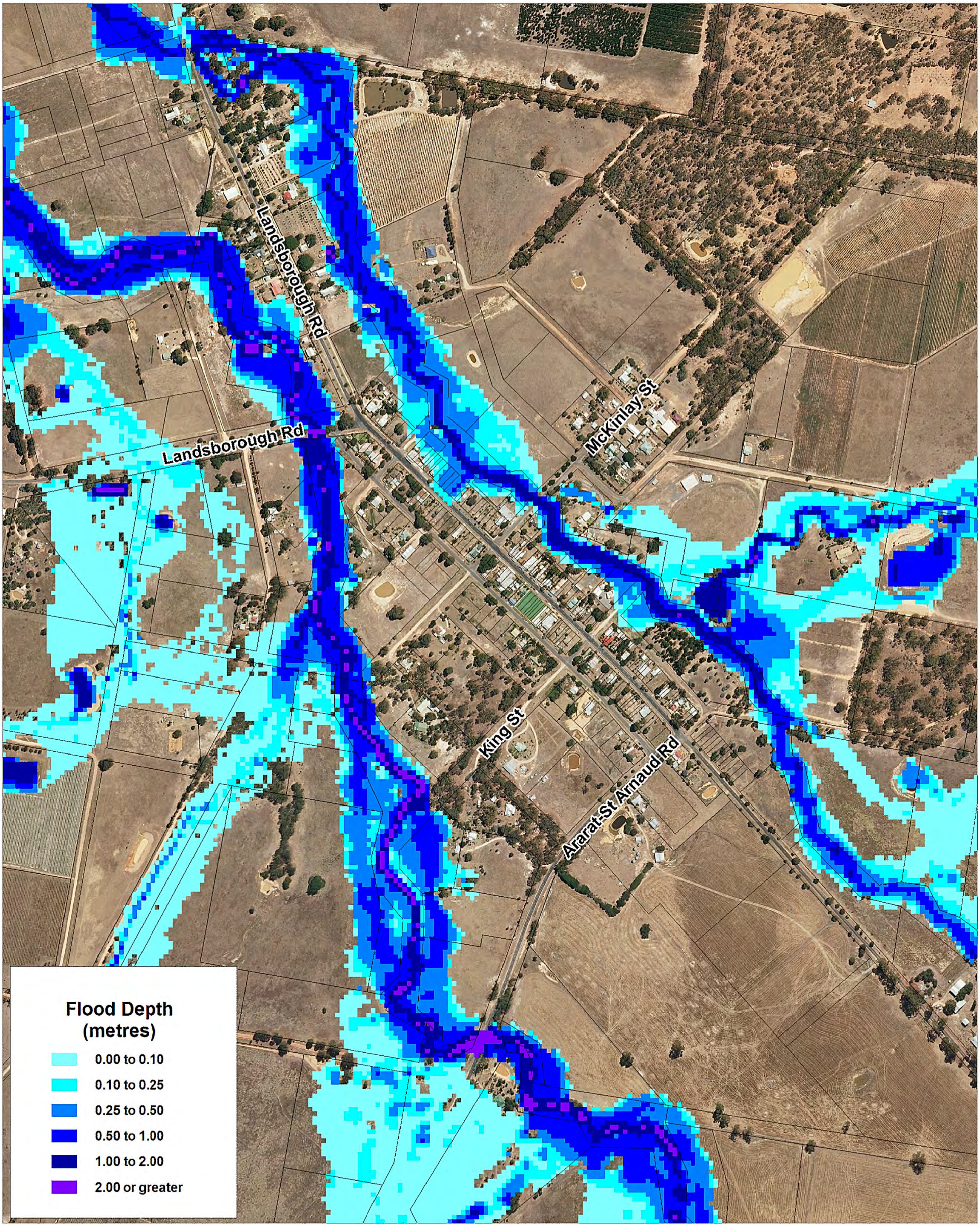

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Depths - Landsborough

Figure: 6-3

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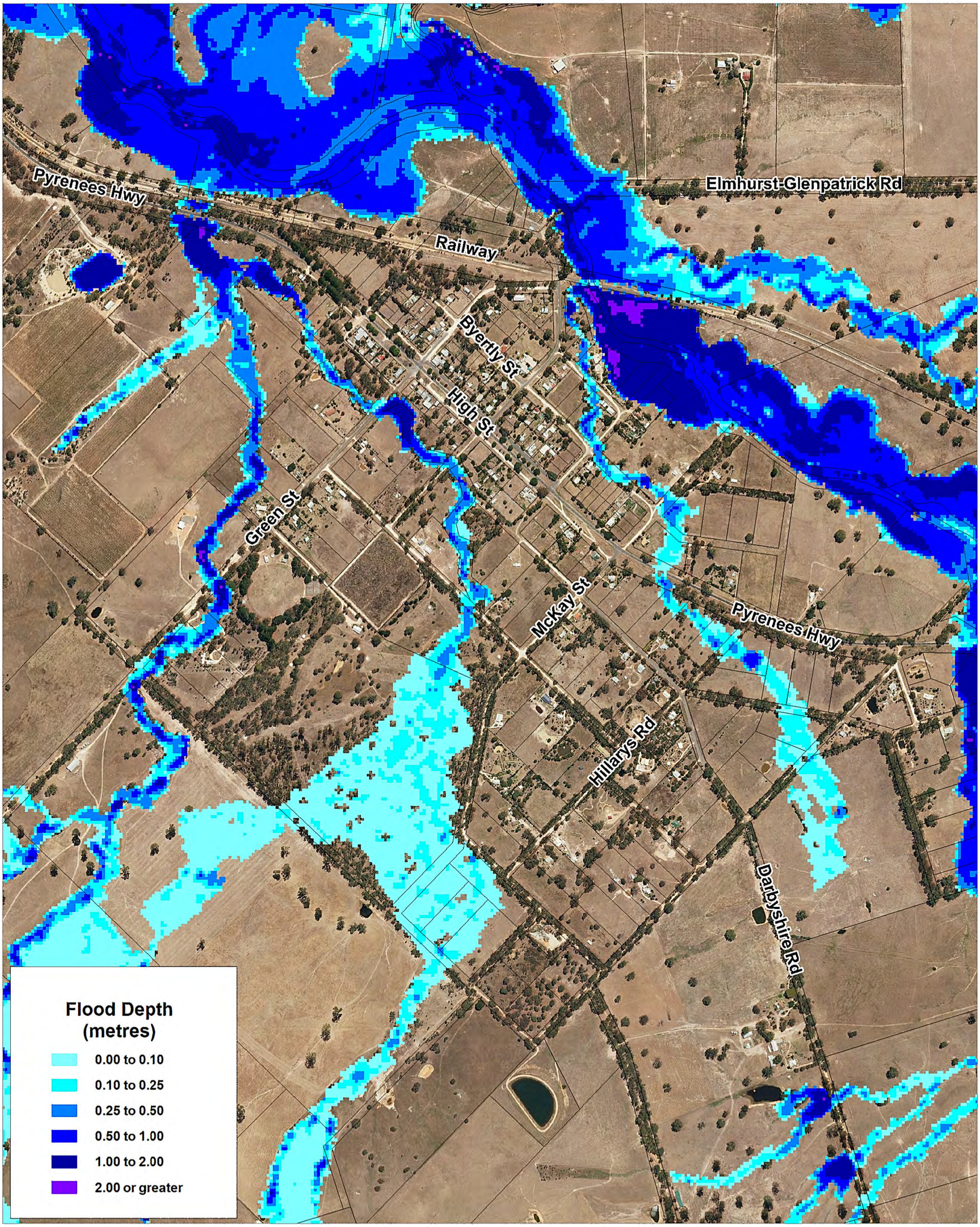

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Depths - Elmhurst

Figure: **6-4**

Rev: **A**

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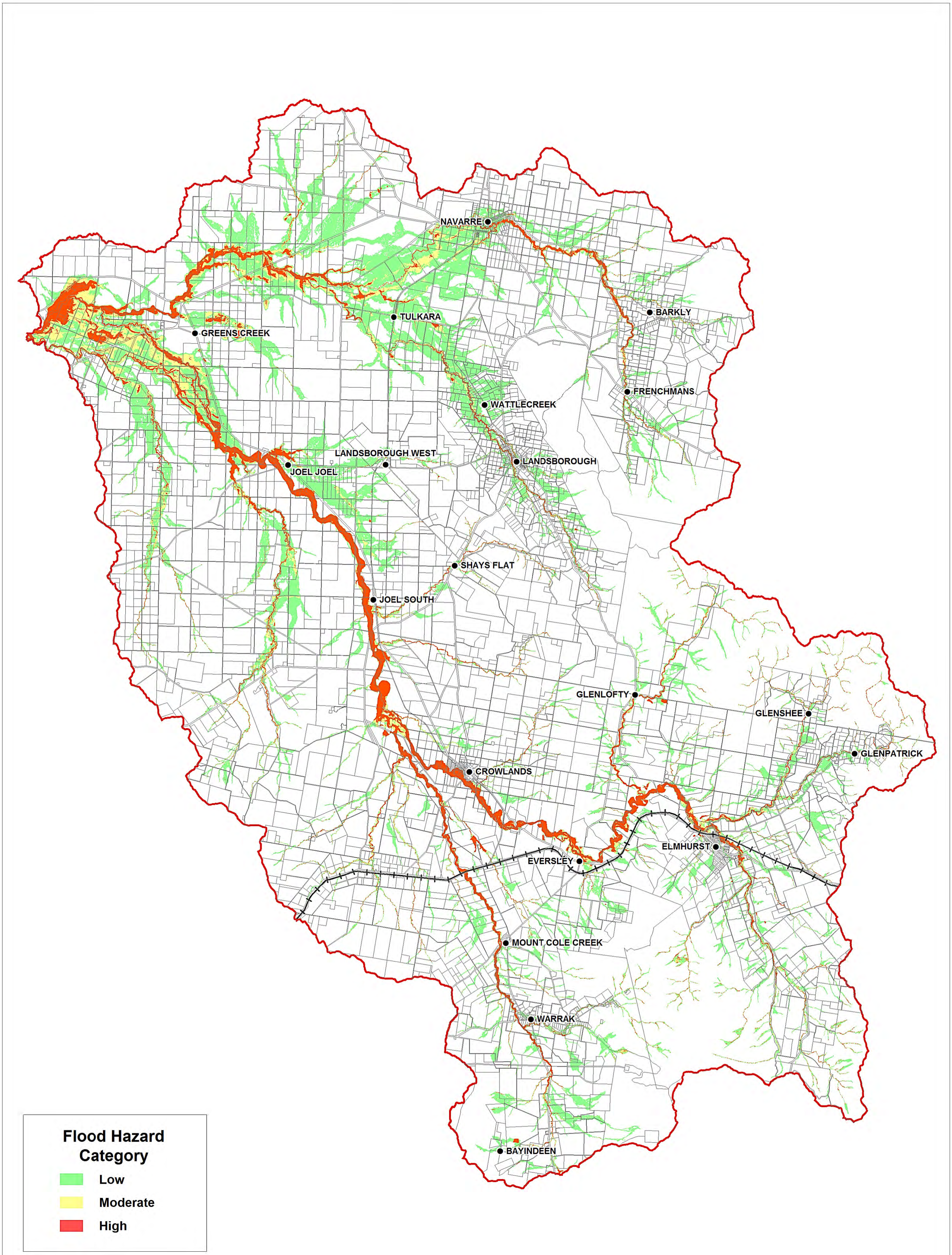

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Hazard - Catchment

Figure: 6-5

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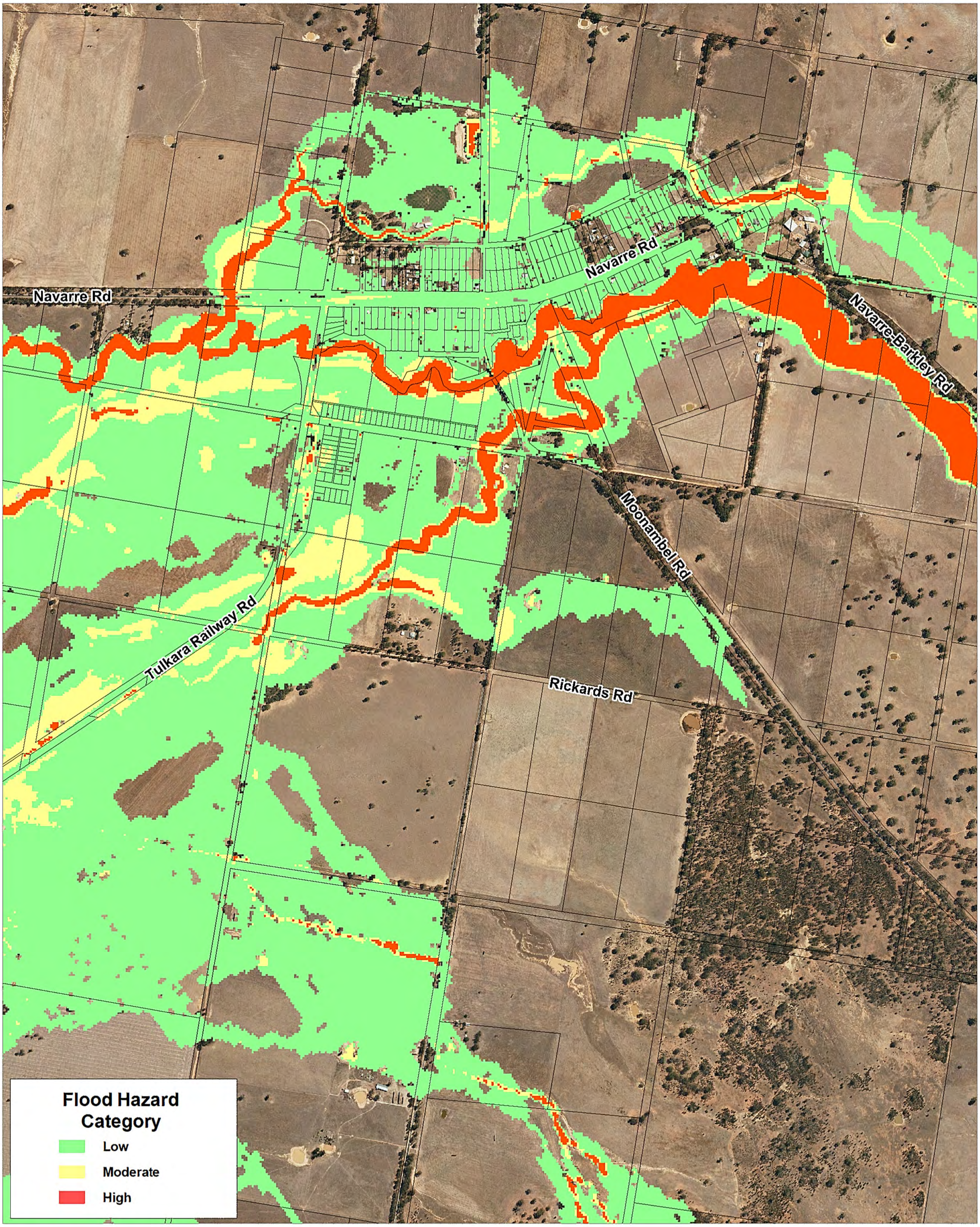

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Hazard - Navarre

Figure: **6-6**

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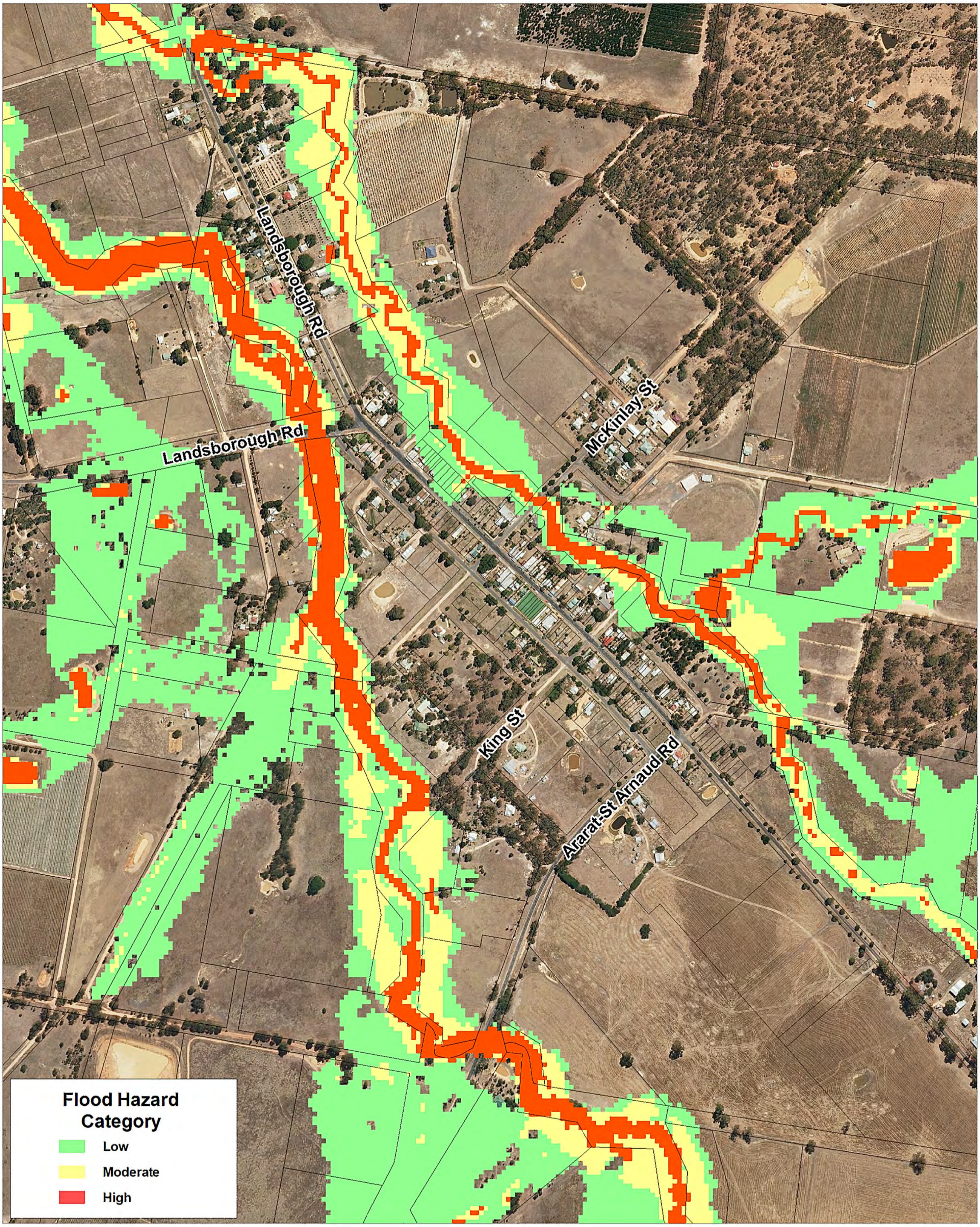

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Hazard - Landsborough

Figure: 6-7

Rev: A

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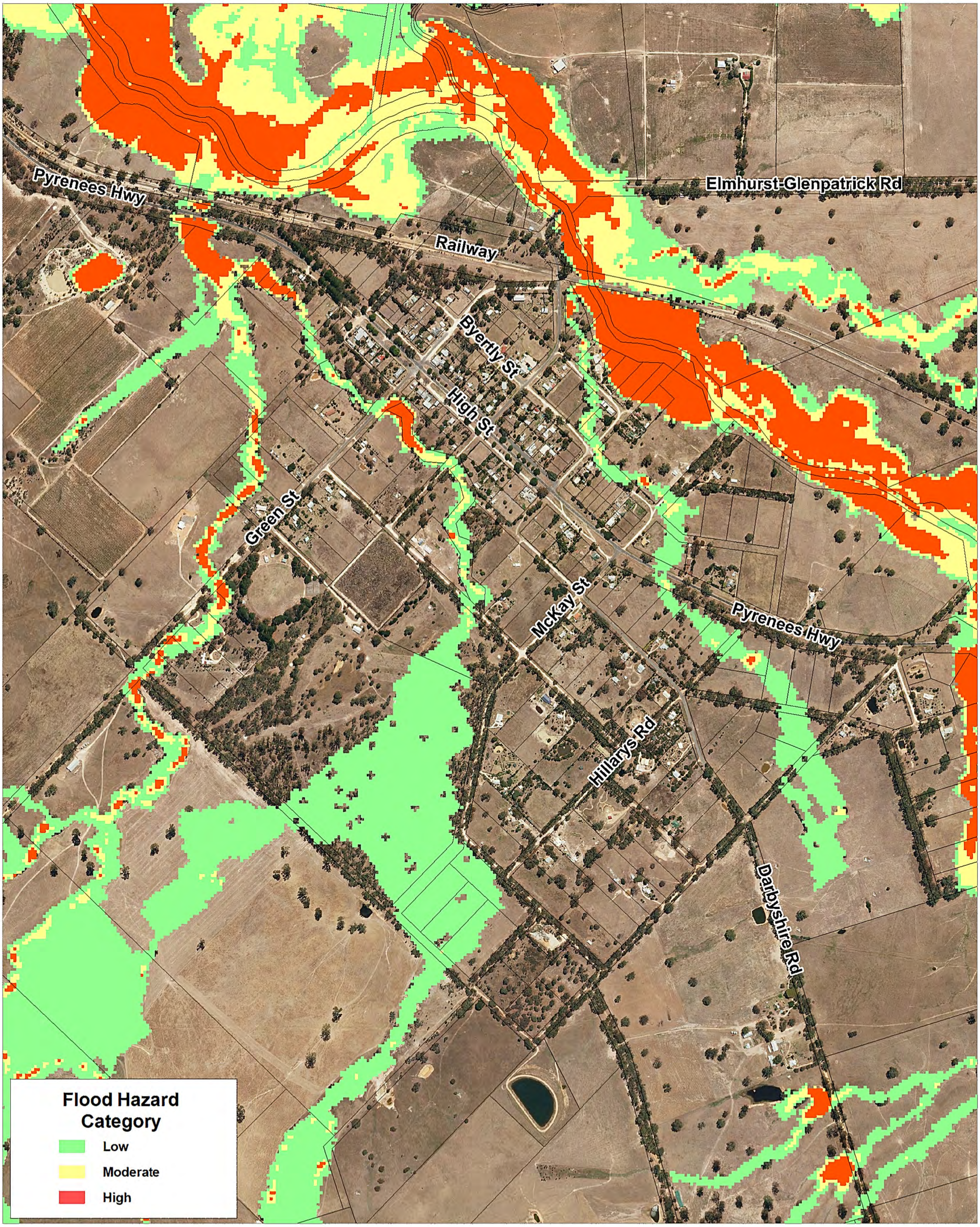

Title:
Upper Wimmera Flood Investigation
1% AEP Design Flood Hazard - Elmhurst

Figure: 6-8

Rev: A

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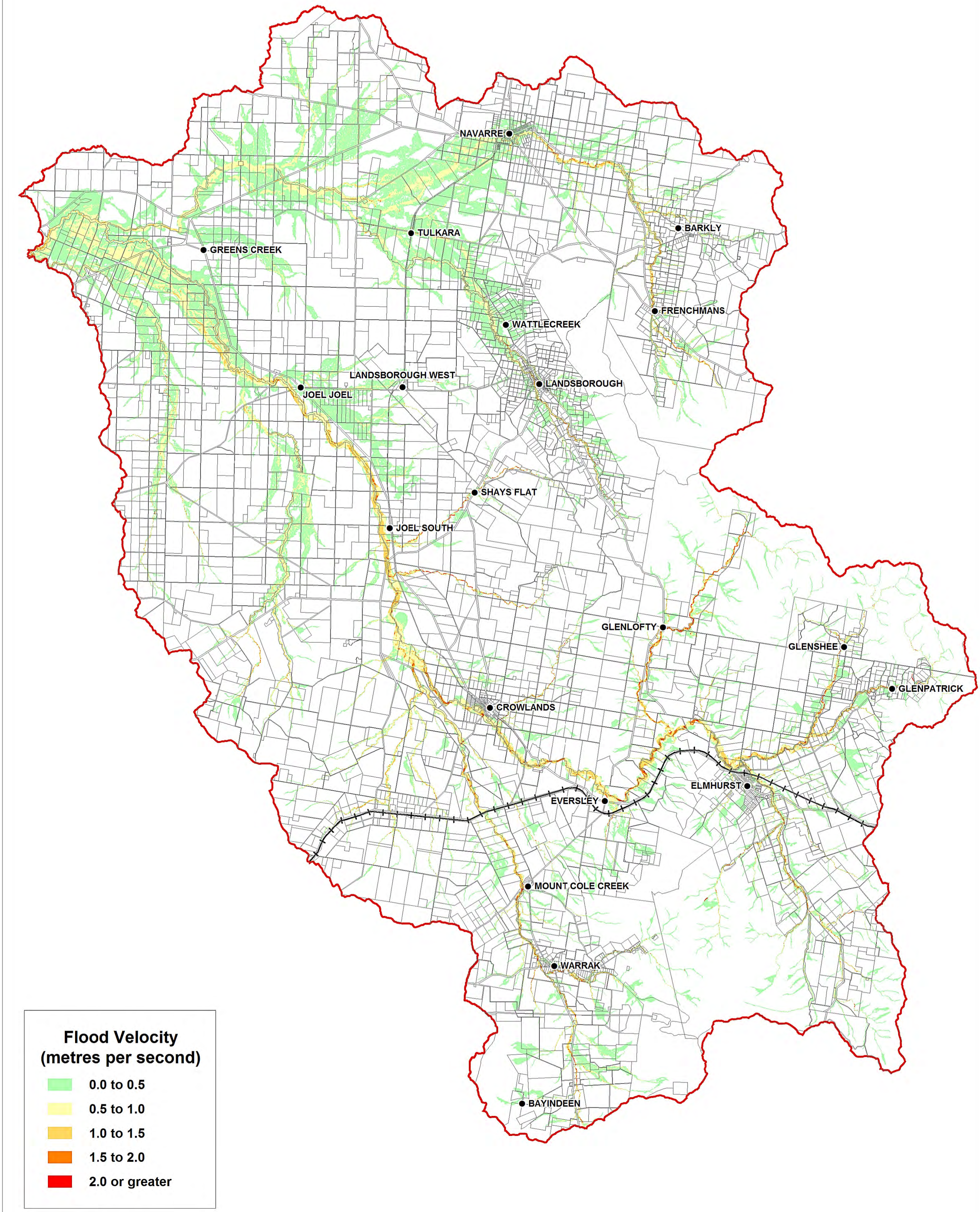

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Velocity - Catchment

Figure: 6-9

Rev: A

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Approx. Scale

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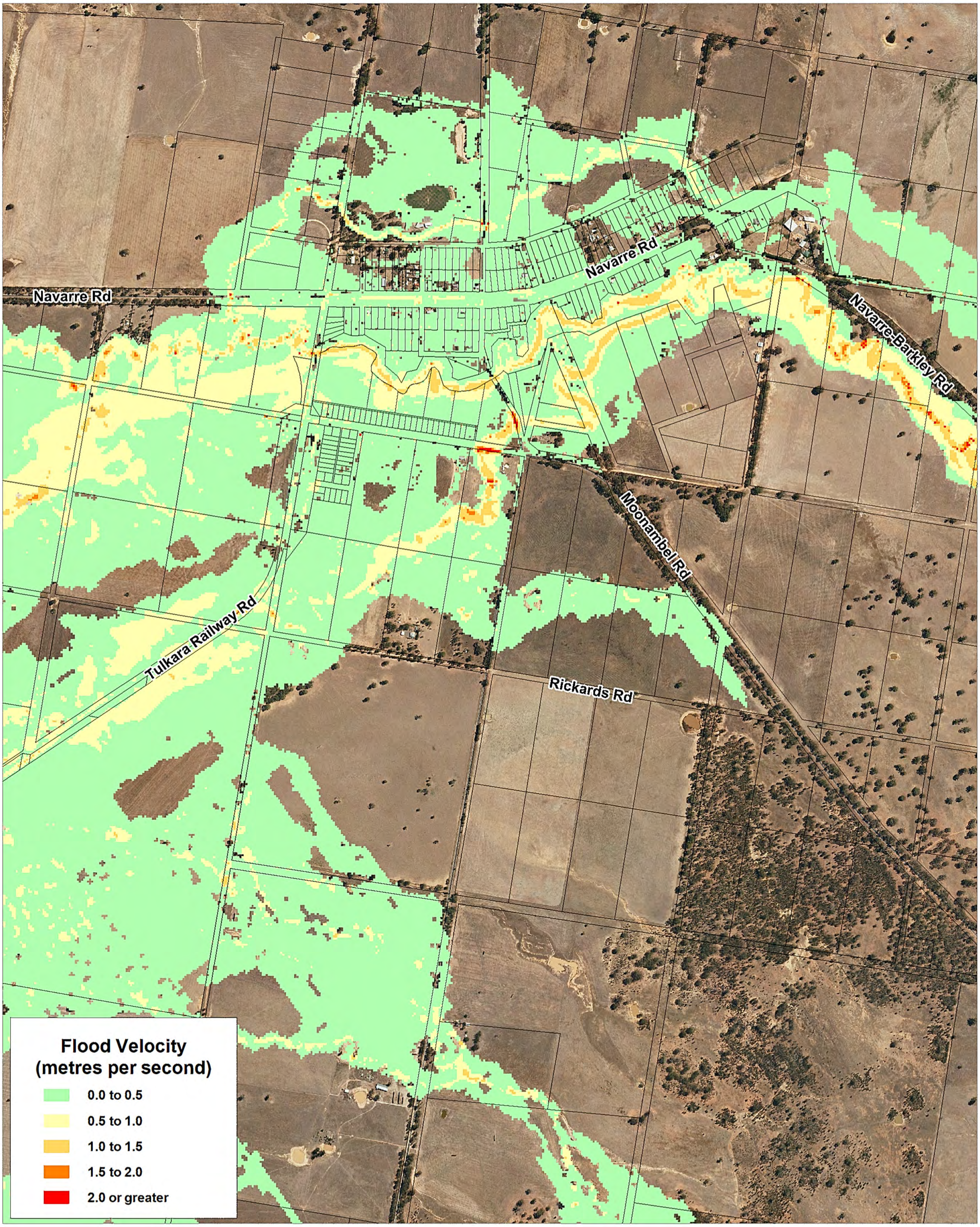

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Velocity - Navarre

Figure: **6-10**

Rev: **A**

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Approx. Scale

Wimmera Catchment Management Authority · Ararat Rural City · Northern Grampians Shire · Pyrenees Shire · Australian Government · State Government Victoria · BMT WBM

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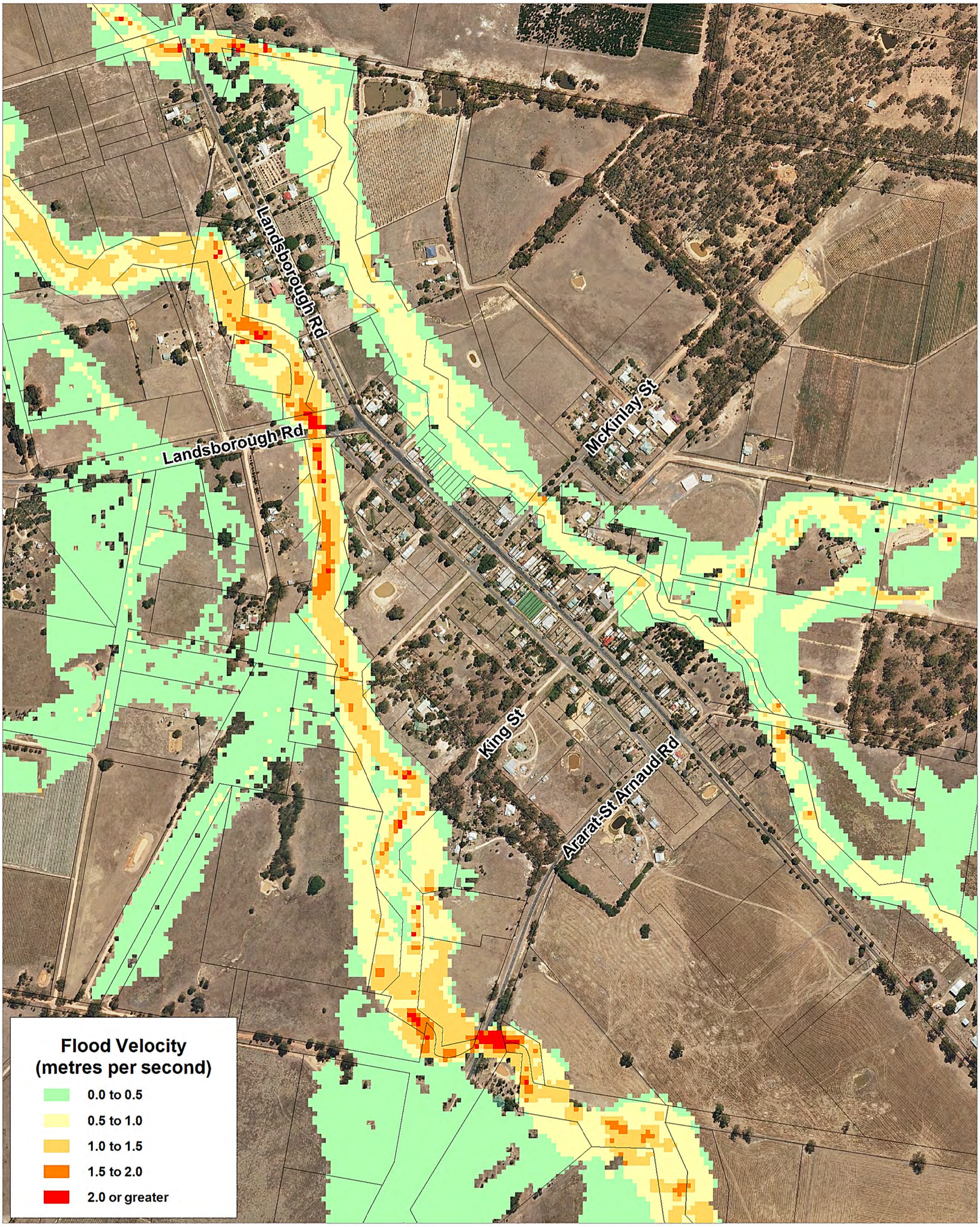

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Velocity - Landsborough

Figure: **6-11**

Rev: **A**

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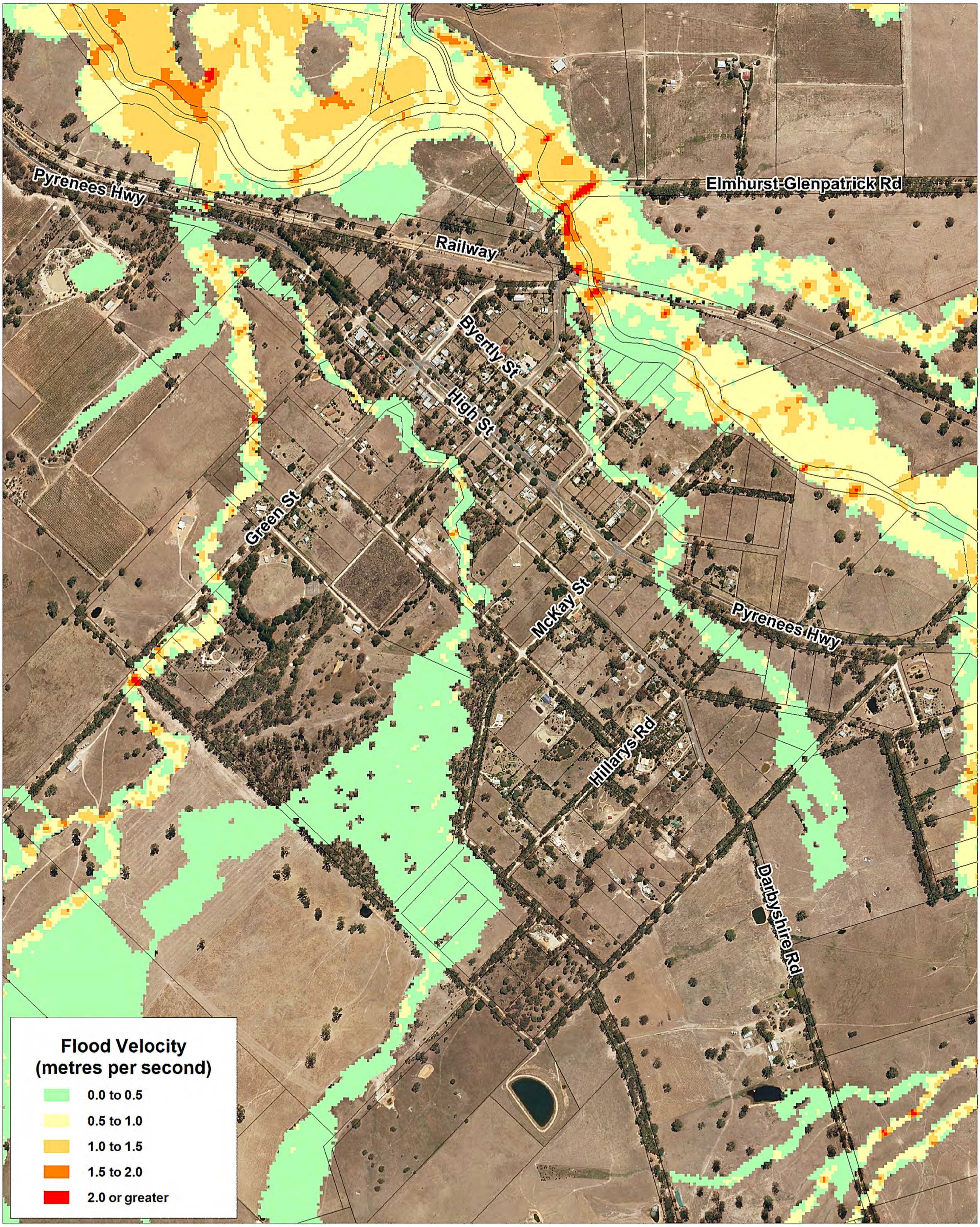

Title:

Upper Wimmera Flood Investigation
1% AEP Design Flood Velocity - Elmhurst

Figure: 6-12

Rev: A

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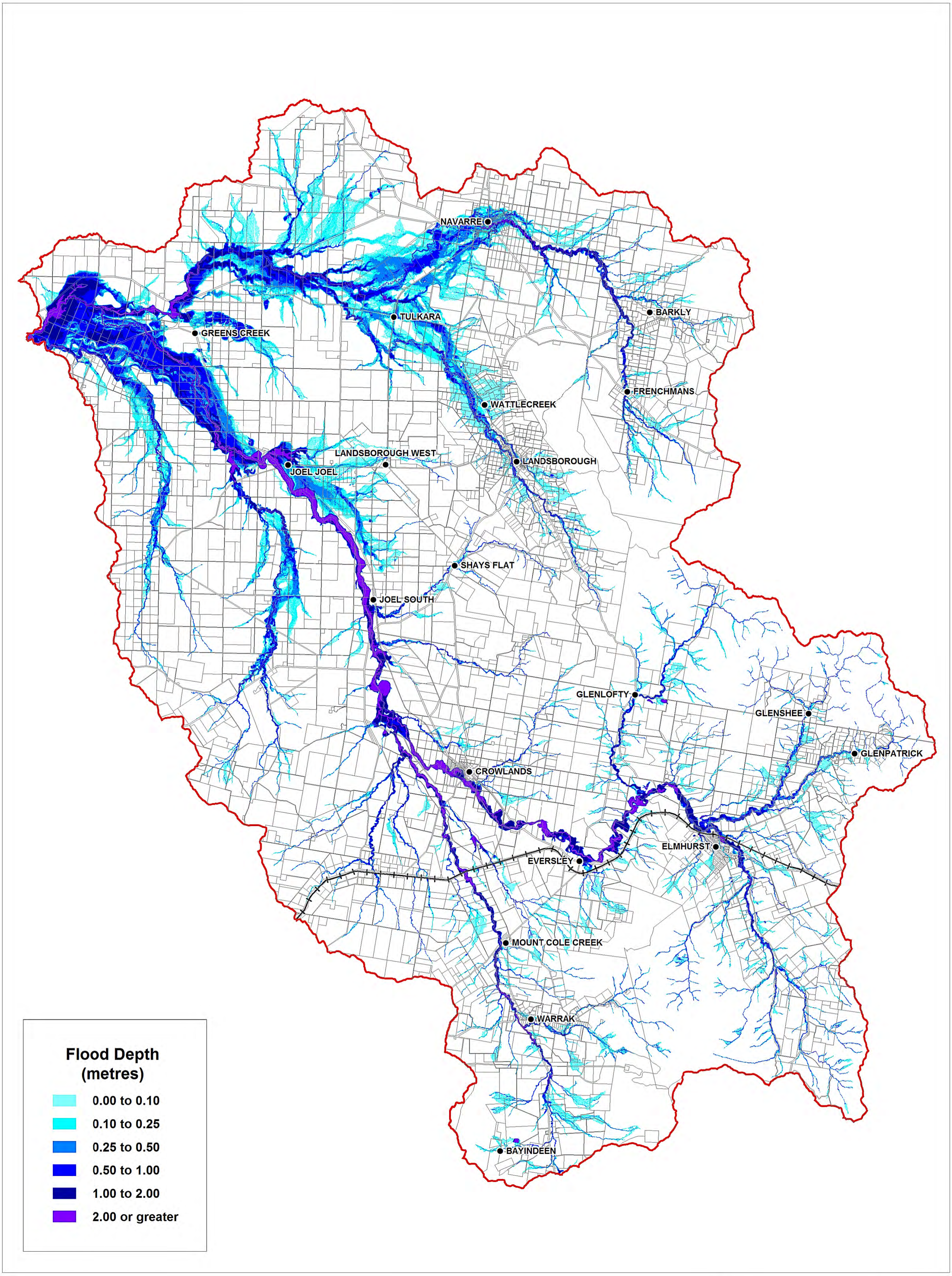
6.4 Increased Rainfall Intensity Sensitivity

Climate change sensitivity modelling was undertaken for the Upper Wimmera catchment for increased rainfall intensities of 10% and 20% for the 1% AEP flood events.

The purpose of this analysis will allow planners to gain an understanding of the potential impact that climate change could have on the Upper Wimmera study area and make future decisions accordingly.

The increased rainfall intensity sensitivity analysis was undertaken using a rainfall intensity increase of 32%. For details on the adjusted parameters refer to Section 3.4.3.



Title:

Upper Wimmera Flood Investigation - Climate Change
1% AEP Design Flood Depths - Catchment

Figure: 6-13

Rev: A

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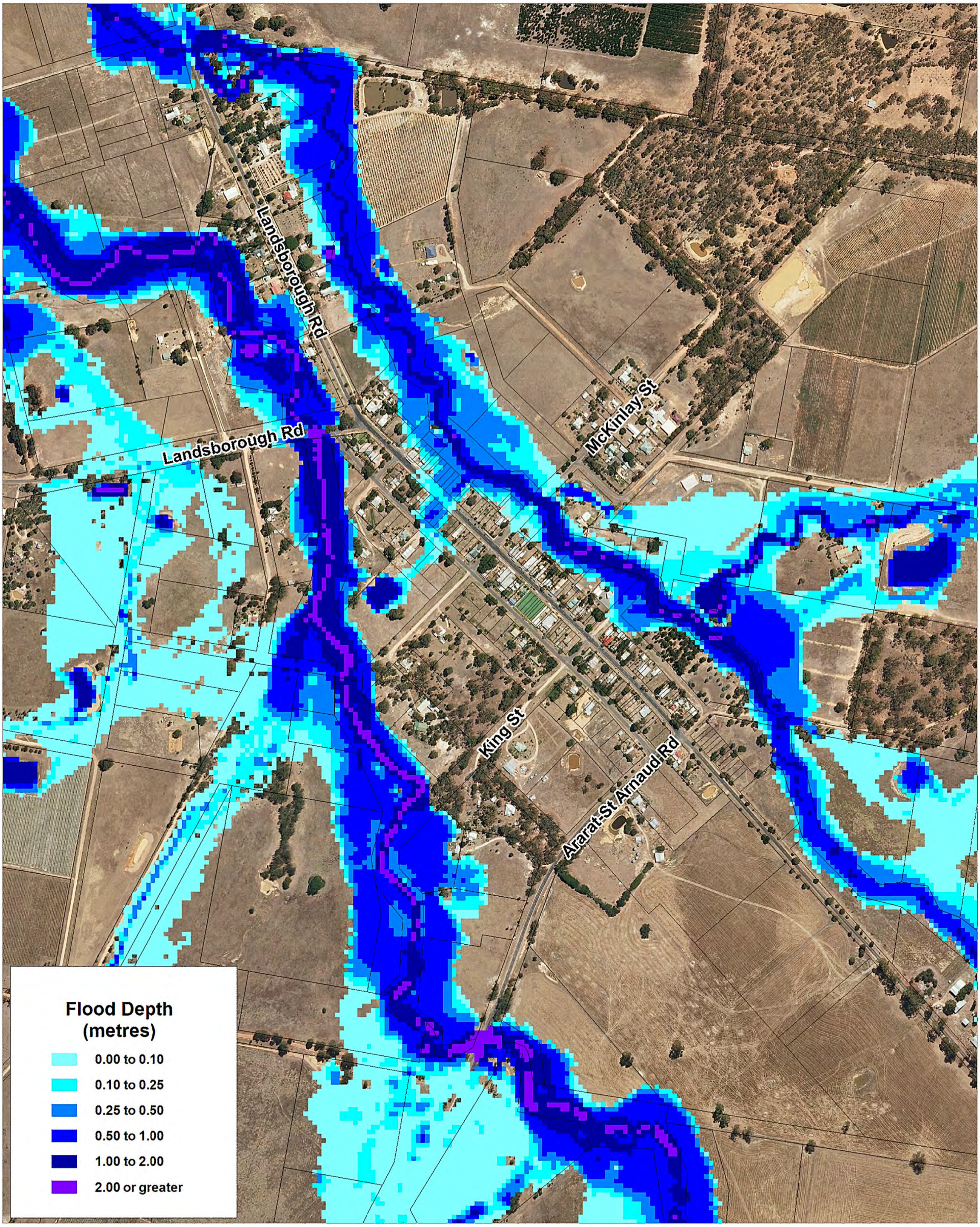

Title:

Upper Wimmera Flood Investigation - Climate Change 1% AEP Design Flood Depths - Landsborough

Figure: **6-14**

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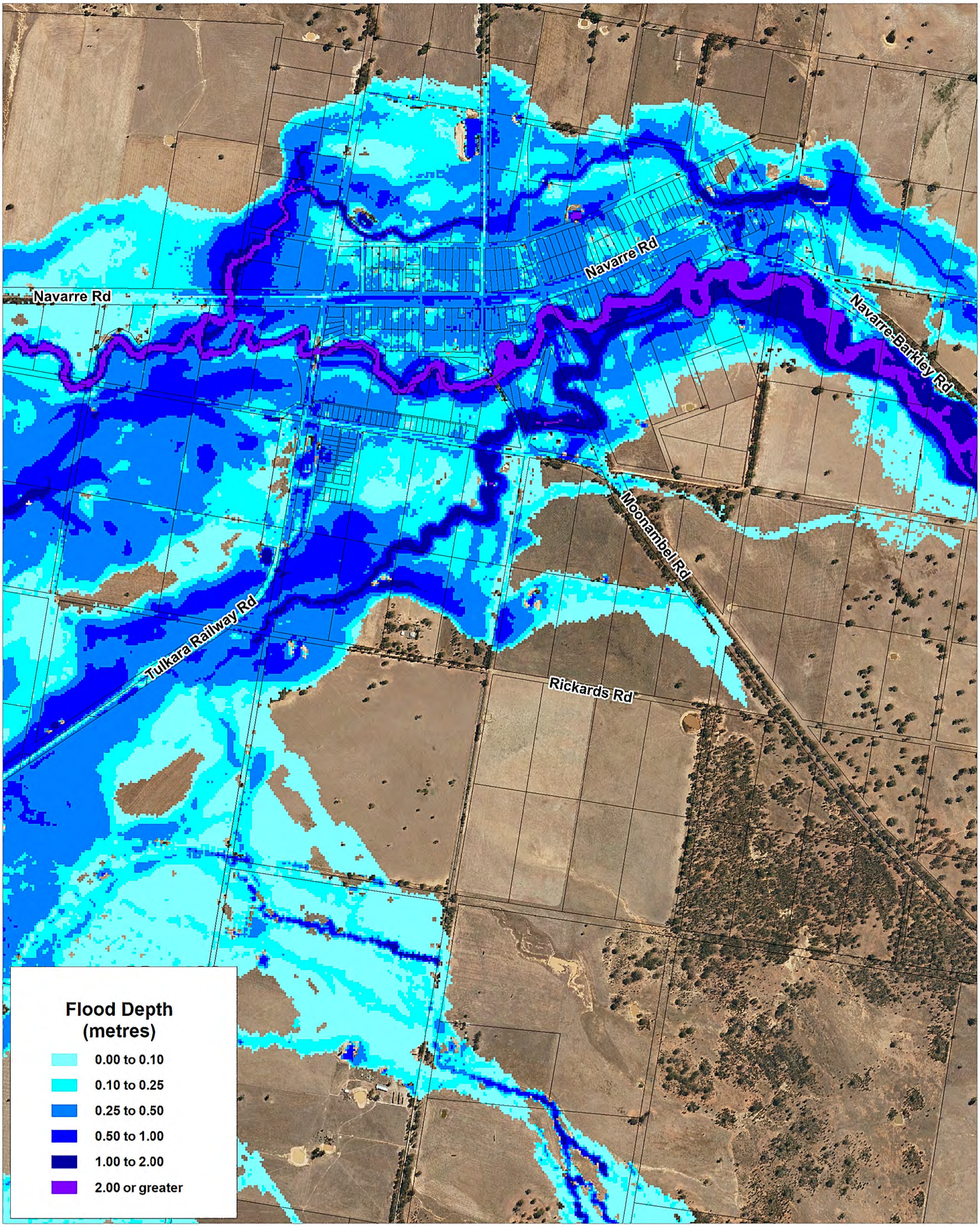

Title:

Upper Wimmera Flood Investigation - Climate Change 1% AEP Design Flood Depths - Navarre

Figure: **6-15**

Rev: **A**

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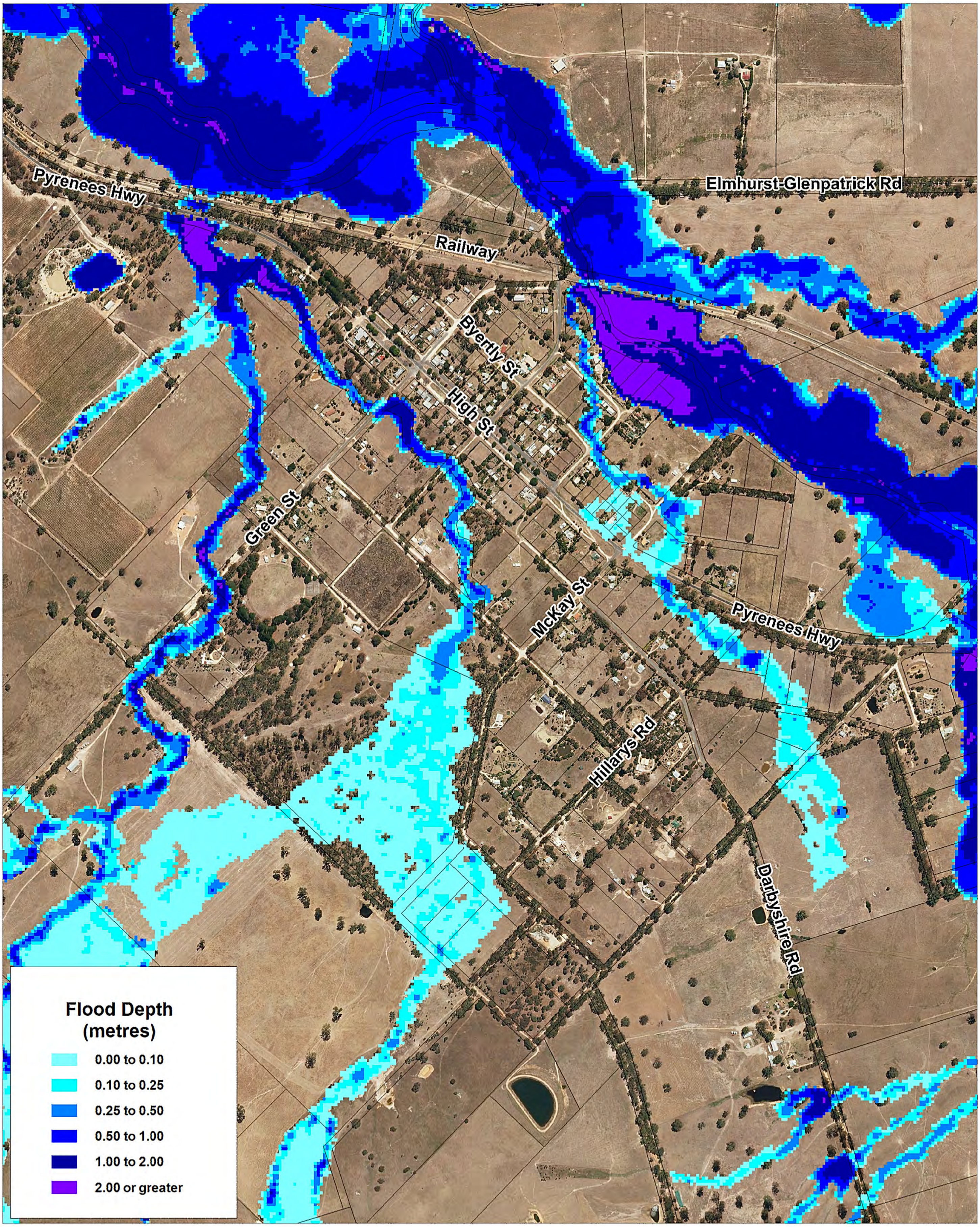

Title:

Upper Wimmera Flood Investigation - Climate Change 1% AEP Design Flood Depths - Elmhurst

Figure: **6-16**

Rev: **A**

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7 Flood Damages Assessment

The section documents the flood damages assessment that was undertaken as part of the Upper Wimmera Flood Investigation.

7.1 Flood Damages

Flood damage assessments are an important component of any floodplain management framework and can be used to guide the mitigation options assessment. This type of analysis enables floodplain managers and decision makers to gain an understanding of the monetary magnitude of assets under threat from flooding. The information determined in the damages assessment is also used to inform the selection of mitigation measures via a cost benefit analysis.

Flood damages can be categorised as either tangible or intangible, depending on whether a monetary value can be assigned to a particular item. Tangible flood damages are those which can readily be assigned a monetary value such as damages to buildings. Tangible flood damages can be further divided into direct or indirect costs. Intangible flood damages are those which cannot be readily assigned a monetary value such as environmental and social costs. Each flood damage category is discussed in more detail below.

Direct tangible damages are the most easily quantifiable damages, as they are those damages that are directly attributable to the floodwater, such as damage to house and business contents. Direct damages can be further divided into:

- Building damages – the internal, external and structural damages caused to property.
- Agricultural damages – the damage to crops, livestock, fences, etc.; and
- Infrastructure damages – the damage to infrastructure such as roads and bridges.

Indirect tangible damages include losses due to the disruption of business, expenses of alternative accommodation, disruption of public services, emergency relief aid and clean-up costs. Thus indirect damages tend to be more difficult to quantify and are often included as a proportion of direct damages.

Intangible flood damages are not included in standard flood damages assessments as it is difficult to assign monetary value, although it is important that they are taken into consideration by floodplain managers and decision makers. The intangible damages are often used as a consideration when comparing one flood management measure against another.

The types of flood damages along with their categorisation are shown in Figure 7-1.

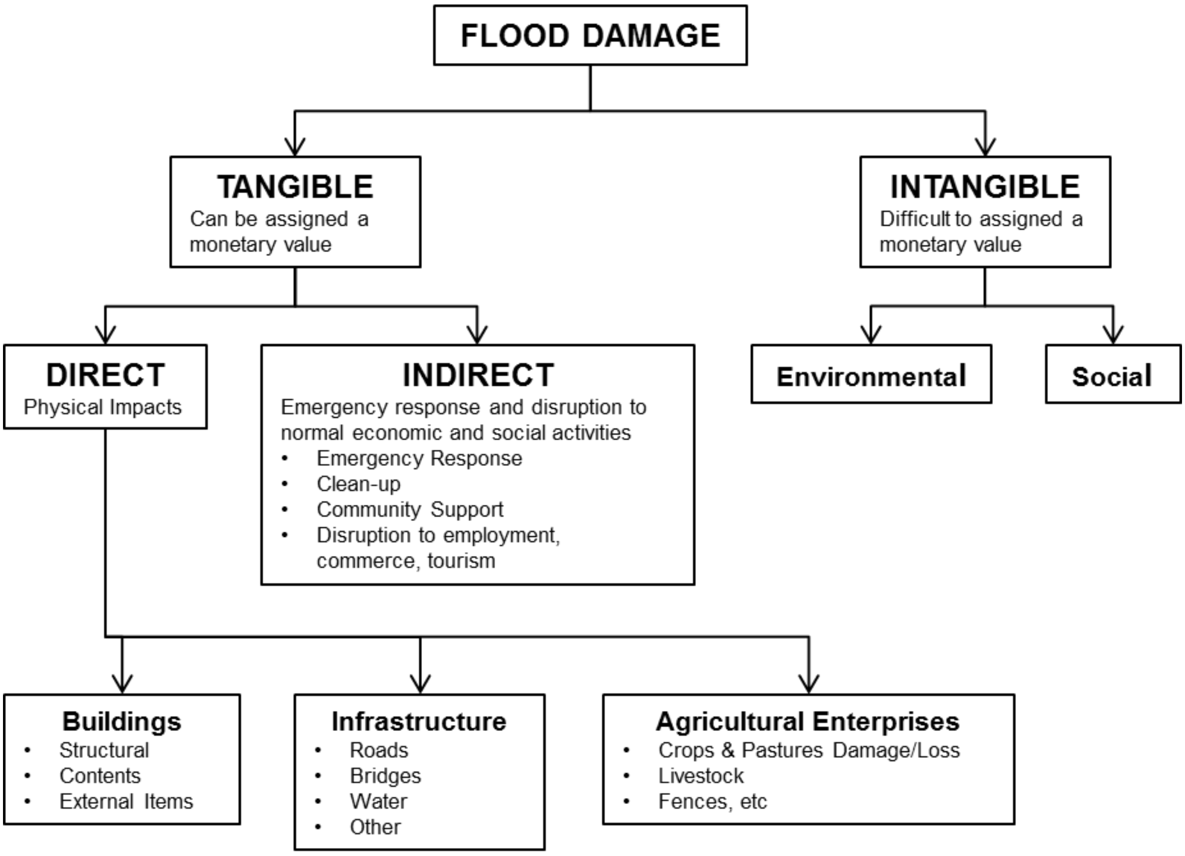


Figure 7-1 Types and Categorisation of Flood Damage Costs - Reproduced from *Rapid Appraisal Method (RAM) For Floodplain Management* (NRE 2000).

Flood damage assessments can either be carried out for an actual flood event or for a potential flood event (a design flood event). An assessment of an actual flood requires an extensive survey and data collection exercise carried out immediately following the flood for best accuracy. Rarely is it feasible to undertake an assessment on an actual flood given the large amount of resources that are required to capture the required information. For this reason several methods, which have been widely adopted throughout Australia and within Victoria, are used to estimate damage costs for the design flood events and accordingly have been adopted for this study.

The methods adopted for this study are the Rapid Appraisal Method (RAM) and ANUFLOOD, described in more detail in the following sections. Ultimately the ANUFLOOD method was adopted to estimate potential building damages while the RAM method was used to estimate potential agricultural and infrastructure damages. The damages assessment has been undertaken for properties that had floor levels collected by both BMT WBM and WCMA that were determined to be at risk from above floor flooding during the 1% AEP flood event.

7.2 Methodology

The basic procedure for calculating monetary flood damages is provided below and is detailed in the following Sections. The basic procedure is:

- Prepare the appropriate relationships between depth of flooding and the assigned monetary value of damages (stage-damage curves).

- Gather the required input information detailing the characteristics of the buildings, agricultural enterprises and infrastructure that will be assessed. This includes data such as floor level, building type, size and condition, agricultural land use type and road type.
- Determine the design flood event impacts on individual buildings, properties, agricultural enterprises and roads. For this assessment the 20%, 10%, 5%, 2%, 1% and 0.5% Annual Exceedance Probability (AEP) and Probable Maximum Flood (PMF) design flood events have been used.
- Produce the total estimated potential damages for each design flood event across the study area and present the results in a probability-damage graph.
- Assume indirect damages based on the magnitude of direct damages.
- Ascertain the most appropriate method of calculating building damages, ANUFLOOD or RAM.
- Determine the average annual damages (AAD).

7.3 Key Assumptions

In order to undertake a damage assessment a number of assumptions are required. The key assumptions for the flood damages assessment for the Upper Wimmera Flood Investigation were as follows.

- The damage rates used in the RAM and ANUFLOOD methods were indexed to a monetary value relative to that at the end of the December quarter of 2013.
- Following the presentation of the flood mapping, BMT WBM and WCMA commissioned floor level survey of all properties likely to be flood affected in the 1% AEP flood event within the Upper Wimmera catchment. These buildings and associated properties were those used in the damages assessment. The majority of the properties were located in the townships of Navarre, Landsborough and Elmhurst.
- The property boundaries were defined by the cadastral layer provided by WCMA. In some instances the cadastral property boundaries were split in order to provide an individual property boundary for each surveyed floor level, a requirement of the damages assessment process.
- The total area of agricultural land and road length inundated within the study area were defined using the VICMAP dataset provided by WCMA.
- There are no damages as a result of flooding in a 50% AEP (2 year ARI) design event.
- Velocities experienced within the floodplain were not of a magnitude to destroy a building beyond repair.
- Indirect damages were 30% of direct damages as recommended in the RAM guidelines (NRE 2000).
- The community is inexperienced with flooding and has 2 to 12 hours warning time before a flood event occurs. This assumption was based on the potentially long time periods between major flood events in the Wimmera catchment.

- The condition of all buildings is fair. This assumption was made as there is no data available describing the condition of individual buildings.
- All agricultural enterprises are dryland broadacre cropping. This assumption was made as there was no data available describing the type of individual agricultural enterprises.
- There is no agricultural land inundated for longer than one week.
- All damage costs have been factored by the consumer price index (CPI) to today's (2013) dollars.

Further assumptions were made for each element of the damages assessment and are outlined in the description provided in the following sections.

7.4 ANUFLOOD Building Damages Assessment

ANUFLOOD is a computer package designed to assess tangible urban flood damages developed by the Centre of Resource and Environmental Studies at the Australian National University in 1983 (Greenway & Smith 1983). While the computer package is no longer in use, the framework developed is still applicable to the calculation of building damages.

The ANUFLOOD methodology uses stage-damage curves to assign a monetary damage value for internal and external damages to a property based on the depth of flooding above floor level and ground level respectively. For the purposes of this assessment the ground elevation of a property is assumed to be the lowest elevation within the property boundary as inspected from the DEM (as described in Section 2.1 and 4.2.1).

7.4.1 ANUFLOOD Stage-Damage Curves

The residential stage-damage curves (Figure 7-2) used for internal damages for this assessment were sourced from the RAM Guidelines (DNRE, 2000). These curves represent those for buildings of fair condition. The RAM Guidelines suggest that the ANUFLOOD curves underestimate flood damages and should be increased by 60%. In order to convert the potential damages to actual damages the curves were also factored by 0.8 to account for an inexperienced community with 2 to 12 hours warning.

For the external damages to residential properties stage-damage curves (Figure 7-2) were sourced from Floodplain Management in Australia (DPIE 1992). It is assumed that the maximum external damages are reached at a depth of 0.5 m above ground level.

The non-residential (commercial/industrial) stage-damage curves (Figure 7-2) used for this assessment were sourced from a journal paper, *Flood Damage Estimation – A review of urban stage urban stage-damage curves and loss functions'* (Smith 1994). These curves represent damages for buildings in fair condition. There are three building size classes:

- small – smaller than 186m^2,
- medium – between 186 and 650m^2, and
- large – larger than 650m^2.

As with the residential damages, the non-residential damages have been increased by 60% and factored by 0.8 to convert from potential to actual damages.

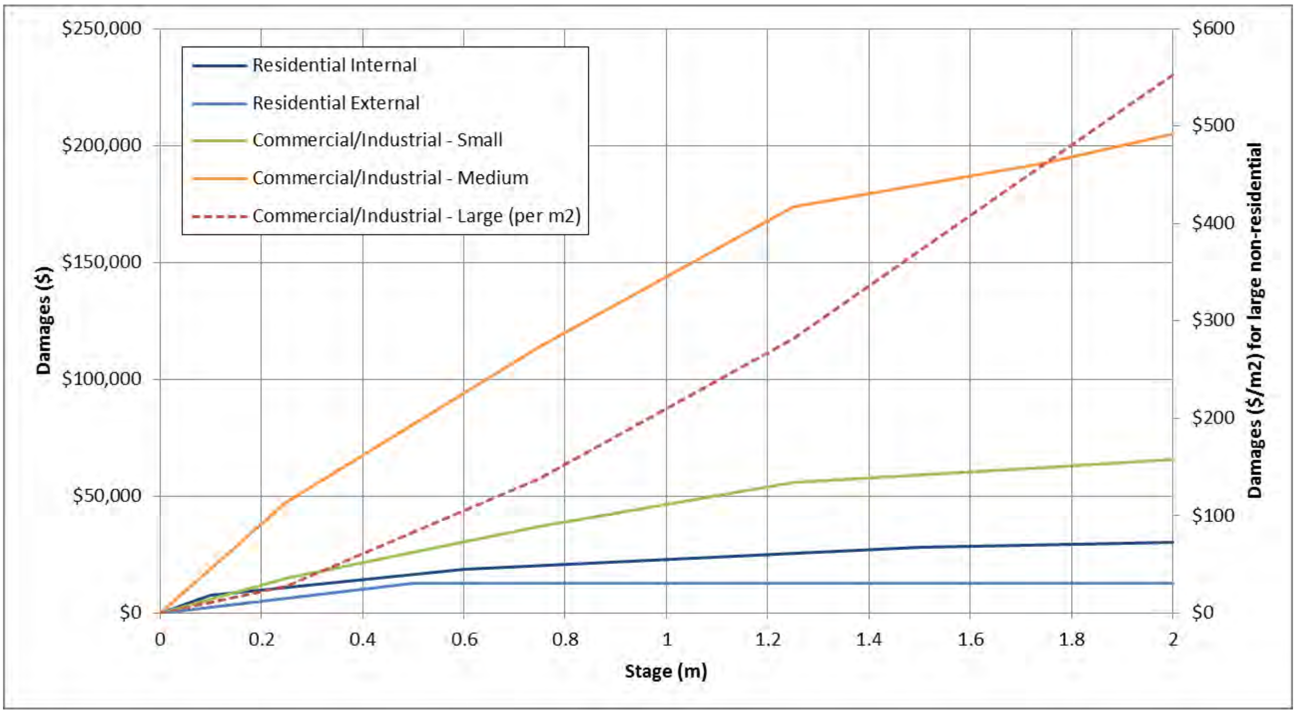


Figure 7-2 ANUFLOOD Stage-Damage Curves

*Note: Stages for internal damages are above floor level while the stages for external damages are above ground level.

7.4.3 ANUFLOOD Building Damages Summary

A summary of the ANUFLOOD building damages for existing conditions is presented in Table 7-1. The summary highlights the number of properties inundated and the associated damages for the range of AEP events. The numbers of properties inundated are properties are based on those which had floor levels information captured. The true number of properties inundated is likely to be greater than those presented in Table 7-1

Table 7-1 Existing Conditions ANUFLOOD Building Damages Summary

Event AEP	No of Properties Inundated	No. of properties with Above Floor Flooding	External Residential Damages	Internal Residential Damages	Commercial/ Industrial Damages	Indirect Damages	Total ANUFLOOD Building Damages
PMF	53	37	$354,900	$402,300	$167,300	$277,300	**$1,201,800**
0.5%	33	7	$91,300	$28,300	$38,500	$47,400	**$205,500**
1%	20	3	$52,700	$20,000	$15,800	$26,600	**$115,100**
2%	12	2	$31,800	$18,500	$0	$15,100	**$65,400**
5%	7	0	$17,300	$0	$0	$5,200	**$22,500**
10%	3	0	$11,800	$0	$0	$3,500	**$15,300**
20%	2	0	$11,800	$0	$0	$3,500	**$15,300**

7.5 Rapid Appraisal Method (RAM) Damages Assessment

The Rapid Appraisal Method (RAM) was developed for the rapid and consistent determination of flood damages. The RAM methodology can determine building, agricultural and road infrastructure damages, all of which have been determined for the Upper Wimmera Flood Investigation.

7.5.1 RAM Building Damages

To determine damages to buildings, the RAM method assumes that if flooding occurs within a property that the maximum building damages will be incurred. The values adopted for this assessment were sourced from the RAM Guidelines (NRE 2000) and are summarised in Table 7-2. In order to convert the potential damages to actual damages the values were also factored by 0.8 to account for an inexperienced community with 2 to 12 hours warning.

For large non-residential buildings (commercial/industrial) with a floor area greater than 1,000m^2 there are three classes defining value of contents:

- low – offices, sporting pavilions, churches, etc.;
- medium – libraries, clothing businesses, caravan parks, etc.; and
- high – electronics, printing, etc.

These value classes were defined on an individual basis using planning zone data and from visual inspection via Google Street View.

Table 7-2 RAM Building Potential Damage Values

Building Type	Potential Damages
All Buildings Other Than Large Non-Residential	$24,200
Large Non-Residential – Low Value of Contents	$53 per m^2
Large Non-Residential – Medium Value of Contents	$94 per m^2
Large Non-Residential – High Value of Contents	$236 per m^2

A summary of the RAM building damages for existing conditions is presented in Table 7-3. The summary highlights the number of properties inundated and the associated damages for the range of AEP events.

Table 7-3 Existing Conditions RAM Building Damages Summary

Event AEP	No of Properties Inundated	Residential Damages	Commercial / Industrial Damages	Total Building Damages
PMF	65	61	$1,309,100	**$197,600**
0.5%	50	43	$938,600	**$123,500**
1%	50	29	$666,900	**$49,400**
2%	28	20	$469,300	**$24,700**
5%	20	14	$345,800	**$0**
10%	16	10	$247,000	**$0**
20%	10	9	$222,300	**$0**

7.5.2 RAM Agricultural Damages

RAM agricultural damages account for damage to crops and clean-up costs. The value of perished stock can also be incorporated; however the RAM Guidelines (NRE 2000) stipulates that many major flood events do not incur any loss of stock. For this reason stock losses have not been included in this assessment. This assumption is consistent with the information collected following the January 2011 flood event, where no stock loss was recorded within the Upper Wimmera catchment.

The values adopted for the assessment, shown in Table 7-4, were obtained from the RAM Guidelines (NRE 2000) for dryland broadacre cropping. Clean-up costs are defined by the area of inundation within and outside of floodway areas. For the purpose of this study, floodway areas have been defined as the areas of high flood hazard based on the hazard mapping prepared for the Upper Wimmera Flood Investigation.

Table 7-4 RAM Agricultural Damage Values

	Damages
Dryland Broadacre Crops Inundated for Shorter Than 1 Week	$124/hectare
Dryland Broadacre Crops within Floodway Areas	$37/hectare *
Dryland Broadacre Crops beyond Floodway Areas	$15/hectare *

** Clean-up costs*

A summary of the RAM agricultural damages for existing conditions is presented in Table 7-5. The summary highlights the area of agricultural land inundated and the associated damages for the range of AEP events.

Table 7-5 Existing Conditions RAM Agricultural Damages Summary

Event (AEP)	Area of Agricultural Land Inundated (hectares)	Crop Damages	Clean-up Costs	Total Agricultural Damages
PMF	75,877	$9,588,700	$1,411,400	**$11,000,100**
0.5%	63,175	$7,983,500	$1,050,200	**$9,033,700**
1%	58,616	$7,407,400	$961,600	**$8,369,000**
2%	53,198	$6,722,700	$860,400	**$7,583,100**
5%	44,560	$5,631,100	$709,100	**$6,340,200**
10%	37,571	$4,747,900	$593,000	**$5,340,900**
20%	29,906	$3,779,300	$468,900	**$4,248,200**

7.5.3 RAM Road Infrastructure Damages

RAM road infrastructure damages are determined by assigning a cost per length of road inundated. The values adopted for this assessment were obtained from the RAM Guidelines (NRE 2000) and are summarised in Table 7-6. The cost values incorporate initial road repair, subsequent accelerated deterioration, initial bridge repair, and subsequent increased maintenance. RAM defines road type in three categories: major sealed roads, minor sealed roads and unsealed roads. Within the study area road types for all roads were defined.

Table 7-6 RAM Road Infrastructure Damage Values

	Cost per kilometre of inundation
Major Sealed Roads	$86,950
Minor Sealed Roads	$27,264
Unsealed Roads	$12,306

A summary of the RAM road infrastructure damages for existing conditions is presented in Table 7-7. The summary highlights the total length of road inundated and the associated damages for the range of AEP events.

Table 7-7 Existing Conditions RAM Road Infrastructure Damages Summary

Event (AEP)	Length of Road Inundated (kilometres)	Road Infrastructure Damages
PMF	229	**$4,406,600**
0.5%	151	**$2,779,400**
1%	130	**$2,354,200**
2%	110	**$1,950,200**
5%	88	**$1,544,500**
10%	74	**$1,285,000**
20%	61	**$1,058,100**

7.6 Average Annual Damages

Average annual damages (AAD) are the average damage (in dollars) per year that would occur in a particular area from flooding over a very long period of time. In many years there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there will be major flood damage (caused by large, rare flood events). Estimation of AAD provides a basis for comparing the effectiveness of different management measures (i.e. the reduction in the AAD) using benefit cost analysis.

The AAD are calculated as the area under the probability-damage curve. The lower limit on the curve is the 50% AEP design flood event and it is assumed to cause zero damages. The probability-damage curve is extrapolated to account for events with a probability between the 20% and 50% AEP.

Following the calculation of the individual direct damage elements, the total tangible flood damages across the study area can be determined.

To define the potential damages to buildings the ANUFLOOD method has been adopted. The reason for this is the RAM method estimates unrealistically high damage values for frequent design floods such as the 10% and 20% AEP events. This is a result of insignificant flooding on an individual property incurring maximum damages.

The total tangible flood damages, for existing conditions for all modelled events, is presented in Table 7-8 and is illustrated in Figure 7-3. The existing conditions AAD for the Upper Wimmera catchment is $2,926,300.

Table 7-8 Existing Conditions Damages Summary

Event (AEP)	ANUFLOOD Building Damages	RAM Agricultural Damages	RAM Road Infrastructure Damages	Indirect Damages	Total Damages	Contribution to AAD
PMF	$924,400	$11,000,100	$4,406,600	$4,937,700	**$21,230,400**	
0.5%	$158,100	$9,033,700	$2,779,400	$3,628,800	**$15,562,600**	$92,000
1%	$88,500	$8,369,000	$2,354,200	$3,301,700	**$14,055,200**	$74,000
2%	$50,300	$7,583,100	$1,950,200	$2,904,000	**$12,458,700**	$132,600
5%	$17,300	$6,340,200	$1,544,500	$2,394,900	**$10,272,600**	$341,000
10%	$11,800	$5,340,900	$1,285,000	$2,010,900	**$8,629,000**	$472,500
20%	$11,800	$4,248,200	$1,058,100	$1,608,800	**$6,913,500**	$777,100
50%	-	-	-	-	-	$1,037,000
					Average Annual Damages	**$2,926,300**

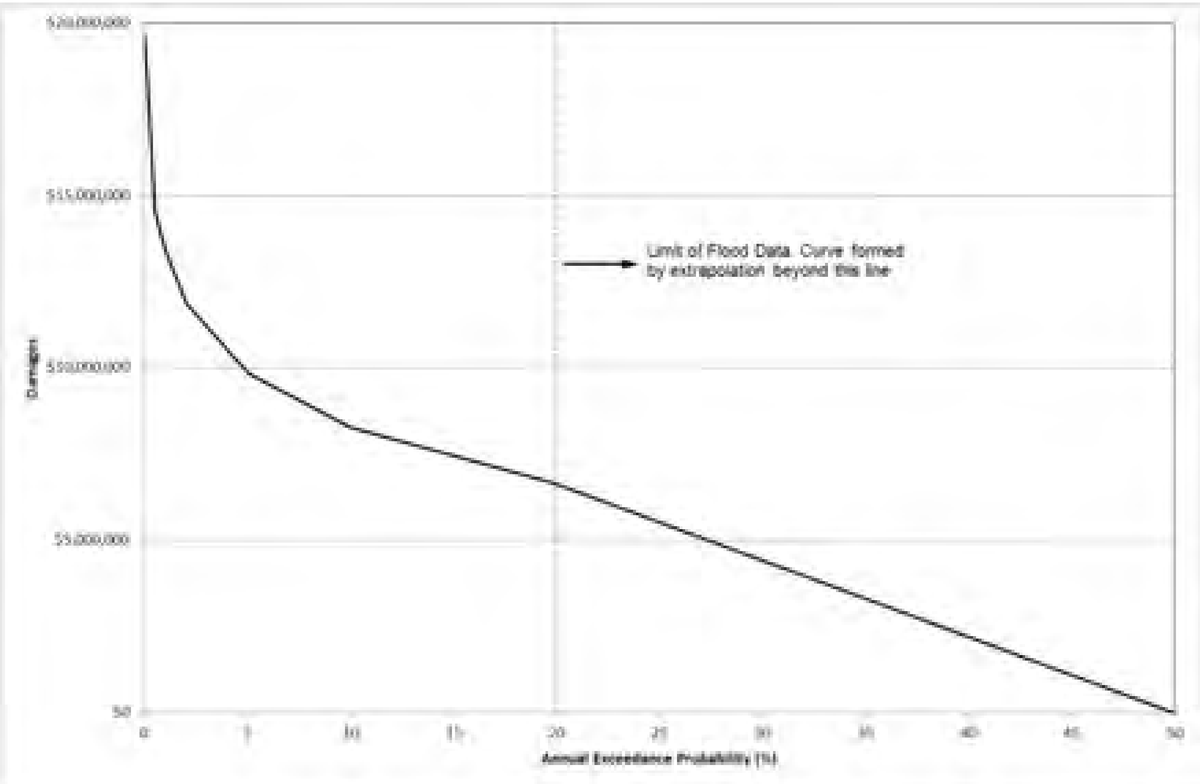


Figure 7-3 Existing Condition Probability-Damages Curve

7.7 Summary

This section has presented the flood damages assessment for the Upper Wimmera catchment. The assessment has shown that the Annual Average Damages for the Upper Wimmera catchment is

$2.93 million, with 3 buildings (combined residential, industrial and commercial properties) exposed to above floor flooding in the 1% AEP flood event.

Considering the relatively small number of buildings inundated above floor level, the magnitude of the determined AAD is somewhat surprising. However, this can be explained by the values determined by the RAM methodology for damages to agricultural land and road infrastructure. Excluding indirect damages, building damages account for only 1% of the total incurred damage during the 1% AEP flood event, whilst agricultural damage and road infrastructure damage account for 77% and 22% respectively. These relative contributions to the overall total damage are consistent with the experiences within the catchment following the January 2011 flood event, whereby the majority of the flood damage was incurred on agricultural land (particularly fencing) and roads infrastructure, rather than building damages.

8 Flood Mitigation Assessment

The purpose of this section is to introduce the possible structural and non-structural flood management options considered for the Upper Wimmera Flood Investigation. Of the identified potential flood management options three were assessed in greater detail. The results of which are documented in this section.

8.1 Flood Mitigation Overview

8.1.1 Background

There are two major categories of floodplain management options that can be used to reduce the risk and consequences of flooding:

(1) Structural Measures – Works that alter the behaviour of flood waters to mitigate the impact of flooding for a certain area.

(2) Non-Structural Measures:

  (a) Land Use Planning Controls – Incorporating flooding into land use planning and implementing building control measures; effective in reducing the impact of flooding to future developments.

  (b) Emergency Management and Response – Aimed at reducing the impact of flooding by improving the community's ability to respond to a flood event.

For a floodplain management plans to be effective it needs to consider and integrate all three of these categories. A comprehensive assessment of all of the management options available and how they will interact has been undertaken in the development of the Upper Wimmera Flood Investigation.

8.1.2 Key Issues

To provide the best possible outcome for the residents of the Upper Wimmera it was important to establish a clear and thorough understanding of the issues to be addressed in order to manage the flood risk within the catchment.

Through consultation with the community and the technical steering committee, understandings of the major factors that influence flood risk in the Upper Wimmera were identified. This understanding was further enhanced through flood modelling and mapping, the outcomes of which are presented in Sections 3 and 4. These factors relate to the physical characteristics of the floodplain which contributes to flood risk in the communities of the Upper Wimmera and the factors that hamper the community's ability to manage the impact of flooding. The major factors are:

- The locations of many of the towns, including Navarre and Landsborough, are on the banks of multiple waterways subject to flooding;
- Limited road access through the majority of the Upper Wimmera catchment during times of flood;

- The steep upper catchment resulting in fast flood responses from heavy rainfall. Flooding is generally fast flowing but confined to recognised flow paths.
- The flat lower catchment results in widespread flooding (flood extents are wide), floodwaters are generally slower in velocity and more likely to simply 'pond' on the floodplain.
- The limited rain and streamflow gauges within the catchment limit the ability for the community and emergency services to respond to a flood event. Flood warning is designed more for the towns downstream on the Wimmera River, such as Horsham, rather than the Upper Wimmera Catchment. Flood warning in the upper reaches of any catchment is challenging due to the rapid response of the upper catchment.

8.1.3 Management Objectives

An element of the Upper Wimmera Flood Investigation includes an assessment of structural mitigation measures to reduce flood risk. The level to which future floods are mitigated will be determined in consultation with the Technical Working Group and through consultation with the community.

The objectives of the management options to be developed as part of the Upper Wimmera Flood Investigation are:

(1) Reduce, as much as practical, the risk of flooding from design events within the communities of the Upper Wimmera.

(2) Ensure that properties outside any proposed flood mitigation works are not negatively impacted upon.

(3) Ensure that proposed structural, planning and contingency measures are socially, economically and environmentally feasible and acceptable to the majority of the community.

(4) Provide flood intelligence and consequence information to the relevant authorities, including emergency services (VicSES), to aid in the response to future flood events.

8.2 Management Option Screening

All mitigation options identified during the development of the investigation, including those identified as part of the Community Consultation process were considered as part of the option screening process. Table 8-1 sets out some the management options assessed together with a description of each option.

8.2.1 Identification of Management Strategies

As identified in Section 2.6, the communities of the Upper Wimmera have had a long history of flooding and have been subject to flooding on at least three separate occasions in recent years. As such, the community have an understanding of the flooding mechanisms that affect the town and how best to manage this flooding.

As part of this investigation, a list of all mitigation options was compiled. This list was compiled from ideas raised at community meetings and via a flood survey provided to the community, as well as some additional options developed by BMT WBM. The list then underwent a screening process.

8.2.2 Screening Process

The purpose of the screening process was to recommend the management options for preliminary analysis. The screening was undertaken by the Technical Working Group. The Technical Working Group screened all management options collated as part of this investigation based on the knowledge of the members and the results of the flood modelling and analysis completed by BMT WBM and presented in Section 4 of this document.

The screening considered the feasibility of each potential management option in terms of:

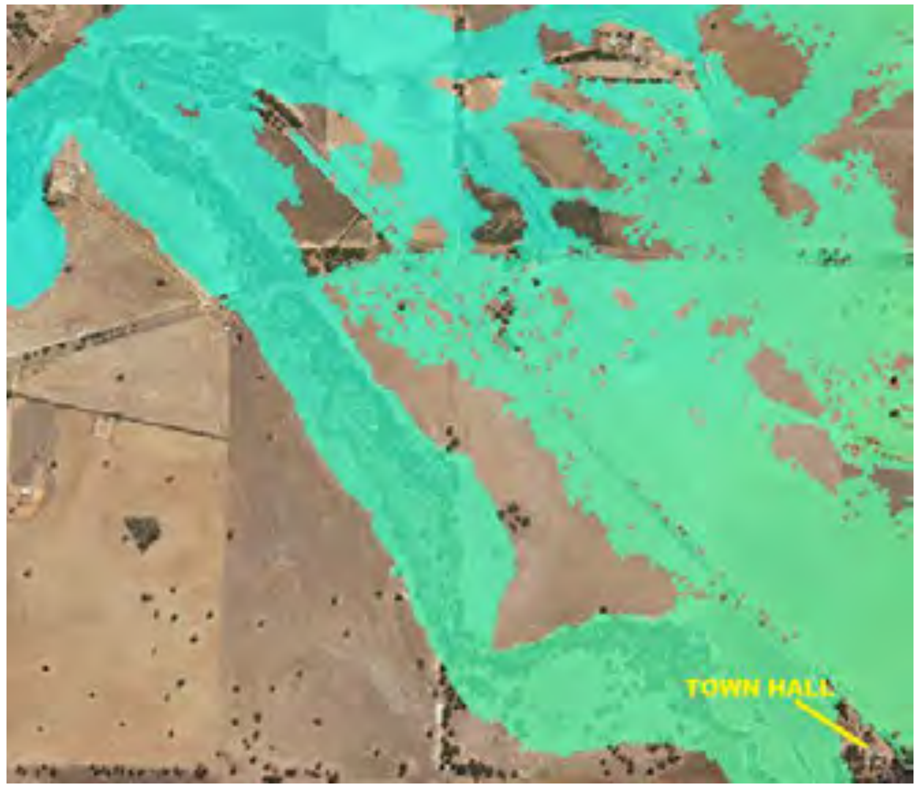
- The option's likelihood of delivering the required flood alleviation to the communities of the Upper Wimmera; and
- The economic, social and environmental costs.

The results of the screening process, together with a description of the management option(s), are presented in Table 8-1.

Table 8-1 Manage Options Considered

Management Option / Focus Area	Description	Further Assessment
Elmhurst	The township of Elmhurst is at minimal risk of flooding from the 1% AEP (shown below). Whilst the railway and Pyrenees Highway are significant hydraulic controls to the free flow of water, the backwaters from the structures do not threaten any existing buildings. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required

Management Option / Focus Area	Description	Further Assessment
Crowlands	The township of Crowlands is at minimal risk of flooding from the 1% AEP event (shown below). There appears to be no inundation of buildings within the area, however, road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required

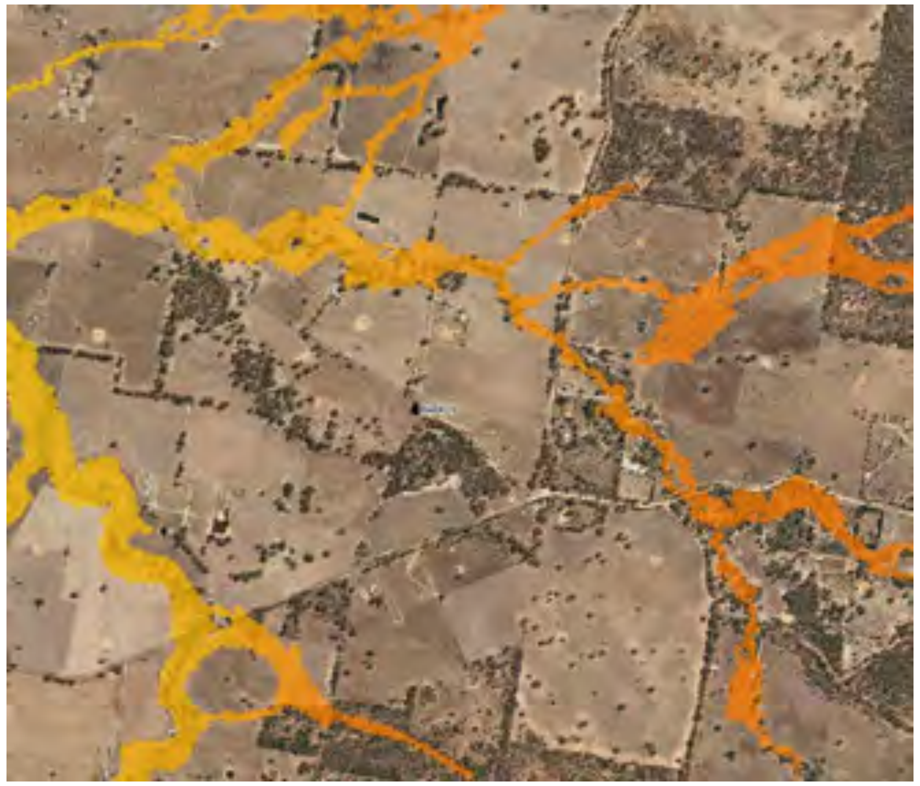
Management Option / Focus Area	Description	Further Assessment
Joel Joel	The primary risk to the township of Joel Joel is caused by isolation. Whilst there appears to be no inundation of buildings from the 1% AEP event (including the town hall) there is substantial flooding within the area (shown below). Road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required

Management Option / Focus Area	Description	Further Assessment
Eversley	The township of Eversley is at minimal risk of flooding from the 1% AEP event (shown below). There appears to be no inundation of buildings within the area, however road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required
Mount Cole Creek	The township of Mount Cole Creek is at minimal risk of flooding from the 1% AEP event (shown below). There appears to be no inundation of buildings within the area from the 1% AEP event, however road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required

Management Option / Focus Area	Description	Further Assessment
Warrak	The township of Warrak is at minimal risk of flooding from the 1% AEP event (shown below). Whilst there appears to be a few inundated buildings from the 1% AEP event within the area, which are typically spread out a distance from each other, the majority of buildings are flood free. Due to the wide distribution of flooded buildings, levees are unlikely to be feasible and these individual buildings could be targeted for floor raising or relocation to higher ground. Road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required

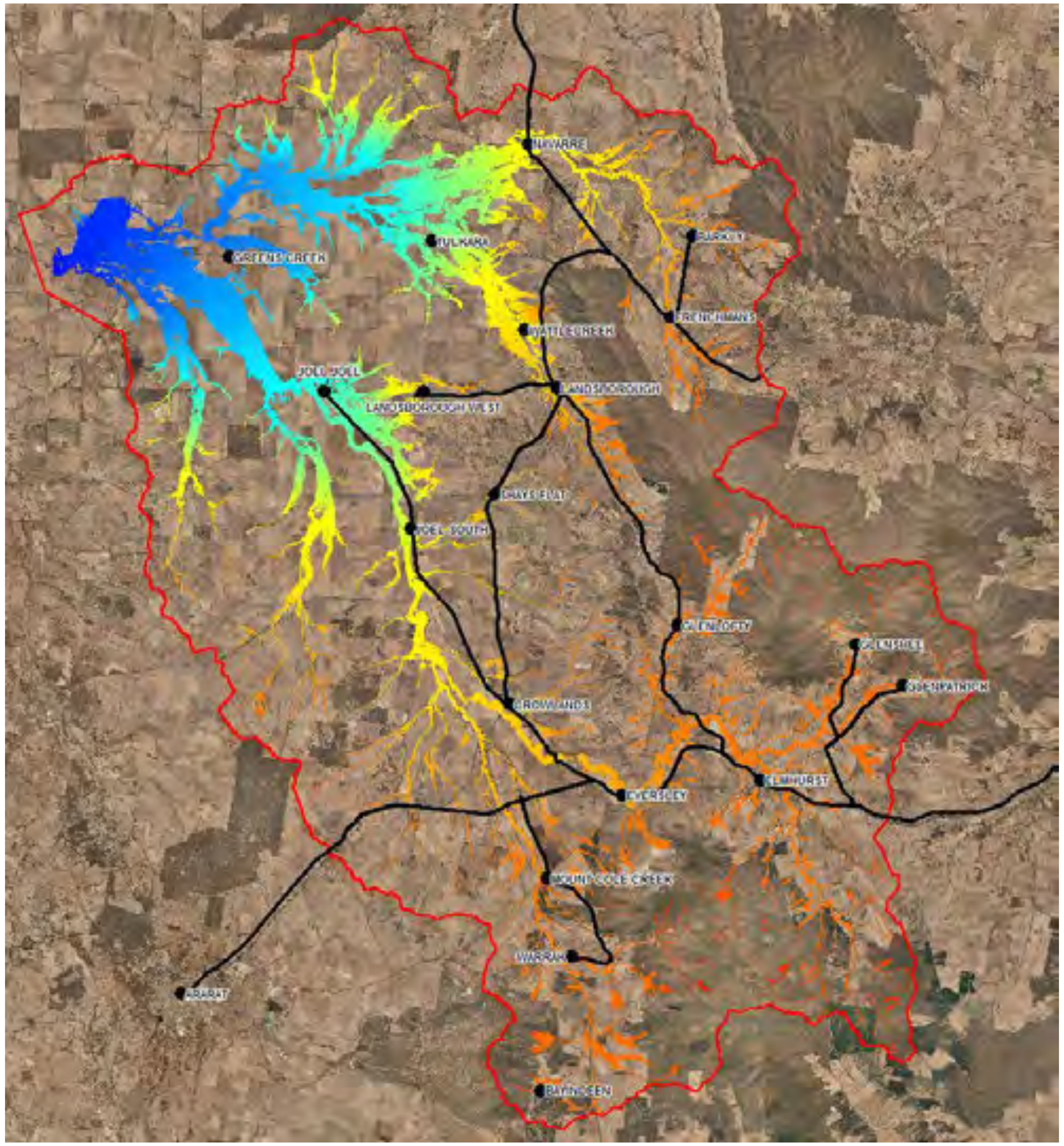
Management Option / Focus Area	Description	Further Assessment
Glenshee	The township of Glenshee is at minimal risk of flooding from the 1% AEP event (shown below). Whilst there appears to be a few inundated buildings from the 1% AEP event within the area, which are typically spread out a distance from each other, the majority of buildings are flood free. Due to the distribution of the flooded buildings, levees are unlikely to be feasible and these individual buildings could be targeted for floor raising or relocation to higher ground. Road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required

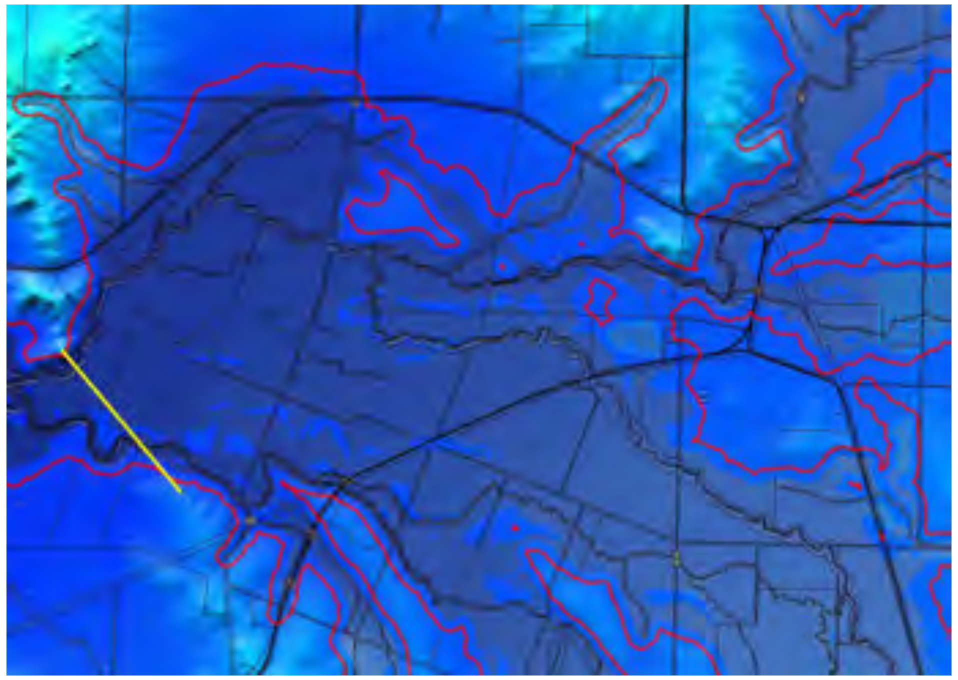
Management Option / Focus Area	Description	Further Assessment
Glenpatrick	The township of Glenpatrick is at minimal risk of flooding from the 1% AEP event (shown below). Whilst there appears to be a few inundated buildings from the 1% AEP event within the area, which are typically spread out a distance from each other, the majority of buildings are flood free. Due to the distribution of the flooded buildings, levees are unlikely to be feasible and these individual buildings could be targeted for floor raising or relocation to higher ground. Road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required
Shays Flat	The township of Shays Flat is at minimal risk of flooding from the 1% AEP event (shown below). There appears to be no inundation of buildings within the area from the 1% AEP event, however road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required

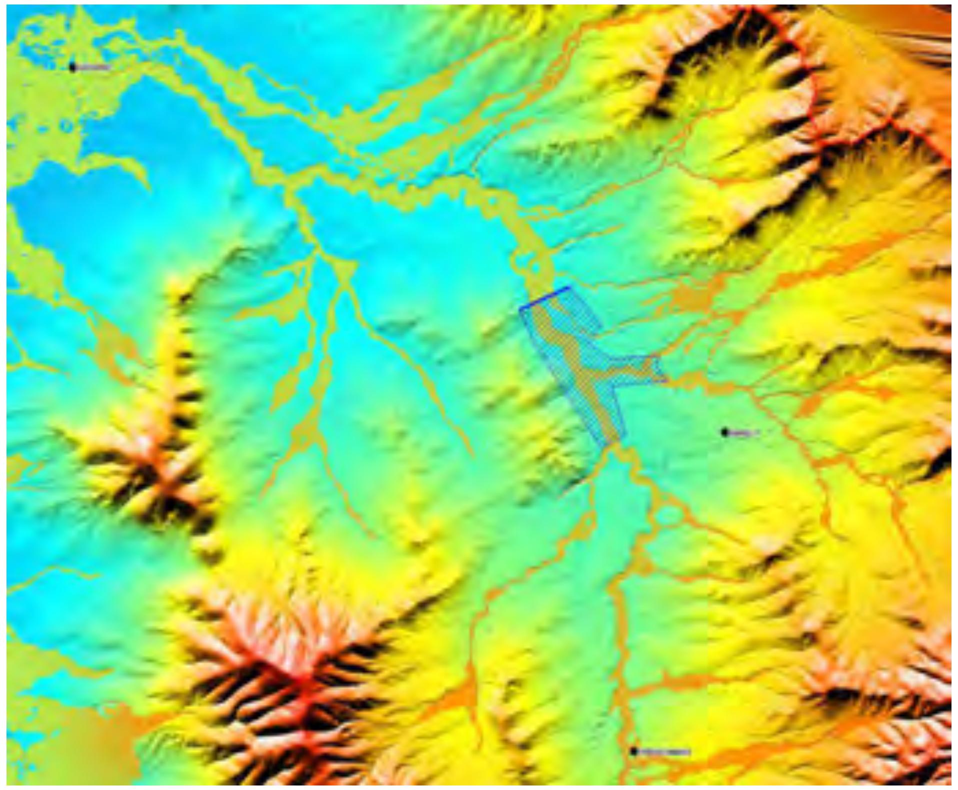
Management Option / Focus Area	Description	Further Assessment
Barkly	The township of Barkly is at minimal risk of flooding from the 1% AEP event (shown below). There appears to be no inundation of buildings within the area from the 1% AEP event, however road access is cut to the town and it risks isolation for a period of time. In the absence of effective structural mitigation measures, non-structural mitigation options should be adopted to manage flood risk in this township. 	No Action Required

Management Option / Focus Area	Description	Further Assessment
Town Levee – Navarre North Side	Navarre is situated between Wattle Creek (to the south) and Young's Creek (to the north). The bulk of the flooding through Navarre originates from Young's Creek in the smaller ARI events (i.e. sub 1% AEP). It could be considered that the creek causes nuisance flooding of the town. A levee built along the south bank of Young's Creek could reduce the flooding through Navarre and consequently reduce the impact on the community. The proposed Levee would follow broadly the two yellow lines in the image below. In addition to the levee, Navarre Road would need to be raised and likely the culverts beneath it enlarged. 	Further Assessment Required
Town Levee – Navarre South Side	In larger events the flooding within Navarre predominantly originates from Wattle Creek, due to its larger contributing catchment compared to Young's Creek, as shown for the 1% AEP event below. To stop flooding from Wattle Creek would likely require a levee the entire length of the town, conceptually drawn as the blue line below. In addition to the levee, Wattle Creek-Navarre Road would need to be raised and likely the bridge beneath it enlarged. 	Further Assessment Required

Management Option / Focus Area	Description	Further Assessment
Town Access - Navarre	During times of flood, extensive flooding in and around Navarre from the 1% AEP event results in all access roads to the township being unable to be travelled upon safely. Options to raise key access roads above flood levels to improve access to the town during floods could be explored. Direct access to Stawell is unlikely to be feasible due to the width of the floodplain in the lower catchment. However, a number of alternative egress routes out of the catchment via upgrading road heights, culverts and bridges may be feasible, including: • North via Navarre Road towards St Arnaud over Young's Creek. • South-easterly towards Avoca via Moonambel Road. • South towards Landsborough via Moonambel Road and Landsborough-Barkly Road (the direct Navarre-Landsborough Road may be feasible but would likely involve greater works).	Further Assessment Required
Town Access - Landsborough	Landsborough itself does not experience significant flooding during design flood events up to and including the 1% AEP design event, however, access to and from the town is severely disrupted during times of flood. Options to raise key access roads above flood levels, to improve access to the town during floods, could be explored. Direct access to Stawell is unlikely to be feasible due to the width of the floodplain in the lower catchment. However, a number of alternative egress routes out of the catchment via upgrading road heights, culverts and bridges may be feasible, including: • South-easterly towards Avoca via Landsborough-Barkly Road and Moonambel Road. • South towards Crowlands via Ararat-St Arnaud Road. A further option would be to extend the works to the Pyrenees Highway, which would grant access to Ararat. • South-westerly towards Avoca via Moonambel Road. • North towards Navarre via Moonambel Road and Landsborough-Barkly Road (the direct Navarre-Landsborough Road may be feasible but would likely involve greater works).	Further Assessment Required

Management Option / Focus Area	Description	Further Assessment
Town Access – whole of catchment	In addition to linking the few key towns within the catchment, a whole of catchment strategy of road improvements could be undertaken. This would allow the majority of the townships free movement within the catchment during a flood. It would also facilitate access by emergency services and relief organisations. The strategy would involve raising those roads away from the key town centres, but are inundated during times of flood or impacted by localised flooding issues. These roads are typically in the upper catchment. In addition to raising selected roads, it may be necessary to increase the capacity of any associated culvert(s) or bridge(s). An example of the proposed roads is presented below, with black lines indicating the key roads targeted as well as the towns that could potentially be linked. Whilst it may not be cost effective to provide a road at the 1%AEP level, it may be beneficial to explore other options for more frequent events. For a lower cost, flood free town linkages could be provided for flood events up to and including the 2% AEP event (as an example). 	Further Assessment Required

Management Option / Focus Area	Description	Further Assessment
Temporary Flood Barriers	Temporary flood barriers could be used to protect critical infrastructure or compliment other management options, however these are not considered suitable as a primary management option.	No Assessment Required
Flood Retention Dams (General)	A major storage could be built on the upper reaches of either the Wimmera River or a number of its tributaries. However, given the nature of the terrain and the volumes of water required to be stored, the size of the storage would be prohibitive. The presence of a dam or retarding basin would also result in a significant residual risk for events larger than the design capacity of the storage. The capital and ongoing cost, amount of land required, social and environmental impacts of this option would be considered prohibitive. The ideal location for any dam or retarding basin is at natural choke-points in the terrain. This minimises the earthworks required, which reduces construction and maintenance costs as well as potential areas of failure.	No Assessment Required
Flood Retention Dam at Glynwylln (catchment outlet)	The catchment mouth at Glynwylln is a natural choke-point in the catchment. A potential location for the dam/retarding basin is shown in yellow (below), and would require an embankment of approximately 1900m in length. Upstream of this point is predominately pastoral land, with only a few residential properties identified that would be affected depending on the design height of the embankment. This location obviously provides no benefit for upstream communities but may alleviate flooding of downstream townships. Depending on the configuration of the dam, it may also potentially serve as a valuable water source for both upstream and downstream communities. 	No Assessment Required

Management Option / Focus Area	Description	Further Assessment
Flood Retention Dam upstream of Navarre	A dam or retarding basin could be constructed upstream of Navarre on Wattle Creek. An example location is shown hatched blue in the below image. This flood storage could mitigate flood hazard within the township of Navarre. Depending on the configuration of the dam, it may also serve as a valuable water source for the surrounding communities. Other locations are likely to be similarly feasible, and all the same limitations are likely to apply as detailed above. 	No Assessment Required

Management Option / Focus Area	Description	Further Assessment
Removal of Vegetation from Waterways - Navarre	Removal of vegetation from the waterway must be done with prior approval from the WCMA and such measures are unlikely to result in significant benefits in terms of flooding behaviour. Any minor benefit in terms of flood level is likely to be outweighed by a reduction in environmental values and stability of the waterways. Example locations and lengths of vegetation removal for the Navarre township are shown below. 	Further Assessment Required
Removal of Vegetation from Waterways - Landsborough	Removal of vegetation from the waterway must be done with prior approval from the WCMA and such measures are unlikely to result in significant benefits in terms of flooding behaviour. Any minor benefit in terms of flood level is likely to be outweighed by a reduction in environmental values and stability of the waterways. Example locations and lengths of vegetation removal for the Landsborough township are shown below. 	Further Assessment Required

Management Option / Focus Area	Description	Further Assessment
Removal of Large Debris from Waterways	The WCMA undertakes a channel maintenance program, which includes the removal of major obstructions, including debris from previous flood events.	No Action Required
Increase Vegetation in Upper Catchment	Increasing the vegetation in the upper catchment may delay the runoff from the catchment and reduce the flood peak downstream. Increased vegetation may not be accepted by the community due to perceptions that vegetation will result in increased flooding issues.	No Action Required
Redesign/Replacement of Existing Bridges	This option would involve increasing the flow capacity of a number of key bridges/waterway crossings in the Upper Wimmera catchment. This may not result in benefits during a flood, however, it may minimise the damage to the structure during a flood and therefore minimise the disruption to a community post-flood. Minimal benefit is likely to occur by enlarging structures once flood waters are on the flood plain, such as in the lower sections of the catchment. For maximum benefit, structures located in a confined valley along key access roads are best upgraded. Therefore this option is likely to be most beneficial in the upper catchments and could be carried out in conjunction with strategic road raising, as detailed above.	No Action Required
Increase Conveyance of the Wimmera River and tributaries	To increase the conveyance of the Wimmera River and its tributaries to carry flood flows would require major channel excavation or realignment works. This work would be prohibitively costly, have large environmental and social impacts, and is unlikely to be feasible due to legislative restrictions. Furthermore, this option would increase flood risk to downstream communities.	No Action Required
Town Drainage	There are no significant town drainage systems in the townships of the Upper Wimmera. Development of such drainage schemes are likely to be costly and unlikely to provide any meaningful benefit in terms of flood mitigation	No Action Required
Do Nothing	The ‘Do Nothing’ option is an acceptable structural mitigation measure. However, as with any other structural mitigation measure, it must be combined with non-structural measures to provide benefits to the community.	N/A
Amendments to Planning Scheme	Refer to Section 10.1.	Further Action Required
House Raising	Whilst a large number of properties are flooded, the modelling and anecdotal information suggests that very few houses are flooded above floor level. Individual house raising / flood proofing may be a viable option for the limited number of properties affected.	No Action Required
Declared Flood Levels	Provision of 1% AEP flood levels for the towns of the Upper Wimmera catchment for the declaration of flood levels as prescribed by Section 204 of the Water Act 1989.	Further Action Required
Town Relocation	Unlikely to be a viable option for these communities.	No Action Required
Building Control Measures (Floor Levels, etc)	Refer to Section 10.2.	Further Action Required
MEMP	Provided as a separate document to VicSES and WCMA.	Further Action Required
Review of Flood Warning System	Refer to Section 9.	Further Action Required
Community Education	Increase the community’s awareness of the risks associated with flooding and the measures put in place to manage these risks. This can be achieved through the SES flood safe program.	Further Action Required

8.3 Structural Management Scheme Assessment

Following the submission of the mitigation options assessment by BMT WBM to the Steering Committee; three structural management schemes were selected for assessment. The approach taken to assess these schemes and to establish a recommended structural management scheme is outlined below.

The basis for the assessment was to undertake flood impact mapping and assessment across all of the modelled design events; the 20%, 10%, 5%, 2%, 1% and 0.5% AEP and the PMF events. Additionally, a benefit-cost ratio, which is an economic assessment based on preliminary cost estimates, was undertaken.

The following sections summarise the assessment methodology used to determine a recommended structural management scheme. For each scheme; a description of the proposed works, an assessment of the effectiveness in reducing the risk of flooding and the economic, social and environmental advantages and disadvantages, has been provided.

8.3.1 Structural Management Schemes

Of the structural management options outlined during the management option screening, three were selected for further feasibility assessment. These options were assessed individually as three structural mitigation schemes and were tested using the hydraulic model.

The three management schemes were:

- **Scheme 1: Removal of Vegetation** – The creek alignments through Navarre and Landsborough are heavily vegetated and this scheme was used to determine the impact on flood levels through the removal of this vegetation.
- **Scheme 2: Town Levee around Navarre** - The design of a levee(s) to prevent flow from entering Navarre for all flood events up to and including the 1% AEP (100 year ARI) flood event.
- **Scheme 3: Whole of Catchment Access** - The design of upgraded roads to ensure safe road access between townships during all flood events up to and including the 1% AEP (100 year ARI) flood event.

8.3.2 Hydraulic Assessment and Flood Impact Mapping

The effectiveness of each structural management scheme identified above was assessed using the hydraulic model documented in Section 4. The existing condition hydraulic model was modified in a manner to represent the proposed structural management scheme and the modified model was then run for all the design flood events.

The results of modified hydraulic model were compared to the existing condition results to ascertain the effectiveness of each hydraulic modelling scheme. The comparison involved the preparation of peak flood heights for modelled scenarios. These were then subtracted from the existing case peak flood heights to produce a flood level difference, or flood impact, grid. The change in peak flood height was then colour contoured and mapped. The impacts maps for the 1% AEP event are presented for each Scheme in the following sections.

The map for each Scheme illustrates no change in flood level, within a +/- 0.05 m tolerance, as a yellow colour, reductions in flood level are shaded with greens and increases in flood level are shaded with browns/reds. A pink colour indicates a region where flooding currently occurs, but would no longer occur if the scheme was implemented, and a blue colour indicates a region where flooding currently does not occur, but would if the scheme was implemented.

8.3.3 Benefit Cost Ratio

The overall financial viability of a scheme is initially assessed by calculating the monetary benefit-cost ratio (BCR). This ratio is used to evaluate the economic potential for the scheme to be undertaken. A monetary benefit-cost ratio of 1.0 indicates that the monetary benefits are equal to the monetary costs. A ratio greater than 1.0 indicates that the benefits are greater than the costs while a ratio less than 1.0 indicates that the costs are greater than the benefits.

In floodplain management, a BCR substantially less than 1.0 may still be considered viable because the economic analysis does not include the intangible benefits of a flood mitigation scheme.

The procedure for calculating benefit-cost ratios is outlined below:

- calculate the average annual benefit associated with the scheme (i.e. the reduction in average annual damages) using the method described in Section 7;
- convert the average annual benefit to a total benefit by multiplying by the present value factor;
- calculate the total cost of the scheme; and
- calculate the monetary BCR using the equation:

$$Benefit\ Cost\ Ratio = \frac{Total\ Benefit}{Total\ Cost}$$

Equation 8-1

In order to calculate the BCR, the annual financial benefit (the change in average annual damages from existing conditions) of a scheme is summed over the financial project life and converted to present value.

A financial project life of 50 years was chosen for the Upper Wimmera Flood Investigation. This does not imply that the projected structural life of the scheme is only 50 years. In fact, some measures could be effective in reducing the frequency of flooding for centuries to come. A financial project life is required in order to determine a timeframe for which the project costs and project benefits can be attributed to.

It is not correct to simply multiply a long term average annual benefit by the financial project life of 50 years to derive a total worth of the benefits. To do so would ignore the important point that the benefits from this scheme (i.e. reduced flood damages) will occur over time and in the future.

For example, a benefit of $2.3 million to be gained in 10 years time is not worth $2.3 million now but only $1.2 million now. This is because $1.3 million could be invested now and appreciates at

6% p.a. over and above inflation for 10 years. This would then be equivalent to \$2.3 million in 10 years time. This is called the Present Value of the benefit. It is a universally accepted economic theory and used in all major project economic analyses. The rate of 6% is called the discount rate and is consistent with the range 6 to 8% typically considered for assessing public works. A discount rate of 6% p.a. was adopted for the Upper Wimmera Flood Investigation.

As an example, Table 8-2 shows the present value of the annual benefit realised at different times over a 50 year period.

Table 8-2 Present Value of Annual Benefits

Year	Average Annual Benefit ($ million)	Present Value ($ million)
0	2.3	2.3
1	2.3	2.2
10	2.3	1.3
25	2.3	0.5
50	2.3	0.1

If the present value benefits for each year are totalled for the 50 years, the total present value of the benefits (total benefit) is \$38.5 million. The calculation of the total benefit can be simplified through the use of a Present Value Factor. Rather than calculating the present value for each year and summing to calculate the total benefit, a Present Value Factor can be used when the average annual benefit is identical in each year. The Present Value Factor is calculated using Equation 8-2. The Present Value Factor is multiplied by the average annual benefit to calculate the total benefit. The Present Value Factor is 15.8 for a 50 year period and a discount rate of 6%.

It is interesting to note that if a longer financial project life was chosen, of say 100 years, then the total present value of the benefits is only \$2 million more at \$40.5 million. This is due to the fact that the present value of the benefits to be accrued in the second 50 year period is low because of the length of time until the benefits are realised.

$$\frac{\left\lfloor 1-\left(\frac{1}{(1+i)^{n}}\right)\right\rfloor}{i}$$

where n is the number of years and i is the discount rate(%).

Equation 8-2

It is important to recognise that the monetary BCR represents only the financial issues that must be considered in respect to the viability of a scheme. Other issues such as social, psychological and environmental impacts, although difficult to quantify, must be included in the complete assessment.

8.3.4 Cost Estimates

In order to calculate a BCR an estimate of the total cost of a management scheme must be determined. While at the conceptual stage these costs are merely a best estimate with a large degree of uncertainty, it is important to provide the best estimate of total costs as possible in order for the viability of each scheme to be assessed and compared. The total management scheme costs comprise of capital costs and ongoing maintenance costs. The capital costs comprise the following components:

- Construction works;
- Design and engineering (15% of construction works cost);
- Administration (9% of construction works cost); and
- Contingency (20% of construction works cost).

The ongoing maintenance costs are estimated to be 2% of the capital cost per annum represented in terms of Net Present Value discounted at 6% over the 50 project life adopted in the Upper Wimmera Flood Investigation.

The construction works costswere derived from the following sources:

- Rawlinsons Australian Construction Handbook 2012 (Rawlinsons 2012);
- VicRoads; and
- Charlton Drainage and Floodplain Management Plan (BMT WBM 2013).

A summary of each Scheme is presented in the following sections. Each summary includes details of the proposed works, the associated flood impacts, construction costs and BCR, as well as the relative advantages and disadvantages of the Scheme. The costs of each Scheme are broken down into more detail in Appendix E

8.4 Scheme 1: Vegetation Removal

8.4.1 Description of Works

In response to the concerns of the local community, this mitigation scheme was designed to determine the impacts on flood heights and velocities if the creeks within both Navarre and Landsborough were ‘cleaned up’ and the vegetation was removed. Approximately 6.5 kilometres of natural channel were identified as a target for vegetation removal.

The scheme did not include any changes to the channel geometry or channel slope; however, the creeks were simulated as having a similar roughness to a maintained grass swale rather than their natural condition.

8.4.2 Flood Impacts

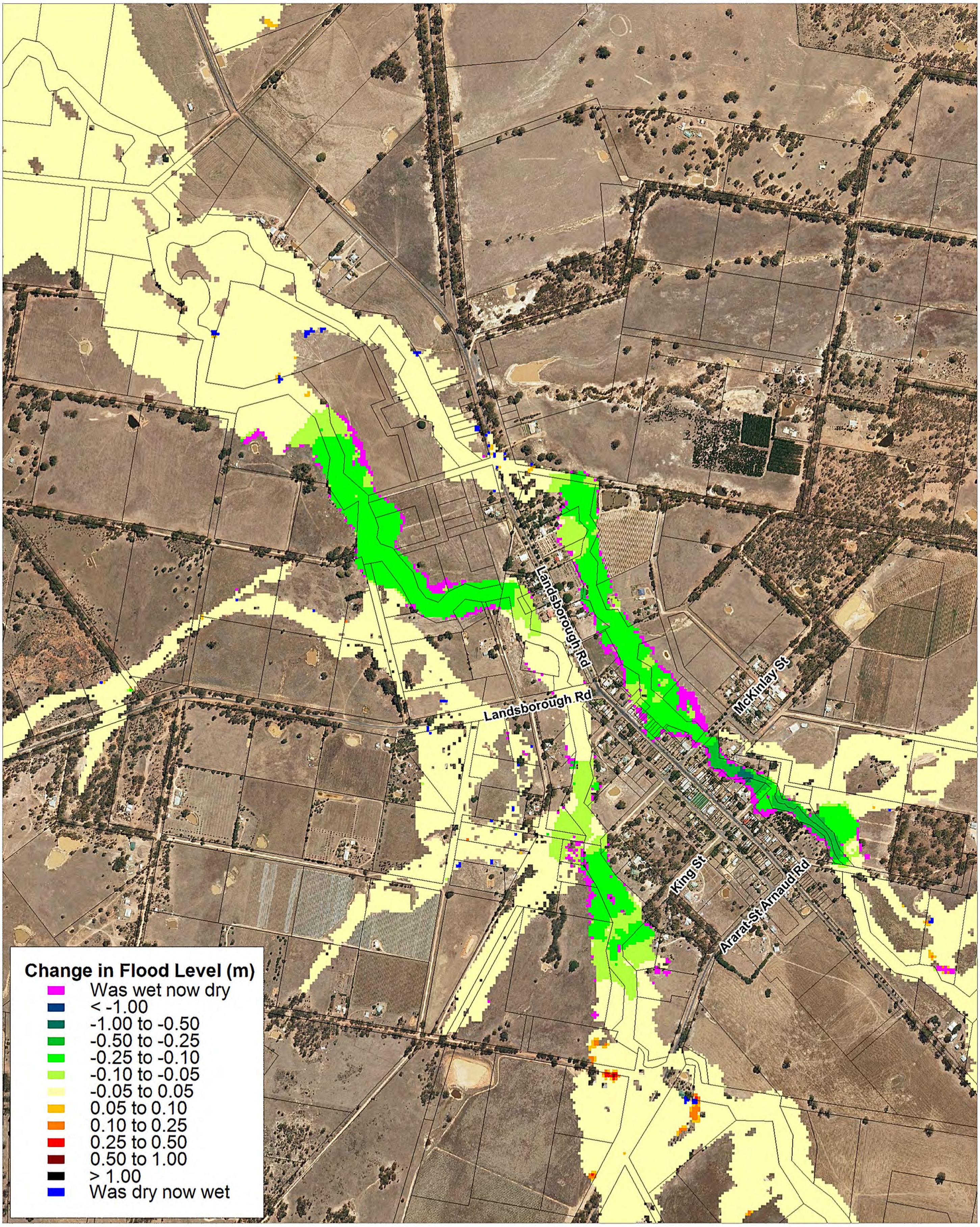
The impact on the 1% AEP design event peak flood levels for Scheme 1 are shown in Figure 8-1 and Figure 8-2 for Landsborough and Navarre respectively. These figures show that the removal of vegetation from the creek in and around Landsborough and Navarre will reduce flood levels by up to 0.25 metres along the creek alignment and for properties adjacent to the creeks. There are additionally a number of properties that will no longer be flooded during the 1% AEP flood event as a result of this scheme.

However, the velocities of the floodwaters through the creeks has increased by up to 1 metre/second during the 1% AEP flood event. Increases in velocity of this magnitude could result in increased erosion of the creek system resulting in addition sediments being deposited further down the system. Whilst the erosion will have localised impacts on both the Navarre and Landsborough communities through increased bank instability and possible movement of the creek alignment, the sediment being transported downstream has the potential to block or reduce the performance of drainage structures resulting in localised damage to infrastructure and impact to communities.

Table 8-3 outlines the number of properties and floor levels inundated and saved for each design event.

Table 8-3 Scheme 1 – Number of Flooded Properties

Event (AEP)	Flooding Occurs Within Property Boundary	No. of Properties Saved	Flooding Occurs Above Floor Level	No. of Flooded Floors Saved
20%	5	0	0	0
10%	6	0	0	0
5%	8	1	1	0
2%	15	0	3	0
1%	16	8	3	0
0.5%	33	0	7	0
PMF	53	0	37	0



Title:

Upper Wimmera Flood Investigation - Mitigation Option 1 Vegetation Removal - 1% AEP Flood Height Impacts

Figure: **8-1**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 100 200m
Approx. Scale

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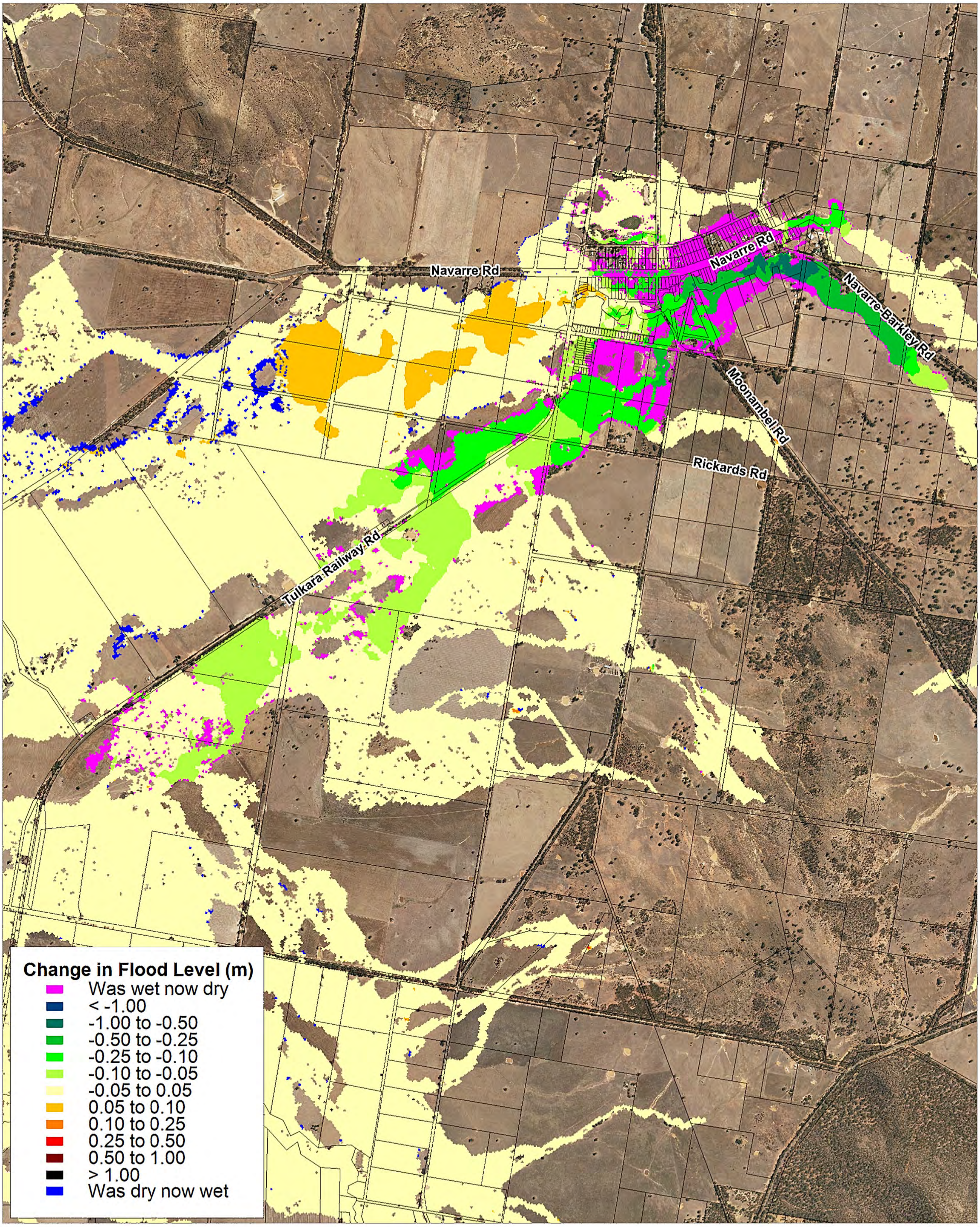

Title:

Upper Wimmera Flood Investigation - Mitigation Option 1 Vegetation Removal - 1% AEP Flood Height Impacts

Figure: **8-2**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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0 0.5 1km

Approx. Scale

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8.4.3 Benefit Cost Ratio

The damages under Scheme 1 for each design flood event are summarised in Appendix B. The AAD is $2,912,500, which is a reduction of $2,200 from the existing conditions AAD of $2,914,700. The benefit cost analysis is summarised in Table 8-4. The BCR for Scheme 1 is 0.03.

Table 8-4 Scheme 1 BCR Summary

Item	Existing	Scheme 1
Damages (PA)	$2,914,700	$2,912,500
Benefit (PA)		$2,200
Benefit (NPV)		$35,000
Capital Cost		$850,000
Maintenance (PA)		$20,000
Maintenance (NPV)		$315,000
Total Scheme Cost		$1,165,000
BCR		**0.03**

8.4.4 Advantages and Disadvantages

Some of the key advantages and disadvantages of Scheme 1 are presented in Table 8-5.

Table 8-5 Advantages and Disadvantages of Scheme 1

Advantages	Disadvantages
Reduce flood levels in and around Navarre and Landsborough	Increased erosion potential
	Potential sedimentation issues downstream
	Very low BCR

8.5 Scheme 2: Navarre Town Levee

8.5.1 Description of Works

Scheme 2 involves construction of a levee to surround the township of Navarre to protect the township from flooding up to and including the 1% AEP flood event.

The alignment of the northern levee follows the southern bank of the creek to the north of Navarre. The proposed levee commences to the east of Navarre at Navarre Road and follows the creek until it crosses back under Navarre Road to the west of Navarre.

The alignment of the southern levee follows the northern bank of Wattle Creek. The proposed levee commences at the Navarre-Barkly Road and continues along the creek bank until the Tulkara Railway Road.

The two proposed levees ensure the majority of Navarre will be protected from flooding for events up to and including the 1% AEP flood event. However, a number of properties, including the sporting field, netball and football clubs, will not be protected by the construction of the levee.

The levee has been designed to a height that allows for 600mm freeboard, as recommended in *Levee Design, Construction and Maintenance* (DNRE, 2002), above 1% AEP design event. The earthen parts of the levee have a top width of 3m with side slopes of 1:5.

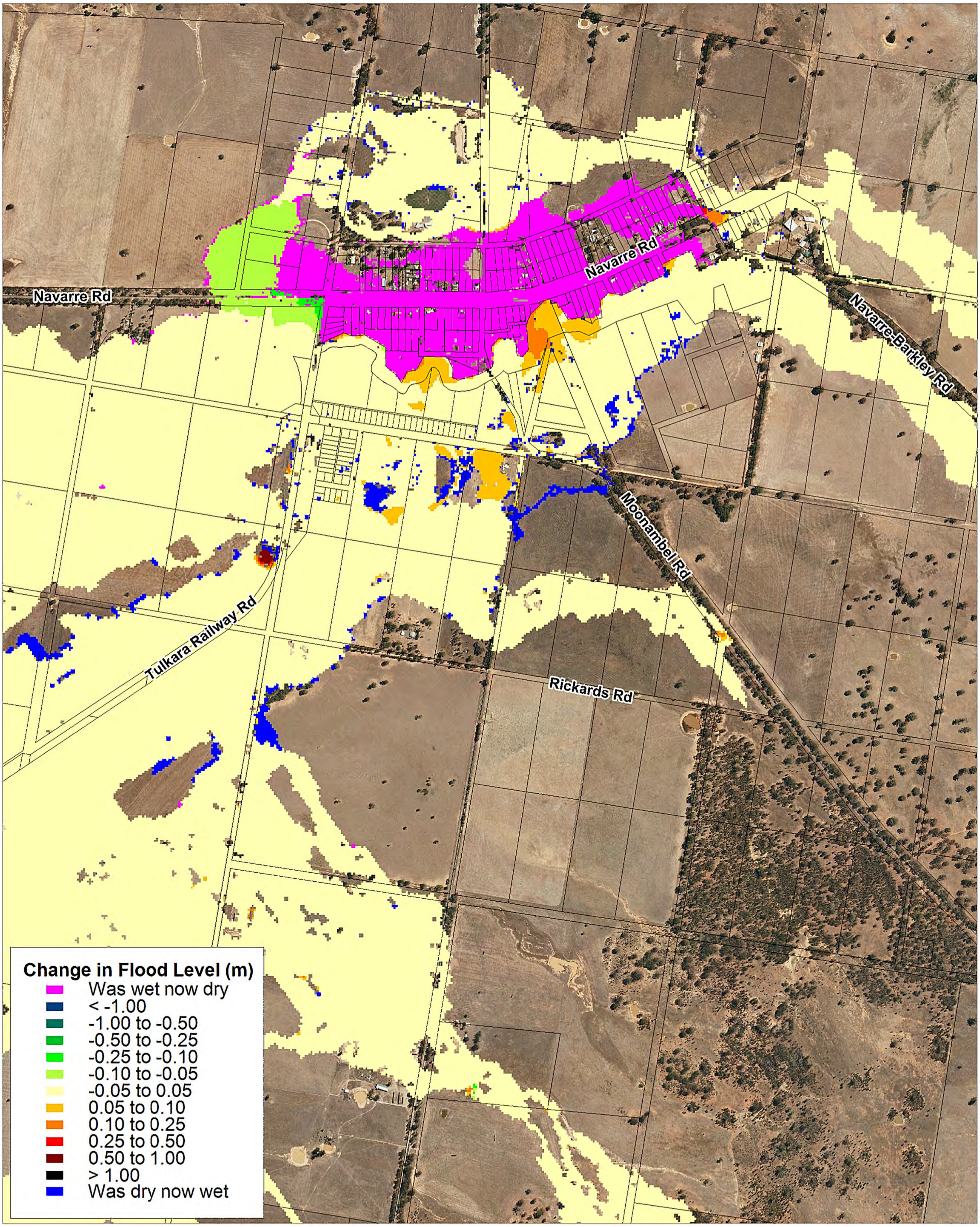
8.5.2 Flood Impacts

The impact on the 1% AEP design event peak flood levels for Scheme 2 is shown in Figure 8-3. This figure confirms that the majority of the Navarre Township will be flood free for flood events up to and including the 1% AEP flood event. A number of properties to the south of Navarre will experience flood level increases of up to 0.25 metres as a result of this mitigation scheme.

Table 8-6 outlines the number of properties and floor levels inundated and saved for each design event.

Table 8-6 Scheme 2 – Number of Flooded Properties

Event (AEP)	Flooding Occurs Within Property Boundary[1]	No. of Properties Saved	Flooding Occurs Above Floor Level[2]	No. of Flooded Floors Saved
20%	5	0	0	0
10%	6	0	0	0
5%	8	1	1	0
2%	11	4	3	0
1%	12	12	3	0
0.5%	33	0	7	0
PMF	53	0	37	0



Title:

Upper Wimmera Flood Investigation - Mitigation Option 2 Levees for Navarre - 1% AEP Flood Height Impacts

Figure: 8-3

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 250 500m

Approx. Scale

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8.5.3 Benefit Cost Ratio

The damages under Scheme 2 for each design flood event are summarised in Appendix B. The AAD is $2,912,200, which is a reduction of $2,500 from the existing conditions AAD of $2,914,700. The benefit cost analysis is summarised in Table 8-7. The BCR for Scheme 2 is 0.02.

Table 8-7 Scheme 2 BCR Summary

Item	Existing	Scheme 2
Damages (PA)	$2,914,700	$2,912,200
Benefit (PA)		$2,500
Benefit (NPV)		$39,000
Capital Cost		$1,500,000
Maintenance (PA)		$36,000
Maintenance (NPV)		$567,000
Total Scheme Cost		$2,067,000
BCR		**0.02**

8.5.4 Advantages and Disadvantages

Some of the key advantages and disadvantages of Scheme 2 are presented in Table 8-8.

Table 8-8 Advantages and Disadvantages of Scheme 2

Advantages	Disadvantages
Protection of the township of Navarre from all flooding up to and including the 1% AEP flood event	Very low BCR
	Disruption to community during construction
	Visual impact on township
	Increased flood levels for those outside of the proposed levees

8.6 Scheme 3: Whole of Catchment Access

8.6.1 Description of Works

Scheme 3 involves undertaking significant road and drainage infrastructure works. The aim of this scheme is to provide whole of catchment road access during all flood events up to including the 1% AEP flood event to ensure that no communities are isolated. Whilst a number of roads will still be inundated, key link roads throughout the catchment will remain open. The key road routes upgraded were highlighted in Section 8.2.1

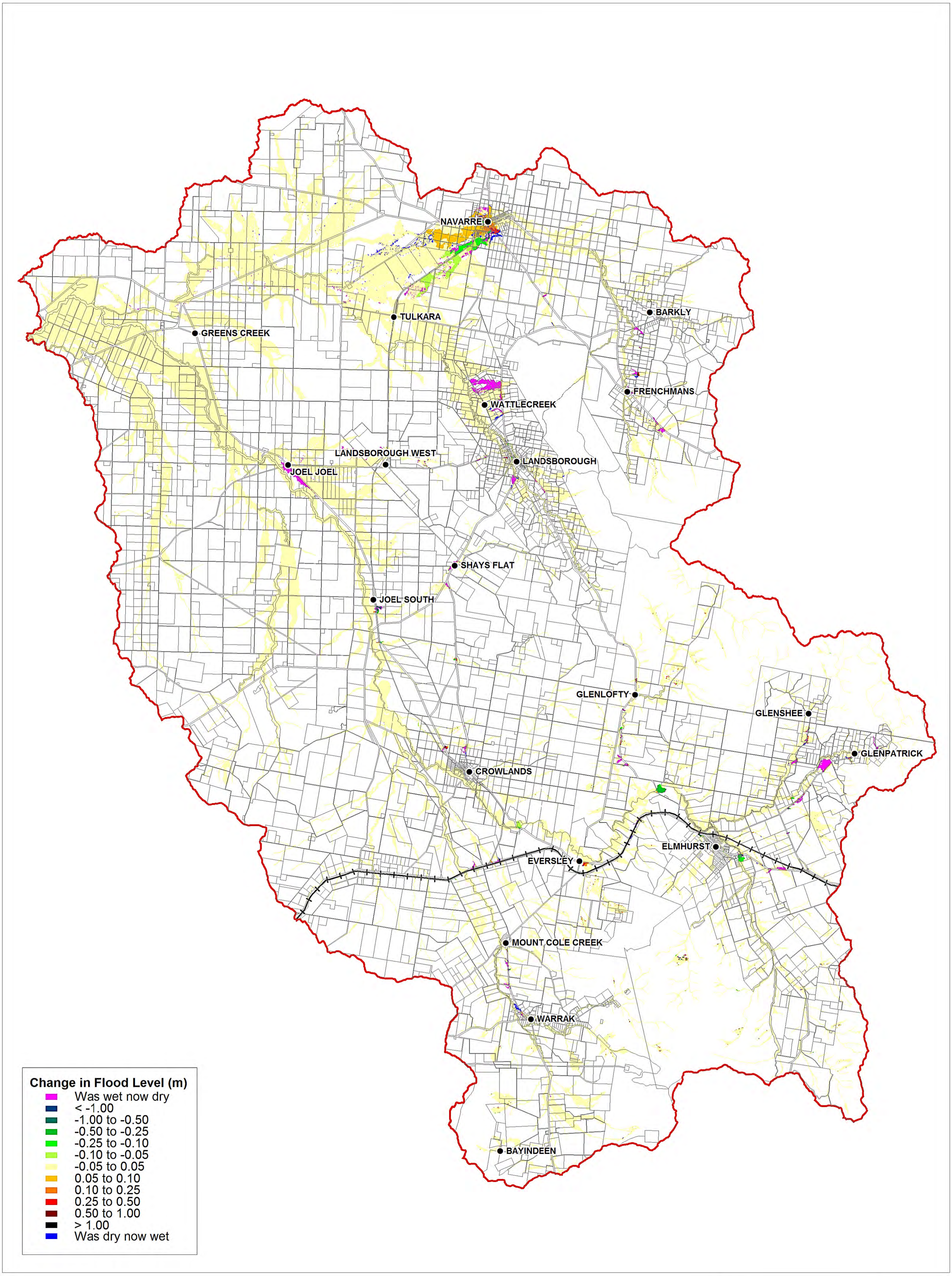
8.6.2 Flood Impacts

The impact on the 1% AEP design event peak flood levels for Scheme 3 is shown in Figure 8-4. This figure shows a number of isolated flood impacts located near the upgraded drainage infrastructure. However, these impacts could be reduced through a detailed design process that would need to be undertaken for the mitigation scheme.

Table 8-9 outlines the number of properties and floor levels inundated and saved for each design event.

Table 8-9 Scheme 3 – Number of Flooded Properties

Event (AEP)	Flooding Occurs Within Property Boundary	No. of Properties Saved	Flooding Occurs Above Floor Level	No. of Flooded Floors Saved
20%	3	2	0	0
10%	5	1	0	0
5%	7	2	1	0
2%	12	3	3	0
1%	18	6	5	1
0.5%	33	0	7	0
PMF	53	0	37	0



Title:

Upper Wimmera Flood Investigation - Mitigation Option 3
Town Access (Road Raising) - 1% AEP Flood Height Impacts

Figure: **8-4**

Rev: **A**

N

0 3.75 7.5km
Approx. Scale

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8.6.3 Benefit Cost Ratio

The damages under Scheme 3 for each design flood event are summarised in Appendix B. The AAD is $2,821,500, which is a reduction of $93,200 from the existing conditions AAD of $2,914,700. The benefit cost analysis is summarised in Table 8-10. The BCR for Scheme 3 is 0.03.

Table 8-10 Scheme 3 BCR Summary

Item	Existing	Scheme 2
Damages (PA)	$2,914,700	$2,821,500
Benefit (PA)		$93,200
Benefit (NPV)		$1,469,000
Capital Cost		$37,320,000
Maintenance (PA)		$896,000
Maintenance (NPV)		$14,123,000
Total Scheme Cost		$51,443,000
BCR		**0.03**

8.6.4 Advantages and Disadvantages

Some of the key advantages and disadvantages of Scheme 3 are presented in Table 8-11.

Table 8-11 Advantages and Disadvantages of Scheme 3

Advantages	Disadvantages
Flood free access for all events up to and including the 1% AEP flood event (both for local communities and emergency response)	Massive disruption to communities during construction
	Very low BCR

8.7 Conclusions

This section has presented the economic assessment for the three modelled structural mitigation schemes for the Upper Wimmera catchment. All three options provide minimal reductions to the Annual Average Damages and consequently result in very low Benefit-Cost Ratios. This is not unexpected due to the majority of the flood damages being incurred through damages to agricultural land and roads, and Schemes 1 and 2 making very little (if any) difference to these values. Whilst there is a noticeable reduction in the damages for Scheme 3, it comes at a significant capital cost; hence the BCR is still very low.

Consequently, there is no preferred structural mitigation scheme recommended by the Steering Committee for the Upper Wimmera Catchment. However, mitigation works should still be considered for protection of individual properties where deemed appropriate. A series of non-structural mitigation works will also be implemented across the catchment, including recommendations for improving the flood warning system and amendments to the planning scheme overlays.

9 Flood Warning Systems

The purpose of this section is to introduce possible options for both structural and non-structural flood warning system considered for the Upper Wimmera Flood Investigation.

9.1 Aim and Function

Put simply, flood warning systems provide a means of gathering information about impending floods, communicating that information to those who need it (those at risk) and facilitating an effective and timely response. Thus flood warning systems aim to enable and persuade people and organisations to take action to increase personal safety and reduce the damage caused by flooding[1]. Effective flood warning systems maximise the opportunity for the implementation of public and private response strategies aimed at enhancing the safety of life and property and reducing avoidable flood damage.

Fully developed flood warning systems consider not only the production of accurate and timely forecasts / alerts but also the efficient dissemination of those forecasts / alerts to response agencies and threatened communities in a manner and in words that elicit appropriate responses based on well developed mechanisms that maintain flood awareness.

Equally important to the development of flood warning mechanisms is the need for quality, robust flood awareness (education) programs to ensure communities are capable of response.

Notwithstanding the above, flood warning systems should respond appropriately to the risk being addressed. Thus, a sophisticated and possibly expensive system may not be suitable for a location or area where flooding results mainly in disruption and only the larger floods inundate a proportionally small number of buildings above floor level.

9.2 Limitations of Flood Warning Systems

No single floodplain management measure is guaranteed to give complete protection against flooding. For example, levees can be overtopped (when a flood exceeds design height, as happened at Nyngan in 1990) or fail (when construction standards are poor or maintenance is inadequate). Likewise, flood response plans can be poorly formulated or applied ineffectually.

Flood warning systems are, by their very nature, complex. They are a combination of technical, organisational and social arrangements. To function effectively they must be able to forecast coming floods and their severity (using data inputs that may include rainfall and /or upstream river heights and / or flows along with modelling techniques or forecasting tools) and the forecast must be available / transmitted available to those who will be affected (the at-risk communities) in ways that they understand and which result in appropriate behaviours on their part (for example, to protect assets or to evacuate out of the path of the floodwaters).

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1 More generally, the objective of early warning is to empower individuals and communities, threatened by natural or similar hazards, to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury, loss of life and damage to property, or nearby and fragile environments (UN, 1997).

It is not surprising, given the above, that flood warning systems often work imperfectly and have, on occasions, failed. Indeed, as Handmer (2000) points out, "flood warnings often don't work well and too frequently fail completely - and this despite great effort by the responsible authorities." While in some cases the problem is the result of a physical, mechanical or technical failure (for example of gauges or telemetry or of communications equipment during a flood event), or perhaps in defining what constitutes success (or failure), the more common reason is that the systems have not been properly conceptualised at the design stage and in terms of their operation, despite the considerable and conscientious efforts of those involved. All too often, too little attention has been paid to issues of risk communication. In particular:

To building a local awareness of flood risk along with knowledge of what can be done to minimise that risk;

Determining what information is required by the at-risk community and with what lead times;

How warnings and required information will be distributed to and within the target communities

Ensuring that recipients of warning messages understand what the message is telling them and what it means for their property and individual circumstances in terms of the damage reducing actions they need to take.

The outcome of the above is that many flood warning systems have an inbuilt likelihood of failure.

In numerous cases where flood warning systems have been developed, the bulk of the effort has been devoted to creating and strengthening data collection networks, devising and upgrading forecasting tools and facilities and utilising new dissemination technologies to distribute the forecast to at-risk communities. While all these things are important, they are never sufficient by themselves to ensure that flood warnings are heeded by those who receive them. Other equally vital elements of the system such as risk communication and the comprehension that people have of the flood problems they may face (and the value that warnings can offer) need at least as much attention at the design stage and in system operation. Systems need to also be appropriate to the circumstances. The lesson from many studies of flood warning systems (e.g. Smith and Handmer, 1986; Phillips, 1998; Handmer, 1997, 2000, 2001 & 2002; Comrie, 2011) is that the status of all elements of the system must be given appropriate attention (and resourcing) if the system is to be made capable of functioning effectively.

Studies of flood warning system failures (e.g. Brisbane in 1974, Charleville and Nyngan in 1990, Benalla in 1993, Canada in 1997, England in 1998, Kempsey and Grafton in 2001, New Zealand in 2005) suggest that the most common reasons for poor system performance are that those in the path of floods, whether emergency responders, householders, the owners of businesses or the operators of infrastructural assets, have either not understood the significance of the warnings they have received or have not known that there were things (or the most appropriate things) they could do to mitigate the effects of flooding. The result has all too often been unnecessary loss of private belongings and commercial and industrial plant, stock and records (for example, through late or non-existent responses) and / or unnecessary risk to life (for example, due to evacuation after it became dangerous rather than when it was relatively safe). Most studies report that warnings were of an adequate technical standard (that is, they were accurate and delivered with good lead times), but the information was poorly communicated and not understood by the target communities. As reported by Anderson-Berry and Soste & Glass, there is often insufficient attention to ensuring that people in flood liable areas understand the flood gauge or forecast heights which are incorporated in warning messages. The result is that those who have been warned fail to appreciate that the information contained in the message has meaning for their own circumstances. Consequently, they fail to take appropriate or adequate protective measures. Such people often claim afterwards that they received no flood warnings. In many cases warnings were issued but the gap between the information provided and what was understood by those at risk was too large. The problem is one of poor communication.

It is clear that a major problem with many flood warning systems is one of inadequate conceptualisation. Flood warning systems (and investments in their implementation) that over-emphasise the collection of input data and / or the production of flood forecasts relative to the attention given to other elements (such as message construction, the information provided in the messages and the education of flood prone communities about floods and flood warnings) will fail to fully meet the needs of the at-risk communities they have been set up to serve.

9.3 The Total Flood Warning System Concept

In 1995 the Australian Emergency Management Institute, following a national review of flood warning practices after disastrous flooding in the eastern states in 1990, published a best-practice manual entitled '*Flood Warning: an Australian Guide* (AEMI, 1995). In describing practices for the design, implementation and operation of flood warning systems in Australia, the manual introduced the concept of the "total flood warning system" (TFWS). It also re-focused attention on flood warning as an effective and credible flood mitigation measure but made it clear that successful system implementation required the development of some elements that hitherto had been given little attention as well as the striking of an appropriate balance between each of the elements. In particular, it was noted that more attention needed to be given to risk communication and the education of communities about the flood risk, the measures that people could take to alleviate the problems that flooding causes and the place of warnings in triggering appropriate actions and behaviours. It also clearly enunciated the need for several agencies to play a part, with clearly-defined roles and with the various elements carefully integrated, and for the members of flood liable communities to be involved. Put another way, "*effective warning systems rely on the close cooperation and coordination of a range of agencies, organisations and the community*" (DoTARS, 2002).

While the original manual has been updated and republished as Manual 21 of the Australian Emergency Manuals Series (EMA, 2009), the concepts, practices and key messages from the original manual endure.

The philosophy that underlies the TFWS concept coupled with the need for a coherent set of linked operational responsibilities and overlapping functions is documented and discussed in the context of guiding principles for effective early warning in UN (1997).

9.4 Total Flood Warning System Building Blocks

An effective flood warning system comprises much more than a data collection network, forecasting tool or model and flood level (or flow) prediction.

An effective flood warning system is made up of several building blocks. Each building block represents an element of the Total Flood Warning System. The blocks (derived from EMA, 2009) along with the basic tools to facilitate delivery against each of the TFWS elements are presented in Table 9-2.

Experience shows that flood warning systems, and this applies even more so to flash flood warning systems, that are not designed in an integrated manner and that over-emphasise flood detection (say) at the expense of attention to the dissemination of warnings, local interpretation and community response inevitably fail to elicit appropriate responses within the at-risk community. It is essential that the basic tools against each of the building blocks are appropriately developed and integrated. Such a system considers not only the production of a timely alert to a potential flash flood but also the efficient dissemination of that alert to those, particularly the threatened community, who need to respond in an appropriate manner. A community that is informed and flood aware is more likely to receive the full benefits of a warning system.

It follows therefore that actions to improve flood response and community flood awareness using technically sound data (such as produced by the Upper Wimmera Flood Investigation) will by themselves result in some reduction in flood losses.

9.5 The Task for the Upper Wimmera Catchment

9.5.1 Introduction

The Upper Wimmera catchment has an area of around 1,500km^2 and is considered, for the purposes of this study, to comprise all of the area and watercourses upstream of Glynwylln. These include the Wimmera River and its tributaries, the major ones being Mount Cole Creek, Wattle Creek (also known as Heifer Station Creek), Howard Creek and Seven Mile Creek. There are several townships within the catchment including Navarre, Landsborough, Elmhurst, Eversley, Crowlands, Joel Joel, Greens Creek and Campbells Bridge (Figure 9-1).

The upper parts of the catchment include the northern slopes of the Great Dividing Range and the Pyrenees. It is relatively steep here with numerous well defined flow paths. In the lower parts, the topography flattens to form a wide and relatively undefined floodplain.

The main watercourse is the Wimmera River which originates south of Elmhurst in the Mount Cole State Forest. It flows in a generally westerly direction past the townships of Elmhurst, Eversley and Crowlands before its confluence with Mount Cole Creek, just downstream from Crowlands. From here, the river flows in a generally northerly direction through Joel Joel before its confluence with Wattle Creek approximately halfway between Greens Creek and Glynwylln. Due to the relatively flat nature of the floodplain in this area, cross catchment flows occur between the creek systems well before the confluence. It then flows on past Glynwylln towards Glenorchy. Beyond Glenorchy, the river flows past Horsham, Dimboola and Jeparit and continues on into Lake Hindmarsh.

Navarre is located towards the north of the Upper Wimmera catchment, approximately 35km north east of Stawell, on the bank of Wattle Creek, one of the Wimmera's main tributaries.

Landsborough is positioned near the centre of the Upper Wimmera catchment, approximately 33km east of Stawell, on the bank of Howards Creek, a tributary of Wattle Creek.

The Upper Wimmera catchment is described in more detail in Section 1.3. A brief history of past floods is also included in Section 1.5.

The analyses undertaken in support of the Upper Wimmera Flood Investigation suggest that typically, the time from the beginning of heavy rain on a wet catchment to the start of stream rises range from around 1 to 2 hours at Eversley, 2 to 4 hours at Crowlands, 3 to 6 hours at Navarre and 6 to 9 (possibly up to 12) hours at Glynwylln. Rates of rise are quite rapid (can be 500mm/hour or more) on a wet catchment with flooding / overbank flows likely to begin within 1 to 4 hours of the initial rise.

It is emphasised that these times are approximate only and are for heavy rain on a wet catchment. Lighter rain or rain on a drier catchment result in much slower response times. For example, in January 2011 the time from start of rain to the start of flooding was of order 50 hours or more. Initial rain wetted up the catchment and the heavy rain that followed caused very quick and significant rises in stream levels with attendant record flooding.

As the majority of the Upper Wimmera catchment is used for grazing (there is some cropping in the lower parts) it is unlikely that the time of year or crop status will influence the spread of floodwaters or the rate at which they rise and fall.

Rainfall and stream flow are recorded at a number of locations within or close to the Upper Wimmera catchment (Table 9-1). Data from most of the telemetered sites are available from the BoM website at intervals ranging from around 30 minutes to daily (around 9am) with most data updated every 3 hours or so during a flood event.

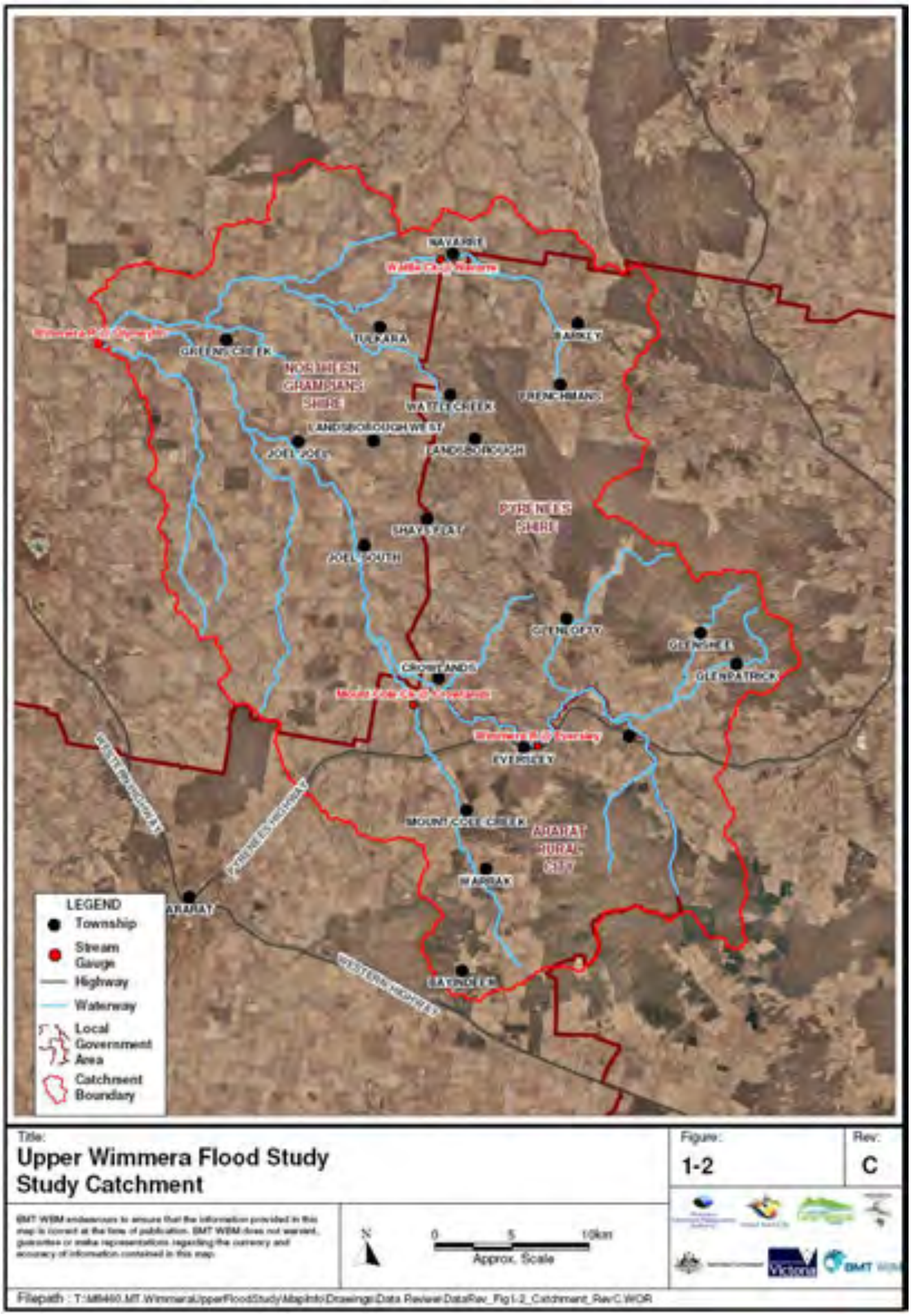


Figure 9-1 Upper Wimmera Study Catchment with Townships and Stream Gauging Sites

9.5.2 Existing Flood Warning System

A formal flood warning system does not exist for any locations or streams within the Upper Wimmera catchment although elements of a system are in place as part of the flood warning system for the Wimmera River at Glenorchy.

In summary the flood warning system for Glenorchy comprises:

- A data collection network to support flood forecast and warning activities at Glenorchy. The network comprises a number of telemetered (ERTS and telephone based) rainfall and river level monitoring sites within and adjacent to the Upper Wimmera catchment (see Table 9-1 and Figure 9-2 below). As sites are generally multi-purpose (i.e. not installed purely for flood warning purposes), the network is funded by a mix of stakeholder agencies.
- Access to data from the data collection network via the BoM website. Data is available at intervals ranging from around 30 minutes to daily (around 9am) with most data updated every 3 hours or so during a flood event.
- A rainfall – runoff model developed and maintained by the Bureau of Meteorology (BoM) for the catchment to Glenorchy. The model provides forecast river flows and levels for Glenorchy only. As the model outputs a full forecast hydrograph for Glenorchy, it is feasible that advice on the likely time to exceed specified levels, the time and duration of peak flows / levels and the time to fall below specified levels could be provided by BoM for Glenorchy along with other characteristic information.
- Established flood class levels for Glenorchy only.
- Municipal Flood Emergency Plans (MFEPs) that include intelligence on flood impacts within the Wimmera catchment from around Glenorchy and downstream. MFEPs are being updated and extended into the Upper Wimmera catchment as part of this project.
- Local arrangements for disseminating flood related information within the Wimmera catchment at Glenorchy and downstream.
- Property specific cards for each house in Glenorchy. A card has been delivered to each property in Glenorchy and provides the building floor level together with the corresponding level at the gauge. Other key levels are included on the card.
- Established procedures for initiating and continuing a coordinated operational response in times of flood.

Table 9-1 The existing data collection network for the Wimmera catchment upstream of Glenorchy

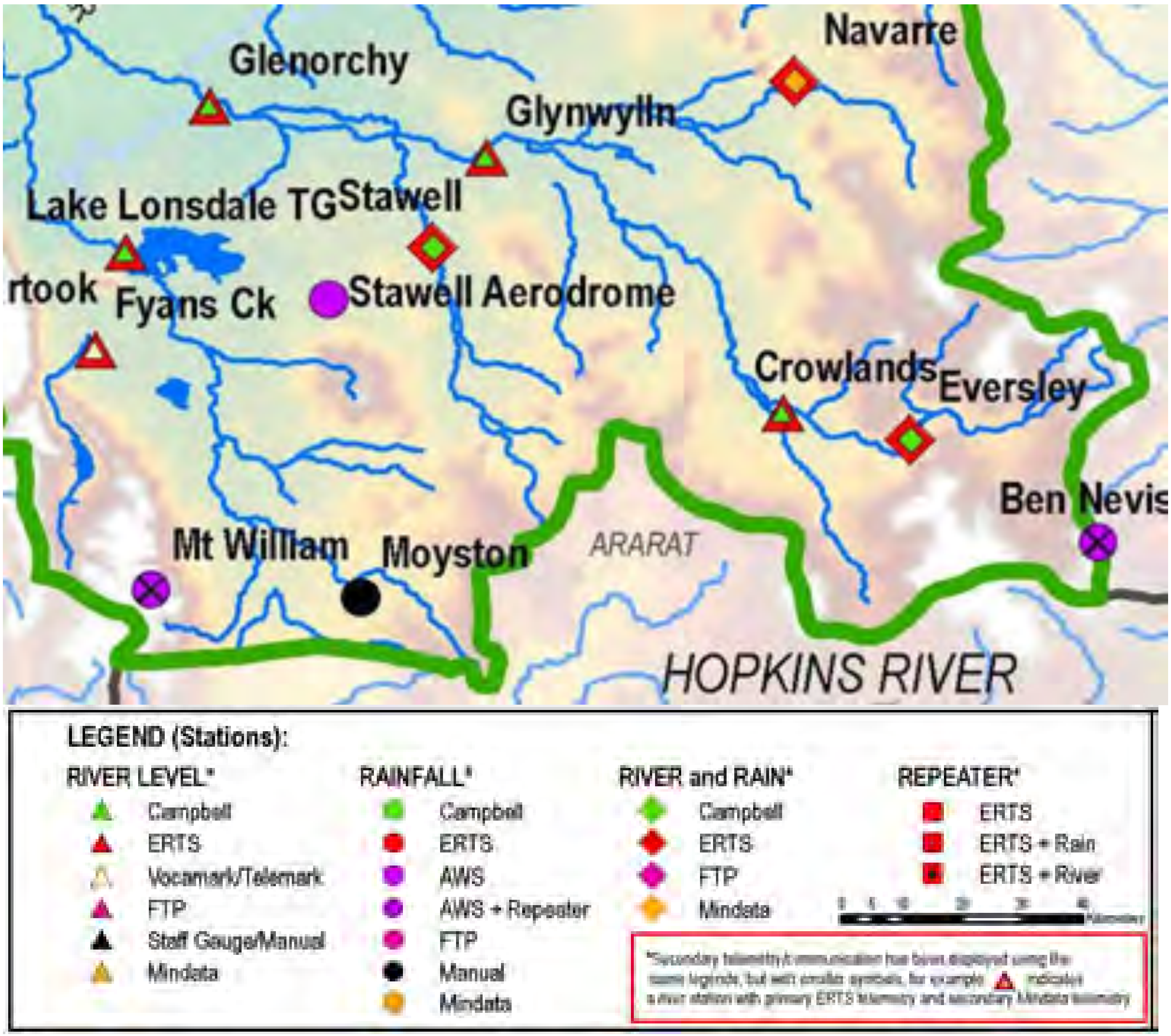
Rainfall stations			River level / flow stations		
Location	**Telemetry type**	**BoM website**	**Location**	**Telemetry type**	**BoM website**
Avoca	TBRG - phone	√	Crowlands	ERTS	√
Pyrenees (Ben Nevis)	TBRG - ERTS	√	Eversley[1]	ERTS	√
Eversley	TBRG - ERTS	√	Glenorchy	ERTS	√
Navarre	TBRG-ERTS	√	Glynwylln[1]	ERTS	√
Moyston	AWS	√	Navarre[1]	ERTS	√
Stawell	TBRG - ERTS	√	Stawell	ERTS	√
Stawell Aerodrome	AWS	√			
Mt William	AWS	√			
Wimmera Highway[2]	TBRG - phone				
Other gauges outside the Upper Wimmera catchment[3]		√			

1 The river gauges at Glynwylln, Eversley and Navarre were damaged during the January 2011 flood. Repairs have been completed and the gauges are again fully operational.

2 Rainfall data from this rain gauge is not routinely available from the BoM website.

3 Data from other gauges outside the Upper Wimmera catchment (e.g. Ararat) are available from the BoM website and assists in the development of a more complete appreciation of areal rainfalls and of likely stream responses across the region.

Figure 9-2 Rainfall and river station in the Upper Wimmera catchment supporting flood warning to Glenorchy (extracted from BoM map)



9.5.3 Flood Risk in the Upper Wimmera Catchment

The Upper Wimmera Flood Investigation has shown that flood risk in the catchment upstream of Glynwylln is “tolerable”. For example, damage to other than roads and the agricultural sector (e.g. fences, pasture, etc) arising from floods less than the 2% AEP (50-year ARI) event is minimal and is associated with over-floor flooding of only two buildings (both buildings begin to be flooded over-floor between the 20-year and 50-year ARI events – one each in Warrak and Wattle Creek) and restrictions to regional access due to roads being flooded. Floods more severe than the 2% AEP event result in an increase in the number of buildings at-risk of over-floor flooding (3 at the 1% AEP event and 7 at the 0.5% AEP event) and further restrictions to regional access due to flooded roads.

Floods develop and rise quickly in the Upper Wimmera catchment when the area is wet: catchment response times are generally less than 6 hours (see Section 9.5.1). This places the catchment in the flash flood category[2] with a need for any rain and water level data to be available locally in real-time. The categorisation also determines where responsibilities lie with respect to the purchase, installation and maintenance of any data collection equipment to support flood warning systems for communities upstream of Glynwylln[3]. In summary, these responsibilities reside at the local level (i.e. with Councils) although the BoM will provide technical assistance[4].

The damage assessment undertaken as part of this project suggests that during a 1% AEP (100-year ARI) event, building damage would account for approximately 1% of the total damage (minus indirect damages) incurred while damage to agricultural land and road infrastructure would account for around 77% and 22% respectively. The percentage for more frequent floods would be even smaller. The damage avoided due to a fully functioning flood warning system would therefore not

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2 A flash flood is defined as a flood that occurs within about 6 hours of the rain that causes it (BoM, 1996).

3 Arrangements for the provision of flood warning services in Victoria were formalised in working arrangements approved by the Commonwealth Government in 1987 (BoM, 1987) and agreed to in-principle by the Victorian Government through the State Disaster Council in early 1988. These arrangements were reiterated and aspects clarified in *Arrangements for Flood Warning Services in Victoria* (VFWCC, 2001) and then endorsed by the relevant Minister at both State and Federal level. State and local entity responsibilities are addressed in the Emergency Management Manual Victoria as well as in applicable State legislation.

4 What this means is that any flood warning system established for a stream or location considered to be subject to flash flooding will need to be paid for and managed by the local council but that the BoM will provide advice aimed at assisting the council establish and develop the technical aspects of the system. Operational responsibility, and thus message construction and dissemination, will also reside with the council. The BoM will, however, assist through the supply of operational software for data management and alerting and continue delivery of existing severe weather and flood warning related services. While it is not specifically stated where responsibilities for other elements of the TFWS reside, it is assumed that arrangements in place for non-flash flood warning systems apply.

be large. On an annual average basis, perhaps of order $100,000 if the short response times were not considered and damage reducing actions were assumed to be highly effective. If the short response time is factored in, the benefits associated with a flood warning system reduce substantially, perhaps at best to around $30,000 to $40,000 (depending on assumptions) on an annual average basis. This suggests that a sophisticated flood warning system requiring a substantial initial injection of capital and incurring on-going costs could not be supported on economic grounds alone.

Feedback received during the course of this project indicated that most residents do not see flooding as a major problem and see little need for a formal (flash) flood warning system. A number of residents suggested that a reinstatement of the “informal” flood warning system whereby the CFA radio network was used to pass information about rainfall and watercourse responses around the communities would cater to local needs.

It is suggested that in view of the likely cost - benefit ratio (i.e. poor economic metrics) and in the absence of substantial community enthusiasm, the likelihood of securing State and Federal funding support for the purchase, installation and development of a sophisticated flash flood warning system would be low, even with the commitment of Councils and the CMA.

A simple and more modest system does however have some attractions, particularly if access to required data along with the tools for determining the likelihood and approximate severity of flooding is made available to those likely to be affected. Capital costs could be quite modest. Benefits would be maximised as the time taken to respond to likely flooding would be minimal. The on-going costs associated with any new telemetry equipment would however still need to be met locally (e.g. by the Councils and / or CMA if other partners could not be found, perhaps through the Surface Water Monitoring Partnership).

Attention would still need to be given to each of the TFWS building block if an effective flash flood warning system was to be established for the Upper Wimmera catchment. Installing additional rain and / or river gauges would not be sufficient. The following section outlines how each of the TFWS elements could be addressed in order to implement an appropriate, functional and sustainable flash flood warning system. An integrated and complete system is proposed in Section 9.6. A staged approach to implementation of the proposed response to each TFWS element, aimed at achieving balanced TFWS growth along with early and best benefit as quickly as possible, is presented in Section 9.7. Indicative costings are provided in Section 9.8.

9.5.4 Data Collection and Collation

9.5.4.1 Introduction

There is a variety of equipment available that will “collect” rain and river level data and make it available to a single entity or to a group of entities, either from the site, through a post box or delivered to a predetermined address. There are a number, but fewer, systems that collect the data, make it available in the desired format at the desired location(s), provide an alert of likely flooding (i.e. detect or predict the likelihood of flooding) after checking the data against pre-determined criteria and that also quality check and collate the data so that it is ready for use. Some of these systems are “turn key” while others are user built. All are modular in that fault-fix maintenance is generally via component plug-out / plug-in and expansion easy to achieve. However, rather than introduce a new "type" of equipment to the Wimmera catchment, it is proposed that any new equipment should be of the same "type" as installed in recent times at other data collection sites within the Wimmera catchment.

9.5.4.2 Event Reporting Radio Telemetry System

Event-Reporting Radio Telemetry System (ERTS) equipment has been installed at a number of sites across Victoria and more specifically in the Wimmera catchment. Base stations are operational at agreed local offices (e.g. the Wimmera CMA's office in Horsham) and at the Bureau of Meteorology's office in Melbourne. All base stations host BoM supplied and maintained Enviromon software. This software manages all the data checking, collation and alerting functions.

Each ERTS flood monitoring system installation sends a signal by radio to one or more base stations every time there is a change in state of the parameter being measured – each increment of rainfall (can be 0.2mm, 0.5mm or 1mm) and a predetermined rise in stream level (usually every 10mm).

Quality and other checks are performed automatically against pre-determined parameters (threshold checking and alerting) on the data as it is received in real-time at each base station. These checks include a comparison of rainfall and river level data received from each of the stations against a pre-set rainfall amount in a specified time period and / or against a pre-set river level threshold. The values selected reflect typical catchment response times as well as catchment and stream characteristics. For the Upper Wimmera catchment, a useful rainfall trigger may be the rainfall intensity over the time of concentration for the catchment or the critical duration that produces the first overbank flows in the vicinity of the nearest downstream at-risk location. Any creek height thresholds would be set based on consideration of a range of factors particular to each gauge location. Trigger values can be adjusted based on experience so that alarms do not trigger unnecessarily or too often but do provide sufficient lead time on a potential flood event.

The local base station can be programmed to initiate an SMS message to the mobile phone (or pager) of key personnel as soon as the trigger value is exceeded. The SMS alert provides a "heads up" to a possible flash flood event. It is aimed at flagging the need for people to more closely monitor rainfall and other flood indicators (e.g. continuing heavy rain and other local indicators of a developing flood, including radar imagery and rainfall data available from the BoM website, etc), and at enabling early activation of flood response and related plans in order to minimise the risk to life and property. For the Upper Wimmera catchment, the "heads up" would also provide the trigger to use the indicative quick look "flood / no-flood" tools developed for the area and included as an Appendix in the Ararat, Northern Grampians and Pyrenees Council MFEPs.

A more detailed explanation of ERTS systems and their benefits when used in flash flood situations is provided by Wright (1994).

9.5.4.3 Possible Additional Data Collection Sites

There are three (3) ERTS rain gauges within the Upper Wimmera catchment (Navarre, Eversley and Ben Nevis) that provide data at a time scale suitable for flash flood warning purposes plus a further six rain gauges in the general vicinity (Moyston, Mt William, Avoca, Ararat and 2 in the vicinity of Stawell). All data is available from the BoM website.

The gauges provide an adequate temporal coverage for rainfall in the Upper Wimmera catchment. In the context of flash flood warning and with due consideration of where avoidable flood damage occurs (e.g. houses flood over-floor), the topography and likely flood producing weather mechanisms and conditions, the spatial coverage is considered to be less than ideal. As a consequence, there is an argument for improved coverage in the upper parts of the catchment upstream of Glynwylln with additional ERTS rain gauge installations as follows:

- In the general vicinity of Mt Avoca;
- Near the catchment boundary about midway between Frenchmans and Glenlofty and southeast of Landsborough (the BoM rain gauge site at Moonambel might be appropriate if no other site can be found in the area);
- Near Mt Langi Gharin; and
- In the vicinity of Tucker Hill to the east of Great Western.

Data from these sites should be captured by the base stations at the Wimmera CMA and BoM offices and displayed on the BoM website. While this will enable data to be accessed by the local community, it is suggested that Councils and the CMA consider whether there is a need to make data more available locally and how that might be achieved.

A further benefit of additional rain gauges across the Upper Wimmera catchment will be a more complete appreciation of the areal and temporal distribution of rainfall through the area. This could be expected to assist the flood forecasting task for Glenorchy.

The four (4) stream gauges already in place within the catchment (at Eversley, Crowlands, Navarre and Glynwylln) provide sufficient indication of flows likely to be experienced at Glenorchy when used in conjunction with recorded rainfall and a fully calibrated rainfall-runoff model. To install additional stream gauges to assist in the recognition and scaling of likely flooding at Glenorchy or of flash flooding within the catchment upstream of Glynwylln is not recommended. The latter occurs too quickly for stream levels to be used to drive flood response (i.e. the benefits would be very low – flooding would occur before damage reducing actions could be fully implemented) while the former is not a high priority given the capabilities of the current flood prediction model.

If additional stream gauges were to be installed, it is suggested they should be installed at locations immediately upstream of a township or road that experienced unacceptable disruption and on the upstream side of a suitable control, such as a culvert or bridge. Querying the hydraulic model developed for this project will deliver levels in mAHD at the proposed gauge location(s). Preliminary flood class levels could then be determined following an examination of both the flood intelligence contained in the MFEPs and the inundation and hazard mapping delivered by this project. The MFEPs should then be updated.

Note that even without the installation of the proposed additional rain gauges, the indicative quick look “flood / no-flood” tool developed as part of this project (refer to Ararat, Northern Grampians and Pyrenees Council MFEPs) will be able to be used with some lead time to provide an initial heads-up of the likelihood and scale of possible flooding at key locations within the catchment.

9.5.4.4 Manual Data Collection and Alerting

Recognising that funding may not be available (either now or into the future) to purchase, install and maintain additional ERTS rain gauges, it is not suggested that manually read rain gauges be deployed and locals co-opted to provide readings during heavy rain. There is insufficient time for this to occur with any certainty of success where success is deemed to be the provision of rainfall information and / or an indication of the scale of likely flooding to those likely to be affected with sufficient lead time to enable implementation of damage reducing actions.

9.5.5 Flood Detection and Prediction

An overview of flood warming services provided within Victoria by the Bureau of Meteorology is available at Appendix F.

There are currently no flood warning systems or arrangements in place for the Upper Wimmera catchment. As the catchment is subject to flash flooding (see Sections 9.5.1 and 0), the BoM will not be providing quantitative flood forecast for the affected areas / townships. However, the BoM will release public issue flood warnings containing current rain and river data (but no stream forecasts) following the exceedance (or expected exceedance) of flood class levels at stream level gauge sites.

In order to assist the warning process and increase awareness of flooding within the community, it is suggested that flood class levels should be established for all existing telemetered stream gauge sites in the Upper Wimmera catchment. When levels at these gauges exceed or are considered by the BoM likely to exceed each of the flood class levels, BoM would issue a warning advising of the expected class of flooding. This would go some way to increasing the likelihood that flood warnings would be broadcast when the consequences of flooding within the generally vicinity of the gauges are sufficient to warrant a warning and also to increasing local awareness along with an appropriate response.

Flood class levels, determined against standard definitions[5] are used to establish a degree of consistency in the categorisation of floods. Using the flood intelligence and inundation maps generated by the Upper Wimmera Flood Investigation (refer to the Hydrology report and also to the MFEP), preliminary flood class levels are proposed for Navarre, Eversley, Crowlands and Glynwylln as follows:

- Navarre:
  - Minor flood level 227.700 m AHD
  - Moderate flood level 227.900 m AHD
  - Major flood level 227.950 m AHD
- Eversley:
  - Minor flood level 264.000 m AHD

[5] Standard definitions for minor, moderate and major flood class level are available from the Bureau's website.

  - Moderate flood level 264.900 m AHD
  - Major flood level 265.250 m AHD
- Crowlands:
  - Minor flood level 246.300 m AHD
  - Moderate flood level 246.500 m AHD
  - Major flood level 246.600 m AHD
- Glynwylln:
  - Minor flood level 192.400 m AHD
  - Moderate flood level 193.000 m AHD
  - Major flood level 193.600 m AHD

The quick look “flood / no flood” tool provided in an Appendix to the Ararat, Northern Grampians and Pyrenees Council MFEPs does provide some guidance on possible flooding at key locations within the Upper Wimmera catchment. Rainfall depths from the upper parts of the catchment upstream of Glynwylln and from the general vicinity of the location are used in the tool to determine the likelihood and severity of flooding through a link to the flood inundation maps delivered as part of the Upper Wimmera Flood Investigation. It is suggested that the inundation maps, quick look tool and associated instructions for its use should be loaded to the Ararat, Northern Grampians and Pyrenees Council websites where they can be accessed by and used by members of the at-risk communities.

9.5.6 Interpretation

The flood inundation maps and MFEP Appendices developed as part of the Upper Wimmera Flood Investigation provide the base information to enable the community and stakeholder agencies to determine the likely effects of a potential flood. This means however that the flood inundation maps and relevant MFEP Appendices would need to be readily available to the Upper Wimmera catchment communities. Without this the proposed flash flood warning system would be severely compromised.

9.5.7 Message Construction and Dissemination

9.5.7.1 Alerting and Notification

According to Rogers and Sorensen (1988), warning people of impending danger encompasses two conceptually distinct aspects—alerting and notification. Alerting deals with the ability of emergency officials to make people aware of an imminent hazard. Alerting frequently involves the technical ability to break routine acoustic environments to cue people to seek additional information. In contrast, notification focuses on how people interpret the warning message. It is the process by which people are provided with a warning message and information.

There are a number of alerting and notification tools and technologies available, some of which both alert and notify (Molino et al, 2002).

As a simple and largely community driven flash flood warning system that builds on the basic TFWS elements that are already in place is being proposed, it is suggested that, at this stage and in view of the rapid onset of flooding following heavy rain on a wet catchment, there is little to be gained by investing in message construction and dissemination approaches and / or equipment.

The alert will come from environmental indicators (i.e. heavy rain) and the notification from application of the quick look "flood / no flood" tool (i.e. likely severity and impact of expected flooding). This will be reinforced by public issue flood warnings from the BoM (i.e. direct to agencies and to communities via radio) when stream levels exceed (or are considered likely to exceed) the flood class levels established for each gauge site.

The message in relation to likely consequences and required actions will be as derived by the individual (or group – see Section 9.5.7.2) as a result of their consideration of information provided by the tool, the MFEP and the flood inundation maps.

It is appropriate to note that the national Emergency Alert (EA) system provides VICSES with a means of delivering short messages to selected areas. While the EA has application for all emergency situations, it is unlikely for a number of reasons to be used during smaller flood events. It may also not be suitable as a means of warning communities in the Upper Wimmera catchment of severe flash flooding events due to the short lead times available.

9.5.7.2 Community Involvement

It is generally recognised that a critical issue in developing and maintaining a (flash) flood warning system is the active and continued involvement of the flood-liable community in the design and development of the total system so that their warning needs are satisfied. It is therefore suggested that the three Councils (Ararat, Northern Grampians and Pyrenees) give strong consideration to championing the formation of a community flash flood action group (or similar). Members of this group could perhaps play a key role in local flash flood warning operations.

Community members should recognise that VICSES is the Control Agency for flood and should always follow directions or instructions issued by the Incident Controller.

9.5.8 Response

The Pyrenees, Ararat and Northern Grampians MFEP Appendices have been populated for the Upper Wimmera catchment as part of the Upper Wimmera Flood Investigation. Information in the MFEP includes all available intelligence relating to flooding in the Wimmera catchment upstream of Glynwylln along with indicative quick look "flood / no-flood" tools based on local and upper catchment rainfall depths. Flood inundation extent and depth maps are included together with a list of properties likely to be flooded and the expected depth of that flooding (including over-floor depth) at each property. A flood intelligence card has also been prepared.

The two most critical issues for the Upper Wimmera catchment are:

- Isolation and lack of access as a result of roads being flooded; and
- The over-floor flooding of a small number of buildings: one in each of Warrak and Wattle Creek beginning a little below the 2% AEP (50-year ARI) flood level and one in each of Warrak, Wattle Creek and Nowhere Creek by the 1% AEP (100-year ARI) flood.

9.5.9 Community Flood Awareness

Following is a list (not exhaustive) of some of the more common misconceptions held by people who live in flood-prone areas. These misconceptions often act as a major barrier to improving flood preparedness and awareness within the community and thus hinder efforts to minimise flood damages and the potential for loss of life.

- The largest flood seen by the community / individual is often confused with the maximum possible flood (i.e. the next flood couldn't be bigger). This idea becomes more entrenched the bigger the flood witnessed previously. The January 2011 flood is now the largest on record (in living memory) for much of the Upper Wimmera catchment.
- Areas that haven't flooded before will not flood in the future. This is an extension of the first bullet point.
- The stream cannot be seen from the house so the house couldn't possibly be at risk of flooding.
- A levee designed to hold the 1% Annual Exceedence Probability (AEP) flood will protect the community from all floods and therefore a flood warning system is not required.
- The 1% AEP flood (i.e. the 100-year ARI flood), once experienced, will not occur for another 100 years.
- The statistics and estimates that underpin hydrology are exact.

Studies repeatedly show that communities that are not aware of flood hazard are less capable of responding appropriately to flood warnings or alerts and experience a more difficult recovery than a flood-aware community. Plain language flood awareness campaigns[6] should aim to erase these misconceptions

There are a number of activities that could be initiated to maintain and renew flood awareness across the Upper Wimmera catchment. The emphasis should be on an awareness of public safety issues (including the flash flood monitoring system) and on demonstrating what people can do to stay safe and protect their property from flooding. Typical initiatives include:

- Making the MFEP publicly available (Council offices, library, website) with a summary provided in Council welcome packages for new residents and business owners and with annual rate notices;
- Championing a community flash flood action group;
- Periodically providing feature articles to local media on previous flood events and their effects on the community;
- Installing flood markers indicating the heights of previous floodwaters (e.g. on power poles, street signs, public buildings, sides of bridges, etc);
- Preparing and distributing property specific flood depth charts for all buildings likely to be affected by flooding within the Upper Wimmera catchment (the data to inform the charts can be

6 Such as the VICSES Local Flood Guide program.

extracted from the spreadsheet of results produced by the hydraulic model developed for the Upper Wimmera Flood Investigation and summarised in the Ararat, Northern Grampians and Pyrenees Council MFEPs);

- Installing flood depth indicators along the edge of roads where there is an appreciable danger to human life due to flood depth and / or velocity (e.g. at strategic locations as indicated by the flood hazard maps delivered by the Upper Wimmera Flood Investigation);
- Photo displays of past flood events in local venues (these could be permanent); and
- Preparing and distributing (as an on-going program) a flash flood action guide or brochure (e.g. Local Flood Guide and as described by Crapper et al (2005), in relation to Shepparton and Mooroopna) aimed specifically at encouraging local residents and businesses to take a pro-active role in preparing their property and themselves for a flood as well as describing what needs to be done during a flood event. These could be given out at local events and with council rate notices and / or other council communications.

9.6 A Solution for the Upper Wimmera Catchment

Table 9-2 provides a brief description of the basic tools needed to deliver against each TFWS building block together with an outline of possible solutions applicable to the Upper Wimmera catchment. The solution has regard for:

- The flash flood nature of the catchment and the very limited lead time available between heavy rain and stream rises;
- The character of the flood risk (i.e. a handful of houses are flooded over-floor with the first floor affected by a flood a little smaller than the 2% AEP event but access along many roads is affected from around the 20% AEP events and more severely from around the 10% AEP events);
- Economic metrics (the contribution of avoidable damages to the value of average annual damages is small); and
- Community feedback.

Table 9-2 Flash Flood Warning System Building Blocks and Possible Solution for the Upper Wimmera catchment with due regard for the EMMV, Commonwealth-State arrangements for flood warning service provision (BoM, 1987; VFWCC, 2001;EMA, 2009)

Flood Warning System Building Blocks	Basic Tools	Possible Solution for the Upper Wimmera catchment
DATA COLLECTION & COLLATION	Data collection network (e.g. rain and stream gauges)	Install up to 4 x new ERTS rain gauges. Priority: In the general vicinity of Mt Avoca; Near the catchment boundary about midway between Frenchmans and Glenlofty and southeast of Landsborough (the BoM rain gauge site at Moonambel might be appropriate if no other site can be found in the area); Near Mt Langi Gharin; and In the vicinity of Tucker Hill to the east of Great Western. No new stream gauges proposed.
	System to convey data from field to central location and / or forecast centre (e.g. radio or phone telemetry).	ERTS is a commercially available radio telemetry data collection system that reports any change in the parameter being measured by radio in real-time to a base station. A number of sites are already installed in the Wimmera catchment and a base station has been installed at the Wimmera CMA office. This base station as well as the BoM offices in Melbourne will receive data.
	Data management system to check, store, display data.	ENVIROMON – base station software provided and maintained by BoM. Will require BoM to add new rainfall sites to data tables accessible via the BoM website. Councils and CMA to consider whether there is a need to make data more available locally and how that might be achieved.
	Arrangements and facilities for system / equipment maintenance and calibration. For example, the Regional Surface Water Monitoring Partnership, data QA'ing and warehousing, etc.	Commercial arrangement between Councils / CMA and a service provider for maintenance. Ideally this would be achieved through the Surface Water Monitoring Partnership as that would also ensure that all data was QA'ed and archived. Include all capitalised system components on Councils' asset management register.
DETECTION & PREDICTION (i.e. Forecasting)	Rainfall rates and depths likely to cause flooding together with information on critical levels / effects at key and other locations.	<u>INITIALLY</u>: Using the tools described below together with data from nearby rainfall stations, individuals and agencies determine the likelihood and scale of possible flooding at key locations.

Flood Warning System Building Blocks	Basic Tools	Possible Solution for the Upper Wimmera catchment
	Appropriately representative flood class levels at key locations plus information on critical levels / effects.	Establish flood class levels at the four (4) existing stream gauge sites. LATER: In order to initiate local alerting of potential flooding, use rainfall rates and depths from the MFEP tools to set rainfall gauge alarm criteria. This will necessitate consideration of who should be alerted and what they should do following the alert.
	Flood forecast techniques (e.g. hydrologic rainfall - runoff model, stream flow and / or height correlations, simple nomograms based on rainfall).	The indicative quick look "flood / no-flood" tools developed for key locations within the Upper Wimmera catchment and included in the Ararat, Northern Grampians and Pyrenees MFEPs provide guidance on the likelihood and scale of possible flooding. Councils responsible for maintaining the tools. Ratify how the tools are to be used and who by – Council, VICSES, WCMA and community.
INTERPRETATION (i.e. an ability to answer the question "*what does this mean for me - will I be flooded and to what depth*".	Interpretative tools (i.e. flood inundation maps, flood information cards, flood histories, local knowledge, flood response plans that have tapped community knowledge and experience, flood related studies and other sources, etc).	Deliverables and intelligence arising from the Upper Wimmera Flood Investigation have been captured to the Ararat, Northern Grampians and Pyrenees MFEPs. This includes flood extent, depth and hazard mapping together with information about which properties are likely to experience over-ground and over-floor flooding along with the expected depth of that flooding. The quick look tools (see above) together with the MFEP enable those at risk to determine, with some lead time, whether they are likely to be flooded and how regional access might be affected. In order to enable community members to determine the likely effects of a potential flood, Councils to make the flood inundation maps and relevant Appendices of the MFEP readily available to the Upper Wimmera catchment communities. This will also inform their development of individual flood response plans (see below). If and after additional rain gauges have been installed, Councils to review the quick look tools to ensure that the tools are making best use of available data. Councils to periodically (and after each major flood event) review the quick look tools and update / refine as necessary as part of maintaining a strong awareness of and engagement in the FFWS and its continuous improvement.

Flood Warning System Building Blocks	Basic Tools	Possible Solution for the Upper Wimmera catchment
MESSAGE CONSTRUCTION	Warning messages / products and message dissemination system.	Short hydrologic response time, hence simple automated messaging is likely to work best, if required. However, as the proposed FFWS is heavily community driven with minimal agency input and with the main issue being loss of access through the region, there are very limited opportunities (in the context of current warning technologies and local infrastructure) to implement a system that would be timely, sufficiently informative and cost effective. Following the exceedance (or expected exceedance) of flood class levels at stream level gauge sites within the catchment, BoM will release public issue flood warnings containing current rain and river data but no stream forecasts. In severe flood situations, the Emergency Alert would be used to disseminate critical information and key messages.
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	Formal media channels[7] – TV, radio and print.	If considered beneficial, Councils to establish and champion a community flash flood action groups(s) and ensure that terms of reference are appropriate and agreed. Environmental indicators (i.e. heavy rain), public issue flood warnings from the BoM and awareness following application of the quick look "flood / no flood" tool (i.e. likely severity and impact of expected flooding) will alert individuals to likely flooding. This alert will be shared within the community, either informally or more formally through the flash flood action group(s). Likely consequences and required actions will be as derived by the individual (or group) as a result of consideration of information provided by the quick look tool, MFEP and flood inundation maps.
	Fax / faxstream, phone / pager (e.g. SMS, voice), voice messaging systems (e.g. Xpedite), tape message services, community radio, internet (e.g. BoM & VICSES websites, email, social media), national Emergency Alert system.	
	Flood wardens	
	Door knocking	
	Informal local message / information dissemination systems or "trees".	

[7] ABC Radio has entered into a formal agreement with the Victorian Government and the Bureau of Meteorology to broadcast, in full, weather related warnings including those for flood. The agreement provides for the interruption of normal programming at any time to allow the broadcast of warning messages. This agreement will ensure that flood (and other) warnings issued by the Bureau are broadcast in their entirety and as soon as possible after they are received in the ABC's studio.

Flood Warning System Building Blocks	Basic Tools	Possible Solution for the Upper Wimmera catchment
	Opportunity for at-risk communities to confirm warning.	BoM issues flood warnings (based on exceedance of flood class levels) to the media and agencies including VICSES. VICSES as the Control Agency for flood also issue flood warning messages that include more detailed information including flood consequences to the media and to a wider audience via the electronic media, websites and social media. LATER: Consider establishing threshold criteria for each rain gauge and initiating an SMS (or similar) alert in order to achieve more lead time on possible flooding. Will require a more formal involvement of Councils / CMA in the FFWS and a more formal community structure for receiving and communicating the alert within communities. This could comprise a local (smart) phone-based information dissemination tree. Alternative alerting mechanisms should be investigated.
RESPONSE	Flood management tools (e.g. MFEP complete with inundation maps and "intelligence", effective public dissemination of flood information, local flood awareness, individual and business flood action plans, etc). Flood response guidelines and related information (e.g. Standing Operating Procedures). Comprehensive use of available experience, knowledge and information.	Evacuation arrangements / planning (Appendix E of the MFEP) remain to be completed. The MFEPs remains to be reviewed and signed-off by Council MEMPCs. Initiate a community engagement program to communicate how the FFWS will work. Response is largely individually determined and driven. Following (or perhaps in concert with) acceptance of the MFEP, encourage and assist residents and businesses to develop individual flood response plans. A package that assists businesses and individuals is available from VICSES and provides an excellent model for community use.
REVIEW	Post-event debriefs (agency, community), etc. Data from Rapid Impact Assessments. Flood "intelligence" and flood damage data from the event collected by residents, Council, Wimmera CMA, etc. Review and update of personal, business and other flood action plans.	Review and update of alarm criteria (if established), local flood intelligence (i.e. flood characteristics, impacts, etc), local alerting arrangements, response plans, local flood awareness material, etc (initially) after every (major) flood. Best done by Councils with input from VICSES, Wimmera CMA and (if established) the Council championed community flash flood action group(s). Councils to develop review and update protocols => who does what when and process to be followed to update material consistently across all parts of the flash flood warning and response system, including the MFEP. Ensure that as part of the above, information contained in Rapid Impact Assessments is captured to the MFEPs.

Flood Warning System Building Blocks	Basic Tools	Possible Solution for the Upper Wimmera catchment
AWARENESS	Identification of vulnerable communities and properties (i.e. flood inundation maps, information on flood levels / depths and extents, etc).	Studies repeatedly show that communities that are not aware of flood hazard are less capable of responding appropriately to flood warnings or alerts and experience a more difficult recovery than a flood-aware community. Thus, the emphasis of activities that aim to maintain and renew flood awareness across the Upper Wimmera catchment should be on an awareness of public safety issues and on demonstrating what people can do to stay safe and protect their property from flooding. Flood intelligence delivered by the Upper Wimmera Flood Investigation has been captured to MFEPs. Develop, print and distribute flood awareness material (Local Flood Guide, property specific flood depth charts, etc), including information on how the FFWS operates, using information collated for the MFEP and available within the Upper Wimmera Flood Investigation report and more generally from the web. Councils to make the MFEPs (including the quick look tool, inundation and hazard maps, etc) publicly available (Council offices, library, website) with a summary provided in Council welcome packages for new residents and business owners and possibly also with annual rate notices. Councils to load and maintain other flood related material on their websites with appropriate links to relevant useful sites (e.g. the Flood Victoria website http://www.floodvictoria.vic.gov.au/centric/home.jsp). Routinely revisit and update awareness material to accommodate lessons learnt, additional or improved material and to reflect advances in good practice. Establish and implement protocols for routinely repeating distribution of flood awareness material. Decide whether to alert residents and visitors to the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at strategic locations along the region's roads (e.g. as indicated by the flood hazard maps delivered by the Upper Wimmera Flood Investigation).
	Activities and tools (e.g. participative community flood education, flood awareness raising, flood risk communication) that aim to build flood resilient communities (i.e. communities that can anticipate, prepare for, respond to and recover quickly from floods while also learning from and improving after flood events).	
	Community education and flood awareness raising including VICSES FloodSafe and StormSafe programs.	
	Local flood education plans – developed, implemented and evaluated locally (e.g. Cities of Maroondah, Whitehorse, Wodonga, Benalla and Greater Geelong).	
	Flood response guidelines, residents' kits, flood markers, flood depth indicators, flood inundation maps and property listings, property specific flood depth charts, flood levels in meter boxes and on rate notices, etc for properties identified as being subject to flooding through the Upper Wimmera Flood Investigation.	

9.7 Suggested Actions Aimed At Improving the TFWS

The availability of "best possible" and timely information on rainfalls and the rapid and easy translation of that information to likely on-ground impacts and the good health of all TFWS elements are fundamental to delivery of an effective flash flood warning system.

A staged approach to the development of an effective flash flood warning system for the Upper Wimmera catchment is proposed. The stages have been ordered and the tasks within each stage grouped to facilitate incremental growth of the TFWS elements in a balanced manner and with full regard for community feedback received as part of this project.

All activities associated with an earlier stage do not necessarily have to be fully completed before activities in subsequent stages are started. Commitment and community engagement are however key to each stage. A timetable and priorities have not, at this stage, been attached to any of the suggested actions.

Stage 1

(1) Councils with the support of VICSES, Wimmera CMA and the Upper Wimmera catchment communities to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements of a TFWS for the catchment.

Stage 2

(1) Wimmera CMA in conjunction with BoM to identify and verify appropriate locations for new ERTS rain gauges in the upper part of the Upper Wimmera catchment. Preliminary work will need to include radio path testing. Long term maintenance, data archival and other responsibilities will need to be agreed before equipment is ordered. Suggested priority for the sites is as follows:

(a) In the general vicinity of Mt Avoca;

(b) Near the catchment boundary about midway between Frenchmans and Glenlofty and southeast of Landsborough (the BoM rain gauge site at Moonambel might be appropriate if no other site can be found in the area);

(c) Near Mt Langi Gharin; and

(d) In the vicinity of Tucker Hill to the east of Great Western.

Note that the Charlton Flood and Drainage Study recommended the installation of a telemetered rain gauge on the western side of the Avoca River either in the area about midway between Avoca and Navarre or in the area midway between but a little to the north of a line drawn between Archdale and Navarre. Depending on the exact location of the site and the likelihood of installation, it is possible that this gauge may reduce the need to install a new rain gauge at the second listed site above.

(1) As soon as possible after the equipment is fully operational, BoM to ingest rainfall data from these new telemetered rain gauges so that it is available to the community from the BoM website via bulletins, data tables and other related products.

(2) Councils through VICSES to formally request BoM to establish flood class levels for the four (4) existing stream gauge sites in the Upper Wimmera catchment. Suggested flood class levels are provided below.

- Navarre:
  - Minor flood level 227.700 m AHD
  - Moderate flood level 227.900 m AHD
  - Major flood level 227.950 m AHD
- Eversley:
  - Minor flood level 264.000 m AHD
  - Moderate flood level 264.900 m AHD
  - Major flood level 265.250 m AHD
- Crowlands:
  - Minor flood level 246.300 m AHD
  - Moderate flood level 246.500 m AHD
  - Major flood level 246.600 m AHD
- Glynwylln:
  - Minor flood level 192.400 m AHD
  - Moderate flood level 193.000 m AHD
  - Major flood level 193.600 m AHD

(1) Following the adoption of flood class levels, plan and implement a joint comprehensive information campaign from BoM, VICSES, Councils and Wimmera CMA aimed at informing the Upper Wimmera catchment community of the changes. The MFEPs will also need to be edited.

Stage 3

(1) Councils and Wimmera CMA to ratify how the indicative quick look “flood / no flood” tools are to be used and who by.

(2) If considered beneficial by Councils (and communities), Councils to establish and champion a community flood action groups(s) and ensure that terms of reference are appropriate and agreed.

Stage 4

(3) Councils and VICSES with input from others as required, to populate the “required actions” column of the Flood Intelligence Cards within the Ararat, Northern Grampians and Pyrenees MFEPs.

(4) Councils, VICSES and VICPOL to complete the documentation / planning of evacuation arrangements for the Upper Wimmera catchment communities (Appendix E of the MFEPs).

(5) If and after additional rain gauges have been installed, Councils to review the quick look tools to ensure that the tools are making best use of available data.

Stage 5

(1) Following formal adoption of the MFEPs, Councils to make the flood inundation and hazard maps, relevant Appendices of the MFEP and the indicative quick look “flood / no flood” tools publicly available (Council offices, library, website) in order to assist community members (and stakeholder agencies) determine the likely effects of a potential flood and inform their development of individual flood response plans.

(2) Councils to consider including flood related information in (say) Council welcome packages for new residents and business owners and also perhaps with annual rate notices.

(3) Councils to consider loading and maintaining other flood related material on their websites with appropriate links to relevant useful sites (e.g. the Flood Victoria website http://www.floodvictoria.vic.gov.au/centric/home.jsp).

Stage 6

(1) VICSES to initiate a community engagement program across the Upper Wimmera catchment aimed at communicating how the (flash) flood warning system will work along with evacuation arrangements. This may need to be repeated as the TFWS continues to mature.

Stage 7

(1) Councils to develop, review and update protocols in conjunction with VICSES and with input from Wimmera CMA and other stakeholders as required => who does what when and the process to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP, quick look tools and personal / business flood action plans. This should include the capture of information contained in Rapid Impact Assessment reports.

(2) Stage 8

(1) Councils to consider the preparation and distribution of property specific flood depth charts and / or meter box flood level stickers for each building within the Upper Wimmera catchment subject to over-ground flooding up to and including the 200-year ARI event. The data to inform the charts can be extracted from the spreadsheet of results produced by the hydraulic model developed for the Upper Wimmera Flood Investigation.

(2) Councils in conjunction with VICSES, to consider periodically providing feature articles to local media on previous flood events and their effects on the community. This could extend to establishing photo displays of past flood events in local venues (these could be permanent).

Stage 9

(1) Councils to encourage and assist residents and businesses to develop individual flood response plans following (or perhaps in concert with) formal adoption of the MFEPs.

Stage 10

(1) VICSES in consultation with Council to establish protocols for routinely reviewing, updating and repeating distribution of flood awareness material, particularly the Local Flood Guides.

(2) Councils to decide whether to alert residents and visitors to the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at strategic locations along the region's roads where there is appreciable danger to human life due to flood depth and / or velocity (e.g. as indicated by the flood hazard maps delivered by the Upper Wimmera Flood Investigation).

Stage 11

(1) Councils in conjunction with VICSES and Wimmera CMA, to consider establishing threshold criteria for each rain gauge and initiating an SMS (or similar) alert in order to achieve more lead time on possible flooding. This will necessitate a more formal involvement of Councils / CMA in the FFWS and a more formal community structure for receiving and communicating the alert within communities. This could comprise a local (smart) phone-based information dissemination tree. Alternative alerting mechanisms should be investigated.

9.8 Estimated costs for the FFWS

The following table provides indicative costs associated with the implementation and on-going operation of each of the TFWS elements proposed for the Upper Wimmera catchment flash flood warning system as discussed above.

Table 9-3 Estimated cost associated with implementation of the Flash Flood Warning System

Item	Estimated cost as at January 2014 (excl GST)	Comments
In-kind estimates developed using at-cost (not commercial) rates for time, consumables, etc		
Data Collection and Collation		
Input from BoM, comprising assistance with site selection, radio path testing and advice on necessary and appropriate equipment for the 4 x ERTS rainfall only stations – see below.	In-kind estimate ~$6,000 total	Subject to operational and other workloads.

Item	Estimated cost as at January 2014 (excl GST)	Comments
4 x ERTS rain only installations. Includes steel instrument housing, BoM spec TBRG, ERTS canister, logger, solar panel, antenna, cabling.	$14,000 per site	Cost covers supply, installation and commissioning of equipment and the establishment of long term maintenance and data archival arrangements. It also includes estimated allowances for cultural heritage assessment and service checks and marking at site. Possible opportunity to partner with Avoca flood warning system partners on the 2nd priority installation and as a result to reduce costs.
Recurrent costs: ERTS rain only site.	$2,000/year/site	Indicative costs only and dependent on the work scope and whether the sites are brought into the Surface Water Monitoring Partnership.
Ingest data to BoM and display data via website bulletins, data tables and other related products	In-kind estimate ~$500 total	Timing subject to operational and other workloads.
Flood Detection and Prediction		
Establish flood class levels for the 4 x existing stream gauging sites.	In-kind estimate ~$1,500 total across all agencies	Expenditures relate to time costs. Timing subject to operational and other workloads
Councils and Wimmera CMA to ratify how the indicative quick look “flood / no flood” tools are to be used and who by.	In-kind estimate ~$2,000 total across all agencies	Expenditures relate to time costs. Timing subject to operational and other workloads
The indicative quick look “flood / no-flood” tools together with the MFEP enable those at risk to determine whether they are likely to be flooded with some lead time.	In-kind estimate ~$3,000/flood	MFEP intelligence will need to be updated following flooding in the Upper Wimmera catchment.
The indicative quick look “flood / no-flood” tools developed for the Upper Wimmera catchment will be used to determine the likelihood and scale of possible flooding.	In-kind estimate ~$500/flood	Councils to maintain the tools. This could be done by plotting flood producing rainfall events and resulting flooding on the chart along with the event date. This may allow some refinement of the tool over time.
Interpretation		

Item	Estimated cost as at January 2014 (excl GST)	Comments
Make relevant parts of the MFEP and flood inundation and related mapping available to the Upper Wimmera catchment communities.	In-kind estimate ~$3,000	Councils to work with communities on how best to achieve access.
The indicative quick look “flood / no-flood” tool together with the MFEP enable those at risk to determine whether they are likely to be flooded with some lead time.	Costed above	MFEP intelligence will need to be updated following flooding in the Upper Wimmera catchment.
Message Construction and Dissemination		
Councils to champion and oversee the establishment of a flash flood action group(s)	In-kind estimates ~$5,000 to set up ~$500/y ongoing	Will need to clearly establish the role for the group(s) along with authority and structure. VICSES should be invited to be involved in setting up the group(s). Liability issues in relation to the provision of advice by group members, and on which community members may rely and act, need to be considered and resolved.
Response		
Councils, VICSES and VICPOL to complete the documentation / planning of evacuation arrangements for the Upper Wimmera catchment communities (Appendix E of the MFEPs)	In-kind estimate ~$2,000 per MFEP	A required element of the MFEPs.
Councils and VICSES, with input from others as required, to populate the “required actions” column of the Flood Intelligence Cards within the MFEPs.	In-kind estimate ~$2,000 per MFEP	A required element of the MFEPs.
Councils to share relevant parts of the MFEPs with the Upper Wimmera catchment communities.	In-kind estimate ~$500 per Council to set up	Will assist the implementation of an informed local response when it next floods.
Initiate a community engagement program to communicate how the FFWS will work.	In-kind estimate ~$3,000 to start ~$1,000 to repeat	VICSES with assistance from Councils Will need to be repeated as the system matures.
Encourage and assist residents and businesses to develop individual flood response plans.	In-kind estimate $500 to promote	Councils and VICSES.
Review and Keeping the System Alive		

Item	Estimated cost as at January 2014 (excl GST)	Comments
Post-event review and on-going maintenance of the system in order to keep it alive within the community (e.g. exercises to test procedures, website maintenance, asset replacement, operational costs, involvement with a community flash flood action group(s) and so on). Assuming that replacement spares were purchased as part of the initial capital investment, asset replacement expenses are considered to be included in site recurrent costs.	In-kind estimate ~$2,000/year for activities. Operational costs are absorbed into incident management activities.	Costs will vary year to year and will depend on rainfall and seasonal conditions.
Community Flood Awareness		
Following the adoption of flood class levels, plan and implement a joint comprehensive information campaign from BoM, VICSES, Councils and Wimmera CMA aimed at informing the Upper Wimmera catchment community of the changes.	Up to $5,000 but expected to be covered by other funding through VICSES	Cost will depend on how much of the work is out-sourced and how much is done by agencies as an in-kind contribution.
Develop and distribute a Local Flood Guide for Upper Wimmera catchment communities.	Up to $12,000 but expected to be covered by other funding through VICSES	Cost will depend on how much of the work is out-sourced and how much is done by VICSES as an in-kind contribution.
Load and maintain flood related material (including the MFEP) to Councils' websites.	In-kind estimate per Council ~$1,000 to cover initial load ~$500 ongoing	
Councils to develop, review and update protocols in conjunction with VICSES and with input from Wimmera CMA and other stakeholders as required => who does what when and the process to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP, quick look tools and personal / business flood action plans. This should include the capture of information contained in Rapid Impact Assessment reports.	In-kind estimate $5,000	Cost will depend on how much of the work is out-sourced.
Develop, print and distribute property specific flood depth charts for all buildings likely to be affected in the Upper Wimmera catchment.	$2,000	Cost will depend on how much of chart preparation is out-sourced.

Item	Estimated cost as at January 2014 (excl GST)	Comments
Install flood depth indicator boards at strategic locations along the region's roads where there is appreciable danger to human life due to flood depth and / or velocity (e.g. as indicated by the flood hazard maps delivered by the Upper Wimmera Flood Investigation).	~$500/board	Locations to be determined from hazard maps.

10 Floodplain Management

The purpose of this section is to introduce possible options for non-structural mitigation measures such as planning controls for the Upper Wimmera Flood Investigation catchment.

10.1 Flood Hazard

In determining the flood hazard within the Upper Wimmera a methodology was used that is designed to determine if it is safe for people and vehicles to move about during a flood event. Hazard is defined in terms of the depth and velocity-depth product of the flood water, as follows:

- Low Hazard – depth less than 400 mm and/or velocity x depth less than 0.4 m^2/s;
- Moderate Hazard - depth less than 800 mm and/or velocity x depth less than 0.8 m^2/s; and
- High Hazard - depth greater than 800 mm and/or velocity x depth greater than 0.8 m^2/s.

Due to the relatively flat nature of the study area and the broadness of the floodplain, there exists a mixture of flood hazard within the catchment. Generally the areas of broad floodplain are categorised as low hazard. Whilst the flooding is extensive in many areas it is generally shallow and slow moving. These areas would be best covered by the LSIO planning control.

Areas of high hazard are usually confined to the waterways. The hazard in waterways is usually due to the depth of the water rather than the velocity. However, where roads cross a waterway, there is often higher velocity due to constriction of the waterway and/or weir flow overtopping the road, therefore resulting in higher hazard. These areas are best suited to the FO planning control.

In the township of Navarre there is extensive flooding, however the hazard outside of main creeks is low. Both the depth and velocity of flood waters in the town is low and consequently the flood hazard is also low during the 1% AEP flood event.

Floodwaters pose little hazard to the townships of Landsborough or Elmhurst. Moderate and high hazard floodwaters are generally confined to the creek systems near the towns. However, road crossings into and out of the town at the creeks show high levels of hazard and therefore the towns may experience isolation due to the hazards along the roads until floodwaters recede.

10.2 Planning Controls

In the long term, one of the most effective means of flood mitigation is the establishment and enforcement of appropriate planning scheme controls in areas identified as at risk of flooding. Planning controls are effective over time as buildings are renewed they can be built in areas outside the floodplain, or if in an area of low flood risk, can be built above the declared flood level.

There exists a number of planning controls that are used within Victoria for ensuring appropriate development in and around flood waters. The most applicable for the Upper Wimmera catchment includes:

- Environmental Significance Overlay (ESO);
- Floodway Overlay (FO);

- Land Subject to Inundation Overlay (LSIO); and
- Special Building Overlay (SBO).

Consistent with the Department of Planning and Community Development's guidelines, it would be recommended to manage the Upper Wimmera catchment through a combination of Floodway and Land Subject to Inundation Overlays. This method allows development to occur within floodwaters deemed low risk but restricts development in high risk areas.

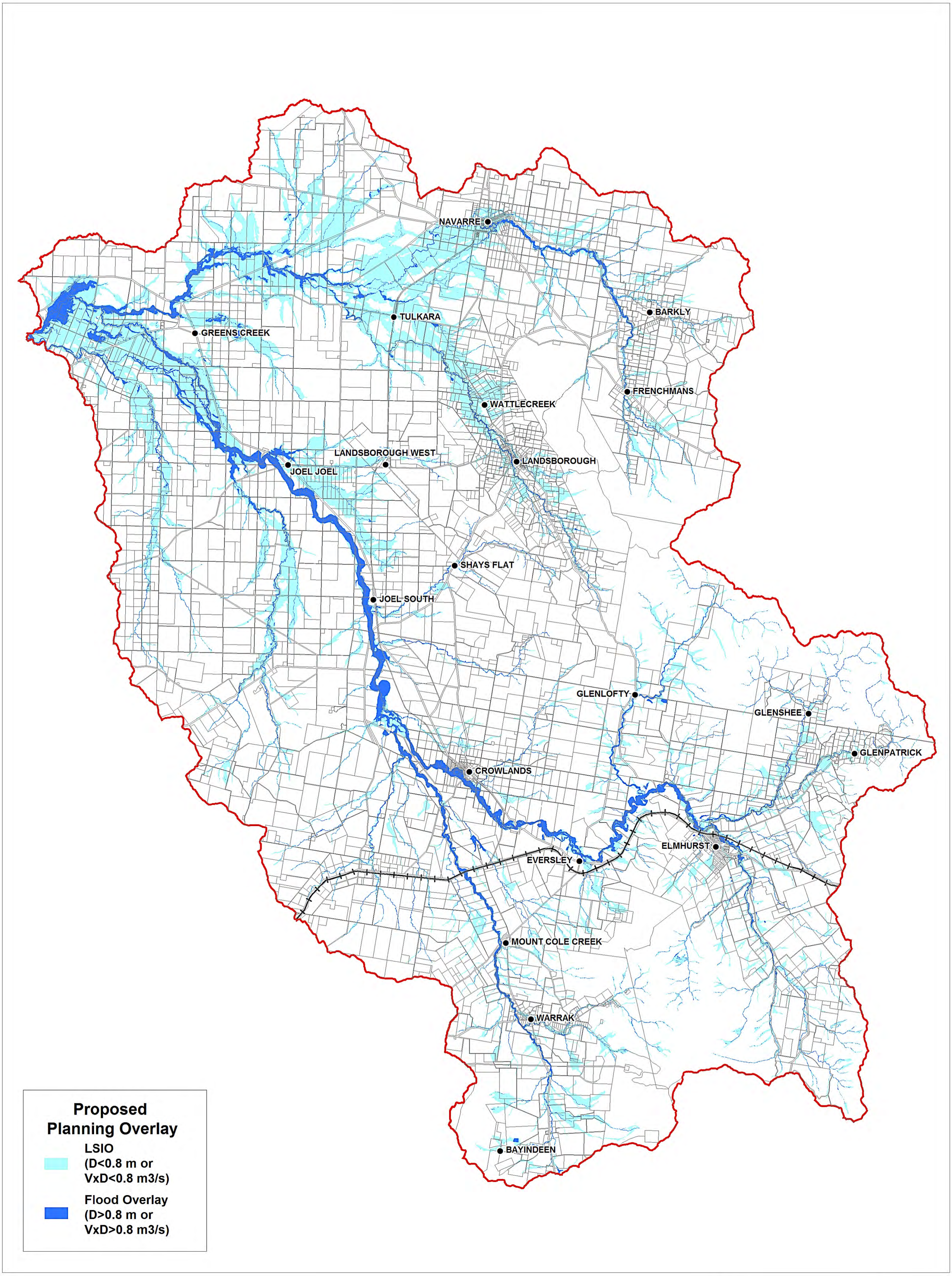
The proposed planning scheme for the Upper Wimmera River catchment is to assign areas identified as High Hazard to the more restrictive Floodway Overlay. Areas identified as Low or Moderate Hazard should be subjected to the less restrictive Land Subject to Inundation Overlay. The proposed planning scheme overlays are presented in Figure 10-1, Figure 10-2, Figure 10-3 and Figure 10-4 for the entire catchment, Navarre, Landsborough and Elmhurst respectively.

10.3 Declared Flood Levels

The 1% AEP flood levels determined by the flood modelling undertaken as part of the flood investigation were supplied to the WCMA, Northern Grampians Shire Council, Pyrenees Shire Council and Ararat Rural City Council. It is understood that these flood levels will be adopted as the Declared Flood Levels, as prescribed by Section 204 of the Water Act 1989. The mapped flood levels have a 1% chance of being equalled or exceeded in any one year.

10.4 Flood Response Plan

A Municipal Emergency Management Plan (MEMP) has been completed as part of the Upper Wimmera Flood Investigation and has been delivered to each of the three Councils within the catchment (Rural City of Ararat, Northern Grampians Shire Council and Pyrenees Shire Council) as a separate document.



Title:

Upper Wimmera Flood Investigation
Proposed Planning Controls - Catchment

Figure: **10-1**

Rev: **A**

N

0 3.75 7.5km
Approx. Scale

Wimmera Catchment Management Authority · Ararat Rural City · Northern Grampians Shire · Pyrenees Shire · Australian Government · State Government Victoria · BMT WBM

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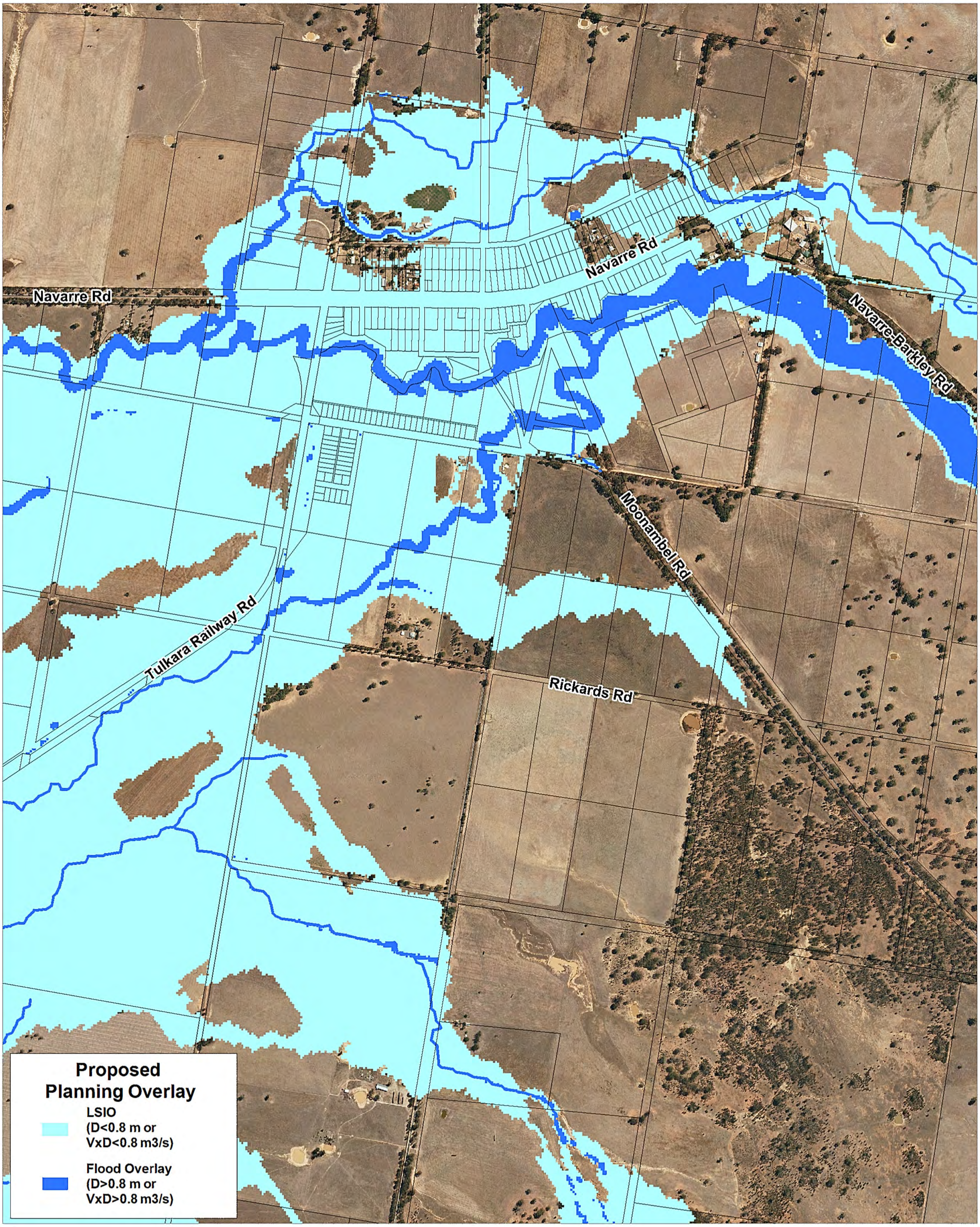

Title:

Upper Wimmera Flood Investigation
Proposed Planning Controls - Navarre

Figure: **10-2**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 250 500m
Approx. Scale

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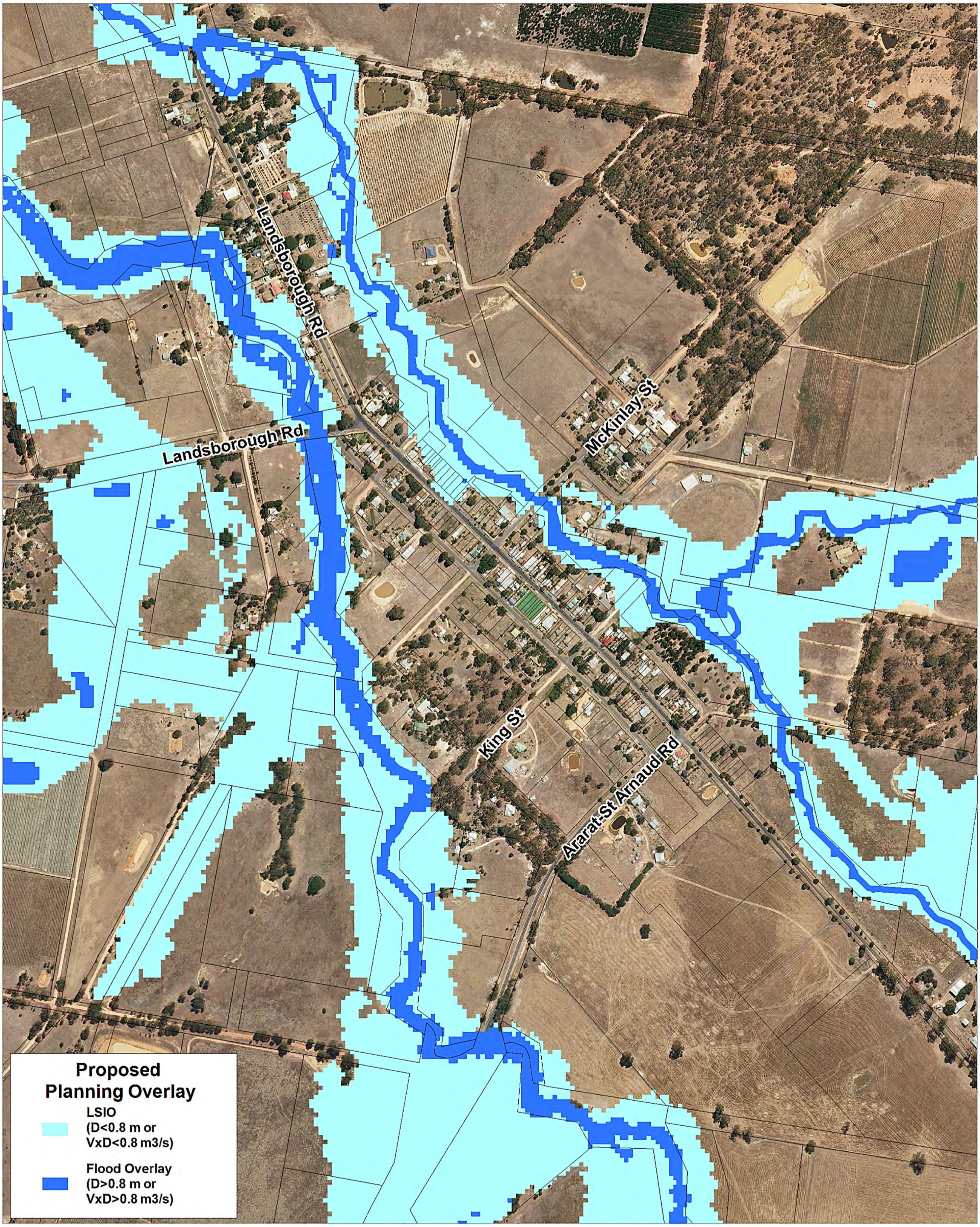

Title:

Upper Wimmera Flood Investigation
Proposed Planning Controls - Landsborough

Figure: **10-3**

Rev: **A**

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N

0 100 200m
Approx. Scale

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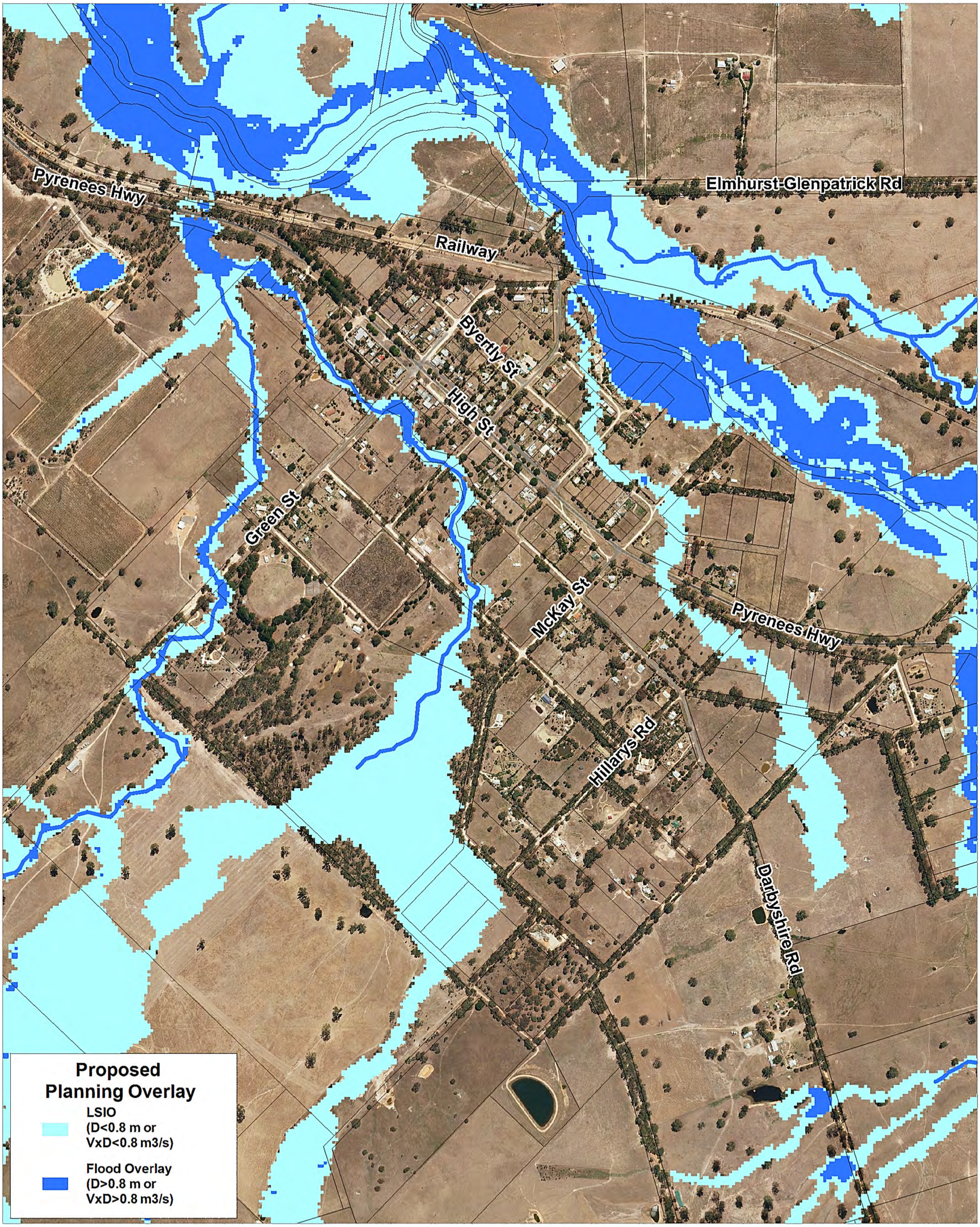

Title:

Upper Wimmera Flood Investigation
Proposed Planning Controls - Elmhurst

Figure: **10-4**

Rev: **A**

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N

0 200 400m

Approx. Scale

Filepath : T:\M8460.MT.WimmeraUpperFloodStudy\MapInfo\Drawings\R.M8460.009.01.Final\UW_Final_Fig10-4_E01_1%_051_Plan_Elmhurst_RevA.WOR

11 Summary and Recommendations

This report has documented the methodology and findings of the Upper Wimmera Flood Investigation. The investigation has defined the flood behaviour for the communities within the Upper Wimmera catchment through the development of calibrated hydrologic and hydraulics models and the determination of flood extents for a range of flood events. These models have been used to determine the flood damages within the catchment and to assess a number of structural mitigation options to alleviated flood risk. Additionally, a number of non-structural mitigation measures have been documents and recommended for adoption within the catchment.

The outcomes of the project have been presented to the Technical Steering Committee and the local communities through a series of public meetings throughout the life of the project. The involvement of the Technical Steering Committee and the local community has ensured that the outcomes of the project have been accepted the stakeholders.

Throughout the report, a series of recommendations have been made that will reduce the flood risk of the Upper Wimmera River catchment. These recommendations include:

- Implementation of Planning Scheme Controls (Section
- Upgrades to the Flood Warning System (Section
- Designated Flood Levels (Section

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