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Mount William Creek Flood Investigation

Final Report

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Mount William Creek Flood Investigation
Final Report

Prepared for:	Wimmera Catchment Management Authority
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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Synopsis:	**This final report documents the methodology and findings of the Mount William Creek Flood Investigation**	

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DISTRIBUTION

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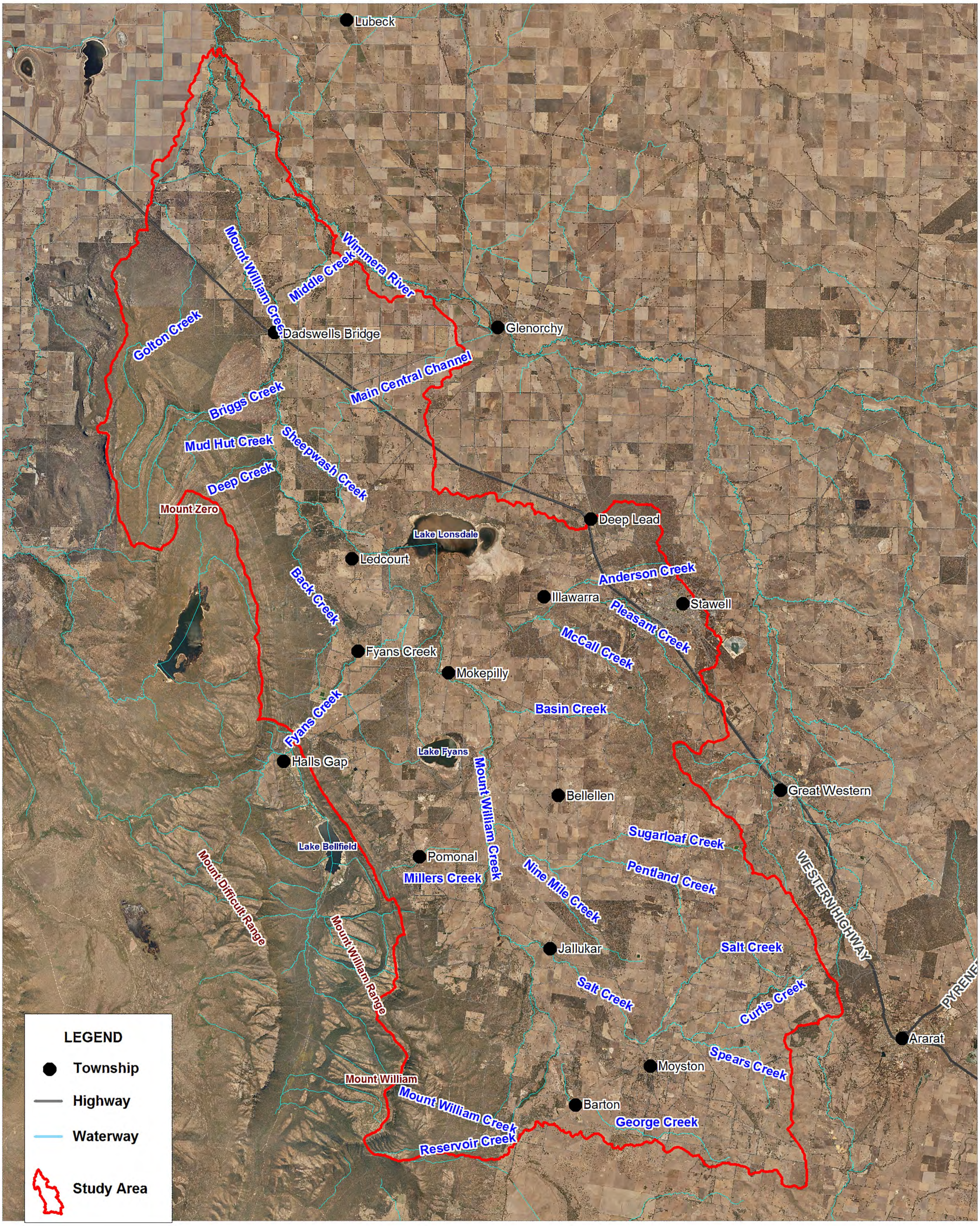
Executive Summary

This Executive Summary outlines the objectives, methodology and key outcomes of the Mount William Creek Flood Investigation. The investigation provides information on flood levels and flood risk within the Mount William Creek Catchment.

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 Mount William Creek 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 (WCMA), in partnership with the Department of Environment and Primary Industries (DEPI), Northern Grampians Shire Council (NGSC), Horsham Rural City Council (HRCC) and Ararat Rural City Council (ARCC) has commissioned this investigation.

The Mount William Creek Catchment has an approximate area of 1,450 km^2 and is located in Central West Victoria. The catchment includes a number of waterways, namely, Mount William Creek, Salt Creek, Fyans Creek, Pleasant Creek, Sheepwash Creek and Golton Creek along with their tributaries. The Wimmera River heavily influences the downstream reaches of the catchment. The majority of the catchment is used for agricultural purposes, predominately grazing. There are several townships within the catchment including Pomonal, Moyston, Stawell, Dadswells Bridge and Halls Gap (refer to Figure 1). However, whilst the township of Halls Gap is located within the Mount William Creek catchment, it will not be mapped as part of the current study as flood mapping has already been undertaken as part of the Halls Gap Flood Study (Water Technology, 2008). The catchment was subject to extensive flooding during 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.



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Mt. William Creek Flood Study
Study Catchment

Figure: 1

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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 (5, 10, 20, 50, 100 and 200 year recurrence intervals and Probable Maximum Flood) and including consideration for climate change;
- A review of Ararat Rural City Council, Horsham Rural City Council and Northern Grampians Shire Council Planning Scheme's current Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO) overlay in the existing planning scheme.;
- Preparation of digital and hard copy floodplain maps for the 1 in 100 year ARI 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 make recommendations regarding the flood warning system within the catchment;
- Provide Ararat Rural City Council, Horsham Rural City Council and Northern Grampians Shire Council with a revised flood response section of the Municipal Emergency Management Plan based upon the flood intelligence derived from the Study;
- 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; and
- Engage the community in all stages of the flood investigation to ensure that most appropriate outcomes are achieved.

Data Collection

As part of the Mount William Creek 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 Mount William Creek Flood Investigation.

Stakeholder Engagement

Community consultation was undertaken throughout the development of the Mount William Creek Flood Investigation. The consultation included a series of public meetings and through community surveys. Community meetings were held in Dadswells Bridge, Pomonal and Moyston. These information sessions were well attended by the local community who provided invaluable information on the history of flooding within the catchment. A large amount of reliable evidence of flood behaviour was provided by the community to check the outputs of the Investigation. Over 300 flood photos and 48 flood marks were provided by the local community to document the flooding that occurred during the January 2011 flood event, and other historic flood events within the catchment. The flood information provided by the residents was invaluable in the development of the study outcomes.

The WCMA formed a Steering Committee for the project which consisted of key stakeholders from WCMA, DEPI, GWM Water, Council, VicSES and the local community. The steering committee provided governance and management of the Investigation and ensured that issues important to the Mount William Creek 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 Mount William Creek 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 December 1992 flood event. To assess the impacts of flooding on the Mount William Creek catchment, the flood model was run for the following Annual Recurrence Interval (ARI) events: 5 year, 10 year, 20 year, 50 year, 100 year and 200 year, along with the Probable Maximum Flood (PMF) event.

A key factor influencing the model sensitivity is the starting water levels of the storages, Lake Lonsdale, Lake Bellfield and Lake Fyans. The project steering committee supported recommendations based on an analysis of historic water levels of storages at times of flood. The adopted starting water levels used for both Lake Belfield and Lake Fyans was full and the current operating level was used for Lake Lonsdale (53,300 ML, 187.12m AHD).

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 five gauges within the catchment has been undertaken using the FLIKE software. The results of the FFA for the Lake Lonsdale (Tail Gauge) gauge provided peak flow estimates for a given AEP event for Mount William Creek. The resulting peak flows verses return period at Lake Lonsdale (Tail Gauge) gauge are shown in Table 1.

Table 1 Mount William Creek at Lake Lonsdale (Tail Gauge): Flood Frequency Analysis Results

ARI	Expected Quantile (ML/day)	90% Quantile Probability Limits	
5	1628	1215	2238
10	3242	2284	5011
20	6105	3854	11707
50	13590	6934	37437
100	24576	10415	91644

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 Mount William Creek catchment to its confluence with the Wimmera River; an area of approximately 1,450 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.

Hydrologic analysis of the Mount William Catchment determined design flood hydrographs for the 0.5%, 1%, 2%, 5%, 10% and 20% AEP and the PMF. Extensive effort was put into deriving the most accurate catchment flood response by undertaking detailed hydrological modelling. Site based and regional flood frequency analysis were completed for gauges within the Mount William Creek and used to guide development calibration of a RORB model of the catchment. Initial RORB model parameters resulted in peak design flows that were consistently smaller than the flows derived by the flood frequency analysis methods. Consequently the loss values for the Fyans

Creek and Mokepilly areas were adjusted to improve the comparison between the RORB flows and the flood frequency derived peak flows. The adopted RORB peak flows are presented in Table 2.

Table 2 Comparison of 1 in 100 Year Peak Design Flows (ML/day)

Location	Site Flood Frequency Analysis	Regional Flood Frequency Analysis	RORB (Initial) Estimate)	RORB (adjusted loss parameters)
Mt William Creek @ Mokepilly	25,037	21,132	18,230	25,105
Fyans Creek @ Fyans Creek	11,932	14,861	9,850	11,801
Mt William Creek @ Lake Lonsdale (Tail Gauge)	24,576	35,960	24,451	33,076

Refer to section 4 for a detailed explanation of the method used to calibrate the RORB model. The calibrated RORB model was used to generate design inflow hydrographs for the hydraulic model within the Mount William Catchment.

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 Dadswells Bridge, Moyston and Pomonal modelled at a higher resolution than the surrounding floodplain by incorporating a fine grid 2D domain into the model. The model covers the entire Mount William Creek catchment.

The Mount William Creek TUFLOW model underwent a calibration process to fit the model to the observed data. The TUFLOW model was calibrated to the January 2011 flood event and validated against the December 1992 flood event. The results demonstrated that the flood model has been effectively calibrated and is suitable for undertaking modelling of existing conditions and flood mitigation scenarios.

January 2011 design flood estimates calibrated well with flood photos and flood levels for the Dadswells Bridge, St Helens Plains and areas downstream of Lake Lonsdale. Upstream of Lake Lonsdale highlighted significant discrepancies between observed data and initial design flood estimates. The areas of Stawell, Moyston, Jallukar and Pomonal were of particular concern. There was not enough flooding along Salt Creek and Mount William Creek resulting in lower flood heights and smaller flood extents in the vicinity of Moyston and Jallukar than that observed during January 2011. Several examples of where this occurred are provided in section 5.3.4.4 of this report.

Flood marks and photographs collected in the Jallukar region clearly highlighted the initial calibration of the January 2011 flood event was not adequately reproducing the flooding extents. Figure 1 shows the initial calibration (shown in red) compared with the final calibration (shown in blue). The initial model calibration shows flooding confined to Mount William Creek which does not extend into the surrounding floodplain. However flood photos and flood marks collected (pink dots) for the region show significant flooding in the area during the January 2011 flood event. Refer to figure 2 for photo 1 and 2. The location of where these photos were taken is shown in figure 1.

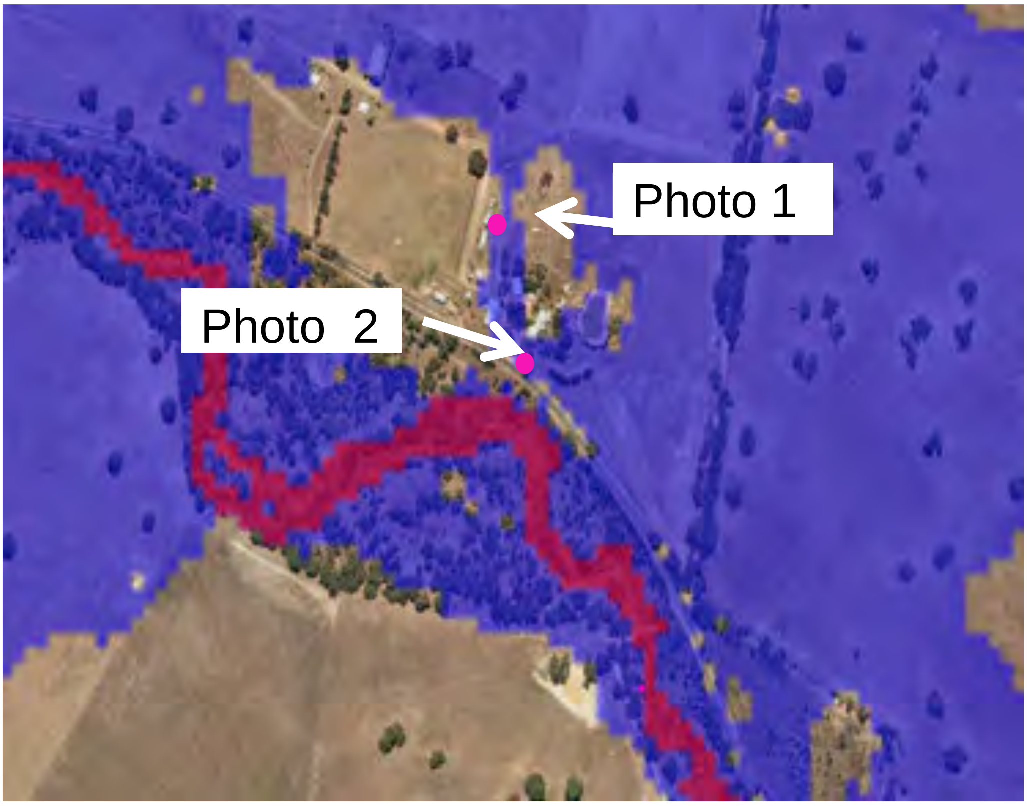


Figure 2 Comparison between initial and final January 2011 calibrations – Jallukar

Figure 3 Flooding of a property on Ararat – Halls Gap Road, Jallukar (left photo 1, right photo 2)

When calibrating the hydraulic model up stream of Lake Lonsdale more weight was applied to the photographs and flood marks rather than the stream gauge records. During large flood events such as the January 2011 event, stream gauge data for Mokepilly, Fyans Creek and Mount William tail gauge was deemed not accurate. As shown in Figure 4, Figure 5 and Figure 6, during large flood events floodwater was found to break out of these waterways upstream of the gauges, bypassing the stream gauge. During large flood events the stream record for these gauges is not representative of the flood behaviour.

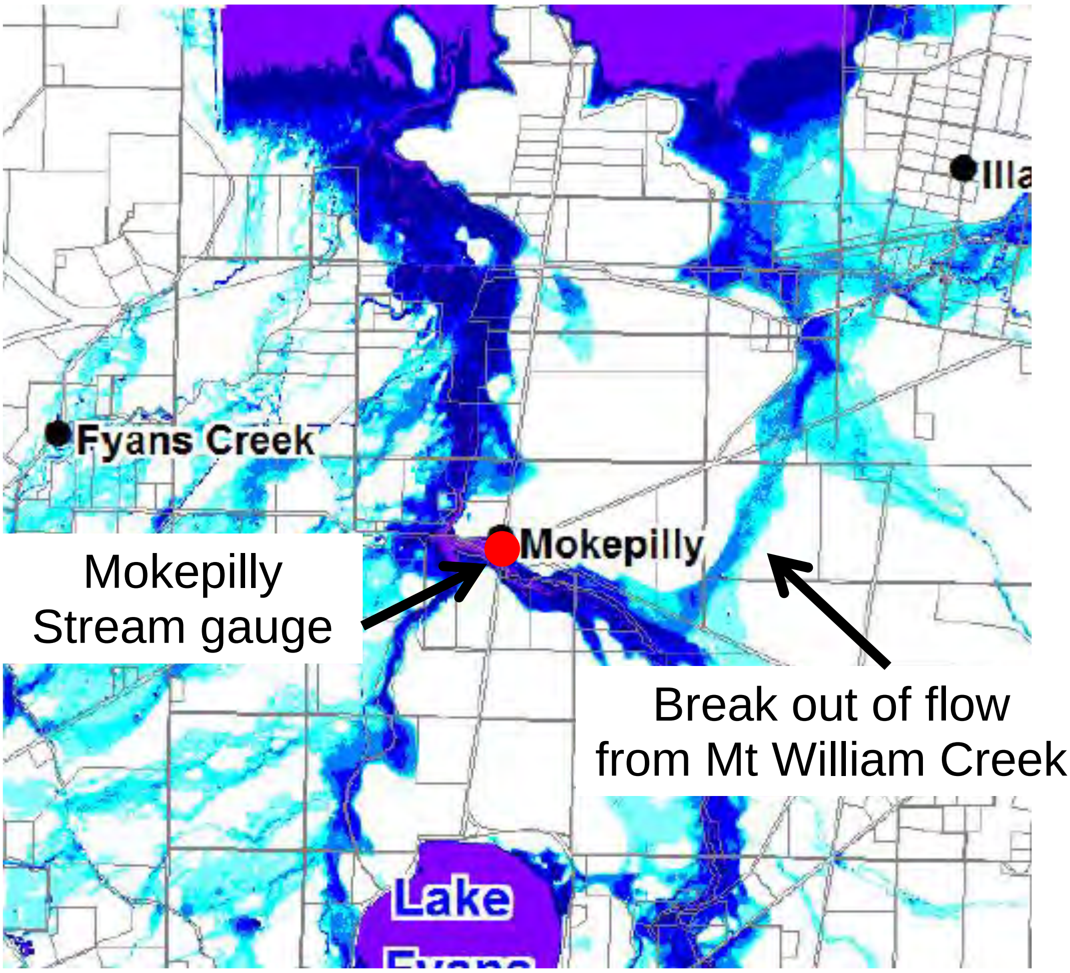


Figure 4 Map of the Mount William Creek 100 year flood extent showing floodwater breaking out of Mt William Creek upstream of the gauge, bypassing the Mokepilly stream gauge.

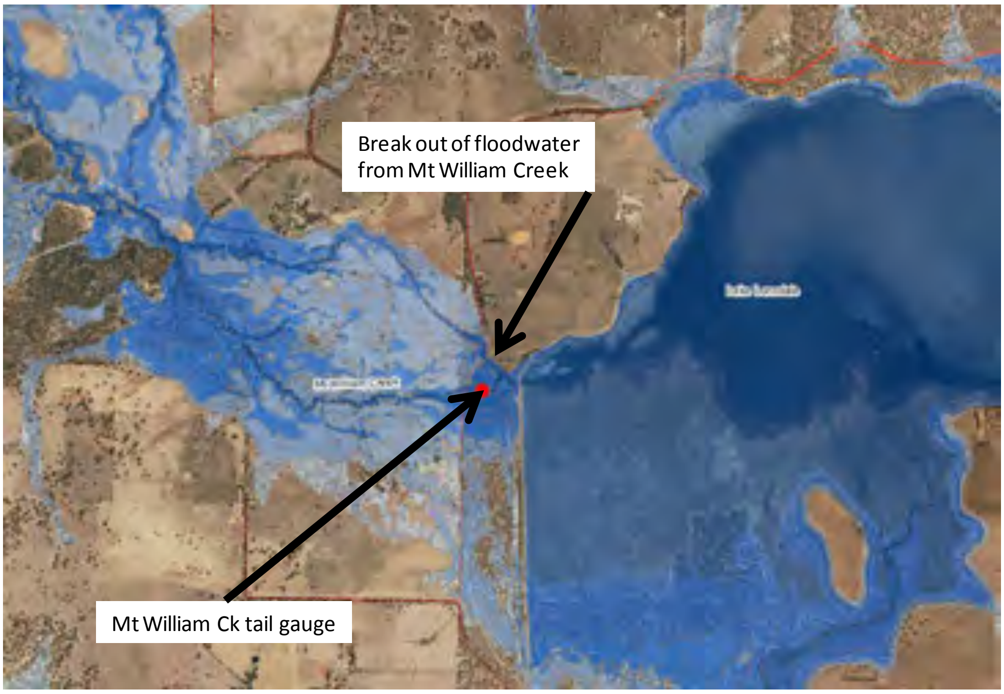


Figure 5 Map of the Mount William Creek 100 year flood extent showing floodwater breaking out of Mt William Creek upstream of the gauge, bypassing the Mount William Creek tail gauge.

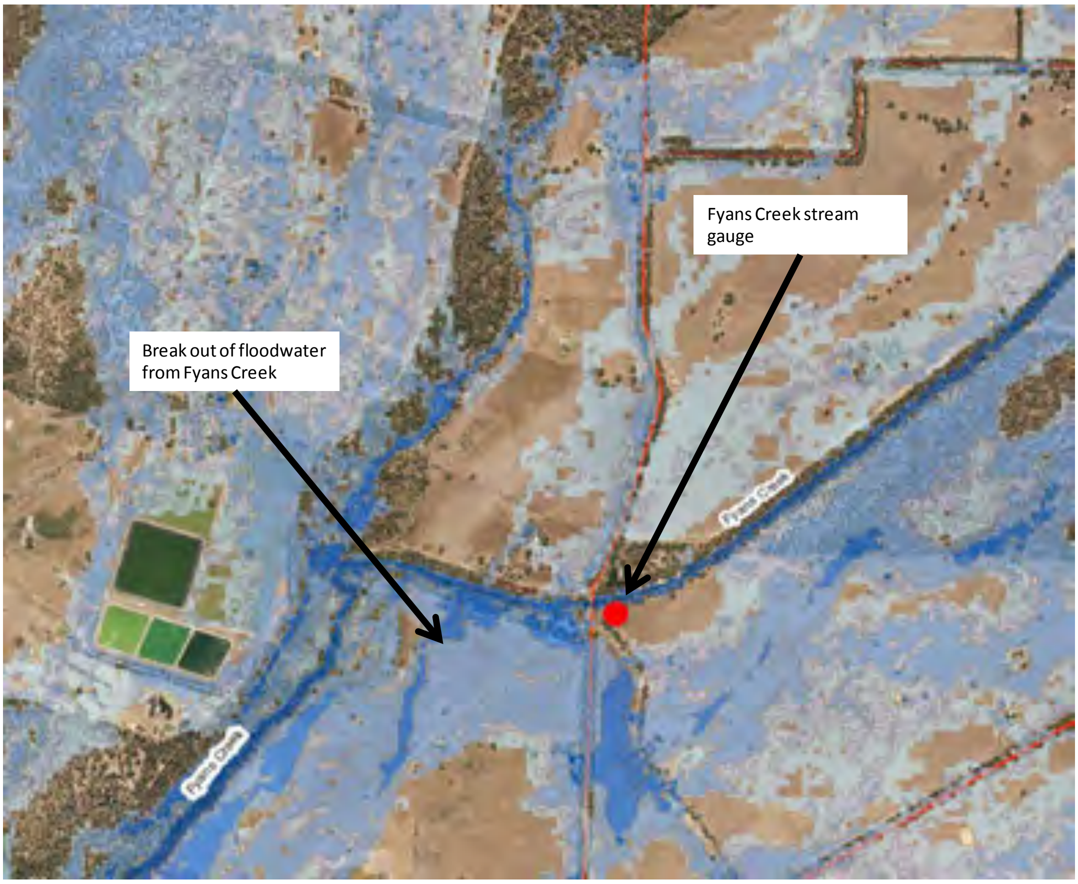


Figure 6 Map of the 100 year flood extent showing floodwater breaking out of Fyans Creek upstream of the gauge, bypassing the Fyans Creek stream gauge.

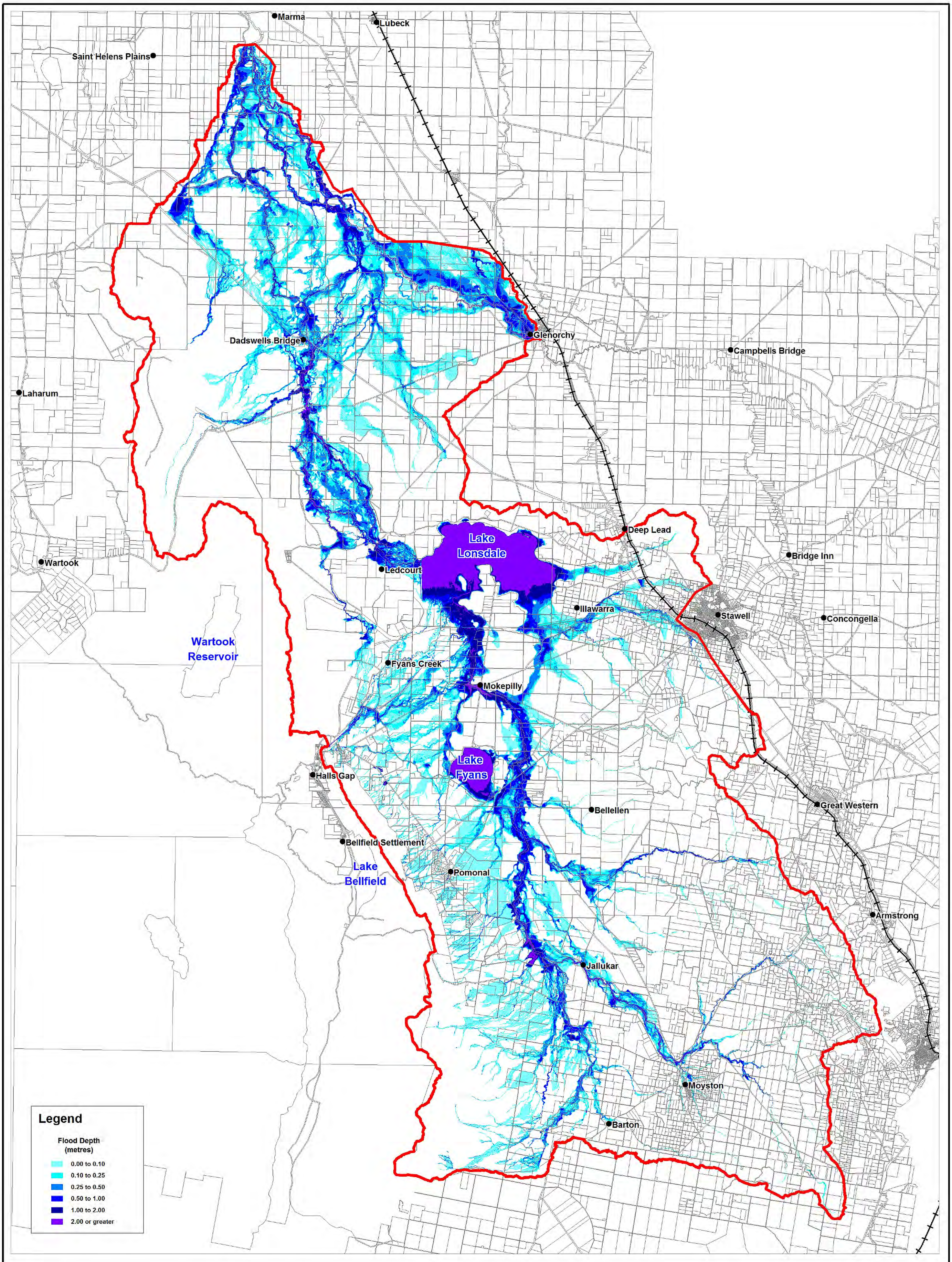
A number of changes were made to improve the calibration so that better agreement could be achieved with flood marks captured and flood photos collected during the January 2011 event, refer to table 2 for a comparison between the recorded and design peak flows. The amendment of the hydraulic model calibration parameters resulted in increased flow along Mount William Creek upstream of Lake Lonsdale which ultimately result in flood extent and flood depths that better reflect survey marks and flood photography of 2011 event. Although changes to more acceptable values resulted in very poor calibration at Mokepilly gauge, the resultant flood extent and flood depths provide a much improved correlation to the community's recollections when compared to the initial calibration. This method used to generate the design flood extents and flood levels is deemed acceptable by the project team given that during 100 year flood event; stream gauge records are not representative of flood behaviour in the Mt William Catchment. Refer to section 10.3.4.4 for recommendations to improve the stream gauge network to be more accurate during flood events.

Table 3 Comparison of Peak Design Flows for January 2011 flood event (ML/day)

Location	Recorded Peak	Modelled Peak
Mt William Creek @ Mokepilly	7,160	38,991
Fyans Creek @ Fyans Creek	6,339	3,070
Mt William Creek @ Lake Lonsdale (Tail Gauge)	35,556	46,250

Existing Conditions Flood Mapping and Results

The flood model was run for the 5 year, 10 year, 20 year, 50 year, 100 year and 200 year ARI 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 100 year ARI event is presented in Figure 7.



Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Depths - Whole of Catchment

Figure: 7

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Approx. Scale

Wimmera Catchment Management Authority
Ararat Rural City
Grampians
Horsham Rural City Council
Australian Government
Victoria
BMT WBM

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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, 12 properties experience above floor flooding, as shown in Table 4. The existing conditions Average Annual Damages for the Mount William Creek catchment were calculated to be $1,624,200. However, agricultural damage and road infrastructure damage account for 56% and 34% of the total damage respectively.

Table 4 Properties flooded and above floor flooding against ARI event

Event ARI	No of Properties Inundated	No. of properties with Above Floor Flooding
PMF	41	35
200y	28	13
100y	24	12
50y	19	10
20y	13	7
10y	4	3
5y	4	2

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 Mount William Creek catchment 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 Mount William Creek catchment 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 Dadswells Bridge, Pomonal and Moyston, are on the banks of various known waterways that are subject to flooding;
- Limited road access through the parts of the Mount William Creek 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.
- Numerous storages within the catchment have a significant impact on the timing and magnitude of the flood peaks throughout the catchment
- 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 Mount William Creek 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 Mount William Creek catchment, 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 Mount William Creek catchment; and
- The economic, social and environmental costs.

In total, over 15 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: Dadswells Bridge Levee** – A levee on the south side of the Western Highway, built to the same height as the existing highway level. This levee is designed to provide protection to a number of businesses on the south side of the Western Highway within the township of Dadswells Bridge
- **Scheme 2: Lake Lonsdale** - A reduction in the operating level of Lake Lonsdale. Currently the operating level of Lake Lonsdale is 187.12 metres AHD, 0.5 metres below the spillway. This scheme will model the Lake Lonsdale operating level as being 185.62 m AHD, 2.0 metres below the spillway. This will allow for an additional 29,630 ML of flood storage within Lake Lonsdale.
- **Scheme 3: Road Access** - Upgrading the Ararat – Halls Gap Road (C222) to minimise flooding over this key access road through the catchment. The intent of this component is to improve access during and following a flood event for the communities of Pomonal and Moyston (either through connection to Halls Gap or Ararat), and in doing so also improves access to the catchment for emergency services.

Hydraulic modelling of the range of design events; that is the 5 year, 10 year, 20 year, 50 year, 100 year and 200 year ARI, as well as 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 5.

Table 5 Structural Management Scheme Benefit-Cost Ratios

Structural Management Scheme	AAD	Capital Cost	Total Scheme Cost	BCR
Existing	$1,624,200			
Scheme 1	$1,616,800	$230,000	$1,491,000	0.08
Scheme 2	$1,548,900	$11,190,000	$12,136,000	0.10
Scheme 3	$1,560,100	$11,990,000	$16,529,000	0.06

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 Schemes 1 and 3 making very little (if any) difference to these values. Whilst there is a noticeable reduction in the damages for Scheme 2, it comes at a significant capital cost; hence the BCR is still very low. However, the capital cost is based on the assumption that water from Lake Lonsdale would need to be ‘purchased’ in order to reduce the operating level. The BCR would improve significantly if this water did not need to be ‘purchased’.

Consequently, there is no preferred structural mitigation scheme recommended by the Steering Committee for the Mount William Creek 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 Mount William Creek Flood Investigation. These were:

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

List of Abbreviations and Acronyms

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) event that exceed this level within the space of a single year.
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 average interval between exceedances of an event. A 100 year ARI event will be exceeded on average once every 100 years. The inverse of ARI is AEP (Annual Exceedance Probability). A 100 years ARI event has an AEP of 0.01 (1%). It is possible to have 0, 1, 2 or more 100 years ARI events in any 100 year period.
CMA	Catchment Management Authority
DEM	Digital Elevation Model – Three dimensional computer representation of terrain
DEPI	Department of Environment and Primary Industries
FFA	Flood Frequency Analysis
FI	Fraction Imperviousness – The fraction of the catchment that is impervious, that is, land which does not allow infiltration of water
FO	Flood Overlay
HRCC	Horsham Rural City Council
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
ML	Mega-Litres (1,000,000 L)
NGSC	Northern Grampians Shire Council
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.
PSM	Permanent Survey Mark
RCBC	Reinforced Concrete Box Culvert (also referred to as a Rectangular Culvert)
RCP	Reinforce Concrete Pipe (also referred to as a Circular Culvert)
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.
VFD	Victorian Flood Database

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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 Mount William Creek 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 (WCMA), in partnership with the Department of Sustainability (DSE), Northern Grampians Shire Council (NGSC), Horsham Rural City Council (HRCC) and Ararat Rural City Council (ARCC) has commissioned this investigation.

The Wimmera Catchment Management Authority (WCMA) has engaged BMT WBM Pty Ltd (BMT WBM) to undertake a flood investigation for the Mount William Creek catchment. This investigation has been prompted by a history of flooding in the catchment and recent significant flooding that resulted in road closures and inundation in the townships of Pomonal, Moyston and Dadswells Bridge.

In order to ensure that best outcomes for the communities of the Mount William Creek catchment, the work undertaken by BMT WBM will be overseen and guided by a Steering Committee which has been established for the Mount William Creek Flood Investigation, consisting of representatives from the key stakeholders and members of the local community. The study outcomes are also subject to independent technical review at the discretion of the steering committee.

This report documents the data collation and analysis that has been undertaken to date.

1.2 Previous Reports

Several previous flood reports and documents have been made available that detail and document the known flooding history of the Mount William Creek catchment. These reports and documents include:

- Dadswells Bridge Flood Study (R.J.Keller & Associates 1990);
- Flood Data Transfer Project – Rural City of Ararat (DNRE 2000);
- Flood Data Transfer Project – Rural City of Horsham (DNRE 2000);
- Flood Data Transfer Project – Shire of Northern Grampians (DNRE 2000).
- Glenorchy Floodplain Management Plan (Water Technology 2006);
- Glenorchy Floodplain Management Study – Flood Study Report (Water Technology 2006);
- Glenorchy Flood Study (Water Technology 2006);
- Halls Gap Flood Study (Water Technology 2008);
- Wimmera River (Glenorchy to Horsham) Flood Scoping Study (Water Technology 2003);

- Wimmera River – Yarriambiack Creek flow modelling Study Report (Water Technology 2009);
- Wimmera Region Flood Report – January 2011 (Water Technology 2011)

The flood data transfer project provides some detailed background information into the available flood data of the Mount William Creek system, whilst the Glenorchy and Wimmera River studies will assist in the lower reaches of the catchment. The Dadswells Bridge Flood Study and Halls Gap Flood Study are of particular relevance to this project as both these projects were undertaken within the study catchment for the Mount William Creek Flood Investigation.

Although not part of the Mount William Creek catchment, the Upper Wimmera Flood Investigation is also currently being undertaken by BMT WBM. Information gleaned from the Upper Wimmera Study has been utilised in this current study where appropriate.

1.3 Catchment Description

The Mount William Creek Catchment has an approximate area of 1,450 km^2 and is located in Central West Victoria (refer to Figure 1-1). The catchment includes a number of waterways, namely, Mount William Creek, Salt Creek, Fyans Creek, Pleasant Creek, Sheepwash Creek and Golton Creek along with their tributaries. The Wimmera River heavily influences the downstream reaches of the catchment. The majority of the catchment is used for agricultural purposes, predominately grazing. There are several townships within the catchment including Pomonal, Moyston, Stawell, Dadswells Bridge and Halls Gap (refer to Figure 1-2). However, whilst the township of Halls Gap is located within the Mount William Creek catchment, it will not be mapped as part of the current study as flood mapping has already been undertaken as part of the Halls Gap Flood Study (Water Technology, 2008).

The catchment originates in the mountainous regions of the Grampians and the West Victorian Uplands, from there Mount William Creek and its tributaries generally flow in a northerly direction towards Lubeck. The upper part of the catchment from the Grampians is extremely steep with numerous well defined flowpaths existing. However, as Mount William Creek and its tributaries flow into the agricultural areas and the main floodplain of the catchment, the topography flattens to form a wide floodplain with many incised creeks and streams including Mount William Creek, Nine Mile Creek, Pentland Creek and Sugarloaf Creek.

The lower reaches of Mount William Creek are heavily influenced by numerous Grampians Wimmera Mallee Water (GWM Water) channels and storages that exist within the catchment. The catchment includes three major storages; Lake Bellfield on Fyans Creek, Lake Lonsdale on Mount William Creek and Lake Fyans (an offstream storage fed from Fyans Creek), and a number of channels which connect these various storages throughout not only the study catchment, but also the wider GWM Water system.

The catchment of Mount William Creek includes a number of rural townships, including Dadswells Bridge, Pomonal and Moyston, which are of particular focus for the current study.

The town of Moyston is located in the south of the study catchment, approximately 15 kilometres west of Ararat, and is part of the Ararat Rural City Council. Salt Creek, a tributary of Mount William Creek is located approximately 1.5 kilometres north of the main town centre.

The town of Pomonal is located in the central west of the study catchment, approximately 20 kilometres south west of Stawell, and is part of Ararat Rural City Council. The town is situated on the banks of Millers Creek (refer to Figure 1-2), a tributary of Mount William Creek

The town of Dadswells Bridge is located in the north of study catchment, approximately 28 kilometres north east of Stawell, and is part of Horsham Rural City Council. The town is situated on the banks of Mount William Creek.

1.4 Study Area

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

1.5 Historical Flooding

The catchment of Mount William Creek (including Fyans Creek) has been subjected to extensive and frequent flash and riverine flooding events throughout history. Many significant flood events have been recorded in the catchment, however, up until the January 2011 event, the highest recorded floods in the catchment occurred in 1909. Whilst extensive flooding was recorded through Western and North Western Victoria between September 2010 and January 2011, the townships within the Mount William Creek were most significantly impacted during the January 2011 flood event.

As documented by the WCMA, the January 2011 flood event is the largest flood event within the Mount William Creek downstream of Lake Lonsdale in recorded history. The township of Dadswells Bridge recorded 161 millimetres of rain in a three day period between the 10^{th} and 12^{th} of January 2011, whilst Mount William (at the headwaters of catchment) received 279 millimetres in the period 10^{th} to 14^{th} January. The significant flooding that resulted from this rainfall led to the townships of Dadswells Bridge, Pomonal and Moyston, as well as the surrounding districts being isolated and cut-off due to the 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 (5, 10, 20, 50, 100 and 200 year recurrence intervals and Probable Maximum Flood) and including consideration for climate change;

(4) A review of Ararat Rural City Council, Horsham Rural City Council and Northern Grampians Shire Council Planning Scheme's current Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO) overlay in the existing planning scheme.;

(5) Preparation of digital and hard copy floodplain maps for the 1 in 100 year ARI 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;

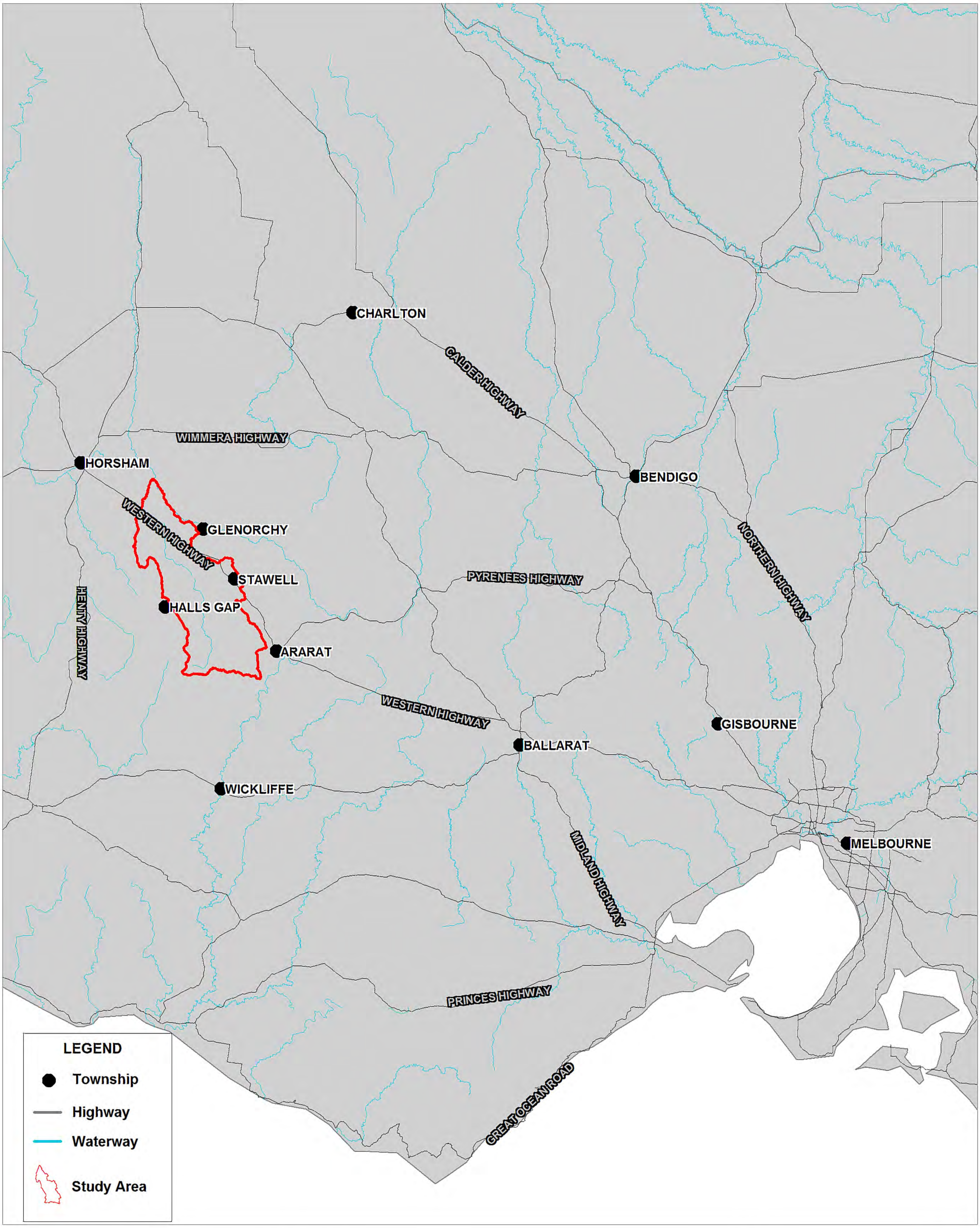
(10) Review and make recommendations regarding the flood warning system within the catchment;

(11) Provide Ararat Rural City Council, Horsham Rural City Council and Northern Grampians Shire Council with a revised flood response section of the Municipal Emergency Management Plan based upon the flood intelligence derived from the Study;

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

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

(14) Engage the community in all stages of the flood investigation to ensure that most appropriate outcomes are achieved.



Title:

Mt. William Creek Flood Study
Catchment Locality

Figure: 1-1

Rev: A

N

0 25 50km

Approx. Scale

Wimmera Catchment Management Authority

Ararat Rural City

Northern Grampians Shire

Horsham Rural City Council

Australian Government

State Government Victoria

BMT WBM

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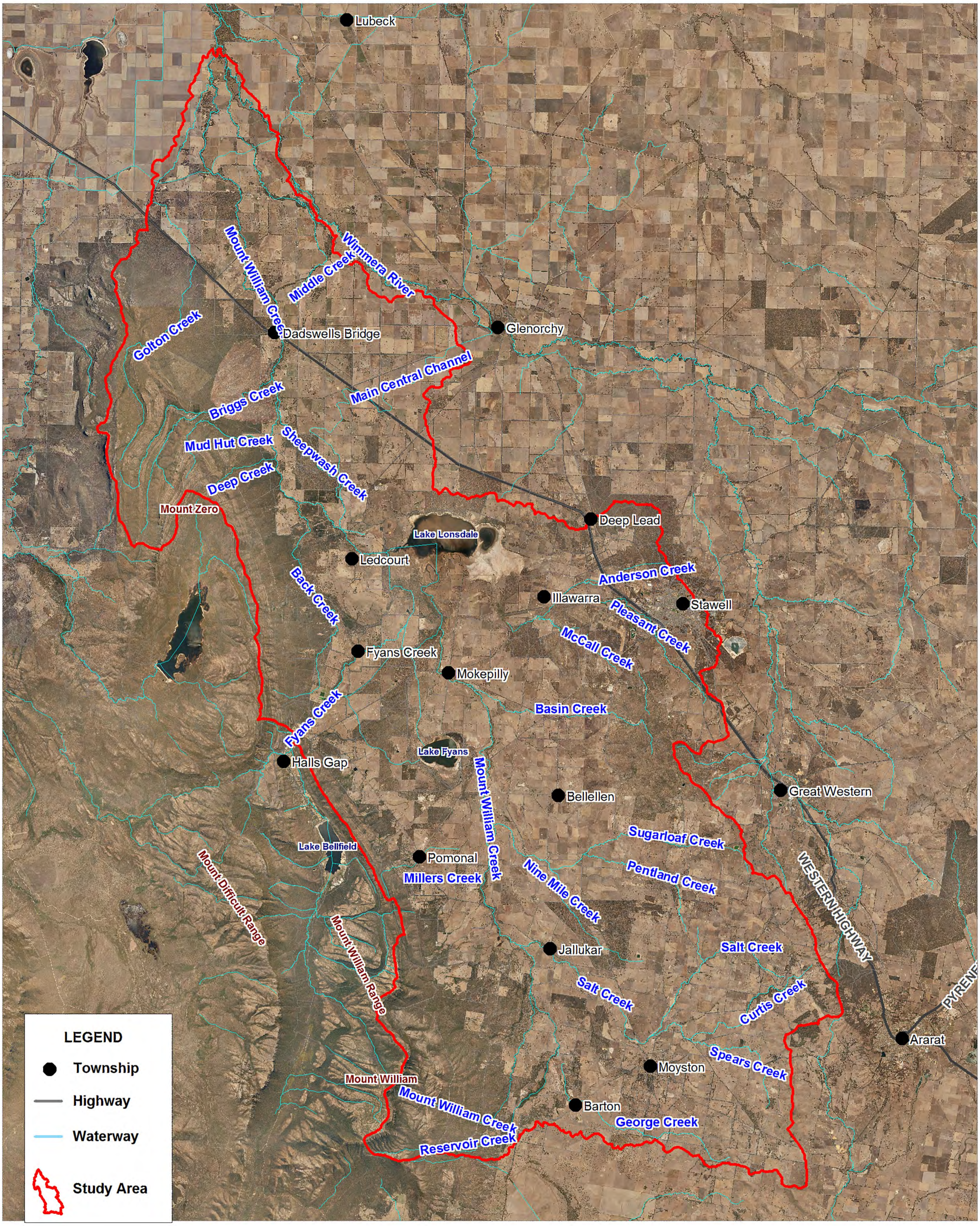

Title:
Mt. William Creek Flood Study
Study Catchment

Figure: 1-2

Rev: B

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

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Approx. Scale

Wimmera Catchment Management Authority

Ararat Rural City

Northern Grampians Shire

Horsham Rural City Council

Australian Government

State Government Victoria

BMT WBM

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2 Data Collation

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

- Wimmera Catchment Management Authority (WCMA);
- Ararat Rural City Council (ARCC);
- Northern Grampians Shire Council (NGSC);
- Horsham Rural City Council (HRCC);
- Department of Environment and Primary Industries (DEPI) (formerly known as Department of Sustainability and Environment (DSE));
- Bureau of Meteorology (BoM);
- Thiess Environmental Services;
- Grampians Wimmera Mallee Water (GWM Water); and
- VicRoads.

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 exists in any one data set that may lead to issues in the modelling.

Wimmera Catchment Management Authority:

- Contour Data Sets
    - 1m contours
    - 5m contours
    - 0.5m Wimmera Trench contours
- LiDAR Data Sets
    - 1m LiDAR (All returns, all ground and thinned data sets provided)
    - 0.5m LiDAR (all returns, all ground and thinned data set provided)
    - WimTch_Thn (coverage of the Wimmera River trench only)
- Ground Survey
    - Point, Cross Section and Structure Survey captured by Price Merrett as part of the Wimmera River – Yarriambiack Creek Flood Study (Water Technology, 2009)

Department of Environment and Primary Industries:

- Permanent Survey Marks (PSM) within the catchment supplied by DEPI (formerly 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 Mount William Creek Flood Investigation. Section 3 details the data verification process that has been undertaken to ensure the accuracy and suitability of the provided topographic information.

The LiDAR (with the exception of Wimmera River trench) has been supplied as three individual data sets: all returns, all ground and thinned.

The ‘all returns’ data set includes every return strike and includes strikes from building roofs, vegetation, parked cars, etc. Whilst this information is not used for the modelling it is used to check the all ground data and ensure that the filtering process that has been undertaken to remove all non-ground strikes is suitable for the catchment. This checking ensures that floodplains controls (levees, embankments, etc) have not been inadvertently removed as part of the filtering process.

The ‘all ground’ data set includes all strikes that have been determined to have hit the ground level. The ‘thinned’ data set is a version of the ‘all ground’ whereby points with similar elevations in close proximity are removed.

For the requirements of this study, BMT WBM has adopted the ‘all ground’ data set for use in the development of the digital elevation model (DEM) for use in both the hydrologic and hydraulic modelling.

2.1.1 Ground Survey

The Permanent Survey Marks supplied by DEPI were concentrated to the north of the Halls Gap – Stawell Road. Consequently there were few survey marks available to check the vertical accuracy of DEM in the south of the catchment, especially around the Pomonal and Moyston.

BMT WBM engaged Ferguson Perry Surveying to capture spot level survey along two key roads in the south of the catchment to provide additional data to not only check the accuracy of the DEM, but to provide additional information to accurately represent the elevation of these key roads across the Mount William Creek floodplain.

Ferguson Perry Surveying provided BMT WBM with 42 spot levels captured along the road centrelines of the Pomonal Road (C221) and the Ararat – Halls Gap Road (C222). The spot levels were used, in addition to the permanent survey marks, to check the vertical accuracy of the provided LiDAR

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. Aerial photography is used, along with the planning scheme overlays, to estimate the fraction imperviousness of the catchment as part of the hydrologic modelling. Similarly, when developing the hydraulic model it can be used to aid in the assignment of roughness to the catchment and any blockages caused by buildings. Finally, aerial photography during a flood event can be used to verify the model results by comparing relative extents and breakaway flows.

The following aerial photo datasets were provided:

- Four (4) geo-referenced tiles covering the entire catchment (photography flown in 2011);
- Two (2) geo-referenced tile covering the entire catchment (photography flown in 2004/5); and
- 343 non-tile non-geo-referenced photographs of Stawell and surrounds from the flood event on the 19th of December 2011 were provided;

2.3 Planning Scheme Information

The planning scheme layers were 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 Shire Council:

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

Ararat Rural City Council:

- Supplied the entire ARCC LGA portion of the catchment

HRCC has not provided digital copies of the planning scheme for their LGA, however, as noted above the data provided by NGSC, includes the HRCC LGA. The information provided by both NGSC and ARCC provided full coverage of the study catchment. The provided digital planning schemes were cross-checked against the current version of the HRCC planning scheme (available on the Planning Schemes website) to ensure its accuracy.

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.

Northern Grampians Shire Council:

- NGSC has supplied information on bridges and major culverts in GIS format. The data is comprehensive for culverts containing information on culvert dimensions, but does not detail length or inverts. The provided data indicates locations for bridges; however, information regarding length, dimensions or inverts is included in this dataset.

Horsham Rural City Council:

- HRCC has supplied information regarding bridge and culverts structures within the catchment. Whilst the data is not in a GIS format, sufficient information is provided to locate the structures within the catchment.

- HRCC has additionally supplied a number of scanned copies of hard copy plans to include data not captured within the GIS data set.

Ararat Rural City Council:

- ARCC has supplied information in GIS format on culverts within the catchment. Culvert length and dimensions have been provided though inverts have not been included. A large area of ARCC has no information regarding drainage structures.

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 and heights. Inverts are not included.

Grampians Wimmera Mallee Water:

- GWM Water has supplied a number of reports and documents which list the available drawings related to the structures along the various creeks and channels within the study catchment. A selection of these drawings has been accessed to determine their appropriateness for the study. Additional drawings will be sought as and when required.
- GWM Water has also provided information on the locations of channels that are to be decommissioned within the catchment following the completion of the Wimmera – Mallee Pipeline.

Department of Environment and Primary Industries:

- DSE (Land and Fire) has supplied information on the location of bridges in GIS format. Locations are given and a class_code, however dimensions, length and inverts have not been provided;
- No information regarding major culverts has been provided.

BMT WBM:

- Following the inception meeting and during the initial community consultation sessions, BMT WBM collected information on approximately 350 drainage structures within the catchment. Where safe access was possible, the structures width and height were measured and the structures photographed. This information has used to cross-check collected data and infill missing information.

2.4.1 Discussion

All required drainage structure information within the catchment has been collated (either through data provided by Council, government authorities and other stakeholders) or by BMT WBM staff.

Some of the information provided does not include structure inverts. Consequently, inverts will be adopted based upon the low points from the digital elevation model (as derived from the provided LiDAR). The assumed invert levels may be incorrect if there was water in the channels at the time the LiDAR was flown (the water level will be recorded, not the ground level). However, for inverts that are determined from the DEM, checks will be made to ensure the assumed inverts are appropriate. These checks include checking cover of the pipe under the road to ensure that the structures have appropriate cover. During larger flood events, these culverts are likely to be flowing full and the road is likely to be overtopped, and therefore, the invert levels will not have a significant influence on the flood modelling and project outputs.

2.5 Stream Gauge Data

Stream 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 min 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 blocked, etc).

Wimmera Catchment Management Authority:

- Revised rating for Mount William Creek @ Lake Lonsdale (Tail Gauge) (Gauge No. 415203D)
- Revised rating for Fyans Creek @ Fyans Creek (Gauge No. 415250A)

Grampians Wimmera Mallee Water:

- Lake Lonsdale Spill Rating and Lake Lonsdale Storage Rating
- Gauge Data from the January 2011 flood event including:
  - Lake Lonsdale
  - Little Weir
  - Fyans Creek

Victoria Data Warehouse:

- Instantaneous Flow (ML/Day), Calculated Average Daily Flow (ML/day) and Station Height (m)
  - 415203 Mount William Creek @ Lake Lonsdale (Tail Gauge) (01/05/1943 to 29/01/2013)
  - 415227 Mount William Creek @ Lake Lonsdale (Head Gauge) (07/07/1987 to 27/03/2001)
  - 415252 Mount William Creek @ Mokepilly (28/09/1988 to 29/01/2013)

- 415214 Fyans Creek @ Lake Bellfield (15/10/1973 to 29/01/2013)
- 415217 Fyans Creek @ Grampians Road Bridge (01/10/1973 to 01/07/2012)
- 415250 Fyans Creek @ Fyans Creek (09/08/1988 to 19/12/2012)
- 415253 Pleasant Creek @ Illawarra (09/11/1988 to 12/03/1992)
- 415702 Main Channel Inlet Channel @ Glenorchy (08/01/1990 to 20/03/2001)
- 415705 Bypass Channel @ Lake Lonsdale (29/10/1990 to 19/12/2012)

The flows and heights for the above gauges can be compared to hydrologic and hydraulic outputs respectively within the streams at those locations. For larger flood events with out of bank flow, the reported gauge flow will potentially be incorrect, especially if the gauge failed during the flood event, and therefore the gauge data may not suitable for hydraulic model calibration in larger events. An example of this was observed with the recorded data for the gauge on Mount William Creek at Mokepilly during the January 2011 flood event (refer to Section 4.4.6 for more details).

Based on the review of the available data, sufficient information exists to undertake calibration of both the hydrologic and hydraulic models. However, should additional information become available, this would assist in improving the model calibration.

2.6 Rainfall Data

Rainfall data is instrumental in the calibration of the hydrologic model. Rainfall data is required with both a spatial and temporal distribution across the catchment to ensure an understanding of how much rain fell in different parts of the catchment (the mountainous upper regions versus the flat lowlands) and over what timescale the rain fell (was it over 24 hours or did it all fall in 30 minutes).

Daily rainfall gauges are used to determine the spatial variability of the rainfall during the modelled flood events. 30 minute rainfall total station and pluviographs (measure rainfall intensity, rainfall depth per minute) are used to determine the temporal distribution of the rainfall during the modelled flood events.

All rainfall data has been sourced from the BoM.

Daily Rainfall

- 79010 Drung Drung (November 1905 to October 2012)
- 79014 Eversley (February 1888 to September 2012)
- 79015 Glenorchy (January 1913 to December 2011)
- 79016 Warranooke (Glenorchy) (January 1878 to September 2012)
- 79019 Great Western (Seppelt) (August 1891 to September 2012)
- 79032 Morrl Morrl (Valley View) (November 1902 to September 2012)
- 79034 Moyston (June 1886 to January 2012)
- 79035 Murtoa (January 1883 to June 2012)

- 79046 Wartook Reservoir (February 1890 to September 2012)
- 79050 Moyston (Barton Estate) (January 1906 to September 2012)
- 79073 Pomonal (January 1955 to May 2012)
- 79074 Halls Gap (May 1958 to September 2012)
- 79077 Dadswells Bridge (November 1968 to September 2012)
- 790982 Horsham (June 1958 to September 2012)
- 79103 Grampians (Mount William) (December 2005 to October 2012)
- 79105 Stawell Aerodrome (February 1996 to October 2012)
- 89019 Mirranatwa (Bowacka) (February 1901 to September 2012)
- 89034 Willaura (Main Street) (July 1902 to October 2012)
- 89080 Maroona (September 2001 to June 2012)
- 89085 Ararat Prison (May 1969 to October 2012)
- 89109 Buangor (Cragie) (May 1996 to September 2012)

30 minute Rainfall Totals

- 79028 Longerenong (May 1997 to August 2012)
- 79105 Stawell Aerodrome (February 1996 to March 2012)
- 79103 Grampians (Mount William) (December 2005 to March 2012)

Pluviographs

- 79046 Wartook Reservoir (May 1974 to September 2012)
- 89019 Mirranatwa (Bowacka) (May 1974 to August 2011)
- 89085 Ararat Prison (November 1981 to June 2011)

Additional pluviographs are located at Lake Bellfield (Halls Gap) and at the stream gauge for Concongella Creek at Stawell. Whilst this data was collected, it was not used in the calibration/validation of the hydrologic model for reasons outlined in Section **4.4.4**.

2.7 Historic Flooding

It is understood that there has been a number of sizable rainfall events in the Mt. William Creek catchment in recent memory. These include extensive and frequent flash flooding within Mt. William Creek and Fyans Creek. The recorded flood event in January 2011 surpassed the previous highest recorded flood event for the catchment, which occurred in 1909. Significant flooding occurred across the catchment in the January 2011 flood event, where rainfall depths of 161mm and 279mm were recorded within the catchment. Several townships within the catchment were cut-off from surrounding areas including Dadswells Bridge, Pomonal and Moyston. A number of buildings in Dadswells Bridge and Pomonal recorded above floor flooding. Lake Lonsdale is estimated to have peaked at 131.7% of operating level with large flows occurring across the spillway. The information detailed in this section is in addition to the reports presented in Section 1.2

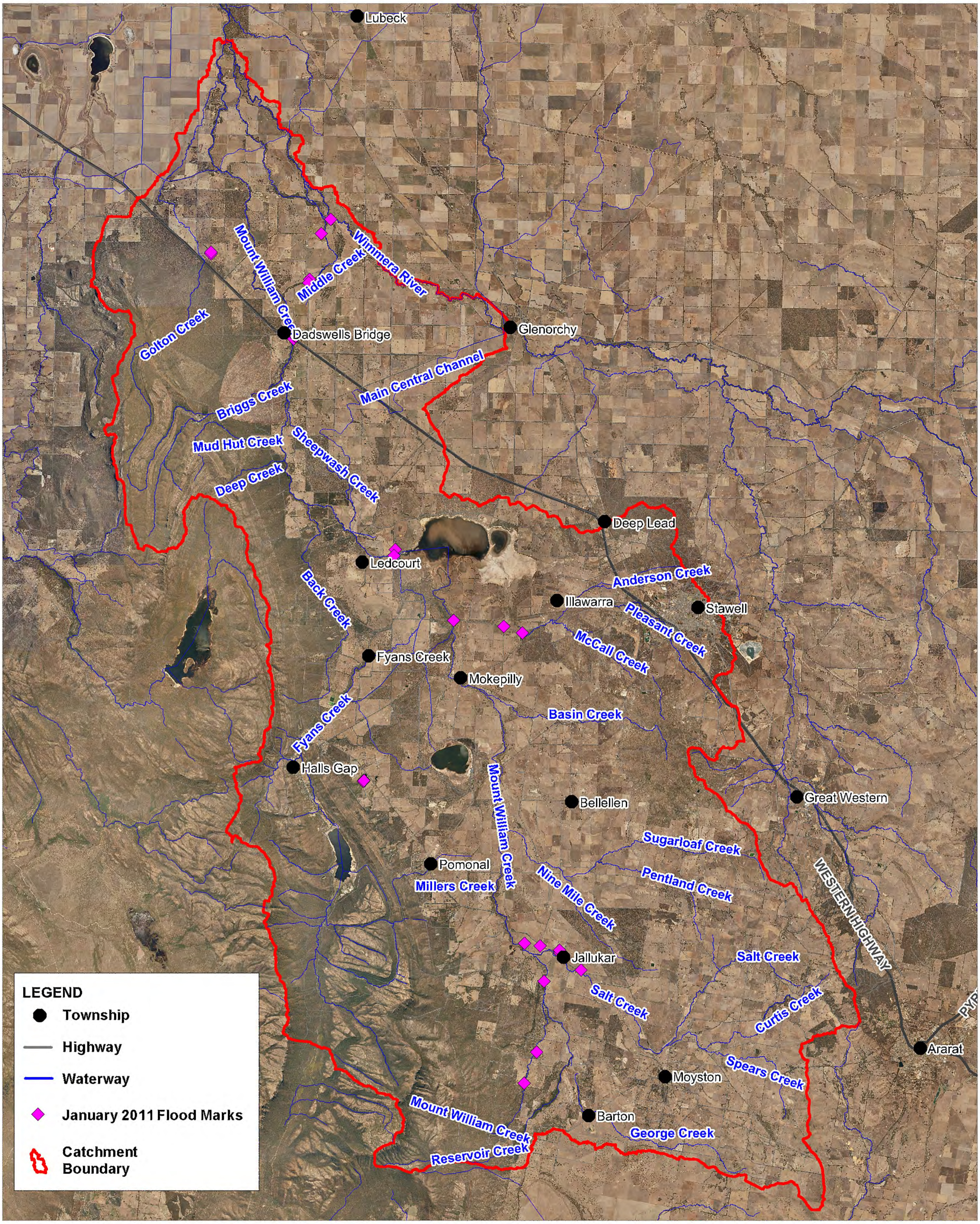
Wimmera Catchment Management Authority:

- January 2011 flood event
  - Survey marks (Refer to Figure 2-1)
  - Flood Extent Line Scan 2011
- Other data
  - Extensive flood photography during both the January 2011 and historical flood events throughout the catchment and surrounds
  - Flight tracks (taken during aerial flyovers of the January 2011 flood event, used to help located the flood photography taken from the aircraft).

The Community:

A series of community meetings were held in Dadswells Bridge, Pomonal and Moyston between the 29th April and 1st May 2013 in relation to the Mount William Creek Flood Investigation. The Dadswells Bridge was well attended by the local community who provided invaluable information on the history of flooding within the catchment.

The survey marks collected by the WCMA (Figure 2-1) are based primarily upon the information provided by the local community. In addition to these survey marks, approximately 300 digital photographs have been provided that document the flooding that occurred during the January 2011 flood event, as well as other flood events within the catchment.



Title:
Mt. William Creek Flood Study
Survey Marks - January 2011

Figure: 2-1

Rev: B

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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Approx. Scale

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2.8 Previous Studies

As noted in Section 1.2, there are a number of studies that have been previously undertaken within the Mount William Creek Catchment. Water Technology undertook the Halls Gap Flood Study in 2008 and the Wimmera River – Yarriambiack Creek Flows Study in 2009. Both of these studies resulted in hydrologic and hydraulic models being adapted and/or developed within the Mount William Creek catchment.

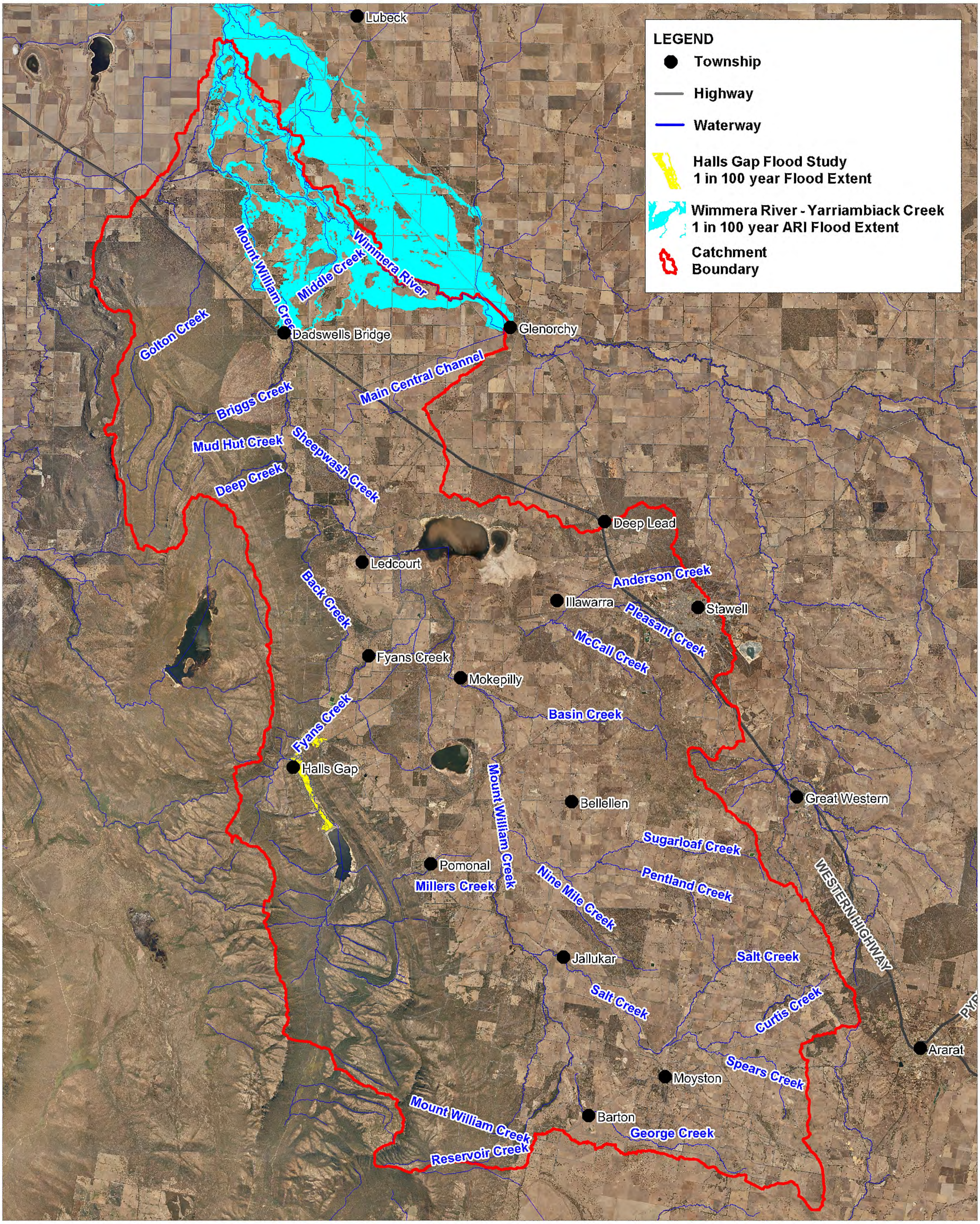
2.8.1 Halls Gap Flood Study (Water Technology, 2008)

The Halls Gap Flood Study focussed on hydrologic and hydraulic modelling of the Fyans Creek catchment downstream of Lake Bellfield, including the township of Halls Gap. This study developed flood mapping for the 1 in 100 year event (amongst others) for the Fyans Creek / Stony Creek catchments, including Halls Gap. The flood study report and flood mapping generated as part of this study are available on the WCMA website. This generated 1 in 100 year flood extent is shown in Figure 2-2.

2.8.2 Wimmera River – Yarriambiack Creek Flows Study (Water Technology, 2009)

The Wimmera River – Yarriambiack Creek flow and flood modelling study involved the hydrologic and hydraulic modelling of the Wimmera River and Yarriambiack Creek between Glenorchy, Horsham and Warracknabeal (Water Technology, 2009). The study area included the Mount William Creek catchment downstream of Dadswells Bridge.

Part of the study involved the generation of 1 in 100 year flood mapping for the Wimmera River downstream of Glenorchy, including Mount William Creek downstream of Dadswells Bridge. The flows study report and generated flood mapping is available of the WCMA website. This derived 1 in 100 year flood extent is shown in Figure 2-2.



Title:
Mt. William Creek Flood Study
Existing Flood Mapping

Figure: 2-2

Rev: B

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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3 Data Verification

This section documents the data verification process that has been undertaken by BMT WBM for the Mount William Creek Investigation. Specifically, this section documents the quality assurance checks that has been performed to ensure that supplied data is fit for purpose.

3.1 LiDAR Verification

As discussed in Section 2.1, BMT WBM has been supplied with multiple sets of LiDAR information from the Wimmera CMA. The quoted accuracy of the LiDAR was also supplied and the verification process sought to confirm these accuracies.

BMT WBM assessed the quoted horizontal and vertical accuracies of the LiDAR dataset in accordance with the guidelines presented the Intergovernmental Committee on Surveying and Mapping's (ICSM's) publication "ICSM LiDAR Acquisition Specification and Tender Template" (ICSM 2010). These guidelines document how the Fundamental Spatial Accuracy Validation process for both Horizontal and Vertical Accuracy can be achieved. The following sections detail the process undertaken to confirm both the quoted vertical and horizontal accuracies.

3.1.1 Vertical Accuracy

The vertical accuracy of a LiDAR dataset can be demonstrated through the comparison of the LiDAR elevations to the elevation of known points within the study catchment. BMT WBM was provided with details of all Permanent Survey Marks (PSMs) within the study catchment by the Department of Sustainability and Environment (DSE). Only the third order PSMs (the most accurate PSMs) were used in the analysis.

Inspection of the different data sets immediately indicates that the values returned from the thinned 1m DEM and the all ground1m DEM produce very similar results. As expected, the all returns DEM included all data unfiltered and as such has not been used. The all ground 1m DEM has been used in conjunction with the WimTch_thn DEM to create a DEM that covered the entirety of the Mount William Creek catchment.

The combined 1m DEM created from the Wimmera CMA LiDAR data was constructed to be used for the hydraulic and hydrological modelling for the Mount William Creek catchment. The elevation information contained within the constructed DEM and the elevations of the PSMs were cross checked to validate the vertical accuracy.

The PSMs were buffered by 5 metres to compensate for PSM digitisation errors (the locations of all the PSMs have been scaled from 1:100,000 maps). Each PSM was then inspected over the buffered region using information from the constructed LiDAR DEM.

There were 148 PSMs that are evident within the extents of the Mount William Creek catchment. Seven of these PSMs were identified as having significant differences (greater than 3 metres) between the PSM elevation and that of the DEM. In each case where this occurred, the two closest PSMs were checked to determine their respective vertical accuracies. It was found that at each of the seven identified PSMs with the significant differences, the neighbouring PSMs showing acceptable vertical accuracy. It was determined that these seven PSMs should be excluded from the analysis.

The Wimmera River Trench DEM has been previously shown to have a proven accuracy of +/- 0.1 m as discussed in the Wimmera River – Yarriambiack Creek Flows Study (Water Technology, 2009). This was confirmed by field survey as discussed in section 4.4.3 of Water Technology's report. The Wimmera River Trench DEM covers the region downstream of Dadswells Bridge.

The results from the statistical assessment of the vertical accuracy of the DEM when compared to PSMs are detailed in Table 3-1 and shown graphically in Figure 3-1. As seen in Figure 3-1, the distribution of the errors closely resembles the bell shape curve. Such a distribution indicates that the vertical errors within the LiDAR data sets are of a random nature and are not biased in being either consistently higher or lower than the PSM elevations.

Table 3-1 Comparison of LiDAR to PSMs

Statistical Measure	Value
Mean	0.02
Median	0.02
Standard Deviation	0.35

In addition to the PSM, additional field survey (42 points) was collected along two key roads in the catchment (C221 Halls Gap – Ararat Road and C222 Stawell – Pomonal Road) to provide some additional certainty to vertical accuracy.

Table 3-2 Comparison of LiDAR to Field Survey

Statistical Measure	Value
Mean	-0.03
Median	-0.05
Standard Deviation	0.11

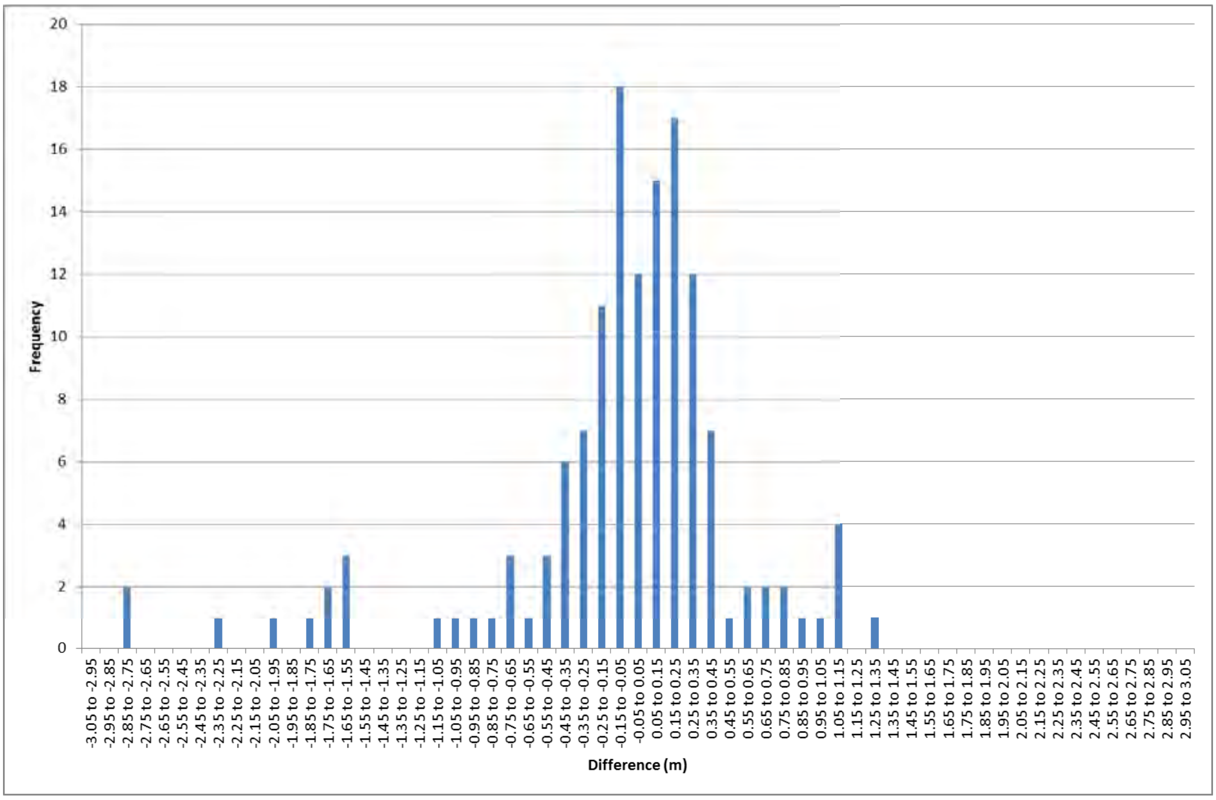


Figure 3-1 Distribution of PSM Differences

3.1.2 Discussion on Vertical Accuracy

The supplied DEM has been checked for vertical accuracy against three independent sources. The field survey collected as part of this study and collected previously as part of the Wimmera River – Yarriambiack Creek Flow Study (Water Technology, 2009) has shown that the DEM has achieved the stated vertical accuracy of +/- 0.15 metres to 1 sigma as stated in the metadata.

The accuracy of the DEM compared to the PSMs is not quite, with an achieved accuracy of +/- 0.40 metres to 1 sigma. However, the PSM's are likely to be less accurate than field survey due to various local factors (it is not uncommon for PSMs to be buried or paved over). The captured field survey has shown that accuracy across the DEM (the field survey includes points in the north and south of the catchment) is within the stated specification and will be suitable for the study.

Additionally, the provided LiDAR has a quoted accuracy of +/-0.5 metres to 1 sigma in areas away from the floodplain of the Wimmera River and in areas not covered by the LiDAR captured as part of the ISC rivers 2011 data set. The achieved accuracy based on the PSM verification is within this quoted accuracy for the DEM derived from the LiDAR captured away from the floodplain and waterways.

3.1.3 Horizontal Accuracy

Whilst the true horizontal accuracy of LiDAR based elevation products can only be determined from system and sensor calibration studies undertaken at the time of the LiDAR capture. BMT WBM verified the horizontal accuracy through an analysis of distinct features which are identifiable in the elevation data with other data sources. This method is outlined in ICSM 2010 as an accepted alternative method for checking horizontal accuracy.

The horizontal accuracy of the LiDAR from Wimmera CMA was checked through the comparison of the alignments of identifiable features (roads, farm dams, ovals, etc) within the terrain with aerial photography, cadastre and DSE permanent survey marks (PSM) throughout the catchment.

The DEM generated from the LiDAR was inspected at several locations throughout the catchment to ensure accuracy throughout the entire model. Visual inspection of the DEM compared to the properties boundaries indicated some discrepancies along certain roads. Where this occurred the aerial photography was inspected which was found to align within the margin of visual inspection. Additionally, GPS tracks taken by BMT WBM staff during the site inspections recorded along the roads were used to verify the road alignment. Similarly the aerial photography at a number of waterways and farm dams were inspected which were found to validate the horizontal accuracy.

3.1.4 Summary

Review of the LiDAR data indicates the Wimmera CMA LiDAR is an accurate representation of the catchment when compared to the available Permanent Survey Marks (PSMs) aerial photography, road alignments and GPS tracks.

The vertical accuracy of the DEM based upon the field survey is consistent with the quoted accuracy (+/- 0.15 metres to 1 sigma) of Level 1, Wimmera River Trench and ISC River 2011 LiDAR data.

The vertical accuracy of the DEM based upon the PSM analysis is consistent with the quoted accuracy (+/- 0.5 metres to 1 sigma) of the Level 2 LiDAR data.

The provided LiDAR is suitable for use in the Mt. William Creek Flood Investigation.

3.2 Verification of Other Data

Where drainage information supplied by third parties overlapped with a structure measured by BMT WBM staff during the site inspections, the measurements where checked for consistency. A sample of these comparisons is provided in Table 3-3. In general the information provided good agreement with the dimensions measured by BMT WBM staff on site. Whilst it is noted that there are minor discrepancies between the quoted value and the measured values, these differences will not significantly alter the capacity of the structure or the modelling results in the vicinity of the structure. Therefore a degree of confidence can be applied where structures have not been cross-checked by BMT WBM that the information provided by third parties is suitable for use in the hydraulic modelling.

Table 3-3 Verification of Culvert Details

Asset Details			Details Provided by Owner		Details Measured by BMT WBM	
Asset ID	Owner	Type	Width or Diameter (mm)	Height (mm)	Width or Diameter (mm)	Height (mm)
054R804280	NGSC	RCBC	1200	900	1220	910
043R800620	NGSC	RCBC	900	300	920	310
Western 4 258.71	VicRoads	RCP	600	-	600	-
N/A	ARCC	RCP	600	-	600	-

4 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 techniques have both been undertaken as part of the hydrological modelling for the Mount William Creek 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 Lake Lonsdale, estimates of rarer events at this site contain smaller uncertainty bounds than the river gauges at Mokepilly, Fyans Creek and Lake Bellfield and which have significantly shorter period of instantaneous flow records.

Rainfall-runoff modelling or hydrological modelling, of the Mount William Creek Catchment 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 Mount William Creek 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. A RORB model had also been previously developed for Fyans Creek as part of the Lake Bellfield Flood Study (URS, 2001) and was subsequently updated as part of the Halls Gap Flood Study (Water Technology, 2008). However, these models lacked the required definition of the entire Mount William Creek 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

4.1 Flood Frequency Analysis

4.1.1 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 Fyans Creek at Lake Bellfield, Fyans Creek at Fyans Creek, Mount William Creek at Mokepilly and Mount William Creek at Lake Lonsdale 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.

4.1.1.1 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 adopted for this Investigation is consistent with the advice published on the ARR website and repeated above.

4.1.2 Data

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

- Fyans Creek at Lake Bellfield (415214);
- Fyans Creek at Grampians Road Bridge (415217);
- Fyans Creek at Fyans Creek (415250);
- Mount William Creek at Mokepilly (415252); and
- Mount William Creek at Lake Lonsdale (Tail Gauge) (415203).

The instantaneous flow record lengths for each of these gauges varied between 24 years (Fyans Creek at Fyans Creek and Mount William Creek at Mokepilly) to 69 years (Mount William Creek at Lake Lonsdale). In addition, the gauge at Lake Lonsdale had recorded average daily flows which extend the stream gauging record (refer to section 4.1.2.4). The length of record for instantaneous maximum flows for each of the gauging sites within the catchment is listed in Table 4-1.

Table 4-1 Stream Flow Gauges in the Mount William Creek Catchment

Station	Name	Start Year – Month Continuous Recording	End Year – Month Continuous Recording
415214	Fyans Creek at Lake Bellfield	1973 - October	Active
415217	Fyans Creek at Grampians Road Bridge	1973 - October	2011 - January
415250	Fyans Creek at Fyans Creek	1988 - August	Active
415252	Mount William Creek at Mokepilly	1988 - September	Active
415203	Mount William Creek at Lake Lonsdale (Tail Gauge)	1943 – May	Active

4.1.2.1 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 five gauges. This water year ensures that the largest event of each year is independent of the largest events of the preceding and following years.

Sensitivity testing of different water years (January – December, July – June, etc) was undertaken and the 1ST October to 30th September water year was determined to be the most appropriate for the Mount William Creek catchment. The adopted water year is consistent with the water year adopted for the Upper Wimmera Flood Investigation.

4.1.2.2 Gauged Data Error

Following the January 2011 flood event, a number of stream gauges across the Wimmera River catchment had their rating curves reviewed and updated as required. Of the gauges within the Mount William Creek catchment, only the Mount William Creek at Lake Lonsdale (Tail Gauge) was re-rated. Figure 4-1 shows the recorded flows for the Mount William Creek at Lake Lonsdale (Tail Gauge) stream gauge based on both the old and new ratings. This graph shows an 8% reduction in the peak flow at this gauge when compared to the previous rating curve for the site, however as expected, the shape of the hydrograph is relatively unchanged.

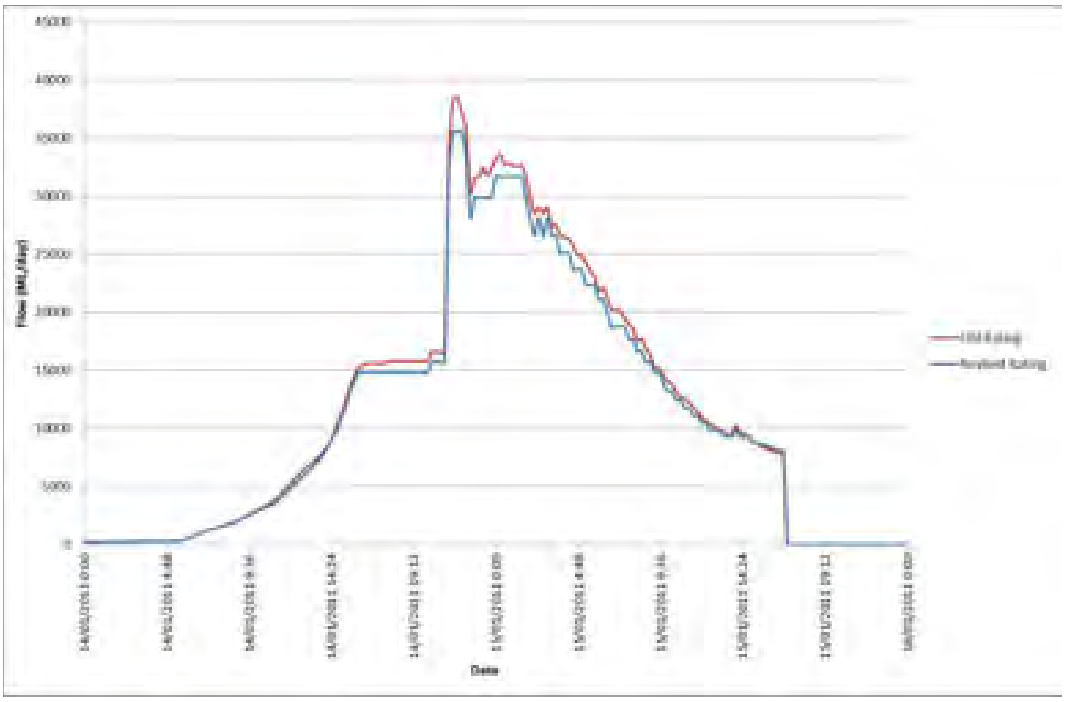


Figure 4-1 Recorded Flow at Lake Lonsdale (Tail Gauge) based on Old and New Ratings

4.1.2.3 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.

4.1.2.4 Extending Instantaneous Flow Record

Where mean daily flows records exist that exceed the instantaneous record, as was the case for the Mount William Creek at Lake Lonsdale gauge, these flows 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 4-2 for the Mount William Creek at Lake Lonsdale gauge. From the plotted data a line was fitted that represents the best fit for the available overlap of data. For the Lake Lonsdale 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 0.99 was noted.

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.

Following this analysis, the gauging record for the Mount William Creek at Lake Lonsdale (Tail Gauge) was able to be extended by an additional 33 years, resulting in a total record length of 102 years when combined with the instantaneous flow records.

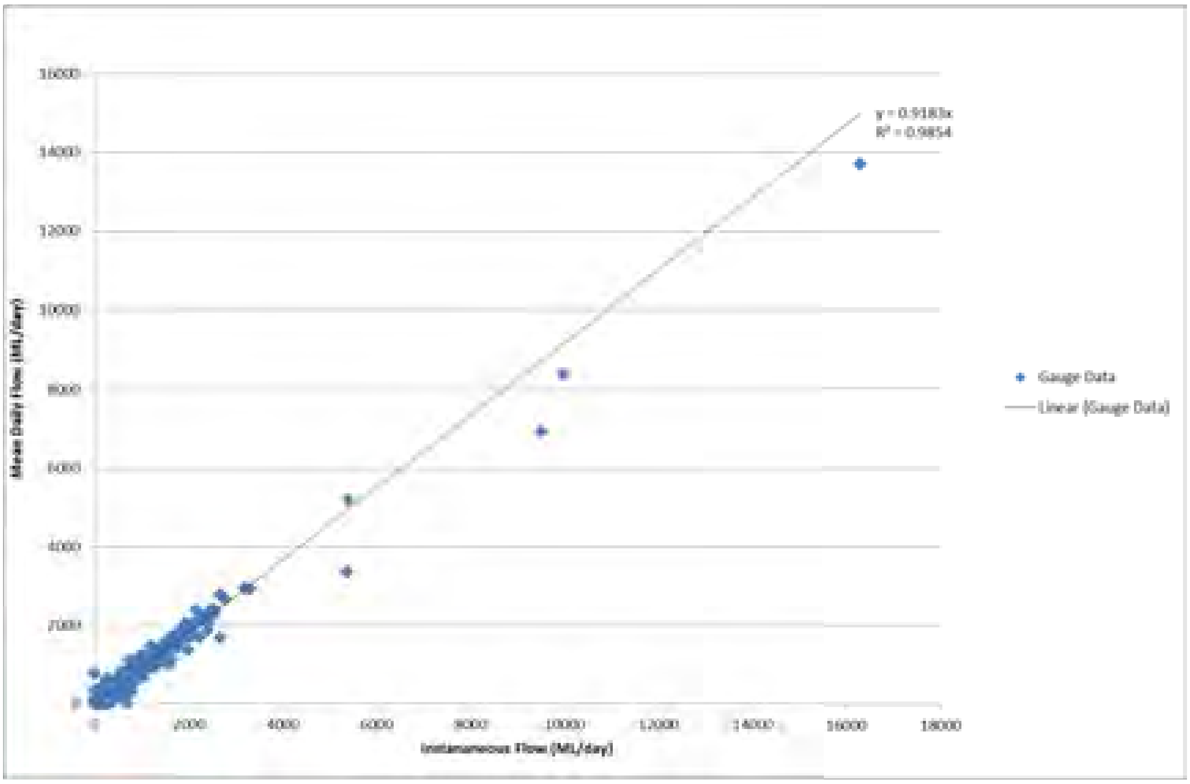


Figure 4-2 Mean Daily vs Instantaneous Flow – Mount William Creek at Lake Lonsdale

Additional stream flow data was made available from RWC (1990) in the form of maximum mean and minimum mean daily flow for the Lake Lonsdale Tail Gauge and for Fyans Creek at Lake Bellfield. This data enabled the stream record to be extended by a further 7 years for Lake Lonsdale (total record length of 110 years).

4.1.3 Flood Frequency Analysis

The FFA was undertaken using the FLIKE software program which uses either a Bayesian inference framework or LH moments. 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. In a similar manner, there is no theoretical basis to select the

Bayesian Inference framework over LH moments (or Vice Versa). Rather, the inference methodology and probability model should be selected to provide the best fit to the available data.

4.1.3.1 Annual Maximum Data

The annual maximum data for each of the gauging stations are listed in Table 4-2 to Table 4-6. 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 4-2 Annual Maximum Series: 415217 Fyans Creek at Grampians Road Bridge

Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)
1	2011	2246	13	1998	778	25	1978	518
2	1985	1987	14	1988	691	26	1996	518
3	2002	1987	15	2004	691	27	1989	432
4	1993	1814	16	1979	691	28	1999	432
5	1987	1555	17	1980	605	29	1991	432
6	1997	1555	18	2007	605	30	2010	432
7	1976	1296	19	2008	605	31	1983	432
8	1986	1210	20	1992	605	32	1995	346
9	1977	1210	21	1982	518	33	2005	259
10	1984	1123	22	1990	518	34	2006	259
11	2001	950	23	2009	518	35	2000	173
12	1994	950	24	1981	518	36	2003	86

Table 4-3 Annual Maximum Series: 415214 Fyans Creek at Lake Bellfield

Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)
1	1996	2333	14	2005	778	27	1998	346
2	1992	2246	15	1987	778	28	1999	259
3	1986	1814	16	1995	691	29	1978	259
4	1975	1814	17	1980	691	30	2001	259
5	2011	950	18	1982	605	31	2000	259
6	1993	950	19	1990	432	32	2002	259
7	1988	864	20	1991	432	33	2007	259
8	1997	864	21	1979	432	34	2004	173
9	1981	864	22	2010	432	35	2003	173
10	1984	864	23	1976	346	36	1983	86
11	1989	864	24	1985	346	37	2009	86

Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)
12	1974	778	25	1994	346	38	2008	86
13	1977	778	26	2006	346			

Table 4-4 Annual Maximum Series: 415250 Fyans Creek at Fyans Creek

Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)
1	1993	6912	9	1990	864	17	1995	346
2	1997	3888	10	2003	864	18	2001	346
3	2011	3456	11	1991	691	19	2008	346
4	2012	1814	12	1996	691	20	2005	346
5	2002	1555	13	1999	691	21	2007	173
6	2004	1382	14	2006	432	22	2010	173
7	1998	1123	15	1992	432	23	2009	86
8	1994	1123	16	2000	346			

Table 4-5 Annual Maximum Series: 415252 Mount William Creek at Mokepilly

Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)
1	2011	7171*	9	2010	2506	17	2005	346
2	1993	6221	10	1990	2419	18	1998	346
3	1997	5270	11	2004	2246	19	2007	173
4	1994	3888	12	1999	950	20	2009	173
5	1992	3197	13	2000	778	21	2006	173
6	1996	2765	14	1991	778	22	1995	86
7	2002	2592	15	2001	778	23	2003	0
8	2012	2592	16	2008	605			

* The Mokepilly gauge did not correctly record the 2011 peak discharge (refer to Section 4.4.6 for details). This event is likely to have been higher than the recorded discharge.

Table 4-6 Annual Maximum Series: 415203 Mount William Creek at Lake Lonsdale (Tail Gauge)

Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)
1	2011	35597	35	1988	864	69	1970	259
2	1975	10022	36	1914	864	70	1949	259
3	1922	3456	37	1994	691	71	1928	259
4	1957	3283	38	1985	691	72	2005	259
5	1912	3283	39	1984	691	73	1923	259
6	1911	3283	40	1981	691	74	1926	259

Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)	Rank	Water Year Ending	Discharge (ML/day)
7	1956	3197	41	1966	691	75	1944	259
8	1919	3110	42	1976	605	76	1950	259
9	1918	3024	43	1991	605	77	1951	259
10	1924	2851	44	1980	605	78	1968	259
11	1974	2765	45	1969	518	79	1971	259
12	1993	2592	46	1977	518	80	1945	259
13	1965	2592	47	1987	518	81	1940	259
14	1936	2506	48	1995	518	82	1938	173
15	1917	2419	49	1998	518	83	1920	173
16	1925	2419	50	1989	518	84	1955	173
17	1961	2333	51	1983	518	85	2010	173
18	1933	2074	52	1973	518	86	1935	173
19	1948	1901	53	1982	518	87	1939	173
20	1947	1901	54	1931	432	88	1942	173
21	1990	1642	55	1986	432	89	1946	173
22	1954	1555	56	1992	432	90	2004	173
23	1916	1555	57	1997	432	91	1962	173
24	1953	1555	58	1979	432	92	1929	173
25	1932	1469	59	1999	346	93	1960	173
26	1952	1469	60	2006	346	94	1921	173
27	1943	1296	61	1996	346	95	1958	173
28	1937	1296	62	2000	346	96	2012	173
29	1913	1296	63	2001	346	97	2007	173
30	1934	1210	64	2002	346	98	2008	173
31	1959	1210	65	1978	346	99	1915	173
32	1964	1210	66	1941	346	100	1963	86
33	1927	950	67	1972	259	101	1967	86
34	1930	864	68	2003	259	102	2009	86

4.1.3.2 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 gauges being analysed. 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 4-7.

Censored data can also be used to include additional historic information within the flood frequency analysis and gauge data that has been recorded incorrectly. This use of censored data was applied to both the Mount William Creek at Mokepilly and Mount William Creek at Lake Lonsdale.

The peak flow recorded at the Mount William Creek at Mokepilly gauge was recorded to be 7171 ML/day, have the gauge malfunctioned during the event and the actual peak is likely to be higher. Therefore this event was included in the flood frequency analysis by using the censored data to state that there was one ungauged event greater than 7171 Ml/day in addition to the recorded gauge data (which excluded the 2011 recording).

Additionally, the 1909 flood event recorded on the Mount William Creek at Lake Lonsdale (Tail Gauge) was included using censored data. In this case, the flood frequency analysis was adjusted to include one ungauged event between the 1974 and 2011 events and 7 years of ungauged flows below this threshold.

Table 4-7 Censored Data Values

Gauge Site	Flow Rate equalled or exceeds 5% of the time
Fyans Creek at Grampians Road Bridge	198 ML/day
Fyans Creek at Lake Bellfield	311 ML/day
Fyans Creek at Fyans Creek	302 ML/day
Mount William Creek at Mokepilly	225 ML/day
Mount William Creek at Lake Lonsdale (Tail Gauge)	475 ML/day

4.1.3.3 Inference Method

As discussed previously (Section 4.1.3), FLIKE has the ability to use both Bayesian and LH moments as the Inference Method for fitting the data as part of a Flood Frequency Analysis.

Initial attempts at the flood frequency analysis for the three of the five selected gauges (Fyans Creek at Grampians Road Bridge, Fyans Creek at Lake Bellfield and Fyans Creek at Fyans Creek) were undertaken using the Bayesian Inference Method. However, the derived fits to the data were considered poor, even with the censoring of the low flow from the data.

In light of the poor fits being developed through the use of the Bayesian Inference Method, and in line with the advice of Kuczera and Franks (2012), the LH moments was explored. LH moments can be used when the selected probability model does not adequately fit all the gauged data, most commonly as a result of low flows exerting undue influence on the fit and giving insufficient weight to the higher flows (Kuczera and Franks, 2012). This can be especially important when considering that the high flows are generally going to be of more interest than the low flows.

The analysis for Mount William Creek at Mokepilly and Mount William Creek at Lake Lonsdale (Tail Gauge) were undertaken using the Bayesian Inference Method in order to utilise the censored flow feature of FLIKE.

4.1.3.4 Results – 415217 Fyans Creek at Grampians Road Bridge

The FFA was undertaken for Fyans Creek at Grampians Road Bridge using the annual maximum data listed in Table 4-2.

Inspection of the results presented in Figure 4-3 to Figure 4-7 indicates that acceptable fits are provided by all distributions.

The GEV distribution (Figure 4-6) has been selected as the preferred fit. Whilst the expected quantiles of the majority of the models are greater than the two largest gauged flows at the site, the GEV distribution's expected quantile is consistent with the second largest gauged flow (although it too overestimated the largest gauged flow). The results for the GEV distribution are shown in Table 4-8. This table lists the 1 in 100 year ARI peak discharge as 3145 ML/day.

Table 4-8 415217 Fyans Creek at Grampians Road Bridge: FFA Results

ARI	Expected Quantile (ML/day)	90% Quantile Probability Limits	
5	1140	881	1426
10	1512	1115	1979
20	1927	1331	2722
50	2575	1564	4164
100	3145	1728	5746

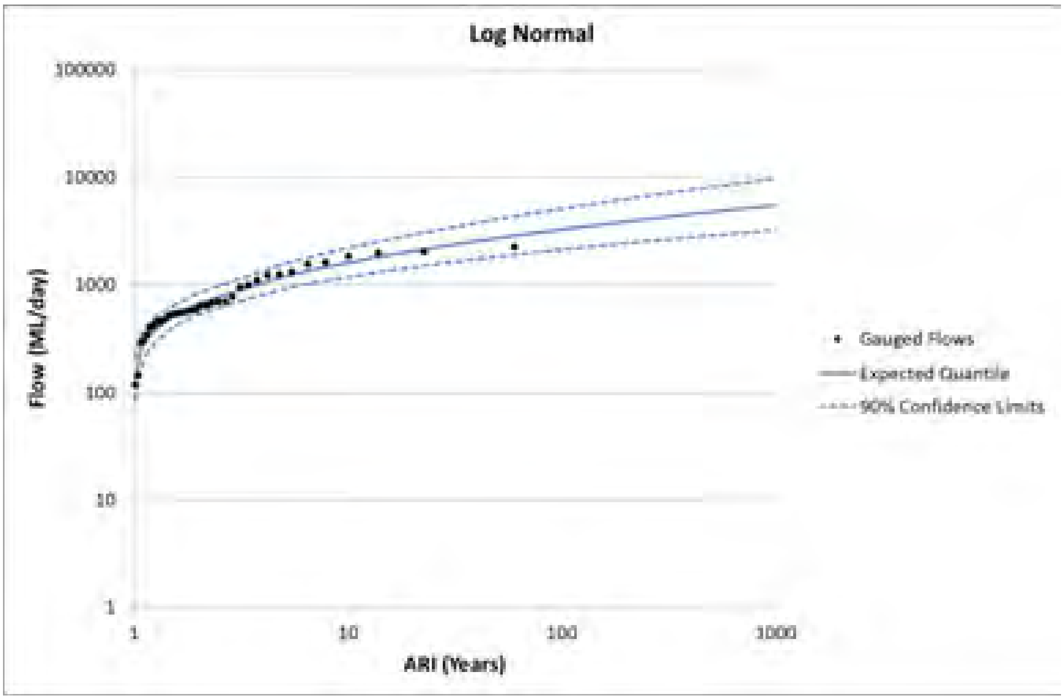


Figure 4-3 FFA Results: Fyans Creek at Grampians Road Bridge - Log Normal Fitting

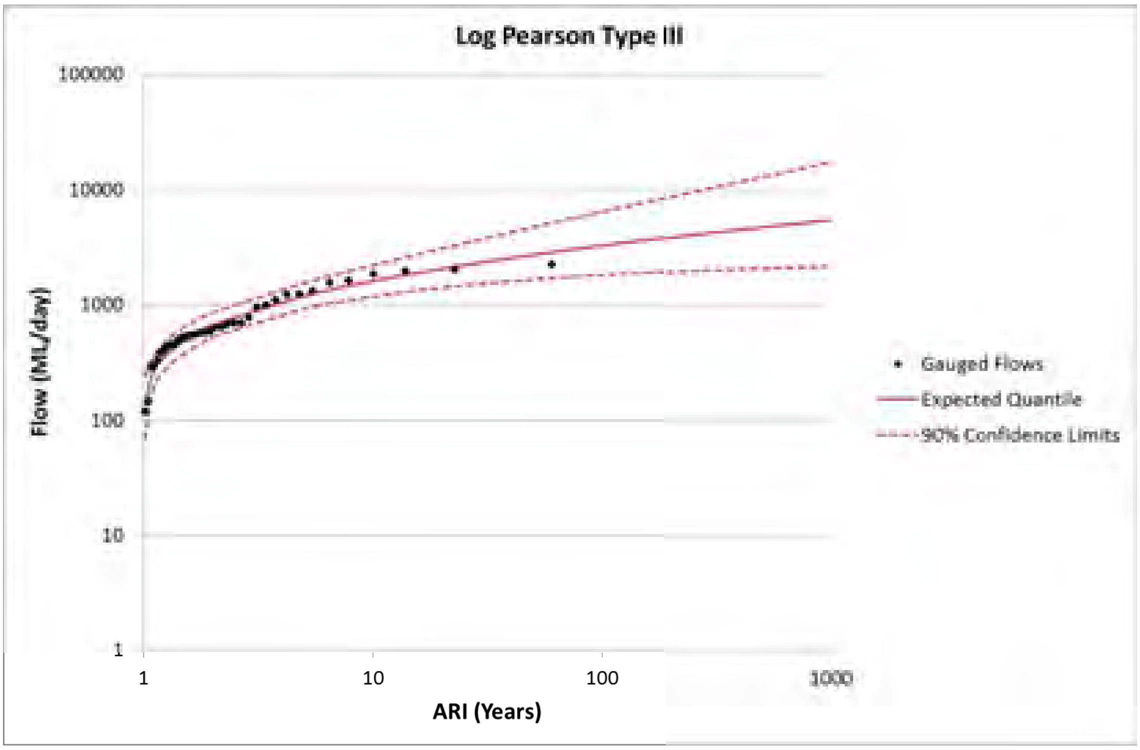


Figure 4-4 FFA Results: Fyans Creek at Grampians Road Bridge - LP3 Fitting

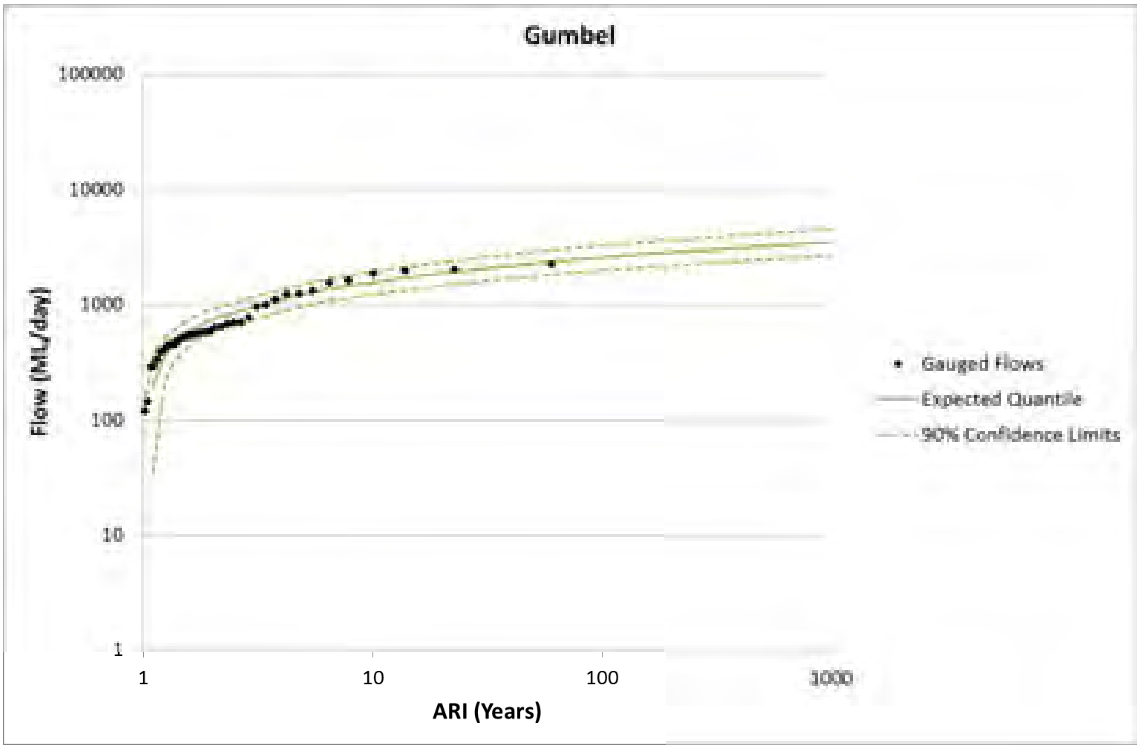


Figure 4-5 FFA Results: Fyans Creek at Grampians Road Bridge - Gumbel Fitting

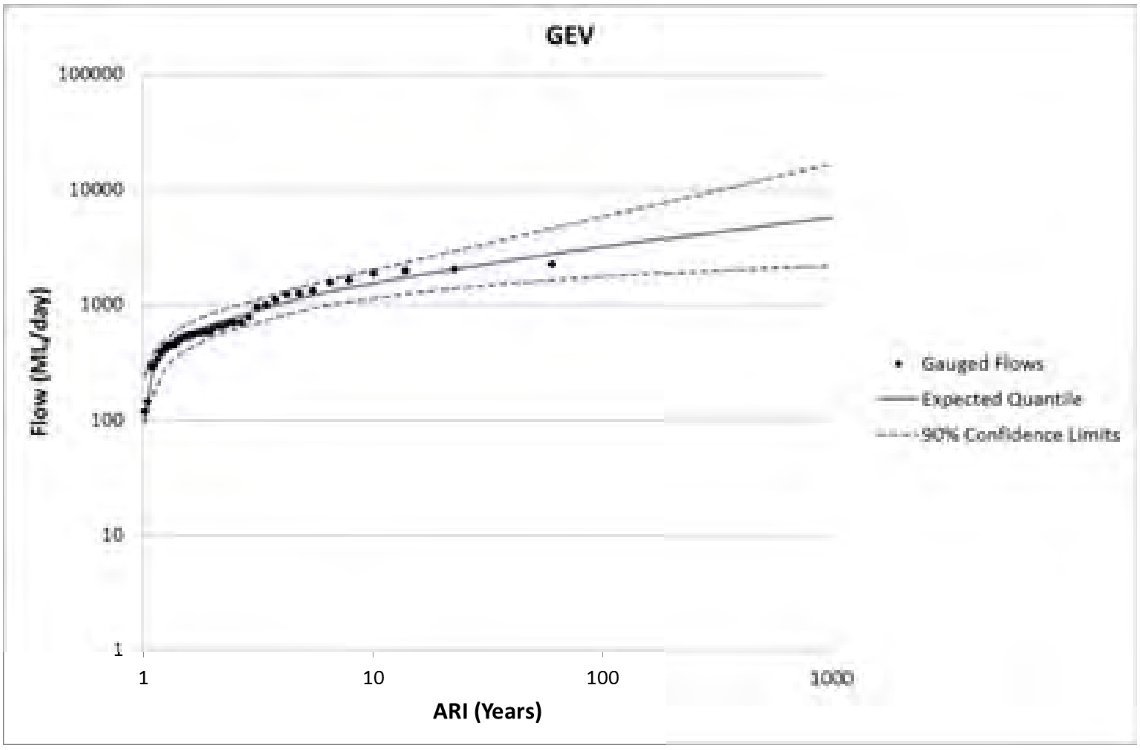


Figure 4-6 FFA Results: Fyans Creek at Grampians Road Bridge - GEV Fitting

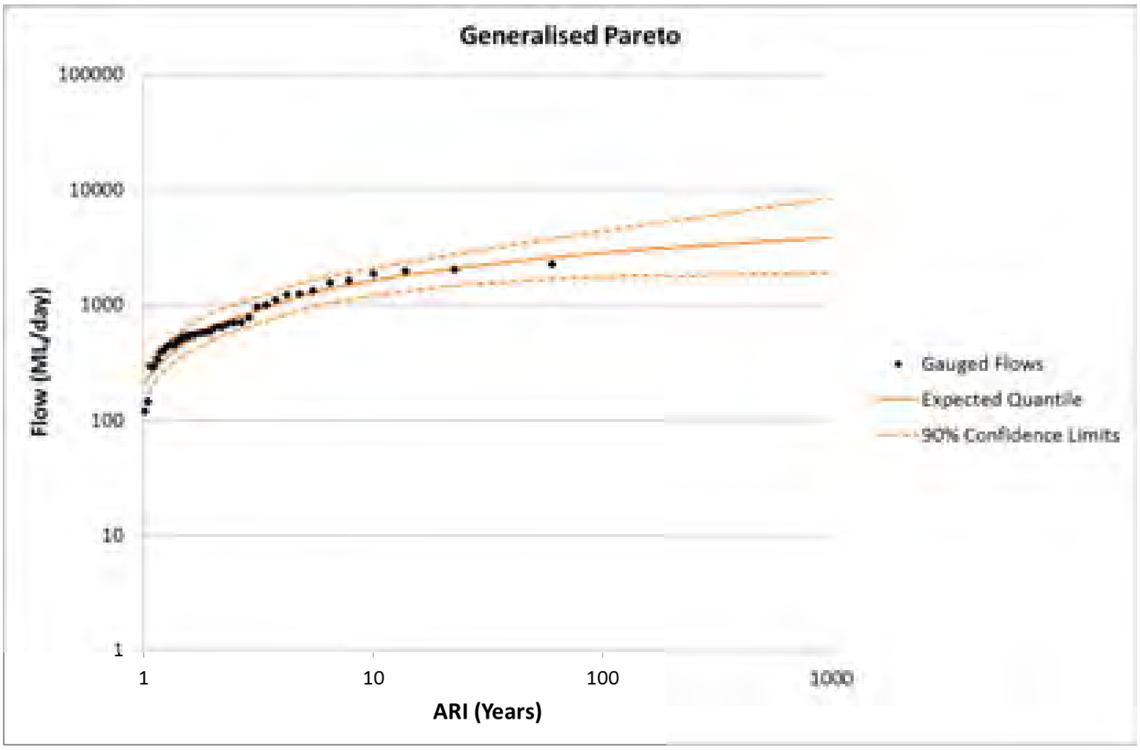


Figure 4-7 FFA Results: Fyans Creek at Grampians Road Bridge - Generalised Pareto Fitting

4.1.3.5 Results – 415214 Fyans Creek at Lake Bellfield

The FFA was undertaken for Fyans Creek at Lake Bellfield using the annual maximum data listed in Table 4-2.

Inspection of the results presented in Figure 4-8 to Figure 4-12 indicates that acceptable fits are provided by all probability models with the exception on the Gumbel model (Figure 4-10).

Whilst the Log Normal (Figure 4-8), Log Pearson Type III (Figure 4-9), GEV (Figure 4-11) and Generalised Pareto (Figure 4-12) distributions provide acceptable fits, the Log Pearson Type III is preferred as the fit to the overall record is better. The results for the Log Pearson Type III distribution are shown in Table 4-9. This table lists the 1 in 100 year ARI peak discharge as 2592 m^3/s.

Table 4-9 415214 Fyans Creek at Lake Bellfield: FFA Results

ARI	Expected Quantile (ML/day)	90% Quantile Probability Limits	
5	1002	743	1313
10	1365	994	1840
20	1737	1201	2497
50	2220	1391	3672
100	2592	1495	4830

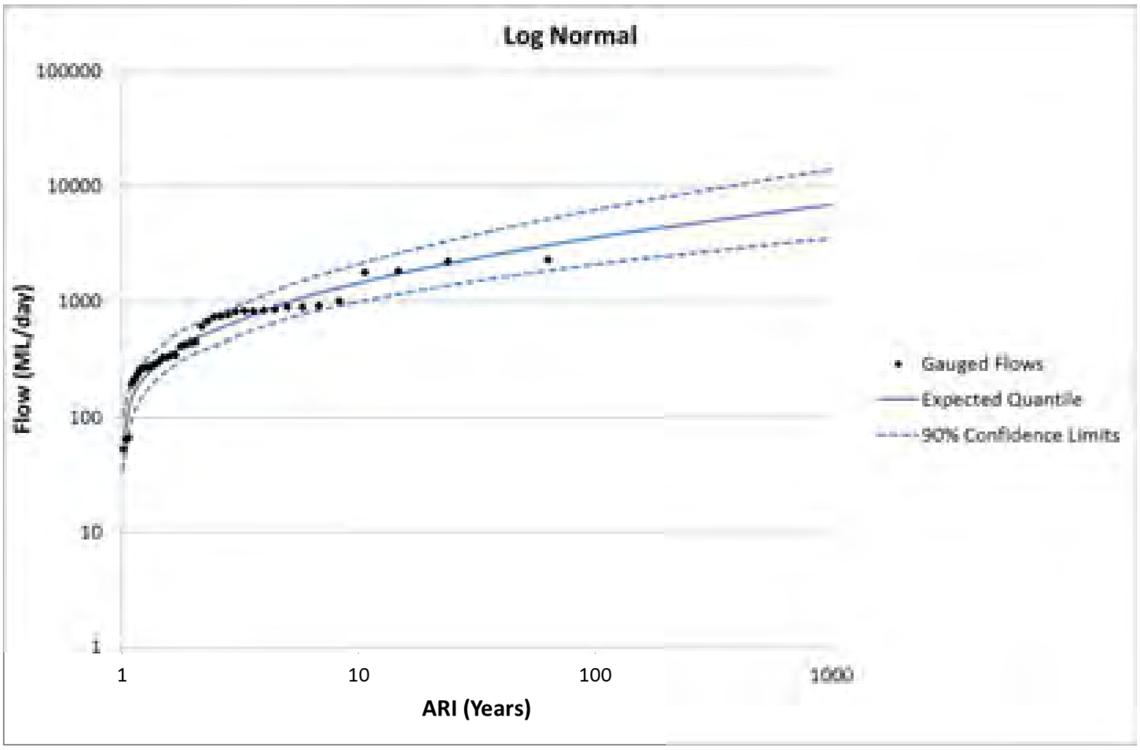


Figure 4-8 FFA Results: Fyans Creek at Lake Bellfield - Log Normal Fitting

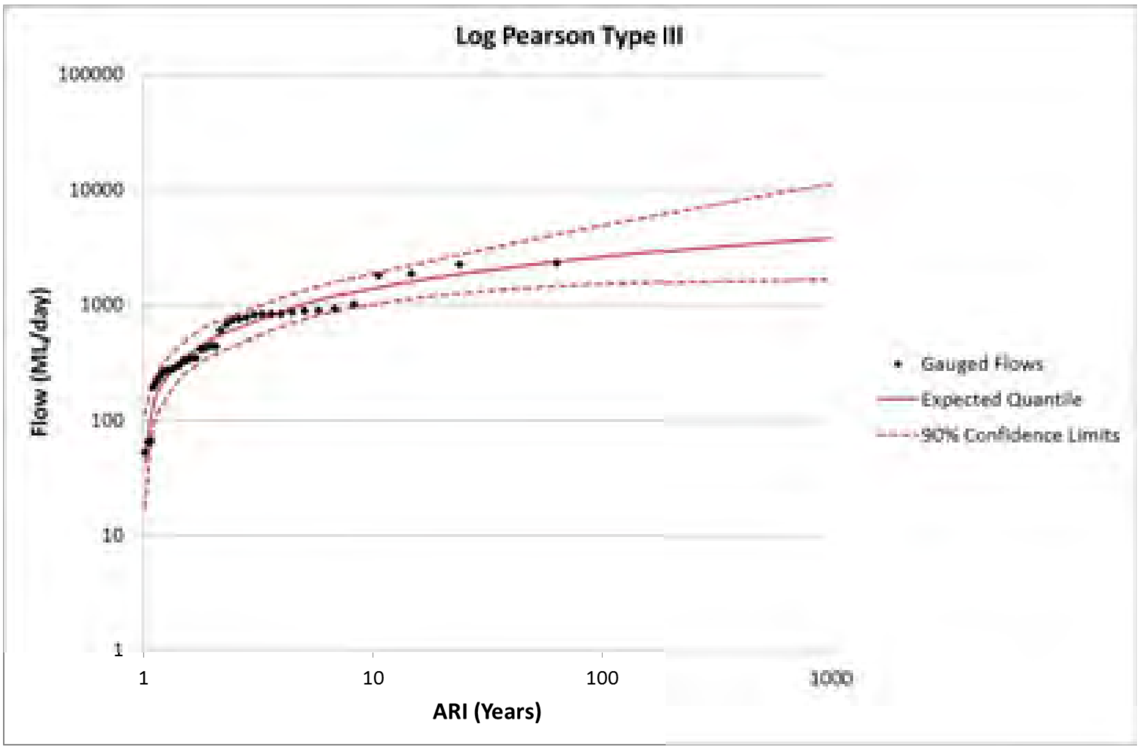


Figure 4-9 FFA Results: Fyans Creek at Lake Bellfield - LP3 Fitting

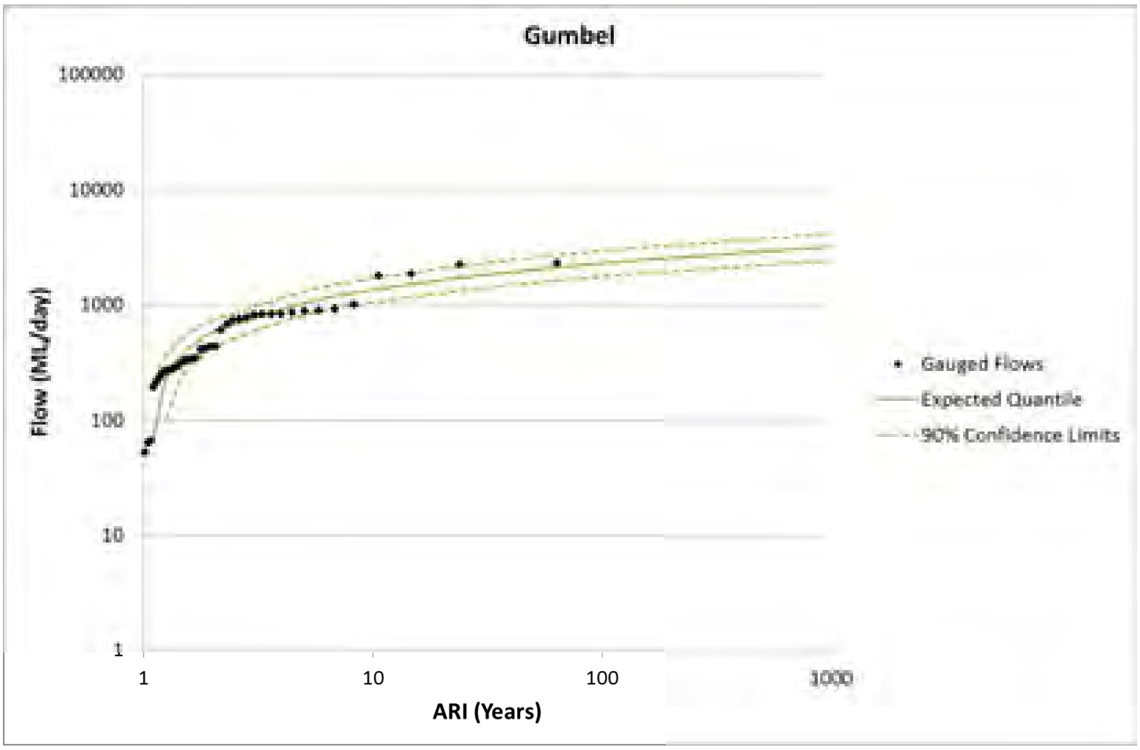


Figure 4-10 FFA Results: Fyans Creek at Lake Bellfield - Gumbel Fitting

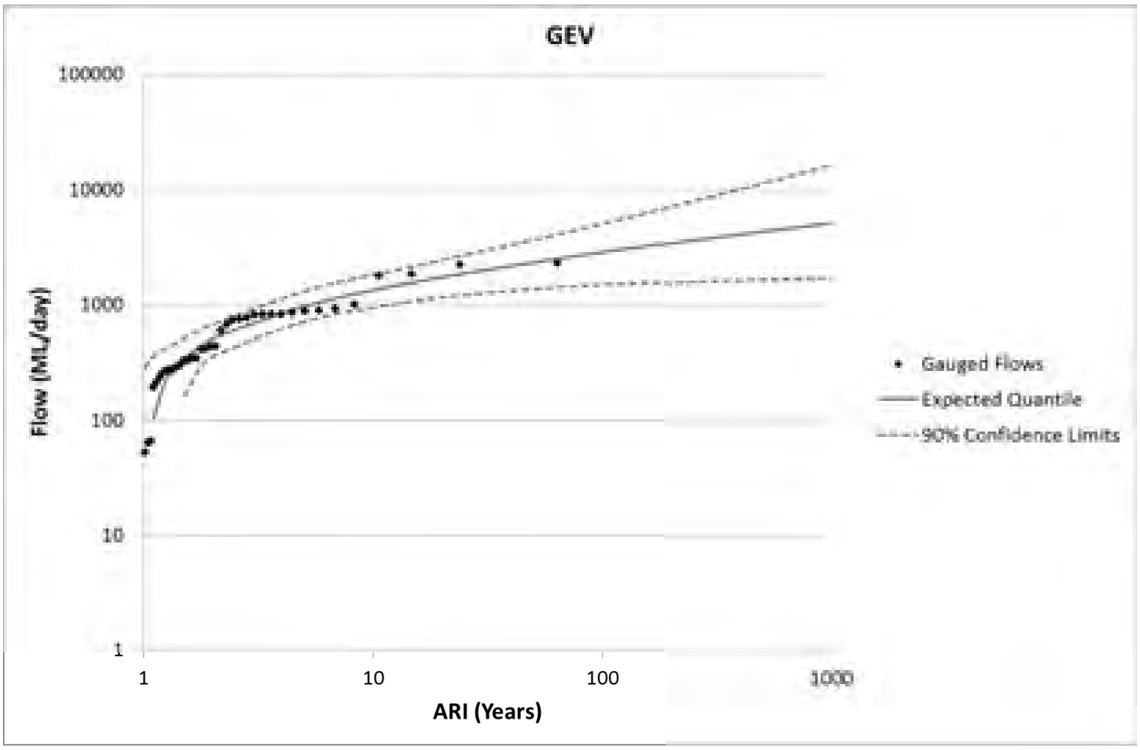


Figure 4-11 FFA Results: Fyans Creek at Lake Bellfield - GEV Fitting

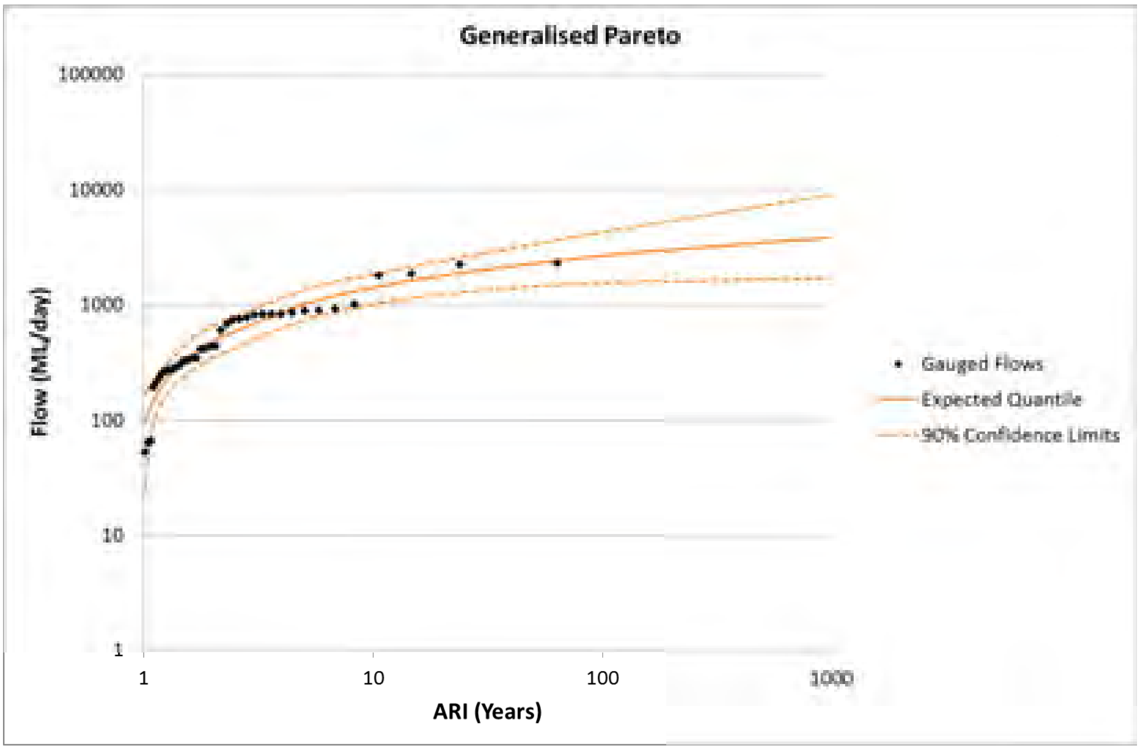


Figure 4-12 FFA Results: Fyans Creek at Lake Bellfield - Generalised Pareto Fitting

4.1.3.6 Results – 415250 Fyans Creek at Fyans Creek

The FFA was undertaken for Fyans Creek at Fyans Creek using the annual maximum data listed in Table 4-4.

Inspection of the results presented in Figure 4-13 to Figure 4-17 indicates that acceptable fits are provided by all distributions.

Whilst the Log Normal (Figure 4-13), Log Pearson Type III (Figure 4-14), GEV (Figure 4-16) and Generalised Pareto (Figure 4-17) distributions provide acceptable fits, the Log Pearson Type III is preferred as the fit to the overall record, with particular emphasis only the high flows, is better. The results for the Log Pearson Type III distribution are shown in Table 4-10. This table lists the 1 in 100 year ARI peak discharge as 11,932 ML/day.

Table 4-10 415250 Fyans Creek at Fyans Creek: Flood Frequency Analysis Results

ARI	Expected Quantile (ML/day)	90% Quantile Probability Limits	
5	1685	959	3041
10	2912	1443	6204
20	4666	1918	12813
50	8130	2532	33342
100	11932	2964	69353

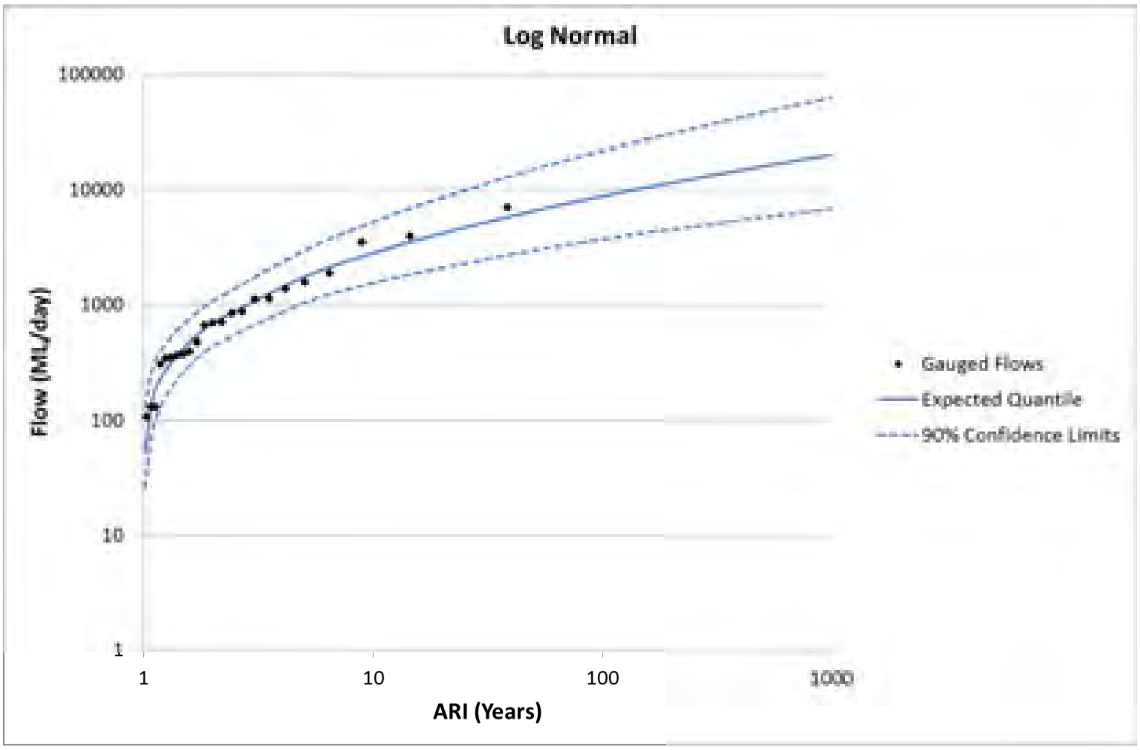


Figure 4-13 FFA Results: Fyans Creek at Fyans Creek - Log Normal Fitting

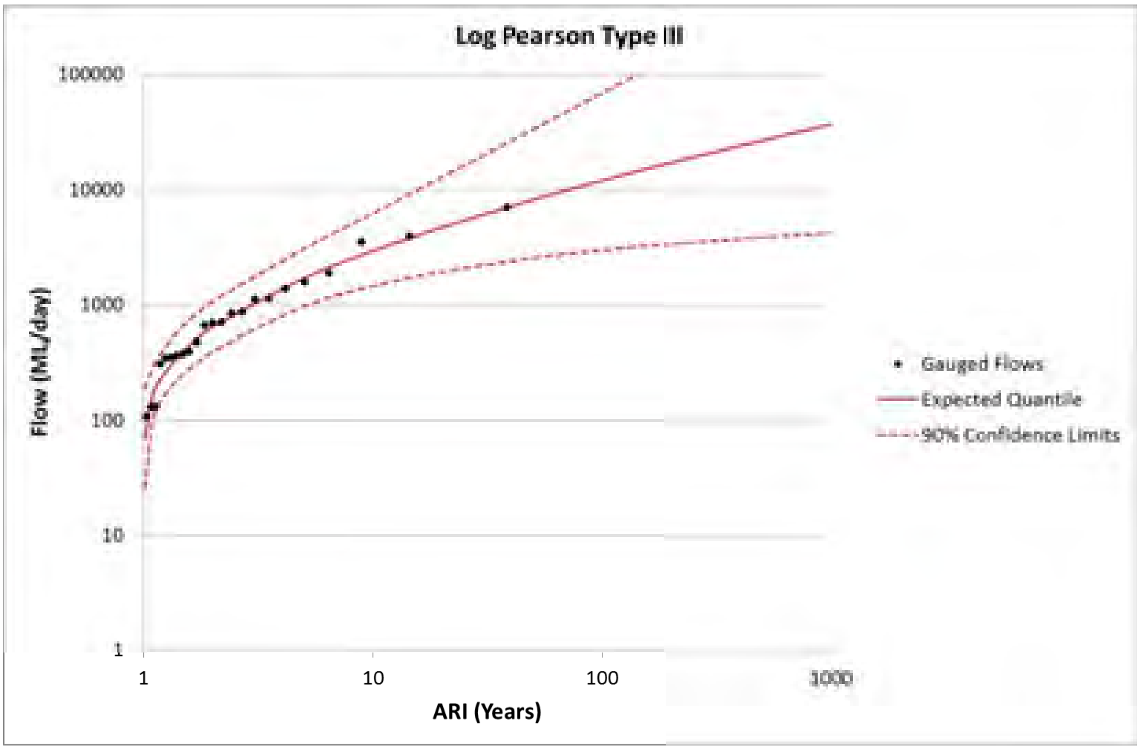


Figure 4-14 FFA Results: Fyans Creek at Fyans Creek - LP3 Fitting

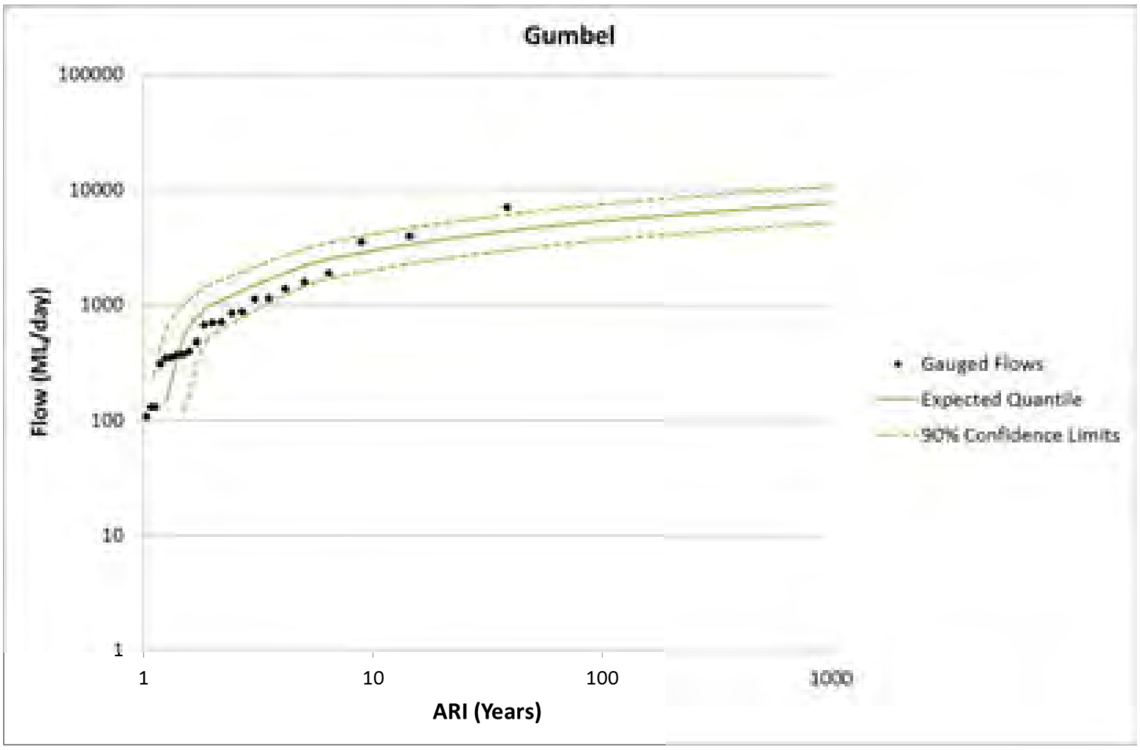


Figure 4-15 FFA Results: Fyans Creek at Fyans Creek - Gumbel Fitting

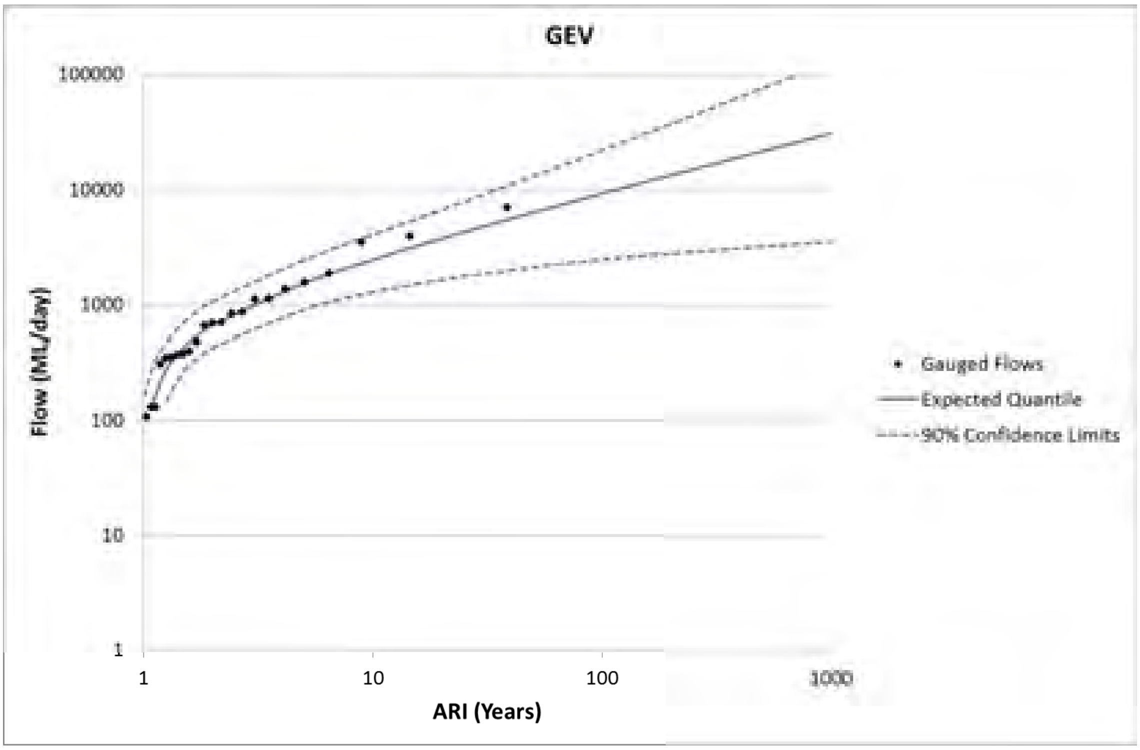


Figure 4-16 FFA Results: Fyans Creek at Fyans Creek - GEV Fitting

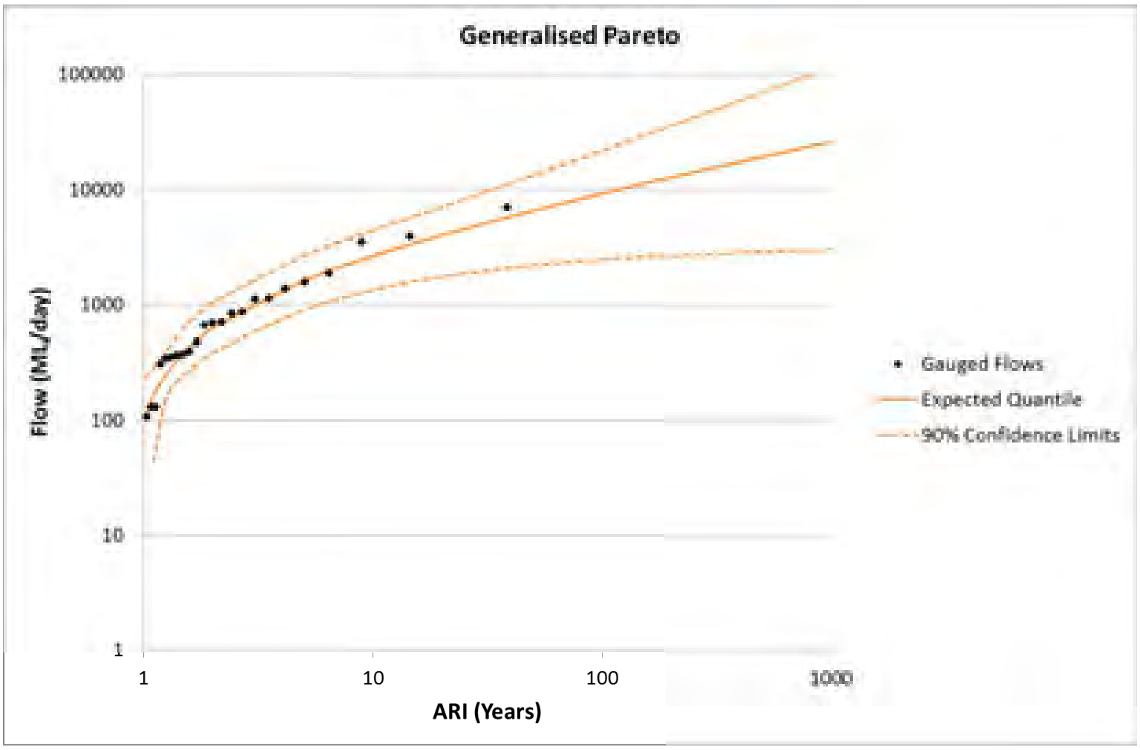


Figure 4-17 FFA Results: Fyans Creek at Fyans Creek - Generalised Pareto Fitting

4.1.3.7 Results – 415252 Mount William Creek at Mokepilly

The FFA was undertaken for Mount William Creek at Mokepilly using the annual maximum data listed in Table 4-5.

Inspection of the results presented in Figure 4-18 to Figure 4-22 indicates that acceptable fits are provided by all distributions.

The GEV distribution (Figure 4-21) has been selected as the preferred fit. Whilst the GEV and LP3 distributions are fairly similar for the more frequent flood events, the expected quantiles of the GEV model increase more dramatically for the less frequent events when compared to the LP3 distribution. The results for the GEV distribution are shown in Table 4-8. This table lists the 1 in 100 year ARI peak discharge as 25037 ML/day.

Table 4-11 415252 Mount William Creek at Mokepilly: FFA Results

ARI	Expected Quantile (ML/day)	90% Quantile Probability Limits	
5	3733	2307	6765
10	6321	3734	17064
20	9921	5113	42042
50	17026	6722	140728
100	25037	7753	349384

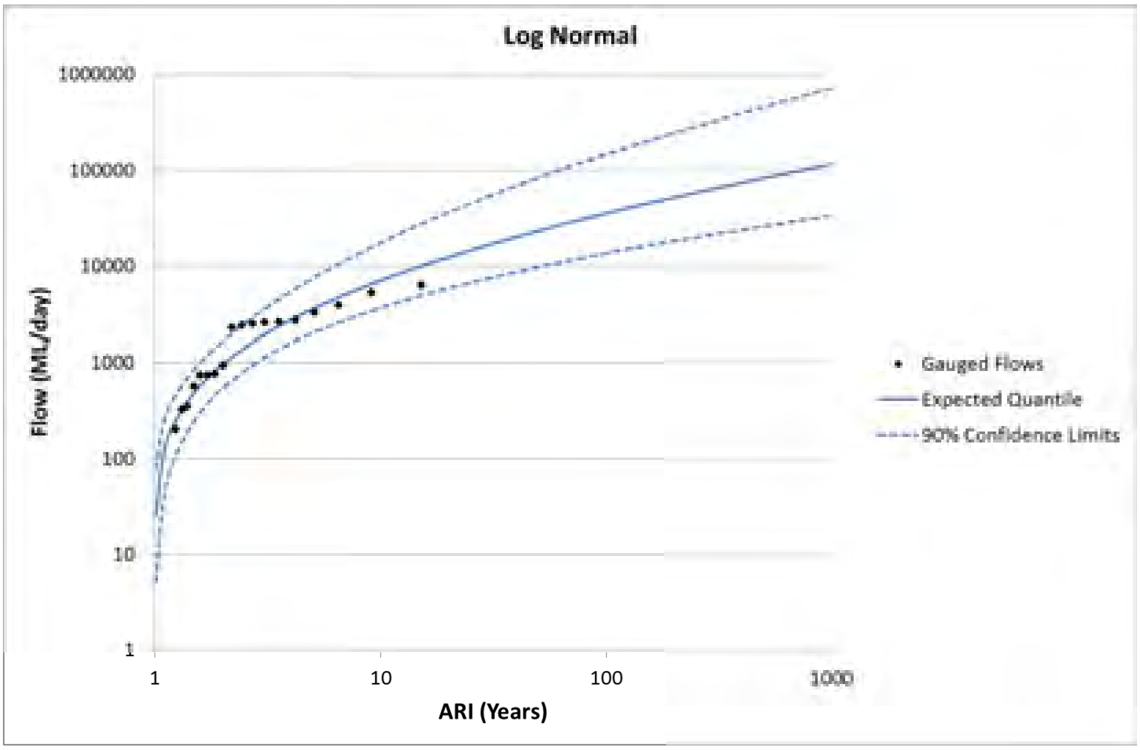


Figure 4-18 FFA Results: Mount William Creek at Mokepilly - Log Normal Fitting

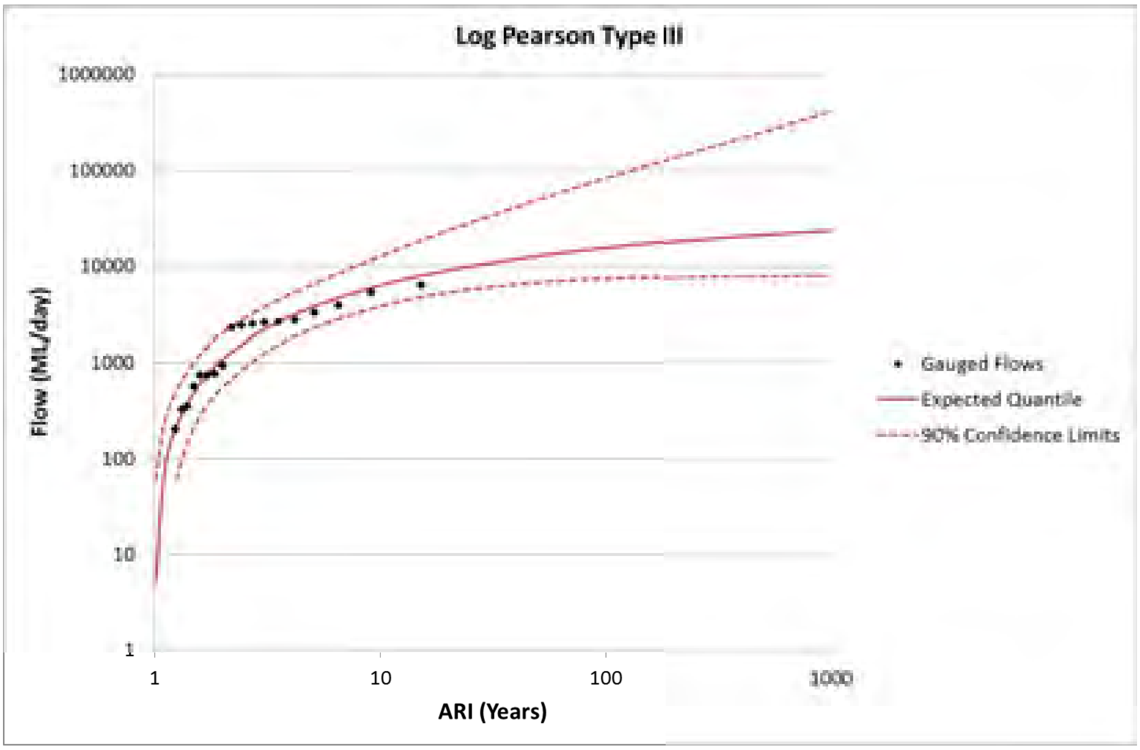


Figure 4-19 FFA Results: Mount William Creek at Mokepilly - LP3 Fitting

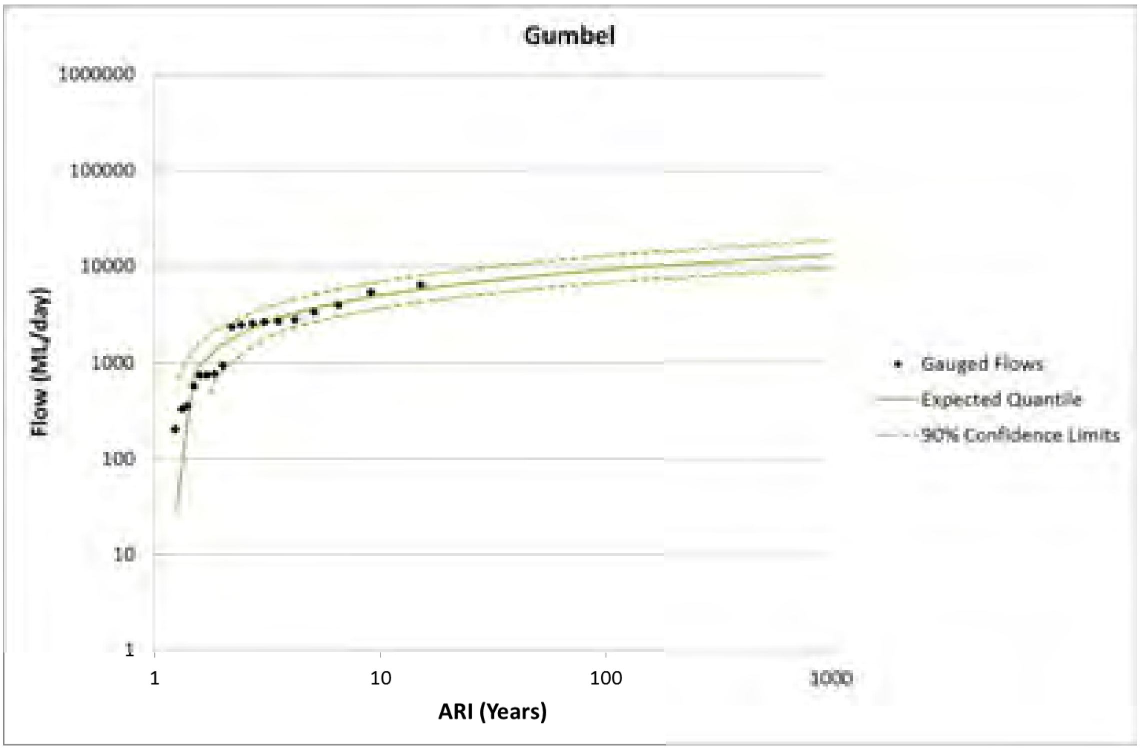


Figure 4-20 FFA Results: Mount William Creek at Mokepilly - Gumbel Fitting

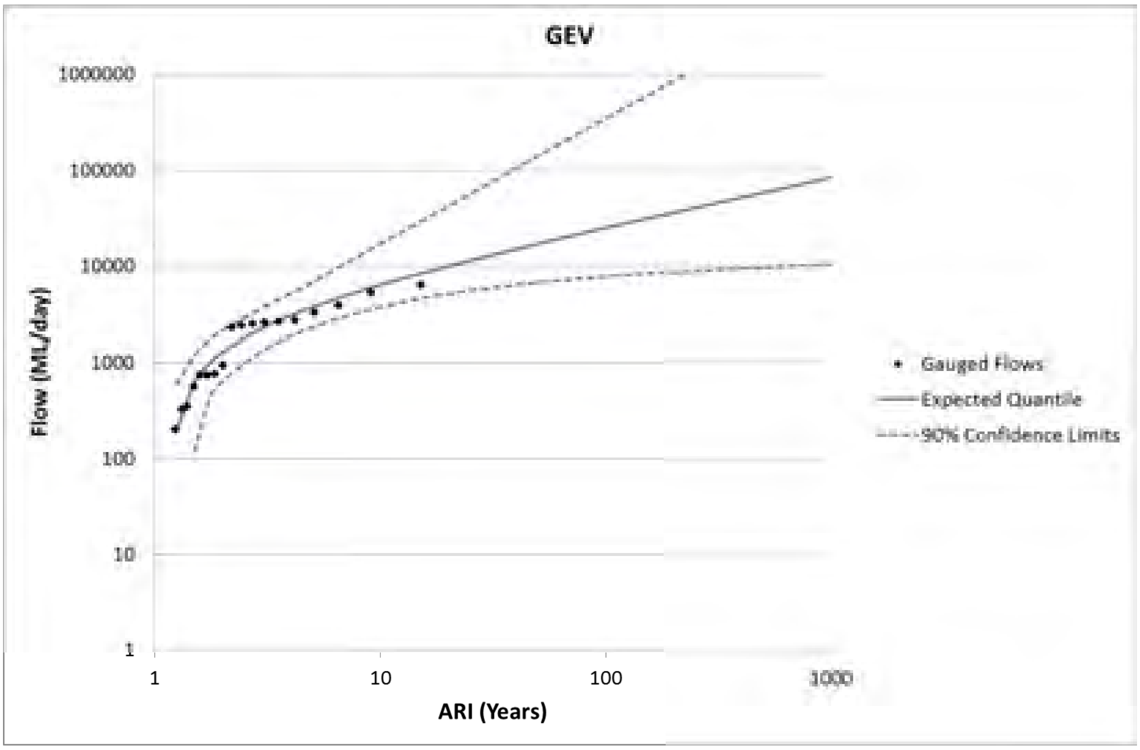


Figure 4-21 FFA Results: Mount William Creek at Mokepilly - GEV Fitting

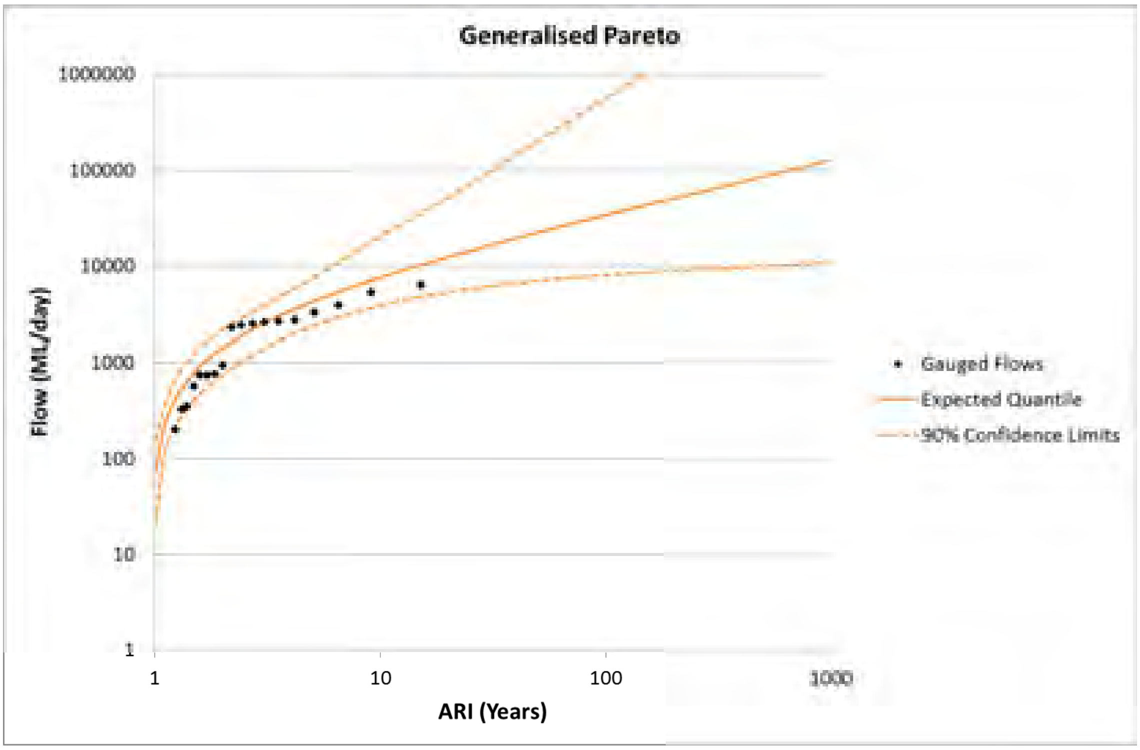


Figure 4-22 FFA Results: Mount William Creek at Mokepilly - Generalised Pareto Fitting

4.1.3.8 Results – Mount William Creek at Lake Lonsdale (Tail Gauge)

The FFA was undertaken for Mount William Creek at Lake Lonsdale (Tail Gauge) using the annual maximum data listed in Table 4-6. Additionally, the 1909 flood event was included in the analysis as the second largest event to have occurred in the gauge record. Inspection of the results presented in Figure 4-23 to Figure 4-27 indicates that acceptable fits are provided by all distributions, with the exception of the Gumbel distribution (Figure 4-25). However, all the remaining distributions contain gauged flows outside of the 90% confidence intervals.

The GEV distribution (Figure 4-26) has been selected as the preferred fit as the two highest gauged flows within the record have the best fit to the expected quantile. The results for the Log Pearson Type III distribution are shown in Table 4-12. This table lists the 1 in 100 year ARI peak discharge as 24576 ML/day.

Table 4-12 Mount William Creek at Lake Lonsdale: Flood Frequency Analysis Results

ARI	Expected Quantile (ML/day)	90% Quantile Probability Limits	
5	1628	1215	2238
10	3242	2284	5011
20	6105	3854	11707
50	13590	6934	37437
100	24576	10415	91644

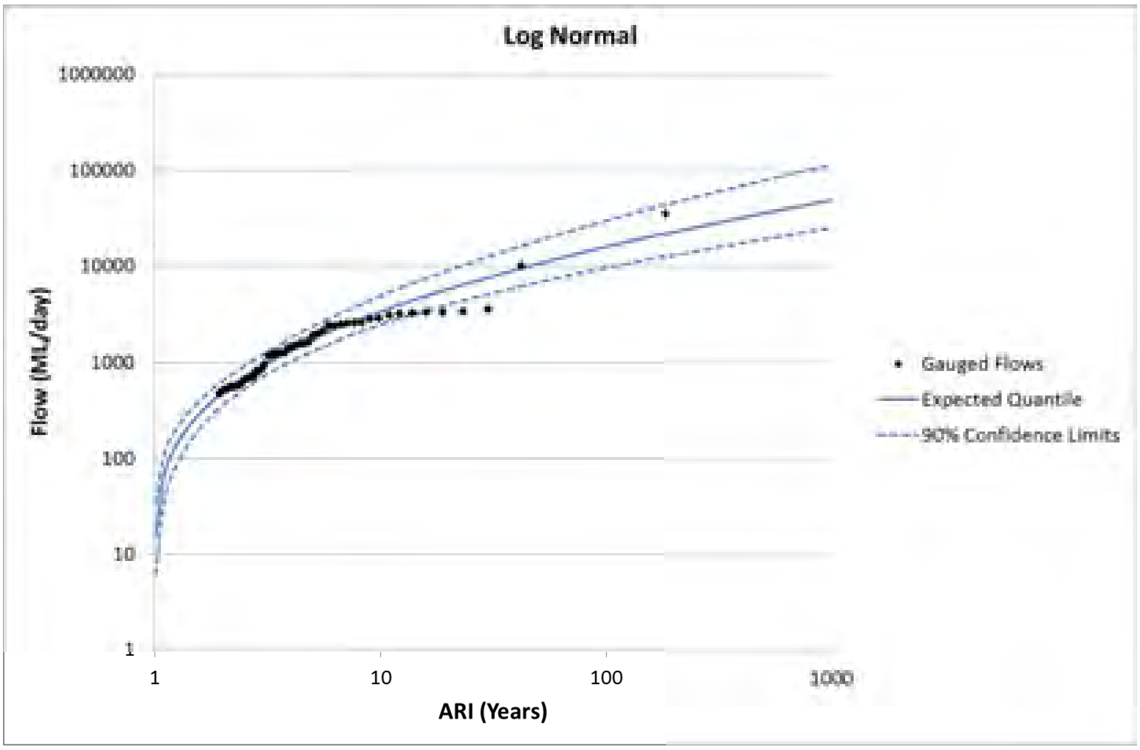


Figure 4-23 FFA Results: Mount William Creek at Lake Lonsdale (Tail Gauge) - Log Normal Fitting

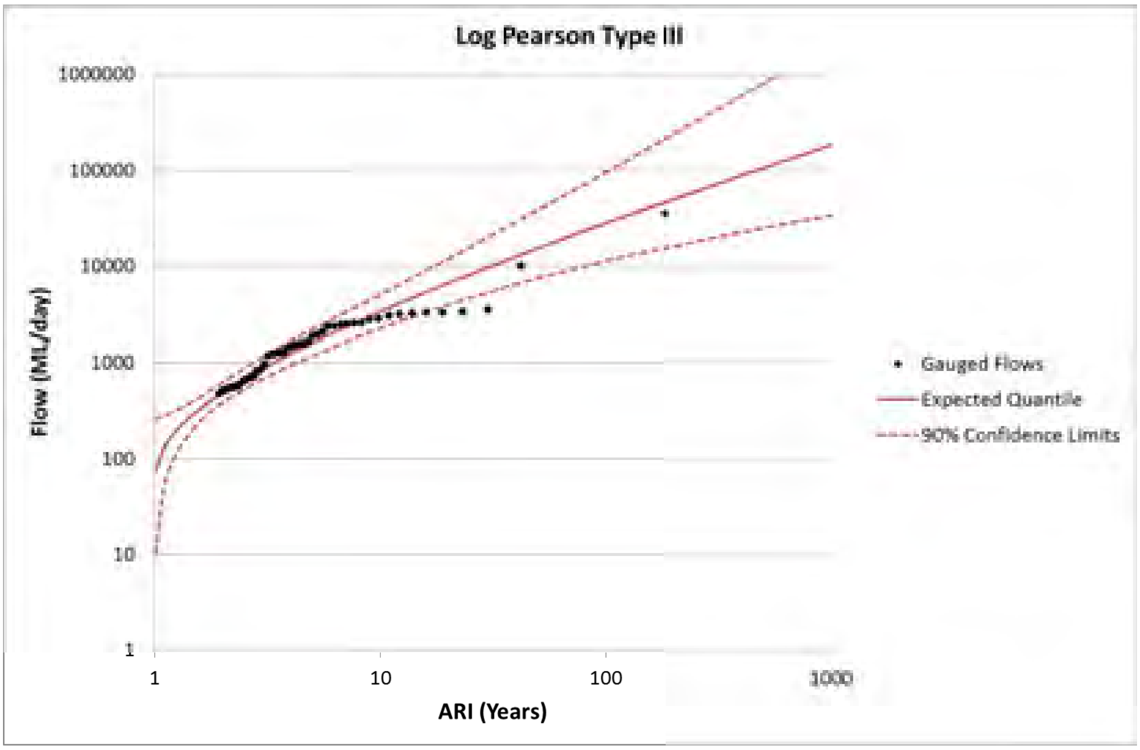


Figure 4-24 FFA Results: Mount William Creek at Lake Lonsdale (Tail Gauge) - LP3 Fitting

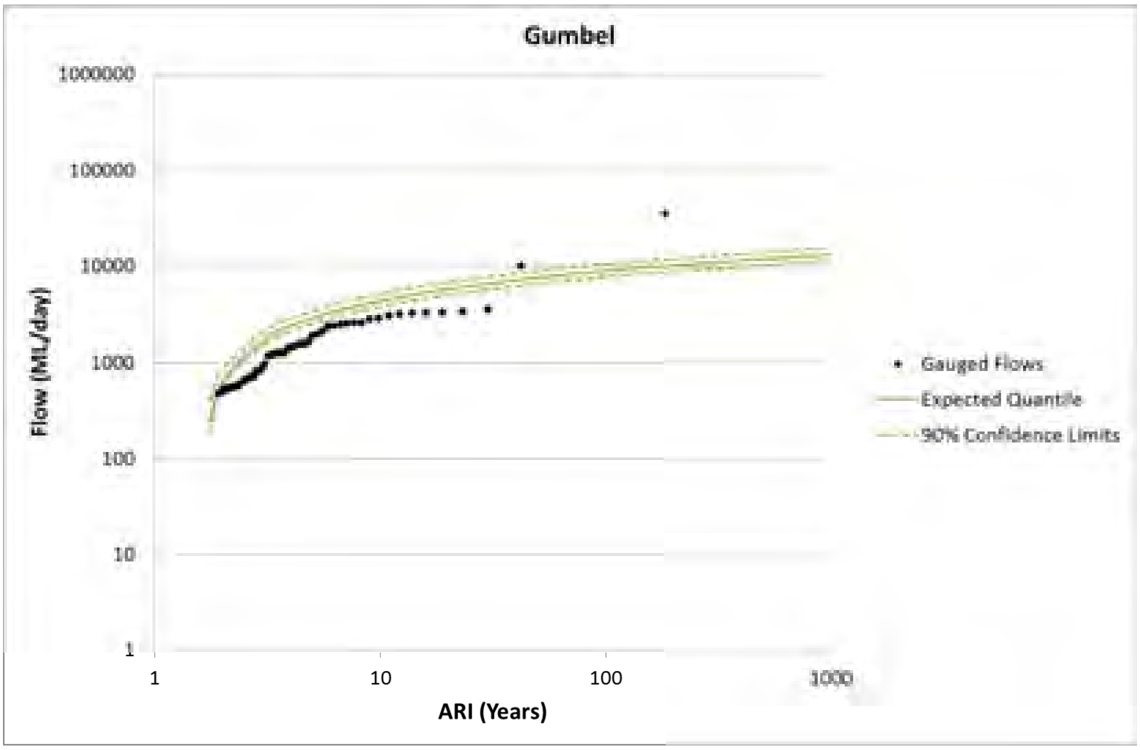


Figure 4-25 FFA Results: Mount William Creek at Lake Lonsdale (Tail Gauge) - Gumbel Fitting

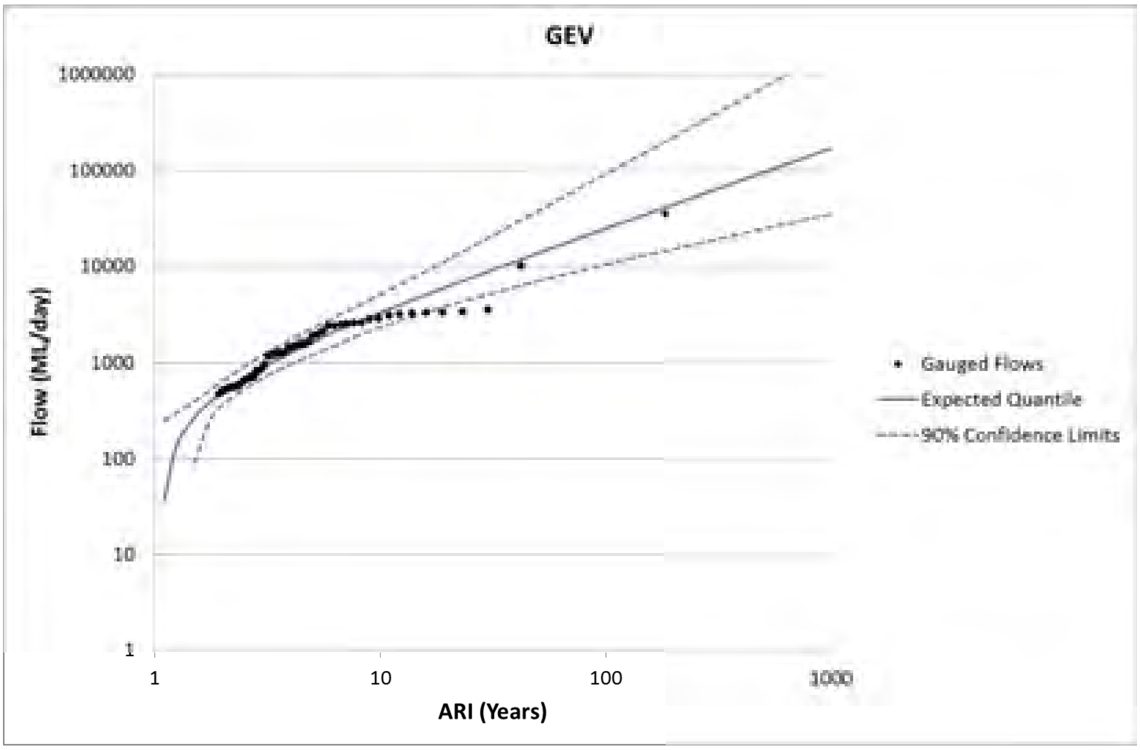


Figure 4-26 FFA Results: Mount William Creek at Lake Lonsdale (Tail Gauge) - GEV Fitting

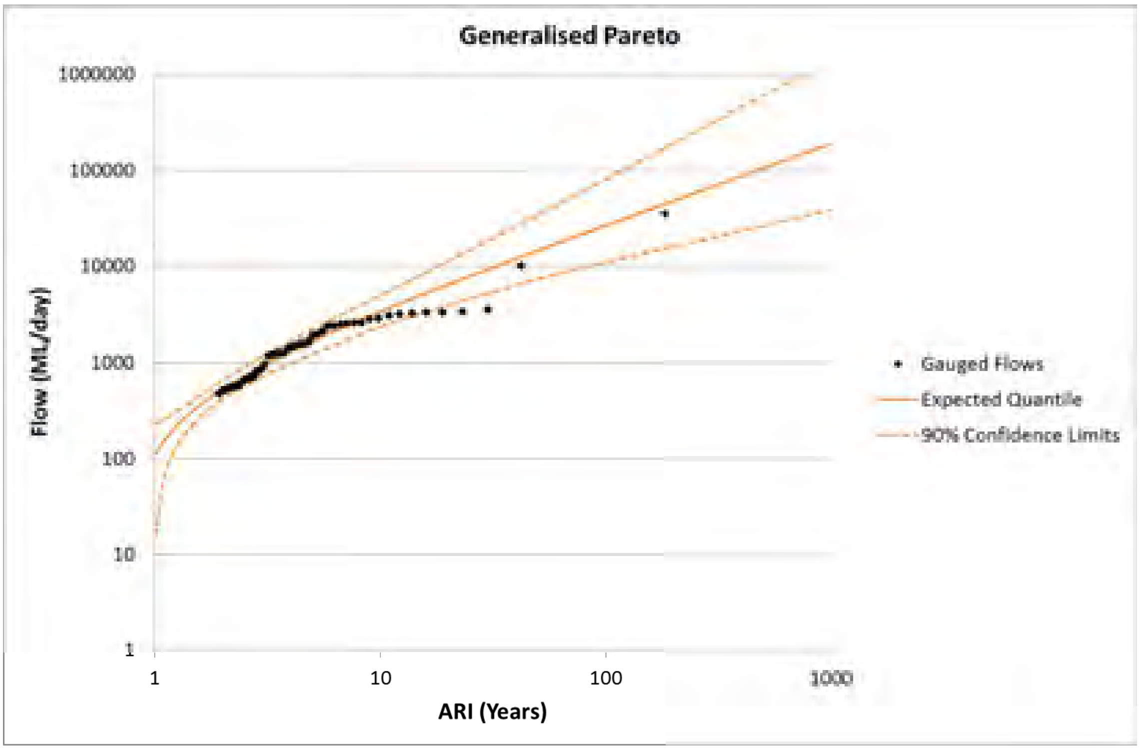


Figure 4-27 FFA Results: Mount William Creek at Lake Lonsdale (Tail Gauge) - Generalised Pareto Fitting

4.1.4 Uncertainty of FFA

The record length of a stream gauge is one of the key considerations in determining the uncertainty of flow estimate for rare flood events. In general, the longer the stream record, the greater the certainty will be regarding flow estimates for rare events. For the gauge on Mount William Creek at Lake Lonsdale (Tail Gauge), the record length is 110 years, so it would be expected that there would be reasonable confidence in the estimates of flow derived from a FFA up to the 1 in 100 year ARI flood.

However, for this gauge, this is still considerable uncertainty in the estimate of the rare flood events and this uncertainty can be explained by the presence of the large storage (Lake Lonsdale) immediately upstream of the stream gauge. The operation of the Lake and the available storage during a flood event has a significant impact on the flows recorded downstream. This in turn impacts upon the flows derived from the flood frequency analysis.

An example of this influence can be seen in the gauged flows which are plotted in each of the figures in Section 4.1.3.8. The two largest flows in these plots are the January 2011 and May 1974 flood events with peak flows at the gauge of 35556 ML/day and 9987 ML/day respectively. For the May 1974 flood event, Lake Lonsdale was full prior to the flood event resulting in minimal storage availability and attenuation of flows through the Lake. However, for the January 2011 flood event, the Lake had available storage. If Lake Lonsdale had been full, the outflows during the January 2011 event would have been noticeably higher than what was recorded.

4.1.5 Discussion

The results from the analysis for Mount William Creek at Lake Lonsdale (Tail Gauge) (refer to Table 4-12) lists the 1 in 100 year ARI peak discharge as 24576 ML/day.

The gauging record at Lake Lonsdale (Tail Gauge) is of sufficient length (69 years of instantaneous records, plus an additional 33 years of mean daily flow records, plus an additional 7 years of maximum 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 maximum ARI 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 in 100 year ARI flood event is the largest event that should be estimated by frequency analysis.

Whilst the analysis of the gauging record at Lake Lonsdale (Tail Gauge) indicates that the January 2011 flood event is approximately between the 1 in 100 and 1 in 200 year ARI flood event (the ARI of the event has been determined to be a 1 in 184 year ARI flood event), the event discharge of 24576 ML/day also falls within the 90% confidence limits of both the 1 in 50 year and 1 in 200 year flood events. This indicates a level of uncertainty in the estimates of peak discharge for rare events at this location.

4.2 Regional Flood Frequency Analysis

Regional Flood Frequency Estimates (RFFE) was completed at the Fyans Creek, Mokepilly and Lake Lonsdale stream gauges (shown in Figure 1-2) and the results listed in Table 4-13. This has been completed using the methodology developed as part of Project 5 of the ARR revision, and which was released in December 2012 as a test version. This method uses catchment area and design rainfall intensity as predictor variables and calculates flood quantiles for a number of AEP events together with uncertainty bounds. The model coefficients are estimated from a set of nearby gauged catchments (region-of-influence approach) using Bayesian generalised least squares (GLS) regression. The model coefficients have been estimated at over 600 gauged catchment locations in Australia including Victoria. A leave-one-out validation technique has shown that the method provides accurate flood quantile estimates over a wide range of circumstances (Rahman et al, 2012).

The results from the ARR RFFE Model 2012 (test version) are presented in Table 4-13 together with key catchment characteristics. It should be noted that the ARR RFFE Model is currently being updated and will change in the near future, however, this revised model is not currently available.

Table 4-13 RFFE Results

Location	Catchment Area	Flows (ML/day)		
		Lower CL	Upper CL	Estimate
Fyans Creek at Fyans Creek	130.52 km^2	5262	41947	14861
Mount William Creek at Mokepilly	564.44 km^2	8545	68092	24132
Mount William Creek at Lake Lonsdale	971.02 km^2	12735	101468	35960

4.2.1 Discussion

The results from the site flood frequency analysis have been compared to the results from the regional flood frequency analysis and are presented in Table 4-14. With the exception of the Mount William Creek at Mokepilly site, the regional flood frequency estimates are noticeably higher than those derived from the stream gauging information. The comparison at the Mount William Creek at Mokepilly site is very good. One of the key reasons behind these results is the inability of the regional flood frequency estimates to include the influence of storages within the catchment (Lake Bellfield is located upstream of the Fyans Creek gauge and Lake Bellfield and Lake Lonsdale are located upstream of the Lake Lonsdale gauge). Consequently, for these sites (Fyans Creek and Lake Lonsdale), the regional flood frequency estimates are higher than the site based flood frequency analysis as the stream gauging records inherently includes the influences of the water storage.

Table 4-14 Comparison of Site FFA and RFFA Results

Location	Site FFA Estimate (ML/day)	RFFE (ML/day)	Difference
Fyans Creek at Fyans Creek	11932	14861	20%
Mount William Creek at Mokepilly	25037	24132	-4%
Mount William Creek	24576	35960	32%

Location	Site FFA Estimate (ML/day)	RFFE (ML/day)	Difference
at Lake Lonsdale			

4.3 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;

$$S = 3600kQ^m$$

where 'S' represents the storage (m^3), 'Q' is the discharge (m^3/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.

4.3.1 Model Description

The RORB model incorporates an area of approximately 1,450 square kilometres. To ensure accurate representation of the hydrological response of the overall catchment, the model was divided into 94 individual sub-catchments. Conceptual reaches (approximate overland flow paths) were defined and five recorded hydrograph locations (Fyans Creek at Lake Bellfield, Grampians Road Bridge and Fyans Creek and Mount William Creek at Mokepilly and Lake Lonsdale) were included for calibration purposes.

Lake Bellfield, Lake Fyans and Lake Lonsdale were represented in the RORB as storage reservoirs. The details for Lake Bellfield were taken from the updated RORB model developed as part of the Halls Gap Flood Study (Water Technology, 2008). The details for Lake Fyans and Lake Lonsdale were taken from stage-storage relationships and operations manuals provided by Grampians Wimmera Mallee Water. Other formal storages identified in the catchment (farm dams, etc), were determined not to be large enough to significantly affect the runoff from the catchment during large storm events. Consequently, there were no other storages included in the hydrologic model.

4.3.2 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 94 individual sub-catchments. The sub-catchment breakdown is shown in Figure 4-28.

4.3.3 Reach Types

The Mount William Creek catchment is predominately a rural catchment with areas of State and National Park and rural townships. Engineered channels exist within the catchment in the form of

GWM Water's channels, however, it is the natural channel system which conveys the bulk of the water during high flows. As such throughout the RORB model Reach Type 1, which is applicable for natural channels, was used.

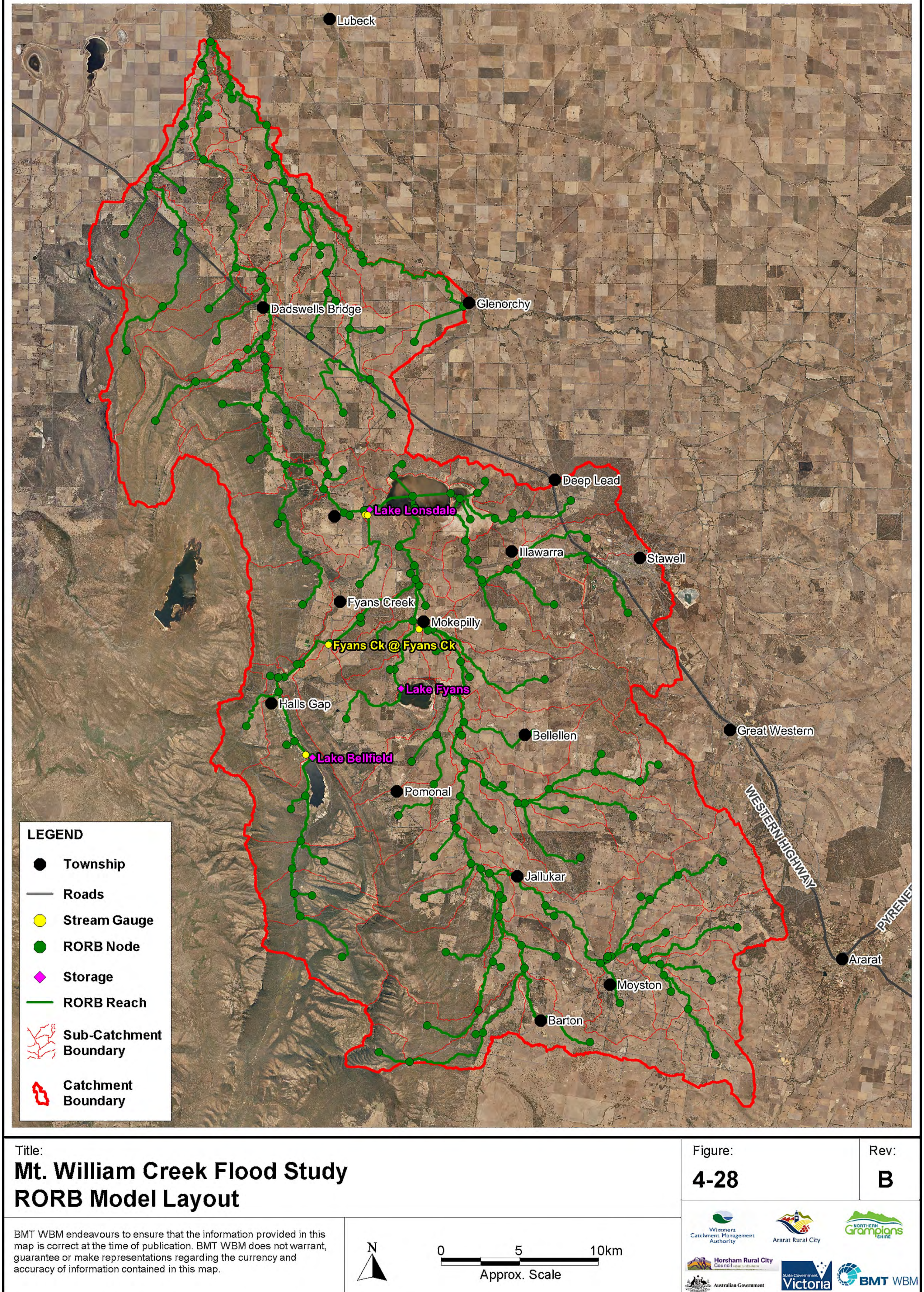
Reach alignments are shown in Figure 4-28.

4.3.4 Fraction Impervious

Whilst the Mount William Creek catchment is predominately a rural catchment, a number of fraction impervious values were adopted for this study for other land-use types such as areas of state park and rural townships. The adopted values are shown in Table 4-15, and are consistent with previous studies undertaken for the WCMA. 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 4-15 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:

Mt. William Creek Flood Study
RORB Model Layout

Figure: **4-28**

Rev: **B**

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4.4 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.

4.4.1 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) Undertake further iterative calibration as part of a joint calibration process with the hydraulics model, if required.

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

4.4.2 Stream Gauge Information

The same five gauges used in the FFA will be used in the RORB calibration; Fyans Creek at Lake Bellfield, Grampians Road Bridge and Fyans Creek and Mount William Creek at Mokepilly and Lake Lonsdale. Whilst all stream gauges were operational for the most recent flood event (January 2011), not all of the streamflow gauges have continuous records covering some of the other significant flooding events to occurred in the catchment.

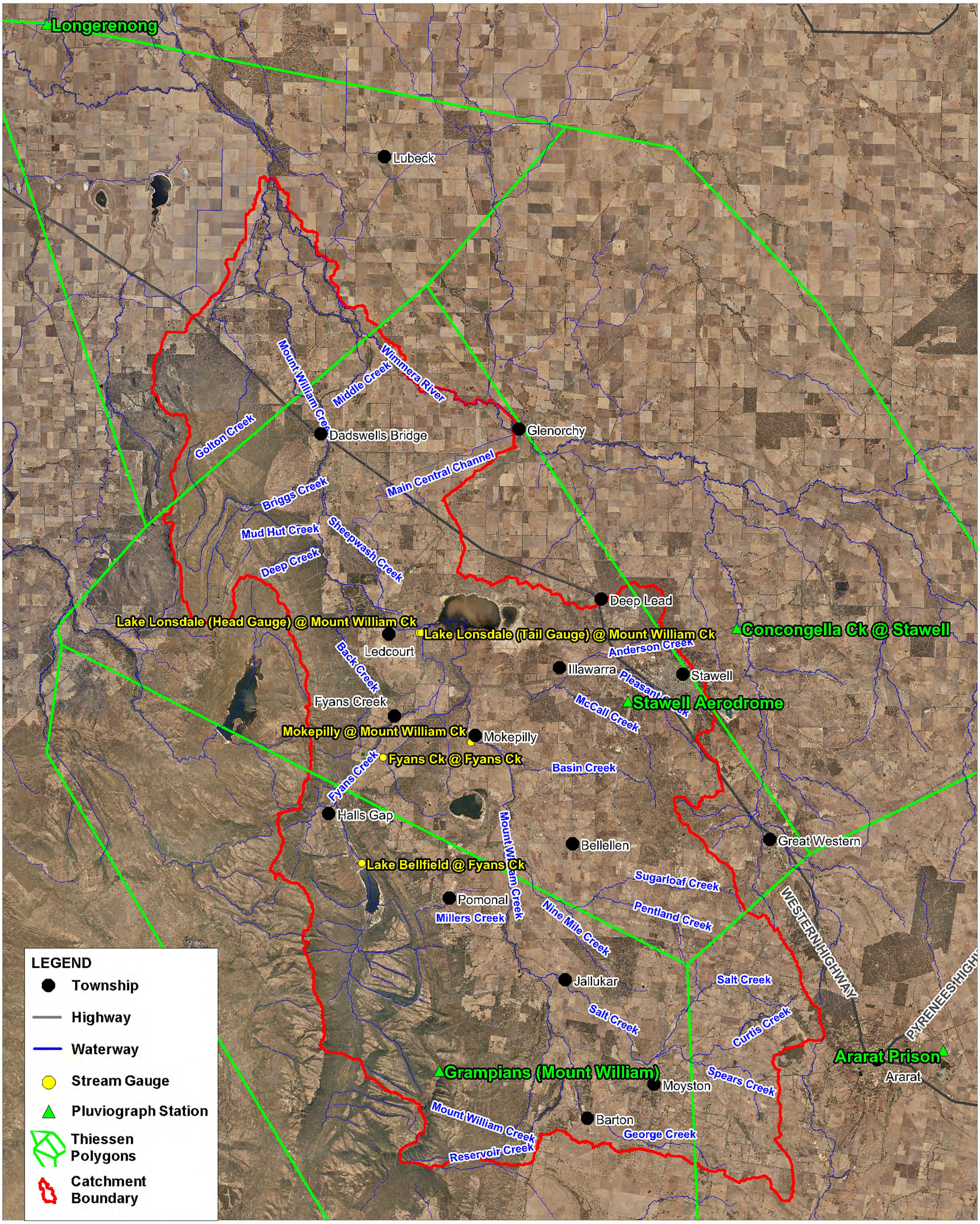
4.4.3 Rainfall Selection and Distribution

There are six pluviograph stations as shown in Figure 4-29 and 21 daily rainfall stations located in and around the study catchment, as shown in Figure 4-29.

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.

The relevant pluviographs that covered the selected events 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:

Mt. William Creek Flood Study
Stream Gauge and Pluviograph Stations (January 2011)

Figure: 4-29

Rev: B

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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Approx. Scale

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

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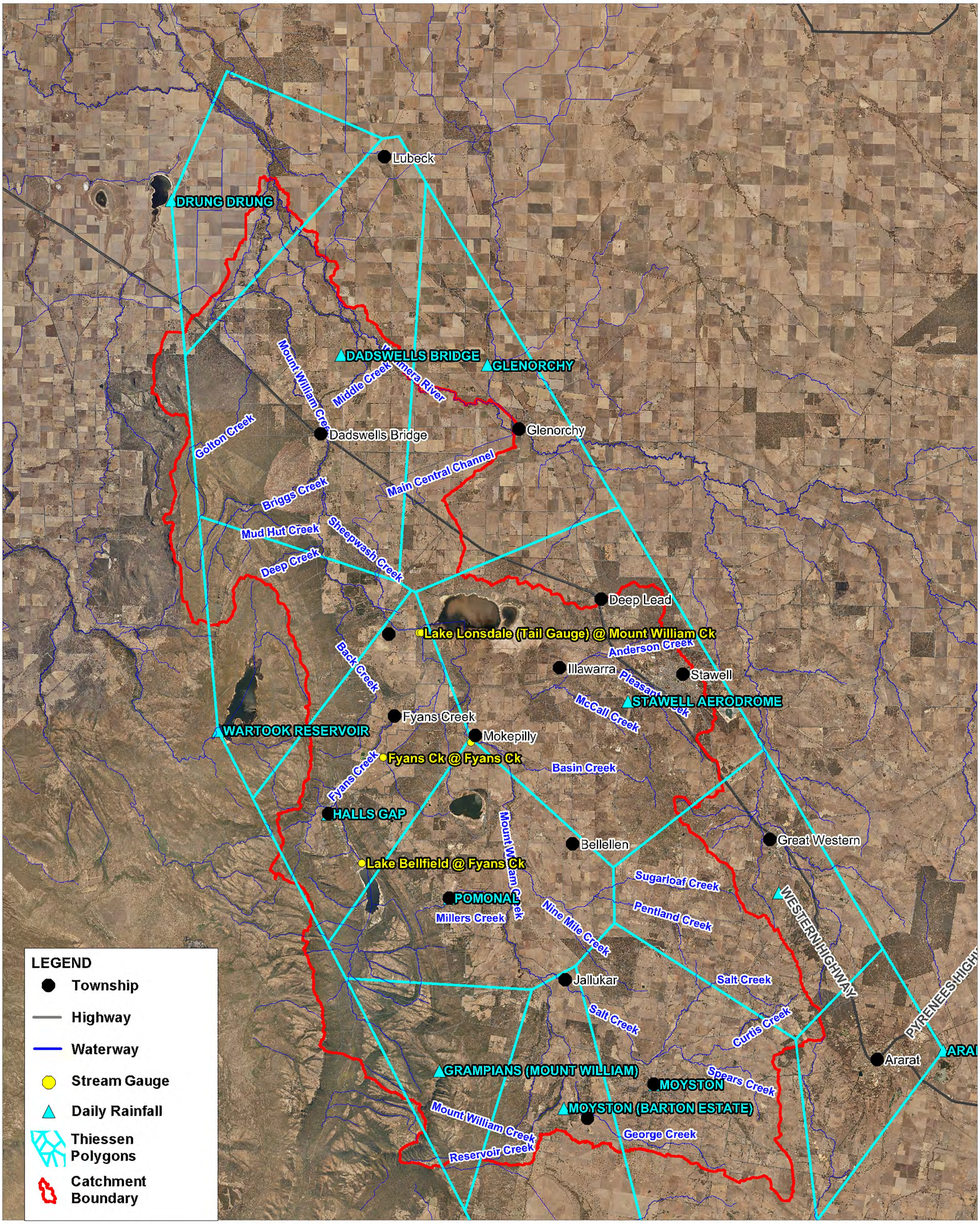

Title:

Mt. William Creek Flood Study
Stream Gauge and Rainfall Stations (January 2011)

Figure: 4-30

Rev: B

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4.4.4 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 Mt William Creek catchment is of the order of 1 - 2 days, whilst the response in the lower catchment could be of the order of 2-5 days depending on the available storage within Lake Lonsdale. It was 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 Mount William Creek catchment which have impacted upon the township of Dadswells Bridge, Moyston and Pomonal amongst others. Unfortunately the amount of data captured for historical events is less than that available for the more recent events which have limited the events that can be used in the calibration and validation process.

As described in the above section there are six stream gauges located within the study catchment, five of which were used in the RORB model calibration and validation process. The Fyans Creek at Lake Bellfield stream gauge was used as an inflow hydrograph to the hydrologic model in order to accurately represent the controlled releases from Lake Bellfield during the calibration and validation events. Consequently the Fyans Creek at Grampians Road Bridge stream gauge, which is located upstream of Lake Bellfield, was not used in the calibration/validation process.

During the investigation of historical flooding and the flood frequency analysis process (Section 4.1), it was established that the largest catchment wide flood events to have occurred since 1910 in chronological order are:

- May 1974
- December 1992;
- October 1996; and
- January 2011.

A brief summary of the hydrologic data available for these events is provided in the following section and Table 4-16 lists the availability of streamflow and rainfall data for each of these events.

4.4.4.1 Calibration and Validation Event Selection Summary

This section provides a summary of the calibration and validation flood events. As shown in Table 4-5, the January 2011 flood was the largest flood event recorded at the gauges within the catchment.

As the January 2011 event was the largest event recorded and has all pluviograph stations in operation, it was deemed the preferred event to use for calibration. The December 1992 event was selected as the second calibration event. The December 1992 event was a relatively small event compared to the January 2011 event and if a reasonable calibration could be achieved for both the smaller 1992 event as well as the largest flood (2011) it would indicate the suitability of the hydrologic model to both large as well as small events. Further, the December 1992 event has all stream gauges operational and was thus preferred over the October 1996 event which was a similar magnitude event. The fourth event considered was the May 1974 event. Although this event has the least amount of gauge information to support a calibration/validation, it was an important event to consider in the context that it was a large event in within the Mount William Creek catchment.

The May 1974 and October 1996 events were therefore used for validation events.

New pluviograph recorders were installed at Halls Gap and at the stream gauge for Concongella Creek at Stawell in the time between the 1996 and 2011 flood events. However, the additional data from these pluviographs was not used in the January 2011 calibration for the following reasons:

- The use of the Theisson Polygons to determine the sub-catchments to be allocated to each pluviograph/AWS showed that the pluviograph located on Concongella Creek at Stawell would not be of influence to the catchment. Rather the AWS gauge at Stawell Aerodrome has greater influence on the distribution of the sub-daily rainfall
- The pluviograph located in Halls Gap would provide detailed information on the rainfall that fell within the Fyans Creek valley. However, the calibration and verification models use a defined hydrograph located at the Lake Bellfield outlet (the site of the pluviograph) to apply the streamflow to the model at this location (required to accurately define controlled releases). Consequently, the influence of the pluviograph located at Lake Bellfield would be confined to the 3 sub-catchments downstream of Lake Bellfield prior to Fyans Creek leaving the Mount Difficult Range. The subcatchments beyond the Mount Difficult Range are better represented by the AWS gauge located on Mount William (the top of the range) and Stawell Aerodrome located on the Mount William Creek floodplain rather than a pluviograph located within the valley. The calibration achieved at the Fyans Creek at Fyans Creek streamgauge (refer to Section 4.4.6) supports this decision. Additionally, the pluviograph data from this gauge is not complete for the January 2011 flood event.

Table 4-16 Calibration and Validation Rainfall Event Rainfall Summary

Data Station		May 1974	December 1992	October 1996	January 2011
Pluviograph Gauge	Mirranatwa	Y	Y	Y[1]	Y
	Ararat Prison	N	Y	Y	Y
	Wartook Reservoir	Y	Y	Y[1]	Y
Automatic Weather Stations (AWS)	Grampians (Mount William)	N	N	N	Y
	Stawell Aerodrome	N	N	N	Y
	Longerenong	N	N	N	Y
Streamflow Gauge	Fyans Creek at Grampians Road Bridge[2]	Y	Y	Y	N
	Fyans Creek at Lake Bellfield[3]	Y	Y	Y	Y
	Fyans Creek at Fyans Creek	N	Y	Y	Y
	Mt William Creek at Mokepilly	N	Y	Y	Y
	Mt William Creek at Lake Lonsdale (Head Gauge)	N	Y	Y	N
	Mt William Creek at Lake Lonsdale (Tail Gauge)	Y	Y	N	Y
	Bypass Channel at Lake Lonsdale	N	N[4]	N[4]	N[4]
	Main Central Channel at Glenorchy[5]	N	Y	Y	N

[1] Gauge available, however not used (Refer to Section 4.4.8 for details)

[2] Gauge is located upstream of Lake Bellfield (which was applied to the RORB model as an inflow hydrograph, therefore not used)

[3] Gauge used as inflow hydrograph

[4] Gauge available, however, zero flow

[5] Gauge records flow entering the Main Central Channel at Glenorchy from the Wimmera River. The Wimmera River is not included in the hydrologic model and water entering the Mount William Creek catchment via the Main Central Channel is accounted for in the hydraulic modelling.

4.4.5 Calibration Parameters

The RORB parameters that are available for calibration are; k_c, *m,* and initial loss (*IL*) and continuing loss (*CL*). 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.

4.4.6 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 4-17 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 4-31 to Figure 4-33.

Table 4-17 Calibrated Parameters and Values for January 2011

Station	k_c	*m*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Fyans Creek at Fyans Creek	12	0.80	110	1.5	0.83	-5%	3%
Mount William Creek at Mokepilly	70	0.80	50	6.9	0.98	4%	18%
Mount William Creek at Lake Lonsdale Tail Gauge	20	0.80	0	0	0.76	77%	4%

The calibration resulted in a very good fit to all available gauges during this event.

The fit achieved at the Fyans Creek at Fyans Creek gauge was good. Both the modelled catchment response to the initial rainfall burst and to the larger second burst were well represented in the RORB model. This resulted in a fairly high NSE value of 0.83, with approximately 5% less volume and a peak water level 3% higher than the recorded levels.

An extremely good fit was achieved at the Mount William Creek at Mokepilly. With the exception of the peak levels the modelled catchment response was extremely well matched to the observed record. This resulted in an NSE value of 0.98 and a total volume within 4% of the observed record. This excess in volume could be accounted for by the increased peak flow. As mentioned above the peak flow rate was not well matched, with the model predicting 18% greater flows at the gauge. Inspection of Figure 4-32 shows the observed record stops increasing and maintains a steady flow of 82.16m^3/s for approximately 16 hours. This behaviour of this gauge was discussed with Theiss Hydrographic Services, who noted it “seemed unusual” and Theiss were going to review the gauge data to determine the reasons for this. In light of this, it was determined that there was likely an issue with the observed record during this period and that the modelled flow was a reasonable representation of the likely flood behaviour during this time.

However, the recorded flows at the Mokepilly gauge are to be treated with a degree of scepticism. As noted in Section 4.1.3.2, there was a malfunction with the gauge during the January 2011 flood event, resulting in the peak flow not being recorded. Additionally, the peak flow through the Mokepilly gauge is an order of magnitude lower than the flow recorded at Lake Lonsdale, despite the catchment of the Mokepilly gauge constituting over half of the catchment of Lake Lonsdale and the fact the flows into Lakes Lonsdale are likely to have been higher than the outflows, even when the Lake was full (there will still be a degree of attenuation of the flow).

The tail-gauge downstream of Lake Lonsdale on Mt William Creek resulted in the worst fit of the three available gauges. However with an NSE value of 0.71, the fit is far from poor. Inspection of Figure 4-33 indicates the flow abruptly stops on the 15th of January. As the flow over the weir at Lake Lonsdale is uncontrolled, it would indicate that there was a gauge failure may have occurred at about this time. If we exclude the records past this point the NSE increases to 0.76 with a modelled volume (up to that point) 77% greater than the observed. A significant number of variations of k_c, including those derived from the equations contained within the RORB model, and IL combinations were trialled to improve the fit of the calibration at the Lake Lonsdale gauge, however, the best fit obtained is presented in Figure 4-33, using the parameters listed in Table 4-17.

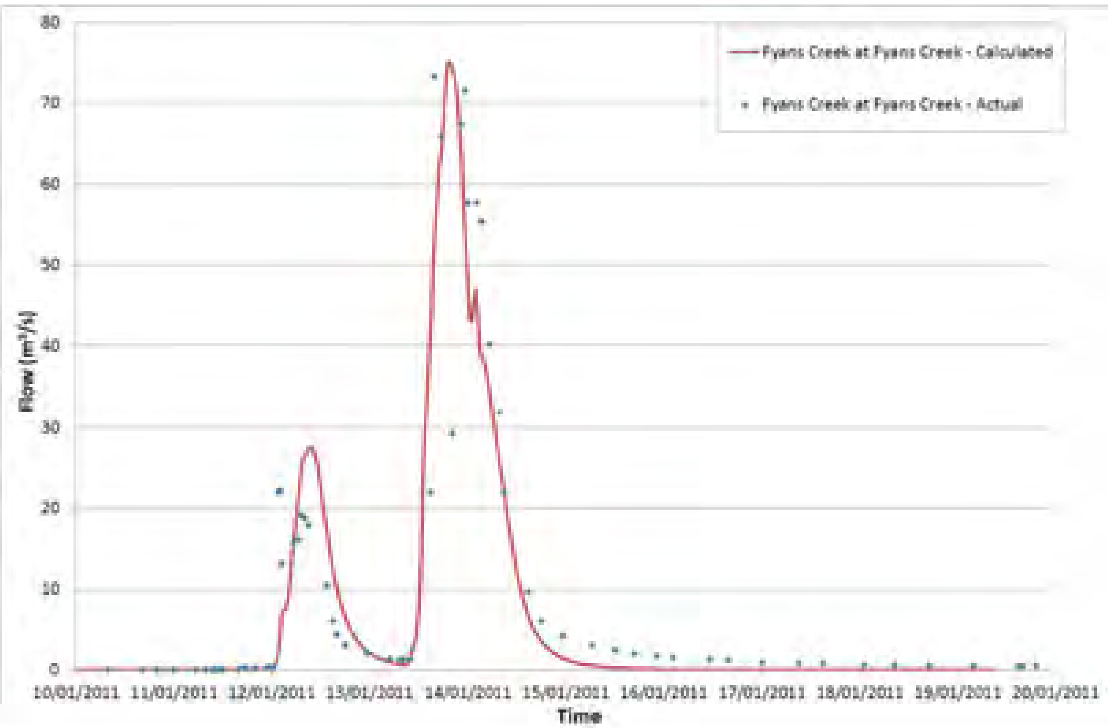


Figure 4-31 Calibrated Hydrograph Comparison for January 2011 – Fyans Creek at Fyans Creek

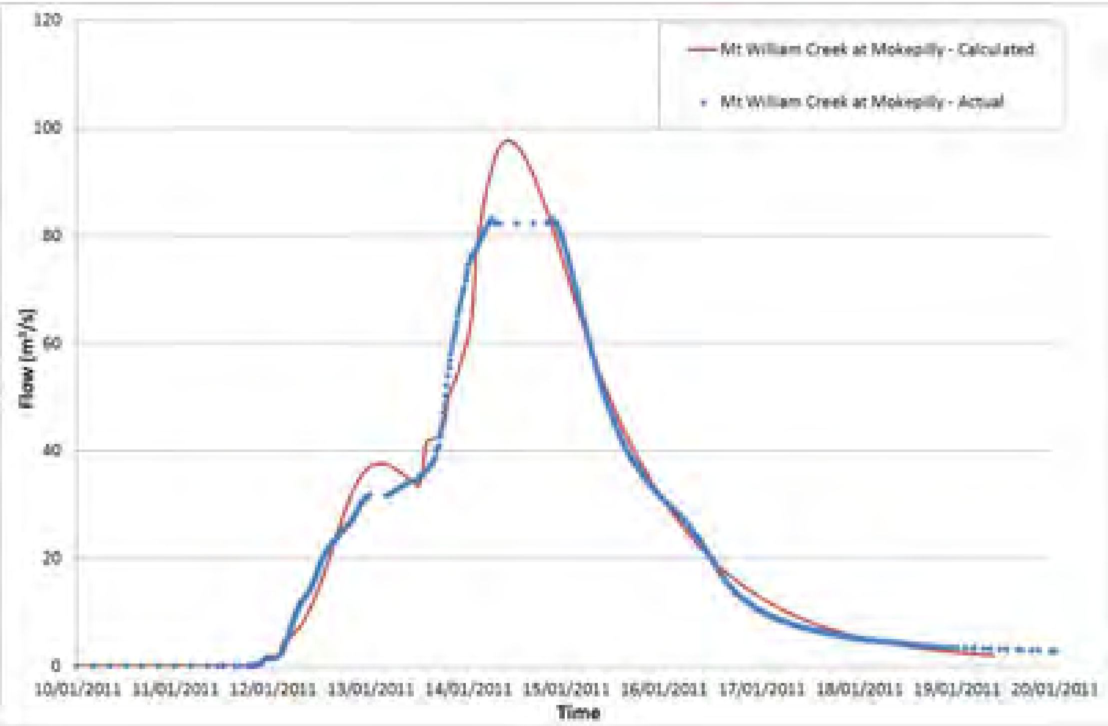


Figure 4-32 Calibrated Hydrograph Comparison for January 2011 – Mount William Creek at Mokepilly

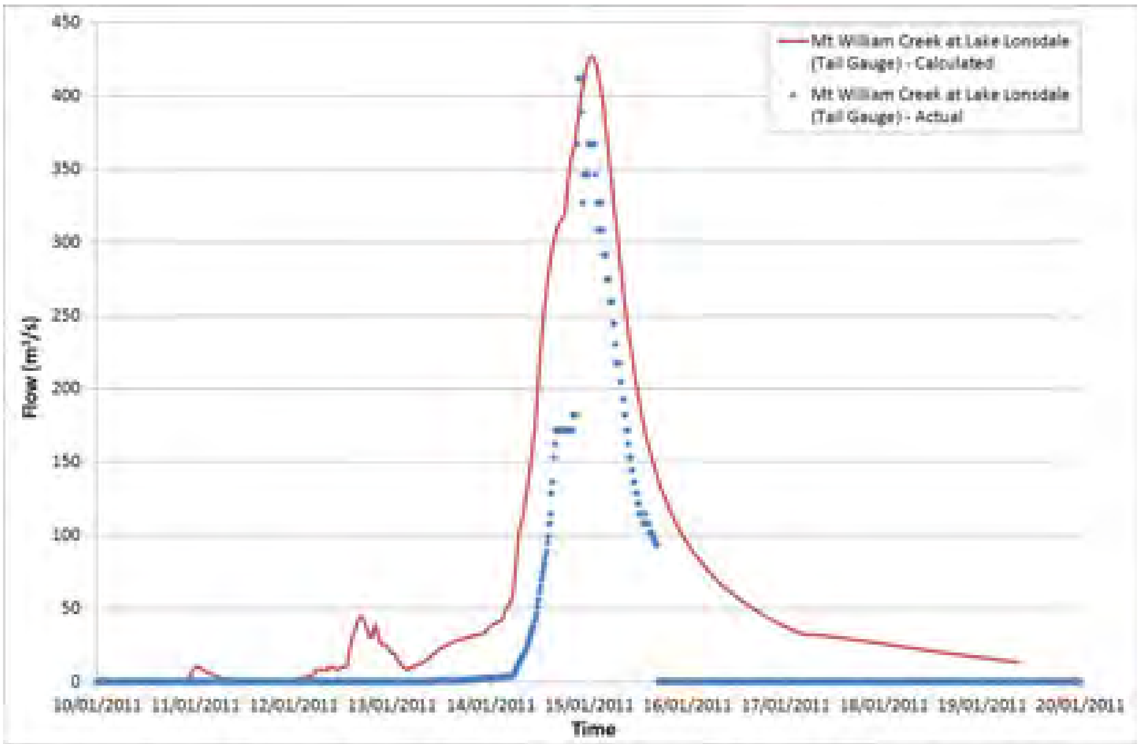


Figure 4-33 Calibrated Hydrograph Comparison for January 2011 – Mount William Creek at Lake Lonsdale Tail Gauge

4.4.7 December 1992 Calibration Results

The same approach to calibration documented above for the January 2011 event was undertaken for the December 1992 event. The best fit for the calibration parameters are listed in Table 4-18 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 4-34 to Figure 4-37.

Table 4-18 Calibrated Parameters and Values for December 1992

Station	k_c	*m*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Fyans Creek at Fyans Creek	11	0.8	30	1	0.84	-5%	-3%
Mount William Creek at Mokepilly	72	0.8	30	2.9	0.81	5%	3%
Mount William Creek at Lake Lonsdale Head Gauge	60	0.8	100	2.5	0.50	42%	74%
Mount William Creek at Lake Lonsdale Tail Gauge	60	0.8	100	2.5	-0.40	39%	112%

Unlike the January 2011 calibration, the calibration of the December 1992 event resulted in a mixture of very good fits in the upper portions of the catchment, whilst a noticeable poor fit at Lake Lonsdale.

The fit at the Fyans Creek at Fyans Creek gauge, with the exception of an additional flow spike, was very good. The initial increase in flows was well represented as was the timing and magnitude of the peak flow. The timing of the second much smaller pulse was slightly delayed, however the magnitude and receding limb were both very well matched. The initial rainfall spike could be removed by significantly increasing the initial losses; however the value necessary and the effect on the initial low flows were such that it was decided not to take that approach. All three empirical calibration parameters; NSE, volume and peak flows were very good.

Similarly, the calibration at Mount William Creek at Mokepilly was very good. Whilst the timing of the two peaks was slightly out, the order of magnitude of the peaks and the trough and the general catchment rising/falling limbs were all well represented in the hydrologic model.

The calibration at the two Mount William Creek at Lake Lonsdale gauges however was poor. Both gauges report similar flows in the order of 30 to 35m^3/s. However the other two gauges (Fyans Creek and Mokepilly) that flow into Lake Lonsdale indicate far higher flows in the order of 50 and 80m^3/s respectively. Whilst attenuation is possible within such a large catchment the total volume through the gauges should be less than the recorded outflow of the lake over time (Lake Lonsdale was full at the commencement of the December 1992 event). However, the volume through Mokepilly and Fyans Creek is approximately 50% greater than that leaving the Lake. A logical conclusion was the initial storage in the RORB model was set too high, however GWM Water data indicates that Lake Lonsdale was at or slightly above full supply level prior to the December 1992 event. A series of sensitivity tests were trialled with the initial water level of Lake Lonsdale below full supply level. Altering the starting level could reduce the initial peak in the hydrograph as the lake absorbed the flow, however the second peak remained considerably higher than the observed record. Due to the inconsistencies in the data, there was a great deal of uncertainty in the calibration of the two Lake Lonsdale gauges to this event.

Further analysis was undertaken in an attempt to understand the reasons behind the poor calibration that was achieved at Lake Lonsdale when very good calibrations were achieved at the Fyans Creek and Mokepilly gauges upstream. During the December 1992 event there was significant rainfall variability across the catchment (between the 11th and 25th of December 1992, Halls Gap received 162 millimetres of rain versus only 63 millimetres at Glenorchy). Whilst there is good coverage of the daily rainfall variance throughout the catchment, there is relatively poor coverage with regard to pluviograph records at this time (there were only three available pluviographs, all of which were located outside of the catchment). This is potentially resulting in the too much rainfall being applied at the wrong time.

However, despite the limitation of the available date for December 1993, the upper catchment responses were well represented and overall indicate a good calibration was achieved.

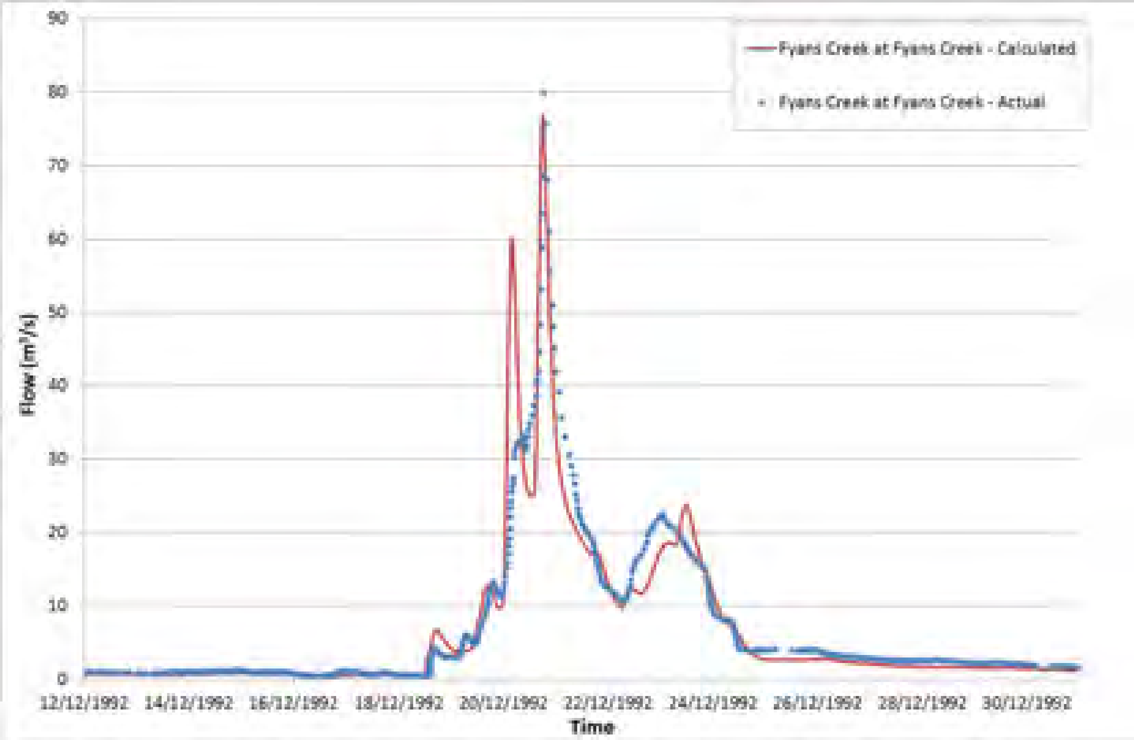


Figure 4-34 Calibrated Hydrograph Comparison for December 1992 – Fyans Creek at Fyans Creek

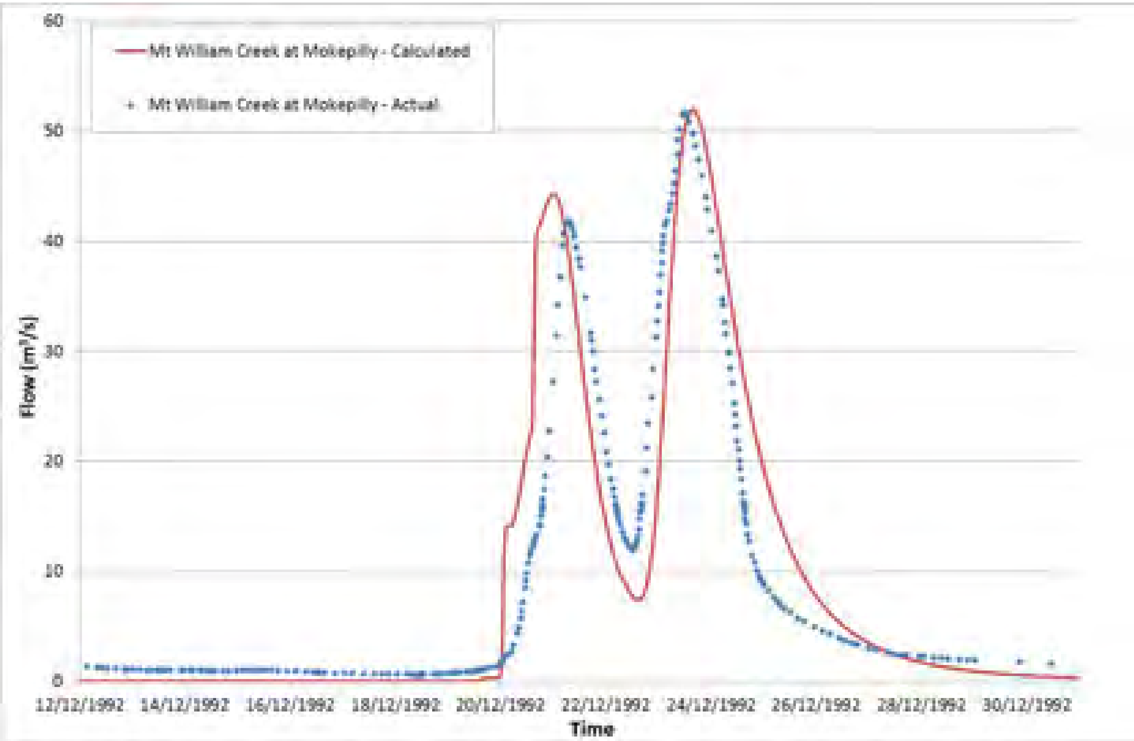


Figure 4-35 Calibrated Hydrograph Comparison for December 1992 – Mount William Creek at Mokepilly

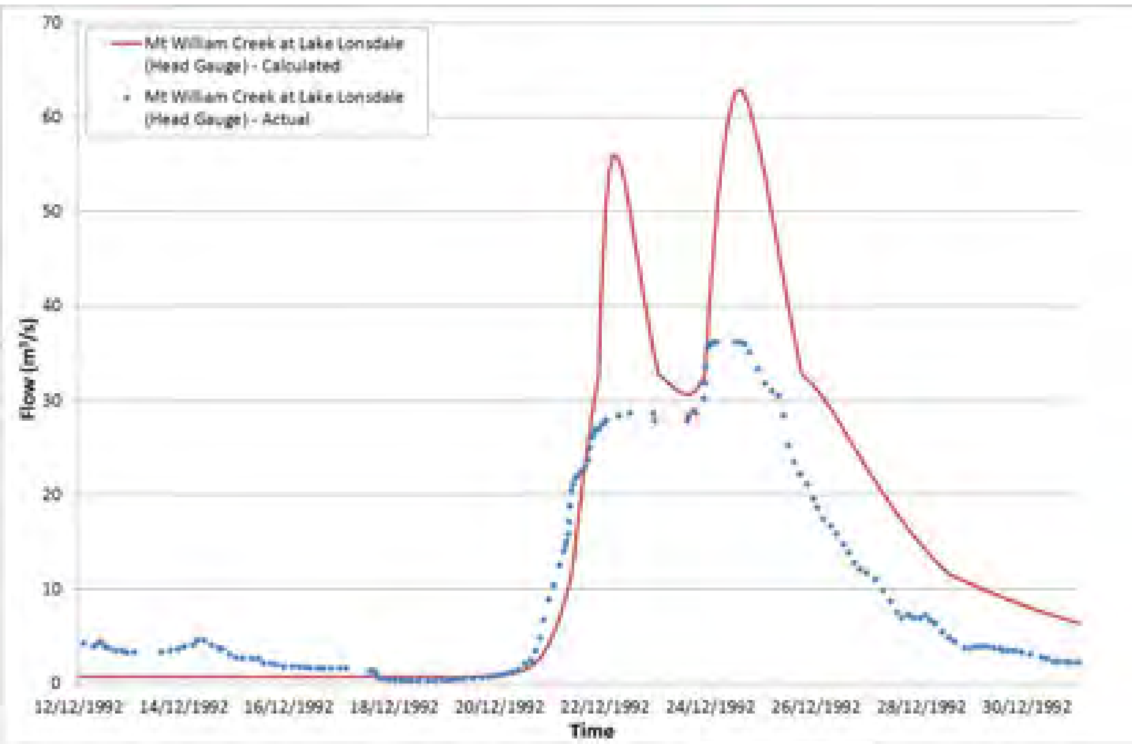


Figure 4-36 Calibrated Hydrograph Comparison for December 1992 – Mount William Creek at Lake Lonsdale Head Gauge

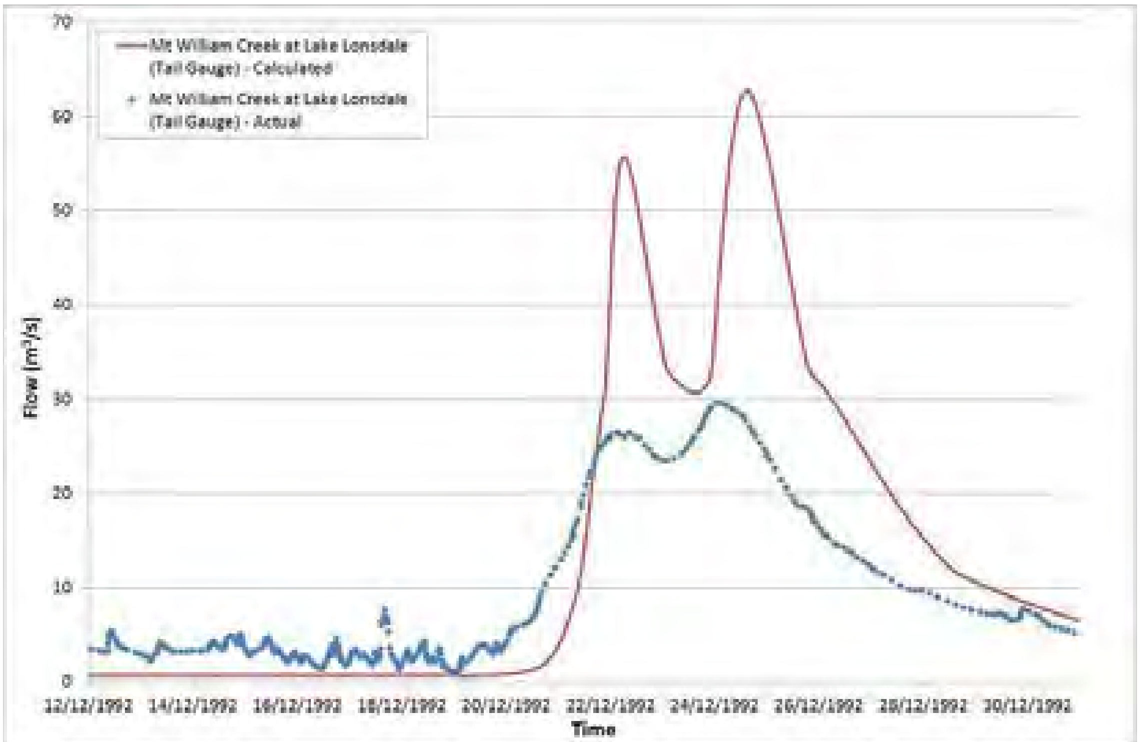


Figure 4-37 Calibrated Hydrograph Comparison for December 1992 – Mount William Creek at Lake Lonsdale Tail Gauge

4.4.8 October 1996 Verification Results

The k_c and m parameters used for the calibration of both the December 1992 and January 2011 events were found to be largely similar, with the exception of the k_c parameter. The k_c derived as part of the December 1992 calibration (a value of 60) was adopted as it was determined to be more appropriate for the catchment upstream. Additionally the k_c of 60 is roughly consistent with the k_c that is derived based upon equation 2.4 of the RORB manual (k_c = 68) and that derived from equation 3.22 of ARR (Book V) ((k_c = 43).

To validate the October 1996 event, the RORB model of Mount William Creek was run with the rainfall described in Section 4.4.4.1 for this event. As outlined above, the rainfall was spatially distributed across the catchment using the three available hyetographs. The validation process only allows adjustments to be made to initial and continuing losses and the catchment parameters (k_c and m) have been determined as part of the calibration process.

Initial verification attempts were quite poor and further investigation of the available pluviographs was undertaken. This investigation highlighted significant discrepancies between the timing of the rainfall on the west side of the Grampians when compared to the east side. Subsequent verification attempts were made using only the single pluviograph from the east side of the Grampians and this resulted in a better fit to the observed record being achieved.

The calibration parameters outlined in Table 4-19 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 4-38 to Figure 4-40.

Table 4-19 Validation Parameters and Values for October 1996

Station	k_c	*m*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Fyans Creek at Fyans Creek	12	0.8	50	1	0.66	10%	-3%
Mount William Creek at Mokepilly	70	0.8	20	0.5	0.57	54%	2%
Mount William Creek at Lake Lonsdale Head Gauge	60	0.8	50	2.5	0.71	43%	32%

The verification of the Fyans Creek at Fyans Creek gauge overall was reasonable. The initial peak in flow was captured, as was the magnitude of the second main peak, if not the timing. The receding limb overall was reasonably well matched if not for the peaks occurring in the calculated flow from continued rainfall within the model. Overall with an NSE of 0.66 and a peak flow difference of -3% the verification at this gauge was deemed to be acceptable for verification.

Similarly, the verification of the Mount William Creek at Mokepilly gauge was deemed acceptable. As with the Fyans Creek at Fyans Creek gauge the modelled catchment response to the subsequent rainfall burst following the main burst was not very well represented. There is some uncertainty surrounding the temporal pattern of the rainfall in this event with the various available pluviograph records indicating quite temporally divergent rainfall distributions. However, the peak flow rate and rate of the falling limb (until the following spikes) show reasonable agreement between the modelled and observed records.

The head gauge at Lake Lonsdale was deemed a reasonable match for a verification event with an NSE of 0.71.

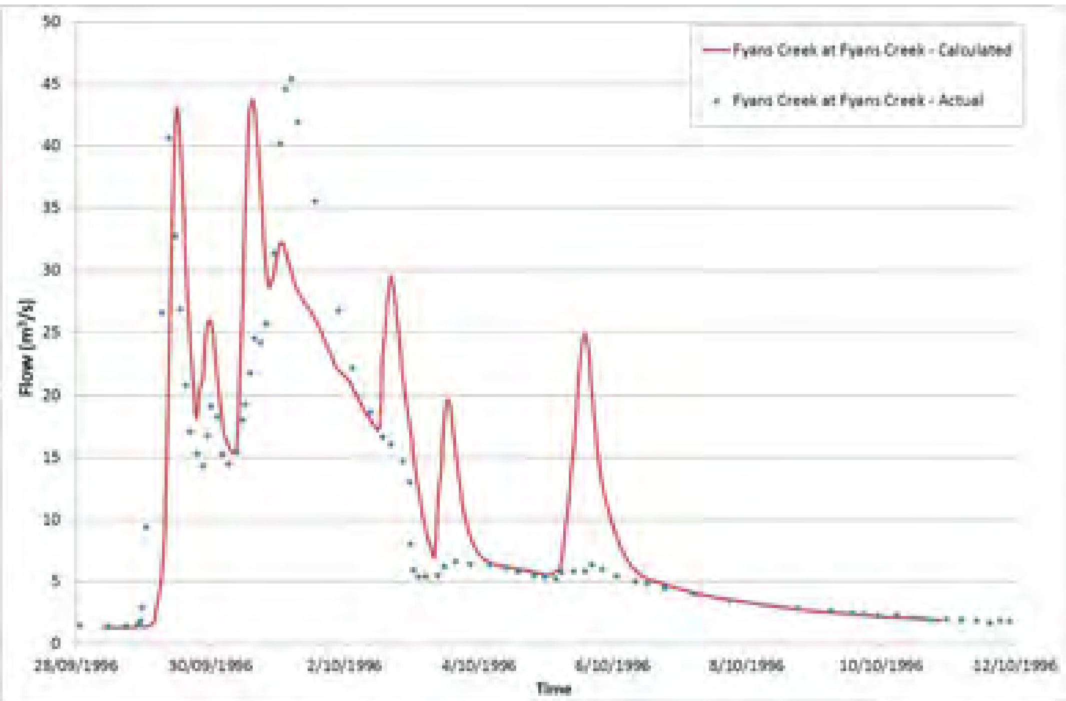


Figure 4-38 Verification Hydrograph Comparison for October 1996 – Fyans Creek at Fyans Creek

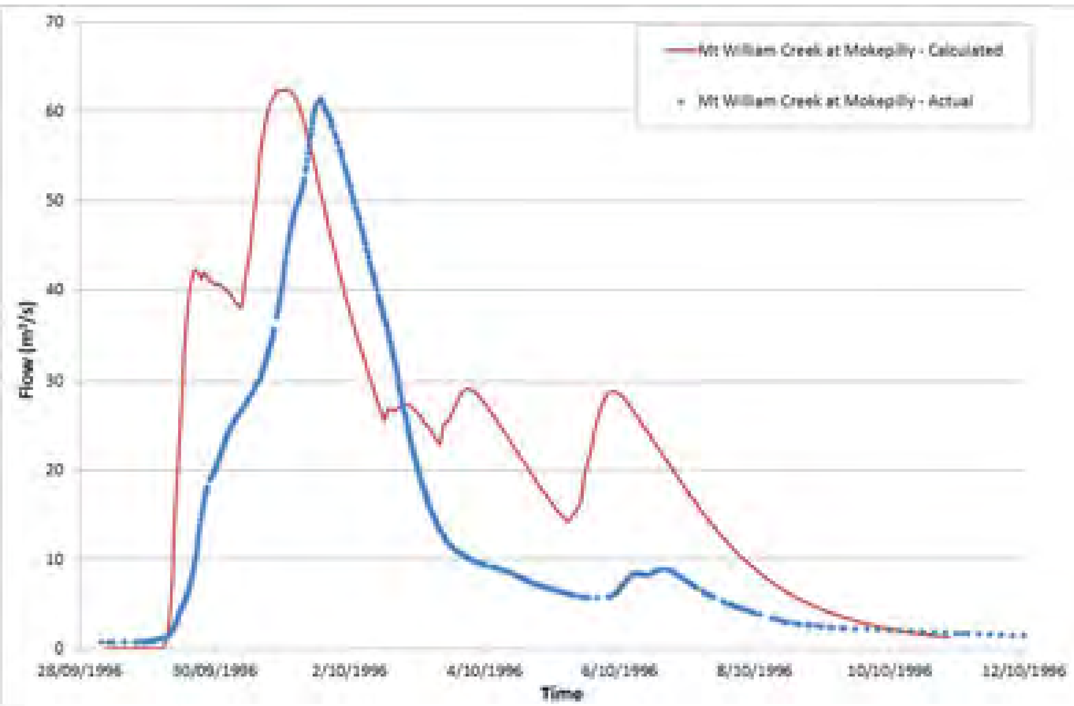


Figure 4-39 Verification Hydrograph Comparison for October 1996 – Mount William Creek at Mokepilly

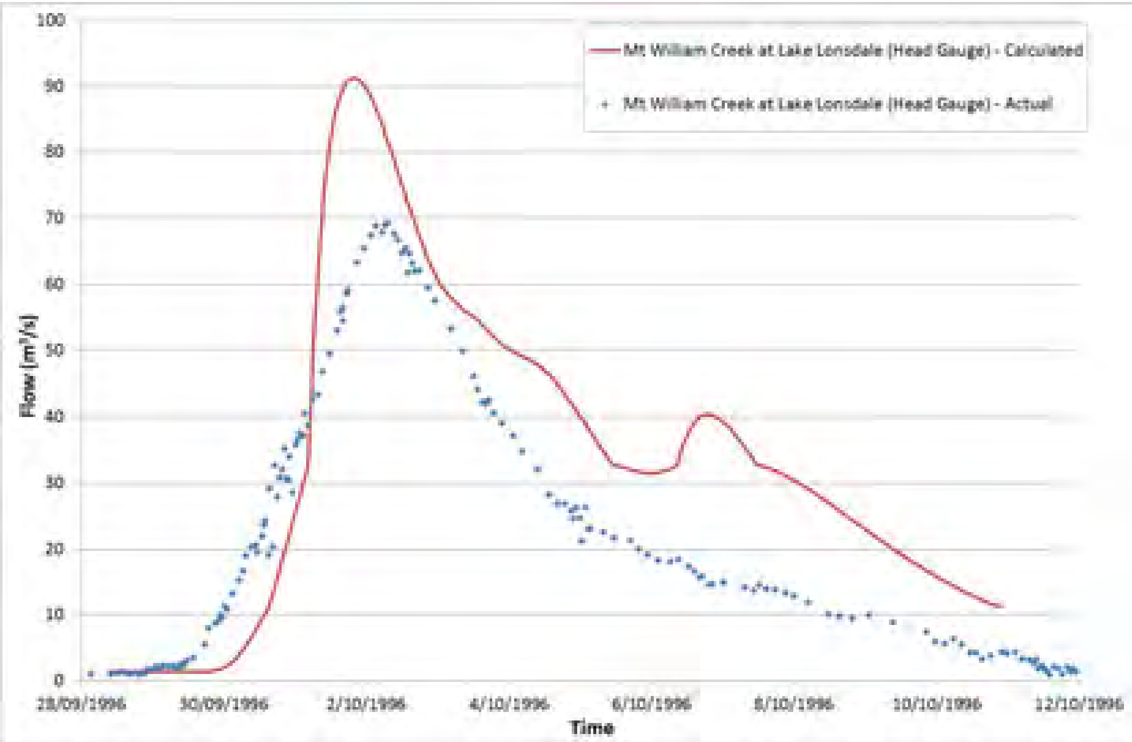


Figure 4-40 Verification Hydrograph Comparison for October 1996 – Mount William Creek at Lake Lonsdale Head Gauge

4.4.9 May 1974 Verification Results

The same approach to validation documented above for the October 1996 event was undertaken for the May 1974 event. The best fit for the calibration parameters are listed in Table 4-20 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 4-41.

Table 4-20 Validation Parameters and Values for May 1974

Station	k_c	*m*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mount William Creek at Lake Lonsdale Tail Gauge	60	0.8	25	1.90	0.89	-14%	-1%

For the verification of the May 1974 event only the tail gauge at Lake Lonsdale was available. By maintaining the same k_c value as the calibration events a good verification was achieved. Whilst volume was slightly lower, 14% less in the model than observed, the peak flow was matched. With an overall NSE value of 0.89 the verification of the May 1974 event was deemed to be successful.

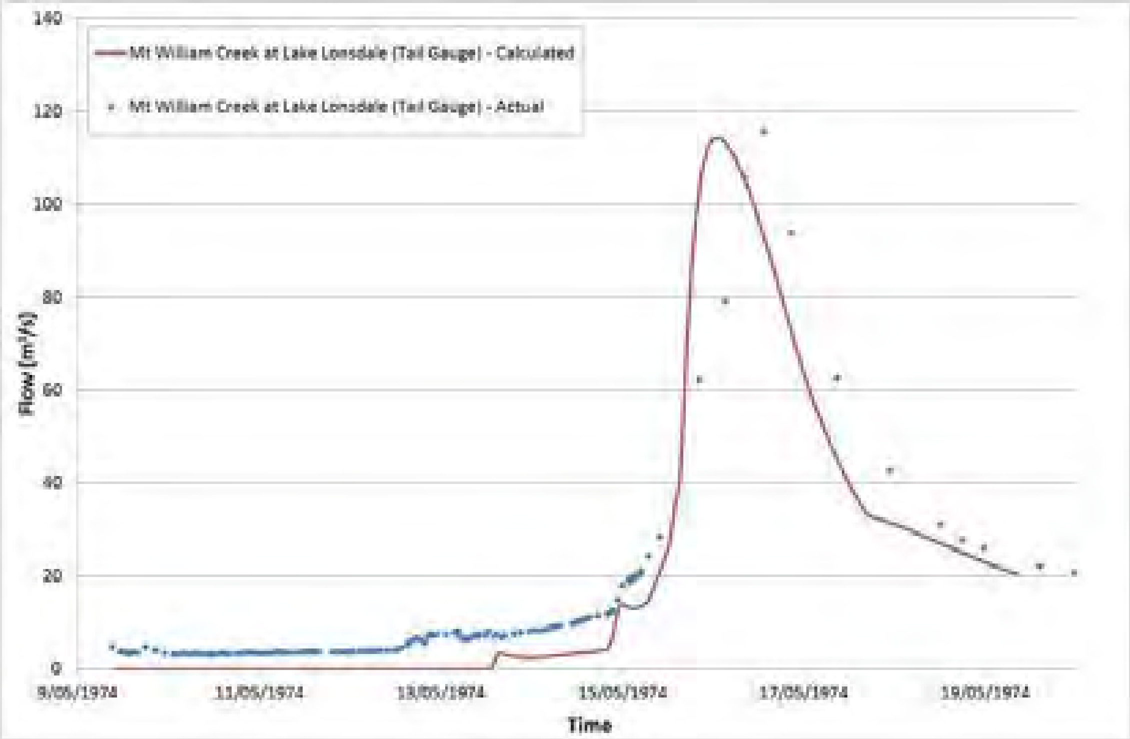


Figure 4-41 Validation Hydrograph Comparison for May 1974 – Mount William Creek at Lake Lonsdale Tail Gauge

4.4.10 Calibration / Validation Conclusions

The RORB model of Mt William Creek catchment has been calibrated to the January 2011 and December 1992 flood event and validated against the May 1974 and October 1996 flood events. The adopted calibration parameters were applied to the validation events.

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 or storage level at the Lake Lonsdale gauge during the December 1996 calibration event;
- Suspect flow data for the Mokepilly gauge during the January 2011 calibration event;
- The limited ability of hydrologic models, including RORB, to represent varying water levels across a storage (a potential issue in large storages such as Lake Lonsdale) and the resultant simplification of the available storage; and
- The potential of the GWM Water channels to be creating additional storages, flow diversions and flood attenuation that cannot be accurately modelled within a hydrologic modelling package.

The calibration of the hydraulic model will enable these uncertainties to be better understood and will allow for better modelling of the behaviour of the lakes and GWM channels and their respective influences on flood flows when compared to the hydrologic model.

4.5 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 ARI (eg: the 1 in 100 year flood event).

4.5.1 Global Parameters

The RORB model parameters for design event modelling are summarised in Table 4-21. 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.

Table 4-21 Initial RORB design parameters

RORB Parameter	Multiple Parameter RORB Model	
	Inter-Station Area	Value
Catchment Area	1,449 km^2	
Initial Loss	All Inter-Station Areas	25
Continuing Loss	All Inter-Station Areas	2.5 (See section 4.5.6 for details)
k_c	Fyans Creek at Fyans Creek	12
	Mount William Creek at Mokepilly	70
	Mount William Creek at Lake Lonsdale Head Gauge	60
	Mount William Creek at Lake Lonsdale Tail Gauge	60
	Catchment Outlet	60
m	All Inter-Station Areas	0.8
Fraction Impervious	Varies, as per land use (Table 4-15)	
Reach Types	Type 1	

4.5.2 Design Event Probabilities

Hydrological analysis was undertaken for the 5, 10, 20, 50, 100, 200 and 500 year Average Recurrence Interval (ARI) design storm events. Hydrological analysis was also undertaken for the Probable Maximum Precipitation (PMP) storm event.

4.5.3 Design Rainfall

In order to define the design rainfall for ARI events, Intensity Frequency Duration (IFD) parameters for the Mount William Creek catchment were generated by the Bureau of Meteorology (http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml accessed 16/04/2013) 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 4-22.

The adopted IFD parameters to define the climate change scenario are also displayed in Table 4-22. These adjusted parameters allow for a 32% increase in rainfall intensity, which is in accordance with Melbourne Water's current practice.

Table 4-22 IFD Parameters

<table>
<tr><th colspan="2">IFD Parameter</th><th>Adopted Value</th><th>Climate Change</th></tr>
<tr><td rowspan="6">Rainfall Intensity (mm/hr)</td><td>2 Year ARI,
1 Hour Duration</td><td>19.00</td><td>25.08</td></tr>
<tr><td>2 Year ARI,
12 Hour Duration</td><td>3.36</td><td>4.44</td></tr>
<tr><td>2 Year ARI,
72 Hour Duration</td><td>0.94</td><td>1.24</td></tr>
<tr><td>50 Year ARI,
1 Hour Duration</td><td>40.51</td><td>53.47</td></tr>
<tr><td>50 Year ARI,
12 Hour Duration</td><td>6.85</td><td>9.04</td></tr>
<tr><td>50 Year ARI,
72 Hour Duration</td><td>1.74</td><td>2.30</td></tr>
<tr><td colspan="2">Skew Coefficient</td><td>0.34</td><td>0.34</td></tr>
<tr><td colspan="2">Geographical Factor F2</td><td>4.37</td><td>4.49</td></tr>
<tr><td colspan="2">Geographical Factor F50</td><td>14.82</td><td>16.56</td></tr>
<tr><td colspan="2">Zone</td><td>2</td><td>2</td></tr>
</table>

4.5.3.1 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 4-22.

4.5.4 Temporal Patterns and Areal Reduction Factors

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.

4.5.5 Calculation of PMP

The probable maximum precipitation (PMP) was derived using the Generalised Southeast Australia Method (GSAM) (BoM 2006). Having a catchment area of 1,449 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 4-23 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 4-23 GSAM Estimate of PMP Rainfall Depth

	Duration			
	24hr	36hr	48hr	72hr
Final PMP Estimate (mm)	480	550	580	610

4.5.6 Design Event Losses

The initial loss and continuing losses are identical to those adopted for the Halls Gap Flood Study (Water Technology, 2008). The losses currently applied to the hydrologic modelling include an initial loss of 25 millimetres and a continuing loss of 2.5 millimetres per hour.

4.5.7 Critical Event Derivation

For each design ARI, 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 ARI were modelled. A summary of the critical duration is presented in Table 4-24.

Table 4-24 RORB Design Event – Critical Duration

ARI	Fyans Creek	Mokepilly	Lake Lonsdale	Dadswells Bridge	Outlet
5	6h	72h	72h	72h	72h
10	72h	72h	72h	72h	72h
20	6h	72h	72h	72h	72h
50	4.5h	18h	18h	18h	18h
100	3h	18h	18h	18h	18h
200	3h	18h	18h	18h	18h
PMP	24h	36h	36h	36h	36h

4.5.8 Determination of Initial Water Levels for Storages

Based on the weekly historical lake volume data provided by GWM Water, BMT WBM undertook an analysis to determine the percentage exceedance of various lake volumes. The data storage level data was available for the period between August 1966 and August 2013 for Lake Bellfield, May 1919 and August 2013 for Lake Fyans and between July 1915 and August 2013 for Lake Lonsdale. The results from this analysis are presented below in Table 4-25 (Lake Bellfield), Table 4-26 (Lake Fyans) and Table 4-27 (Lake Lonsdale). These results are also presented graphically in Figure 4-42 (Lake Bellfield), Figure 4-43 (Lake Fyans) and Figure 4-44 (Lake Lonsdale). As part of the analysis for Lake Bellfield and Lake Lonsdale, the stream gauge records downstream of the storage (Fyans Creek at Lake Bellfield and Mount William Creek at Lake Lonsdale Tail Gauge respectively) were used to identify the five largest flows that have occurred downstream of the storages (where overlapping records existed). The volume of Lake Bellfield and Lake Lonsdale prior to the commencement of the flood event was determined and these starting volumes were also included in Figure 4-42 and Figure 4-44 for Lake Bellfield and Lake Lonsdale respectively. Whilst this approach can be considered conservative as it does not account for inflows in the various lakes, it does give some context to the lake conditions that are present during previous historical flood events (as recorded by the two stream gauges located immediately downstream of the storages).

The plots also graph the full service volume and operating volume for each of the three lakes within the Mount William Creek catchment. Lake Bellfield has two operating volumes; the ‘April-September’ operating volume which is 2,500 ML lower than the full service volume to provide for flood storage, whilst the ‘October – March’ operating volume is identical to the full service volume. Additionally, the operating level and full service level for Lake Fyans are the same volume (Lake Fyans is an offline storage with minimal natural catchment).

Table 4-25 Lake Bellfield - % Exceedance Values

% Exceedance	Lake Volume (ML)	Lake Level (m)
1	78740	276.54
2	78600	276.51
5	78500	276.49
10	77860	276.35
20	76230	276.01
50	63380	273.15
Full Supply	**78560**	**276.50**
Operating (April – September)	**76060**	**275.97**
Operating (October – March)	**78560**	**276.50**

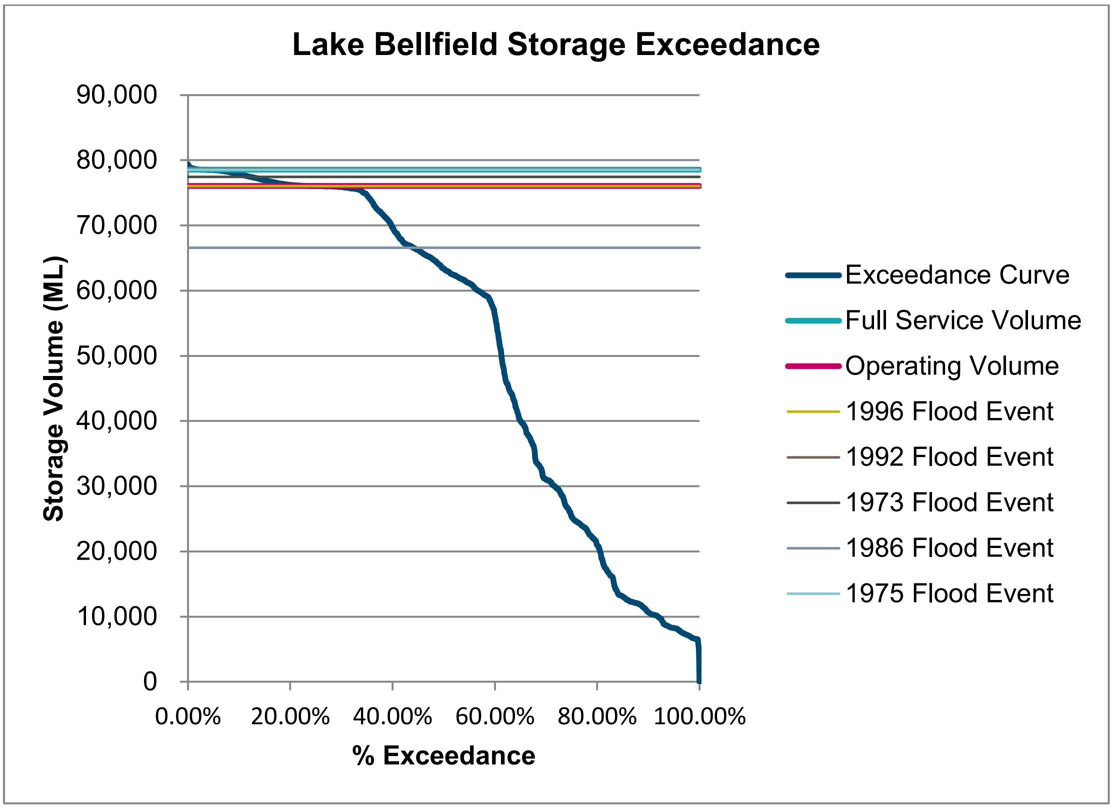


Figure 4-42 Lake Bellfield Plot

Table 4-26 Lake Fyans - % Exceedance Values

% Exceedance	Lake Volume (ML)	Lake Level (m)
1	21090	204.30
2	20950	204.28
5	20330	204.16
10	19480	204.00
20	18360	203.78
50	15810	203.24
Full Supply	**18460**	**203.80**
Operating	**18460**	**203.80**

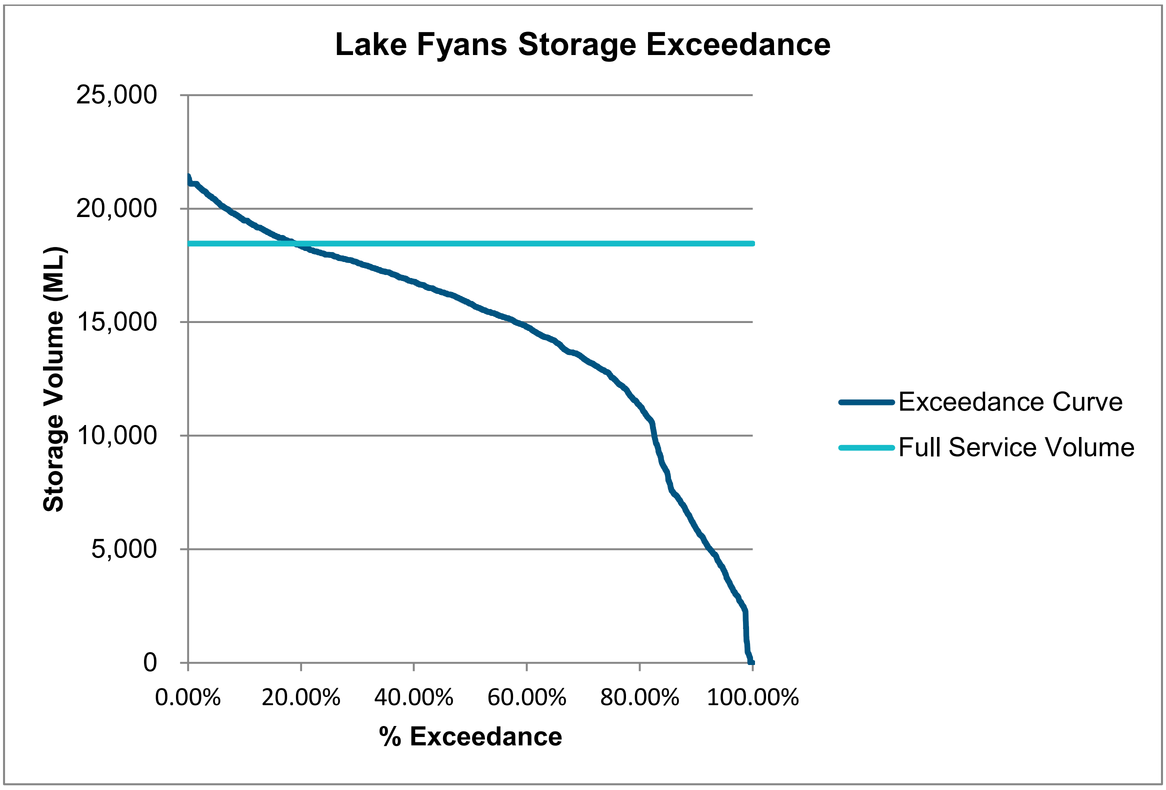


Figure 4-43 Lake Fyans Plot

Table 4-27 Lake Lonsdale - % Exceedance Values

% Exceedance	Lake Volume (ML)	Lake Level (m)
1	66980	187.68
2	66090	187.64
5	65745	187.63
10	64500	187.58
20	56240	187.24
50	32860	186.15
Full Supply	**65480**	**187.62**
Operating	**53300**	**187.12**

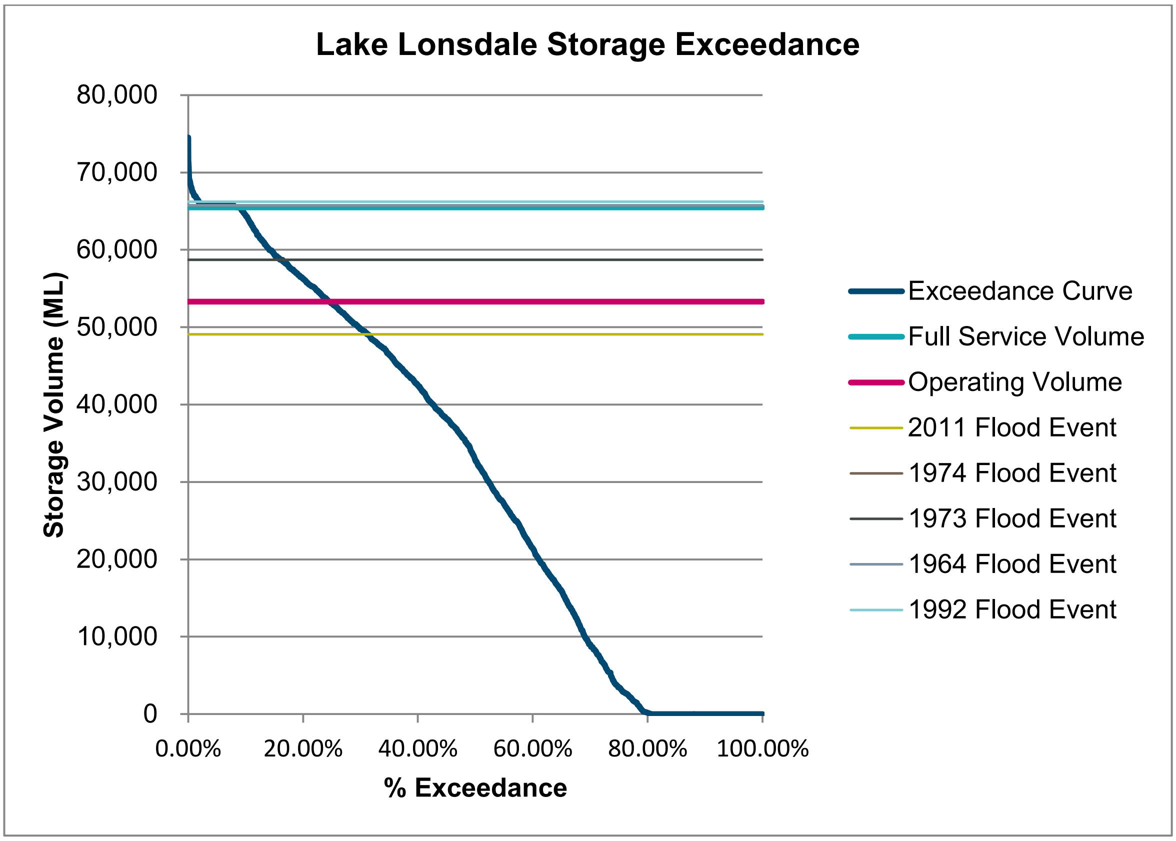


Figure 4-44 Lake Lonsdale Plot

BMT WBM, in conjunction with WCMA staff undertook some further analysis to determine how the historical Lake Lonsdale starting levels would have changed based upon the new operating rules that have been implemented by GWM Water. Figure 4-45 shows the results of this analysis, where the 'modelled volume' is the volume determined by a REALM water allocation model based on the current operating rules and 'recorded volume' is the historical lake level as recorded by the reservoir keeper. This analysis shows that based on the historic data, over 50% of the flood events occurred when the storage was at or exceeding the full storage volume. However, when the new operating rules were applied to this data, the modelled data shows over 50% of the flood events occur when the storage was at its operating level.

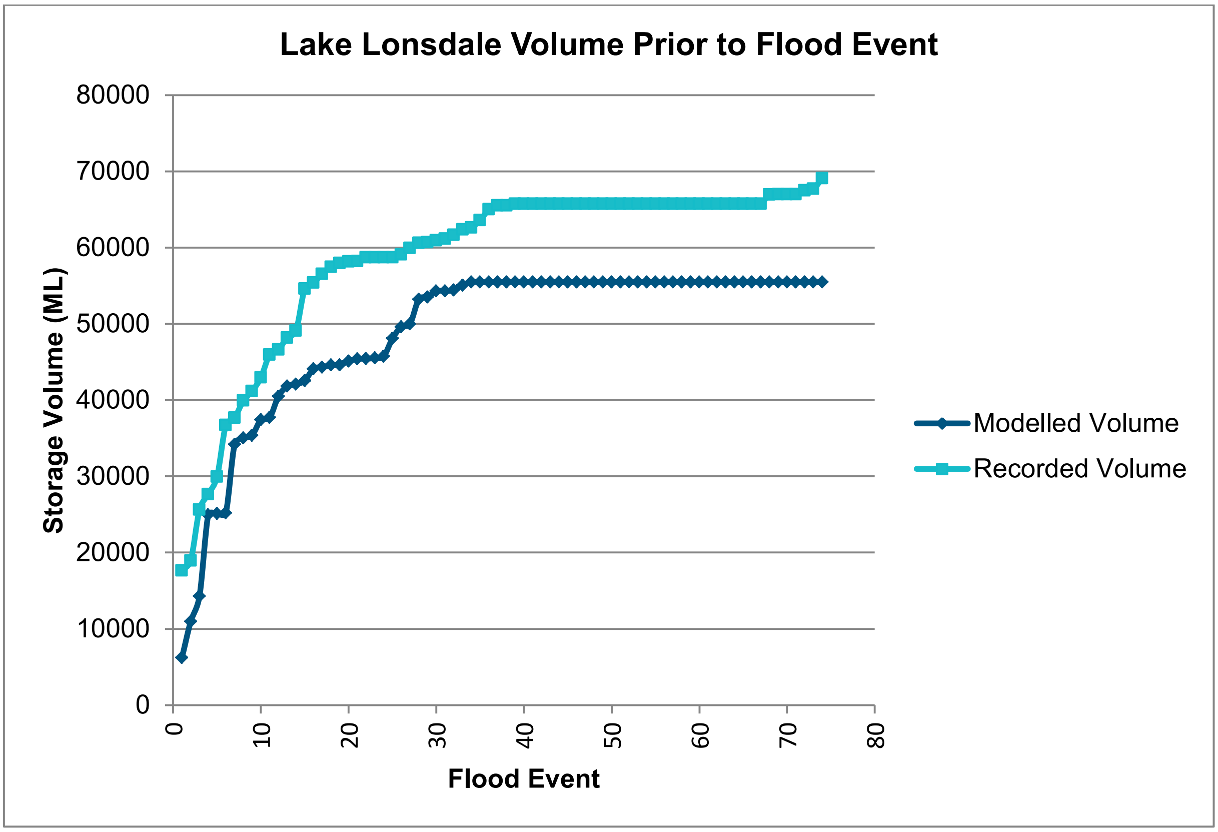


Figure 4-45 Lake Lonsdale Level Analysis

4.5.8.1 Discussion

The analysis undertaken on Lake Bellfield and Lake Lonsdale has shown 4 of the 5 largest flood events recorded at the respective stream gauge downstream of the storage have occurred when the lake level prior to the flood event was equal to or above the operating level.

In the case of Lake Lonsdale, the January 2011 flood event, which was the largest in terms of gauged flow downstream of the storage, was the only event in the top 5 to have occurred with an initial lake level below the operating level. However, it is noted that these events all occurred prior to the current operating rules for Lake Lonsdale.

In all three lakes, the operating lake levels roughly correspond to the 20% exceedance value, meaning that the operating levels in each of the lakes are likely to be exceeded 20% of the time (based on the historical weekly volume data).

For Lake Lonsdale and Lake Fyans the full service levels roughly correspond to the 5% exceedance value, meaning that the full service levels are likely to be exceeded 5% of the time (based on the historical weekly volume data).

4.5.8.2 Recommendations for Starting Lake Levels

BMT WBM recommends that full service level for both Lake Bellfield and Lake Fyans and the current operating level for Lake Lonsdale be adopted as the starting lake levels for the design events for the Mount William Creek Flood Investigation.

4.5.9 Wimmera River Inflow

The hydrologic model detailed in the previous sections accounts for inflows from Mount William Creek only. In addition to the hydrographs calculated by the hydrologic model, the hydraulic model will also require an inflow to account for the flow along the Wimmera River. Following discussions with WCMA, it has been determined that the flows along the Wimmera River will be based upon the modelling undertaken as part of the Wimmera River – Yarriambiack Creek Flows Study (Water Technology, 2009).

The Wimmera River – Yarriambiack Creek Flows Study involved the use of the Bureau of Meteorology's calibrated URBS model to determine the hydrology of the Wimmera River. Recent flooding along the Wimmera River in 2010/2011 may have resulted in changes to this calibrated URBS hydrologic model, and consequently the design flows that are determined. However, these changes are unlikely to have a significant impact on the outcomes of this study and the impact of the 2010/2011 floods on the Wimmera River design flows has not been determined as part of this study.

4.5.10 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 4-28. Hydrographs of the 18 hour ARI events are shown in Figure 4-46. These flows assume the recommended starting lake levels as detailed in Section 4.5.8.2

Table 4-28 Initial RORB Design Peak Flow Values

ARI	Peak Flow (ML/day)						
	5	10	20	50	100	200	PMF
Fyans Creek at Fyans Creek	1555	2765	4752	7344	9850	12701	60653
Mount William Creek at Mokepilly	2160	4234	7517	12960	18230	24451	189821
Mount William Creek at Lake Lonsdale	86	778	5184	15466	24451	34560	293933
Dadswells Bridge	1296	2678	4838	13565	21859	31536	302400
Catchment Outlet	1901	3715	6566	12096	19786	29030	312854

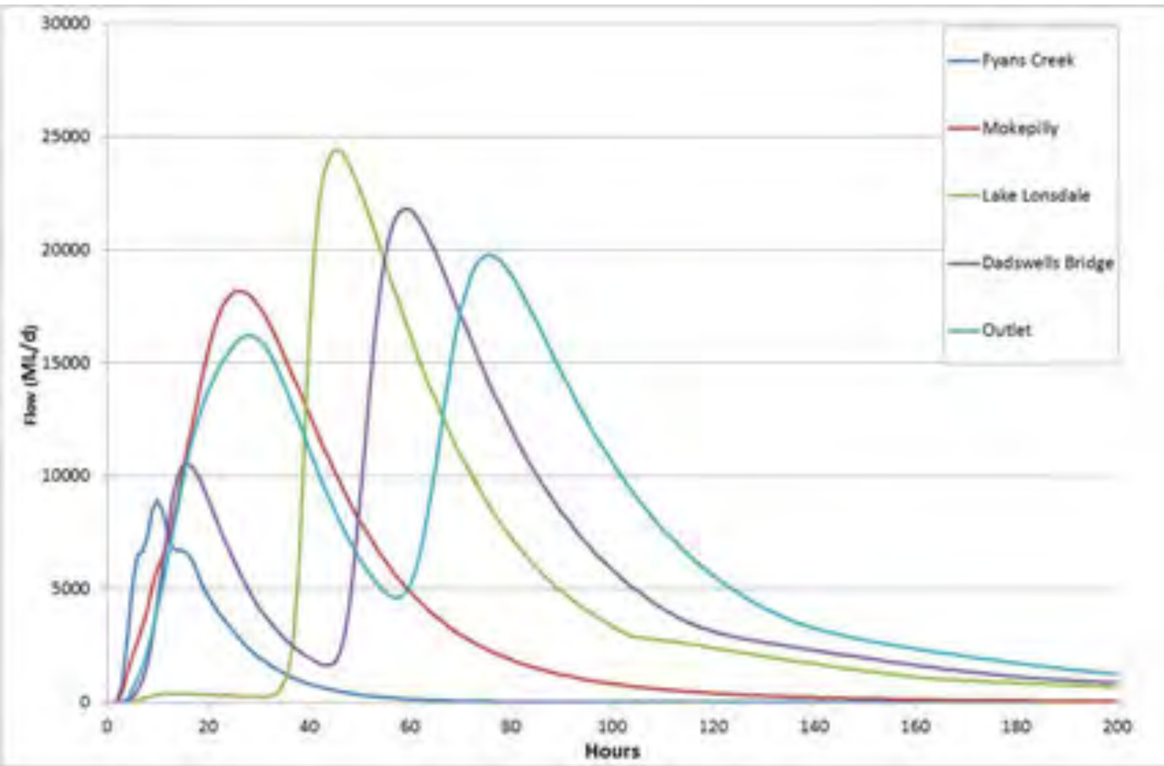


Figure 4-46 1 in 100 year ARI 18 Hour Initial Design Hydrographs

4.5.11 Sensitivity Analysis - Climate Change

The rainfall intensities were factored by 32% to account for the expected increases in rainfall intensity due to climate change. No allowance has been made for changed temporal patterns or changed rainfall losses due to the impact of climate change. This analysis has tested a single variable that will be impacted by climate change and a more detailed assessment may be required as the understanding of the impacts of climate change on hydrology and stream flow improves.

Figure 4-47, Figure 4-48, Figure 4-49 and Figure 4-50 show the change the flood hydrograph for both the 1 in 5 year and 1 in 100 year flood events at Fyans Creek, Mokepilly, Lake Lonsdale and Dadswells Bridge respectively.

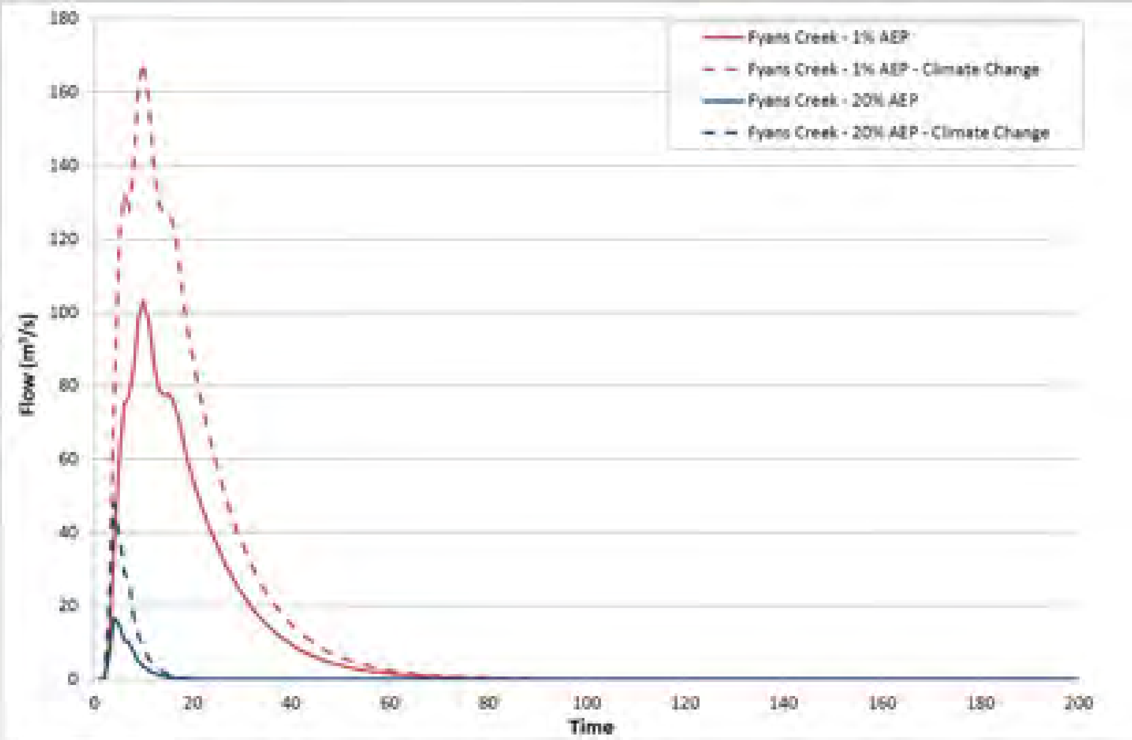


Figure 4-47 Climate Change Sensitivity – Fyans Creek

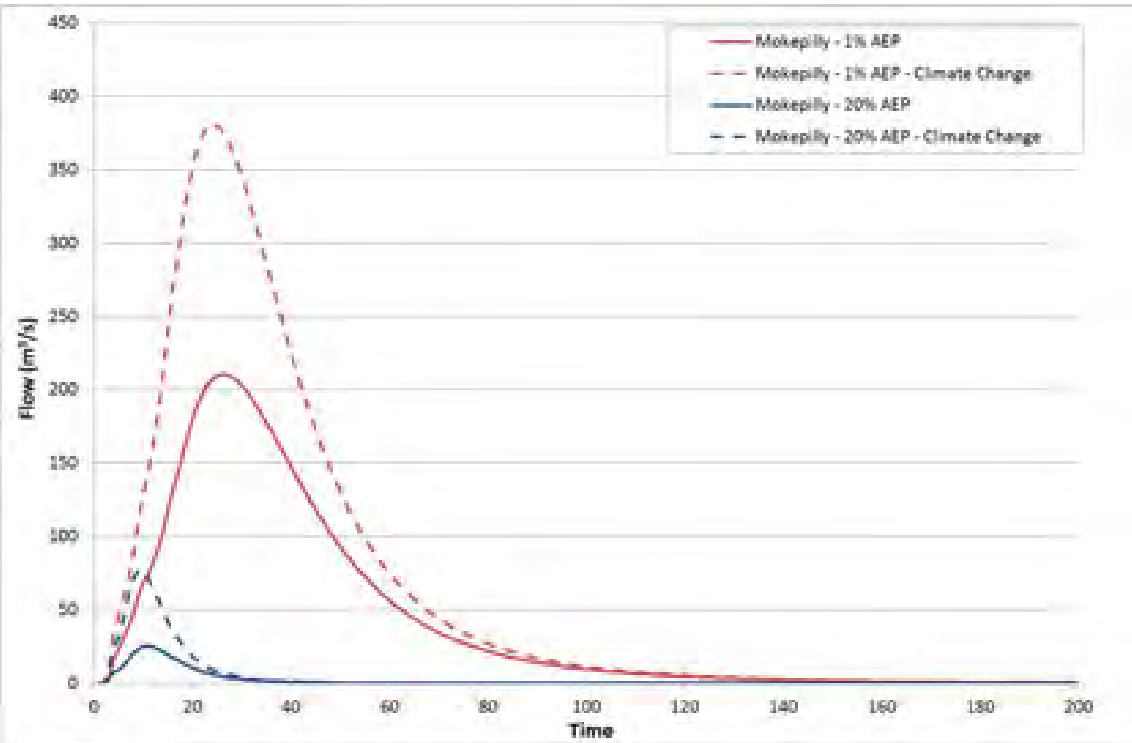


Figure 4-48 Climate Change Sensitivity – Mokepilly

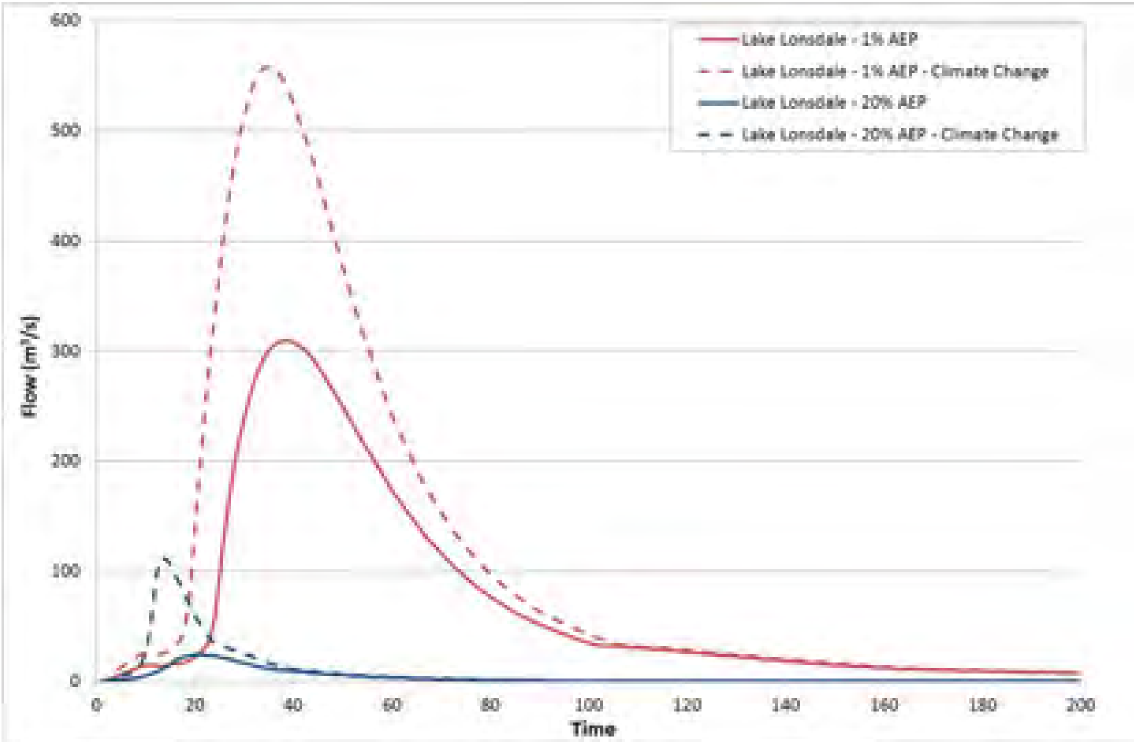


Figure 4-49 Climate Change Sensitivity – Lake Lonsdale

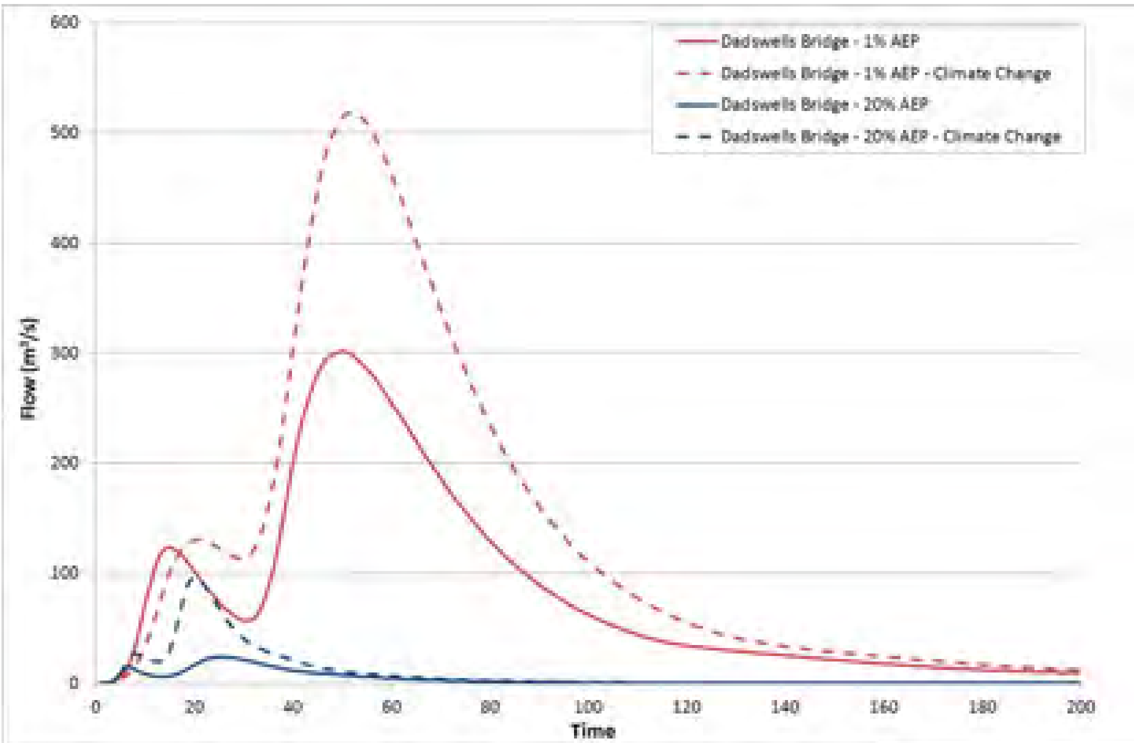


Figure 4-50 Climate Change Sensitivity – Dadswells Bridge

4.6 Discussion

An analysis of the design flows derived from the RORB model was undertaken to compare the peak flows determined with those determined from the site flood frequency analysis and regional flood frequency analysis. This analysis (Table 4-29 has shown that the RORB derived design flows are consistently underestimated by the RORB model when compared to the site based flood frequency analysis and the regional flood frequency analysis. As previously noted (Section 4.2.1), the comparisons between the site based flood frequency analysis and regional flood frequency analysis for the Mokepilly gauge are very good and indicate that the RORB derived design flows should be higher than currently presented. Whilst the design flows derived from the RORB model are generally consistent with those from the site based flood frequency analysis at the Lake Lonsdale gauge, the Fyans Creek flows derived from RORB are lower than both the site based flood frequency analysis and regional flood frequency analysis derived flows.

Consequently, it is recommended to adjust the loss parameters for both the Fyans Creek and Mokepilly inter-station areas to increase the RORB derived design flows to result in a more favourable comparison to the flows derived by the flood frequency analysis.

Table 4-29 Comparison of Initial Peak Design Flows

Location	1 in 100y ARI Flow (ML/day)		
	RORB Model	Site FFA	RFFE
Fyans Creek at Fyans Creek	9850	11932	14861
Mount William Creek at Mokepilly	18230	25037	24132
Mount William Creek at Lake Lonsdale	24451	24576	35960

4.7 Summary

BMT WBM has successfully calibrated the RORB hydrologic model to the January 2011 and December 1992 flood events and verified the calibration against the May 1974 and October 1996 flood events. Additional work was undertaken to determine the sensitivity of the peak flows to the levels within Lake Bellfield, Lake Fyans and Lake Lonsdale.

As discussed in Section 4.6, the initial RORB parameters resulted in peak design flows that were consistently smaller than the flows derived by the flood frequency analysis methods. Consequently, the loss values for the Fyans Creek and Mokepilly interstation areas were adjusted to improve the comparison between the RORB flows and flood frequency derived peak flows. The adopted RORB model design parameters are summarised in Table 4-30 and the resultant peak flows are presented in Table 4-31.

Table 4-30 Adopted RORB design parameters

RORB Parameter	Multiple Parameter RORB Model	
	Inter-Station Area	Value
Initial Loss	Fyans Creek at Fyans Creek	20
	Mount William Creek at Mokepilly	20
	Mount William Creek at Lake Lonsdale Head Gauge	25
	Mount William Creek at Lake Lonsdale Tail Gauge	25
	Catchment Outlet	25
Continuing Loss	Fyans Creek at Fyans Creek	1.5
	Mount William Creek at Mokepilly	1.5
	Mount William Creek at Lake Lonsdale Head Gauge	2.5
	Mount William Creek at Lake Lonsdale Tail Gauge	2.5
	Catchment Outlet	2.5
k_c	Fyans Creek at Fyans Creek	12
	Mount William Creek at Mokepilly	70
	Mount William Creek at Lake Lonsdale Head Gauge	60
	Mount William Creek at Lake Lonsdale Tail Gauge	60
	Catchment Outlet	60
m	All Inter-Station Areas	0.8

Table 4-31 Adopted RORB Design Peak Flow Values

ARI	Peak Flow (ML/day)						
	5	10	20	50	100	200	PMF
Fyans Creek at Fyans Creek	3252	4740	6739	9180	11801	14595	60653
Mount William Creek at Mokepilly	5292	8209	12752	19293	25105	31814	189821
Mount William Creek at Lake Lonsdale	880	4570	12818	23832	33076	43397	293933
Dadswells Bridge	1292	4029	11057	21152	29940	40289	302400
Catchment Outlet	1864	3724	9595	17868	27298	37244	312854

A comparison of the peak flows determined through the design event modelling and those adopted from the Flood Frequency Analysis are shown in Table 4-29 for all three gauge locations within the Mount William Creek study area. This table shows that flows derived from the RORB model are generally comparable to those flows determined by the site flood frequency analysis for the Fyans Creek and Mokepilly stream gauges, whilst the adopted flow at the Lake Lonsdale gauge is higher than the site flood frequency analysis and lower than the regional flood frequency analysis.

Table 4-32 Comparison of Adopted Peak Design Flows

Location	1 in 100y ARI Flow (ML/day)		
	RORB	Site FFA	RFFE
Fyans Creek at Fyans Creek	11801	11932	14861
Mount William Creek at Mokepilly	25105	25037	24132
Mount William Creek at Lake Lonsdale	33076	24576	35960

4.8 Discussion and Recommendations

BMT WBM has completed a site based and regional flood frequency analysis for a number of the gauges within the Mount William Creek and developed a calibrated RORB model of the catchment. A comparison between the derived peak flows from both the Flood Frequency Analysis and the calibrated RORB models does provide good agreement (Table 4-29) for the 1 in 100 year ARI flood event.

Consequently, BMW WBM recommended that:

- The calibrated RORB model be used to generate design inflow hydrographs for the hydraulic model within the Mount William Creek catchment;
- Inflows for the Wimmera River are to be based upon the modelling from the Wimmera River – Yarriambiack Creek Flows Study (Water Technology, 2009);
- Water levels for the modelling of Lake Bellfield, Lake Fyans and Lake Lonsdale are adopted as presented in Section 4.5.8.2; and
- The parameters presented in Section 4.7 are adopted for the design event modelling within RORB.

5 Hydraulic Modelling

TUFLOW, a fully 2D hydraulic modelling package with the ability to dynamically nest 1D elements was adopted for this study. The TUFLOW model contains three nested fine mesh 2D domains allowing flooding behaviour to be more accurately represented within the townships of Dadswells Bridge, Pomonal and Moyston. 1D pipe elements have been used to model major road culverts.

5.1 Model Description

The 2D model domain extends from the catchment outlet, located at approximately at the Horsham-Lubeck Road, up to and including the upper reaches of the catchment, covering an area of approximately 1450 square kilometres of the Mount William Creek Catchment, as shown in Figure 5-1. The model extent allows for the flood behaviour within the study area, from the upper catchment to the confluence of the Mount William Creek system with the Wimmera River, to be accurately represented without the influence of boundary effects.

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 Mount William Creek 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 Dadswells Bridge, Pomonal and Moyston 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, three nested fine mesh domains with a grid element size of 5 metres was adopted for each township. The areas enclosed by the three model domains are shown in Figure 5-1. 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 within the TUFLOW hydraulic model 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 2.0 metre spacing within the 4 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.

5.2 Model Development

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

5.2.1 Topography

As described in Section 2.1, various data sources were available to generate the DEM of the study area. The DEM used to inform the topography of the hydraulic model was more detailed than that used in the hydrologic modelling. The TUFLOW hydraulic model relies on topographic to be defined at 9 locations for each grid cell (cell corners, mid points on cell sides and cell centre). Representation of the topography in this manner allows the accurate representation of the underlying topography without the need to unduly manipulate the storage associated with each model cell.

5.2.2 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 5-1 and the layer is shown in Figure 5-2. 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 5.3).

As the majority of the lower Mount William Creek 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 5-1 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
Building footprints	1.00
Unmaintained grass/crops	0.04
Maintained grass/sports ovals	0.035
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

Land Use	Manning's 'n'
Waterway or Parks with very heavy brush/bush	0.12

5.2.3 Hydraulic Structures

Throughout the Mount William Creek catchment there are a number of hydraulic structures and controls. Whilst the majority of these structures are drainage culverts and bridges, there are a number of water supply/irrigation control structures that can play a significant role in the floodplain behaviour within the catchment.

5.2.3.1 Drainage Structures

The drainage structures (both culverts and bridges) were included in the hydraulic model using two different approaches, depending upon the structure size.

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 5.3).

5.2.3.2 Flow Control Structures

A number of irrigation channels and structures exist within the Mount William Creek floodplain which has a significant impact on the flood behaviour, especially within the lower sections of the catchment. Numerous structures have been included in the TUFLOW hydraulic model and are based upon information supplied by GWM water, captured by BMT WBM staff in the field or extracted from existing models of the catchment (namely Wimmera River – Yarriambiack Creek Flows Study, Water Technology, 2009).

5.2.4 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 4.2. There are three main types of boundaries used in the Mount William Creek hydraulic model, 2D-2D linking, external and internal flow boundaries as shown in Figure 5-1.

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 downstream of the Horsham – Lubeck Road, the discharge point for the Mount William Creek catchment into the Wimmera River. 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).

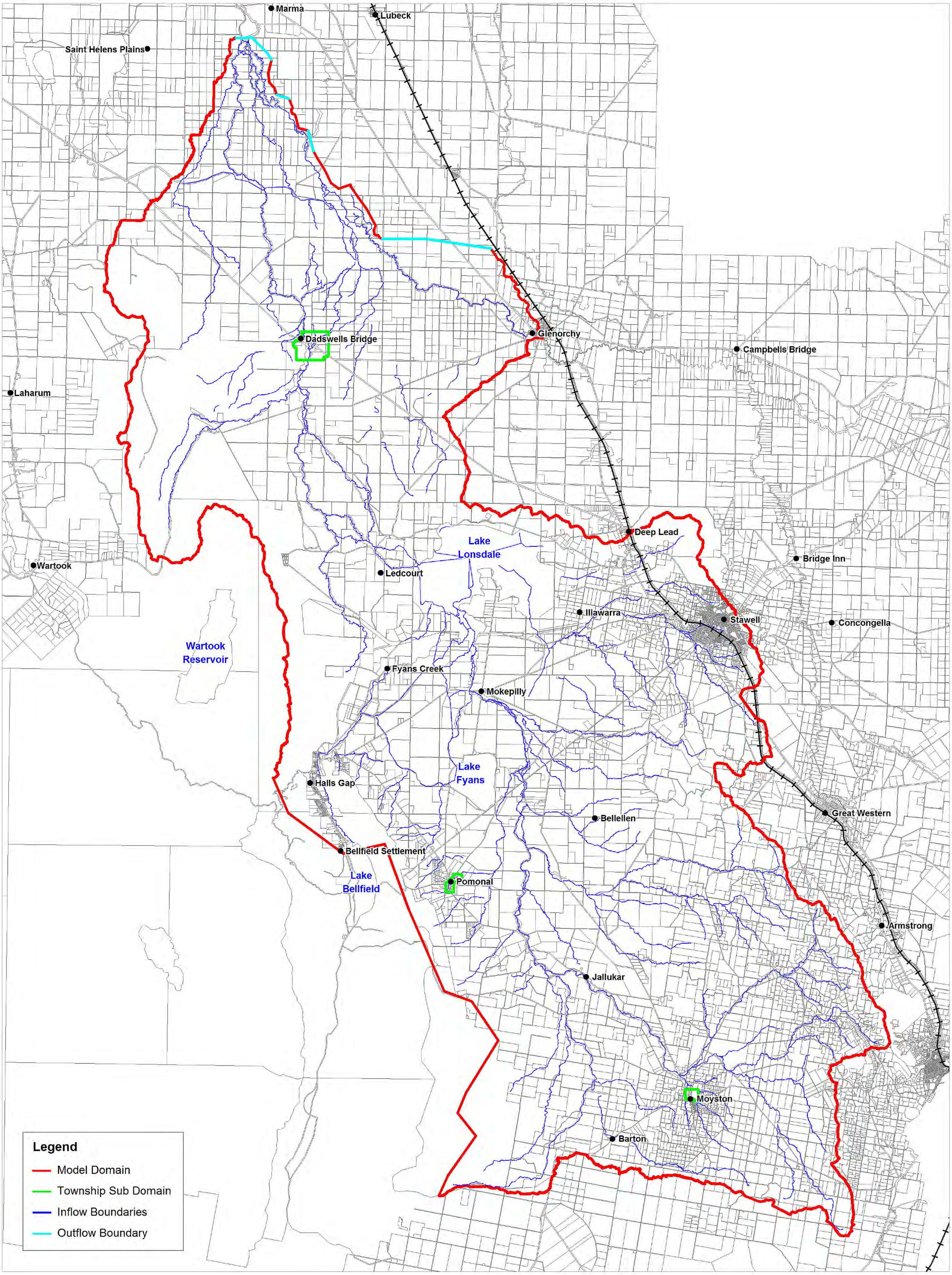
In addition to the internal and external boundaries the 2D hydraulic model includes a number of 2D-2D boundaries. These boundaries are included to allow water to flow freely between the main broader floodplain grid and the three fine mesh grids used to increase the resolution of the Dadswells Bridge, Pomonal and Moyston 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).

5.2.5 Mount William Township Fine Mesh Domain

Given the high social and economic sensitivity of the Dadswells Bridge, Pomonal and Moyston Townships in comparison to rural parts of the floodplain, a fine mesh domain with a grid element size of four metres has been established to improve the definition of flood behaviour within these three townships.

The three 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.

Preliminary hydraulic models of the entire catchment were used to determine the extents of all three fine mesh domains. The extent of these domains ensures that all flooding likely to impact upon houses within the townships of Dadswells Bridge, Pomonal or Moyston will be included in the fine mesh, rather than the coarser floodplain mesh.



Title:

Mount William Creek Flood Investigation
TUFLOW Model Setup

Figure: 5-1

Rev: A

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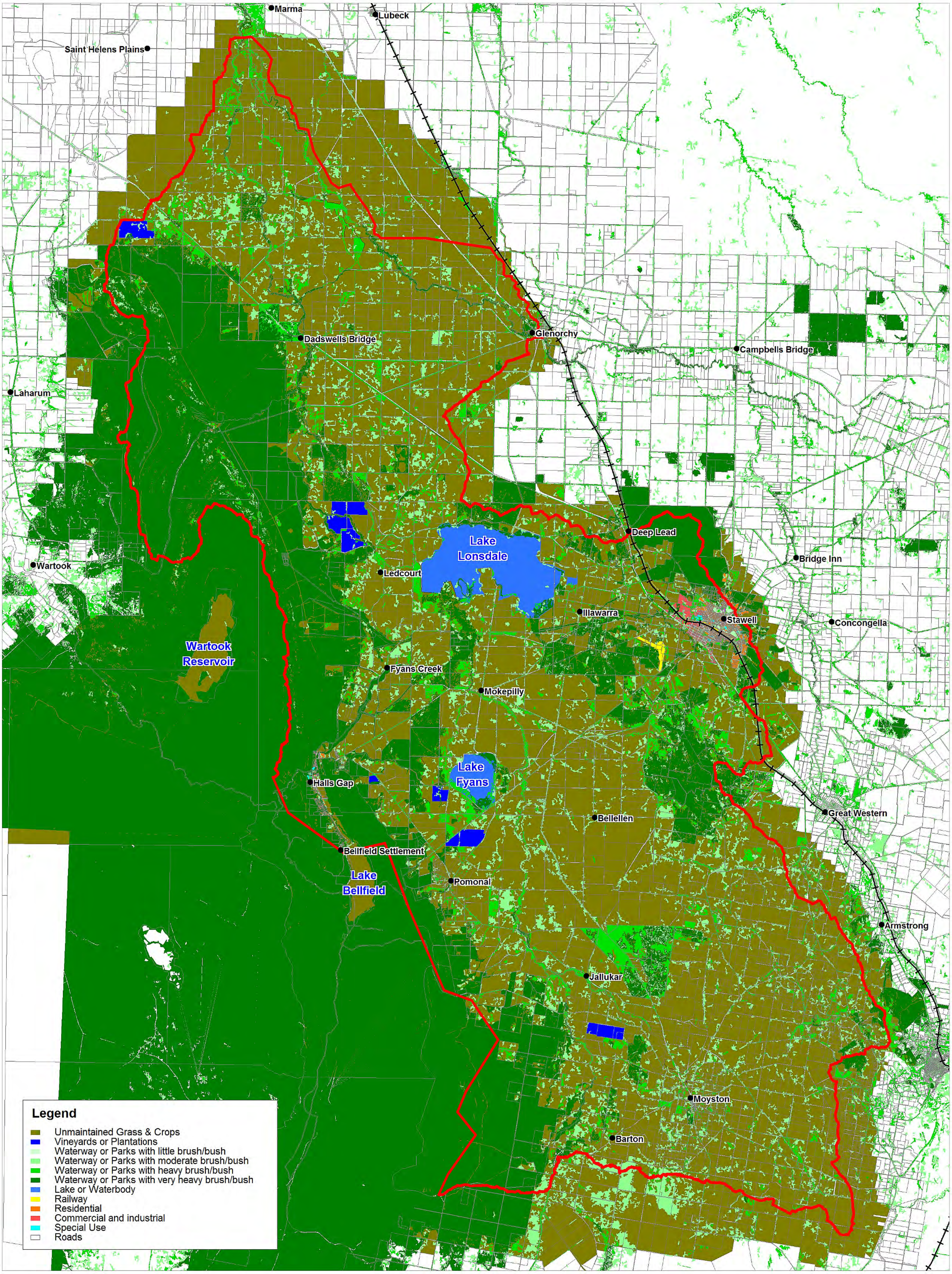

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Mount William Creek Flood Investigation
Manning's 'n' Distribution

Figure: 5-2

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5.3 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 4.4, 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 Mount William Creek TUFLOW model underwent a calibration process to fit the model to the observed data. The TUFLOW model was calibrated against the January 2011 flood event and validated against the December 1992 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.

5.3.1 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 January 2011 calibration storm event to the TUFLOW model and optimise the model parameters to achieve model calibration.

(5) Validate the model parameters against the December 1992 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.

5.3.2 Calibration and Validation Data

During the January 2011 flood event, the following data was available for use in the hydraulic model calibration:

- Recorded heights and instantaneous flow as recorded by the various stream gauges;
- Flood level marks were surveyed throughout the catchment following the January 2011 flood event.
- Aerial photography taken during the January flood events. The photography was not taken at the time of flood peak, however, it does provide an indication of flood extent.
- Anecdotal evidence of flood behaviour and heights which has been provided by the community.

5.3.3 Event Selection

Following the completion of the hydrologic model calibration process, four historic storm event inputs were available to be used to calibrate the hydraulic model. The two events that were used to calibrate the hydrologic model were also used to calibrate and validate the TUFLOW hydraulic model.

The January 2011 is the key calibration event as it resulted in the highest recorded flows within the catchment as well as being an event that occurred in recent history. Consequently, there is a large amount of reliable 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 Dadswells Bridge, Pomonal and Moyston, as well as the outskirts of Stawell. This evidence included a series of flood marks obtained from photography captured by the local community during the flood event and remnant high water marks captured post flood.

The December 1992 event was chosen as a validation event. The December 1992 event had been calibrated as part of the hydrologic modelling and was chosen as it would validate the calibrated hydraulic model against a smaller, more frequent flood event within the Mount William Creek catchment.

This approach will ensure a degree of confidence that the hydraulic model can adequately represent large (January 2011) and medium (December 1992) flood events throughout the study area.

5.3.4 January 2011 Calibration Event – Hydraulic Model Setup, Assumptions and Results

The January 2011 flood event was the third in a series of flood events to occur in western and northern Victoria between September 2010 and January 2011. Whilst the Mount William Creek catchment largely escaped significant flooding during the September 2010 and December 2010 flood events, the rainfall associated with these events helped to ‘wet’ the catchment and potentially exacerbate the flooding that occurred during January 2011.

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 than the hydrologic model it is possible to more precisely mimic the observed record. However the hydrologic inputs ultimately limit 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.

5.3.4.1 Initial Calibration

The initial calibration of the January 2011 flood events was undertaken based upon the calibrated hydrology (Section 4.4.6) and surveyed flood marks that were available within the catchment. Additionally, the recorded flows at each of the three gauge locations were compared to the hydraulic model data. The comparisons between the observed (recorded) data and the modelled (TUFLOW) data are shown in Figure 5-3, Figure 5-4 and Figure 5-5 for the stream gauges located at Fyans Creek, Mokepilly and Lake Lonsdale respectively.

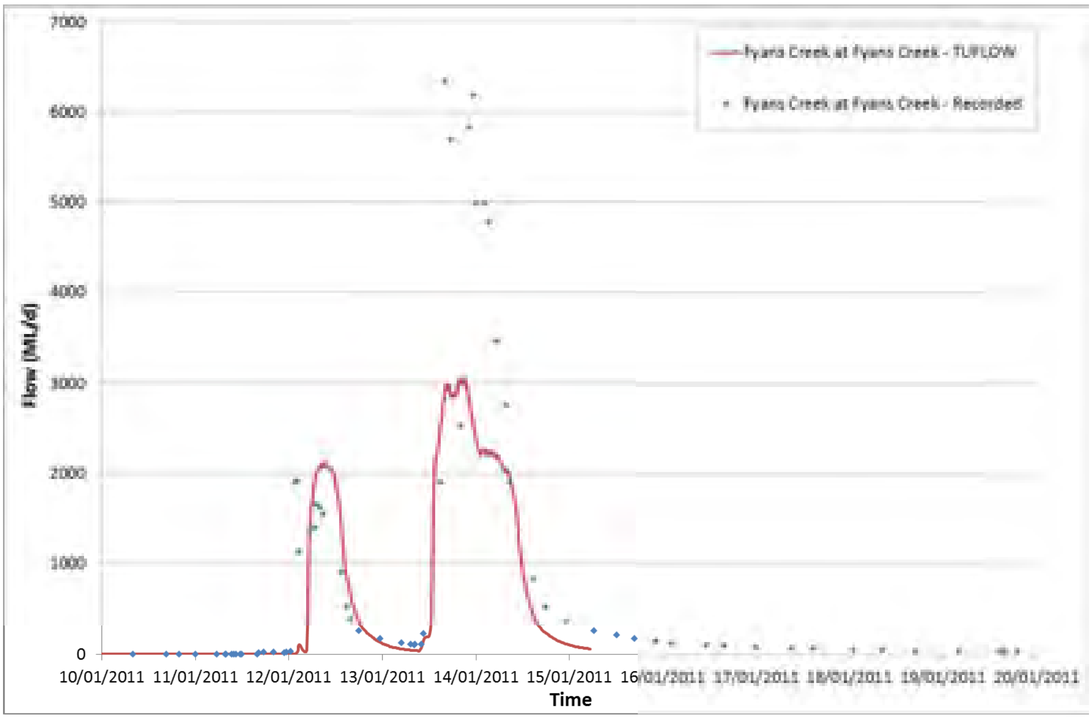


Figure 5-3 Initial January 2011 Calibration: Fyans Creek at Fyans Creek

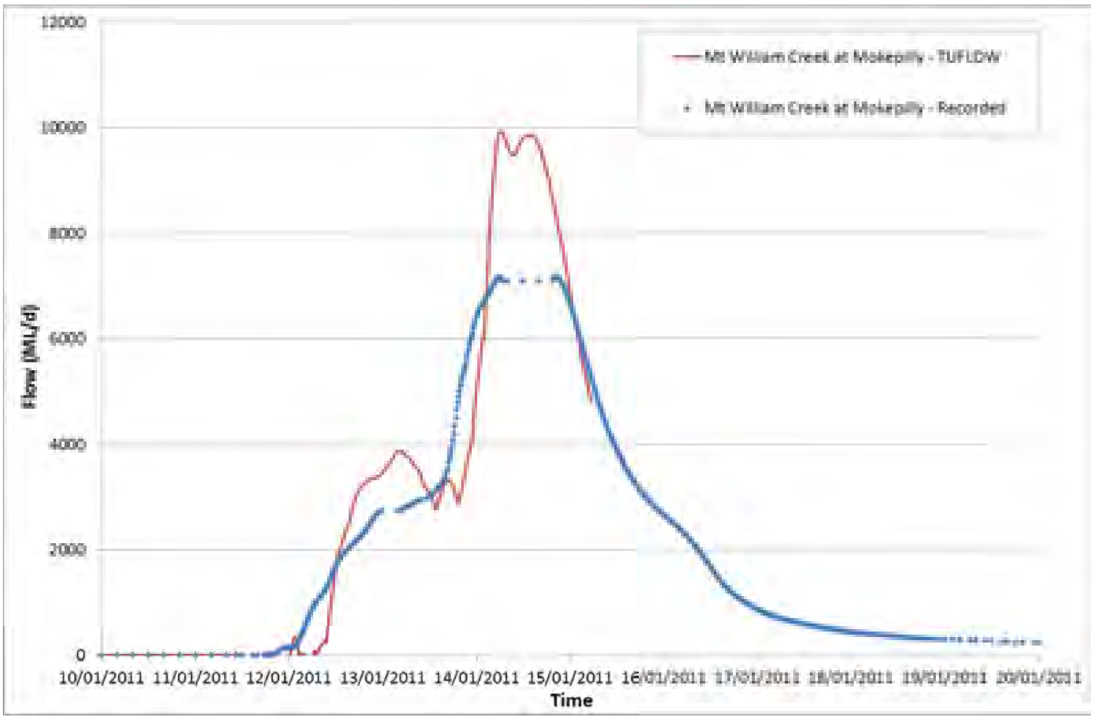


Figure 5-4 Initial January 2011 Calibration: Mount William Creek at Mokepilly

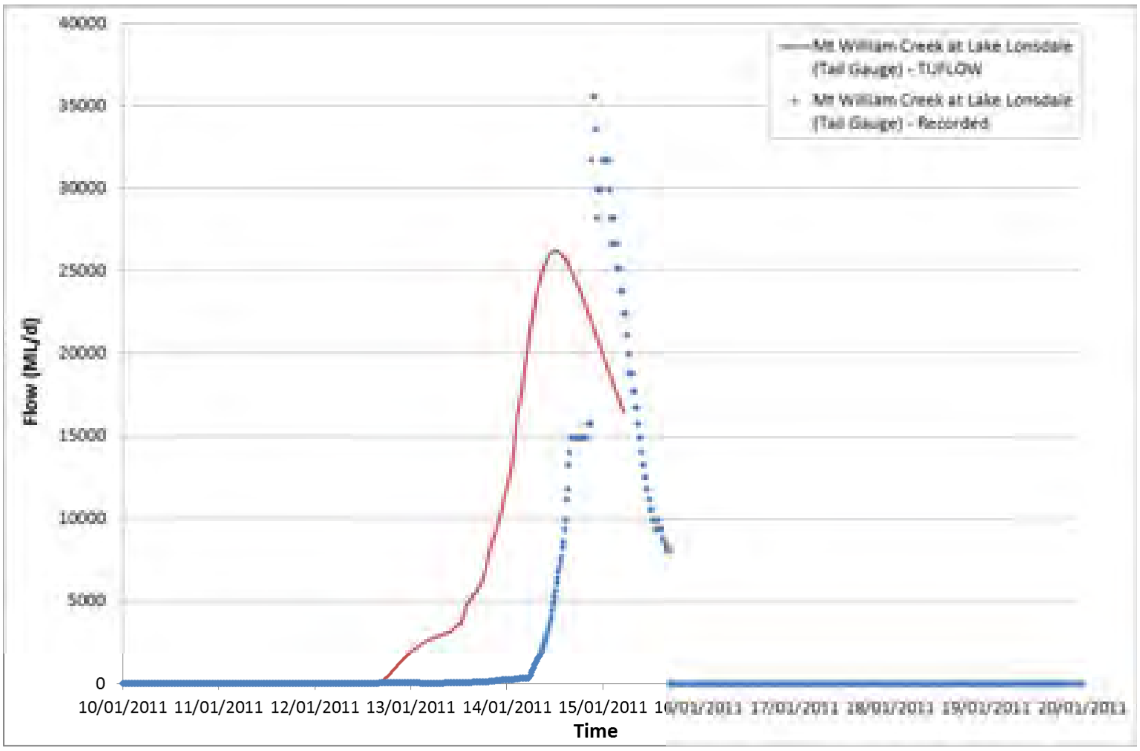


Figure 5-5 Initial January 2011 Calibration: Mount William Creek at Lake Lonsdale

Table 5-2 presents a comparison the peak flows at each of the gauges within the catchment used during the calibration process. In this table, it should be noted that a comparison between the peak flows at the Mokepilly gauge is not meaningful when considering that the gauge did not accurately record the peak flow. From the graphs above and table below, it is clearly evident that the hydraulic model is underestimating the peak flows at both the Fyans Creek and Lake Lonsdale gauges. However, based on the shape of the fit at the Mokepilly gauge, it can be inferred that the hydraulic model is replicating the flow at this gauge location quite well.

Table 5-2 Initial January 2011 Flow Comparison

Stream Gauge	Recorded Peak Flow (ML/day)	Modelled Peak Flow (ML/day)	Difference (%)
Fyans Creek at Fyans Creek	6339	3070	-52%
Mount William Creek at Mokepilly	7160	9932	39%
Mount William Creek at Lake Lonsdale	35556	26192	-26%

The model results are generally replicating the shape and timing of the observed gauge records, although the peak flows are considerably lower. The result at Fyans Creek in particular matches both the rising and falling limbs of both hydrograph peaks, although the peak flow of the second peak is considerably underestimated.

Following community meetings that were held as part of the investigation, WCMA in conjunction with local landholders, identified 48 flood marks from the January 2011 flood event that were surveyed. Figure 5-11 the comparison of modelled flood levels to the surveyed marks (this information is also presented graphically in Figure 5-12). These figures show that the hydraulic model is generally overestimating the flood marks. Despite this, there are 9 of the survey marks which are not shown to be flooding based on the hydraulic model results. The tendency for the hydraulic model to be too high when comparing to the survey marks is in contrast to the results previously presented that show that the modelled flows are generally being underestimated. However, this can be explained by the fact that many of the surveyed flood marks have been inferred from photos taken by members of the local community during the time of the flood. Many of these photos are likely to have been taken either prior to or following the peak flood level occurring and will therefore not represent the peak flood level at a particular location.

In general, the calibration is acceptable for Dadswells Bridge and floodplain downstream towards the Wimmera River. However the calibration is poor along Fyans Creek and the upper Mount William Creek (in some cases the flood levels are too high and in other areas too low).

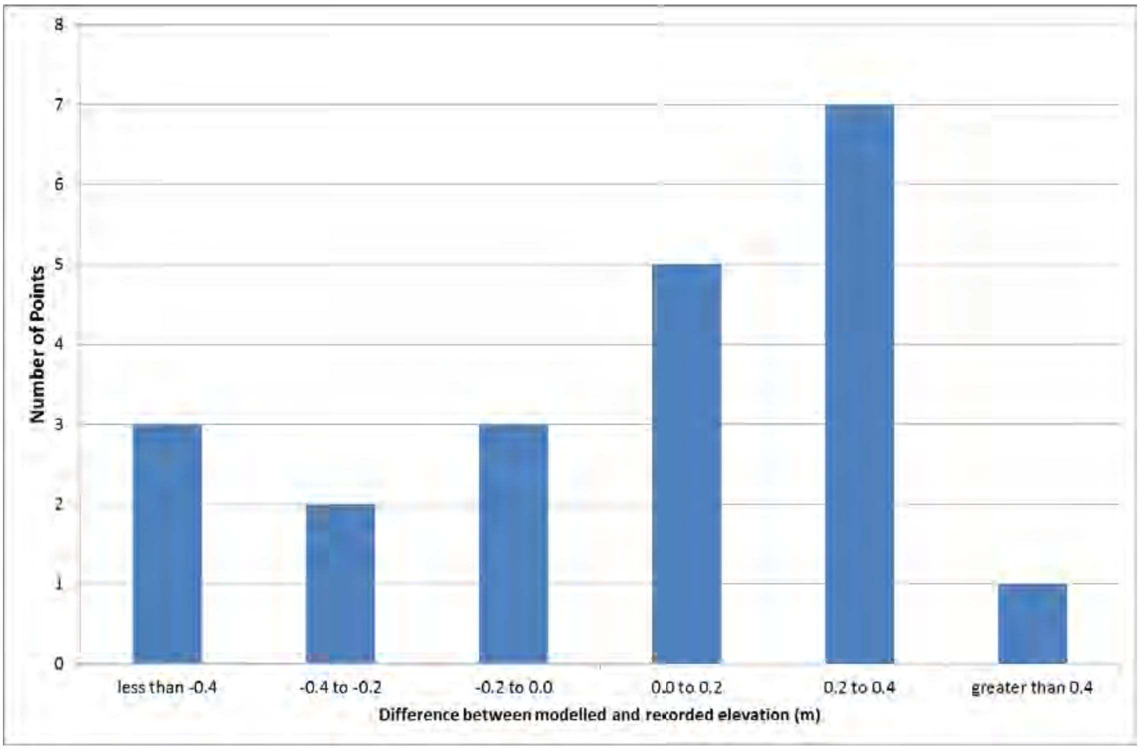
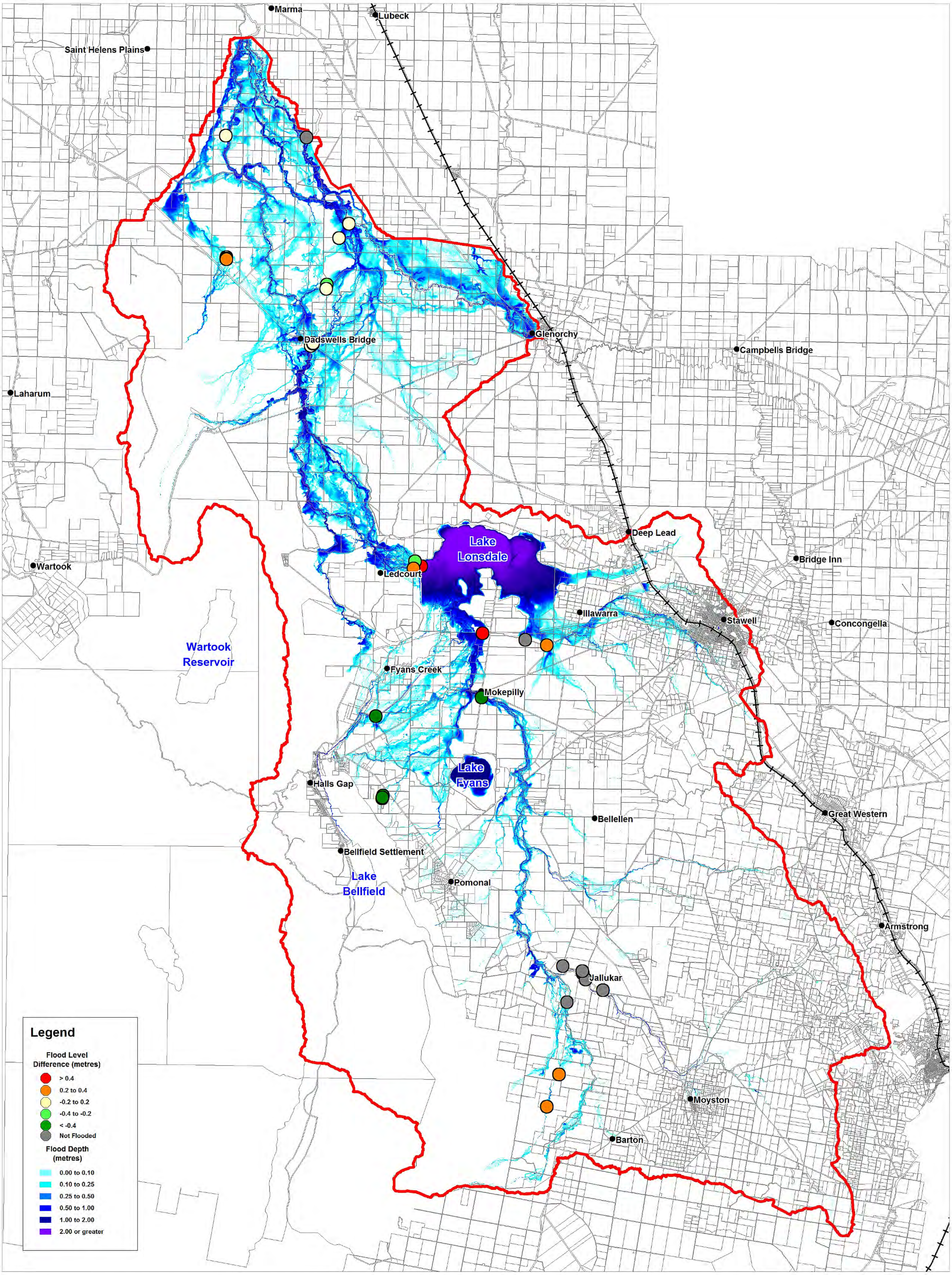


Figure 5-6 Initial January 2011 Calibration – Distribution of Surveyed Flood Marks



Title:
Mount William Creek Flood Investigation
Initial January 2011 Calibration

Figure: 5-7

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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Approx. Scale

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5.3.4.2 Community Feedback

Following the preparation of the initial January 2011 calibration, the WCMA (Clare Wilson) undertook an extensive community consultation phase within the Mount William Creek catchment. The intent of this consultation was to provide members of the community, as well as members of the local Councils, an opportunity to view and provide comments on the initial January 2011 calibration. The majority of these comments were provided back to BMT WBM as 'mark-ups' on maps prepared by the WCMA. In general the comments were positive, especially with regard to the areas in and around Dadswells Bridge and St Helens Plains. However, the comments highlighted a number of issues with this calibration in relation to the flooding around Stawell, Moyston, Jallukar, Pomonal and the properties in the vicinity of Reids Lane (Halls Gap). Some of the key comments received from the consultation include:

- Not enough flooding along Salt Creek and Mount William Creek in the upper catchment, resulting in lower flood heights and smaller flood extents in the vicinity of Moyston and Jallukar than what was observed (and photographed) during January 2011.
- The modelling shows significant shallow sheet flow flooding in and around Pomonal and areas to the north along Ararat-Halls Gap Road, extending to the vicinity of Reids Lane (Halls Gap), flooding that does not correlate well with the recollections of the local community.
- The flooding shown in and around Dadswells Bridge and St Helens Plains is generally consistent with the community's experiences.

5.3.4.3 Final Calibration

Following the extensive community consultation period, a number of changes were made in an attempt to improve the calibration. Specifically, these changes related to trying to improve modelled calibration results so that better agreement could be achieved with flood marks captured following the flood event and numerous photographic records provided by the Community. For this final calibration, more weight was applied to the photographs and flood marks provided by the community rather than the stream gauge records. This was especially relevant for the catchment upstream of the Mokepilly gauge where there some significant discrepancies between the initial calibration and photographic records of the flood event. The reasons for this include:

- There is some doubt regarding the accuracy of the stream gauge information, especially for the gauge at Mokepilly.
- Stream gauging records for high flows (such as January 2011) can be susceptible to errors. Re-rating of stream gauges can help to alleviate these errors, however, this was not done for either the Fyans Creek or Mokepilly stream gauges following the January 2011 flood event.
- The majority of the flood marks captured in the upper catchment are based upon photography provided by members of the community. These photographs are unlikely to have captured the peak flood level of the January 2011 and hence calibrating to these levels is likely to underestimate the flood levels and flood extents for the flood event.
- Photographs provided by the community clearly shows flooding that has occurred in particular areas, and whilst these photos may not capture the peak inundation, that do provide an

indication of where floodwaters where. A number of these photographs are reproduced in the following section of this report.

In order to address the community's comments in relation to the shallow sheet flows across the upper portions of the catchment, BMT WBM staff were accompanied by WCMA staff (Clare Wilson) and Ararat City Council Staff (Joel Hastings) for an additional site visit that covered a number of areas in the upper Mount William Creek catchment, including Reids Lane (Halls Gap), Pomonal and Moyston. Following these additional site visits, a number of changes were made to the hydraulic model to improve its ability to represent a number of smaller drainage depressions and creek systems in the hydraulic model. These changes related to stream re-enforcement to ensure that the capacity of the stream networks was adequately represented in the hydraulic model. The site visits showed that many of these smaller drainage depressions and creeks were not being adequately represented in the Digital Elevation Model due to the presence of heavy vegetation along the creek alignments. The poor representation of these creeks resulted in the capacity of the drainage lines being underestimated by the hydraulic model, resulting in unrealistic overland flow (often at shallow depth).

As discussed previously (Section 4.4.6 and Table 4-17), the calibration parameters for the January 2011 flood resulted in some initial loss and continuing loss values that outside the ranges generally considered acceptable. This was especially the case for the catchment upstream of the gauge at Mokepilly, where a continuing loss of over 6 mm/hr was applied to achieve the hydrologic model calibration. Whilst the stream gauge information supported the adoption of these loss values for the Mokepilly gauge inter-station area, the resultant hydraulic model results indicated that there was not enough water in this part of the model domain. Therefore, the hydrologic model was re-run using an initial loss of 15 mm and a continuing loss of 1.5 mm/hr and these boundaries were applied to the hydraulic model. The adoption of these loss rates for this portion of the catchment resulted in a very poor calibration at the Mokepilly gauge (Figure 5-9); however, the resultant flood extent and flood depths provided a much improved correlation to the community's recollections when compared to the initial calibration. The significantly increased flow down Salt Creek and Mount William Creek (upstream of Mokepilly) also results in a poorer calibration at Lake Lonsdale (Figure 5-10). The calibration at Fyans Creek (Figure 5-8) is unchanged. Table 5-3 shows a numerical comparison of the peak flows for each of the three gauge sites based on this final calibration.

As observed in Table 5-3, the hydraulic model is significantly overestimating the peak at the Mokepilly gauge. However, it is worth considering the magnitude of the recorded peak flows during the January 2011 flood event. Lake Lonsdale recorded a peak of 35,556 ML/day, a peak flow that is likely to be less than the inflows into the lake from upstream due to the attenuation of the flow that occurs across the lake. However, the gauges at Mokepilly and Fyans Creek that represent 58% and 13% of the Lake Lonsdale catchment respectively only record peak flows of 7160 ML/day (Mokepilly) and 6339 ML/day (Fyans Creek). It is considered extremely unlikely that the remaining catchment upstream of Lake Lonsdale (mostly consisting of the Pleasant Creek catchment), constituting 29% of the overall Lake Lonsdale catchment would have delivered the required flows into Lake Lonsdale.

There is a much better correlation when considering the relative magnitudes of the modelled flows, with the Mokepilly catchment contributing the bulk of the flow for the Lake Lonsdale inflow. However, this indicates that the recorded flow data for the Mokepilly gauge is unreliable for the January 2011 flood events and should be ignored for the hydraulic model calibration.

Figure 5-11 shows a graphical representation of the performance of the hydraulic model in comparison to the surveyed flood levels. This figure shows that the hydraulic model has a bias to overestimate the recorded flood marks; however, this is not surprising in light of the fact that the majority of these flood marks are based upon photos of the flood event. These photos are unlikely to have been taken at the peak of the flood event and consequently the flood mark levels are likely to underestimate the flood level (which should result in the hydraulic model overestimating the flood levels for the flood marks). Figure 5-12 shows the performance of the hydraulic model across the catchment.

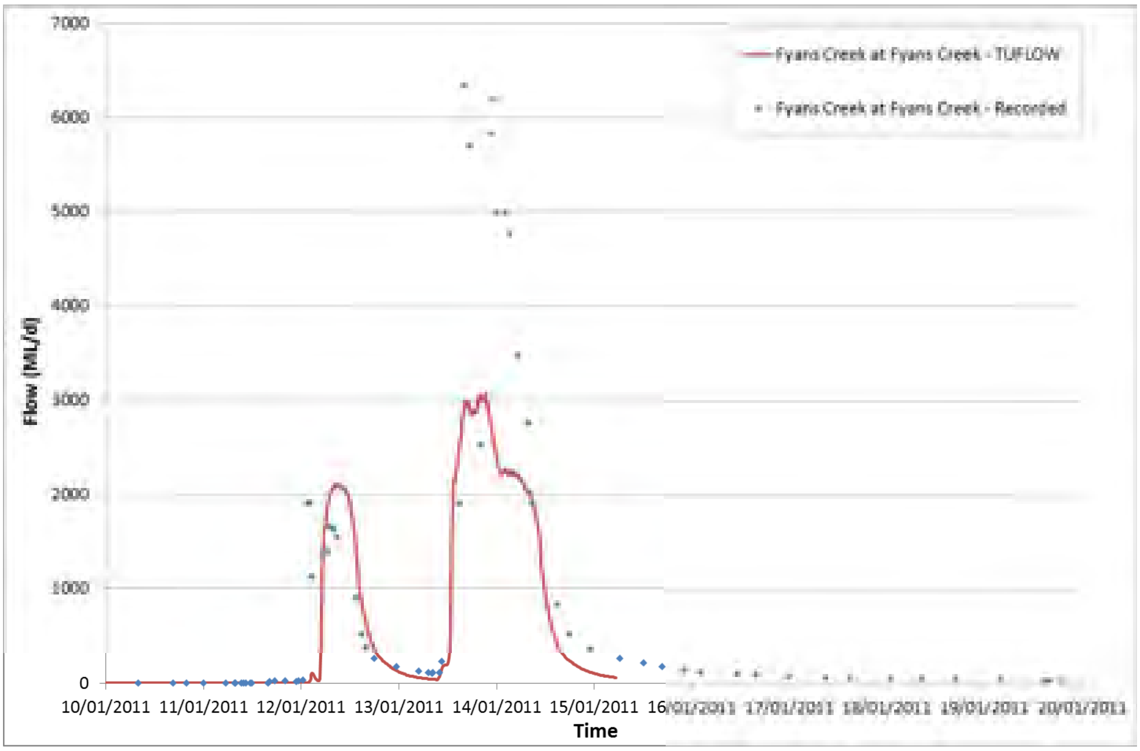


Figure 5-8 Final January 2011 Calibration – Fyans Creek at Fyans Creek

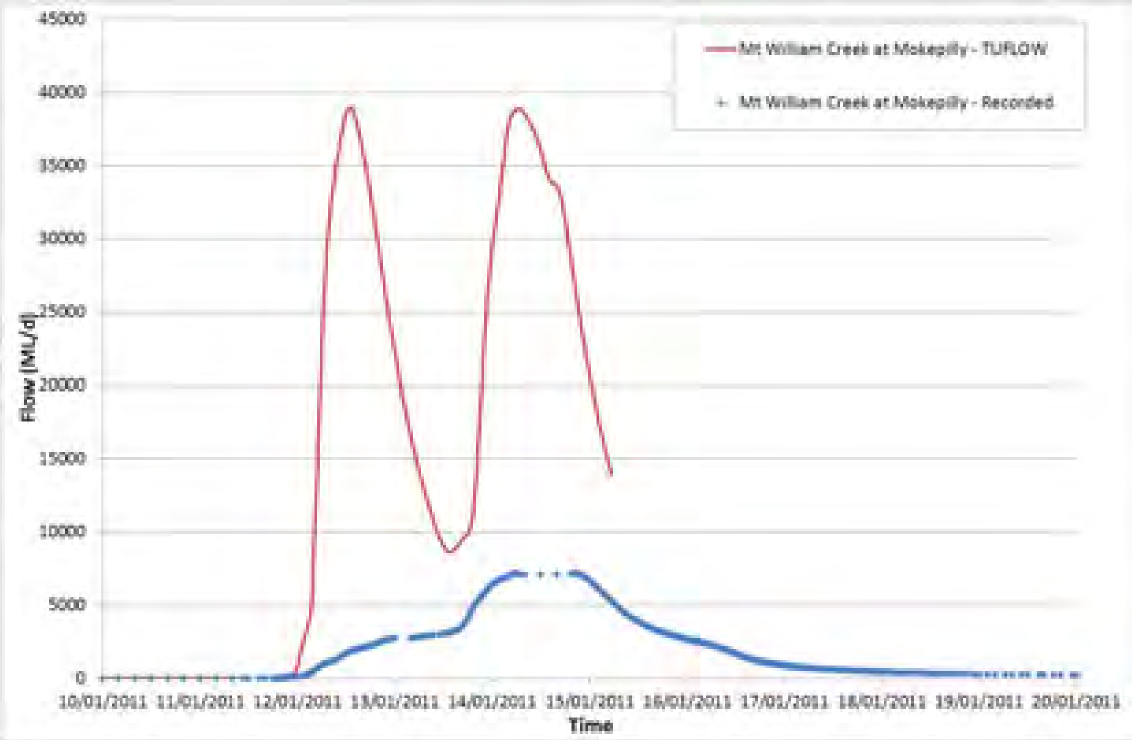


Figure 5-9 Final January 2011 Calibration – Mount William Creek at Mokepilly

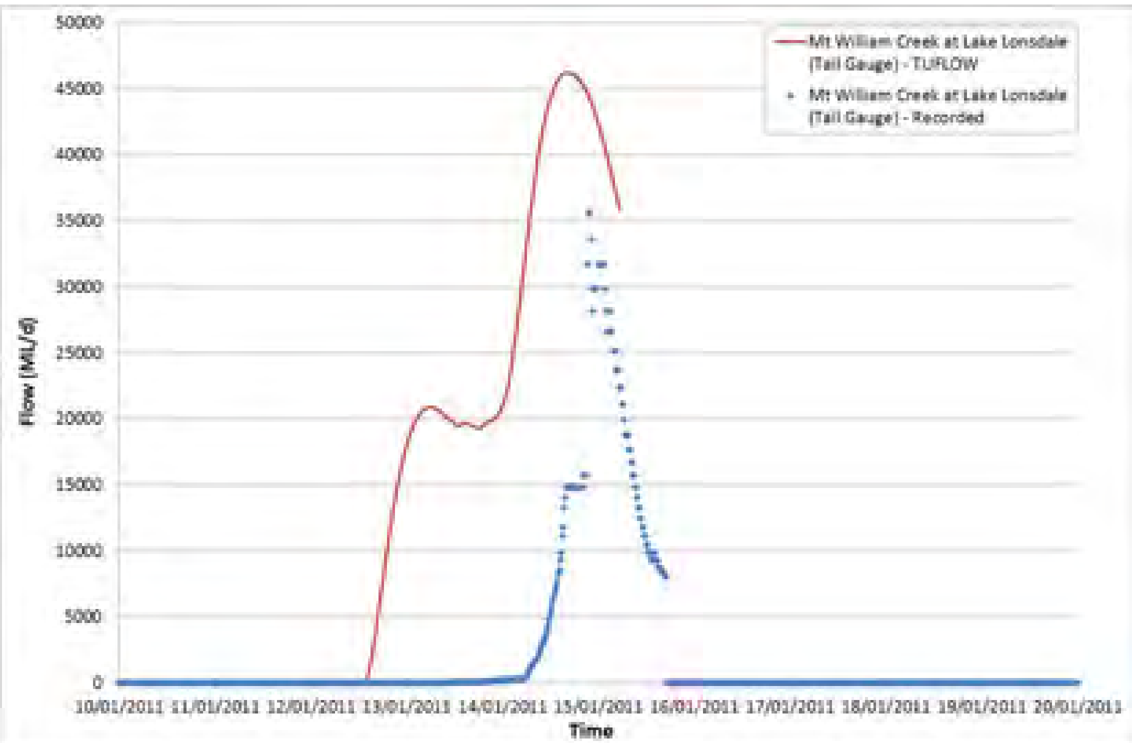


Figure 5-10 Final January 2011 Calibration – Mount William Creek at Lake Lonsdale

Table 5-3 Final Calibration – January 2011 Flow Comparison

Stream Gauge	Recorded Peak Flow (ML/day)	Modelled Peak Flow (ML/day)	Difference (%)
Fyans Creek at Fyans Creek	6339	3070	-52%
Mount William Creek at Mokepilly	7160	38,991	545%
Mount William Creek at Lake Lonsdale	35556	46,250	30%

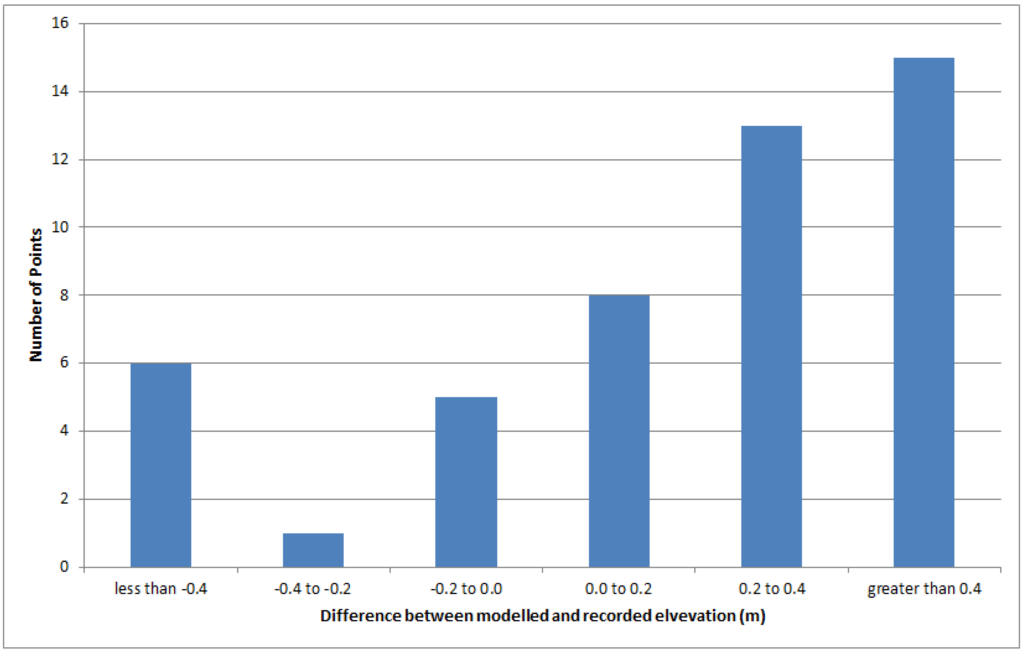
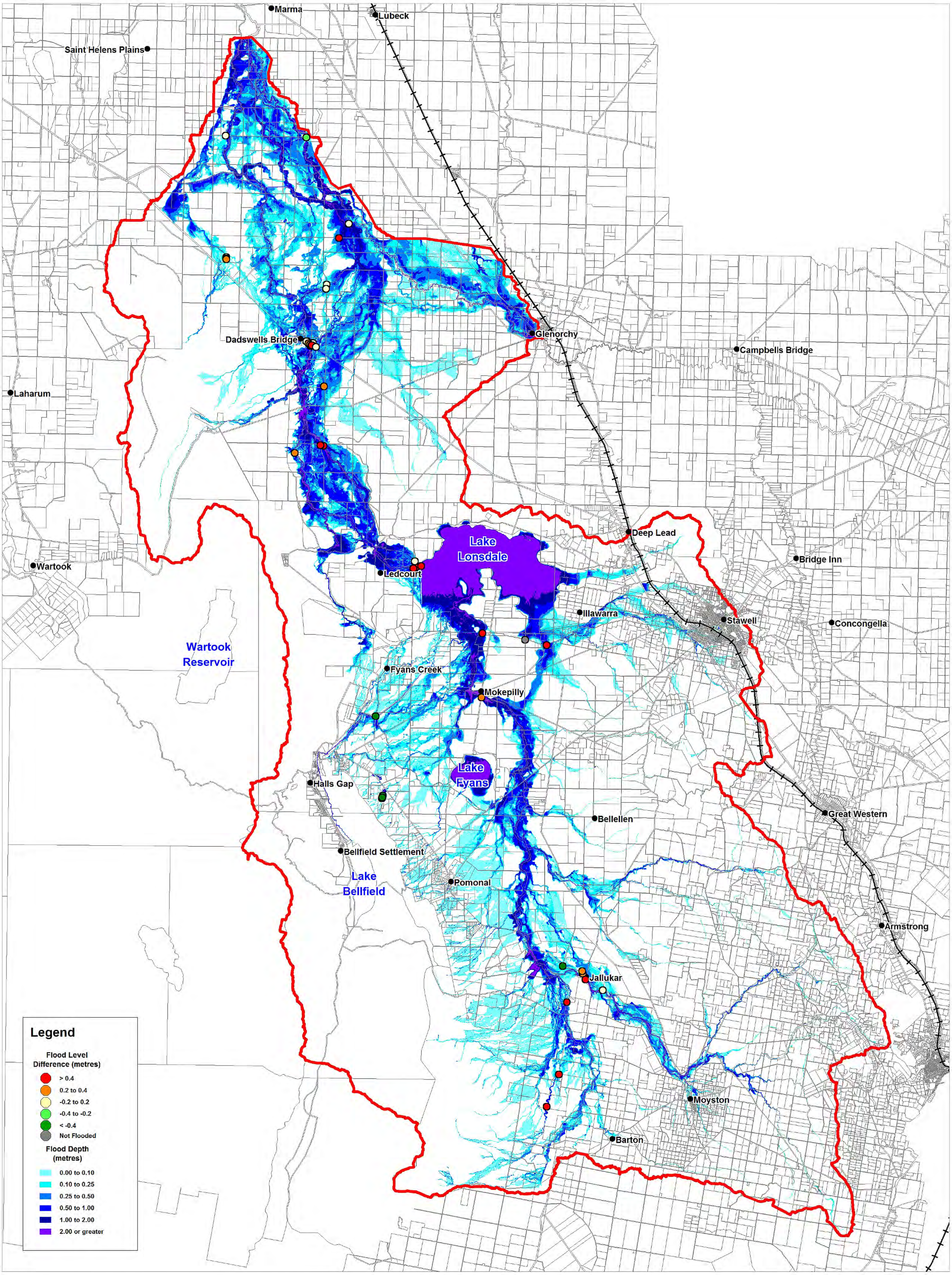


Figure 5-11 Final January 2011 Calibration – Distribution of Surveyed Flood Marks



Title:

Mount William Creek Flood Investigation
January 2011 Calibration

Figure: **5-12**

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Approx. Scale

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5.3.4.4 Evidence to Support Final Calibration

As discussed in the previous section, whilst the final calibration of the January 2011 flood event for the Mount William Creek catchment has resulted in the adoption of some more acceptable loss rates for the catchment upstream of the Mokepilly stream gauge. However, this has conversely resulted in some very poor comparisons between the modelled results and both the stream gauging and flood marks that were recorded both during and following the flood event.

Whilst the WCMA (Clare Wilson), the local Councils and the community are generally happy with the final calibration for the January 2011 flood event, it is important to provide sufficient evidence to support the adoption of a result that varies significantly from the recorded data (stream gauges and flood marks). This section is designed to provide the evidence required to support the final January 2011 calibration results for the Mount William Creek catchment.

The following sub-sections have been structured to provide supporting evidence for the adoption of the final calibration based upon particular towns/regions within the Mount William Creek catchment.

5.3.4.4.1 Jallukar

The flood marks and photographs that were collected in the Jallukar region indicated that there were a number of serious discrepancies between the initial calibration result and the January 2011 flood event. Figure 5-13 shows how the initial calibration (shown in red) compares to the final calibration (shown in blue). The initial model calibration shows flooding confined to Mount William Creek which does not extend into the surrounding floodplain. This property is located on the Ararat – Halls Gap Road, between Pomonal and Moyston. The pink dots in this figure represent surveyed flood marks that were captured following the January 2011 flooding and Figure 5-14 shows a selection of photographs at this location.

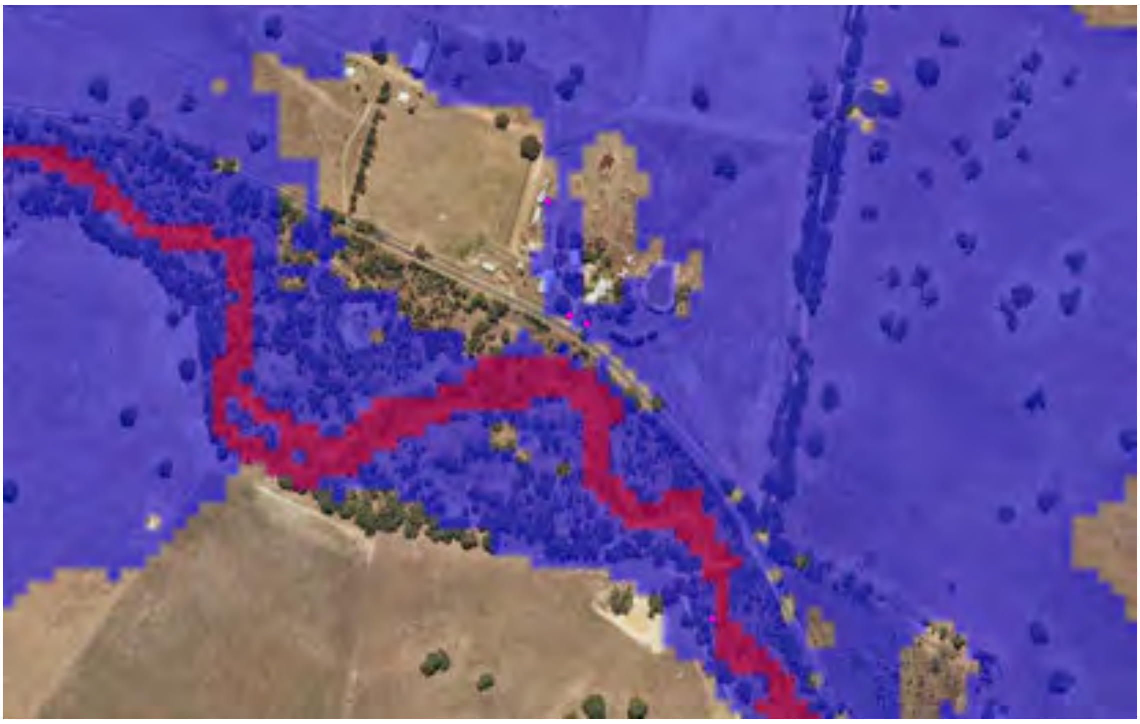


Figure 5-13 Comparison between initial and final January 2011 calibrations – Jallukar (1)

Figure 5-14 Flooding of a property on Ararat – Halls Gap Road, Jallukar

Figure 5-13 and Figure 5-14 clearly show that the initial calibration of the January 2011 flood event does not adequately reproduce the flooding of Mount William Creek in the Jallukar region. The amendment of the hydrologic model calibration parameters (as discussed in section 5.3.4.3) resulted in increased flow along this section of Mount William Creek which ultimately resulted in a flood extent and flood depths that better reflected the obtained survey marks and flood photography.

Additional flood marks and photography were provided for an air strip and aircraft hangar (also located on Ararat – Halls Gap Road). Figure 5-15 shows how the initial calibration (shown in red) compares to the final calibration (shown in blue) at this location. In a similar vein to the previous example, Figure 5-15 and Figure 5-16 show that the final calibration provides a much better representation of the flooding at this location when compared to the initial calibration. The provided photo (Figure 5-16) was taken after the flood peak (at approximately at the same time at the peak flood height was recorded at the Mokepilly gauge, approximately 20 kilometres downstream) and hence does not depict the peak inundation at this site.

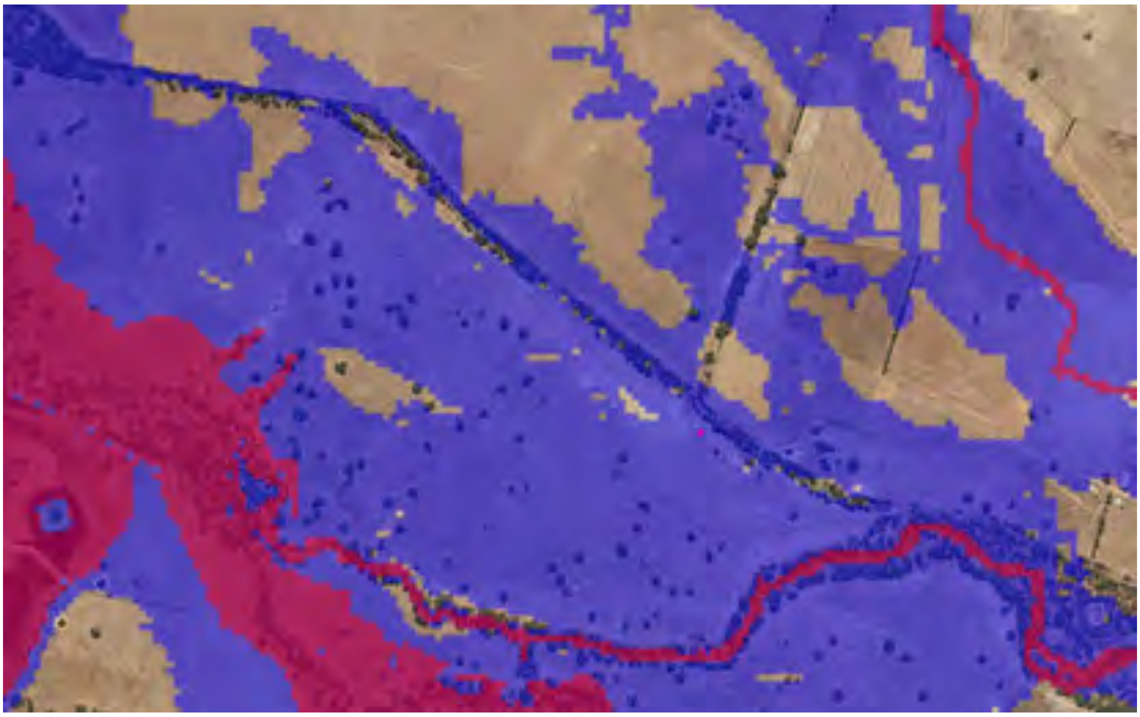


Figure 5-15 Comparison between initial and final January 2011 calibrations – Jallukar (2)

Figure 5-16 Flooding of the Air Strip on Ararat – Halls Gap Road, Jallukar

Further photography was provided along Ararat – Halls Gap Road in the vicinity of Lady Summers Bridge. This region of the catchment experienced extensive flooding during the January 2011 flood event resulting in the road closure of the Ararat – Halls Gap Road at this location. Like the previous comparisons, Figure 5-17, shows significant variation in the flood extents based upon the initial calibration (shown in red) and the final calibration (shown in blue). The initial calibration only shows flood water at the site of the bridge itself, with no inundation of the approach road either to the north-west or to the east. The green dot in Figure 5-17 shows the approximate location where the photograph shown in Figure 5-18 was taken. Although there photograph metadata did not include a time stamp, it clearly shows inundation of the Ararat – Halls Gap Road to a degree only reproduced by the final calibration.

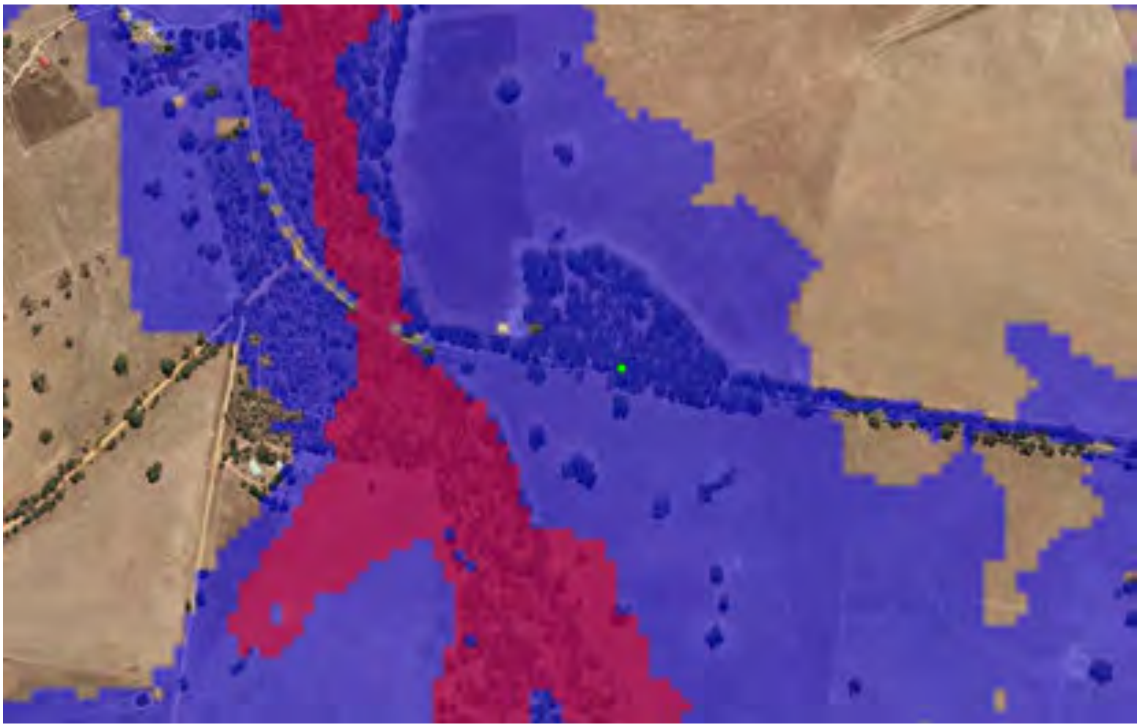


Figure 5-17 Comparison between initial and final January 2011 calibrations – Jallukar (3)

Figure 5-18 Flooding of Ararat – Halls Gap Road (East of Lady Summers Bridge)

5.3.4.4.2 Moyston

The township of Moyston is located within the catchment of Salt Creek, a tributary of Mount William Creek. Moyston is located upstream of the Mokepilly gauges and is therefore influenced by the changes made to the parameters between the initial and final calibrations of the January 2011 flood event.

Figure 5-19 shows the comparison between the initial calibration (shown in red) and the final calibration (shown in blue) for a house and shed in on Presbyterian Road, Moyston. The local resident also provided some photographs, one of which is shown in Figure 5-20, of the flooding around the property. The photographs were taken the morning following the peak inundation (the peak occurred during the night at Moyston), and therefore do not show the peak inundation of the property. However, the photograph shows water between the house and shed, a pattern of inundation not shown in the initial calibration but reflected in the final calibration of the January 2011 flood event.

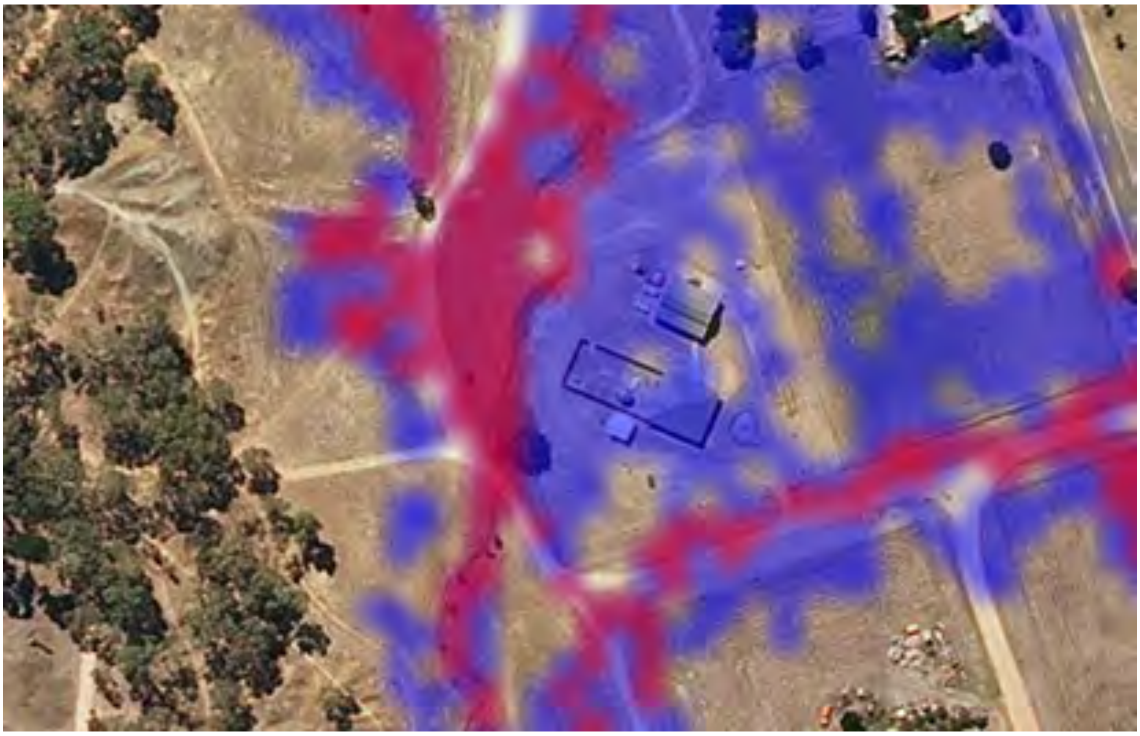


Figure 5-19 Comparison of initial and final January 2011 calibrations - Moyston

Figure 5-20 Flooding between house and shed - Presbyterian Church Road, Moyston

5.3.4.4.3 Pomonal

The flooding around Pomonal, especially to the west of the Ararat – Halls Gap Road was significantly influenced by the ability of the underlying DEM to represent the various channels and creeks in the region. As shown in Figure 5-21, the initial calibration (shown in red) showed some large areas of shallow sheet flows that upon review of the topography in the region (undertaken during a site visit with WCMA and ARCC staff) was unrealistic.

Further review of the topography indicated that a number of drainage lines and creeks were not appropriately represented in the hydraulic model, resulting in the underestimate of flooding during the January 2011 flood event. The final calibration (shown in blue, Figure 5-21), shows a flood extent for the January 2011 flood event that is more representative of the underlying terrain. To achieve these changes to the flood extent, a number of changes were made to the digital elevation model, including stream enforcement and the lowering of a number of drainage channels (as discussed in section 5.3.4.3).

These additional site visits also identified a number of additional drainage lines that were not shown in contain water in the initial calibration. The application of inflow boundaries was amended to ensure all drainage lines and creeks in the vicinity of Pomonal were shown to contain floodwaters.

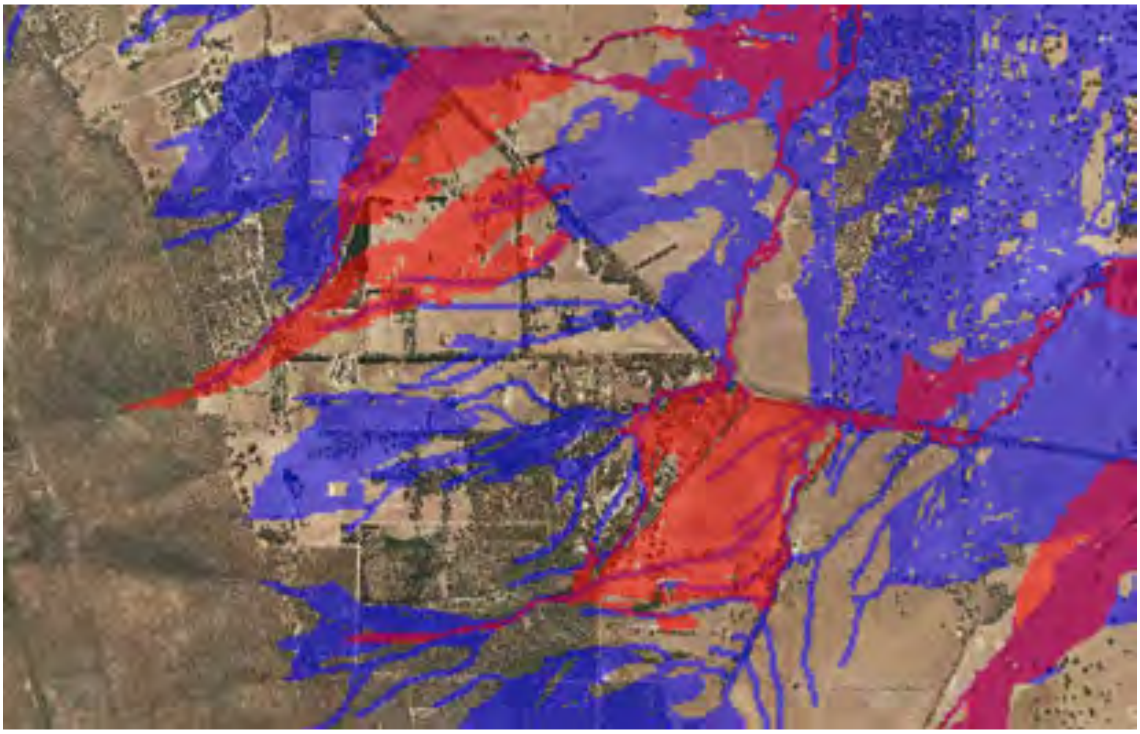


Figure 5-21 Comparison of initial and final January 2011 calibrations - Pomonal

5.3.4.4.4 Halls Gap (Reids Lane)

The region around Reids Lane (Halls Gap) exhibited similar behaviour to Pomonal during the initial calibration in terms of shallow sheet flow. Additional site visits (undertaken by BMT WBM in conjunction with WCMA and ARCC staff) sought to confirm and validate the flood behaviour shown in this region during the January 2011 flood event.

Like the region around Pomonal, the underlying DEM failed to adequately represent the natural drainage lines and creeks due to the presence of the heavy vegetation. The heavy vegetation limits the ability of the LiDAR to determine the ground surface due to the filtering process that is undertaken to create the DEM (as discussed in section 5.3.4.3).

Figure 5-22 shows how the initial calibration (shown in red) compares to the final calibration (shown in blue) in the region around Reids Lane (Halls Gap). Local residents were able to confirm the final calibration is a more reflective representation of the flooding that occurred during the January 2011 flood event.

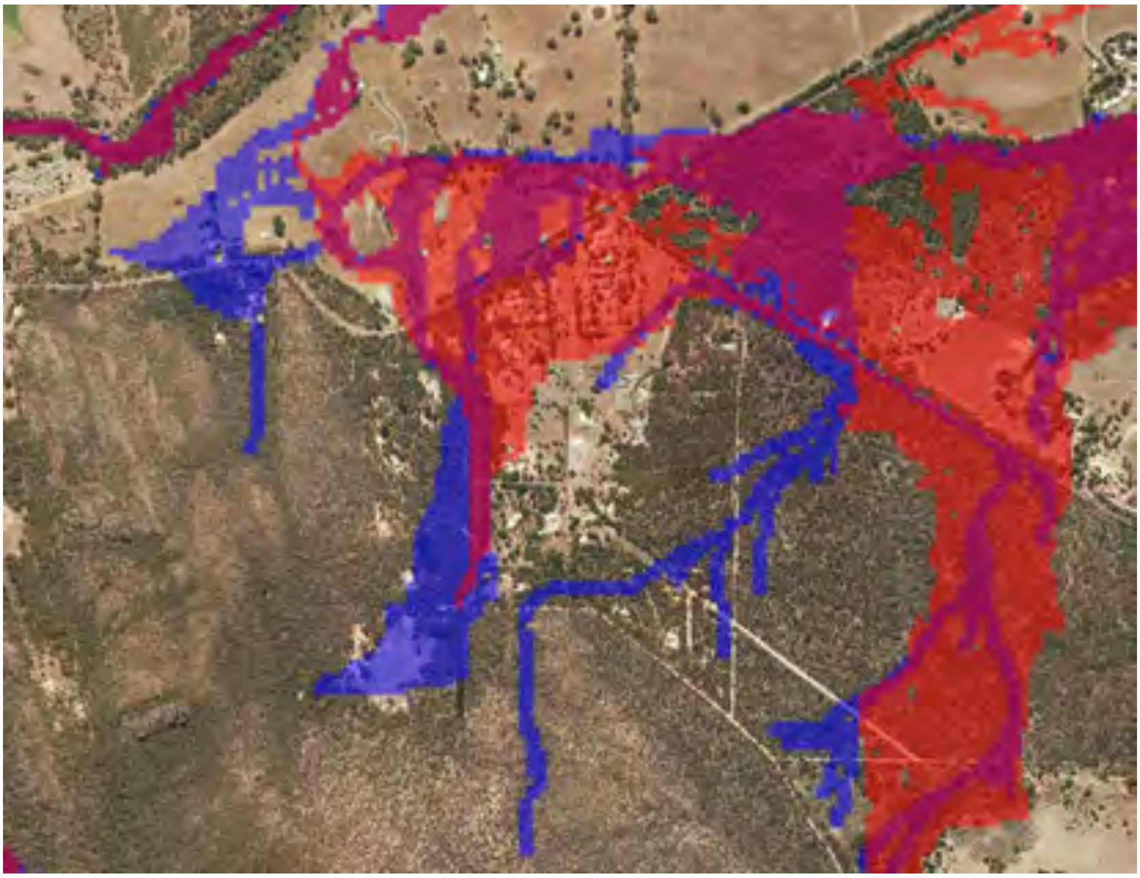


Figure 5-22 Comparison of initial and final January 2011 calibrations – Halls Gap (Reids Lane)

5.3.5 December 1992 Verification Event – Hydraulic Model Setup, Assumptions and Results

To validate the TUFLOW hydraulic model the December 1992 flood event was run through the model using exactly the same model schematisation as used in the calibration of the January 2011 flood event (as presented in the previous section). The only change between the January 2011 calibration model and December 1992 verification model are the inflow boundaries.

The comparisons between the observed (recorded) data and the modelled (TUFLOW) data are shown in Figure 5-23, Figure 5-24 and Figure 5-25 for the stream gauges located at Fyans Creek, Mokepilly and Lake Lonsdale respectively.

In a similar vein to the January 201 calibration, the hydraulic model does a good job at replicating the timing and shape of the recorded gauge hydrographs. However, as previously, the model is not as good at replicating the peak flows.

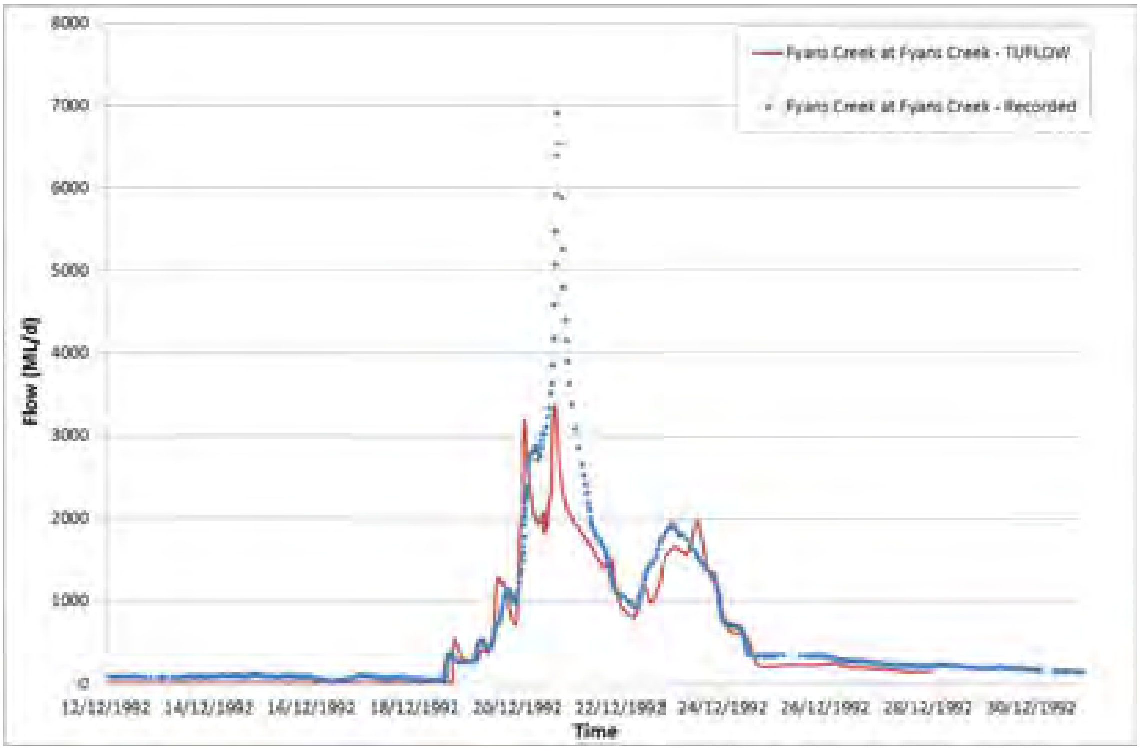


Figure 5-23 December 1992 Verification: Fyans Creek at Fyans Creek

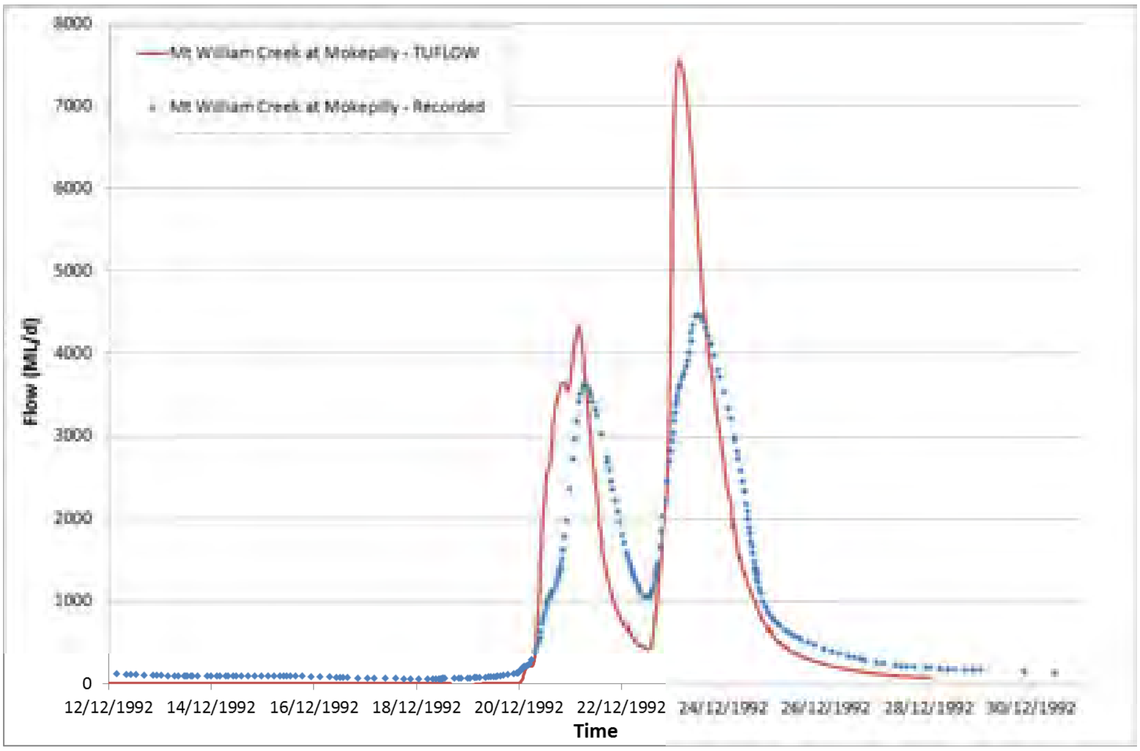


Figure 5-24 December 1992 Verification: Mount William Creek at Mokepilly

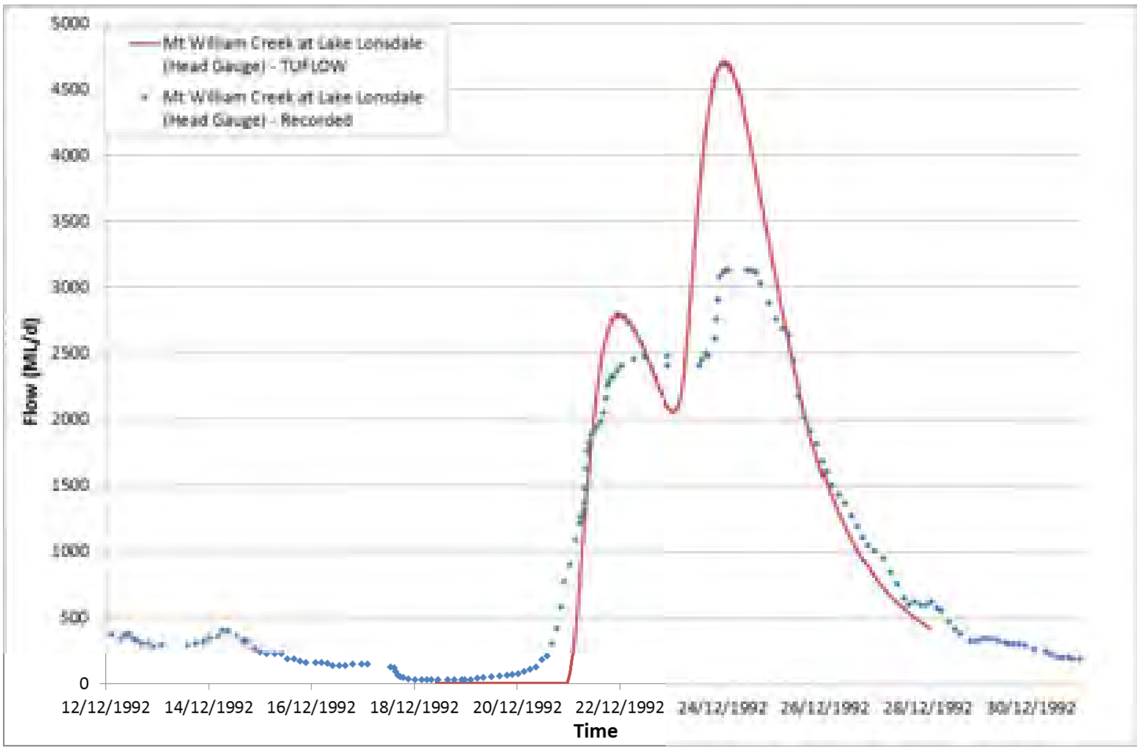


Figure 5-25 December 1992 Verification: Mount William Creek at Lake Lonsdale

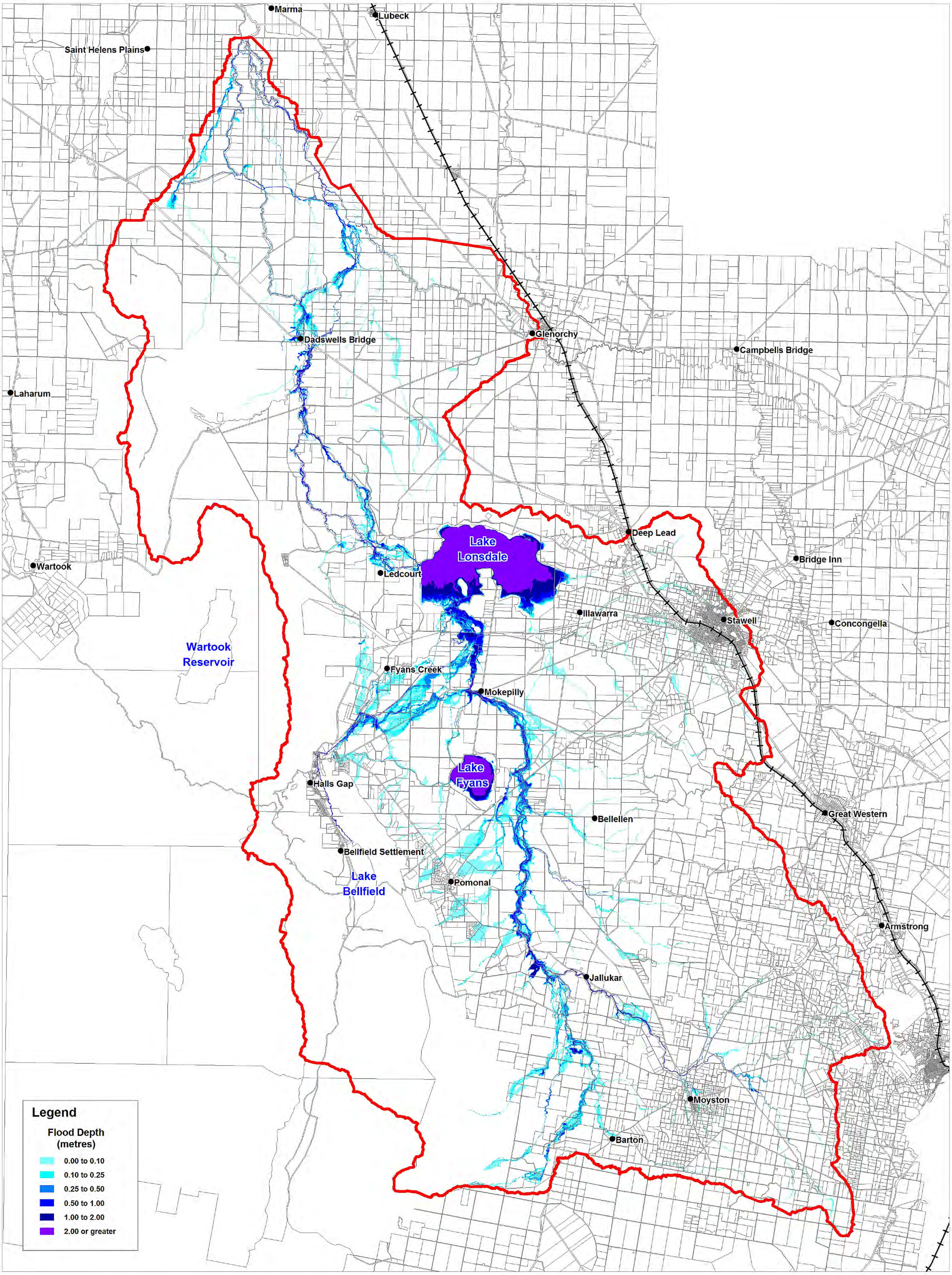
In addition, Table 5-4 presents a comparison the peak flows at each of the gauges within the catchment used during the verification process. From the graphs above and table below, it is clearly evident that the hydraulic model is underestimating the peak flows at Fyans Creek, but overestimating the peak flows at Mokepilly and Lake Lonsdale.

Table 5-4 December 1992 Verification: Flow Comparison

Stream Gauge	Recorded Peak Flow (ML/day)	Modelled Peak Flow (ML/day)	Difference (%)
Fyans Creek at Fyans Creek	6905	3366	-51%
Mount William Creek at Mokepilly	4464	7546	70%
Mount William Creek at Lake Lonsdale	3123	4717	51%

As mentioned previously, despite poor correlation between the modelled and recorded peak flows, the hydraulic model is able to replicate the shape and timing of the recorded hydrographs. The calibration that was achieved with the hydrologic model for this event is considered better, with more comparable results between the hydrologic model and the observed data.

Figure 5-26 shows the flood depths across the catchment for the December 1992 verification event. However, there are no flood marks available to comparison.



Title:

Mount William Creek Flood Investigation
December 1992 Calibration

Figure: **5-26**

Rev: **A**

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5.3.6 Calibration and Validation Summary

Overall, the calibration of the January 2011 flood event and verification of the December 1992 flood event can be described as average. Whilst some elements of the catchment give good agreement between the hydraulic model results and the observed data, a number of the gauge and flood marks suggest some areas of the model are poor. The final calibration of the January 2001 flood event (section 5.3.4.3) better reflects a number of the flood marks and flood photography obtained during and after the flood event, however, the comparison to the gauging record is worse that obtained as part of the initial calibration (section 5.3.4.1).

However; flood mark data, flood photography, and the response from the community of Mount William Creek indicate that the final January 2011 calibration is a significantly improved representative of the actual flood event. Despite the apparent inability of the model to replicate the gauge data, this indicates the model is doing of very good job of simulating the actual flood event.

The January 2011 flood event calibration has highlighted a number of potential issues with the gauging record within the catchment. The December 1992 verification result is generally much better in matching the hydraulic model result to the observed data. This indicates that the stream gauges within the catchment are potentially suspect during high flows (such as January 2011) but provide a reliable gauging record during minor and moderate flows.

The hydraulic model has been calibrated and then verified against actual flood event within the Mount William Creek catchment. The resulting calibration has delivered acceptable results to the community, despite the poor comparisons to the gauge data. The ability of the hydraulic model to deliver an acceptable calibration in the eyes of the community is an important consideration in the project outcomes because without the acceptance of the community, it will be difficult to implement any of the project outcomes (planning scheme amendments, etc.)

Therefore, it is recommended that the calibrated hydraulic model (as discussed in the previous sections) be adopted for the design event modelling of the Mount William Creek catchment.

5.4 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 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 Mount William Creek study area along with being used to formulate the components Mount William Creek Flood Investigation.

6 Quality Assurance

To ensure that results and outcomes that have established as part of the Mount William Creek Flood Investigation and can be used for any future assessments or works to be undertaken within the Mount William Creek 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 Mount William Creek flood model for both the hydrologic and hydraulic modelling components, an overview of which is provided below.

6.1 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.

6.2 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.

7 Flood Mapping and Results

This section provides a brief overview of the floodplain mapping process used in Mount William Creek 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 are imported into GIS to generate a digital model of the flood properties and produce the required flood mapping outputs.

The existing conditions flooding will be mapped for the 5 year, 10 year, 20 year, 50 year, 100 year and 200 year ARI and PMF flood events.

7.1 Flood Depth Mapping

Peak flood depth mapping for the 1 in 100 year ARI flood event is presented in Figure 7-1 (entire catchment), Figure 7-2 (Dadswells Bridge), Figure 7-3 (Moyston) and Figure 7-4 (Pomonal). This figure shows quite extensive flooding throughout the Mount William Creek catchment. Generally flooding is fairly well contained along the creek system in the upper catchment, having extensive floodplain flows are observed through the middle portion of the catchment and especially downstream of Lake Lonsdale.

Despite the operating level of Lake Lonsdale allowing for some flood storage, extensive flooding is shown downstream of the Lake as floodwaters flow towards Dadswells Bridge.

Dadswells Bridge is shown to have extensive flooding through the township and surrounds with the Western Highway cut in numerous locations east and west of the town. The townships of Pomonal and Moyston are also impacted by floodwaters, however, not to the same degree as Dadswells Bridge. Generally the floodwaters in and around Pomonal and Moyston are confined to identifiable waterways. There is a large amount a shallow floodplain flow along Fyans Creek as floodwater flow towards Lake Lonsdale.

7.2 Flood Hazard Mapping

Existing conditions peak flood hazard is mapped for the 1 in 100 year ARI flood event. The 1 in 100 year ARI flood hazard is shown in Figure 7-5 through Figure 7-8.

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.

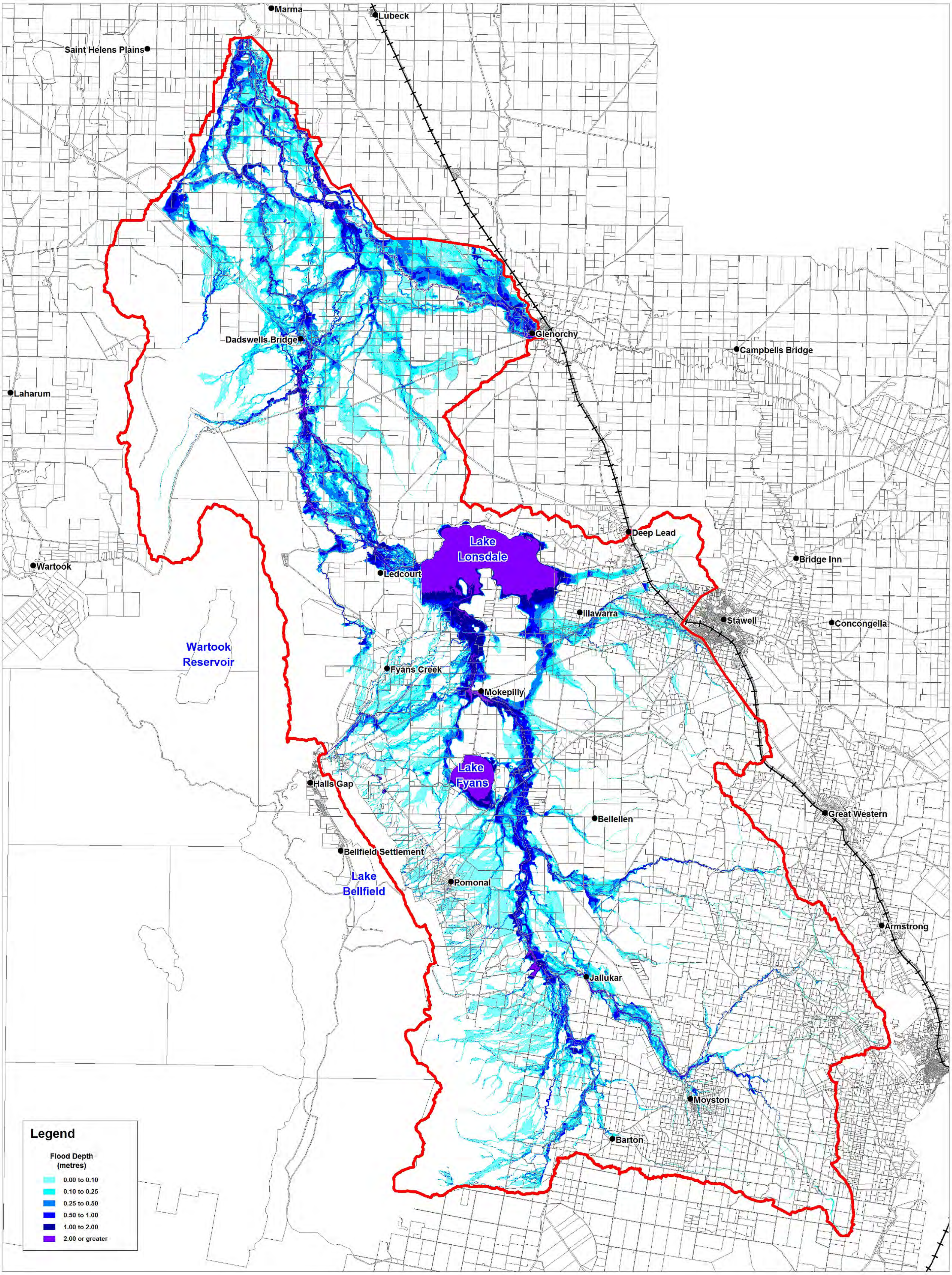
In the township of Dadswells Bridge there is extensive flooding, however the hazard outside of main creeks is low. Both the depth and velocity of flood waters in the town is low and consequently the flood hazard is also low during the 1 in 100 year ARI flood event.

Floodwaters pose little hazard to the townships of Moyston or Pomonal. 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.

7.3 Flood Velocity Mapping

Existing conditions flood velocity is mapped for the 1 in 100 year ARI 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 in 100 year ARI flood event peak velocity is shown in Figure 7-9 through Figure 7-12.

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



Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Depths - Whole of Catchment

Figure: 7-1

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Approx. Scale

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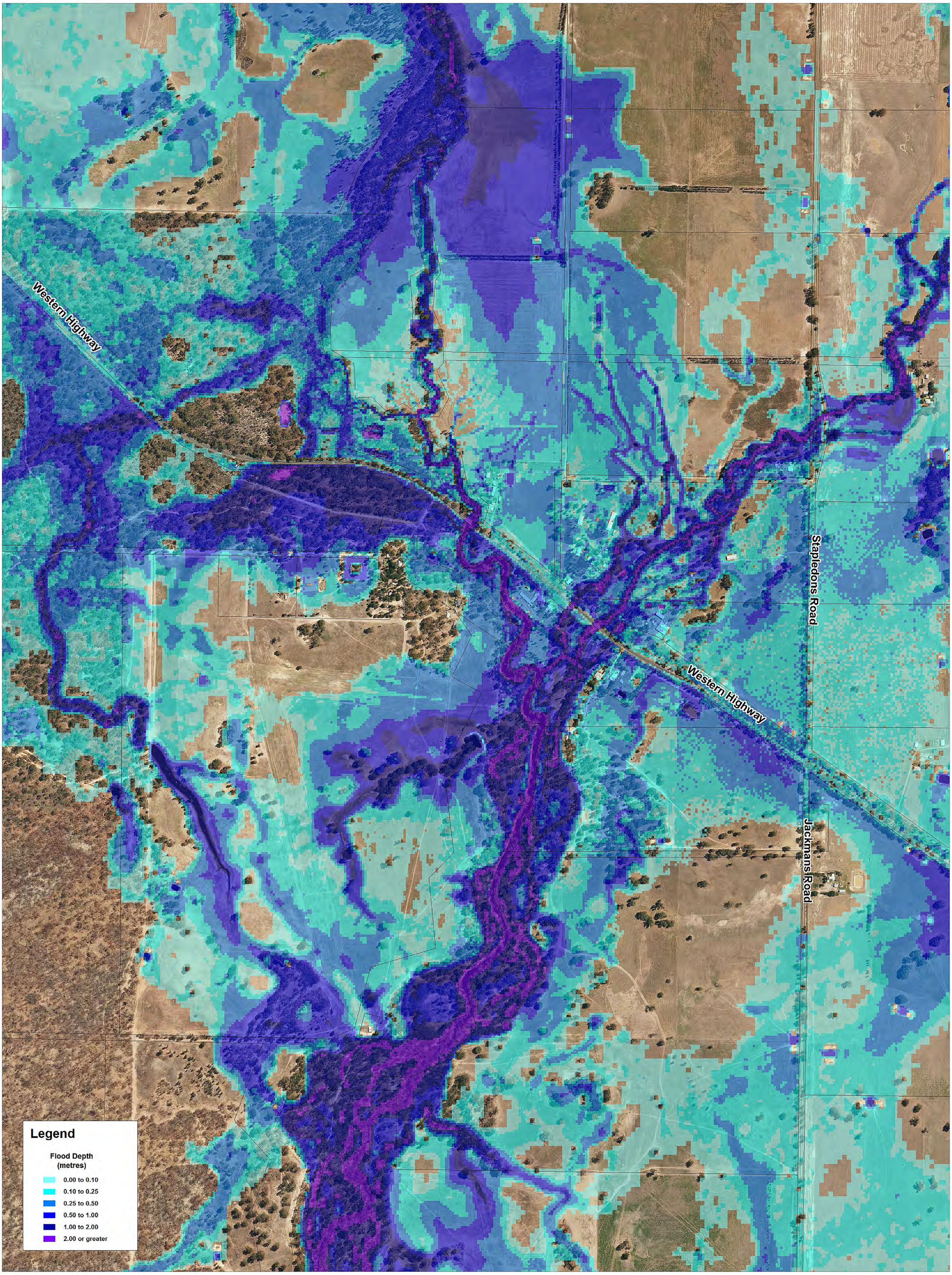

Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Depths - Dadswells Bridge

Figure: 7-2

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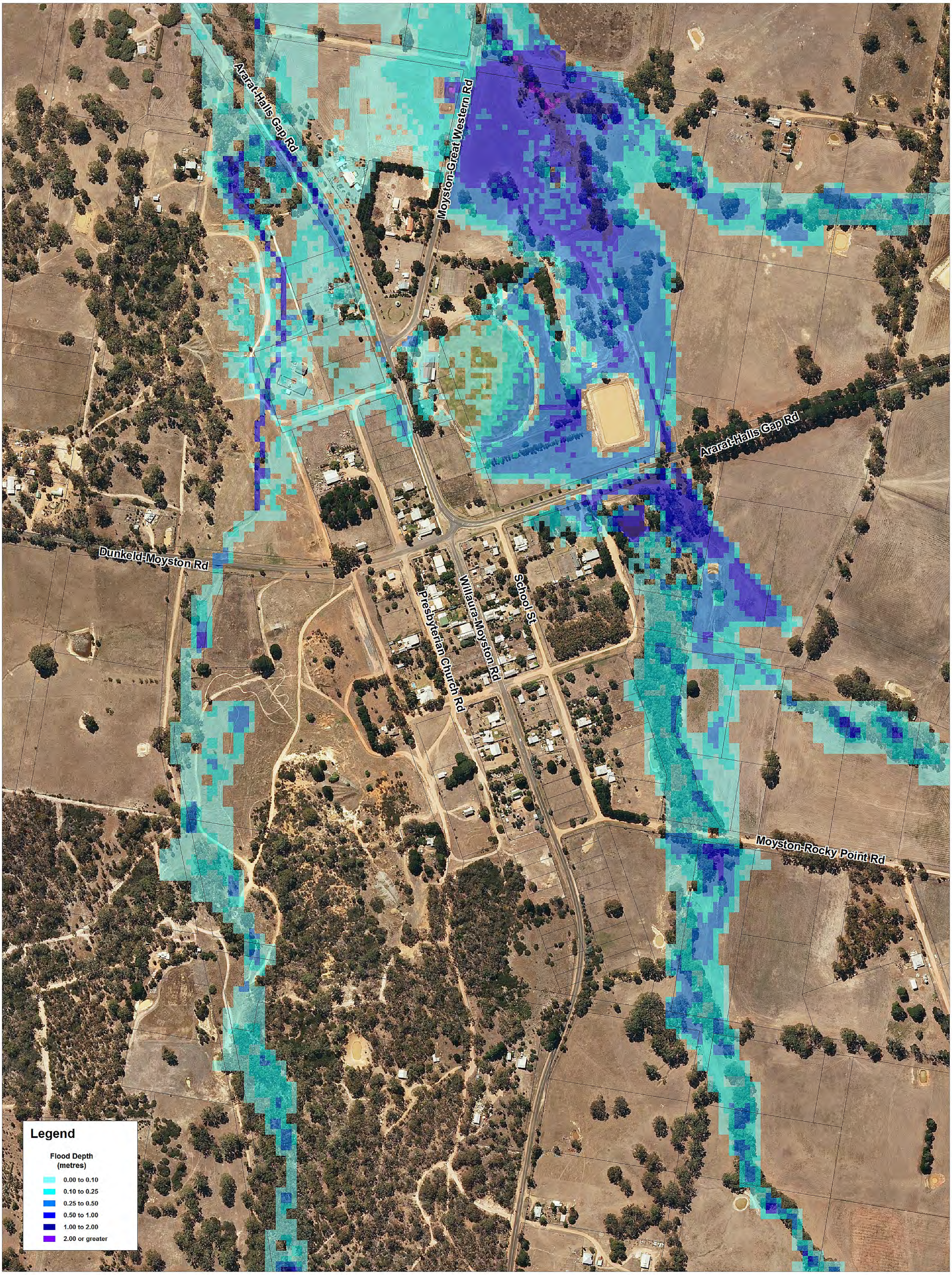

Title:	Figure:	Rev:
Mount William Creek Flood Investigation **1 in 100 Year ARI Flood Depths - Moyston**	7-3	A

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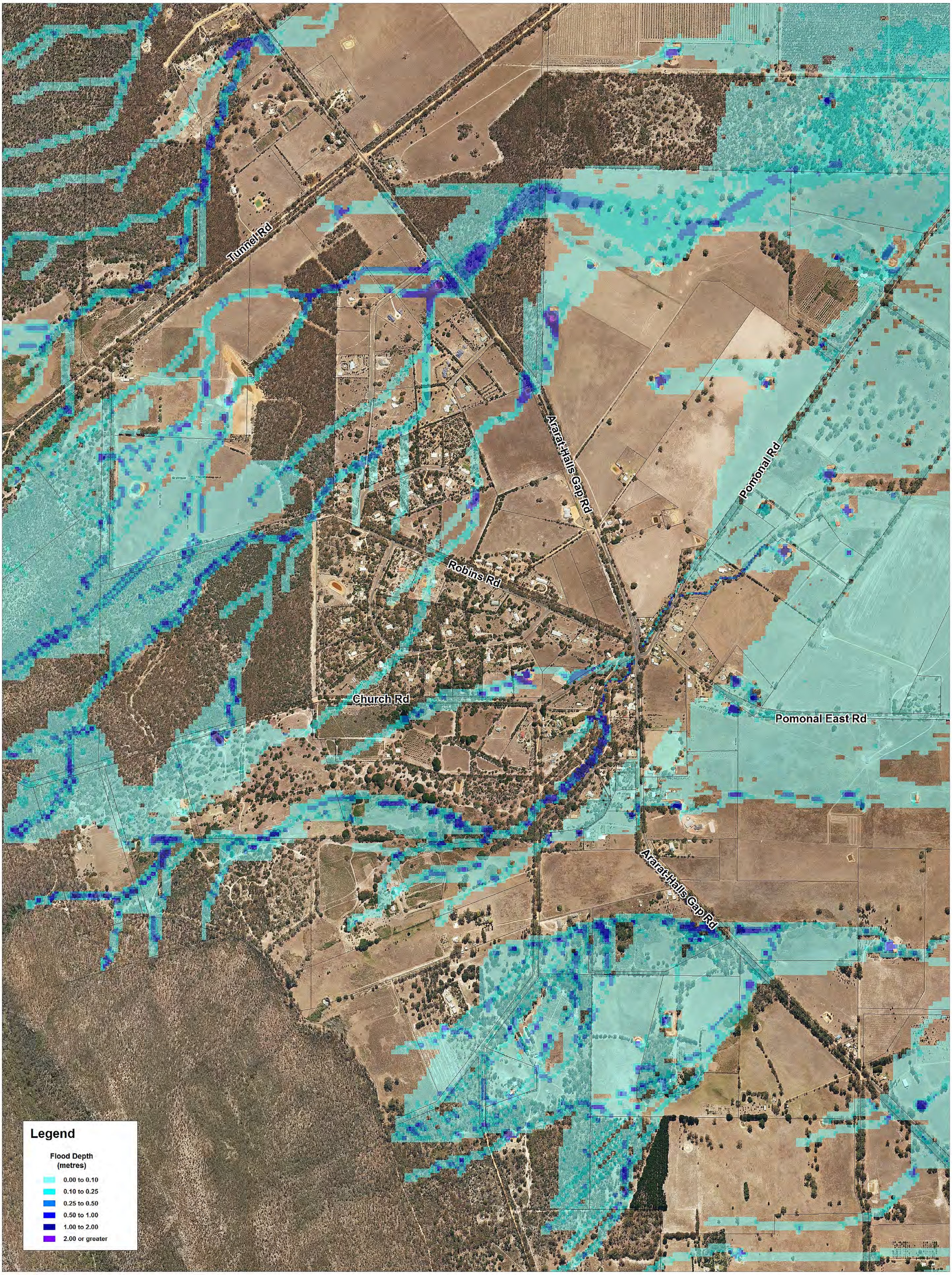

Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Depths - Pomonal

Figure: 7-4

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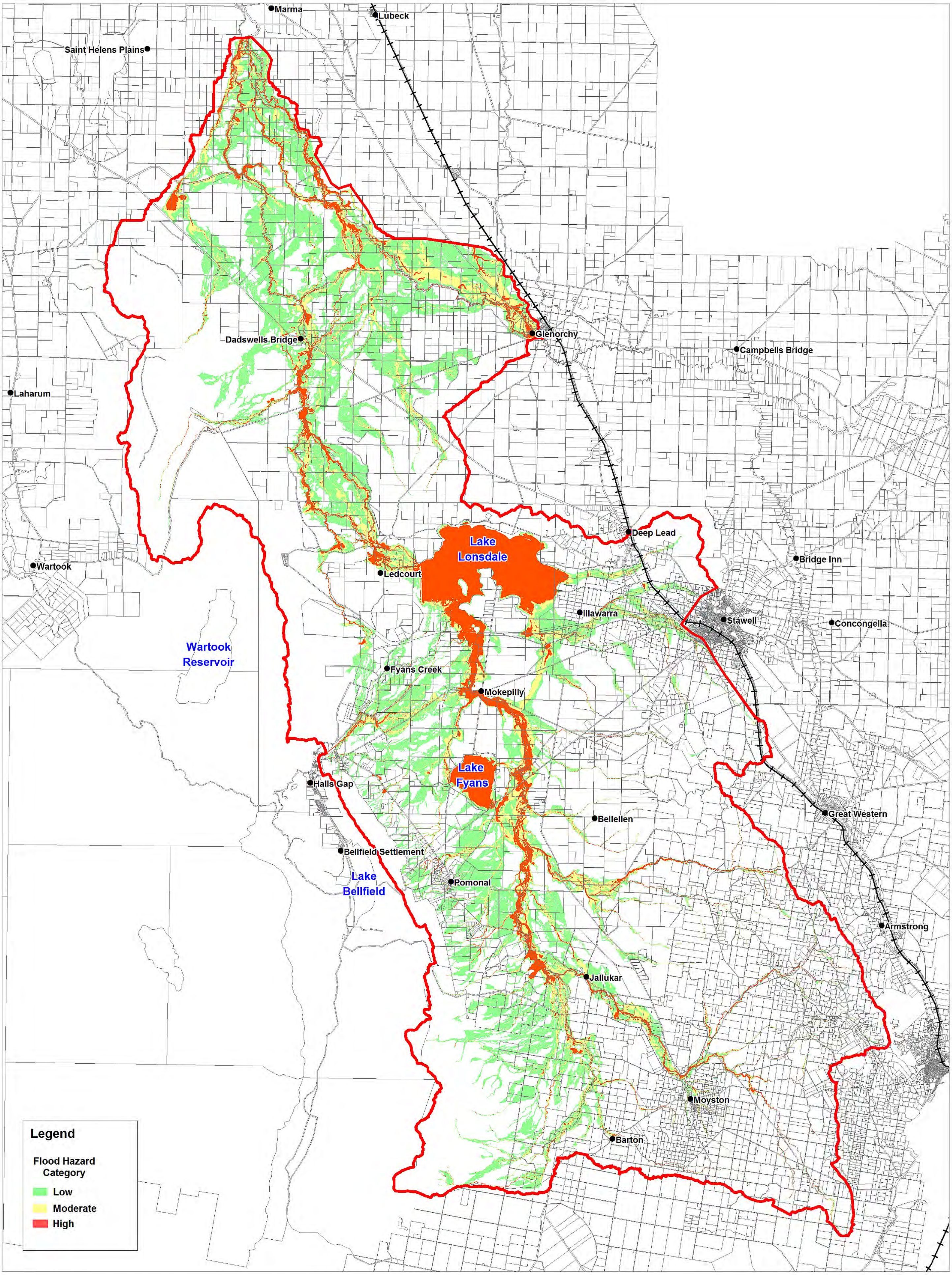

Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Hazards - Whole of Catchment

Figure: **7-5**

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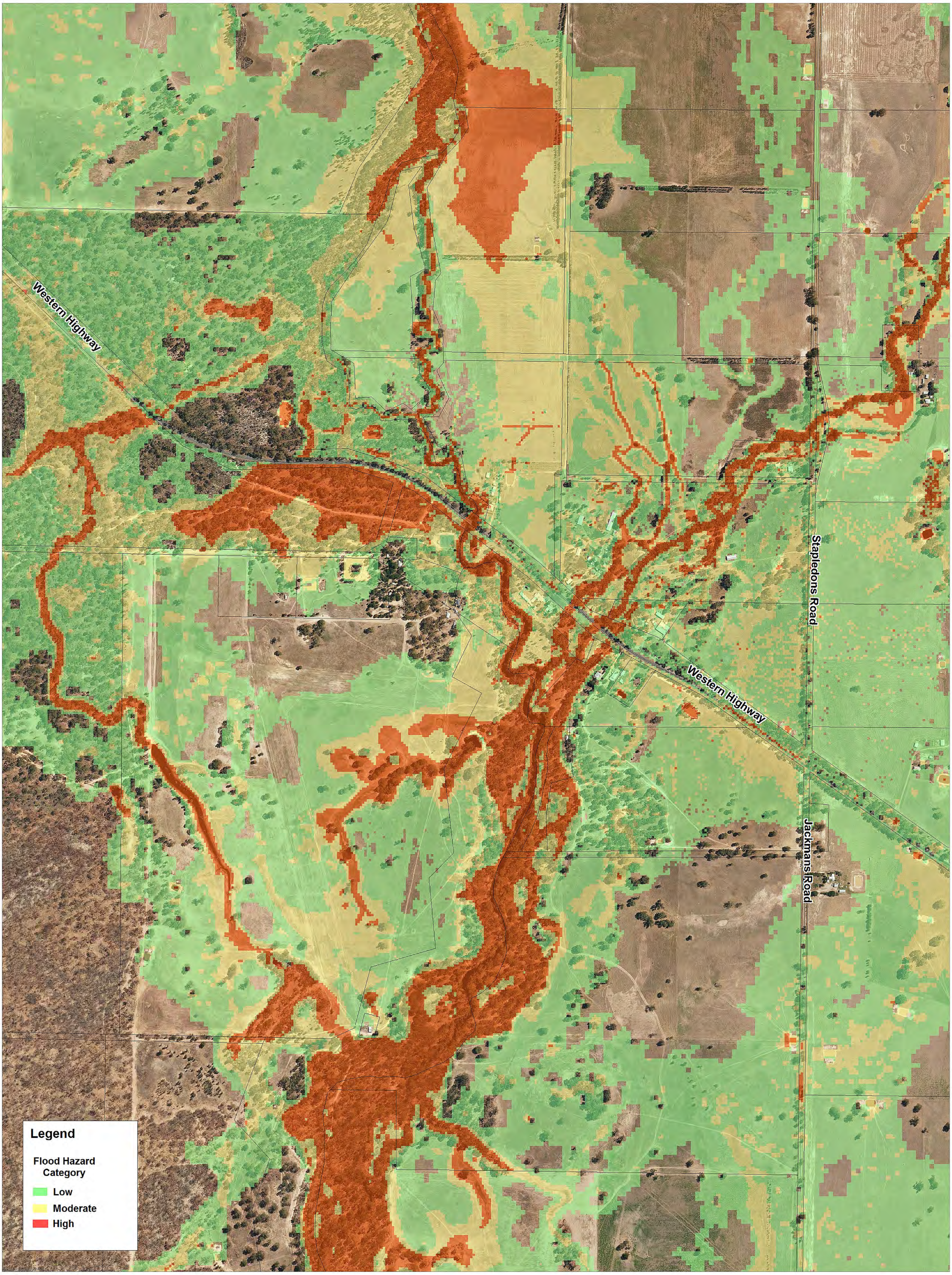

Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Hazards - Dadswells Bridge

Figure: 7-6

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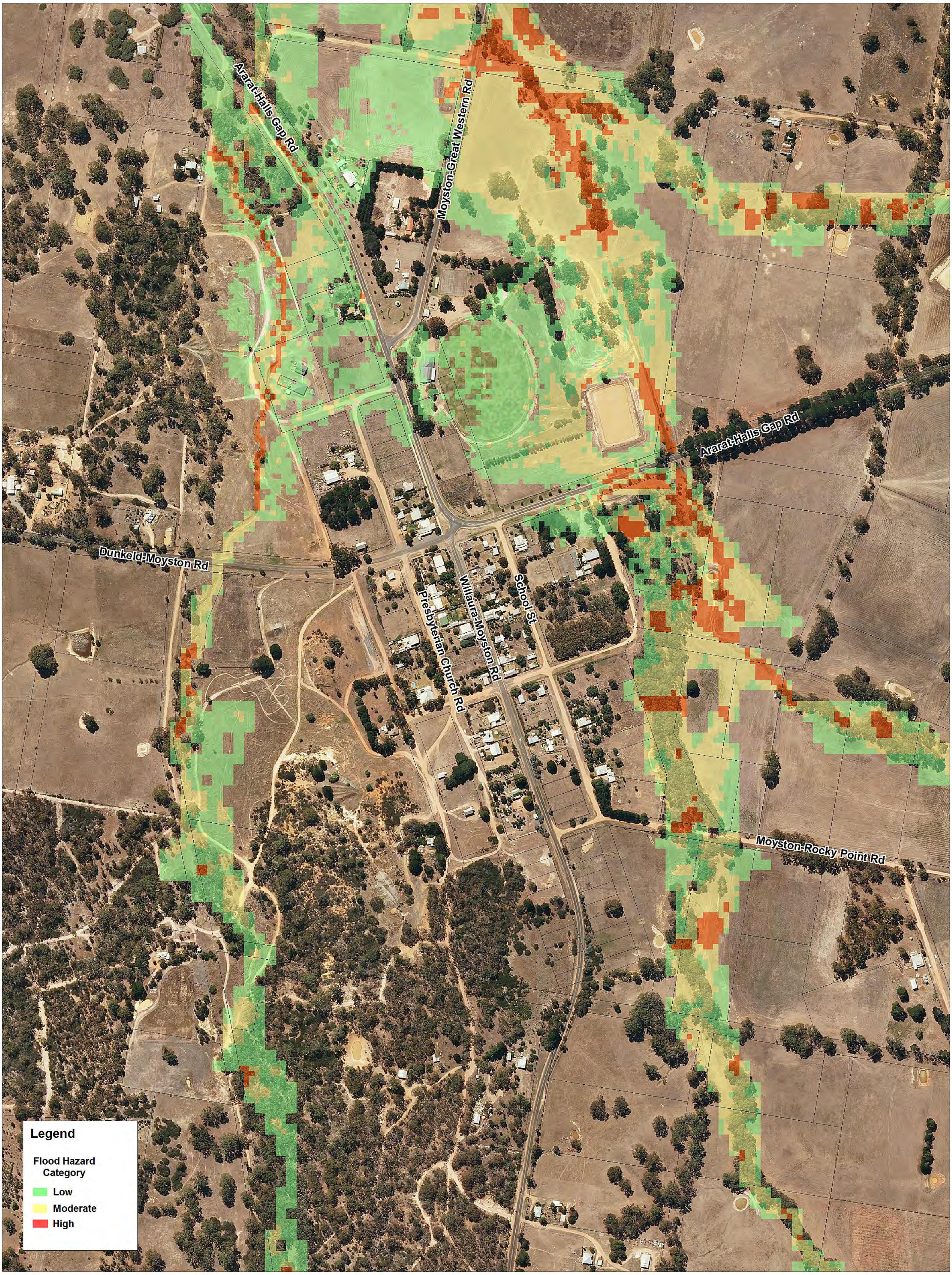

Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Hazards - Moyston

Figure: **7-7**

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Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Hazards - Pomonal

Figure: 7-8

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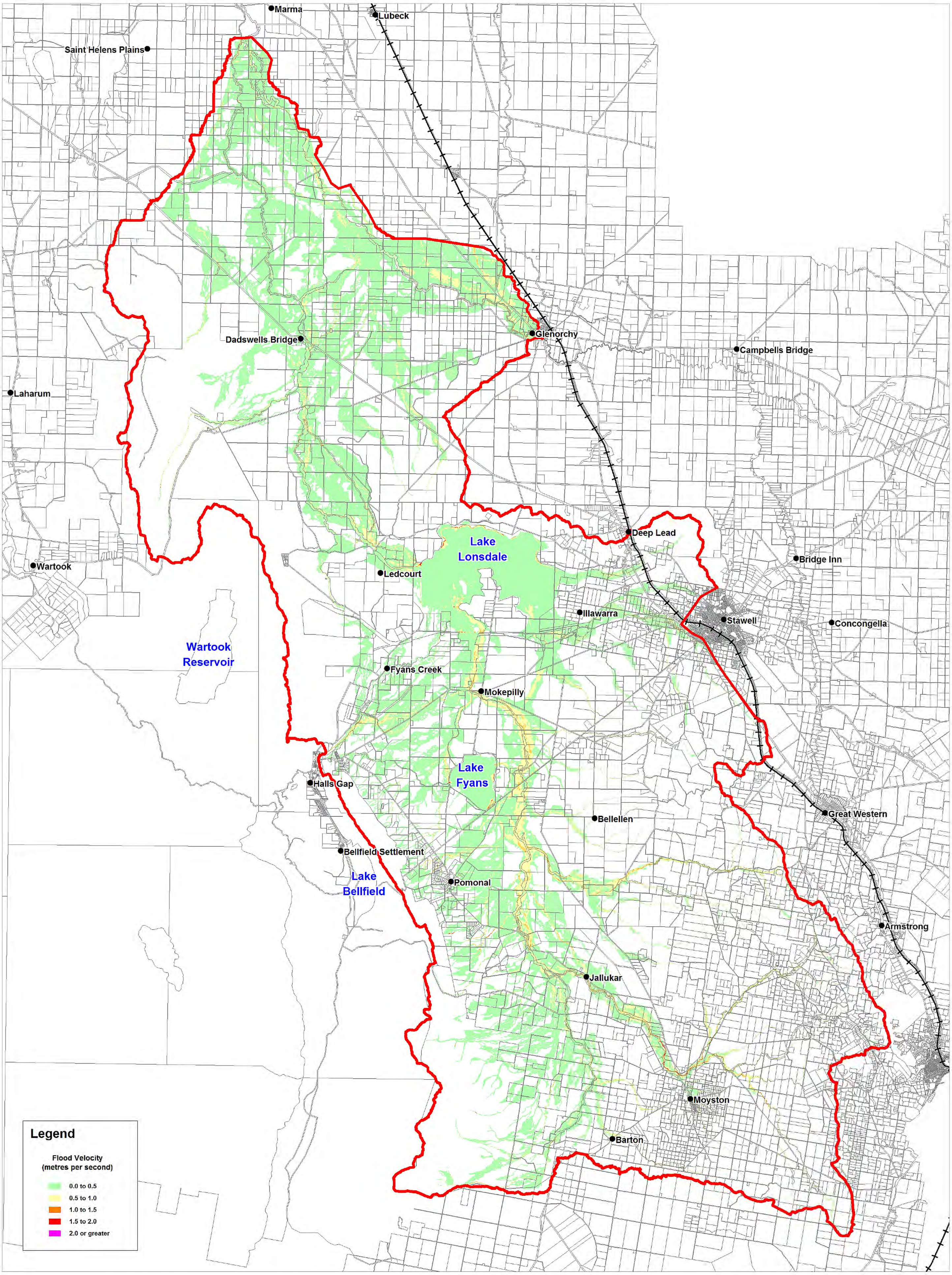

Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Velocities - Whole of Catchment

Figure: 7-9

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Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Velocities - Dadswells Bridge

Figure: **7-10**

Rev: **A**

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Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Velocities - Moyston

Figure: 7-11

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Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flood Velocities - Pomonal

Figure: 7-12

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8 Flood Damages Assessment

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. However 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 8-1.

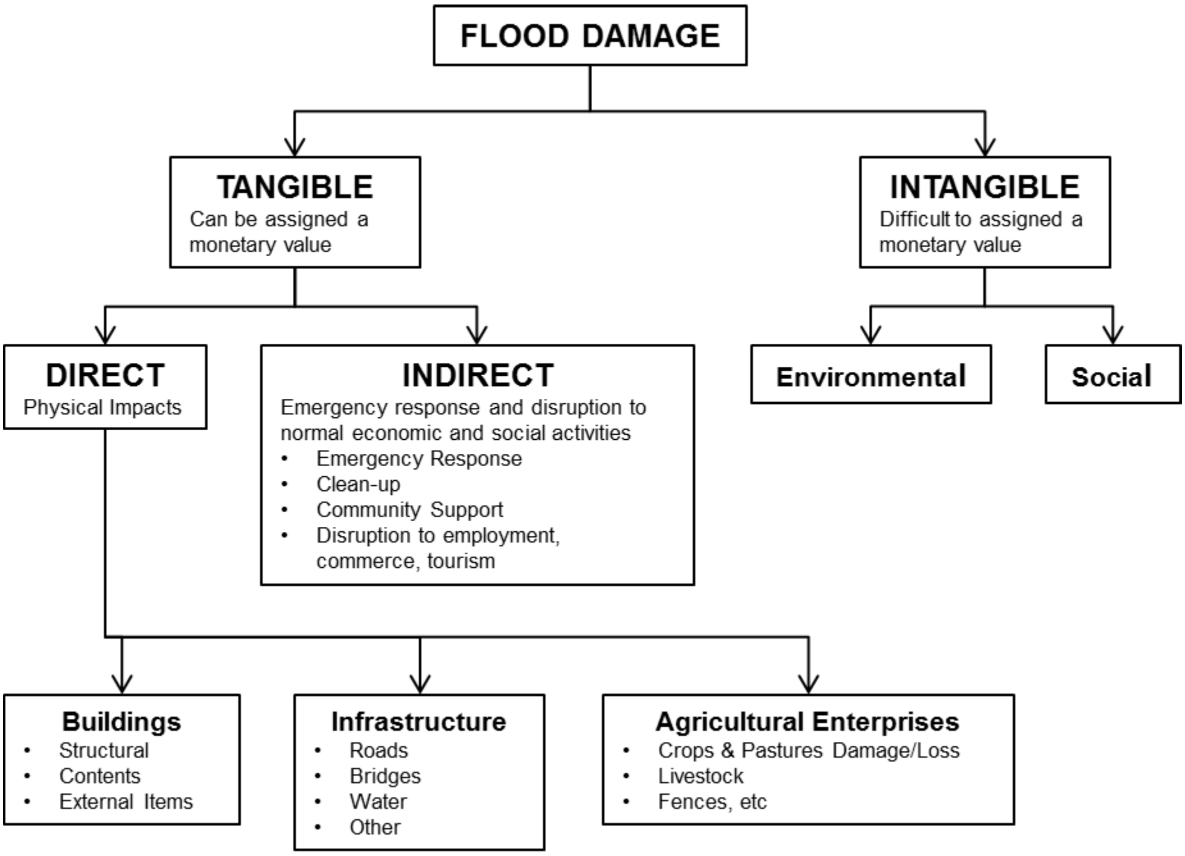


Figure 8-1 Types and Categorisation of Flood Damage Costs - Reproduced from *Rapid Appraisal Method (RAM) For Floodplain Management* (NRE 2000).

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 resources that are required. For this reason several methods, which have been widely adopted throughout Australia and within Victoria, are used to estimate damage costs and accordingly have been adopted for this study.

The methods adopted for the 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 WCMA.

8.1 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 5, 10, 20, 50, 100 and 200 year Annual Recurrence Interval (ARI) 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).

8.2 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 Mount William 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 2012.

- Following the presentation of the draft flood mapping, WCMA commissioned floor level survey of all properties likely to be flood affected in the 100y ARI flood event within the Mt William catchment. These buildings and associated properties were those used in the damages assessment. The majority of the properties were located in the townships of Dadswells Bridge, Stawell, Pomonal and Moyston.

- 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 were defined in the VICMAP dataset provided by WCMA and were confined to the study area.

- There are no damages as a result of flooding in a 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 commercial buildings is fair and the value of contents as medium. This assumption was made as there is no data available describing the condition or contents of individual commercial buildings.
- The condition of all residential buildings was based on external photographs provided by the surveyors. Buildings were classed as in either fair or poor condition.
- 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.

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

8.3 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 Volume 1, Section2.2).

8.3.1 ANUFLOOD Stage-Damage Curves

The residential stage-damage curves (Figure 8-2) 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 8-2) 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 8-2) 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.

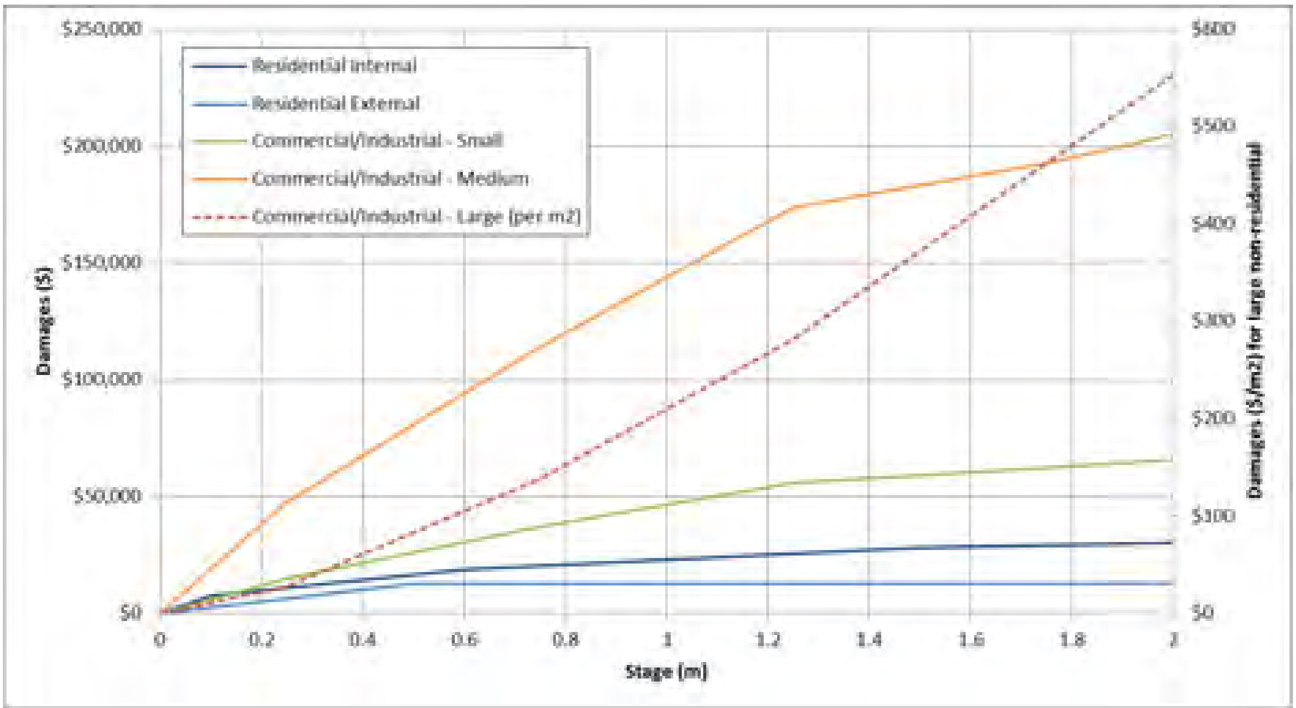


Figure 8-2 ANUFLOOD Stage-Damage Curves

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

8.3.3 ANUFLOOD Building Damages Summary

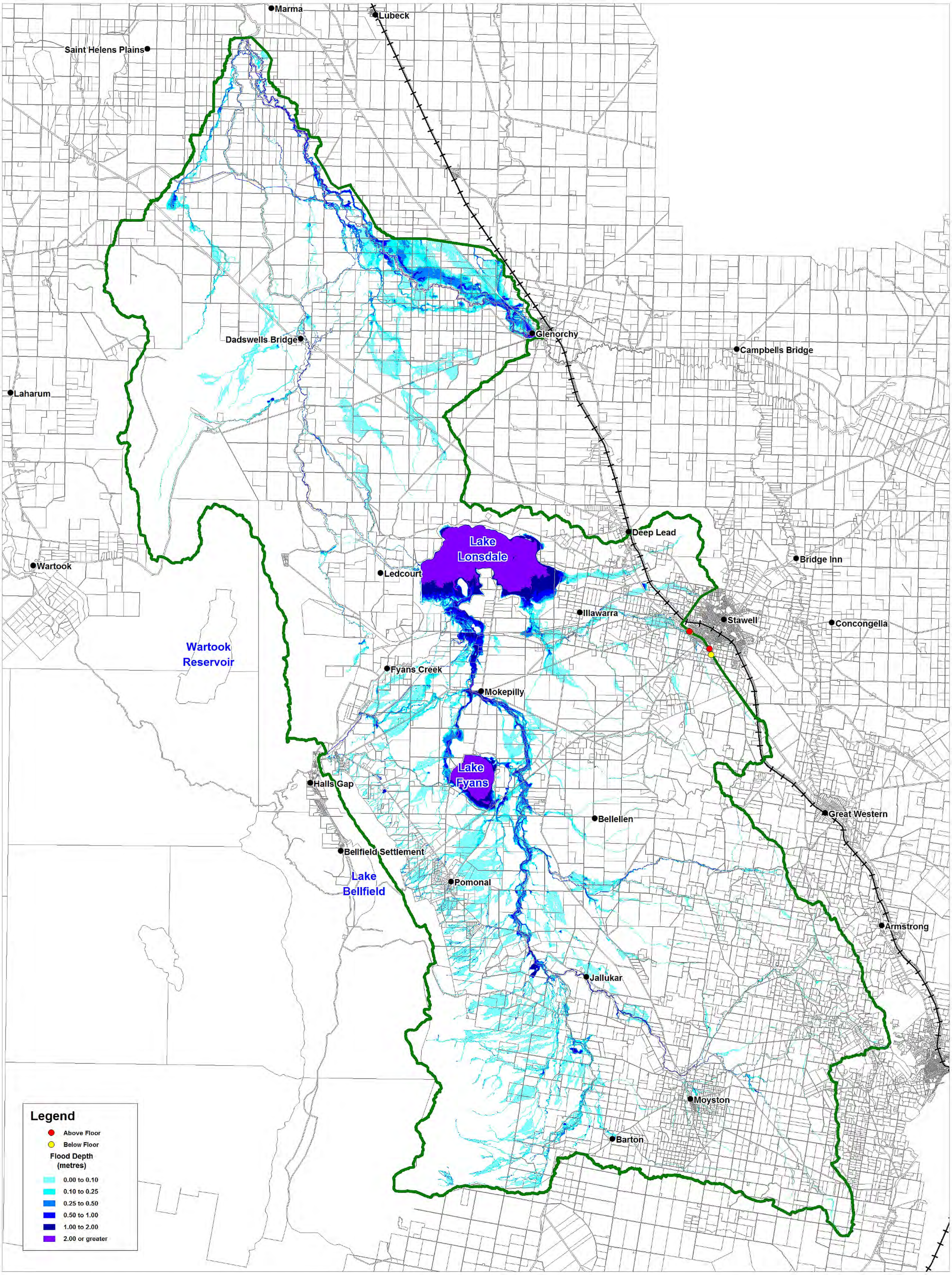
A summary of the ANUFLOOD building damages for existing conditions is presented in Table 8-1. The summary highlights the number of properties inundated and the associated damages for the range of ARI events.

Table 8-1 Existing Conditions ANUFLOOD Building Damages Summary

Event (ARI)	No. of Properties Inundated	No. of properties with above floor flooding	External Residential Damages	Internal Residential Damages	Commercial and Industrial Damages	Indirect Damages	Total ANUFLOOD Building Damages
PMF	41	35	$253,500	$347,400	$1,149,300	$525,100	$2,275,300
200y	28	13	$99,800	$35,500	$568,000	$211,000	$914,300
100y	24	12	$76,000	$31,900	$495,800	$181,100	$784,800
50y	19	10	$63,200	$20,700	$404,300	$146,400	$634,600
20y	13	7	$32,700	$13,600	$192,600	$71,700	$310,600
10y	4	3	$7,600	$1,900	$57,900	$20,200	$87,600
5y	4	2	$6,800	$0	$52,800	$17,900	$77,500

8.4 Flooded Floor Levels

A visual summary of the buildings flooded above and below floor level for each of the modelled flood events are provided in Figure 8-3 (5 year ARI), Figure 8-4 (10 year ARI), Figure 8-5 (20 year ARI), Figure 8-6 (50 year ARI), Figure 8-7 (100 year ARI), Figure 8-8 (200 year ARI) and Figure 8-9 (PMF). In each of these figures, a red dot indicates a building which is flooded above the floor level, whilst a yellow dot indicates a building which is flooded to a level below the floor level. Only buildings within the Mount William Creek catchment for which floor level information was captured are included on these maps.



Title:

Mount William Creek Flood Investigation
1 in 5 Year ARI Flooded Buildings – Whole of Catchment

Figure: 8-3

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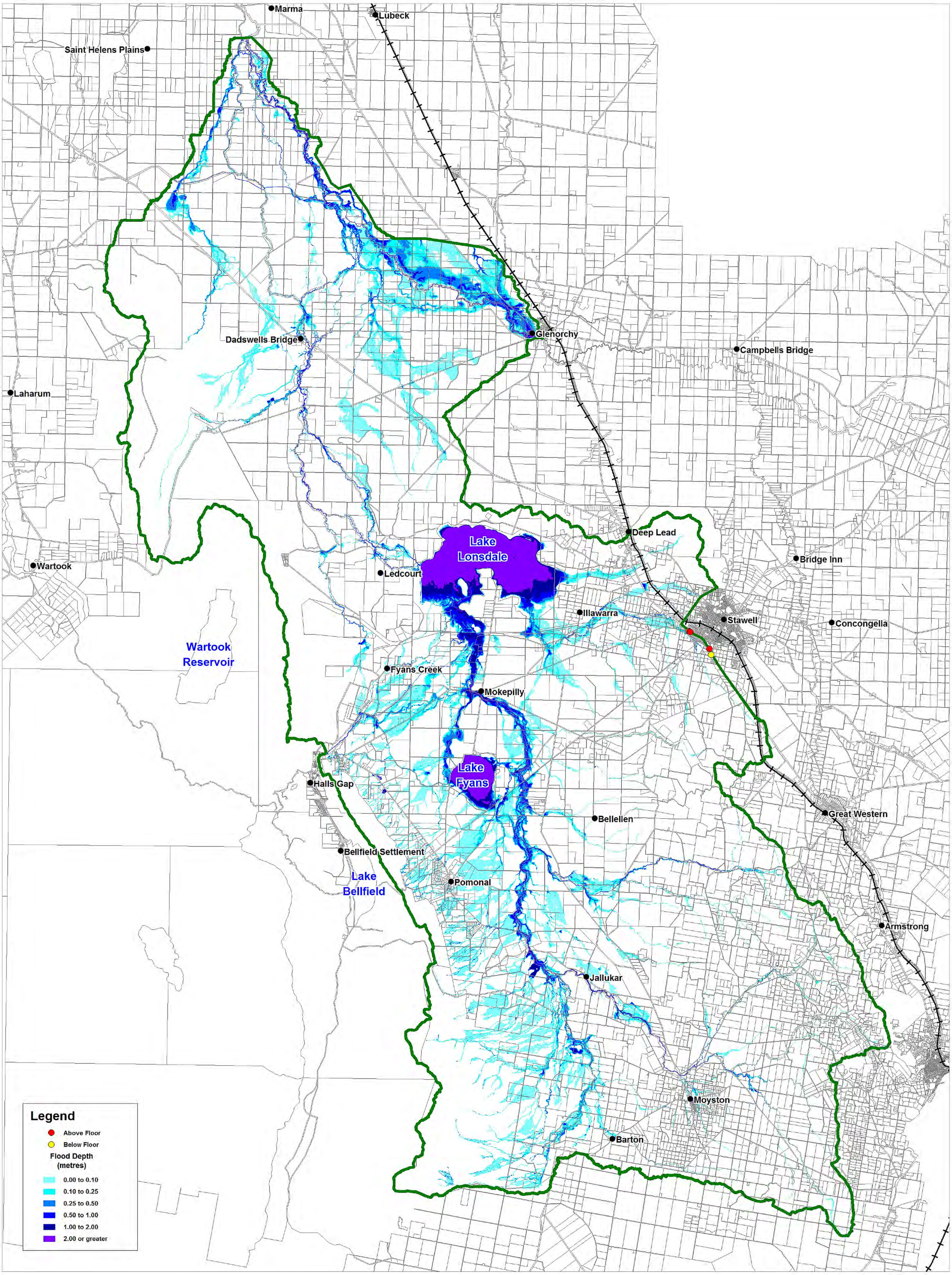

Title:
Mount William Creek Flood Investigation
1 in 10 Year ARI Flooded Buildings – Whole of Catchment

Figure: **8-4**

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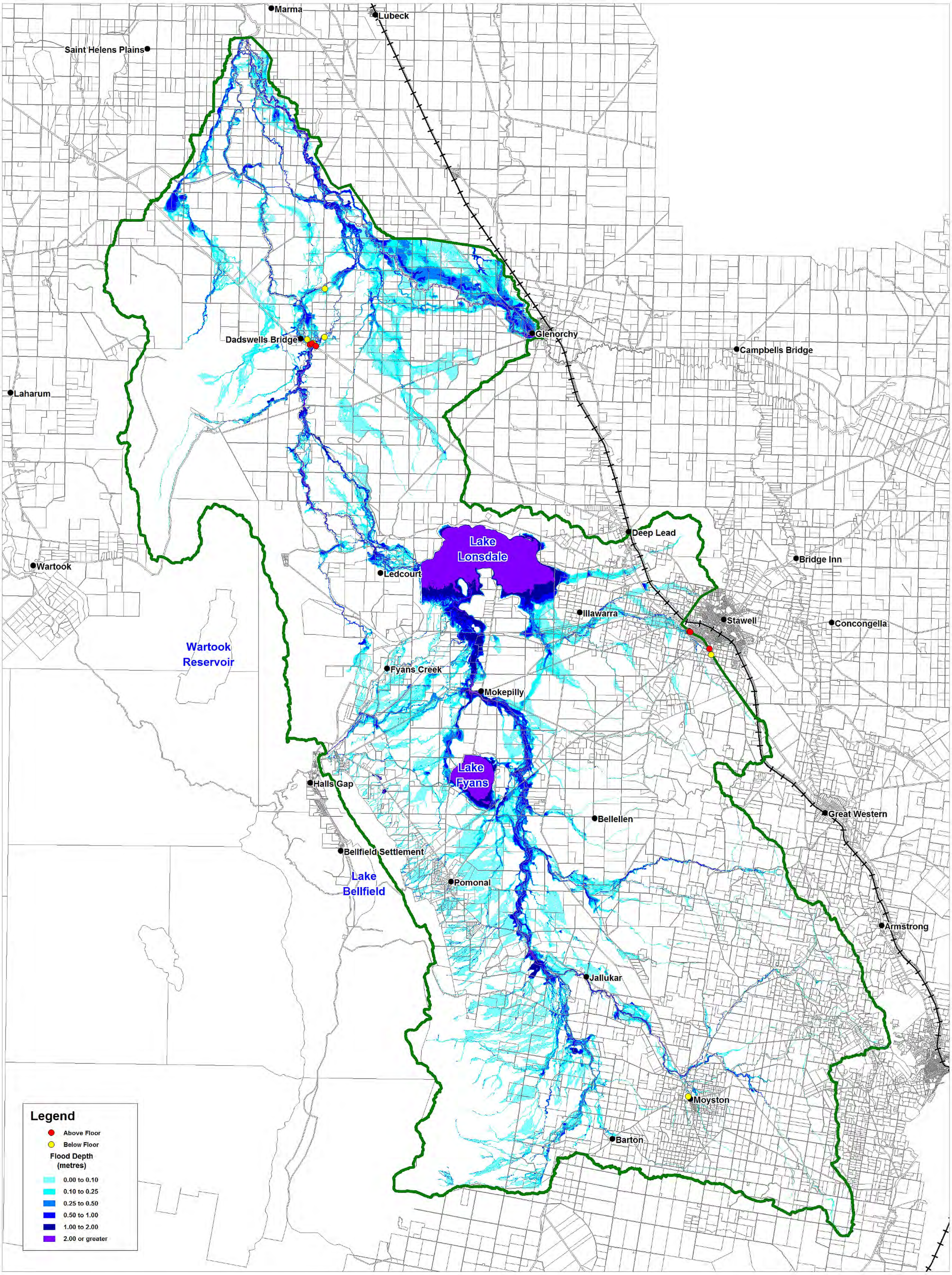

Title:

Mount William Creek Flood Investigation
1 in 20 Year ARI Flooded Buildings – Whole of Catchment

Figure: 8-5

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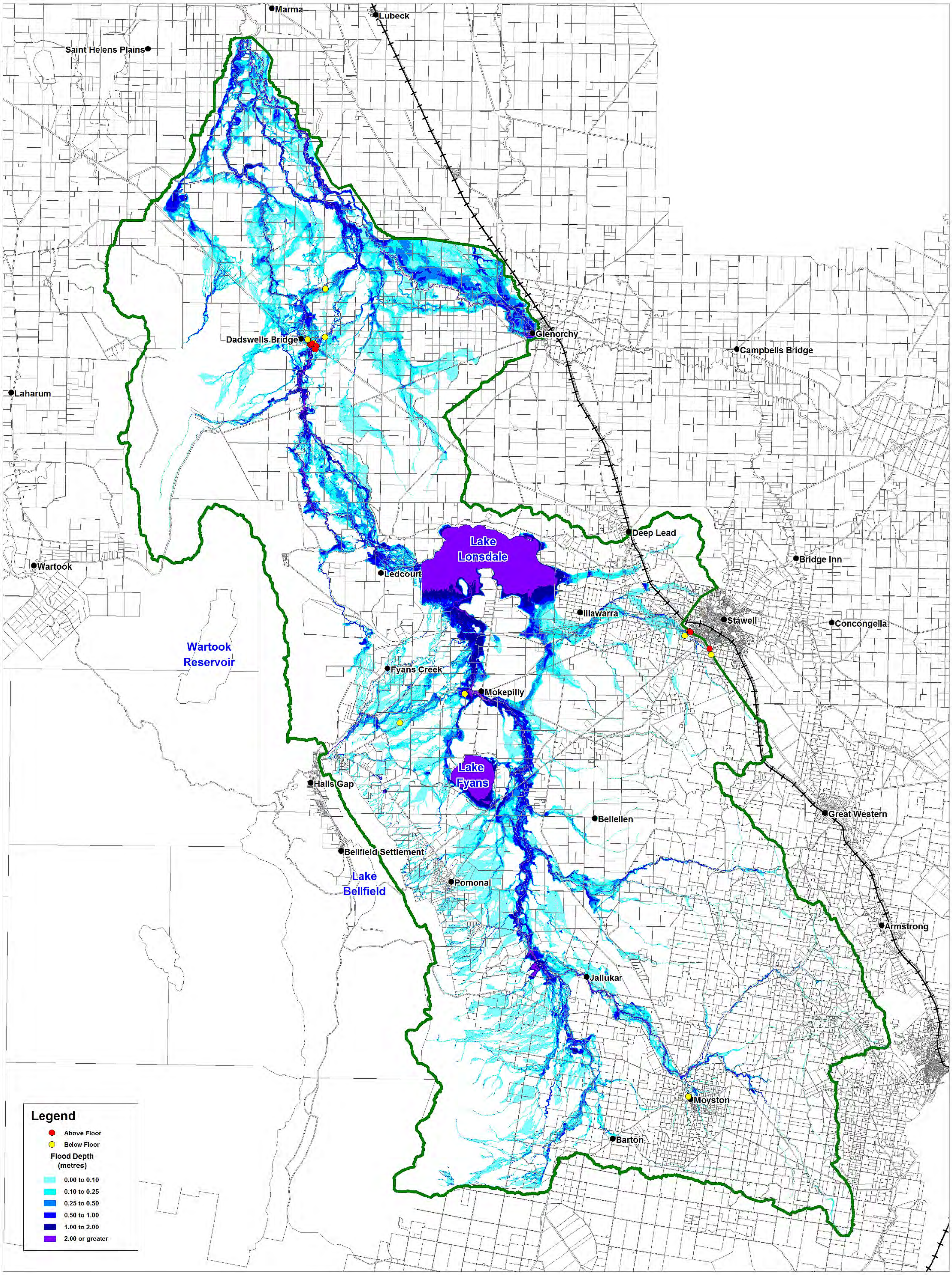

Title:

Mount William Creek Flood Investigation
1 in 50 Year ARI Flooded Buildings – Whole of Catchment

Figure: **8-6**

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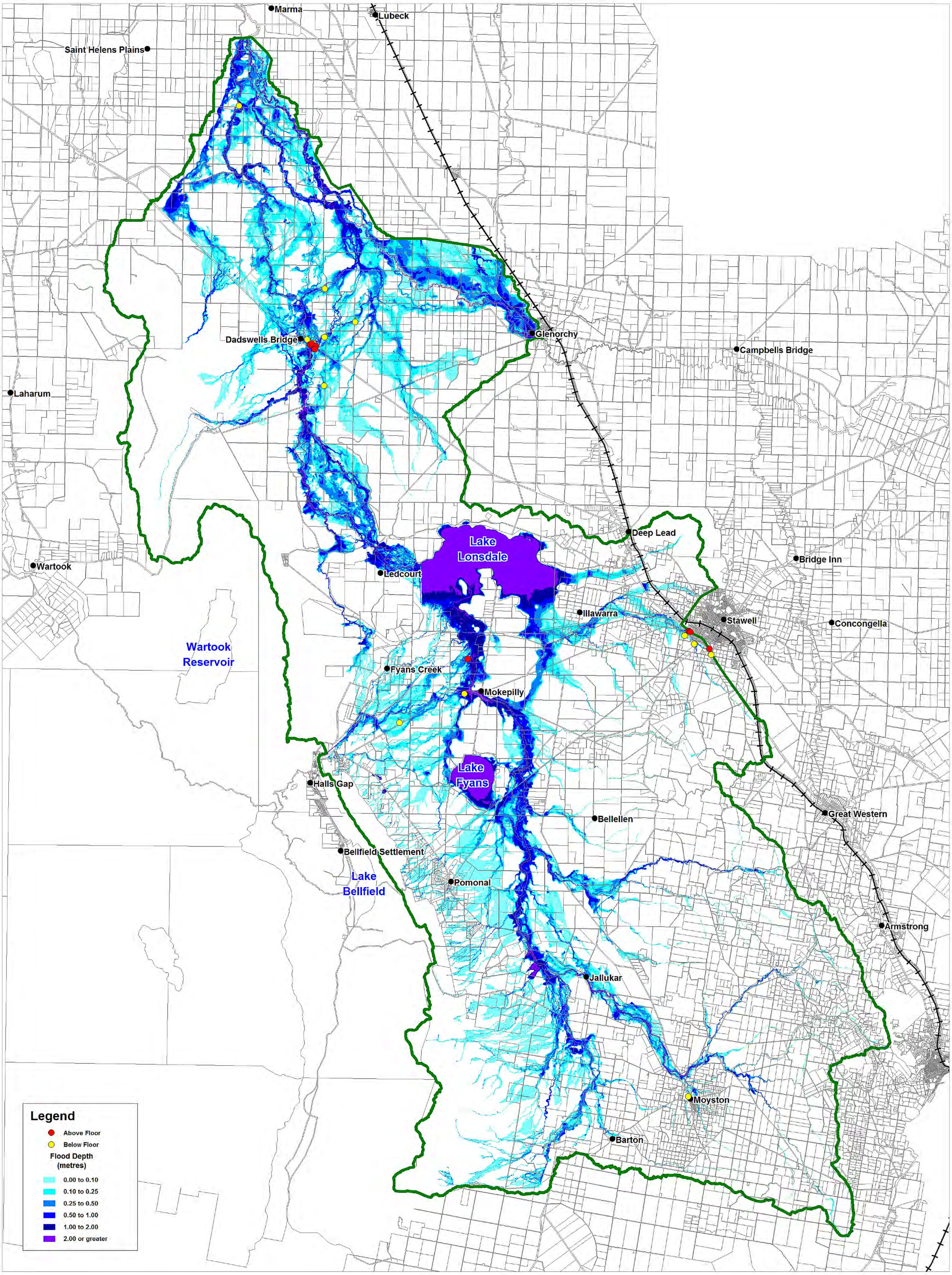

Title:

Mount William Creek Flood Investigation
1 in 100 Year ARI Flooded Buildings – Whole of Catchment

Figure: **8-7**

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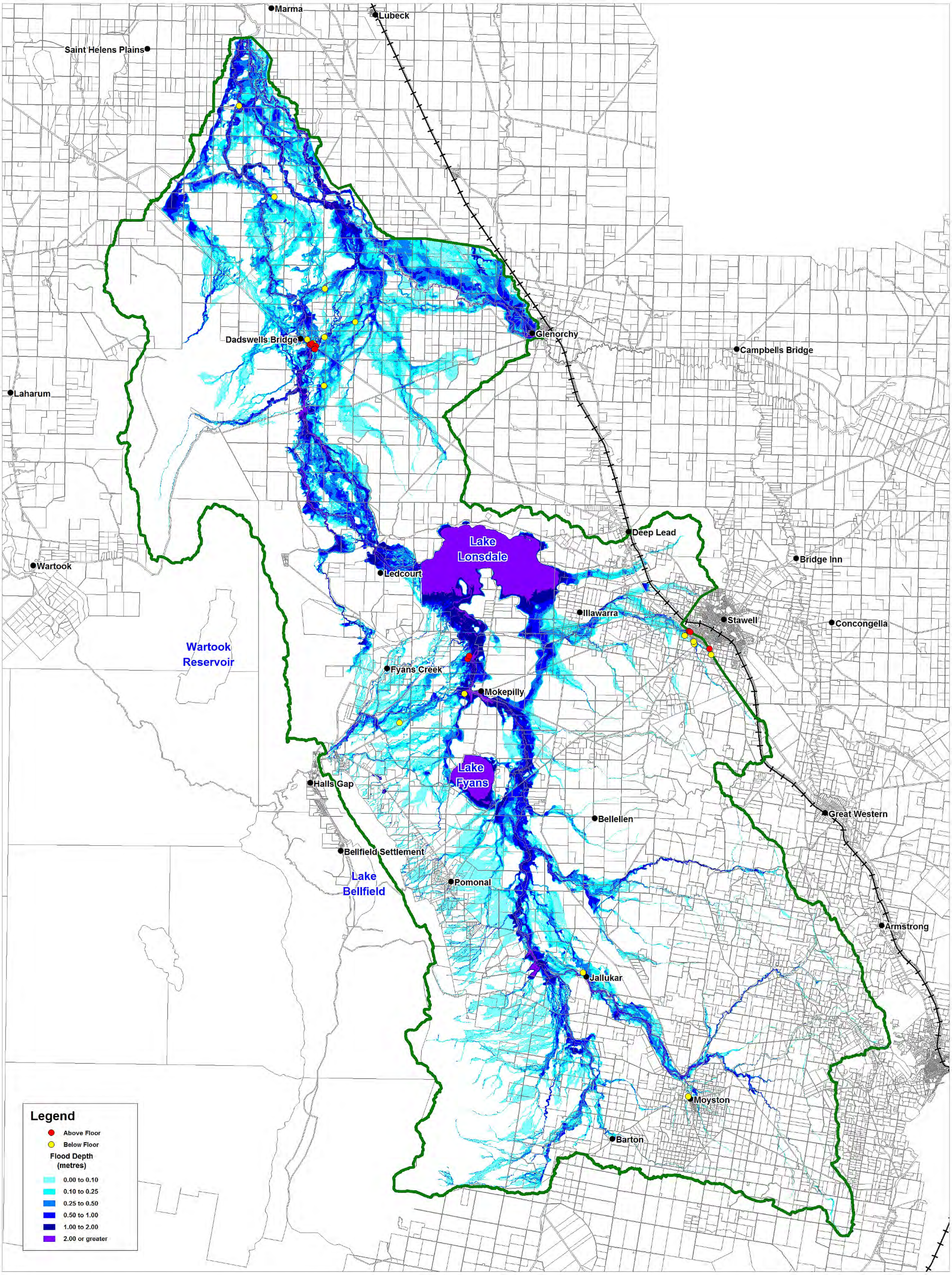

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Mount William Creek Flood Investigation
1 in 200 Year ARI Flooded Buildings – Whole of Catchment

Figure: **8-8**

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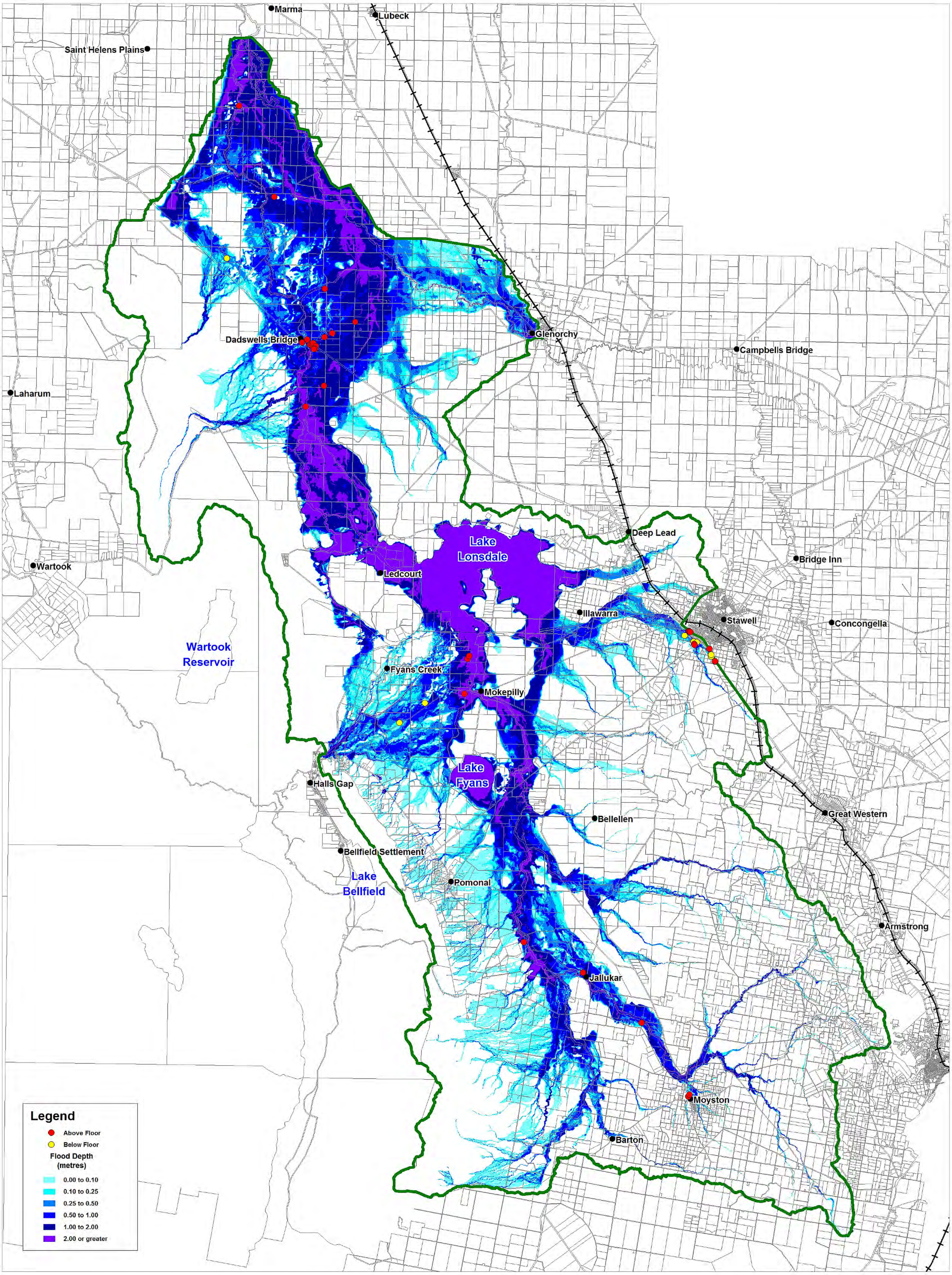

Title:

Mount William Creek Flood Investigation
PMF Flooded Buildings – Whole of Catchment

Figure: **8-9**

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Approx. Scale

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

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8.5 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 Mt William Flood Investigation.

8.5.1 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 8-2. 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 8-2 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 8-3. The summary highlights the number of properties inundated and the associated damages for the range of ARI events.

Table 8-3 Existing Conditions RAM Building Damages Summary

Event (ARI)	No. of Properties Inundated	Residential Damages	Commercial and Industrial Damages	Total Building Damages
PMF	43	$741,000	$321,100	$1,062,100
200y	29	$494,000	$222,300	$716,300
100y	25	$419,900	$197,600	$617,500

Event (ARI)	No. of Properties Inundated	Residential Damages	Commercial and Industrial Damages	Total Building Damages
50y	20	$321,100	$172,900	$494,000
20y	14	$222,300	$123,500	$345,800
10y	5	$74,100	$49,400	$123,500
5y	5	$74,100	$49,400	$123,500

8.5.1.1 Differences between ANUFLOOD and RAM Building Damages

As observed in Table 8-1 and Table 8-3, the number of inundated properties determined as part of the ANUFLOOD and RAM methodologies are different (ANUFLOOD has less properties inundated). This discrepancy is due to the way in which the two methodologies determine whether a property is inundated or not. ANUFLOOD uses the surveyed ground elevation (captured near the site of the inhabited building) to determine whether or not the property is considered inundated. The RAM methodology will consider a property inundated if floodwaters have entered the cadastral boundary of the property. Consequently, the RAM methodology will generally have a slightly higher number of inundated properties when compared to the ANUFLOOD methodology.

8.5.2 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.

The values adopted for the assessment, Table 8-4 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 with flood depths exceeding 0.5m.

Table 8-4 RAM Agricultural Damage Values

Crop Type	Damages
Dryland Broadacre Crops Inundated for Shorter than 1 week	$124 per hectare

Crop Type	Clean-Up Costs
Dryland Broadacre Crops within Floodway Area	$37 per hectare
Dryland Broadacre Crops beyond Floodway Area	$15 per hectare

A summary of the RAM agricultural damages for existing conditions is presented in Table 8-5. The summary highlights the area of agricultural land inundated and the associated damages for the range of ARI events.

Table 8-5 Existing Conditions RAM Agricultural Damages Summary

Event (ARI)	Area of Agricultural Land Inundated (hectares)	Crop Damages	Clean Up Costs	Total Agricultural Damages
PMF	37,171	$4,697,300	$940,300	$5,637,600
200y	27,420	$3,465,200	$479,400	$3,944,600
100y	25,273	$3,193,800	$431,400	$3,625,200
50y	22,379	$2,828,100	$373,800	$3,201,900
20y	17,279	$2,183,500	$282,400	$2,465,900
10y	13,625	$1,721,800	$219,000	$1,940,800
5y	11,217	$1,417,500	$178,400	$1,595,900

8.5.3 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 8-6. 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 8-6 RAM Road Infrastructure Damage Values

Road Type	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 8-7. The summary highlights the total length of road inundated and the associated damages for the range of ARI events.

Table 8-7 Existing Conditions RAM Road Infrastructure Damages Summary

Event (ARI)	Length of Road Inundated (kilometres)	Road Infrastructure Damages
PMF	345	$6,959,400
200y	199	$3,844,300
100y	175	$3,330,700
50y	147	$2,704,600
20y	106	$1,899,300
10y	80	$1,432,900

Event (ARI)	Length of Road Inundated (kilometres)	Road Infrastructure Damages
5y	62	$1,065,600

8.6 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 2y ARI 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 5y and 2y ARI.

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. This methodology is consistent with the damages assessment undertaken for the Upper Wimmera Catchment Flood Investigation. The reason for this is the RAM method estimates unrealistically high damage values for frequent design floods such as the 10y and 5y ARI 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 8-8 and is illustrated in Figure 8-10. The existing condition AAD for the Mt William catchment is $1,624,200.

Table 8-8 Existing Conditions Damages Summary

Event (ARI)	ANUFLOOD Building Damages	RAM Agricultural Damages	RAM Road Infrastructure Damages	Indirect Damages	Total Damages	Contribution to AAD
PMF	$1,750,200	$5,637,600	$6,959,400	$4,304,200	$18,651,400	
200y	$703,400	$3,944,600	$3,844,300	$2,547,700	$11,040,000	$74,200
100y	$603,700	$3,625,200	$3,330,700	$2,267,900	$9,827,500	$52,200
50y	$488,100	$3,201,900	$2,704,600	$1,918,400	$8,313,000	$90,700
20y	$238,900	$2,465,900	$1,899,300	$1,381,200	$5,985,300	$214,500
10y	$67,400	$1,940,800	$1,432,900	$1,032,300	$4,473,400	$261,500
5y	$59,600	$1,595,900	$1,065,600	$816,300	$3,537,400	$400,500
2y	-	-	-	-	-	$530,600
					Average Annual Damages	**$1,624,200**

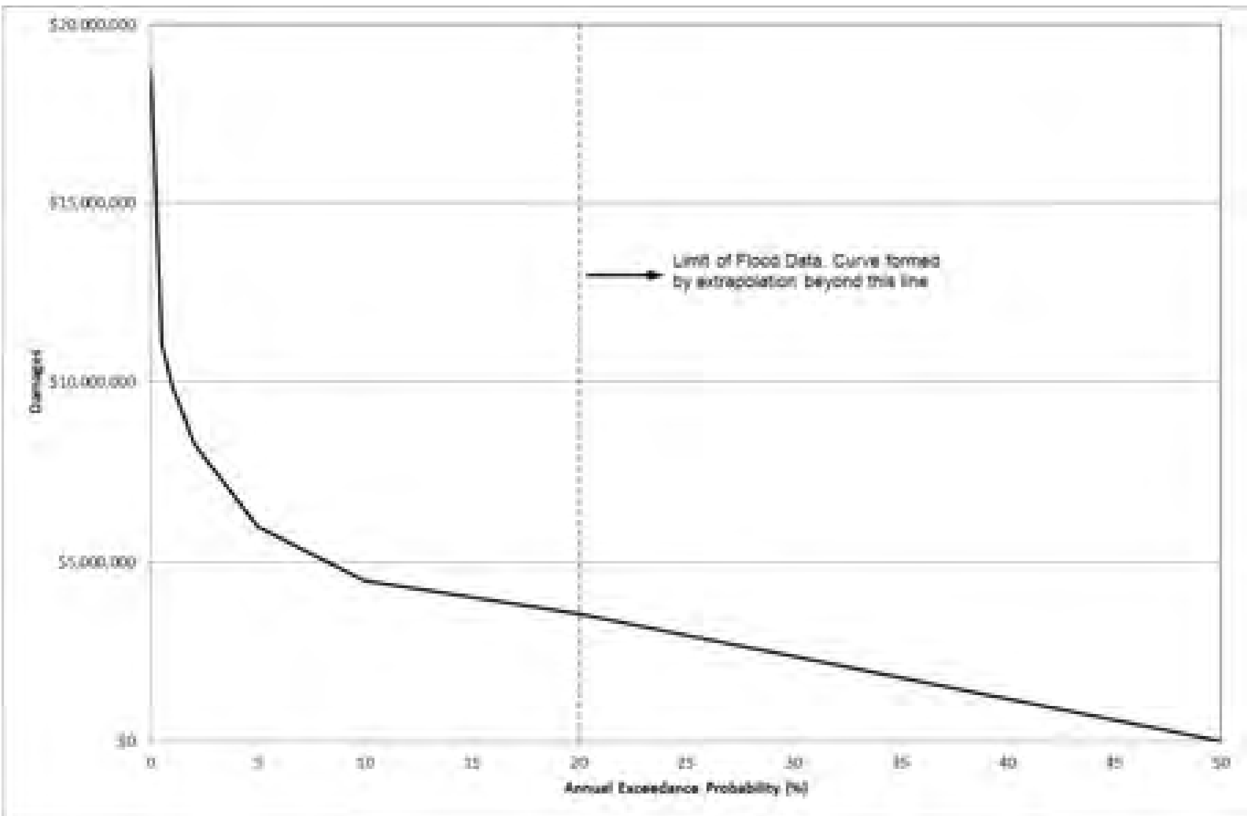


Figure 8-10 Existing Condition Probability-Damages Curve

8.7 Summary

This memorandum has presented the flood damages assessment for the Mt William catchment as part of the Mt William Flood Investigation. The assessment has shown that the Annual Average

Damages for the Mt William catchment is $1.426 million, with 12 buildings (combined residential, industrial and commercial properties) exposed to above floor flooding in the 100y ARI 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 9% of the total incurred damage during the 100y ARI flood event, whilst agricultural damage and road infrastructure damage account for 56% and 34% respectively. These relative contributions to the overall total damage determined are consistent with the experiences of 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.

9 Flood Mitigation Assessment

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

9.1 Flood Mitigation Overview

9.1.1 Background

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

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

(7) 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.

9.1.2 Key Issues

To provide the best possible outcome for the residents of the Mount William Creek catchment, 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 Mount William Creek catchment were identified. This understanding was further enhanced through flood modelling and mapping, the outcomes of which are presented in Sections 5 and 7. These factors relate to the physical characteristics of the floodplain which contributes to flood risk in the communities of the Mount William Creek catchment 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 Dadswells Bridge, are on the banks of waterways subject to flooding;
- Limited road access along key access routes 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 upper 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 Mount William Creek catchment. Flood warning in the upper reaches of any catchment is challenging due to the rapid response of the upper catchment.
- The influence of major water storages, including Lake Lonsdale, on the flooding of Dadswells Bridge and the St Helens Plains.

9.1.3 Management Objectives

An element of the Mount William Creek 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 local community.

The objectives of the management options to be developed as part of the Mount William Creek Flood Investigation are:

(8) Reduce, as much as practical, the risk of flooding from design events within the communities of the Mount William Creek catchment.

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

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

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

9.2 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 for further assessment. The WCMA, in consultation with the Technical Steering Committee, determined the three structural management schemes that were to be tested in the hydraulic model

9.2.1 Structural Management Schemes Assessment

The basis for the assessment was to undertake flood impact mapping and assessment across all of the modelled design events; 5, 10, 20, 50, 100 and 200 year ARI 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.

9.3 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:

9.3.1 Scheme One

Scheme One is focussed on providing improved flood protection to the township of Dadswells Bridge. This scheme includes two key components:

- A levee on the south side of the Western Highway, built to the same height as the existing highway level. This levee is designed to provide protection to a number of businesses on the south side of the Western Highway within the township of Dadswells Bridge. The exact level of protection this levee provides will be determined as part of the modelling process.

9.3.2 Scheme Two

Scheme Two has two key focus areas, the Pleasant Creek floodplain immediately downstream of Stawell and the Mount William Creek floodplain downstream of Lake Lonsdale, including Dadswells Bridge. This scheme will also help to provide Northern Grampians Shire Council will some guidance regarding flood mitigation works within the township of Stawell (however, flood mapping for these regions will not be shown in the final flood investigation reporting).

The key components of this scheme include:

- A reduction in the operating level of Lake Lonsdale. Currently the operating level of Lake Lonsdale is 187.12 metres AHD, 0.5 metres below the spillway. This scheme will model the Lake Lonsdale operating level as being 185.62 m AHD, 2.0 metres below the spillway. This will allow for an additional 29,630 ML of flood storage within Lake Lonsdale.
- A number of proposed flood mitigation works within Stawell, including
  - Increasing the drainage capacity of the culverts underneath Black Range Road, adjacent to the Grampians Gate Caravan Park
  - Construction of a pipe along Cooper Street between Austin Street and Seaby Street
  - Amendment to the bridges over the main drain on Darcy Street and Smith Street

A number of additional mitigation elements were suggested for Stawell by the Northern Grampians Shire Council and are based on potential future works. However, the model setup was deemed not sufficient to allow these measures to be tested. It is recommended that these measures be tested at some point in the future when more detailed flood modelling of Stawell is undertaken.

9.3.3 Scheme Three

Scheme Three looked to reduce the impact of flooding on the local communities without specifically intending to prevent flooding within specific areas.

The key components of this scheme are:

- Upgrading the Ararat – Halls Gap Road (C222) to minimise flooding over this key access road through the catchment. The intent of this component is to improve access during and following a flood event for the communities of Pomonal and Moyston (either through connection to Halls Gap or Ararat), and in doing so also improves access to the catchment for emergency services.
- Determining the impact of the decommissioning of the Main Central Channel during times of flood.

9.4 Assessment Methodology

The following sections summarise the assessment methodology adopted in order to recommend a structural management scheme. For each scheme; a description of the proposed works, an assessment of the effectiveness in reducing the risk of flooding has been provided. An assessment of the economic, social and environmental advantages and disadvantages will be included in a future report.

9.4.1 Hydraulic Assessment and Flood Impact Mapping

The effectiveness of each structural management scheme identified above has been assessed using the hydraulic model developed as part of the Mount William Creek Flood Investigation. Each scheme has been incorporated into the hydraulic model forming a hydraulic modelling scheme. The results of each hydraulic modelling scheme were then compared to all design event results to ascertain the effectiveness of each hydraulic modelling scheme.

The comparison involved the preparation of peak flood heights for each hydraulic modelling scheme. 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 modelled design events are presented for each scheme.

The map for each scenario in the hydraulic assessment 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.

9.4.2 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 8;
- 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 9-1

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 Mount William Flood Investigation.

As an example, Table 9-1 shows the present value of the annual benefit realised at different times over a 50 year period.

Table 9-1 Present Value of Annual Benefits

Year	Average Annual Benefit ($ million)	Present Value ($ million)
0	2.3	2.3
1	2.3	2.2

Year	Average Annual Benefit ($ million)	Present Value ($ million)
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 9-2. 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 9-2

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.

9.4.3 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 costs were 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.

9.5 Scheme 1: Dadswells Bridge Levees

9.5.1 Description of Works

Two levees were incorporated into the hydraulic model. At the request of the Steering Committee these were set at the road level. For the purposes of the mitigation option this was 165 m AHD for the western levee and 165.2 m AHD for the eastern levee.

For this scheme no changes to the channel geometry, channel slope or the structures under the Western Highway were made to the model.

9.5.2 Flood Impacts

The impact on the 1 in 100 year ARI design event peak flood levels for Scheme 1 is shown in Figure 9-1. This figure shows that the western levee is ineffective in the 100 year ARI event, however the eastern levee is of sufficient height to remove flooding from these businesses. There is a small impact upstream of the eastern levee on flood waters but does not negatively impact on any surrounding buildings. The floodwaters along the western levee peak at approximately 165.1 m AHD, 100 mm greater than the proposed flood levee height.

Flood level impacts for events other than the 1 in 100 year ARI flood events are located in Appendix D.1. These figures show that in the 50 year ARI event both levees are effective in removing all flooding from the enclosed businesses. There is negligible negative impacts caused by the western levee, however there is a slight increase in flooding of the field directly to the south of the eastern levee (area coloured blue).

For events of smaller magnitude there is negligible benefit or impact caused by the two proposed levees.

9.5.3 Change in Flooded Floors

The implementation of Scheme One would result in a number of surveyed building's floor levels that were flooded under existing conditions to be now flood free.

Table 9-2 Change in Flooded Floors – Scheme One

Event (ARI)	Existing Flood Flooded	Floor Flooded in Scheme One	Change
5	2	2	0

Event (ARI)	Existing Flood Flooded	Floor Flooded in Scheme One	Change
10	3	3	0
20	7	5	-2
50	10	8	-2
100	12	10	-2
200	13	13	0
PMF	35	35	0

9.5.4 Benefit Cost Ratio

The damages under Scheme 1 for each design flood event are summarised in Appendix B. The AAD is $1,616,800, which is a reduction of $7,400 from the existing conditions AAD of $1,624,200. The benefit cost analysis is summarised in Table 9-3. The BCR for Scheme 1 is 0.08.

Table 9-3 Scheme 1 BCR Summary

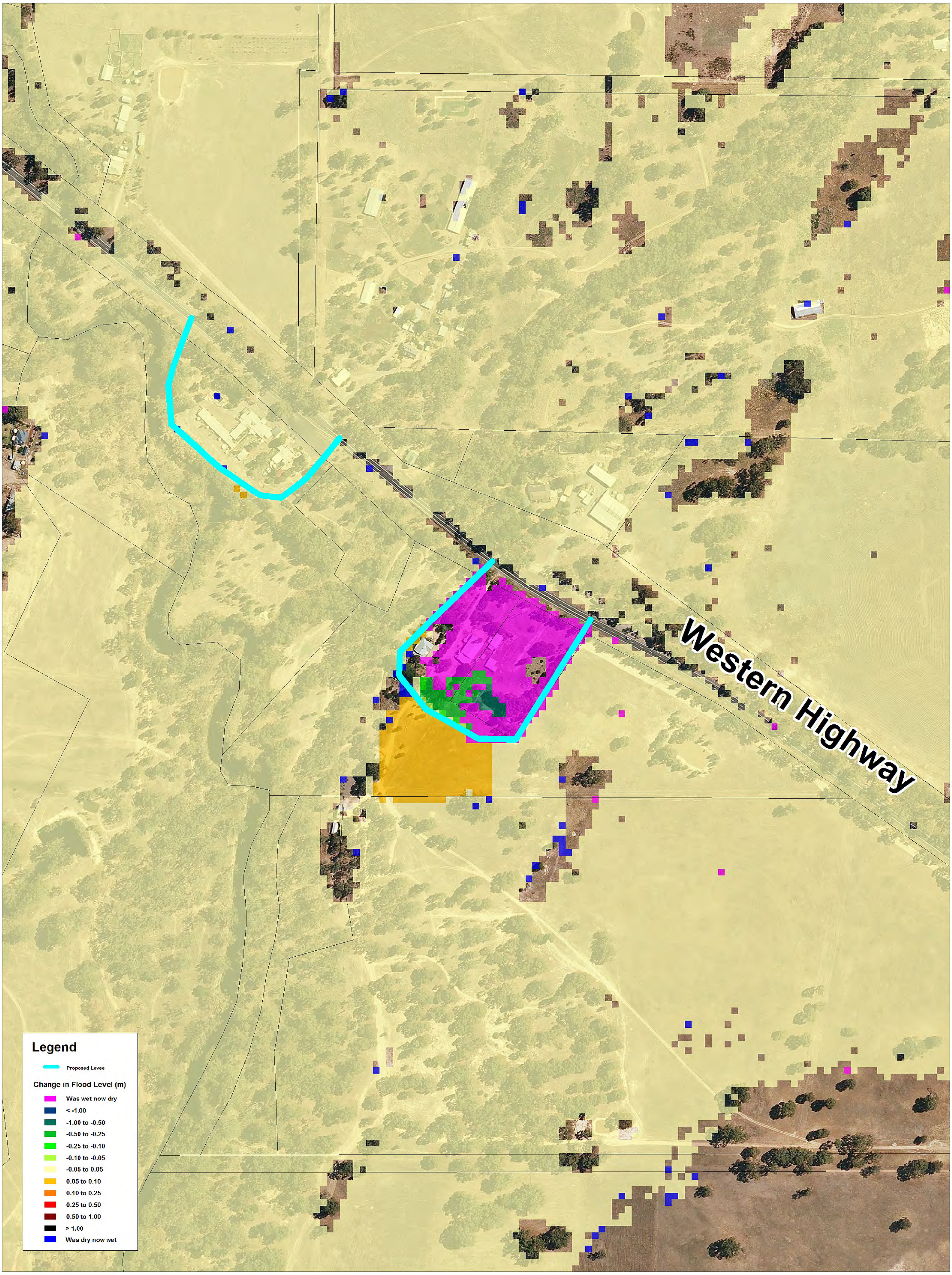
Item	Existing	Scheme 1
Damages (PA)	$1,624,200	$1,616,800
Benefit (PA)		$7,400
Benefit (NPV)		$117,000
Capital Cost		$230,000
Maintenance (PA)		$80,000
Maintenance (NPV)		$1,261,000
Total Scheme Cost		$1,491,000
BCR		**0.08**

9.5.5 Advantages and Disadvantages

Some of the key advantages and disadvantages of Scheme 1 are presented in Table 9-4.

Table 9-4 Advantages and Disadvantages of Scheme 1

Advantages	Disadvantages
Reduce flood levels in and around Dadswells Bridge	Only protects a small portion of Dadswells Bridge
Provides flood protection up to and including the 50 year ARI flood event for iconic Dadswells Bridge businesses	Low BCR



Title:

Mount William Creek Flood Investigation Mitigation Option 1
1 in 100 Year ARI Flood Impacts

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9.6 Scheme 2: Lake Lonsdale and Stawell Works

9.6.1 Description of Works

Scheme 2 involves the reduction in water level within Lake Lonsdale by 1.5 metres from the current operating level (2.0 metres below the spillway) to 185.62 mAHD.

This scheme also includes a number of drainage infrastructure changes within the Stawell region as detailed previously in Section 9.3.2.

9.6.2 Flood Impacts

The impact on the 100 year ARI design event peak flood levels for Scheme 2 is shown in Figure 9-2. This figure shows very large reductions in flood level downstream of Lake Lonsdale. Whilst not removing the flooding within the township of Dadswells Bridge downstream it does result in reductions of water levels between 0.1 and 0.25m. There is a significant reduction in reduction in overbank flooding with the majority of floodwaters contained within the main channel under this scheme.

The upgrading of culverts underneath the Black Range Road results in flood level reductions of up to 0.5 metres in the 1 in 100 year flood event (Figure 9-3) and reductions in flood extent upstream of road, resulting in benefits for the caravan park and residential properties in this region. Importantly, there are no increases in flood level downstream of the culverts as a result of the culvert upgrade.

Flood level impacts for events other than the 1 in 100 year ARI flood events are located in Appendix D.2.

9.6.3 Change in Flooded Floors

The implementation of Scheme Two would result in a number of surveyed building's floor levels that were flooded under existing conditions to be now flood free.

Table 9-5 Change in Flooded Floors – Scheme Two

Event (ARI)	Existing Flood Flooded	Floor Flooded in Scheme Two	Change
5	2	2	0
10	3	3	0
20	7	3	-4
50	10	7	-3
100	12	8	-4
200	13	13	0
PMF	35	35	0

9.6.4 Benefit Cost Ratio

The damages under Scheme 1 for each design flood event are summarised in Appendix B. The AAD is $1,548,900, which is a reduction of $75,300 from the existing conditions AAD of $1,624,200. The benefit cost analysis is summarised in Table 9-3. The BCR for Scheme 1 is 0.10.

Table 9-6 Scheme 1 BCR Summary

Item	Existing	Scheme 2
Damages (PA)	$1,624,200	$1,548,900
Benefit (PA)		$75,300
Benefit (NPV)		$1,187,000
Capital Cost		$11,190,000
Maintenance (PA)		$60,000
Maintenance (NPV)		$946,000
Total Scheme Cost		$12,136,000
BCR		**0.10**

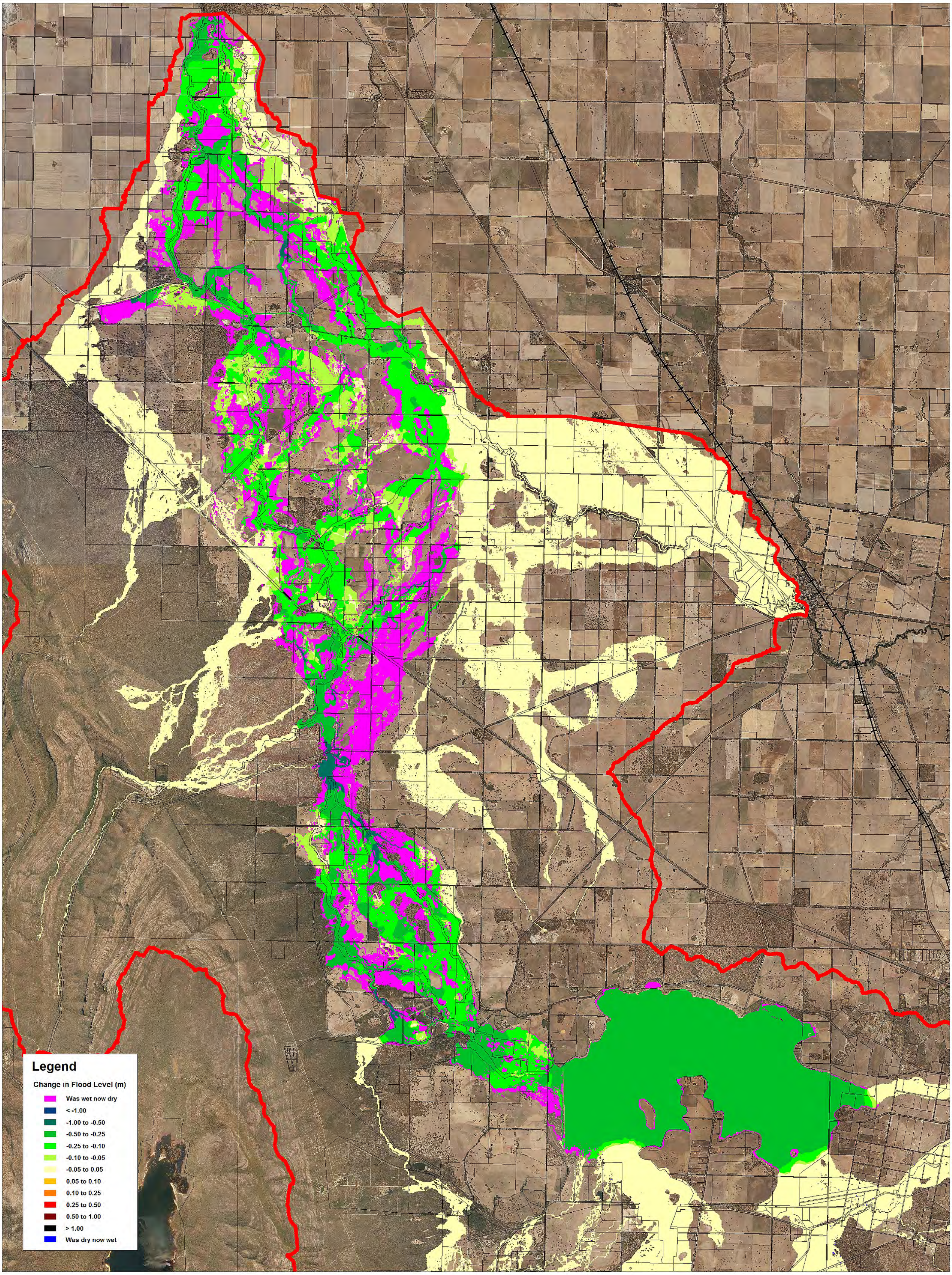
The bulk of the capital costs for this scheme relate to the purchase of the required volume of water from Lake Lonsdale to enable the water level to be reduced from 187.62 mAHD to 185.62 mAHD. The costs of this scheme and therefore the BCR would change substantially depending on the costs incurred to lower the lake level (either through purchase of water rights, or compensation for lost water). However, these costs do not include the environmental or social costs of the lower lake level and the subsequent loss of social and environmental amenity.

9.6.5 Advantages and Disadvantages

Some of the key advantages and disadvantages of Scheme 2 are presented in Table 9-4.

Table 9-7 Advantages and Disadvantages of Scheme 2

Advantages	Disadvantages
Significant reduction of flooding between Lake Lonsdale and the Wimmera River	Reduction in Lake Lonsdale level may impact ability to provide environmental flows to the Wimmera River system
Reduced flood risk for Stawell Caravan Park	Reduction in Lake Lonsdale level may impact the recreational and environmental amenity of the lake and surrounds
	Low BCR



Title:

Mount William Creek Flood Investigation Mitigation Option 2
1 in 100 Year ARI Flood Impacts - Lake Lonsdale

Figure: **9-2**

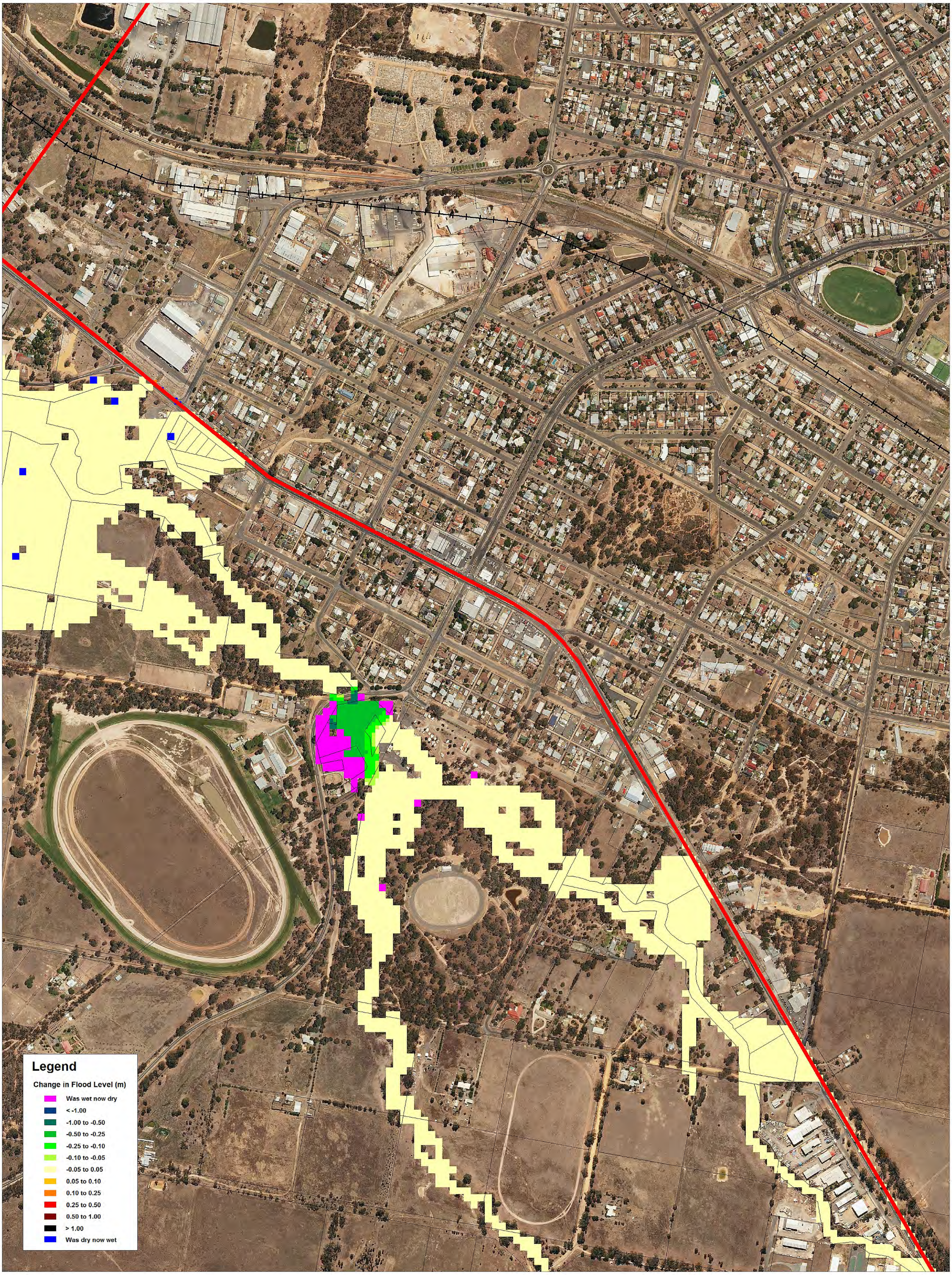
Rev: **A**

N

0 2.5 5km

Approx. Scale

Filepath : T:\M20045.JL.MtWilliamCkFS\MapInfo\Drawings\R.M20045.007.01.FinalReport\MtW_Fig9-2_Dif_hMax_M02_100yr_047_Lake_RevA.WOR



Title:

Mount William Creek Flood Investigation Mitigation Option 2
1 in 100 Year ARI Flood Impacts - Stawell Works

Figure: 9-3

Rev: A

N

0 125 250m
Approx. Scale

Filepath : T:\M20045.JL.MtWilliamCkFS\MapInfo\Drawings\R.M20045.007.01.FinalReport\MtW_Fig9-3_Dif_hMax_M02_100yr_047_Stawell_RevA.WOR

9.7 Scheme 3: Whole of Catchment Access

9.7.1 Description of Works

Scheme 3 involves significant road works and drainage infrastructure works to be undertaken. The aim of this scheme is to provide road access between Moyston and Pomonal. During the January 2011 storm event the area around Lady Summers Bridge suffered significant overtopping. This scheme involved upgrading the section of road between Moyston and Pomonal to approximately the 1 in 100 year ARI event and enlarging any culvert or bridge structures.

The second component of this scheme was determination of the flood level benefit of reinstating the Main Central Channel.

9.7.2 Flood Impacts

The impact on the 100 year ARI design event peak flood levels for Scheme 2 is shown in Figure 9-4. Generally there is a reduction in water level downstream of the road, but only a minor increase in levels along the upstream edge. The identified roads are shown to be flood free during the 1 in 100 year ARI flood events (they will be overtopped in larger events).

Figure 9-5 shows the effect on flooding in the catchment if the main central drain was reinstated. The reinstatement of the drain it was found to have a positive effect on flooding behaviour within the catchment. However, the benefit of the reinstatement was more related to the fact that the channel also acts as a levee (it was perched above the surrounding floodplain) and diverted flood waters from the local catchment rather than diverting flows away from Mount William Creek.

Flood level impacts for events other than the 1 in 100 year ARI flood events are located in Appendix D.3

9.7.3 Change in Flooded Floors

The implementation of Scheme Three would result in no change to the number of flooded floors below the 200 year ARI event within the Mount William Creek catchment. The additional flooded floor is the result of the road upgrade and floodwaters backing up behind the embankment.

Table 9-8 Change in Flooded Floors – Scheme Three

Event (ARI)	Existing Flood Flooded	Floor Flooded in Scheme Three	Change
5	2	2	0
10	3	3	0
20	7	7	0
50	10	10	0
100	12	11	0
200	13	14	+1
PMF	35	35	0

9.7.4 Benefit Cost Ratio

The damages under Scheme 1 for each design flood event are summarised in Appendix B. The AAD is $1,560,100, which is a reduction of $64,100 from the existing conditions AAD of $1,624,200. The benefit cost analysis is summarised in Table 9-3. The BCR for Scheme 1 is 0.06.

Table 9-9 Scheme 3 BCR Summary

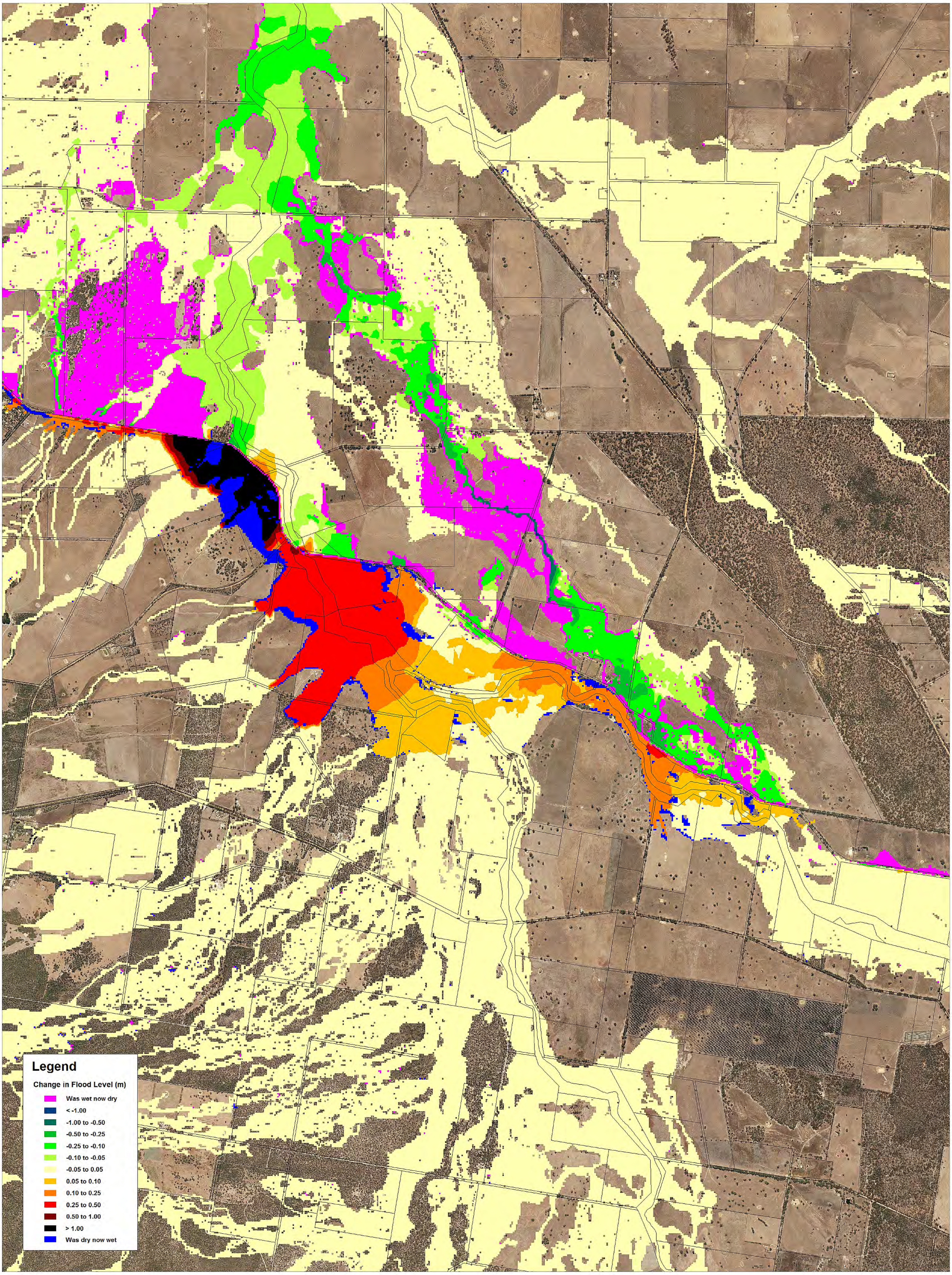
Item	Existing	Scheme 3
Damages (PA)	$1,624,200	$1,560,100
Benefit (PA)		$64,100
Benefit (NPV)		$1,010,000
Capital Cost		$11,990,000
Maintenance (PA)		$288,000
Maintenance (NPV)		$4,539,000
Total Scheme Cost		$16,529,000
BCR		**0.06**

9.7.5 Advantages and Disadvantages

Some of the key advantages and disadvantages of Scheme 3 are presented in Table 9-4.

Table 9-10 Advantages and Disadvantages of Scheme 3

Advantages	Disadvantages
Flood free access between Ararat and Halls Gap, via Moyston and Pomonal (Route C222)	Significant disruption to key access route for extended periods of time
	Low BCR



Title:

Mount William Creek Flood Investigation Mitigation Option 3
1 in 100 Year ARI Flood Impacts - Road Upgrades

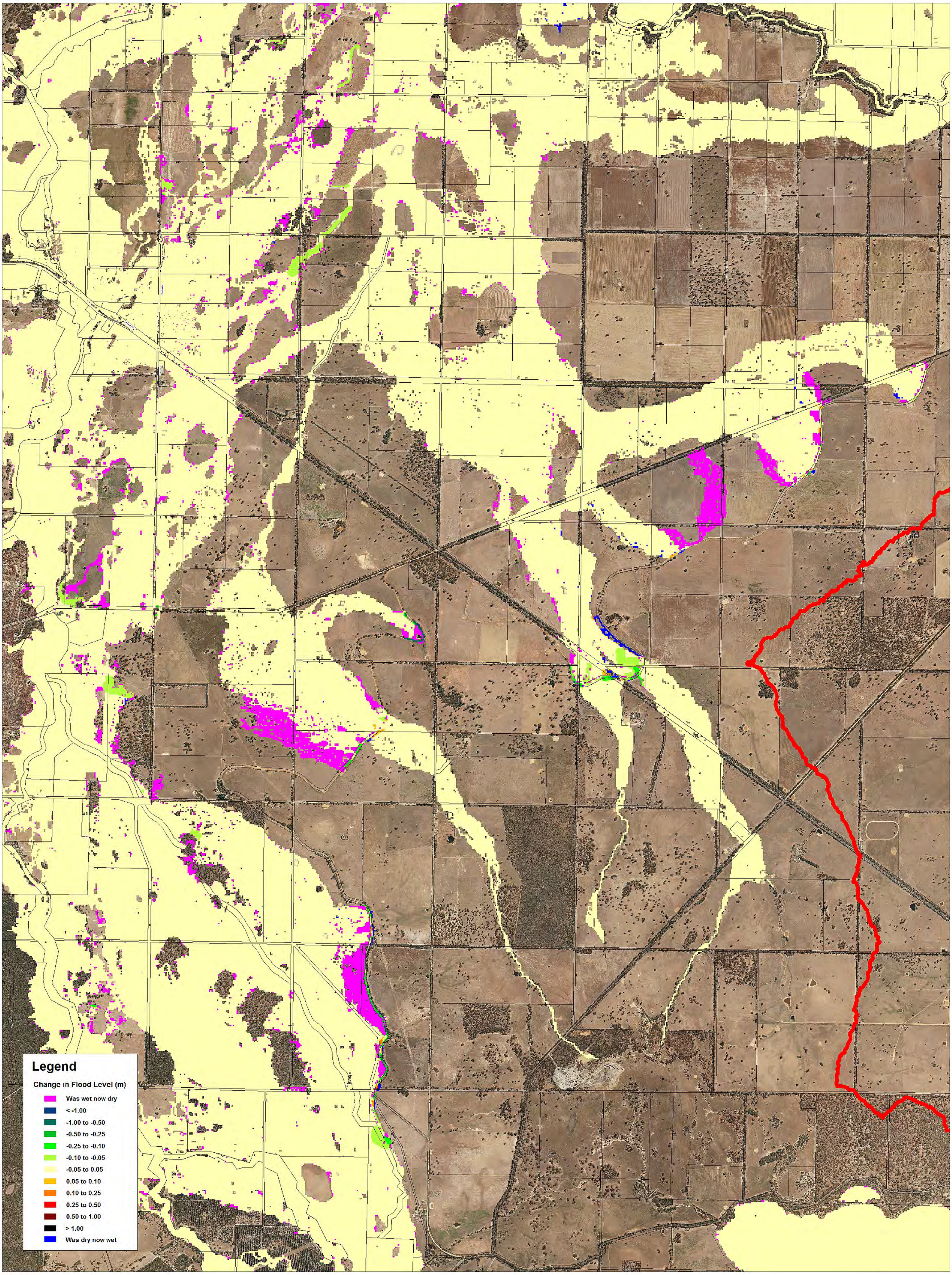
Figure: 9-4

Rev: A

N

0 0.75 1.5km
Approx. Scale

Filepath : T:\M20045.JL.MtWilliamCkFS\MapInfo\Drawings\R.M20045.007.01.FinalReport\MtW_Fig9-4_Dif_hMax_M03_100yr_047_UpgRd_RevA.WOR



Title:

Mount William Creek Flood Investigation Mitigation Option 3
1 in 100 Year ARI Flood Impacts - Channel Reinstatement

Figure: **9-5**

Rev: **A**

N

0 0.75 1.5km
Approx. Scale

Filepath : T:\M20045.JL.MtWilliamCkFS\MapInfo\Drawings\R.M20045.007.01.FinalReport\MtW_Fig9-5_Dif_hMax_M03_100yr_047_Channel_RevA.WOR

9.8 Flood Mitigation Conclusions

This section has presented the economic assessment for the three modelled structural mitigation schemes for the Mount William Creek 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 3 making very little (if any) difference to these values. Whilst there is a noticeable reduction in the damages for Scheme 2, it comes at a significant capital cost; hence the BCR is still very low. However, the capital cost is based on the assumption that water from Lake Lonsdale would need to be ‘purchased’ in order to reduce the operating level. The BCR would improve significantly if this water did not need to be ‘purchased’.

Consequently, there is no preferred structural mitigation scheme recommended by the Steering Committee for the Mount William Creek Catchment. However, mitigation works should still be considered for protection of individual properties where deemed appropriate. The use of individual building levees/bunds or the possibility of house raising are option to alleviate flood risk for individual properties (subject to such actions not impacting upon the flood risk of a neighbour)

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.

10 Flood Warning Systems

10.1 Flood Warning Systems

10.1.1 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 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).

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 flood warning 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.

10.2 Flooding within the Mount William Creek Catchment

10.2.1 Catchment Overview

Mount William Creek is a tributary to the Wimmera River. It rises to the south of Jallukar and to the south west of Barton in the mountainous regions of The Grampians and the West Victorian Uplands. From there, the creek and its tributaries flow in a generally northerly direction towards Lubeck, some distance downstream from Glenorchy, where it joins the Wimmera River.

Mount William Creek has a catchment area of approximately 1,300 km2. It includes a number of waterways in addition to Mount William Creek: Salt Creek, Fyans Creek, Pleasant Creek, Sheepwash Creek and Golton Creek along with their tributaries. The downstream reaches are heavily influenced by the Wimmera River, particularly during flood events.

The upper part of the catchment is extremely steep with numerous well defined flow paths. Further through the catchment (i.e. to the north), the topography flattens to form a wide floodplain with many incised creeks and streams including Mount William Creek, Nine Mile Creek, Pentland Creek and Sugarloaf Creek.

The lower reaches of Mount William Creek are heavily influenced by numerous Grampians Wimmera Mallee Water (GWMW) channels and storages. There are three major storages in the catchment: Lake Bellfield and Lake Fyans, Lake Lonsdale on Mount William Creek and Lake Fyans (an offstream storage supplied by Fyans Creek). There are also a number of channels that connect with these storages as well as with the wider GWMW system.

The majority of the catchment is used for agricultural purposes, predominately grazing.

There are several townships within the catchment including Pomonal, Moyston, Stawell, Dadswells Bridge and Halls Gap (Figure 1-2).

The town of Moyston is located towards the southern end of the catchment, approximately 15 km west of Ararat, and is within the Rural City of Ararat. Salt Creek, a tributary to Mount William Creek is located approximately 1.5 km north of the main town centre.

The town of Pomonal is located in the central west of the catchment, approximately 20 km south west of Stawell, and is also within the Rural City of Ararat. The town is situated on the banks of Millers Creek, a tributary to Mount William Creek.

The town of Dadswells Bridge is located in the north of the catchment, approximately 28 km north east of Stawell, and is within the Rural City of Horsham. The town is situated on the banks of Mount William Creek adjacent to the Western Highway.

It is noted that while Halls Gap is within the Mount William Creek catchment[1], it is not included in the current assessment. A flood study was completed for the town in 2008 (Water Technology, 2008).

Stawell is also not included in the current assessment as the consideration did not extend beyond the Western Highway (i.e. it did not include any part of the town to the north and east of the Western Highway).

10.2.2 Flood Behaviour

Flooding in the Mount William Creek catchment is generally caused by significant rainfall over the catchment upstream of Lake Lonsdale. This usually results from a large regional event. Locally intense rainfall can lead to flash flooding in the upper reaches around Moyston and Pomonal but

1 Halls Gap is subject to flash flooding, where flash flooding is defined as flooding which occurs within 6 hours of rain (BoM, 1996), and is therefore usually the result of intense local rain and is characterised by rapid rise in water levels.
Halls Gap is located along the base of a valley between two steep ranges - the Mount William Range to the east and the Mount Difficult Range to the west. Numerous well-defined gullies (i.e. drainage lines) drain the Mount Difficult Range (i.e. western ridge) and flow from west to east through the town. Stony Creek is the largest of these. Stony Creek is a tributary to Fyans Creek.

significant flooding downstream of Lake Lonsdale and around Dadswells Bridge would not be expected unless Lake Lonsdale was spilling. However, flooding of Dadswells Bridge and the lower Mount William Creek catchment (including Saint Helens Plains) can occur without Lake Lonsdale spilling. Additionally, floods through Dadswells Bridge often exhibit a twin peak hydrograph (such as in 1996 and 2011), when the first peak occurs as a result of the flow from the catchment downstream of Lake Lonsdale and the second peak occurs once Lake Lonsdale is spilling.

In general terms, response time for the upper parts of the catchment is considered to be of order 1 - 2 days, while response in the lower catchment is considered to be of order of 2 - 5 days and highly dependent on the available storage within Lake Lonsdale.

10.2.3 Flood Risk in the Mount William Creek Catchment

The Mount William Creek Flood Investigation has shown that flood risk in the catchment is “tolerable”. For example, damage to other than roads and the agricultural sector (e.g. fences, pasture, etc) arising from floods less than the 100-year ARI flood event is minimal and arises from flooding of twenty-five (25) properties (twelve (12) of which also experience over-floor flooding) and from disruption and restrictions to regional access due to roads being flooded. Seven (7) of the over-floor flooded buildings are in Dadswells Bridge (the motel, 2 x houses and 2 x shops) with the balance at Stawell (1 x house, 2 x shops and a nursery). The majority of these premises begin to flood over-floor between the 20-year and 50-year ARI events. Floods more severe than the 1 in 100 year ARI flood event result in an increase in the number of buildings at-risk of over-floor flooding (a further 4 at the 1 in 200 year ARI flood event and a further 13 at the PMF) and additional disruption and restrictions to regional access due to flooded roads.

Floods develop and rise quickly in the upper parts of the Mount William Creek catchment around Moyston and Pomonal, particularly when the area is wet. Catchment response times would be expected to be generally less than 6 hours. This places the upper 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 those communities[3]. In summary, these responsibilities reside at the local level (i.e. with the Rural City of Ararat) although the BoM will provide technical assistance[4].

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. 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.

The situation at Dadswells Bridge is different. Response time is very much longer and as a result responsibility for the provision of a flood forecast and warning service resides with the Bureau of Meteorology as the agency responsible for the monitoring of situations likely to lead to flooding and for the prediction of floods throughout rural and provincial Victoria. The rainfall–runoff model used by the BoM to forecast Wimmera River flood levels at Glenorchy, Horsham and downstream could provide a useful starting point for development of a forecasting service, provided that the additional data required to inform the model was available to BoM via telemetry (see Sections 10.3 and 10.4). The capital and on-going costs associated with the data collection system and associated telemetry would however still need to be met locally, probably, as the direct beneficiary, by the Rural City of Horsham.

The damage assessment undertaken as part of this project suggests that during a 1 in 100 year ARI flood event, building damage would account for approximately 8% of the total damage (minus indirect damages) incurred while damage to agricultural land and road infrastructure would account for around 49% and 48% 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 be large. On an annual average basis, perhaps somewhere between $60,000 and $80,000 if the flood warning system focussed on Dadswells Bridge and it was assumed that damage reducing actions were highly effective. As there are no properties flooded over-floor in either Moyston or Pomonal by even the 200-year ARI event, the benefit of providing a (flash) flood warning service for these two towns is, in relative terms, minimal.

This suggests that a sophisticated flood warning system requiring a substantial initial injection of capital and incurring on-going costs would probably be difficult to support on economic grounds alone, for any location within the catchment. On a priority basis with due regard for risk and damages, Dadswells Bridge is considered the highest priority location.

If focus is directed to the lead time a flood forecasting system can achieve rather than on the accuracy of the forecast provided, there is potential for a system to deliver some value to Dadswells Bridge and possibly to upstream communities. Thus a simple and more modest system does have some attractions, provided that 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 Rural City of Horsham, possibly the Rural City of Ararat and / or CMA if other partners could not be found, perhaps through the Surface Water Monitoring Partnership).

Attention would need to be given to each of the TFWS building blocks if an effective flood warning system was to be established for the Mount William Creek catchment and / or Dadswells Bridge. Installing additional rain and / or river gauges would not be sufficient.

10.2.4 Flood Mitigation Options

Typically, there are a range of structural and non-structural flood mitigation options available, a number of which could potentially be applied to locations within the Mount William Creek catchment. While structural options are discussed and explored in other sections of this study report along with land use planning and related options, it is noted that structural measures do not provide a cost-effective approach to reducing flood risk. Further, floods larger than the design event would potentially overwhelm any measures implemented. A flood warning system therefore remain a consideration as it offers opportunities to reduce flood related damages and flood related risk to personal safety across the catchment, notwithstanding the poor economic metrics (i.e. poor benefit – cost ratio).

The following section outlines how each of the TFWS elements could be addressed in order to implement an appropriate, functional and sustainable flood warning system. An integrated and complete system along with 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 10.4. Indicative costings are provided in Section Appendix E.

10.3 The Task for Mount William Creek

10.3.1 The Problem

The upper parts of the Mount William Creek catchment, say around Moyston and Pomonal, are subject to flash flooding. Catchment response times would be expected to be generally less than 6 hours, particularly on a wet catchment. At Dadswells Bridge, downstream from Lake Lonsdale, response time is very much longer.

10.3.2 Existing Flood Warning System

A formal flood warning system does not exist for any locations within the Mount William Creek catchment. A formal flood warning system does however exist for the Wimmera River at Glenorchy and at Horsham.

10.3.3 What Will Need to be Done

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 (TFWS).

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 communities. 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 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 flood warning system.

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

Attention will need to be given to each of the TFWS building blocks if a flood warning system is to be established for communities within the Mount William Creek catchment. The following section outlines how each of the TFWS elements could be addressed in order to implement a functional flood warning system, where the emphasis is on lead time and what needs to be done ahead of a large flood rather than on the accuracy of the forecast.

10.3.4 Data Collection and Collation

10.3.4.1 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.

However, in all cases there are costs: a capital and installation cost and an on-going cost.

Rather than introduce a new type of equipment to the wider 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.

10.3.4.2 Turn-Key Data Collection & Alerting Systems

10.3.4.2.1 Introduction

Turn-key systems are ‘complete’ or integrated systems. The vendor provides all equipment including the base station software and then installs and configures all components. Maintenance is usually undertaken under contract to the vendor. Systems are generally scalable.

Capital and operating costs are not generally available “off-the-shelf” but are often more expensive than the ERTS, loggers and other equipment already installed in and around the Wimmera River catchment. The technology being used however offers significantly increased functionality.

10.3.4.2.2 Greenspan

Greenspan (part of TYCO Integrated Systems) is a local supplier of turnkey flood warning systems with operational systems in Australia, Asia and the Philippines. Standard or customised solutions are offered that include site investigation, system design services, installation, testing, commissioning, operation and maintenance. Solutions are tailored to the location and include integrated hydrologic and hydraulic modelling that trigger alerts of likely flooding. Processing is generally done off-site in Greenspan’s office and authorised users log-in to obtain data and forecasts. Alarms set within the system enable SMS and email messages to be sent to nominated persons. Systems can also be configured to initiate remotely controlled (radio linked) warning signs and other alerting equipment.

A number of Greenspan flood warning focussed systems are in operation and include:

- Sipan Sihaporas Hydro Electric Power Scheme in Indonesia;

- San Roque Dam and Hydro Power Scheme in the Philippines;
- SMART (Stormwater Management and Road Tunnel) in Kuala Lumpur in Malaysia;
- Public protection system for the Bruce Highway at Proserpine for Queensland Main Roads;
- Flash flood warning system for Warringah Mall in Brookevale in NSW.

10.3.4.2.3 Prospect Environmental

Prospect Environmental is also a local supplier of turnkey flood and other disaster warning systems with operational systems in Australia. Customised solutions are offered that are designed to meet a client's needs from initial investigation through to system design, installation, testing and operation. Equipment is sourced domestically and internationally. Warning systems are based on Whelen Mass Notification products which are built to US FEMA specifications and are capable of alerting (via a number of audible tones), informing (via pre-recorded messages) and directing (via a public address system). Monitoring is web / cloud based and includes conventional sensors as well as cameras. A range of smart devices is also available that can be used to control creek crossings and other high risk areas as well as to initiate targeted messaging and more general alerts. A number of systems have been installed for Queensland Councils over the past year including for the Lockyer Valley and Somerset Regional Councils.

10.3.4.3 Other Automated Data Collection and Alerting Systems

10.3.4.3.1 Introduction

Other automated systems in the context of this report are those that are built up by the system owner using readily available hardware that is compatible with existing hardware and that can easily operate with existing data interrogation and storage software.

10.3.4.3.2 Campbell Data Logger

Campbell data loggers provide a level of functionality and reliability that has seen them installed at many water resources sites across Victoria over the past 10 years or so. They generally collect data at a combination of predetermined frequencies and exceedance criteria. When paired with a modem, they can be interrogated by computer via the telephone system (fixed and mobile) and can also be set to send an SMS to one or more pre-determined telephone numbers or to email to one or more addresses when alarm criteria (either single or multi-parameter with simple or conditional rules) are exceeded. The alarm rules are user-specified and can be used (say) to alert to the likelihood of flooding and the detection of flooding. Quality control of data accessed direct from site is an end-user responsibility. Any data loaded to the State Data Warehouse for long-term archive is subject to rigorous quality control and correction.

10.3.4.3.3 Other Data Loggers

A variety of other data loggers with similar functionality and pricing are readily available within Australia, mostly off-the-shelf. However, they are not as widely used as the Campbell logger within Victoria. It is suggested that while there are no functional reasons for not considering these alternatives for the Mount William Creek catchment, there are likely to be additional costs associated with their use. These are likely to include, for example, additional capital cost as at least one logger is likely to be required for the equipment maintenance pool, additional installation costs due to the need to gain familiarity with logger setup, and additional on-going operating and maintenance costs due to the need to establish new procedures for data retrieval and on-site activity.

10.3.4.3.4 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 the data checking, collation and alerting functions.

Each ERTS flood monitoring 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 Mount William Creek 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[5] as soon as the trigger rate / value is exceeded. The SMS alert provides a 'heads up' to a possible 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 parts of the Mount William Creek catchment and specifically at Moyston and Pomonal, 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 Rural City of Ararat MFEP.

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

5 Key personnel could include members of the at-risk communities.

10.3.4.4 Existing Data Collection Network

The Bureau of Meteorology (BoM) collects and records rainfall at a number of locations within or close to the Mount William Creek catchment. However, data from only three of these sites are available from the BoM website at a sub-daily interval. Rainfall data from the Mt William AWS and the Stawell Aerodrome AWS are available at 30 minute intervals (more frequently during very heavy rain events) while data from the Stawell ERTS at the Concongella gauging site is available at hourly intervals, although the site provides data to BoM in near real-time (i.e. as it is recorded). Data from all three sites is available through the rainfall and river height data (by catchment) map and in table format.

Stream level data is available from the BoM website for two locations within the Mount William Creek catchment:

- Fyans Creek at Fyans Creek (415250); and
- Mt William Creek at Lake Lonsdale Tail gauge (415203).

There are additional water monitoring sites, operated primarily for water and catchment management purposes, at:

- Fyans Creek at Lake Bellfield (415214);
- Fyans Creek at Grampians Road Bridge (415217) upstream of Lake Bellfield;
- Mount William Creek at Mokepilly (415252); and
- Lake Lonsdale Head Gauge (415227)

10.3.4.5 Possible Additional Data Collection Sites

It is considered that the AWS at Mt William, particularly when used in conjunction with the AWS at Stawell, provides a sufficient indication of rainfall within the upper and middle parts of the catchment to inform a rainfall based indicative quick look ‘flood / no-flood’ tool developed for the local communities (refer to Appendix F). It is also considered that there is limited value in installing additional stream gauges within the upper and middle catchment for the sole purpose of informing that part of the catchment about creek level rises.

Three of the stream gauges already in place within the catchment (Fyans Creek at Fyans Creek, Mount William Creek at Mokepilly and Mount William Creek at Lake Lonsdale downstream) provide some indication of flows likely to be experienced at Dadswells Bridge. However, data from only two of these sites is currently available through the BoM: Fyans Creek at Fyans Creek and Mount William Creek at Lake Lonsdale downstream.

While the Mount William Creek at Mokepilly site is telemetered and instrumented with a Rimco rain gauge, Next G modem, HS40 pumped air bubbler and a Campbell CR800 logger, the BoM does not access the site. Data is therefore not available to inform BoM flood forecasting activities or for display through the data maps and tables available on the BoM website. The flood mapping and experience of the January 2011 floods has shown that this gauge in inaccessible during times of flood and the current gauge location is located downstream of a flow break-out point on Mount

William Creek. There are a number of ways in which this gauge could be better utilised during times of flood including:

- Upgrading the gauge telemetry to ERTS to enable real-time access to the data via the BOM;
- Consideration to moving the gauge location further upstream (just downstream of the junction of Mount William Creek, Pentland Creek, Nine Mile Creek and Sugarloaf Creek) where the flow is more confined and access to the gauge site during times of flooding is improved;
- Review and update the gauge rating of this site. Through discussions with the Steering Committee, it is understood that the causeway that acts at the downstream control at the site has been upgraded recently and that the current rating may no longer be accurate as a result. Additionally, the current study has highlighted a number of concerns with the recorded flows at the Mokepilly gauge, some of which may be resolved with a detailed review of the gauge rating.

The following discussion is predicated on the opinion that a flood forecast and warning service is required for Dadswells Bridge. That implies that Dadswells Bridge should be classified as a key river level and quantitative flood forecast location (see Appendix E[6]).

If a flood forecasting service is to be established for Dadswells Bridge, it is suggested that BoM access should be established to rain and river data from the Mokepilly stream gauging site. It is further suggested that this data should be made available to the local community via the data maps and tables on the BoM website.

Instrumenting and telemetering a water level site at Dadswells Bridge would assist determination of likely flooding in the area. However, the cost of purchasing, installing, telemetering and maintaining a new river monitoring site is not trivial. It is therefore suggested that while not ideal, a PALS (Portable Automated Logger System) equipment could be installed initially at Dadswells Bridge to assist flood forecasting and warning activities. A location has been selected on the basis of ease of access during the early stages of a flood and the ability to relate levels at the sites to flood inundation mapping delivered as part of the current study.

Two sites have been identified – a primary (preferred) location and an alternative location – see Table 10-1. While it is not suggested that both locations should be instrumented during a future flood, one of them should be. The PALS should be deployed and located in the early stages of a flood event during which Lake Lonsdale is expected to or is spilling. The Lake Lonsdale head gauge level together with recorded and expected rainfalls and knowledge of the Lake Lonsdale full supply level (FSL) will provide guidance on whether spill is occurring or is likely.

The data collected from the PALS site will assist local flood response, confirmation of the flood inundation maps and associated flood impacts, and inform update of the Rural City of Horsham MFEP. It will also assist any rainfall–runoff modelling undertaken for the Wimmera River as well as

[6] The lowest classification for a location is "data". This essentially only requires that data for the site is available to BoM for publication on the website and in relevant flood warnings for the region. The next classification is "information". This requires that flood class levels are established for the site and that data is again available to BoM for publication on the website and in catchment specific flood warnings that provide a "now-cast" for the location (i.e. the creek at the location has exceeded the flood class level). The highest classification is "forecast" location. Forecasts can be either qualitative (i.e. the creek will exceed the flood class level by a time) or quantitative (i.e. forecast height and time). BoM requires that for both, data is available via telemetry and flood class levels are established. The latter also requires a rating table, either as a result of gauging activity at site or application of hydraulic techniques to develop a theoretical rating table that is then consolidated and refined over time by physical gauging checks at site. A more detailed description of location classifications is provided in Appendix A.

the development by BoM of a flood prediction capability for the town. It should be noted however that BoM will almost certainly require that this site is instrumented and telemetered on a permanent basis if Dadswells Bridge is to be classified as a forecast location (see Figure 10-1).

Figure 10-1 Potential PALS locations for Dadswells Bridge

Table 10-1: Potential PALS locations, gauge zeroes and applicable design flood levels

Location							
Gauge zero for PALS unit (mAHD)	5 Year ARI (mAHD)	10 Year ARI (mAHD)	20 Year ARI (mAHD)	50 Year ARI (mAHD)	100 Year ARI (mAHD)	200 Year ARI (mAHD)	PMF (m AHD)
634571.354E 5913394.967N	Primary / preferred location Mt William Creek main channel immediately upstream of the Western Highway at the Bridge						
161.71	163.785	164.227	184.555	164.713	164.785	164.820	165.294
634904.264E 5913125.352N	Alternative location Mt William Creek overflow channel immediately upstream of the Western Highway between the Big Koala and Dadswells Bridge Town Hall						
162.47	163.716	164.113	164.505	164.713	164.798	164.871	165.495

Important notes:

1. Maps showing the proposed PALS locations are provided in Appendix B.

If the site was instrumented and telemetered on a permanent basis, the data would enable local confirmation of creek rises and developing flood conditions, visually and via the BoM's website.

The installation of staff gauges at both PALS locations would facilitate a more informed use of the flood extent and depth maps delivered by this study during future flood events. The staff gauges would need to be set either to AHD (refer to discussion on page 56 of Comrie, 2011) or to a local datum with the correction to AHD determined as part of installation. Local residents would however need to be instructed on how to read the gauges so as to avoid possible confusion over water levels and conflicting reports after the installation of a PALS during an event.

Regardless of whether a PALS is installed, it is suggested that data from the existing stream gauge at Lake Lonsdale downstream will enable the 'approximate severity of flooding at Dadswells Bridge' tool (refer to the Rural City of Horsham MFEP) to be used with some lead time to provide a heads-up of the likelihood and scale of possible flooding at Dadswells Bridge.

10.3.5 Flood Detection & Prediction

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

It is necessary to know the levels at which floods begin to impact on the community in order to establish an effective flood warning system. In effect, to ensure that flood warnings are only provided when the consequences of flooding within an at-risk community are sufficient to warrant a warning and the coordinated mobilisation of resources to affect an appropriate response. Flood class levels, determined against standard definitions[7] are used to establish a degree of consistency in the categorisation of floods.

Following consideration of the flood intelligence and inundation maps generated by the current study, preliminary flood class levels are proposed for Mount William Creek at Dadswells Bridge with reference to the preferred PALS location immediately upstream of the Western Highway Bridge as follows:

- Minor flood level 164.20 mAHD
- Moderate flood level 164.45 mAHD
- Major flood level 164.60 mAHD

There are currently no flood warning arrangements in place for Dadswells Bridge: the BoM does not currently provide a flood forecasting and warning service for the town. Further, if approached to develop a service, it is not clear what priority BoM would attach to development activities even though such work would be undertaken on a cost recovery basis[8].

The tools provided in Appendices to the Horsham and Ararat MFEPs do however provide some indicative guidance on the likelihood and severity of flooding at Dadswells Bridge and within the upper catchment communities respectively. It is stressed that the tools do not provide a prediction of expected flood height. They provide indicative guidance only that can then be related to the flood inundation maps produced as part of the current study. It is suggested that the inundation maps, the indicative quick look flood / no flood tools and associated instructions for their use should be loaded to the Ararat, Northern Grampians and Horsham Council websites where they can be accessed by and used by members of the at-risk communities.

7 Standard definitions for minor, moderate and major flood class level are available from the BoM website.

8 Pers comm: Elma Kazazic and Karen Hudson 8th July 2014.

As part of a more comprehensive and formal forecasting capability, it is suggested that a rainfall–runoff model that makes use of rain and river data telemetered from each of the data collection sites could be developed for Dadswells Bridge. The BoM's Wimmera catchment model would provide a useful start. This type of model provides a prediction of flow and / or gauge height at key locations using measured and / or predicted rainfall. It generally requires a stream gauge at each forecast location so that initial conditions can be fed into the model and the forecast hydrograph (or levels) can be tracked against the actual stream response in terms of timing and levels. Forecast levels then need to be translated into areas affected. This can be done through a linked hydraulic model or through reference to comprehensive flood inundation maps together with flood intelligence available from the MFEP.

As suggested above, a rainfall–runoff model developed by BoM could be used to provide a timely and best available flood prediction for Dadswells Bridge. While the BoM is best positioned (as the agency responsible for the monitoring of situations likely to lead to flooding and for the prediction of floods throughout rural and provincial Victoria) to develop the model further and to run it in the lead up to and during flood events, it is currently considered almost certain that BoM would require the additional data to be available via telemetry before considering the matter further.

10.3.5.1 Use of Existing Gauges

The installation of a PALS at Dadswells Bridge will provide the best possible outcome for flood warning for the Dadswells Bridge community. However, it is acknowledged that with a relatively small number of impacted properties (in relation to other flood prone communities across Victoria), the installation of such a system is unlikely in the near future. Therefore is it important to provide the local communities with tools to assist using the currently available information, some of which have been discussed in the previous section.

The Lake Lonsdale Tail Gauge can be utilised to help **inform but not predict**, the magnitude of flooding at Dadswells Bridge. The Lake Lonsdale Tail Gauge **cannot** be used to predict flooding at Dadswells Bridge because flooding of Dadswells Bridge can still occur without Lake Lonsdale spilling. The catchment upstream of Dadswells Bridge (and downstream of Lake Lonsdale) is of sufficient size to result in flooding of the local area during times of heavy rainfall. Whilst flooding originating from water spilling from Lake Lonsdale (in combination with heavy local rainfall) will result in more significant flooding, the lead time for this flooding is longer. Table 10-2 provides a summary of the Lake Lonsdale Tail Gauge heights and how they relate to the modelled design flood events. Due to the ability of the catchment downstream of Lake Lonsdale to result in flooding of Dadswells Bridge, the indicative flood/no flood tools included in the Horsham MFEP should also be consulted during times of heavy rainfall and local observations made be made to confirm the expected flood magnitudes.

Table 10-3 and Table 10-4 provide similar expected flood magnitude tables for the Mokepilly and Fyans Creek gauges respectively. As previously stated these tables can help **inform but not predict** the magnitude of flooding within the catchment.

Table 10-2 Expected Flood Magnitude Vs. Lake Lonsdale Tail Gauge Heights

Flood Magnitude (ARI)	Lake Lonsdale Tail Gauge Height (mAHD)	Flow (ML/day)
1 in 5 year	181.49	980
1 in 10 year	182.22	3420
1 in 20 year	183.95	7990
1 in 50 year	184.36	16150
1 in 100 year	184.54	23570
1 in 200 year	184.68	32420
Probable Maximum Flood	186.35	*

Table 10-3 Expected Flood Magnitude Vs. Mokepilly Gauge Heights

Flood Magnitude (ARI)	Mokepilly Gauge Height (mAHD)	Flow (ML/day)
1 in 5 year	192.86	8204
1 in 10 year	193.17	13020
1 in 20 year	193.45	19300
1 in 50 year	193.76	28390
1 in 100 year	193.99	36850
1 in 200 year	194.18	45620
Probable Maximum Flood	195.78	*

Table 10-4 Expected Flood Magnitude Vs. Fyans Creek Gauge Heights

Flood Magnitude (ARI)	Fyans Creek Gauge Height (mAHD)	Flow (ML/day)**
1 in 5 year	200.54	770
1 in 10 year	200.55	790
1 in 20 year	200.57	810
1 in 50 year	200.61	840
1 in 100 year	200.66	860
1 in 200 year	200.74	880
Probable Maximum Flood	202.89	*

Table Notes

* PMF flows have not been listed. If gauge heights and/or flows greater than the 1 in 200 year ARI flood events are expected, consult the flood depth maps for the PMF flood event

** Tabulated flows for Fyans Creek are flows within the channel only and do not account for out of bank flows (refer to provided flood depth maps for extent of flows).

10.3.6 Interpretation

The flood inundation maps and MFEP Appendices developed as part of this study provide the base information to enable the community and stakeholder agencies to determine the likely effects of a potential flood within the Mount William Creek catchment and more particularly at Moyston, Pomonal and Dadswells Bridge. This means however that the flood inundation maps and relevant Appendices of the MFEPs would need to be readily available to the Mount William Creek communities.

10.3.7 Message Construction and Dissemination

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).

Where time permits, the community alerting task is often achieved via local radio announcements. Active alerting is usually only undertaken occasionally and generally involves door knocking although in NSW the SES has employed loud-hailers to make street announcements and in Queensland a number of local councils in areas subject to flash flooding have recently installed mass notification systems that utilise public address speakers (see Section 3.3.2). In areas subject to flash flooding in South Australia and again in Queensland, a system developed by BoM that alerts and notifies selected stakeholder agency staff using an SMS message generated by Enviromon when rainfall or river level exceeds pre-set criteria, has been implemented. It is understood that StreetData is used by some Councils in South Australia in preference to the normal SMS service. Within Victoria, many of the Councils involved in flood warning system upgrades in recent years and that utilise ERTS equipment have implemented Premier Global Services' Xpedite VoiceREACH system to alert and notify residents and property owners in flood-prone urban areas. Melbourne Water are piloting an in-house developed SMS alerting system for residents in an area subject to flash flooding alongside Brushy Creek in the City of Maroondah which is triggered by the exceedance of rain or water level alarm criteria[9].

Both Xpedite (http://www.pgi.com/au/en/company/press-room/press-releases.php/(folder)/2003-06/(release)/release_2003-06-04.php) and StreetData (www.streetdata.com.au) are available and operational within Victoria. Both use existing technology, are quick and effective, are relatively cheap to implement and maintain, but require good quality broadband internet access from the host computer. For either to be truly effective, the at-risk or target community needs to be flood aware.

[9] Melbourne Water and the City of Maroondah collaborated with VICSES on the roll-out of a StormSafe program for residents affected by flash flooding along this reach of Brushy Creek. This has included helping pilot area residents develop personal residential flood response plans and the supply of fully equipped household flood kits.

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 parts of the Mount William Creek catchment of severe flash flooding events due to the short lead times available.

It is suggested that, at this stage, 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 indicative quick look “flood / no flood” tools (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 Dadswells Bridge.

10.3.8 Response

The Horsham, Ararat and Northern Grampians MFEP Appendices have been populated for the Mount William Creek catchment as part of this study. Information now incorporated in the MFEPs includes:

- All available intelligence relating to flooding in the Mount William Creek catchment;
- Indicative flood tools based on rainfall depths from nearby AWS’ and the level at the Lake Lonsdale tail gauge;
- Flood inundation extent and depth maps developed as part of the current study;
- A list of properties likely to be flooded in the catchment along with the expected depth of flooding at each property;
- Flood intelligence cards for Dadswells Bridge, Moyston and Pomonal; and
- Other useful flood related intelligence.

The two most critical issues for the Mount William Creek 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 at Dadswells Bridge and near Stawell.

10.3.9 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 was larger than the 1909 flood

- 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.
- A levee designed to hold the 1 in 100 year ARI flood event will protect the community from all floods and therefore a flood warning system is not required.
- The 1 in 100 year ARI flood event, 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[10] should aim to erase these misconceptions

There are a number of activities that could be initiated to maintain and renew flood awareness within the Mount William Creek catchment and at Dadswells Bridge. The emphasis should be on an awareness of public safety issues (including the availability of data) 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;
- Active support of and engagement with a community flood action group (or similar);
- 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 properties likely to be affected by flooding within the catchment (the data to inform the charts can be extracted from the hydraulic model developed for the current study and from the flooded property tables in the Horsham, Ararat and Northern Grampians MFEPs);
- Installing flood depth indicators along the edge of roads where there is 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 Mount William Creek 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 flood action guide or brochure (e.g. a Local Flood Guide or Floodsafe brochure 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

10 Such as the VICSES FloodSafe program.

well as describing what people need to do during a flood event. These could be given out at local events and with council rate notices and / or other council communications.

10.4 Suggested System for Mount William Creek

Table 10-5 provides a brief description of the basic tools needed to deliver against each TFWS building block together with an outline of possible solutions that would be applicable to the Mount William Creek catchment.

Table 10-5 Flood Warning System Building Blocks and Possible Solution for the Mount William Creek catchment with due regard for the EMMV, Commonwealth-State arrangements for flood warning service provision (BoM, 1987; VFWCC, 2001; and EMA, 2009)

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Mount William Creek
DATA COLLECTION & COLLATION	Data collection network (e.g. rain and stream gauges)	INITIALLY: Establish an agreement between the Rural City of Horsham and WCMA / DEPI that PALS will be available when required for installation at Dadswells Bridge and that comprehensively addresses the issue of who pays for equipment installation, operation and recovery. It is important that this matter is addressed with some priority and certainly before the next flood. AFTER FUNDING SORTED: Install staff gauges at both the primary / preferred and the alternative PALS locations at Dadswells Bridge, ideally to AHD. Check gauge zeroes and location coordinates and if required, adjust install locations. Through the Surface Water Partnership Agreement, secure telemetry access for BoM to rainfall and river level information from the Mt William Creek at Mokepilly site. Approach BoM to resolve the classification of Dadswells Bridge – data, information or forecast location. If Dadswells Bridge is classified as a forecast location, install an ERTS river (possibly with rain) gauge at Dadswells Bridge.
	System to convey data from field to central location and / or forecast centre (e.g. radio or phone telemetry).	Determine whether to install an additional (ERTS) rain gauge in the upper catchment, probably in the vicinity of Moyston, to assist forecasting through Lake Lonsdale to Dadswells Bridge.
	Data management system to check, store, display data.	BoM to add Mokepilly and Dadswells Bridge (and other sites?) to data display tables and maps accessible via the BoM website. Will need to display current data and accommodate data from an expanded data collection network.
	Arrangements and facilities for system / equipment maintenance and calibration. For example, the Regional Surface Water Monitoring Partnership, data QA'ing and warehousing, etc.	Establish a commercial arrangement between the Rural City of Horsham and a service provider for maintenance of staff gauges, ERTS equipment and sites that are part of the Dadswells Bridge flood warning system. Ideally this would be through the Surface Water Monitoring Partnership as this will also ensure that all data is QA'ed and archived. Include capitalised system components on asset management register.

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Mount William Creek
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.	INITIALLY: Using data from the existing rain gauge network / AWSs determine an indication of the likelihood and scale of possible (flash) flooding at locations within the middle and upper catchment using the indicative quick look “flood / no flood” tool described below. Using Lake Lonsdale tail gauge levels and the ‘approximate severity of flooding at Dadswells Bridge’ tool described below, determine the likelihood and scale of possible flooding at Dadswells Bridge with some lead time (i.e. around 8 to 12 hours).
	Appropriately representative flood class levels at key locations plus information on critical levels / effects.	Confirm proposed flood class levels for Dadswells Bridge at the Western Highway Bridge (primary / preferred PALS location). Together with VICSES and WCMA, Rural City of Horsham formally request through DEPI that BoM adopt and publish the agreed flood class levels for Dadswells Bridge.
	Flood forecast techniques (e.g. hydrologic rainfall-runoff model, stream flow and / or height correlations, simple nomograms based on rainfall).	INITIALLY: Request BoM develop a rainfall-runoff forecasting model to provide quantitative flood forecasts for Dadswells Bridge. This will require a request through WCMA to DEPI to BoM from Council, VICSES and WCMA that Dadswells Bridge is classified as a: Key river level site / location; and Quantitative flood forecast location. INTERIM: The indicative tools developed for the upper and middle reaches of the catchment and for Dadswells Bridge and included in the respective MFEPs, provide guidance on the likelihood and scale of possible flooding based on data from the existing rain gauge network and water levels at the Lake Lonsdale tail gauge. Councils responsible for maintaining the tools. Decide how the tools are to be used and who by – Councils, VICSES, CMA, community? NEXT: BoM to provide a quantitative flood forecasting service for Dadswells Bridge.
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 Mount William Creek Flood Investigation have been captured to the MFEP. The quick look tools described above together with the MFEP enable those at risk to obtain an indication of whether they are likely to be flooded with some lead time. In order to enable community members to determine the likely effects of a

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Mount William Creek
		potential flood, Councils to make the flood inundation maps and relevant Appendices of the MFEPs readily available to the Mount William Creek catchment communities. This will also inform their development of individual flood response plans (see below). 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 flood warning system and its continuous improvement.
MESSAGE CONSTRUCTION	Warning messages / products and message dissemination system.	INITIALLY: Prior to approaching BoM (or at around the same time) to request a quantitative flood forecasting service for Dadswells Bridge, Councils and VICSES to determine what information can and should be disseminated and with what authority. As part of this, determine the role of the indicative quick look tools for the upper and middle catchment and for Dadswells Bridge. While simple automated messaging is likely to work well, the proposed flood warning system is heavily community driven with minimal agency input, albeit that loss of access through the region is a significant issue, and thus 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. During riverine flood events, reliance will be on Control Agency (VICSES) communications arrangements and systems (e.g. use of OSOM through the ICC). 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[11] – TV, radio and print. 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.	INITIALLY: Utilise the informal communications networks within the catchment to assist information dissemination. LATER: If Council(s) established an ERTS base station and installed BoM supplied Enviromon software, alerts on exceedance of rain and water level criteria at ERTS and logger sites could be disseminated to key personnel. Environmental indicators (i.e. heavy rain), public issue warnings from BoM and awareness following application of the indicative quick look tools (i.e. likely

[11] 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 Mount William Creek
	Flood wardens Door knocking Informal local message / information dissemination systems or 'trees'. Opportunity for at-risk communities to confirm warning details.	severity and impact of expected flooding) will alert individuals to likely flooding. This alert will be shared informally within the community. Likely consequences and required actions will be as derived by the individual as a result of consideration of information provided by the quick look tool, MFEP and flood inundation maps. 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. Alternative alerting mechanisms could include use of a siren or similar.
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 MFEPs) remain to be completed. The MFEPs remains to be reviewed and signed-off by Council MEMPCs following update with flood intelligence arising from the Mount William Creek Flood Investigation. Consider establishing arrangements for the supply of sandbags and sand within Dadswells Bridge with sufficient lead time to enable non-weatherboard buildings and / or buildings at risk of minimal over-floor flooding (see list in MFEP) to be sandbagged / protected. Arrangements established in conjunction with Council(s) and VICSES should be detailed in the MFEP(s). Initiate a community engagement program to communicate how the FWS will work. Response is to a large extent 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, WCMA, etc.	Review and update of alarm criteria and "quick look" tools, local flood intelligence (i.e. flood characteristics, impacts, etc), local alerting arrangements, response plans, local flood awareness material, etc (initially) after every flood that exceeds the 5-year ARI flood level at Dadswells Bridge or causes substantial damage to private property in the upper and / or middle reaches of the catchment. Best led by Councils with input from VICSES, WCMA and the community.

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Mount William Creek
	Review and update of personal, business and other flood action plans.	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 flood warning and response system, including the MFEPs. Ensure that as part of the above, information contained in Rapid Impact Assessments is captured to the MFEPs.
AWARENESS	Identification of vulnerable communities and properties (i.e. flood inundation maps, information on flood levels / depths and extents, etc). 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 Mount William Creek Flood Investigation.	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. VICSES with input from Councils and others to prepare a Local Flood Guide for the upper and middle reaches of Mount William Creek and for Dadswells Bridge that are consistent with: Flood intelligence included in the Council MFEPs The flood warning system for Mount William Creek / Dadswells Bridge Updates to the data collection network and data availability. Consider producing and distributing property specific flood depth charts using information collated for the MFEPs and available within the report on the Mount William Creek Flood Investigation. Councils to make the MFEPs (including the quick look tools, 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 respective 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, improvements to any of the TFWS elements applicable to Mount William Creek and / or Dadswells Bridge, and to reflect advances in good practice. Routinely repeat distribution of awareness material and consider other measures. Decide whether to alert residents and visitors to the risk of flooding in more direct

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Mount William Creek
		ways. This could include the installation of flood depth indicator boards at key locations within the catchment and around Dadswells Bridge and on surrounding roads, particularly main traffic routes.

10.5 Suggested Actions

A staged approach to the development of a flood warning system for Mount William Creek and Dadswells Bridge is proposed. The stages have been ordered and the tasks within each stage grouped to facilitate growth of all elements of the TFWS in a balanced manner and with full regard for matters discussed in Section 10.3. While it may be tempting to immediately move to install additional rain and river gauges and to develop a forecast capability, there are other more fundamental matters that experience tells us need to be addressed first. Thus early attention is directed at ensuring roles and responsibilities are agreed, understood and accepted and that there is a firm foundation for the development of an effective flood warning system: one that does not fail when it is needed most and one to which all stakeholder entities have an explicit commitment.

The suggested overall system for Mount William Creek and Dadswells Bridge provides for the complete development of a flood warning system. It is acknowledged that at present, sufficient funding is unlikely to be available to deliver the full system in the near future. However, the suggested actions present a way forward to deliver components of the system as funding becomes available. Such an approach ensures that the development of the flood warning system proceeds in a logical manner that can then be built upon in the future as funding becomes available. Indicative costs for the total flood warning system are provided in Appendix E.

10.5.1 Stage 1

(1) WCMA and the three Councils, with support from VICSES, to formally advise DEPI of the need for a flood warning service for Dadswells Bridge and elements of a flash flood warning system for other parts of the Mount William Creek catchment, and request that:

- Data tables and maps, accessible through the BoM web site, be updated for Mount William Creek as new data becomes available;
- Flood class levels determined for Dadswells Bridge are adopted and published by BoM;
- Dadswells Bridge is classified as a key river level site / location and a quantitative flood forecast location;
- BoM be asked to develop a rainfall-runoff forecast model to provide quantitative flood forecasts for Dadswells Bridge; and
- BoM commence delivery of and support for a quantitative flood forecasts service for Dadswells Bridge.

(2) Councils, WCMA, VICSES, DEPI, BoM and other entities to determine the responsible entity in relation to "ownership" of each element of the flood warning system for Mount William Creek / Dadswells Bridge, where ownership is considered to denote overall responsibility for funding as well as the functioning of the system element and, in the event of failure, either fault-fix or the organisation of appropriate fault-fix actions and payments. VFWCC (2001) provides guidance on the matter although recommendation 1 from the Comrie (2001) suggests that some clarifications may be required.

10.5.2 Stage 2

(3) The Rural City of Horsham to establish an agreement with WCMA / DEPI that provides access to (up to) 2 x PALS when required and that comprehensively addresses the issue of who pays for equipment installation, operation, recovery and related matters.

(4) Councils to share the MFEPs with the Mount William Creek communities.

(5) The Rural City of Horsham, in conjunction with VICSES, to establish and document in the MFEP arrangements for the timely supply of sandbags and sand within Dadswells Bridge with sufficient lead time to enable buildings at risk of minimum over-floor flooding to be sandbagged / protected.

(6) Councils and VICSES to encourage and assist residents and businesses to develop individual flood response plans.

(7) Councils to load and maintain flood related material (including the MFEP) on their websites.

(8) The Rural City of Horsham in conjunction with VICSES to determine whether alerts on exceedance of rain or creek level alarm criteria are required to be sent to key Municipal and / or VICSES personnel and / or key community members by an Enviromon base station at the (say) the Council offices. Costs will also need to be determined.

(9) The three Councils with the support of VICSES, WCMA and the Mount William Creek 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 Mount William Creek catchment to Dadswells Bridge.

10.5.3 Stage 3

(10) Install staff gauges to AHD at the primary and alternative PALS locations at Dadswells Bridge and determine / check gauge zeroes.

(11) The Rural City of Horsham and VICSES to confirm proposed flood class levels for Dadswells Bridge at the primary PALS location upstream of the Western Highway Bridge.

(12) The Rural City of Horsham in conjunction with VICSES to update the MFEP with staff gauge datums, PALS site location coordinates and other relevant details, if and as required.

(13) The Rural City of Horsham to secure telemetry access for BoM to rainfall and river level information from the Mount William Creek at Mokepilly site through negotiations with the Surface Water Monitoring Partnership..

(14) VICSES to initiate a community engagement program across the Mount William Creek catchment in order to communicate how the flood warning system will work. This will need to be repeated as the system matures.

10.5.4 Stage 4

(15) If Dadswells Bridge is classified as a forecast location, the Rural City of Horsham to request BoM undertake radio path testing and to arrange the installation of an ERTS river (possibly with rain) gauge at Dadswells Bridge.

(16) The Rural City of Horsham, in conjunction with BoM, to determine whether to install an additional (ERTS) rain gauge in the upper catchment, probably in the vicinity of Moyston, to assist forecasting through Lake Lonsdale to Dadswells Bridge. This will also involve radio path testing.

(17) The Rural City of Horsham to establish on-going maintenance arrangements for all new equipment and staff gauges, ideally through the Surface Water Monitoring Partnership.

(18) BoM to add all sites to appropriate data tables and maps accessible via the BoM website.

10.5.5 Stage 5

(19) Develop review and update protocols => who does what when and processes to be followed to update material consistently across all parts of the flood warning and response system, including the MFEPs.

(20) BoM to develop and operationalise a rainfall-runoff based flood forecast model for Mount William Creek to Dadswells Bridge.

10.5.6 Stage 6

(21) VICSES to develop and distribute Local Flood Guides for Dadswells Bridge and Mount William Creek that are consistent with:

- Flood intelligence included in the Council MFEPs
- The flood warning system developed for the catchment and for Dadswells Bridge
- Updates to the data collection network and data availability.

10.5.7 Stage 7

(22) Council to oversee the development, printing and distribution of property-specific flood depth charts for properties within the Mount William Creek catchment.

10.5.8 Stage 8

(23) Install flood depth indicator boards at key locations in and around the catchment at strategic locations as indicated by the flood hazard maps delivered by the Mount William Creek Flood Investigation.

11 Floodplain Management

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

11.1 Flood Hazard

In determining the flood hazard within the Mount William Creek catchment, 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 flood hazard. These areas are best suited to the FO planning control.

In the township of Dadswells Bridge 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 in 100 year ARI flood event.

Floodwaters pose little hazard to the townships of Moyston or Pomonal. 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.

11.2 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 Mount William Creek 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 Mount William Creek 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.

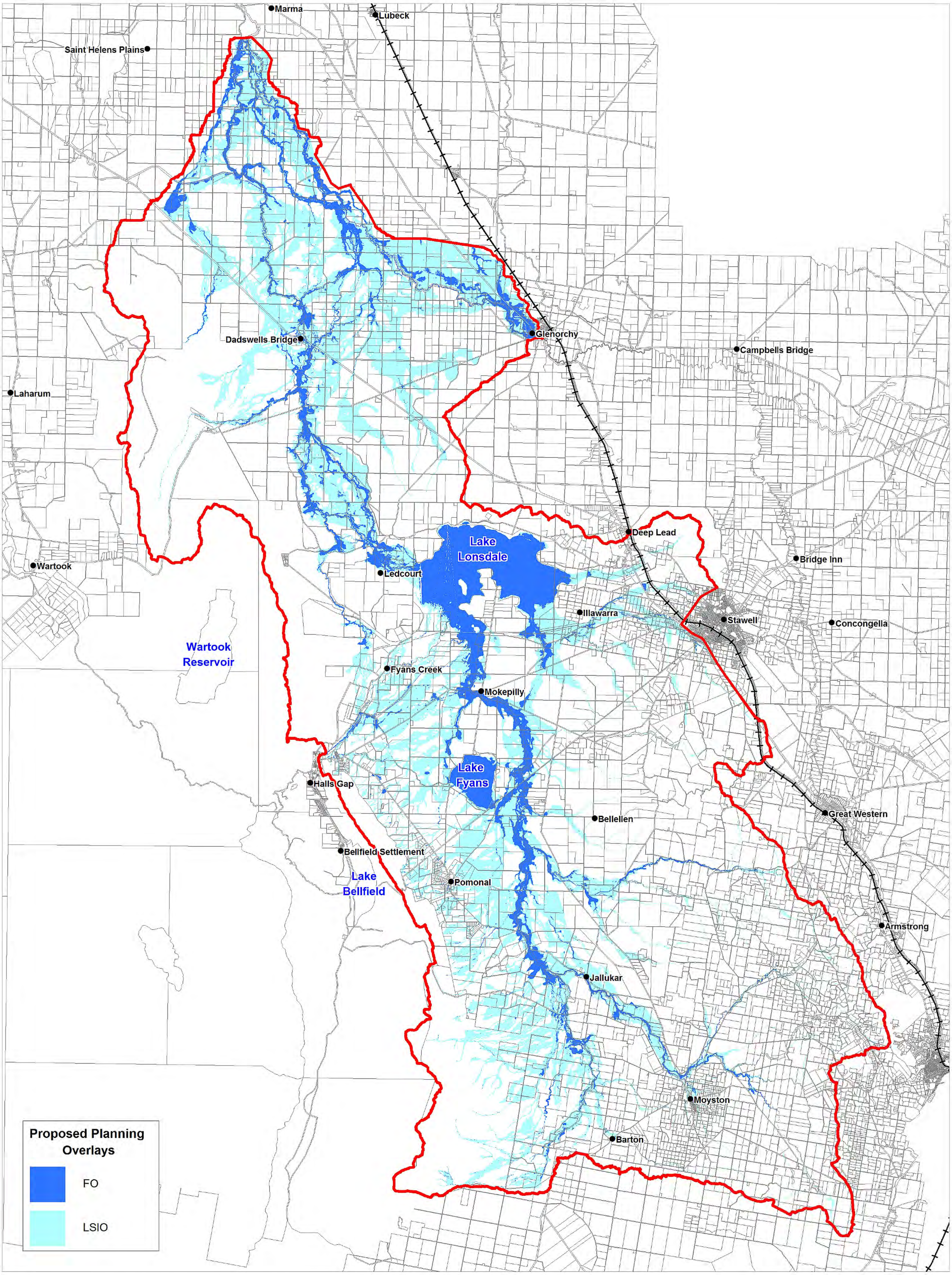
The proposed planning scheme for the Mount William Creek catchment is to assign areas identified as High Hazard to the more restrictive Floodway Overlay. Areas identified as Low or Moderate Hazard should be subjected to the less restrictive Land Subject to Inundation Overlay. The proposed planning scheme overlays are presented in Figure 11-1, Figure 11-2, Figure 11-3 and Figure 11-4 for the entire catchment, Ararat LGA, Horsham LGA and Northern Grampians LGA respectively.

11.3 Declared Flood Levels

The 1 in 100 year ARI flood levels determined by the flood modelling undertaken as part of the flood investigation were supplied to the WCMA, Ararat Rural City Council, Horsham Rural City Council and Northern Grampians Shire 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.

11.4 Flood Response Plan

An update to the relevant Municipal Emergency Management Plans (MEMP) has been completed as part of the Mount William Creek Flood Investigation and has been delivered to VicSES for each of the three Councils within the catchment (Ararat Rural City Council, Horsham Rural City Council and Northern Grampians Shire Council) as a separate document.



Title:

Mount William Creek Flood Investigation
Draft Planning Overlays - Whole Catchment

Figure: **11-1**

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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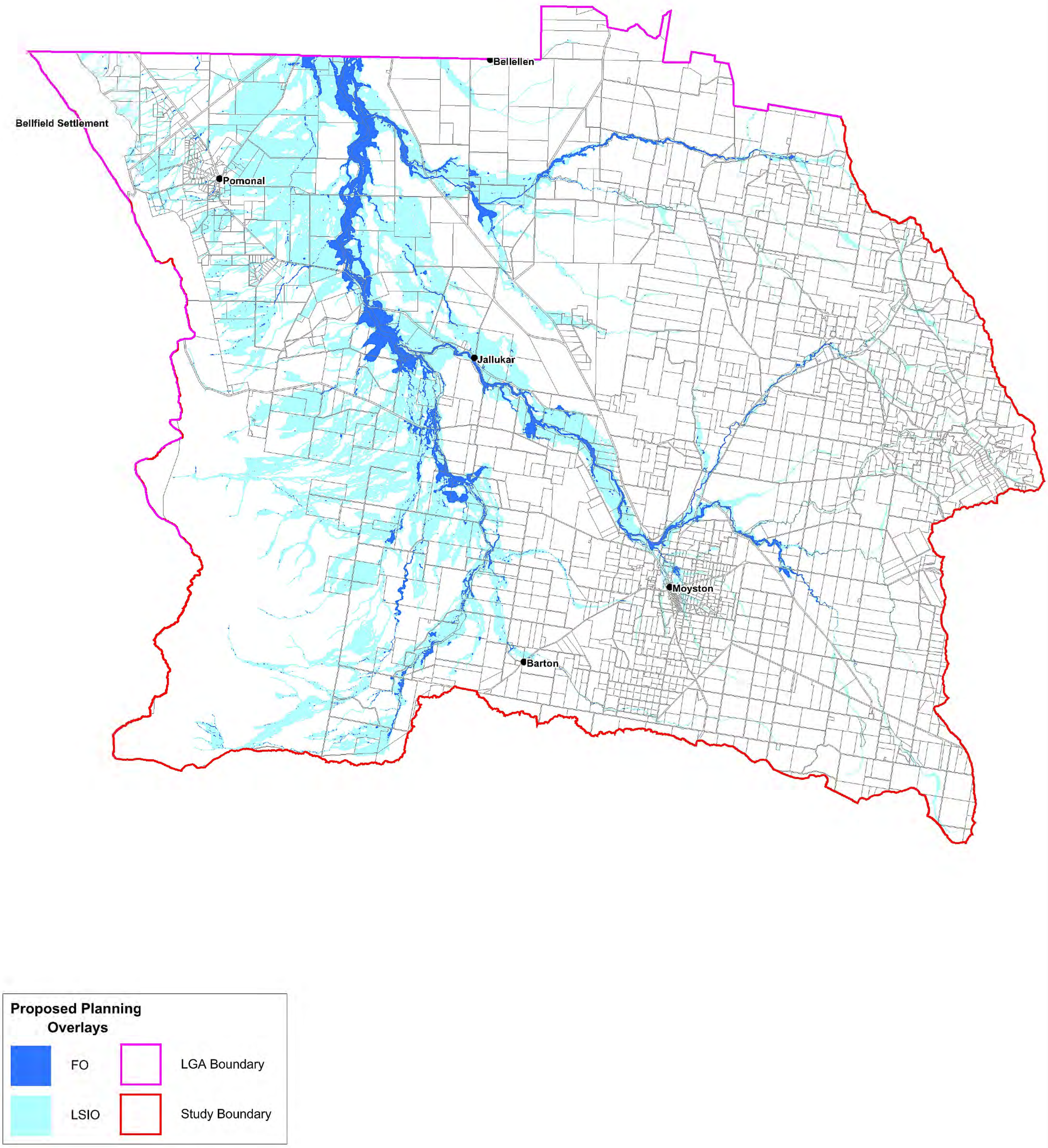

Title:

Mount William Creek Flood Investigation
Proposed Planning Controls - Rural City of Ararat

Figure: **11-2**

Rev: **A**

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Approx. Scale

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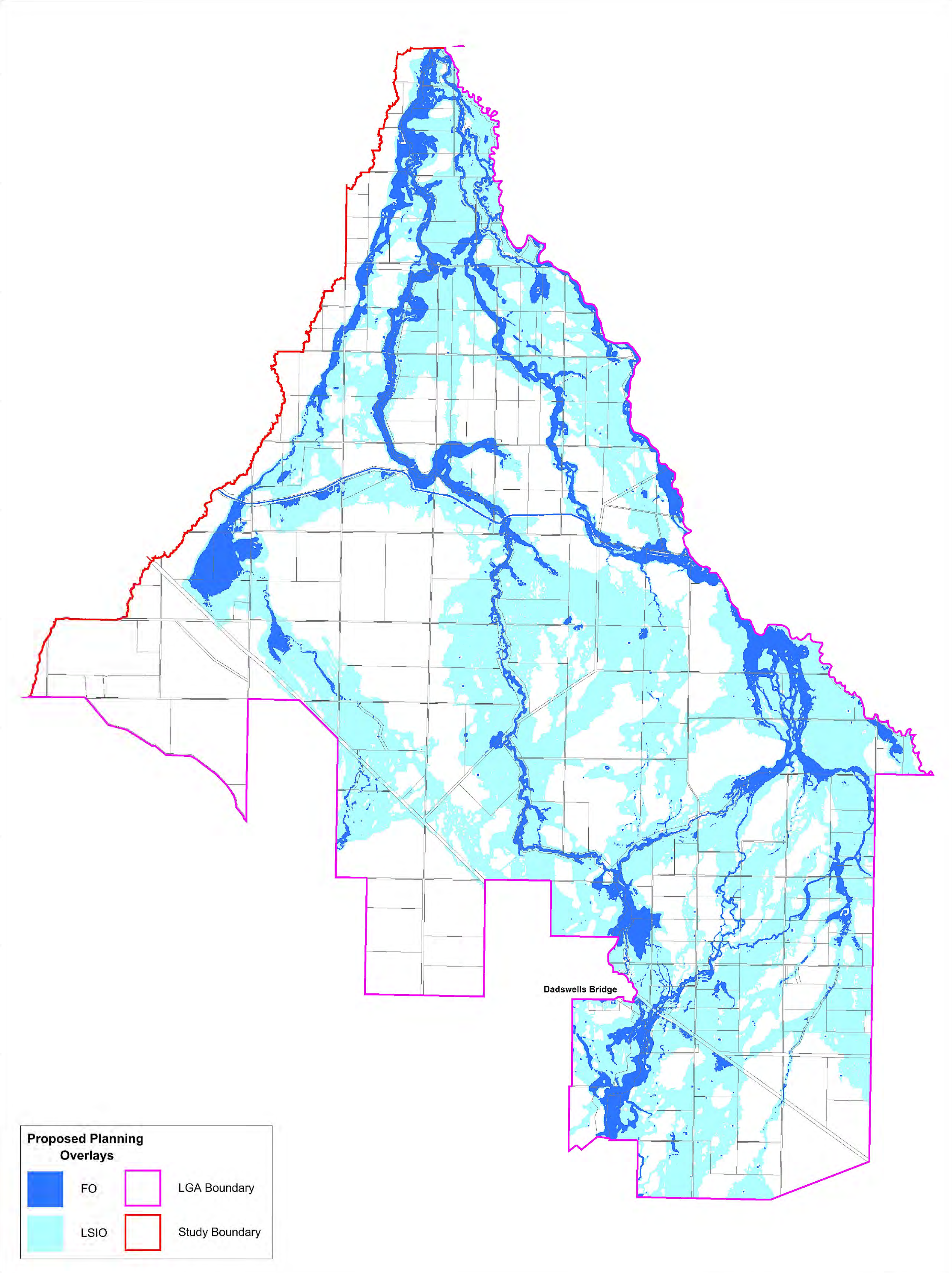

Title:

Mount William Creek Flood Investigation
Proposed Planning Controls - Horsham Rural City Council

Figure: **11-3**

Rev: **A**

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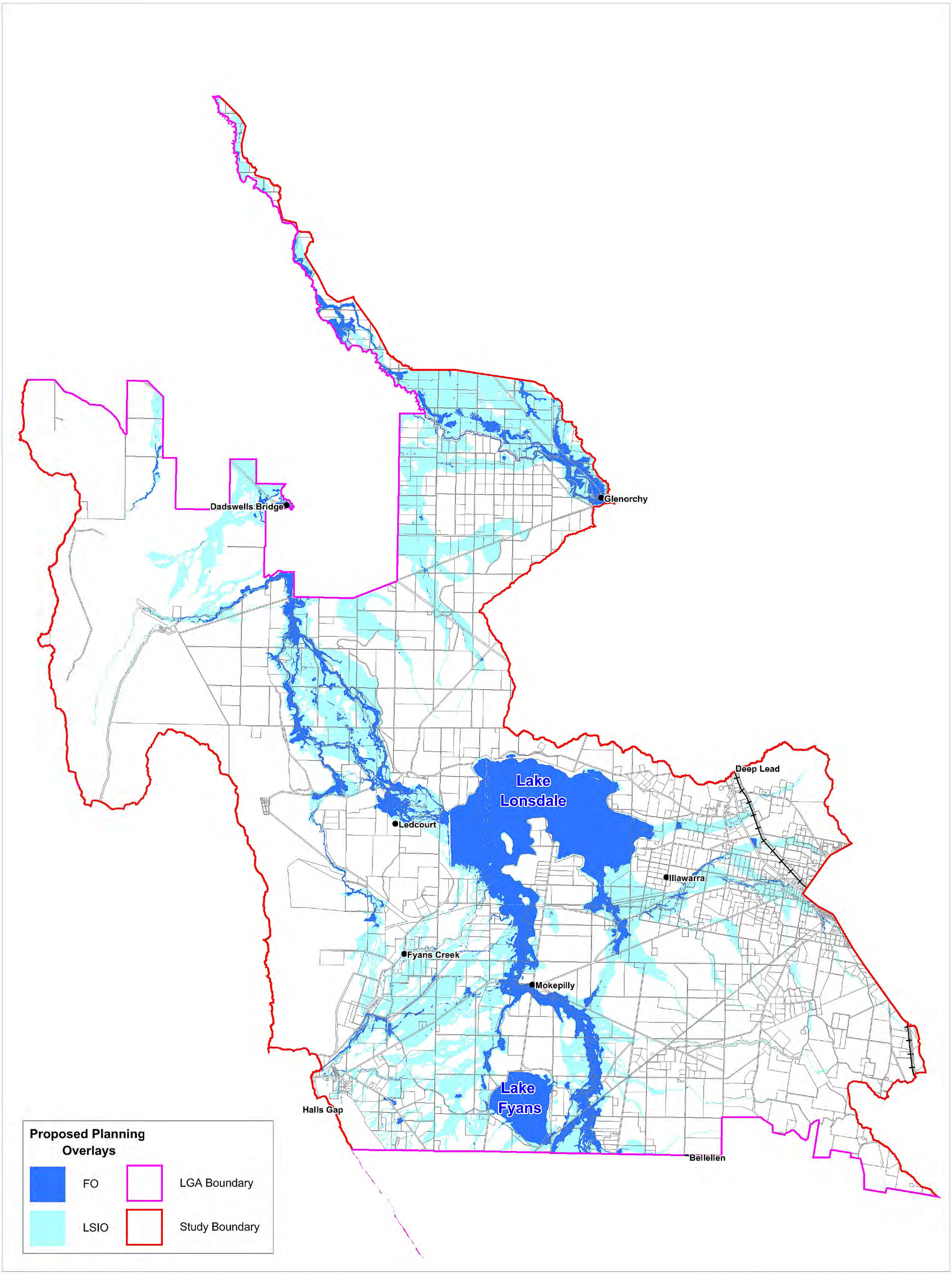

Title:

Mount William Creek Flood Investigation
Proposed Planning Controls - Northern Grampians Shire Council

Figure: **11-4**

Rev: **A**

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12 Summary and Recommendations

This report has documented the methodology and findings of the Mount William Creek Flood Investigation. The investigation has defined the flood behaviour for the communities within the Mount William Creek 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 Mount William Creek catchment. These recommendations include:

- Implementation of Planning Scheme Controls (Section 11.2
- Designated Flood Levels (Section 11.3)

Further, it is recommended that the WCMA, in conjunction with local Councils (ARCC, HRCC, NGSC), develop a flood mitigation strategy to build on the recommendations contained within this report. Specifically, this report should look to ways to implement the suggested improvements for the flood warning system within the catchment (Section 10), a task which is beyond the scope of the current study.

13 References

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