BMT WBM

Mount William Creek Flood Investigation

Final Report

Reference: R.M20045.007.01.FinalReport.docx
Date: December 2014

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)

Offices

Brisbane
Denver
London
Mackay
Melbourne
Newcastle
Perth
Sydney
Vancouver

Document Control Sheet

BMT WBM Pty Ltd
Level 5, 99 King Street
Melbourne Vic 3000
Australia
PO Box 604
Collins Street West Vic 8007

Tel: +61 3 8620 6100
Fax: +61 3 8620 6105

ABN 54 010 830 421

www.bmtwbm.com.au

Document:	R.M20045.007.01.FinalReport.docx
Title:	Mount William Creek Flood Investigation Final Report
Project Manager:	Joel Leister
Author:	Joel Leister
Client:	Wimmera Catchment Management Authority
Client Contact:	Jack Purcell and Clare Wilson
Client Reference:	WCMA 2012 - 2013 - 017

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

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	17/10/2014	DR		JL	
1	11/12/2014	MT		JL	

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
WCMA (pdf)	1	1									
WCMA (hardcopy)	0	4									
BMT WBM File	1	1									
BMT WBM Library	1	1									

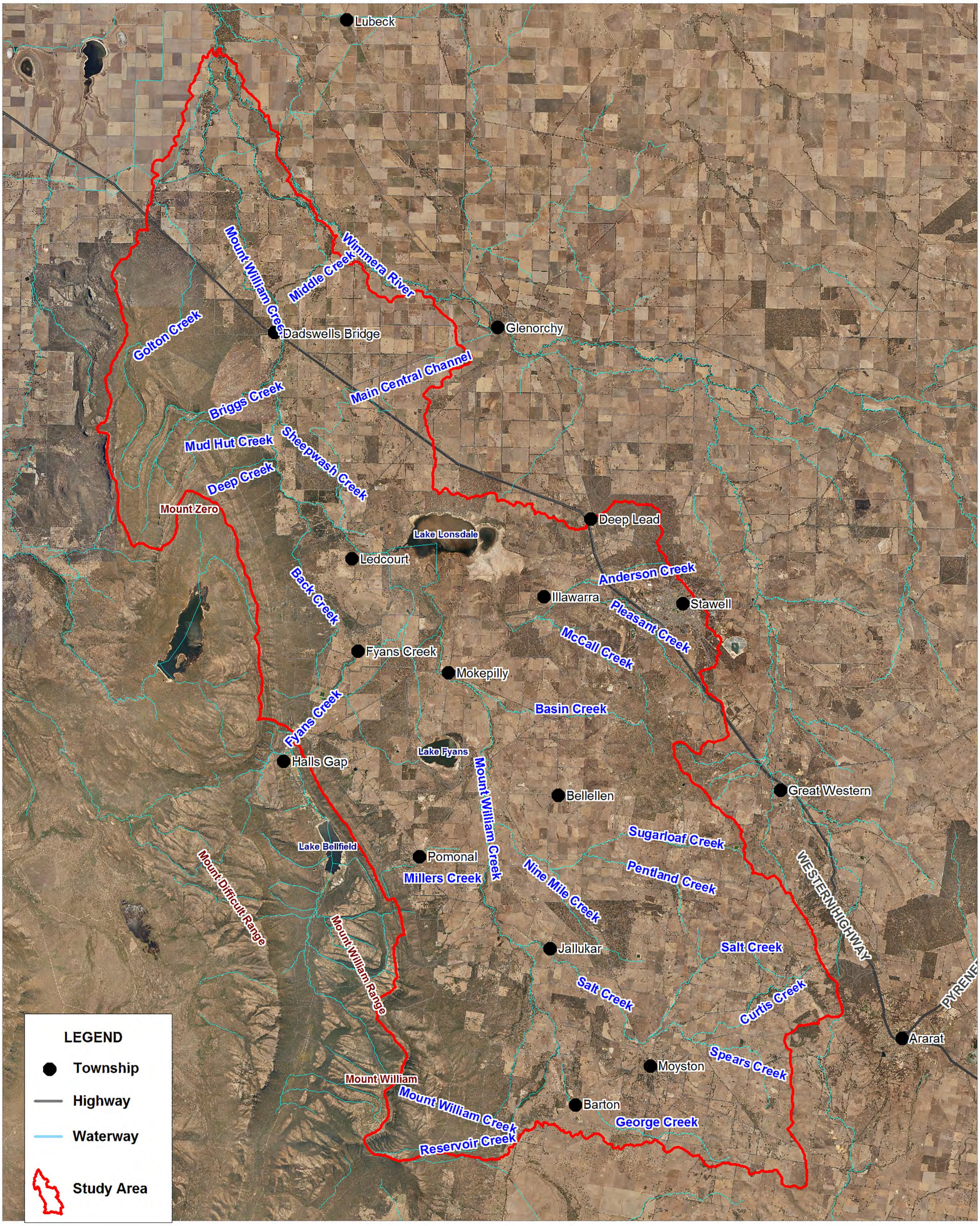
Executive Summary

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.



Title:

Mt. William Creek Flood Study
Study Catchment

Figure: 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.

N

0 5 10km

Approx. Scale

Filepath : T:\M20045.JL.MtWilliamCkFS\MapInfo\Drawings\R.M20045.007.01.FinalReport\MtW_FigES1_Catchment_RevB.WOR

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.

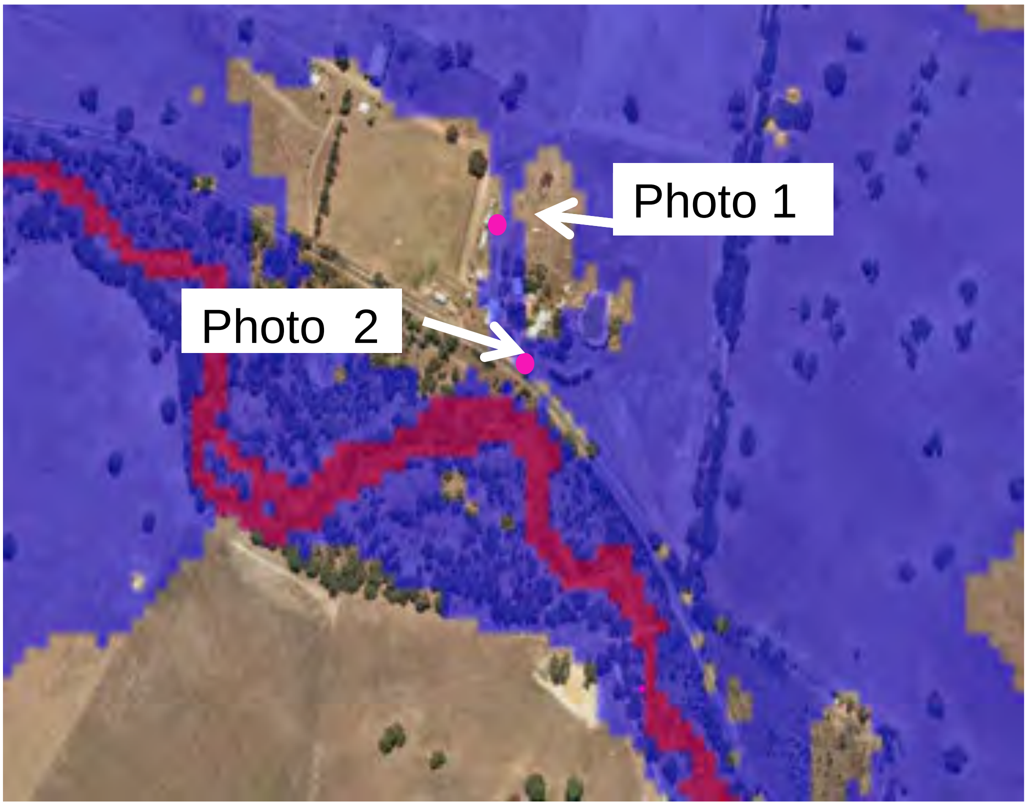


Figure 2 Comparison between initial and final January 2011 calibrations – Jallukar

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.

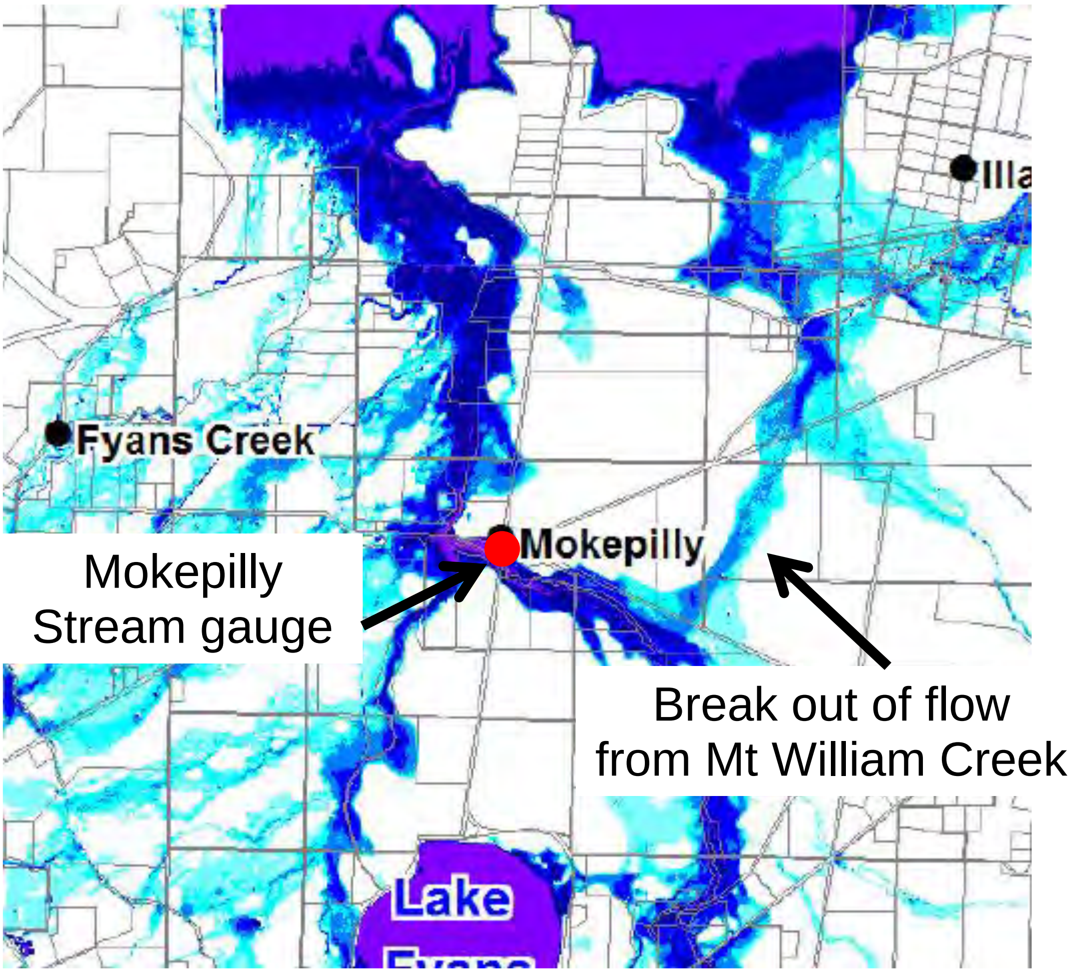


Figure 4 Map of the Mount William Creek 100 year flood extent showing floodwater breaking out of Mt William Creek upstream of the gauge, bypassing the Mokepilly stream gauge.

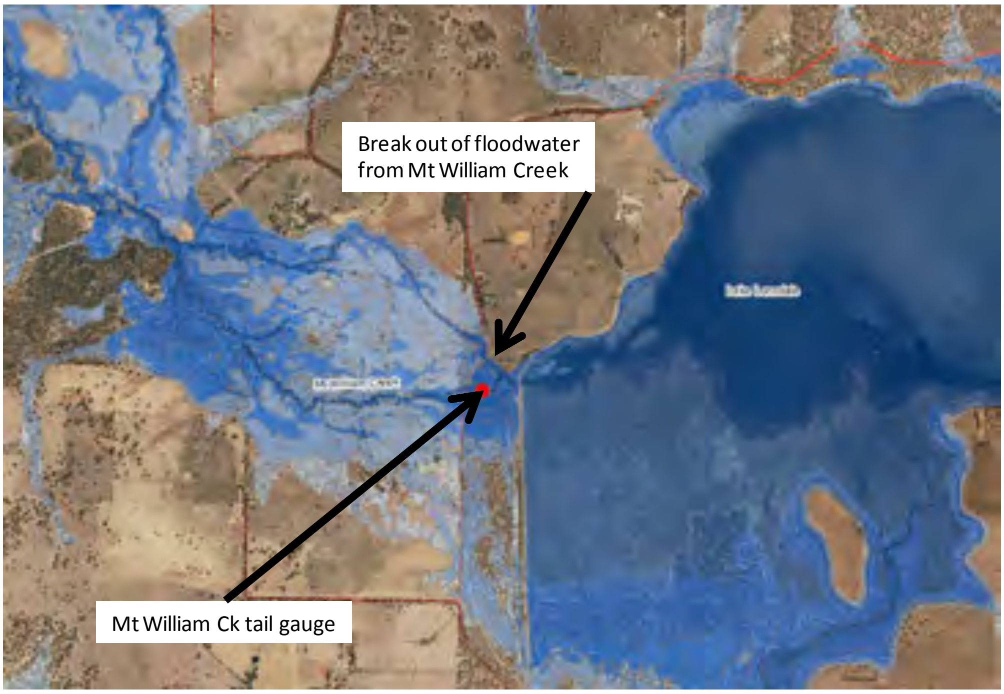


Figure 5 Map of the Mount William Creek 100 year flood extent showing floodwater breaking out of Mt William Creek upstream of the gauge, bypassing the Mount William Creek tail gauge.

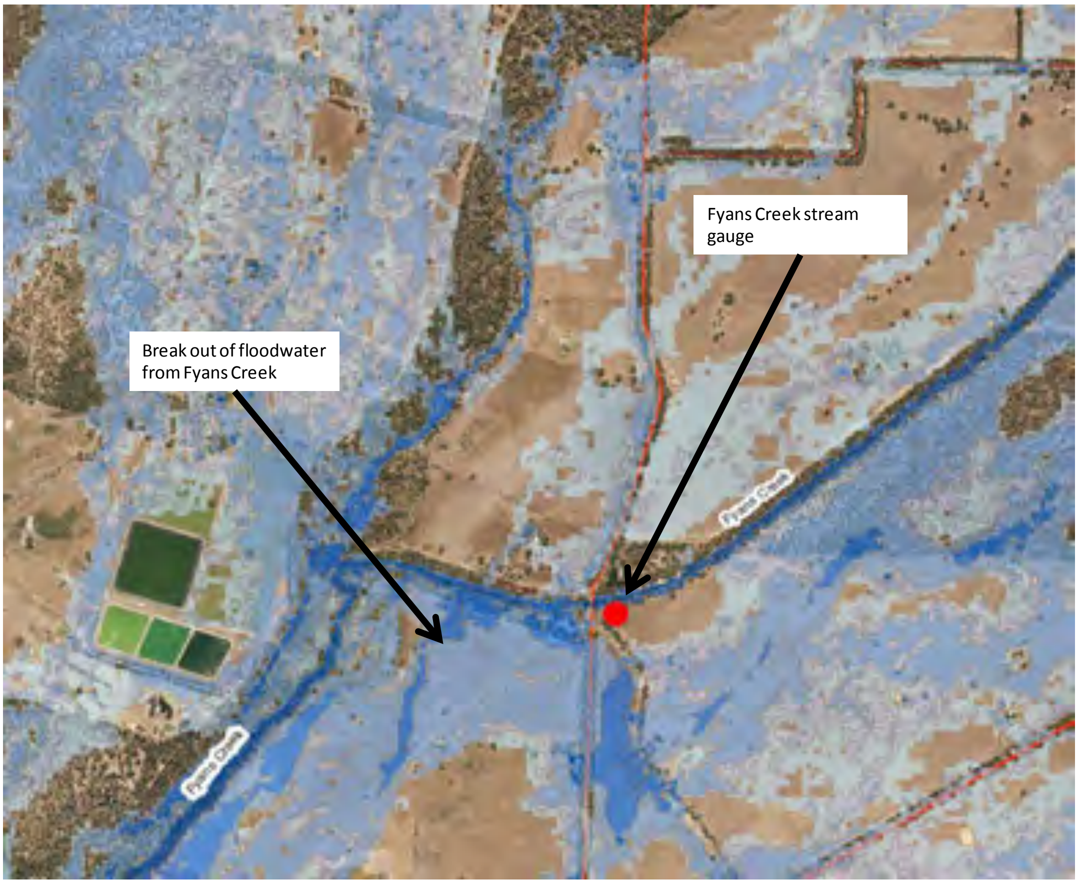


Figure 6 Map of the 100 year flood extent showing floodwater breaking out of Fyans Creek upstream of the gauge, bypassing the Fyans Creek stream gauge.

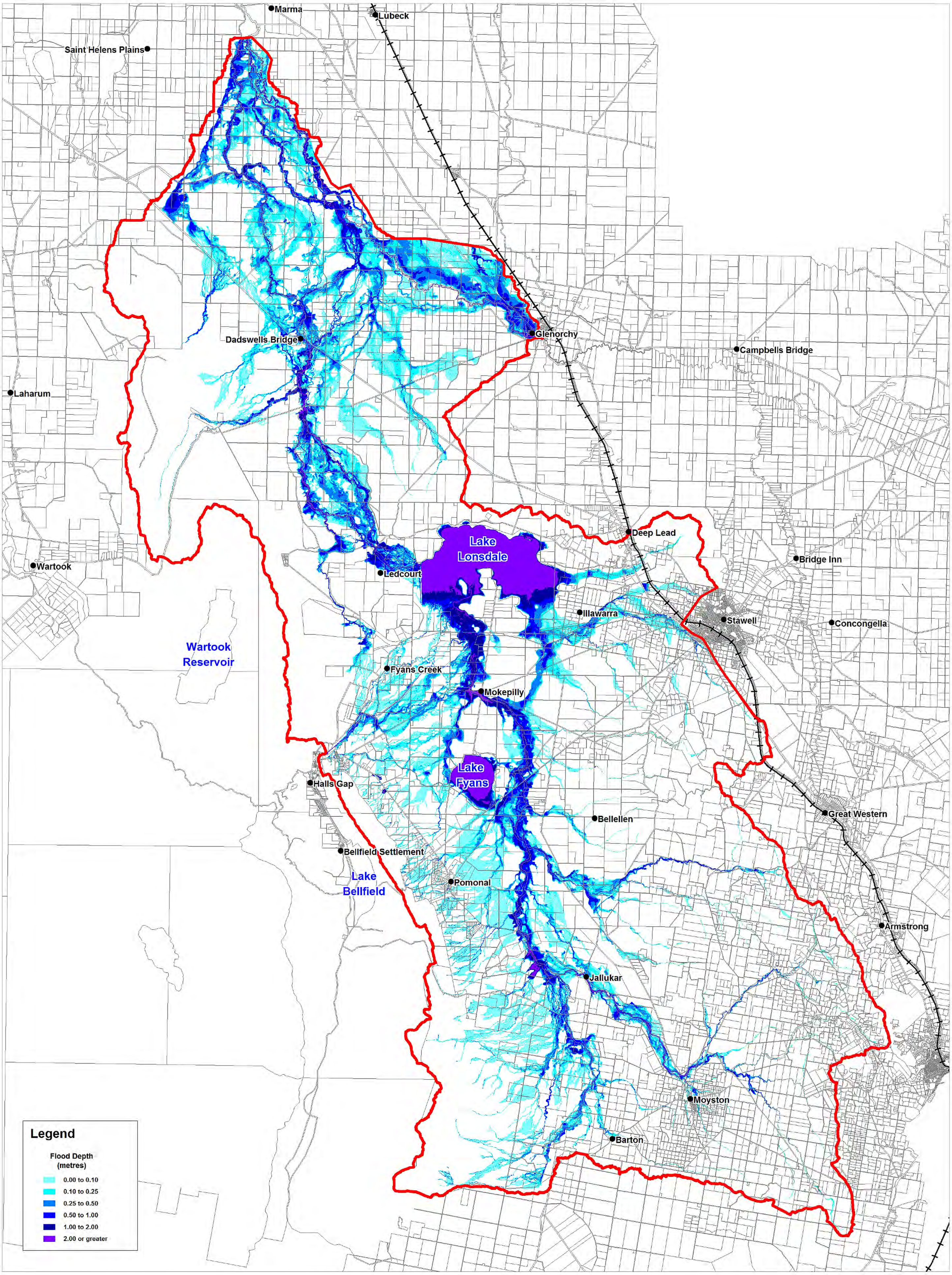
A number of changes were made to improve the calibration so that better agreement could be achieved with flood marks captured and flood photos collected during the January 2011 event, refer to table 2 for a comparison between the recorded and design peak flows. The amendment of the hydraulic model calibration 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

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

Filepath : T:\M20045.JL.MtWilliamCkFS\MapInfo\Drawings\R.M20045.007.01.FinalReport\MtW_FigES7_E01_100yr_047_dMax_catch_RevA.WOR

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

Contents

List of Figures

List of Tables