WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Burrumbeet Flood Investigation

Summary Study Report

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Glenelg Hopkins CMA

CITY OF BALLARAT

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PROJECT DETAILS

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Cover Photo: Creek Street Miners Rest, taken the 14/1/2011 (Source: GHCMA)

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EXECUTIVE SUMMARY

This report details the input data, approach and outcomes for the Burrumbeet Flood Investigation.

The study has been initiated by the Glenelg Hopkins Catchment Management Authority (GHCMA) in order to define the extent and characteristics of flooding in the Burrumbeet Creek catchment so that future planning decisions may be soundly based and measures may be put in place to minimise risk to the community.

The study provides information on flood levels and flood risk within the Burrumbeet Creek catchment. The study involved a rigorous technical analysis of the drivers for flooding, which provided confidence in the use of this information to guide floodplain management in and around Miners Rest, Invermay and other communities in the study area.

Community consultation was undertaken during the early stages of the study, primarily in order to gather data and accounts of flooding. The flood information provided by residents was invaluable in the development of the study outcomes.

A hydrologic analysis of Burrumbeet Creek was undertaken to determine design flood hydrographs for the 20%, 10%, 5%, 2%, 1% and 0.5% annual exceedance probability (AEP) flood events in Burrumbeet Creek as well as the probable maximum flood (PMF) and climate change scenarios. A rigorous approach was applied to test and validate the design flows by utilising a number of hydrologic approaches including Flood Frequency Analysis, regional comparisons, and development of a detailed hydrologic (RORB) and hydraulic (TUFLOW) model. The adopted design flood flows at key points in the study area, listed in Table 1, are considered appropriate for the definition of flood risk in the study area.

Table 1 Design peak flows at key locations in Burrumbeet Creek catchment

Location	Burrumbeet Creek Catchment Design Peak Flow (m^3/s)					
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
Invermay	5.4	9.4	17	27	33	39
Miners Rest	26	38	56	93	118	145
Burrumbeet Creek Gauge	44	63	89	122	155	181

To place the design peak flows in a historical context, the approximate AEP (and Average Recurrence Interval, ARI) of significant historical flood events are provided in Table 2. The January 2011 event is the largest gauged event recorded at Burrumbeet Creek gauge over 36 years of record. Prior to the January 2011 and September 2010 flood there were no events of similar or greater magnitude on record.

Table 2 Burrumbeet Creek, Approximate AEP/ARIs for significant historical flood events

Historical event (year)	Peak Flow (m^3/s)	Approximate AEP/ARI (based at Burrumbeet Creek Gauge)
January 2011	130	1.6% / 1 in 60 years
September 2010	69	6.6% / 1 in 15 years

A digital terrain model (DTM) was developed from field and LiDAR survey. Using the DTM, a hydraulic model was established to simulate flood behaviour within the study area. The hydraulic model was calibrated to two historic flood events (January 2011 and September 2010). There was a good level of calibration data available for these recent events which enabled a high level of model calibration to be achieved. The outputs of the hydraulic modelling are considered appropriate for the definition of flood risk in the study area.

A flood risk assessment was undertaken which involved the estimation of tangible flood damages for a range of design events. The average annual damage (AAD) was then calculated to be approximately $270,661 per year with current floodplain conditions and flows. These results showed that up to and including the 5% AEP flood event relatively minor flood damages are predicted with only 3 properties flooded above floor from a total of 112 flood affected properties. From the 2% AEP flood, damages increase more rapidly. Table 3 below summarises the flood damage calculations.

Table 3 Flood Damage Assessment Costs for Existing Conditions

Parameter	Annual Exceedance Probability					
	0.5%	**1%**	**2%**	**5%**	**10%**	**20%**
Buildings Flooded Above Floor	42	36	18	3	2	1
Properties Flooded Below Floor	145	142	142	109	98	82
Total Properties Flooded	**187**	**178**	**160**	**112**	**100**	**83**
Direct Potential External Damage Cost	$640,092	$577,386	$531,120	$362,444	$295,502	$234,627
Direct Potential Residential Damage Cost	$2,362,337	$1,973,852	$807,184	$72,118	$60,487	$34,408
Direct Potential Commercial Damage Cost	$22,461	$16,044	$8,221	$4,442	$0	$0
Total Direct Potential Damage Cost*	**$3,024,891**	**$2,567,282**	**$1,346,525**	**$439,004**	**$355,989**	**$269,035**
Total Actual Damage Cost *(0.8*Potential)*	**$2,419,913**	**$2,053,826**	**$1,077,220**	**$351,203**	**$284,791**	**$215,228**
Infrastructure Damage Cost	**$890,151**	**$773,693**	**$662,319**	**$499,168**	**$404,209**	**$334,512**
Indirect Clean Up Cost	$241,943	$207,058	$102,404	$15,193	$11,628	$5,814
Indirect Residential Relocation Cost	$32,042	$27,353	$13,286	$1,563	$1,563	$782
Indirect Emergency Response Cost	$33,275	$24,956	$19,965	$14,974	$9,983	$4,991
Total Indirect Damage Cost	**$307,260**	**$259,367**	**$135,655**	**$31,729**	**$23,174**	**$11,587**
Total Damage Cost	**$3,617,324**	**$3,086,886**	**$1,875,193**	**$882,100**	**$712,173**	**$561,327**

Average Annual Damage	**$270,661**

A feasibility assessment was undertaken on 8 flood mitigation options. Based on the outcomes of the feasibility assessment four options were investigated in more detail including preliminary cost estimates. The options assessed were:

- Levee at Miners Rest along Albert Street
- High flow bypass channel south of Miners Rest
- Retarding basin upstream of Miners Rest
- Flood channel north of Miners Rest

Of the options tested, the levee at Miners Rest was the most cost effective, providing a substantial benefit at and above the 5% AEP flood for relatively low cost. This could be combined with the flood channel to the north of Miners Rest to provide a significant reduction in flood impacts for the township. The high flow bypass channel would have a moderate benefit to flood damage at Miners

Rest for a higher cost. The retarding basin option was the least cost-effective option, providing only a moderate reduction in flood damage at a very high cost.

Draft flood related planning overlay maps including the Land Subject to Inundation Overlay (LSIO) and Floodway Overlay (FO), were prepared to reflect the study outcomes. The LSIO is used to define land subject to overland flooding from waterways, while the FO delineates land that is subject to high hazard flooding based on the depth and velocity of flood water and the frequency of flooding.

Flood maps for historic and design flood events were also produced. These maps will assist VICSES and Council in planning for and responding to flood situations. This information was integrated into a proposed flood intelligence tool as part of the Ballarat Flood Emergency Plan (MFEP).

An assessment of flood warning issues and options was undertaken, resulting in a detailed report on flood warning options as part of a total flash flood warning system for Burrumbeet Creek. The following staged approach to the development of a flash flood warning system is proposed:

1. Work to ensure roles and responsibilities are agreed, understood and accepted across all relevant agencies. The initial focus of the flash flood warning system is on Miners Rest, but could be extended as knowledge, time and resources permit.
2. Establishment of a robust framework for communicating and disseminating flood related information.
3. Secure the funding needed to buy, install and operate field equipment as well as other services needed to build elements of the flash flood warning system.
4. On-going flood awareness activities.

In light of the study outcomes it is recommended that:

- The GHCMA and Ballarat City Council adopt the determined design flood levels and proceed with the planning scheme amendment process.
- In conjunction with VICSES, the City of Ballarat Council and GHCMA continue to engage the community in the treatment of flood risks through regular flood awareness programs such as the VICSES FloodSafe program, starting with the development of a local flood guide.
- In consultation with VICSES, the City of Ballarat Council and GHCMA explore further the recommendations for enhanced flood response through co-operation with VICSES and Police, utilising the flood inundation maps and flood intelligence tools included in the Municipal Flood Emergency Plan (MFEP). Consideration should be given to the use of the MFEP during an emergency.
- City of Ballarat Council and GHCMA explore further the recommendations for the development of the proposed total flash flood warning system for Miners Rest and other areas within the Burrumbeet Creek catchment in conjunction with the Bureau of Meteorology and VICSES.

ACKNOWLEDGEMENTS

Numerous organisations and individuals have contributed both time and valuable information to the Burrumbeet Flood Investigation. The study team acknowledges the contributions made by these groups and individuals, in particular:

- Brad Henderson and Johanna Thielemann (Glenelg Hopkins CMA & Project Manager)
- Jessie Keating & Rob Leeson (City of Ballarat Council)
- Simone Wilkinson (Department of Sustainability and Environment)

The study team also wishes to thank all those stakeholders and members of the public who participated in the steering group and community information sessions and provided valuable records (including flood photos) and discussed their experiences and views on flooding in and around the Burrumbeet Creek catchment.

GLOSSARY OF TERMS

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be of extreme magnitude.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A design flood is a probabilistic or statistical estimate, being generally based on some form of probability analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood damage	The tangible and intangible costs of flooding.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.
Flood mitigation	A series of works to prevent or reduce the impact of flooding. This includes structural options such as levees and non-structural options such as planning schemes and flood warning systems.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.

Freeboard	A factor of safety above design flood levels typically used in relation to the setting of floor levels or crest heights of flood levees. It is usually expressed as a height above the level of the design flood event.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
LiDAR	Spot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Probable Maximum Flood	The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequence and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.
TUFLOW	A hydraulic modelling tool used in this study to simulate the flow of flood water through the floodplain. The model uses numerical equations to describe the water movement.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Overview

The Glenelg Hopkins Catchment Management Authority (GHCMA), in partnership with City of Ballarat Council (BCC) commissioned Water Technology in association with Michael Cawood & Associates and Planning & Environmental Design to undertake the Burrumbeet Flood Investigation. This study involved detailed hydrological and hydraulic modelling of Burrumbeet Creek, flood mapping of relevant areas, flood warning assessment, provision of planning documentation and provision of recommendations for flood mitigation works.

The objective of the Burrumbeet Flood Investigation was to define the extent and characteristics of flooding in the Burrumbeet Creek catchment so that future planning decisions may be soundly based and measures may be put in place to minimise risk to the community.

The study addressed the following aspects:

- Examine contributing factors to flood events within the Burrumbeet Creek catchment;
- Determine flood levels and extents for a range of flood modelling scenarios within the study area;
- Provide draft documentation to be used to update the City of Ballarat Planning Scheme to reflect the findings of the investigation;
- Consider and provide recommendations for the provision of a flood warning system for the study area;
- Provide draft documentation for inclusion in the City of Ballarat Municipal Flood Emergency Plan;
- Consider and provide recommendations about achievable flood mitigation options.

1.2 Study Catchment and Floodplain

The Burrumbeet Flood Investigation study area covers the Burrumbeet Creek catchment to the north-west of Ballarat in western Victoria. Burrumbeet Creek has a catchment extending from the northern suburbs of Ballarat and Invermay in the south-east and Learmonth in the north, flowing through Miners Rest and Windermere, and terminating at Lake Burrumbeet. Under full conditions Lake Burrumbeet overflows to Baillie Creek, a tributary of the Hopkins River. The study area is within the Glenelg Hopkins CMA boundary and the City of Ballarat.

The study area covers the whole Burrumbeet Creek catchment above Lake Burrumbeet and is approximately 206 sq. km in size. Elevation across the study area ranges from to 377 to 607 m AHD. Steeper areas are found in the east of the catchment east of Invermay and Mount Rowan. The central and western parts of the catchment tend to have low relief and surface slope. The study area is shown in Figure 1-1 and the topography in Figure 1-2.

The main branch of Burrumbeet Creek is approximately 35 km long and traverses the catchment in a westerly direction. Many tributaries are found within and around the catchment. Some of these include:

- Blind Creek (flows west into Burrumbeet Creek)
- Burrumbeet Creek (flows south-west into Lake Burrumbeet at the south-east end of the Lake)
- A major tributary (unnamed) of Burrumbeet Creek originates between Mount Hollowback and Mount Blowhard and joins Burrumbeet Creek north-west of the Miners Rest township
- Willow Creek (a small farmers drain to the south of Windermere)
- A separate system is drained by Canico Creek, which flows north into Lake Burrumbeet (on the southern side of the Lake).

Townships within the study area include the northern suburbs of Ballarat, Invermay, and Miners Rest, and smaller settlements of Mount Rowan, Cardigan, Windermere, Burrumbeet, Blowhard and Learmonth. Land use is primarily agricultural, with some residential and industrial areas in the northern suburbs of Ballarat and the settlements previously mentioned, and some forest in the east of the catchment.

Figure 1-1 Study area showing Burrumbeet Creek gauge catchment and previously modelled 100 year ARI flood extent (Lawson and Treloar, 2003)

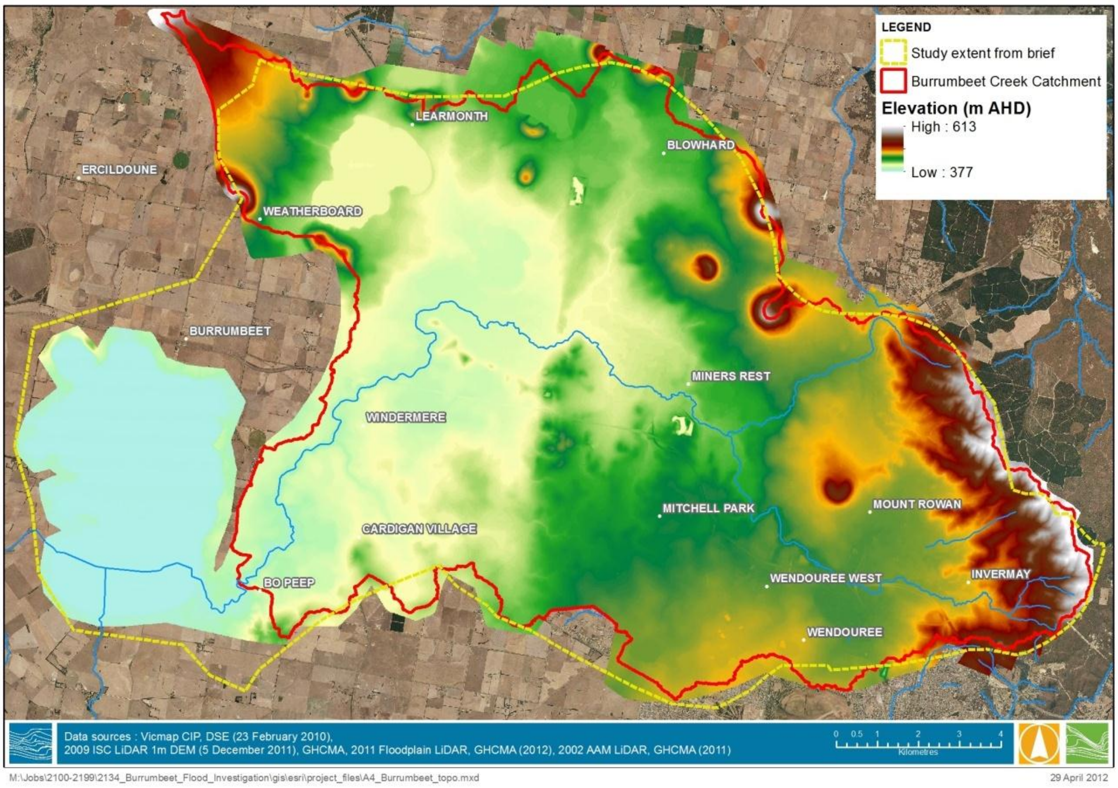

Figure 1-2 Topography of study area

1.3 Historical and Recent Flood Events

The Burrumbeet catchment is characterised by swamps and broad floodplains and has a long history of flooding and drainage issues. Historical flood events were identified by Lawson and Treloar (2003) by consultation with the community, in 1993, 1997 and 2000. However there is little recorded evidence of these historical events.

The annual flood series at the Burrumbeet Creek gauging station is shown in Figure 1-3, presenting the maximum peak instantaneous flow recorded in every year since 1976. The record shows that gauged flows prior to 2010 were moderate in magnitude, and were greatly exceeded by the 2010 and 2011 events.

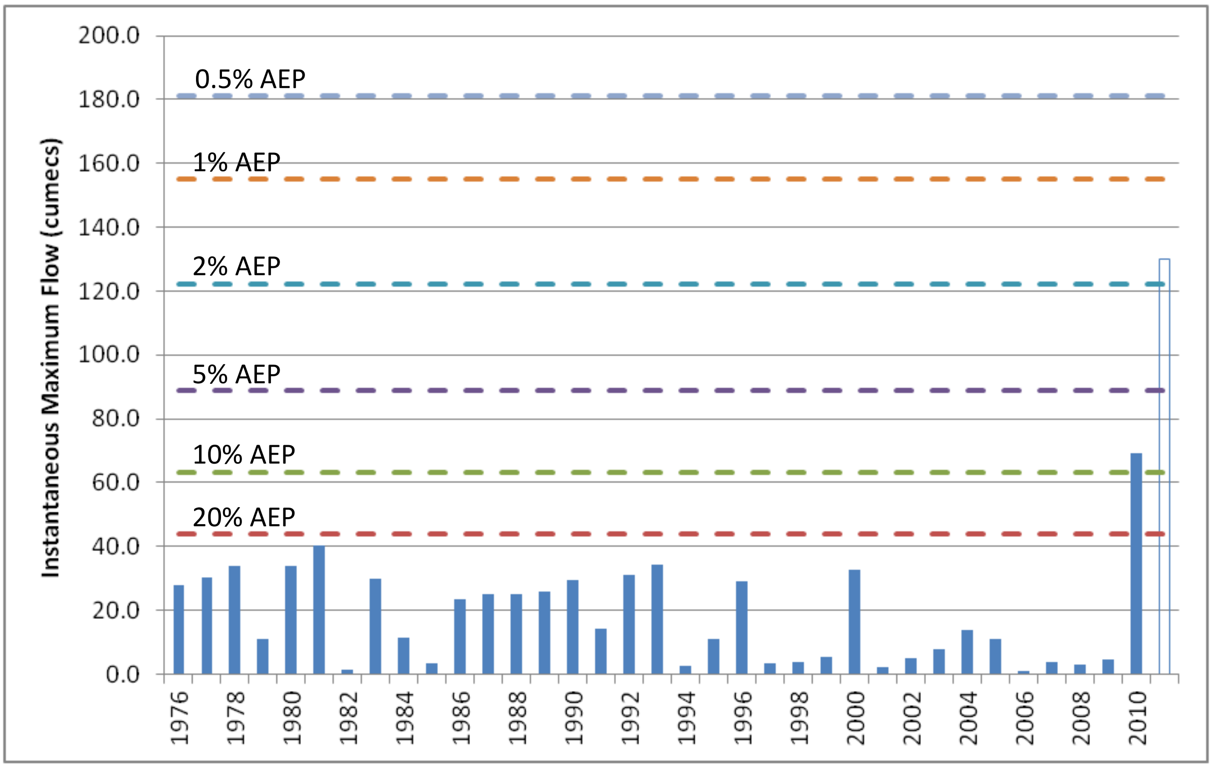

Figure 1-3 Annual Series for Burrumbeet Creek @ Lake Burrumbeet, also showing AEP design flows. Note that peak flow for 2011 was not recorded at the gauge and was estimated for this study.

September 2010

Heavy rain was recorded in the Burrumbeet Creek catchment from late Friday 3rd into Saturday 4th as a result of the deepening of a low pressure system over South Australia and its passage into Bass Strait. The highest daily rainfall totals for the month were generally recorded on the 4th with 46 mm recorded at Ballarat Aerodrome.

Flooding of Invermay, Mount Rowan and Miners Rest started soon after rainfall began (around 10pm to midnight on Friday 3rd) and peaked around 10-18 hours after rainfall began (in the morning of Saturday 4th). Inundation of floodplains in the west of the catchment followed 2-4 hours after Miners Rest. Extensive floodplain inundation occurred on Burrumbeet Creek and wetland and swamp areas throughout the catchment. Miners Rest wetland overtopped, inundating urban properties to its south-west. Miners Rest Road, Garlands Road, Victoria Street, Pound Hill Road and numerous minor roads were inundated. The September flood event was approximately a 7% Annual Exceedence Probability (AEP) event.

January 2011

The extreme rainfall observed during the month was generated by the passing of complex and persistent low pressure systems. A broad slow moving trough centered over western Victoria and a ridge of high pressure to the south of Tasmania were the main drivers for the rainfall which commenced on Sunday 9th January. The two systems created exceptionally humid conditions and unstable easterly flow across Victoria. The trough strengthened on Wednesday 12th and developed into a low pressure system over eastern South Australia on Thursday 13th as a high pressure system moved into the Tasman Sea. The low pressure system cleared the State on Friday evening after adding an additional 50 mm to 100 mm of rain. The Mt Emu Creek and Burrumbeet Creek catchments received between 200 mm and 300 mm of rain for the month. The highest daily falls were recorded on the 14th with 95 mm recorded at Ballarat Aerodrome. The highest rainfall intensity occurred early on Thursday 13th with 9.5 mm recorded in half an hour at Ballarat Aerodrome.

The rainfall was characterized by a slow build-up and flooding did not commence until approximately 48 hours after rainfall commenced (on Tuesday 11th). There were two minor flood peaks before the main peak during the night of Thursday 13th to Friday 14th. In Miners Rest, the embankment at Albert Street was overtopped, resulting in extensive flooding of properties in Dundas Place, James Court and Douglas Close. The Miners Rest wetland again overflowed causing widespread shallow inundation of downstream properties. The capacity of the Ballarat Airport drainage system was exceeded and extensive flooding of roads and aprons occurred. Numerous roads were inundated including Midland Highway, Gillies Road, Miners Rest Road, Albert St, Howe St, Sunraysia Highway and Pound Hill Road.

The event of 13-14th January 2011 was the largest flood on record and was estimated to be approximately a 1.6% AEP event. An aerial image of flooding in Miners Rest on 14th January 2011, close to the peak of that event, is shown in Figure 1-4.

Figure 1-4 Flooding in Miners Rest on 14th January 2011 (shadow of clouds obscures some of the flooding)

1.4 Supporting Documents

A number of reports were prepared at each stage of the study. These reports were provided as standalone documents, and a summary of each is provided in Table 1-1. In addition to these documents, flood maps and GIS layers were provided for each of the design, climate change and probable maximum flood events.

Table 1-1 Supporting documents

Number	Title	Summary
R01	Data Review	Review of flood related information for the study area, a review of available topographic and structure data (bridges and culvert information), and verification of topographic data including the identification of a discrepancy between the supplied ISC LiDAR data and field survey. It was agreed in consultation with the GHCMA that a correction factor be applied to the LiDAR dataset to resolve this discrepancy.
R02	Methodology	Outline of hydrologic analysis and hydraulic modelling methodology
R03	Hydrology and Hydraulics	Hydrologic and hydraulic modelling and analysis report, summarising results of flood frequency analysis, RORB modelling, hydraulic model construction and calibration, estimation of design events, and results of design event, climate change and probable maximum flood simulations.
R04	Hydraulics	This standalone hydraulics report was originally produced as a draft report during the study but has been combined with the hydrology report R03 in the final study documentation.
R05	Mitigation Options	Summary and assessment of mitigation options.
R06	Planning Scheme Amendment	Documentation to support an application for planning scheme amendment to update local flooding controls in light of the study outcomes. Planning Scheme amendment documentation are separate documents to the study report.
R07	Flood Warning Assessment Report	Review of flood warning systems and assessment of flood warning options for the Burrumbeet Creek catchment.
R08	Municipal Flood Emergency Plan Appendices	Appendices to the Ballarat City Council Flood Emergency Plan, detailing flood threats, flood rise and recession rates, travel times, evacuation arrangements and flood warning systems. These Appendices are a separate document to the study report.

2. DATA REVIEW

On inception of the project a detailed review was undertaken of all available flood related information as well as topographic data, structure information, and hydrological data. Details of this review are provided in Report 1 of the study, while a short overview is provided herein.

2.1 Flood Related Information

A floodplain management study was completed by Lawson and Treloar in 2003, however there was limited calibration data available at the time. Discrepancies between the modelled design levels and observed flood levels in the recent 2010-2011 events reduced confidence in the 2003 mapping and highlighted the need for a revised analysis based on the recently available data. A number of smaller flood studies have been undertaken in localized parts of the catchment.

A number of other flood related studies have been completed in the Burrumbeet Creek catchment:

- Flood Study of Wendouree area west of the Midlands Highway and of the Miners Rest Area (Keller 1996)
- Invermay Area Flood Study for Bungaree (Keller, 1993)
- Flood Study for Burrumbeet Creek at Glue Pot Road (Keller, 1990)
- Design Flood Estimation for Burrumbeet Creek at Glue Pot Road (Mein, 1990)
- Burrumbeet Creek Flood Study CELLS Modelling for Glue Pot Road (Keller, 1991)
- City of Ballarat Flood Mitigation Strategy (Ballarat City Council, 1995)
- Ballarat North Reclamation Project (KBR, 2006)

Water Technology (2011) has also recently completed a flood analysis for the proposed Ballarat Airport Infrastructure Upgrade. In the study a number of options for the upgrade of drainage infrastructure were investigated using one and two dimensional hydraulic modelling.

Historical flood records were also collected, which included flood data, aerial photographs and flood photographs from the 2010-2011 events, as summarised in Table 2-1.

Table 2-1 Flood data summary for 2010-2011 events

Event	Data Available
September 2010	74 Flood photos from GHCMA 15 Flood marks (surveyed) including 11 at peak WL
January 2011	182 flood photos from GHCMA Aerial visible and colour infrared flood photos (14 Jan) 42 Flood marks (surveyed) at peak WL

2.2 Site Visits

A site visit was undertaken by Water Technology staff with Johanna Theilemann from GHCMA and representatives from Ballarat City Council on 12 December 2011. This site visit focussed on waterways, structures and drainage infrastructure around Invermay, Miners Rest and Macarthur Park.

A further site visit was undertaken by Water Technology staff on 15 December 2011, to gather information on the Burrumbeet Creek @ Lake Burrumbeet gauge and the Lake Burrumbeet outlet structure.

The study area was visited again by Water Technology staff on 7 June 2012, to gather information on structures that had not been captured by survey, including the Lake Learmonth outlet structure.

2.3 Topographic Data

2.3.1 Available Datasets

Available topographic data for this study included LiDAR, an existing digital elevation model (DEM), as well as field survey. Verification of topographic data from various sources provided guidance on the suitability of the data for use in the hydrologic and hydraulic modelling.

Three sources of topographic and field survey data were obtained to prepare the hydrological and hydraulic models. These included:

- Existing Digital Elevation Models (DEM). This information was used in the schematisation and development of the RORB hydrologic model of the Mt Emu Creek catchment.
- Light detection and ranging (LiDAR) data. The LiDAR information was used to create a digital elevation model (DEM) of the study area as the basis of the hydraulic model; and
- Field survey (captured in February/March 2012 by ThinkSpatial for this study)

In addition, the structure information was also compared to available drawings where available.

Details of each of the topographic data sets are provided in the data review report.

2.3.2 Data Verification

The accuracy of the hydraulic modelling relies to a large degree on the accuracy of the topographic datasets. Therefore a detailed verification process was undertaken for the LiDAR using the field survey information.

It was expected that the LiDAR and field survey would line up quite closely. The only expected area of significant discrepancy was below the water level within the river channel, as LiDAR cannot penetrate the water column. However, the Index of Stream Condition (ISC) LiDAR was found to be consistently around 0.3 m higher than the surveyed levels.

A range of additional checks were undertaken to determine the possible sources of the discrepancy and possible inconsistency was identified in the post-processing of the ISC LiDAR.

To progress with the hydraulic model development for this study, it was agreed with GHCMA that a suitable correction factor be applied to the ISC LiDAR dataset.

2.4 Structure Information

The available structure information included structure drawings as well as a field survey. Review of the data from various sources provided guidance on the reliability of the data for use in the hydrologic and hydraulic modelling.

Information (dimensions, inverts) of the key hydraulic structures (bridges/culverts) along Burrumbeet Creek and tributaries was required for input into the hydraulic model and to understand the impacts of local drainage in particular on flooding issues in the township.

Once all relevant structures (including local drainage) were identified, detailed field survey of each structure was undertaken by ThinkSpatial in February/March 2012. An overview of all surveyed structures is provided in Figure 2-1.

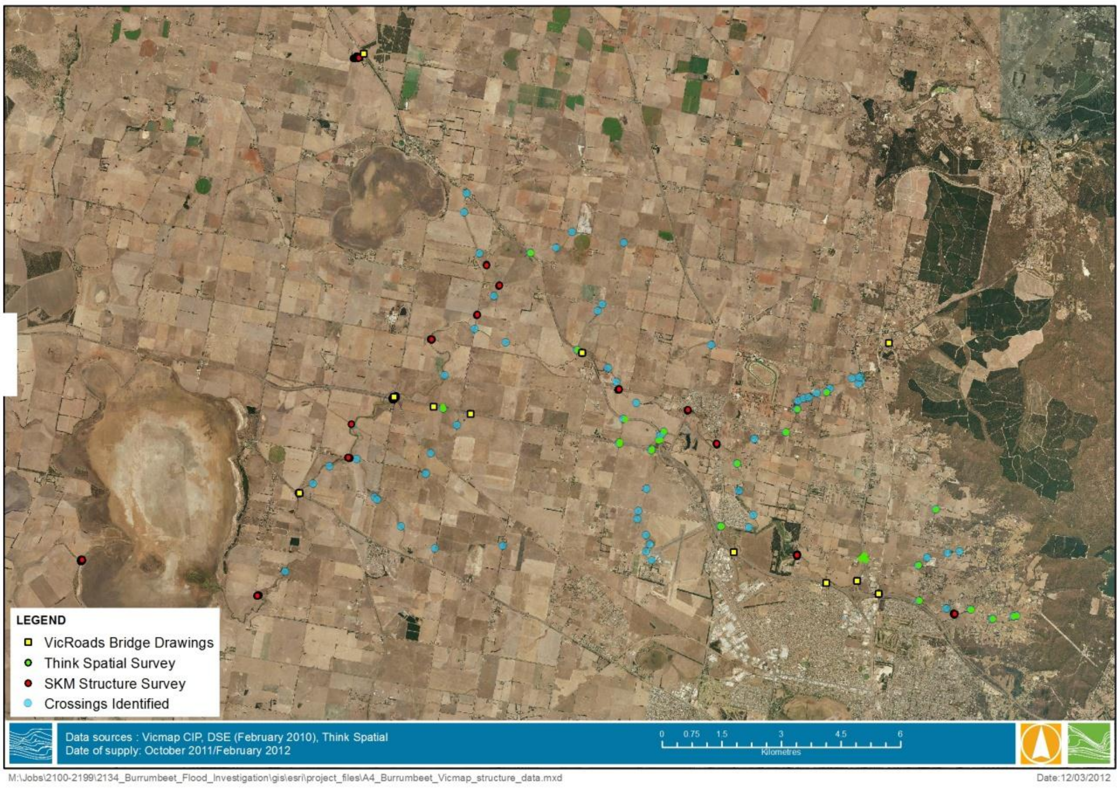

Figure 2-1 Location of bridges and culverts surveyed in the study area

2.4.1 Floor Survey

The following floor level survey was undertaken during previous studies and for this study specifically:

- 97 buildings in the Burrumbeet study area (including Miners Rest) had their floor levels surveyed as part of the 2003 Lawson and Treloar Flood Study,
- 45 buildings in the Burrumbeet study area (including Miners Rest) had their floor levels surveyed by GHCMA in the January 2011 survey. Of these, 31 are within the modelled 100 ARI extent and an additional 5 are within the modelled PMF extent,
- 13 additional buildings in the Burrumbeet study area (including Miners Rest) had their floor levels surveyed by Think Spatial for this study.

2.5 Airport Drainage Details

The Ballarat Airport has recently been upgraded and the drainage channels around the airport have been altered. Design drawings of the new layout and drainage details were provided by Ballarat City Council. The new design is summarised in Figure 2-2 below.

Figure 2-2 Airport Upgrade Details

2.6 Hydrological Data

Hydrological data required for the study included streamflow, rainfall, and water storage information.

2.6.1 Streamflow Data

Streamflow data was required for the hydrological analysis. There is a stream flow gauge on Burrumbeet Creek upstream of Lake Burrumbeet (236215), with a record length of approximately 36 years. The conditions at the gauge are shown in Figure 2-3. The gauge was washed out in the January 2011 flood, and the flood flow was not recorded, however peak water levels were measured around the gauge to allow estimation of the peak flow. This gauge was critical to the hydrology and hydraulic modeling for this study. Details of the gauging station data and its analysis are discussed in Report 3 of this study.

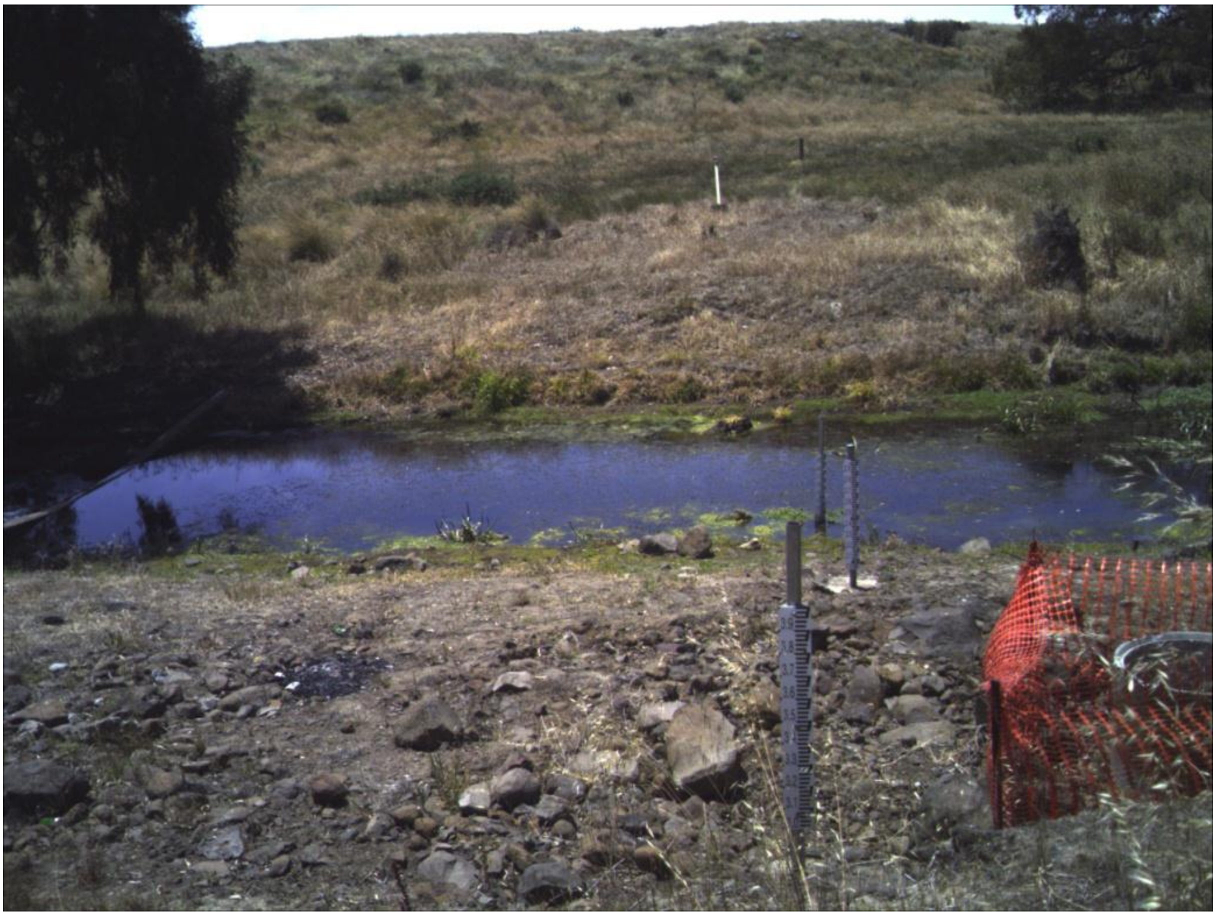

Figure 2-3 Burrumbeet Creek @ Lake Burrumbeet (236215) gauge site

2.6.2 Rainfall Data

Both pluviograph and daily rainfall records were used for the hydrological analysis. Pluviograph rainfall data indicates the temporal distribution pattern while daily rainfall data provides the spatial variation. Figure 2-4 shows the locations of daily rainfall and pluviograph stations in the region.

Table 2-2 Daily rainfall station details

Station Name	Station Number	Period of Record	Years of data	% complete
Bungaree (Kirks Reservoir)	087014	1881 - Present	130	99
Ballarat Aerodrome	089002	1908 - Present	103.6	99
Glen Park (White Swan Reservoir)	089048	1953 - Present	58.7	99
Addington	089106	1956 - Present	53.8	97
Creswick	088019	1949 - Present	47.5	75
Ballarat Hopetoun Rd	089111	2004 - Present	7.3	99
Burrumbeet	089007	1949 - 2001	46.4	88
Ballarat Botanical Gardens	089001	1881 - 1995	113.4	99
Smeaton Weir	088016	1878 - 1972	92.1	97
Creswick	088018	1898 - 1952	53.7	99
Ballarat Mount Pleasant	089050	1886 - 1942	44	78

Station Name	Station Number	Period of Record	Years of data	% complete
Observatory				
Learmonth	089061	1898 - 1940	32.2	74
Windermere	089073	1903 - 1938	30.2	87
Allendale Post Office	088080	1901 - 1931	29.9	100
Ballarat School of Mines	089096	1883 - 1907	23.3	95
Ballarat Survey Office	089049	1859 - 1890	30.2	97

Table 2-3 Pluviograph station details

Station Name	Station Number	Period of Record	Years of data	% complete
Ballarat Hopetoun Rd	089111	1999 - Present	11.8	94
Ballarat Aerodrome	089002	1954 - 1999	44.6	99

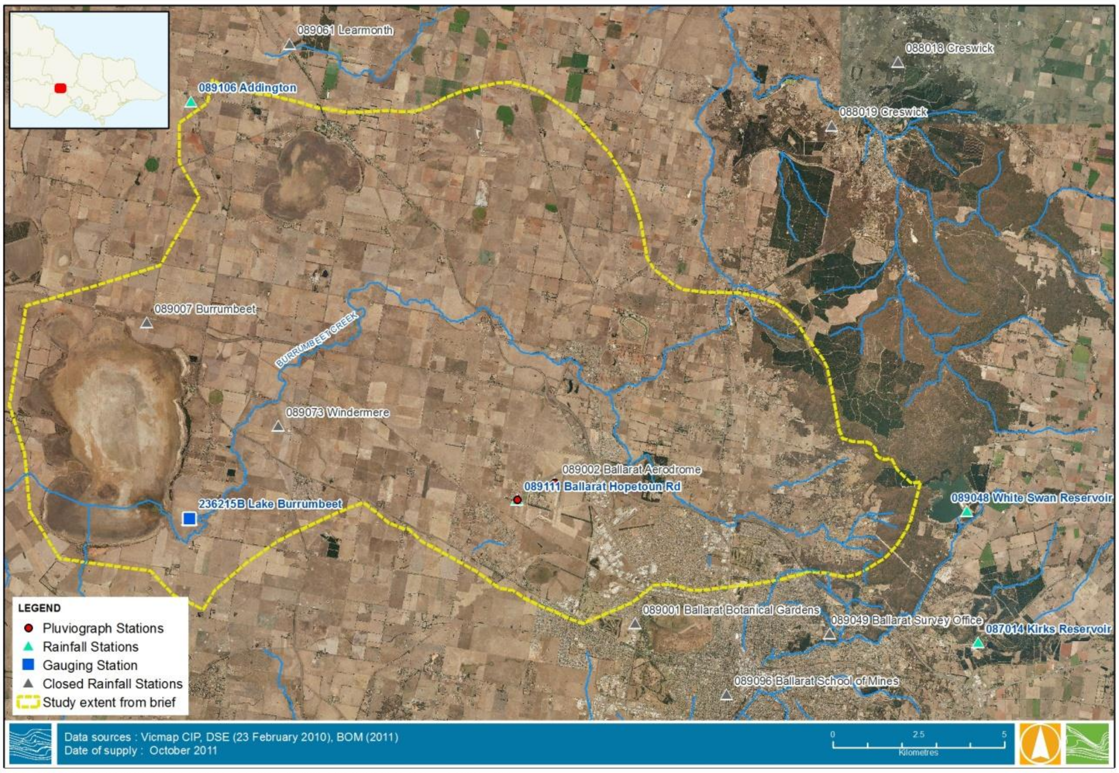

Figure 2-4 Daily rainfall, pluviograph and stream flow gauge locations

2.6.3 Storages

There are two important water storages that are likely to affect the hydrology of Burrumbeet Creek within the study area, Lake Burrumbeet and Lake Learmonth.

Lake Burrumbeet is located at the end of Burrumbeet Creek. The Lake Burrumbeet outlet structure was described in Lawson and Treloar (2003). The structure is a 30.7 m wide weir with a crest level of 378.7 m AHD, and removable wooden boards to a height of 379.1 m AHD. Anecdotal evidence cited by Lawson and Treloar (2003) suggests that the boards have not been in operation since their implementation in 1996. The boards were thought to have been implemented to control outflows from Lake Burrumbeet under flood conditions, but there appear to be no operating rules in place for the weir, nor any feasible way to remove or replace the boards at full level. At the time of the site visit on 15th December 2011, the boards were in place and the lake was full to the top of the boards.

Lake Learmonth is located in the north-west of the catchment. Lake levels are supplemented by diversions from the Coghills Creek catchment to the north, via Morton's Cutting. An outlet structure on the eastern shore regulates lake levels and controls discharge to Burrumbeet Creek. Lawson and Treloar (2003) describe the Morton's Cutting and Lake Learmonth structures in some detail.

3. PROJECT CONSULTATION

3.1 Overview

A key element in the development of this flood investigation was the active engagement of residents in the study area. This engagement was developed over the course of the study through community consultation sessions, public questionnaires and meetings with a Steering Committee. The community consultation sessions were largely managed by the GHCMA and City of Ballarat Council. The aims of the community consultation were as follows:

- To raise awareness of the study and to identify key community concerns; and
- To provide information to the community and seek their feedback/input regarding the study outcomes including the existing flood behaviour.

3.2 Steering Committee

The Flood Investigation was led by a Steering Committee consisting of representatives from Glenelg Hopkins Catchment Management Authority (GHCMA), City of Ballarat Council (COB), Department of Sustainability and Environment (DSE), Bureau of Meteorology (BoM), State Emergency Service (SES), and Water Technology.

The Steering Committee met on 4 occasions at key points throughout the study, to review and manage the development of the study.

3.3 Community Consultation

The main aim of the community engagement process was to provide information regarding the development of the study and to seek feedback, both verbally and through more formal feedback methods. All community meetings were supported by media releases to local papers and meeting notices.

The public consultation process was led by the Glenelg Hopkins CMA and City of Ballarat Council. The following community meetings were held as part of the consultation process:

- Initial community meeting, 6th March 2012 – The first public meeting was held to outline the objectives of the study to the community and to obtain any flood information from the community;
- Second community meeting, 28th February 2013 – This meeting presented the results of the flood modelling (calibration and 1% AEP events only). Community feedback was sought on the flood modelling results and their preference/suggestions for flood mitigation options.
- Third community meeting, 12th November 2013 – This meeting presented the result of the study and the draft planning overlays.

4. FLOOD BEHAVIOUR

4.1 Overview

The study area covers the whole of the Burrumbeet Creek catchment, including steep headwater streams, upland swamps and wetlands, broad floodplains and gorges. Flooding of these diverse flood-prone areas in the Burrumbeet Creek catchment can occur from a number of sources including:

1. Flooding in Burrumbeet Creek floodplain due to widespread and prolonged rainfall;
2. Flash flooding in tributaries due to intense local rainfall; and
3. Flooding in tributaries and upper catchment floodplains due to the filling of swamps and wetlands and extended ponding due to poor drainage.

The flood behaviour associated with these different flooding mechanisms has been assessed using a range of industry standard approaches and tools:

- Hydrological analysis – this involves the analysis of the magnitude of previous flood events at the Burrumbeet Creek gauge, the development of a rainfall-runoff model for the entire Burrumbeet Creek catchment, and the prediction of future runoff events of a given magnitude,
- Hydraulic analysis – the physical understanding of what a given flood event may look like in the Burrumbeet Creek catchment . A hydraulic model was used to predict the extent of flooding, flood depths and flow velocities for a range of possible future flood events.

The results of the hydrologic and hydraulic analysis for the study area are discussed in detail in the following sections. Refer to Report 3 of this study for additional details.

4.2 Hydrology

4.2.1 Flood Frequency Analysis

A flood frequency analysis was used to estimate the magnitude of flood events at the streamflow gauge on Burrumbeet Creek (upstream of Lake Burrumbeet) in terms of a probability of occurrence. This allows the quantification of previous flood events and also enables the estimation of the frequency of future flood events.

The flood frequency analysis was based on an annual series of maximum flows at the Lake Burrumbeet gauge with 36 years of data.

The 2011 flood peak flow was not recorded as the Burrumbeet Creek at Lake Burrumbeet gauge was washed out in the early stages of the flood. Flood pegging was undertaken around the gauge to give a record of the peak water level. The peak magnitude of the 2011 flood was estimated using hydraulic modelling of the gauge site.

The Log-Pearson III, Generalised Extreme Value (GEV) and Generalised Pareto distributions were fitted, with the Log-Pearson III distribution giving the best fit overall. The design flows resulting from the flood frequency analysis are given in Table 4-1.

Table 4-1 Adopted Flood Frequency Analysis for Burrumbeet Creek Gauge

AEP	Peak Design Flow (m^3/s)		
	Log Pearson III (7 low flows excluded)	5%-95% Confidence Limits	
20%	34	24	51
10%	55	38	88
5%	80	53	145
2%	120	73	271
1%	155	88	426
0.5%	194	101	653

4.2.2 Hydrologic Modelling

The catchment hydrologic model, RORB, was employed to estimate runoff hydrographs for the catchment. RORB (Laurenson et al 2007) is a nonlinear rainfall runoff and streamflow routing model for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be subdivided into subareas, connected by conceptual flow reaches. The structure of the RORB model is shown in Figure 4-1.

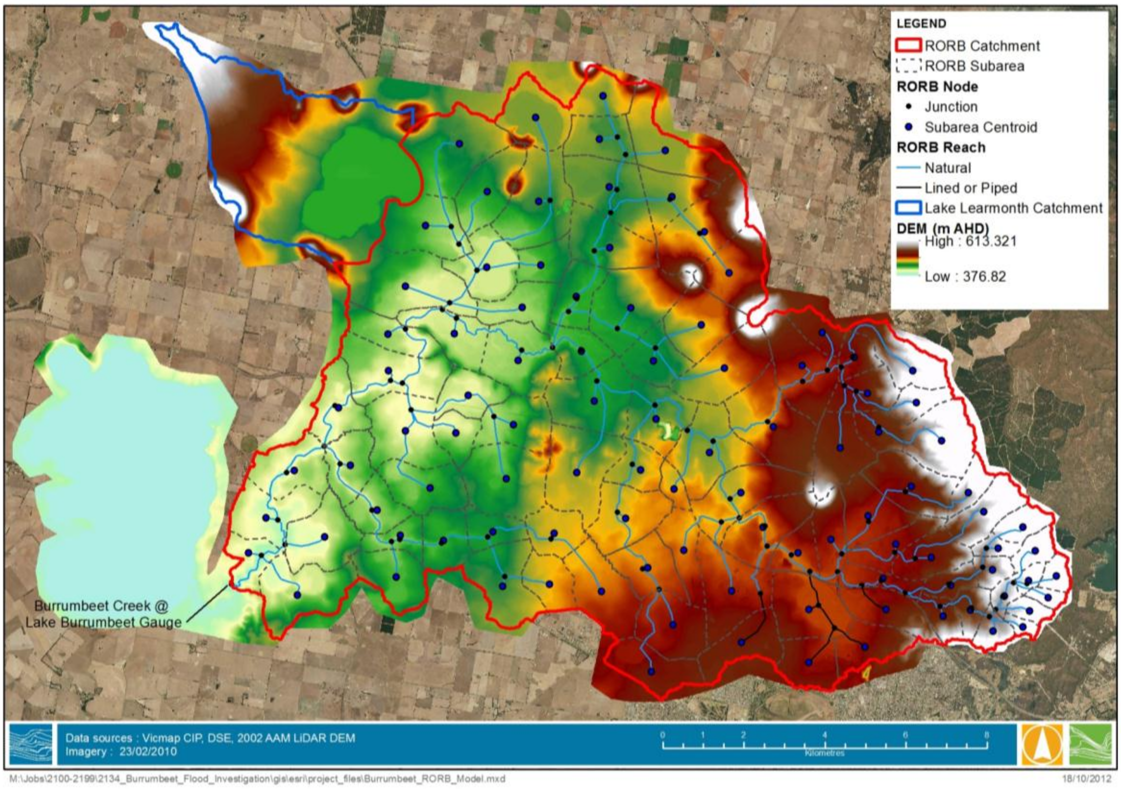

Figure 4-1 RORB Model Structure

The RORB model parameters were determined through a joint calibration with the hydraulic model. This calibration compared the results of the hydraulic model against observed flood hydrographs at the Burrumbeet Creek gauge. This model calibration required concurrent pluviographic and daily rainfall data, and streamflow. Four calibration events (1981, 2000, September 2010 and January 2011) were selected to calibrate the models over a range of flows.

4.2.3 Design Event Hydrology

Design event runoff hydrographs were developed using the calibrated routing parameters, and loss parameters adopted from the Hill et al (1998) research. The runoff hydrographs were then routed through the calibrated hydraulic model to enable peak flow estimation at key locations. The resulting design flows were found to be consistent with the flood frequency analysis. The critical storm duration for design events ranged from 9 hours to 36 hours at the key locations of Invermay, Miners Rest and the Burrumbeet Creek gauge. In addition to the design events, climate change hydrographs were developed for sensitivity testing. These were based on the design events with an increase in rainfall intensity of 20%, based on discussions with the GHCMA.

The Probable Maximum Flood (PMF) was estimated for Burrumbeet Creek and the tributaries using a combined approach of modelling the Probable Maximum Precipitation in RORB and applying the RORB rainfall excess hydrographs for each subarea to the hydraulic model.

The adopted peak design flows are provided in Table 4-2.

Table 4-2 Adopted Peak Flows for Burrumbeet Creek

Scenario	AEP	Peak Flow (m^3/s)		
		Invermay	Miners Rest	Lake Burrumbeet Gauge
Design	20%	5.4	26	44
	10%	9.4	38	63
	5%	17	56	89
	2%	27	93	122
	1%	33	118	155
	0.5%	39	145	181
PMF	PMF	306	1467	1871
Climate Change	10%	9.4	38	63
	1%	33	116	155
	0.5%	39	145	181

4.3 Hydraulics

4.3.1 Overview

This section discusses the application of the hydraulic models to simulate and map flood behaviour (extents, depth, velocities) for a range of flood magnitudes.

The hydrologic analysis previously discussed, provided runoff hydrographs for the hydraulic model. These inflow hydrographs were routed through the calibrated hydraulic model. This enabled the modelling and mapping of flood depths, extents, velocities over a range of flood magnitudes. It also provided a tool for understanding the flood behaviour across the study area.

A detailed description of the hydraulic model setup, calibration and design event simulation is provided in Report 3 of this study. This section outlines the key outcomes from the hydraulic model investigation.

The mapping outputs were applied for flood response planning, and land use planning purposes (Section 7 and 8 respectively).

4.3.2 Understanding Flood Behaviour

Table 4-3 describes the flood characteristics in the Burrumbeet Creek catchment for each design event. The critical duration in Table 4-3 refers to the duration of design storm that produces the highest peak flood discharges for that flooding source. The tributary catchments have shorter critical storm durations than the main Burrumbeet Creek floodplain, meaning that they are responsive to short, high intensity storms, whereas the Burrumbeet Creek flows are more responsive to sustained long duration rainfall.

4.3.3 Climate Change Sensitivity Tests

The sensitivity of flood behaviour to projected Climate Change was tested using a scenario of 20% increase in rainfall intensity for the 10%, 1% and 0.5% AEP events. The increased rainfall intensity was simulated in the RORB model to give input runoff hydrographs for the hydraulic modelling. The resulting hydrograph peak flows for Burrumbeet Creek at key locations were increased by 18-91%. Table 4-4 describes the key changes to flooding characteristics in the Burrumbeet Creek catchment for each design event with climate change effects, compared to the base design event.

Table 4-3 Summary of Flood Behaviour for Various Design Flood Events

Event	Invermay (upper catchment to Gillies Rd)	Mt Rowan	Ballarat Urban (south of freeway)	Miners Rest (Gillies Rd to Glenanes Rd)	Learmonth (north of western highway)	Cardigan (south of western highway, west of Airport to Lake Burrumbeet)	Airport
20% AEP	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area but increases to 17 hours east of railways due to the impoundment of floodwaters by the railway. • Flooding to the east of railway and between railway and Midland Highway. • Inundation of Millers Road and Olliers Road, Slatey Creek Rd, Cootamundra Rd and numerous minor roads	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area. • Flooding is short duration across the whole area. • Inundation of Gillies Road and some minor local roads.	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-9 hours over majority of area. • There is lasting ponding in some areas and extensive inundation of the road network.. • Note that local drainage is not included in the model.	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 5 hours over majority of area. • Limited flooding of urban areas along Clarke St (due to local rainfall). • Limited flooding of Creek Street and Hamlin St. • Ford on Victoria Street is inundated. • Inundation of Garlands Road. • Limited overtopping of Miners Rest Wetland and shallow inundation of a limited number of Sharpes Road and Raglan St properties	Critical Duration – 9 hrs in tributaries, and 24hrs for Burrumbeet Creek • Flooding begins 4hrs after rainfall commences in Burrumbeet Creek. • Peak occurs after 4-6 hours in upper tributaries, and 8-12hours in the floodplain. • Flooding occurs in wetland areas to the north of the catchment but these flows do not extend to Burrumbeet Creek or tributaries. • Extensive floodplain inundation on Burrumbeet Creek and wetland area to the immediate west of Sunraysia highway. Limited inundation of the Highway. • Inundation of Pound Hill Road at various locations. • No inundation of Western Highway.	Critical Duration – 9 hrs in tributaries and 24 hours in Burrumbeet Creek. • Flooding begins 3hrs after rainfall commences for tributaries and 10hrs for Burrumbeet Creek. • Burrumbeet Creek located within gorge over this section and therefore flood extent confined by terrain. • Peak occurs after 16 hours for Burrumbeet Creek. •	Critical Duration – 9 hrs • Flooding begins less than 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area. • Flooding is contained in Airport channel and no flooding of airport infrastructure occurs • Limited overtopping of Blind Creek Rd and McCartneys Rd. • Extensive ponding occurs in swampy areas upstream of Airport.
10% AEP	Critical Duration – 9 -24 hrs depending on proximity to Burrumbeet Creek. • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-7 hours over majority of area but increases to 20 hours east of railway due to the impoundment of floodwaters by the railway. • Flooding to the east of railway and between railway and Midland Highway. • Overtopping of railway. • Inundation of Millers Road and Olliers Road,	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area. • Flooding is short duration across the whole area. • Inundation of Gillies Road and some minor local roads.	Critical Duration – 24 hrs • Flooding begins 4hrs after rainfall commences. • Peak occurs after 10 hours over majority of area. • There is lasting ponding across the area and extensive inundation of the road network.. • Note that local drainage is not included in the model.	Critical Duration – 36 hrs • Flooding begins 6hrs after rainfall commences. • Peak occurs after 10 hours over majority of area. • Flooding of urban areas along Clarke St (due to local rainfall). • Flooding of Creek Street and Hamlin St. • Ford on Victoria Street is inundated. • Inundation of Garlands Road. • Inundation of Miners Rest Road (to the west of Albert Road) • Limited overtopping of Miners Rest Wetland via western outlet and shallow inundation of numerous Sharpes Road and Raglan St properties •	Critical Duration – 9 hrs in tributaries, and 36hrs for Burrumbeet Creek • Flooding begins 6hrs after rainfall commences in Burrumbeet Creek. • Peak occurs after 6-8 hours in upper tributaries, and 14 hours in the floodplain. • Flooding occurs in wetland areas to the north of the catchment and there is some overflow from one of these areas to Burrumbeet Creek tributary. • Extensive floodplain inundation on Burrumbeet Creek and wetland area to the immediate west of Sunraysia highway. Limited	Critical Duration – 9 hrs in tributaries and 36 hours in Burrumbeet Creek. • Flooding begins 3hrs after rainfall commences for tributaries and 8 hrs for Burrumbeet Creek. • Burrumbeet Creek located within gorge over this section and therefore flood extent confined by terrain. • Peak occurs after 3-7hrs in tributaries and 19 hours for Burrumbeet Creek. •	Critical Duration – 9 hrs • Flooding begins less than 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area. • Flooding is mostly contained in Airport channel and only limited flooding of non-critical airport infrastructure occurs • Some overtopping of Blind Creek Rd and McCartneys Rd. • Extensive ponding occurs in swampy areas upstream of

Event	Invermay (upper catchment to Gillies Rd)	Mt Rowan	Ballarat Urban (south of freeway)	Miners Rest (Gillies Rd to Glenanes Rd)	Learmonth (north of western highway)	Cardigan (south of western highway, west of Airport to Lake Burrumbeet)	Airport
	Slatey Creek Rd, Cootamundra Rd and numerous minor roads				inundation of the Highway. • Inundation of Pound Hill Road at various locations. • No inundation of Western Highway.		Airport.
5% AEP	Critical Duration – 9 hrs. • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area but increases to 9 hours east of railway due to the impoundment of floodwaters by the railway. • Flooding to the east of railway and between railway and Midland Highway. • Overtopping of railway. • Inundation of Millers Road and Olliers Road, Slatey Creek Rd, Cootamundra Rd and numerous minor roads.	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area. • Flooding is short duration across the whole area. • Inundation of Sulky Road, Gillies Road and some minor local roads.	Critical Duration – 24 hrs • Flooding begins 4hrs after rainfall commences. • Peak occurs after 8-10 hours over majority of area. • There is lasting ponding across the area and extensive inundation of the road network.. • Note that local drainage is not included in the model.	Critical Duration – 24 - 36 hrs • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 6-10 hours over majority of area. • Flooding of urban areas along Clarke St (due to local rainfall). • Flooding of Creek Street and Hamlin St. • Ford on Victoria Street is inundated. • Inundation of Garlands Road. • Extensive ponding of surface water to the immediate south of Macarthur Park due to flows from south of the freeway (Wendouree). • Inundation of Miners Rest Road (to the west of Albert Road) • Some overtopping of Miners Rest Wetland via western outlet and shallow inundation of numerous Sharpes Road and Raglan St properties	Critical Duration – 9 hrs in tributaries, and 24-36hrs for Burrumbeet Creek • Flooding begins 4-6hrs after rainfall commences In Burrumbeet Creek. • Peak occurs after 3-8 hours in upper tributaries, and 10-14 hours in the floodplain. • Flooding occurs in wetland areas to the north of the catchment and there is some overflow from one of these areas to Burrumbeet Creek tributary. • Extensive floodplain inundation on Burrumbeet Creek and wetland area to the immediate west of Sunraysia highway. Limited inundation of the Highway. • Inundation of Pound Hill Road at various locations. • No inundation of Western Highway.	Critical Duration – 9 hrs in tributaries and 24 hours in Burrumbeet Creek. • Flooding begins 3hrs after rainfall commences for tributaries and 6 hrs for Burrumbeet Creek. • Burrumbeet Creek located within gorge over this section and therefore flood extent generally confined by terrain although there are limited pocks of floodplain inundation occurring. • Peak occurs after 3-7hrs in tributaries and 16 hours for Burrumbeet Creek. •	Critical Duration – 9 hrs • Flooding begins less than 3hrs after rainfall commences. • Peak occurs at approximately 3 hours over majority of area. • Flooding is mostly contained in Airport channel and only limited flooding of non-critical airport infrastructure occurs • Some overtopping of Blind Creek Rd and McCartneys Rd. • Extensive ponding occurs in swampy areas upstream of Airport.
2% AEP	Critical Duration – 9 hrs. • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area but increases to 7 hours east of railway due to the impoundment of floodwaters by the railway. • Flooding to the east of railway and between railway and Midland Highway and downstream of Midland Highway.	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area. • Flooding is short duration across the whole area. • Inundation of Sulky Road,	Critical Duration – 24-36 hrs • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 8-12 hours over majority of area. • There is lasting ponding across the area and extensive inundation of the road network.	Critical Duration – 24 hrs • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 6-10 hours over majority of area. • Flooding of urban areas along Clarke St (due to local rainfall). • Extensive flooding of Creek Street and Hamlin St. • Ford on Victoria Street is inundated. Overtopping of Albert St and inundation of Dundas Place, James Court and Douglas Close. • Inundation of Garlands Road.	Critical Duration – 9 hrs in tributaries, and 24-36hrs for Burrumbeet Creek • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 3-8 hours in upper tributaries, and 10-14 hours in the floodplain. • Flooding occurs in wetland areas to the north of the catchment and there is some overflow from one of these areas to Burrumbeet Creek tributary. • Extensive floodplain	Critical Duration – 9 hrs in tributaries and 24 hours in Burrumbeet Creek. • Flooding begins 3hrs after rainfall commences for tributaries and 6 hrs for Burrumbeet Creek. • Burrumbeet Creek located within gorge over this section and therefore flood extent generally confined by terrain although there are limited pockets of floodplain inundation occurring. • Peak occurs after 3-7hrs in tributaries and 15 hours for	Critical Duration – 9 hrs • Flooding begins less than 3hrs after rainfall commences. • Peak occurs at approximately 3 hours over majority of area. • Capacity of Airport channel is exceeded and some flooding of roads and aprons occurs. • Overtopping of Blind Creek Rd and McCartneys Rd.

Event	Invermay (upper catchment to Gillies Rd)	Mt Rowan	Ballarat Urban (south of freeway)	Miners Rest (Gillies Rd to Glenanes Rd)	Learmonth (north of western highway)	Cardigan (south of western highway, west of Airport to Lake Burrumbeet)	Airport
	• Overtopping of railway. • Inundation of Millers Road and Olliers Road, Slatey Creek Rd, Cootamundra Rd and numerous minor roads.	Gillies Road and some minor local roads. • Minor flooding of Midland Highway.	• Note that local drainage is not included in the model.	• Inundation of Howe St • Extensive ponding of surface water to the immediate south of Macarthur Park due to flows from south of the freeway (Wendouree). • Limited inundation of Sunraysia Highway to the south and west of Miners Rest. • Extensive inundation of Miners Rest Road (to the west of Albert Road) • Some overtopping of Miners Rest Wetland via western outlet and shallow inundation of numerous Sharpes Road, Raglan St and Howe St properties	inundation on Burrumbeet Creek and wetland area to the immediate west of Sunraysia highway. Inundation of the Highway from Burrumbeet Creek as well as tributaries. • Inundation of Pound Hill Road at various locations. • No inundation of Western Highway.	Burrumbeet Creek.	• Extensive ponding occurs in swampy areas upstream of Airport.
1% AEP	Critical Duration – 9 hrs. • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area and is 5 hours east of railway due to the impoundment of floodwaters by the railway. • Extensive flooding to the east of railway and between railway and Midland Highway and downstream of Midland Highway. • Overtopping of railway and Midland Highway. • Inundation of Millers Road and Olliers Road, Slatey Creek Rd, Cootamundra Rd and numerous minor roads.	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area. • Flooding is short duration across the whole area. • Inundation of Sulky Road, Gillies Road and some minor local roads. • Minor flooding of Midland Highway.	Critical Duration – 24-36 hrs • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 8-12 hours over majority of area. • There is lasting ponding across the area and extensive inundation of the road network. • Note that local drainage is not included in the model.	Critical Duration – 24-36 hrs • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 6-10 hours over majority of area. • Flooding of urban areas along Clarke St (due to local rainfall). • Overtopping of wetland low flow outlet and inundation of properties along Raglan St and Sharpes Road. • Extensive flooding of Creek Street and Hamlin St. • Ford on Victoria Street is inundated. Overtopping of Albert St and inundation of Dundas Place, James Court and Douglas Close. • Inundation of Garlands Road. • Inundation of Howe St • Extensive ponding of surface water to the immediate south of Macarthur Park due to flows from south of the freeway (Wendouree). • Limited inundation of Sunraysia Highway to the south and west of Miners Rest. • Extensive inundation of Miners	Critical Duration – 9 hrs in tributaries, and 24-36hrs for Burrumbeet Creek • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 3-6 hours in upper tributaries, and 10-14 hours in the floodplain. • Flooding occurs in wetland areas to the north of the catchment and there is some overflow from two of these areas to Burrumbeet Creek tributary. • Extensive floodplain inundation on Burrumbeet Creek and wetland area to the immediate west of Sunraysia highway. Inundation of the Highway from Burrumbeet Creek as well as tributaries. • Inundation of Pound Hill Road at various locations. • Potential very shallow inundation of Western Highway.	Critical Duration – 9 hrs in tributaries and 24 hours in Burrumbeet Creek. • Flooding begins 3hrs after rainfall commences for tributaries and 4 hrs for Burrumbeet Creek. • Burrumbeet Creek located within gorge over this section and therefore flood extent generally confined by terrain although there are increasing pockets of floodplain inundation occurring. • Peak occurs after 3-7hrs in tributaries and 14 hours for Burrumbeet Creek.	Critical Duration – 9 hrs • Flooding begins less than 3hrs after rainfall commences. • Peak occurs at approximately 3 hours over majority of area. • Capacity of Airport channel is exceeded and some flooding of roads and aprons occurs. • Overtopping of Blind Creek Rd and McCartneys Rd. • Extensive ponding occurs in swampy areas upstream of Airport.

Event	Invermay (upper catchment to Gillies Rd)	Mt Rowan	Ballarat Urban (south of freeway)	Miners Rest (Gillies Rd to Glenanes Rd)	Learmonth (north of western highway)	Cardigan (south of western highway, west of Airport to Lake Burrumbeet)	Airport
				Rest Road (to the west of Albert Road). • Overtopping of Miners Rest Wetland via western outlet and extensive shallow inundation of numerous Sharpes Road, Raglan St and Howe St properties. Overtopping of southern spillway does not produce significant flooding.			
0.5% AEP	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area and is 5 hours east of railway due to the impoundment of floodwaters by the railway. • Extensive flooding to the east of railway and between railway and Midland Highway and downstream of Midland Highway. • Overtopping of railway and extensive flooding of Midland Highway. • Inundation of Millers Road and Olliers Road, Slatey Creek Rd, Cootamundra Rd and numerous minor roads.	Critical Duration – 9 hrs • Flooding begins 3hrs after rainfall commences. • Peak occurs after 3-5 hours over majority of area. • Flooding is short duration across the whole area. • Inundation of Sulky Road, Gillies Road and some minor local roads. • Minor flooding of Midland Highway.	Critical Duration – 24-36 hrs • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 8-12 hours over majority of area. • There is lasting ponding across the area and extensive inundation of the road network. • Note that local drainage is not included in the model.	Critical Duration – 24-36 hrs • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 6-10 hours over majority of area. • Flooding of urban areas along Clarke St (due to local rainfall). • Extensive flooding of Creek Street and Hamlin St. • Ford on Victoria Street is inundated. Overtopping of Albert St and inundation of Dundas Place, James Court and Douglas Close. • Inundation of Garlands Road. • Inundation of Howe St. • Extensive ponding of surface water to the immediate south of Macarthur Park due to flows from south of the freeway (Wendouree). • Inundation of Sunraysia Highway to the south and west of Miners Rest. • Extensive inundation of Miners Rest Road (to the west of Albert Road). • Overtopping of Western Highway by tributary to south-west of Miners Rest. • Overtopping of Miners Rest Wetland via western outlet and extensive shallow inundation of numerous Sharpes Road, Raglan St and Howe St properties. Overtopping of southern spillway	Critical Duration – 9 hrs in tributaries, and 24-36hrs for Burrumbeet Creek • Flooding begins 4-6hrs after rainfall commences. • Peak occurs after 3-6 hours in upper tributaries, and 10-14 hours in the floodplain. • Flooding occurs in wetland areas to the north of the catchment and there is some overflow from two of these areas to Burrumbeet Creek tributary. • Extensive floodplain inundation on Burrumbeet Creek and wetland area to the immediate west of Sunraysia highway. Inundation of the Highway from Burrumbeet Creek as well as tributaries. • Inundation of Pound Hill Road at various locations. • Potential very shallow overtopping of Western Highway.	Critical Duration – 9 hrs in tributaries and 24 hours in Burrumbeet Creek. • Flooding begins 3hrs after rainfall commences for tributaries and 4 hrs for Burrumbeet Creek. • Burrumbeet Creek located within gorge over this section and therefore flood extent generally confined by terrain although there are increasing pockets of floodplain inundation occurring. • Inundation from tributaries of Blind Creek Road at a couple of locations. • Peak occurs after 3-7hrs in tributaries and 14 hours for Burrumbeet Creek.	Critical Duration – 9 hrs • Flooding begins less than 3hrs after rainfall commences. • Peak occurs at approximately 3 hours over majority of area. • Capacity of Airport channel is exceeded and some flooding of roads, aprons and building pads occurs. • Overtopping of Blind Creek Rd and McCartneys Rd. • Extensive ponding occurs in swampy areas upstream of Airport.

Event	Invermay (upper catchment to Gillies Rd)	Mt Rowan	Ballarat Urban (south of freeway)	Miners Rest (Gillies Rd to Glenanes Rd)	Learmonth (north of western highway)	Cardigan (south of western highway, west of Airport to Lake Burrumbeet)	Airport
				does not produce significant flooding.			
PMF	Critical Duration – 3 hrs (GSDM) • Flooding begins less than 2 hrs after rainfall commences. • Peak occurs at approximately 2 hours over majority of area. • Extensive flooding to the east of railway and between railway and Midland Highway and downstream of Midland Highway. • Overtopping of railway and extensive flooding of Midland Highway. • Inundation of Western Freeway. • Inundation of all roads within flood extent.	Critical Duration – 3 hrs (GSDM) • Flooding begins less than 2 hrs after rainfall commences. • Peak occurs at approximately 2 hours over majority of area. • Flooding is short duration across the whole area. • Inundation of all roads within flood extent. • Extensive flooding of Midland Highway.	Critical Duration – 3 hrs (GSDM) • Flooding begins less than 2 hrs after rainfall commences. • Peak occurs at approximately 2 hours over majority of area. • There is lasting ponding across the area and extensive inundation of the road network. • Some overtopping of Western Freeway occurs • Note that local drainage is not included in the model.	Critical Duration – 3 hrs (GSDM) • Flooding begins less than 2 hrs after rainfall commences. • Peak occurs after 2-4 hours over majority of area. • Extensive inundation of most urban areas including areas west of Creswick St, south of Market St/Sharpes Rd, and East of Raglan St. • Flooding of urban areas along Clarke St (due to local rainfall). • Limited flooding of newer subdivisions on Howe St including Macarthur Park. • Inundation of all roads within flood extent including Howe St, Albert St, Clarke St, Coghills Creek Rd, Miners Rest Rd and Sunraysia Hwy. • Inundation of Sunraysia Highway to the south and west of Miners Rest. • Overtopping of Western Highway by tributary to south-west of Miners Rest.	Critical Duration – 3 hrs (GSDM) in tributaries, and 12hrs (GSAM) for Burrumbeet Creek • Flooding begins 2 hours after rainfall commences. • Peak occurs at approximately 2 hours in upper tributaries, and 12-14 hours in the floodplain. • Flooding occurs in wetland areas to the north of the catchment and there is significant overflow from two of these areas to Burrumbeet Creek tributary. • Extensive floodplain inundation on Burrumbeet Creek and wetland area to the immediate west of Sunraysia highway. • Extensive inundation of Sunraysia Highway from Burrumbeet Creek as well as tributaries. • Extensive inundation of Pound Hill Road. • Extensive inundation of Western Highway.	Critical Duration – 3 hrs (GSDM) in tributaries, and 12hrs (GSAM) for Burrumbeet Creek • Flooding begins 2 hours after rainfall commences. • Peak occurs at approximately 2 hours in upper tributaries, and 14-16 hours in Burrumbeet Creek. • Burrumbeet Creek located within gorge over this section and therefore flood extent generally confined by terrain although there are sections of wider inundation particularly downstream o fOld Western Highway. • Inundation of numerous roads that cross tributaries, including Blind Creek Road.	Critical Duration – 3 hrs (GSDM) • Flooding begins less than 2 hrs after rainfall commences. • Peak occurs at approximately 2 hours over majority of area. • Extensive inundation of the airport infrastructure including limited inundation of runways • Inundation of numerous roads including Blind Creek Rd and McCartneys Rd.

Table 4-4 Summary of Climate Change Effects on Flood Behaviour for Various Design Flood Events with an Increase in Rainfall Intensity of 20%

Event	Invermay (upper catchment to Gillies Rd)	Mt Rowan - Sulky	Ballarat Urban (south of freeway)	Miners Rest (Gillies Rd to Glenanes Rd)	Learmonth (north of western highway)	Cardigan (south of western highway, west of Airport to Lake Burrumbeet)	Airport
10% AEP	• Flood levels in the upper tributaries are relatively unaffected • The impact on flood levels is greater in the main Burrumbeet Creek floodplain • Flood levels are generally increased by less than 0.3 m, but are locally increased by up to 0.5m around Midland Highway and the rail line • Flood extent is increased significantly in parts, particularly between rail line and Midland Highway on the northern tributary, and between Midland Highway and Gillies Road on Burrumbeet Creek.	• Flood levels in the upper tributaries are relatively unaffected • The impact on flood levels is greater in the main Burrumbeet Creek floodplain • Flood levels are generally increased by less than 0.3 m, but are locally increased by up to 0.7m upstream of Kennedys Rd. • Flood extent is significantly increased at Sulky Road, across Kennedys Rd and upstream of Sharpes and Garlands Roads	• Flood levels are increased by up to 0.1 m. • The extent is only increased slightly with no notable areas of increased extent	• Flood levels in Burrumbeet Creek are increased by up to 0.3m. • Flood levels in the Miners Rest wetland are only increased slightly, with a corresponding slight increase in overflow into Raglan St and Sharpes Rd properties • Flood extent is increased significantly around Cummins Road and between Victoria St and Miners Rest Rd	• Flood levels in the upper tributaries are relatively unaffected • The impact on flood levels is greater in the main Burrumbeet Creek floodplain • Flood levels are generally increased by less than 0.4 m, but are locally increased by up to 0.5m around Sunraysia Hwy • Flood Extent is increased significantly in the wetland systems between Pound Hill Road and Sunraysia Hwy, and the floodplain north of Western Highway	• Flood levels in the upper tributaries are relatively unaffected • Flood levels in Burrumbeet Creek are increased by up to 0.5m. • Flood Extent is increased significantly in the tributary floodplain south of Western Highway, south of Remembrance Drive and just upstream of the outlet to Lake Burrumbeet	• Flood levels are increased by up to 0.15m. • The capacity of the Airport channel is just exceeded with some overflow through Airport areas. • Where the Airport creek meets the Western Fwy/Sunraysia Hwy interchange, levels are raised by up to 0.5m and a new flow path is formed along the southern side of Sunraysia Hwy.
1% AEP	• Flood levels in the upper tributaries are relatively unaffected • The impact on flood levels is greater in the main Burrumbeet Creek floodplain • Flood levels are generally increased by less than 0.3 m, but are locally increased by up to 1m upstream of Swinglers Rd. • Flood extent is increased significantly in parts, particularly around the Midland Hwy/Western Fwy interchange	• Flood levels in the upper tributaries are relatively unaffected • The impact on flood levels is greater in the main Burrumbeet Creek floodplain • Flood levels are generally increased by less than 0.2 m, but are locally increased by up to 1m around Ross Rd. • Flood extent has minimal increases in most areas. There is a significant increase in extent around the intersection of the rail line and Midland Highway where a new breakout is initiated, and around Ross Rd.	• Flood levels are generally increased by less than 0.1 m, but locally increased by up to 0.3 at Giot Drive. • Flood extent has minimal increases in most areas. There is a significant increase in extent around Giot Drive	• Flood levels in Burrumbeet Creek are increased by up to 0.3m. • Flood levels in the Miners Rest wetland are only increased slightly, with a corresponding slight increase in overflow into Raglan St and Sharpes Rd properties • Flood Extent has minimal increases in most areas upstream of Miners Rest. Downstream of Miners Rest the extent tends to be increased by around 20-30m at the margins.	• Flood levels in the upper tributaries are relatively unaffected • Flood levels in the Burrumbeet floodplain are generally increased by less than 0.2, but increased reach 0.5m north of Western Hwy. • Flood Extent has minimal increases in most areas although there is some increase in the wetland systems to the west of Sunraysia Highway, the floodplain between Pound Hill Rd and Sunraysia Hwy, and the floodplain between Pound Hill Rd and Western Hwy.	• Flood levels in the upper tributaries are increased by up to 0.2m. • Flood levels in Burrumbeet Creek are increased by up to 0.4m. • Flood Extent is increased minimally in tributaries and gorge section of Burrumbeet Creek. Flood extent is increased by around 20-30m in the tributary floodplain south of the Western Freeway	• Flood levels are increased by up to 0.2m. • There is a slight increase in extent of flooding in the Airport area. • Where the Airport creek meets the Western Fwy/Sunraysia Hwy interchange, levels are raised by up to 0.4m.

Event	Invermay (upper catchment to Gillies Rd)	Mt Rowan - Sulky	Ballarat Urban (south of freeway)	Miners Rest (Gillies Rd to Glenanes Rd)	Learmonth (north of western highway)	Cardigan (south of western highway, west of Airport to Lake Burrumbeet)	Airport
0.5% AEP	• Flood levels in the upper tributaries are relatively unaffected. • The impact on flood levels is greater in the narrow valley sections, and reaches 0.35 m upstream of Gillies Rd. • Flood Extent is increased significantly east of Old Midland Highway and around the floodplain margins between Midland Highway and Gillies Rd.	• Flood levels are generally increased by less than 0.2 m, but are locally increased by up to 0.7m around Ross Rd. • Flood extent has minimal increases in most areas. There is a significant increase in extent around the intersection of the rail line and Midland Highway where a new breakout is initiated, and around Ross Rd.	• Flood levels are generally increased by less than 0.1 m, but locally increased by up to 0.4 at Giot Drive. • Flood extent has minimal increases in most areas. There is a significant increase in extent around Giot Drive	• Flood levels in Burrumbeet Creek are increased by up to 0.2m. • Flood levels in the Miners Rest wetland are only increased slightly, with a corresponding slight increase in flood extent in Raglan St and Sharpes Rd properties • Flood Extent has minimal increases in most areas. There is a significant increase in extent upstream of Victoria St	• Flood levels in the upper tributaries are relatively unaffected • Flood levels in the Burrumbeet floodplain are increased by up to 0.2. • Flood Extent has minimal increases in most areas although there is some increase in the wetland systems to the west of Sunraysia Hwy, and the floodplains just upstream of Sunraysia Hwy	• Flood levels in the upper tributaries are increased by up to 0.2m. • Flood levels in Burrumbeet Creek are increased by up to 0.4m. • Flood levels in the tributary floodplain south of Western Hwy are increased by up to 0.45m. • Increases in flood extent are minimal, except in the tributary floodplain south of Western Hwy, where the extent is increased by 30-40m. There is also an increase in extent upstream of the rail line.	• Flood levels are increased by up to 0.1m. • There is a slight increase in extent of flooding in the Airport area. • Where the Airport creek meets the Western Fwy/Sunraysia Hwy interchange, levels are raised by up to 0.45m. • Extents are increased south of the Western Fwy, and extensive overtopping of the freeway is initiated.

5. IMPACTS OF FLOODING

5.1 Overview

The impact of flooding is assessed by estimating the likely cost of damages associated with a range of flood events in the Burrumbeet Creek catchment. Flood damage estimates have been calculated for a range of flood events from a 20% AEP to the 0.5% AEP event.

Key datasets that were required for the assessment process included:

- Topographic data (as described in Section 2) including aerial imagery and LiDAR,
- Location and description of buildings with floor levels and details of other infrastructure
- Design flood levels (from Section 4)
- Flood damage cost from available literature.

The information presented in this section is for the existing conditions in the Burrumbeet Creek floodplain, excluding urban areas of Wendouree. These urban areas have been modelled in this study in order to determine the effect on runoff and downstream flows but are not included in the final mapping outputs on request of Council as the local urban drainage network impacts on flooding were not considered.

5.1.1 Topographic Data

The detailed terrain model developed for this study was used for the assessment, as detailed in Reports 1 and 3 of this study.

5.1.2 Property Survey Data

Floor level survey of buildings in the study area was available for 155 properties, as detailed in Section 2.4.1.

The remaining properties were taken into account during the damages assessment through manually locating buildings using high resolution aerial imagery. Where floor survey could not be obtained, a freeboard of 200 mm was assumed above the topographic elevation derived from LiDAR.

5.1.3 Design Flood Levels

Design flood levels predicted by the hydraulic modelling (Section 4) were used to assess the damage risk at each property.

Due to the nature of the study area the design flood level for each flood event depends on the property under consideration. Detailed hydraulic model outputs were used to assess the site specific flood level for each property in the damage assessment.

5.1.4 Flood Damage Cost Information

Six key sources were used for flood damage cost estimation methodology:

- ANUFLOOD cost curves, from CRES (1992)
- 'Rapid Appraisal Method (RAM) For Floodplain Management' (Read Sturgess & Associates, 2000);
- 'Economic Costs of Natural Disasters in Australia' (Bureau of Transport Economics, 2001); and,
- 'Guidance on the Assessment of Tangible Flood Damages' (Queensland Government Department of Natural Resources and Mines, 2002).
- Impact of velocity on flood damage assessments in a recent study by Geoscience Australia (Middelmann-Fernandes, 2010)

- 'www.abs.gov.au' (The Australian Bureau of Statistics).

5.2 Assessment of Flood Damages Cost

5.2.1 Existing Conditions

The flood damages assessment covers the study extent as detailed in Figure 1-1 excluding those urban areas in Ballarat immediately south of the Western Highway. The economic costs and benefits focussed on urban areas, although farm buildings were included.

5.2.2 Direct Damages to Buildings (commercial, residential, rural)

Floods can potentially cause a high level of damage to buildings, including structural damage (eg. walls, floors, doors, etc.), contents damage (eg. carpets, furniture, etc.) and external damage (eg. gardens, etc.).

For each building, a depth of above floor inundation was calculated under existing conditions for the design flood levels adopted from Section 4, using the floor levels from the property data described in Section 2.4.1. External damage was incorporated using the properties flooded below floor level for the same design events and property data.

Stage-damage curves estimate the relationship between the depth of above floor inundation of a building and the potential flood damage cost. This relationship is typically calculated by post-flood survey. ANUFLOOD stage-damage curves for residential and commercial buildings (NRM, 2002), were factored up by 60% to bring them up to a representative 1999 flood damage cost level, as recommended by Read Sturgess & Associates (2000). They were then factored up to a June 2011 flood damage cost level using Building Price Index (BPI) and Consumer Price Index (CPI) from the Australia Bureau of Statistics website (www.abs.gov.au). At the time of the study, data for 2012 was not currently available.

The total potential flood damage cost for existing conditions was then calculated by applying the updated stage-damage curves to each building and summing the individual potential flood damage costs.

The total potential flood damage cost represents the flood damage cost if no remedial action is taken. In reality, communities at risk of flooding will usually have some warning and will be able to take steps toward reducing the cost of flood damage (i.e. evacuation, doorstep sandbagging or removing valuable items to a safe level above flood waters). Read, Sturgess & Associates (2000), estimated that for communities such as Miners Rest, having prior flood experience and some warning time (2-4 hours), the ratio of actual to potential flood damage cost could be around 0.8. With increased warning time this ratio can be reduced to around 0.4. In this study a ratio of 0.8 was applied to the total potential flood damage cost as a conservative estimate of the total actual flood damage cost.

The total actual flood damage cost along with the number of residential, commercial and agricultural buildings inundated for the adopted existing condition design flood levels are presented in Table 5-1.

As presented in Table 5-1 the estimated actual flood damage cost for buildings under existing conditions is approximately **$2,053,826** for the 1% AEP event.

5.2.3 Direct Damages to Infrastructure

Floods can potentially cause significant damage to roads and other inundated infrastructure such as bridges. Roads can suffer initial damage from flooding as well as accelerated deterioration due to water intrusion under the pavement. While for agricultural land, the type of land use (e.g. crop type) is important for estimating likely damages.

The RAM method (Read Sturgess & Associates, 2000) includes costings for roads and bridges, and agricultural enterprises in addition to the direct building costs. The costs for roads and bridges from the RAM method were adopted and updated in the NRM (2002) report. These values were applied to the present study and factored up by CPI to June 2011 dollars. Agricultural land was not included in the damages assessment at Burrumbeet as the land within the study area affected by flooding is predominantly limited to commercial and residential property.

The length of inundated major, minor and unsealed roads was calculated for the adopted existing condition design flood levels, and used to estimate the total cost of flood damage to infrastructure, Table 5-2.

5.2.4 Indirect Damages

Indirect flood damages are damages sustained as a consequence of a flood but are not due to the direct impact of a flood (e.g. emergency services, clean-up costs, alternative accommodation, disruption to business, etc.). Indirect costs are much harder to quantify than direct costs, so only the more readily estimated costs are usually included.

Read, Sturgess & Associates (2000) recommend estimating indirect costs as 30% of total direct costs (depending on population density). This is a fairly coarse approximation and has not been adopted in this case. Instead a more detailed analysis has been undertaken, using methodology from BTE (2001).

Included in the estimate of indirect flood damage costs are residential and commercial clean-up, alternative accommodation and relocation of household goods, and emergency response costs, Table 5-3.

5.2.5 Total Existing Conditions Damages

The total flood damage cost for the Burrumbeet study area under existing conditions is a sum of the actual flood damage cost of buildings, the road flood damage cost and the indirect flood damage cost, Table 5-4. The total existing conditions flood damage cost for the 1% AEP event is **$3,086,886.**

This gives an annual average damage (AAD) cost of **$270,661**. The AAD is a measure of the flood damage per year averaged over an extended period. It is calculated by the area under the flood frequency and total flood damage curve. It can be thought of as the collective total that should be put aside every year to cover the private and public cost of flood events within the study area.

Table 5-1 Total Actual Flood Damage Cost to Buildings for Existing Conditions

Parameter	**Annual Exceedence Probability**					
	0.5%	**1%**	**2%**	**5%**	**10%**	**20%**
Buildings Flooded Above Floor	42	36	18	3	2	1
Properties Flooded Below Floor	145	142	142	109	98	82
Total Properties Flooded	187	178	160	112	100	83
Direct Potential External Damage Cost	$640,092	$577,386	$531,120	$362,444	$295,502	$234,627
Direct Potential Residential Damage Cost	$2,362,337	$1,973,852	$807,184	$72,118	$60,487	$34,408
Direct Potential Commercial Damage Cost	$22,461	$16,044	$8,221	$4,442	$0	$0
Total Direct Potential Damage Cost*	**$3,024,891**	**$2,567,282**	**$1,346,525**	**$439,004**	**$355,989**	**$269,035**
Total Actual Damage Cost *(0.8*Potential)*	**$2,419,913**	**$2,053,826**	**$1,077,220**	**$351,203**	**$284,791**	**$215,228**

*Note that these costs are for property damage only and do not include road repairs or indirect clean-up costs.

Table 5-2 Total Actual Flood Damage Cost to Infrastructure for Existing Conditions

Parameter	Annual Exceedence Probability					
	0.5%	1%	2%	5%	10%	20%
Infrastructure Damage Cost	**$890,151**	**$773,693**	**$662,319**	**$499,168**	**$404,209**	**$334,512**

Table 5-3 Total Indirect Damage Cost for Existing Conditions

Parameter	Annual Exceedence Probability					
	0.5%	1%	2%	5%	10%	20%
Indirect Clean Up Cost	$241,943	$207,058	$102,404	$15,193	$11,628	$5,814
Indirect Residential Relocation Cost	$32,042	$27,353	$13,286	$1,563	$1,563	$782
Indirect Emergency Response Cost	$33,275	$24,956	$19,965	$14,974	$9,983	$4,991
Total Indirect Damage Cost	**$307,260**	**$259,367**	**$135,655**	**$31,729**	**$23,174**	**$11,587**

Table 5-4 Total Flood Damage Cost for Existing Conditions

Parameter	Annual Exceedence Probability					
	0.5%	1%	2%	5%	10%	20%
Total Damage Cost	**$3,617,324**	**$3,086,886**	**$1,875,193**	**$882,100**	**$712,173**	**$561,327**

6. FLOOD RISK MITIGATION

6.1 Overview

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

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

The following discussion outlines the preliminary assessment of structural mitigation measures for the study area. Non-structural mitigation measures are discussed further in Sections 6.3 and 8.3.

6.2 Structural Mitigation Measures

6.2.1 Overview

Structural mitigation measures are physical works to reduce the likelihood of flooding in a given location. The full list of potential structural mitigation measures for the Burrumbeet Creek study area and the source of the suggestion are shown in Table 6-1.

Table 6-1 Suggested mitigation options

Option No.	Detail	Source
1	Levee at Miners Rest	Ballarat City Council
2	Retarding basin upstream of Miners Rest	Ballarat City Council
3	Upgrade railway line in Invermay	Ballarat City Council
4	Increase Channel Capacity through excavation	2003 Floodplain Management Plan
5	Reduction in Exotic Vegetation in the Creek Channel	2003 Floodplain Management Plan
6	High flow bypass channel south of Miners Rest (location 12)	2003 Floodplain Management Plan
7	Increase Capacity of Bridges	2003 Floodplain Management Plan and Ballarat City Council
8	Flood channel to the north of Miners Rest	Ballarat City Council

All options were subject to a preliminary feasibility assessment with details provided in Report 5 of this study. Options 1, 2 and 8 were investigated in detail, using hydrologic and/or hydraulic modelling.

6.2.2 Assessment Criteria

Each mitigation option was assessed against a number of criteria, potential reduction in flood damage, cost of construction, feasibility of construction and environmental impact. The score for each criterion was based on a ranking system of 1 to 5, with 1 being the worst score and 5 the best. Each criteria score was then weighted according to the weighting shown in Table 6-2 below. The reduction in flood damage was the most heavily weighted criteria as this is the main objective for all flood mitigation.

Table 6-2 Prefeasibility assessment criteria

Score	Reduction in Flood Damages	Cost ($)	Feasibility/Constructability	Environmental Impact
Weighting	**2**	**1**	**0.5**	**0.5**
5	Major reduction in flood damage	Less than $50,000	Excellent (Ease of construction and/or highly feasible option)	None
4	Moderate reduction in flood damage	$50,000 – $100,000	Good	Minor
3	Minor reduction in flood damage	$100,000 – $500,000	Average	Some
2	No reduction in flood damage	$500,000 – $1,000,000	Below Average	Major
1	Increase in flood damage	Greater than $1,000,000	Poor (No access to site and/or highly unfeasible option)	Extreme

6.2.3 Assessment Outcome

Each of the suggested mitigation options was assessed using the outlined assessment criteria as shown in Table 6-2. In some instances additional modelling or review was undertaken to provide input to the assessment as detailed in Report 5.

Using the feasibility assessment above, the 8 mitigation options were ranked by weighted score. The ranking of the top 4 options is shown below in Table 6-3. The fourth option shown in the table was assessed and incorporated after completion of the main mitigation options assessment. All other options were found to be unfeasible on the basis of low associated damage reduction, high costs and other constructability or environmental issues. A discussion for each of the top four options is provided in the following sections.

Table 6-3 Weighted feasibility mitigation Scores

Rank	Option No.	Mitigation Option	Weighted Score
1	1	Levee at Miners Rest	18
2	6	High flow bypass channel south of Miners Rest	17
3	2	Retarding basin upstream of Miners Rest	14.5
4	8	Flood channel to the north of Miners Rest	NA

6.2.4 Levee at Miners Rest

Albert St has been identified as a potential location for a levee to protect the township of Miners Rest (Figure 6-1). The levee would need to be raised to the 1% flood level plus freeboard. It is assumed the levee would be constructed adjacent to the road; however it could equally be constructed through raising of the road surface.

The Albert St levee could prevent flooding of almost 40 properties. The change in flood level and extent that could be achieved by the levee is shown in Figure 6-2. The effect of the levee on water levels in the floodplain is minimal, with water levels raised locally by up to 50 mm, although approximately 4 properties on the Burrumbeet Creek side of the levee are affected by increased water levels of between 20 to 50 mm. This increase in flood levels does not change the current flood conditions for each property; two of the properties are currently flooded above floor level and this is not changed, while flood levels for those flooded below floor do not increase flooding above the surveyed floor level.

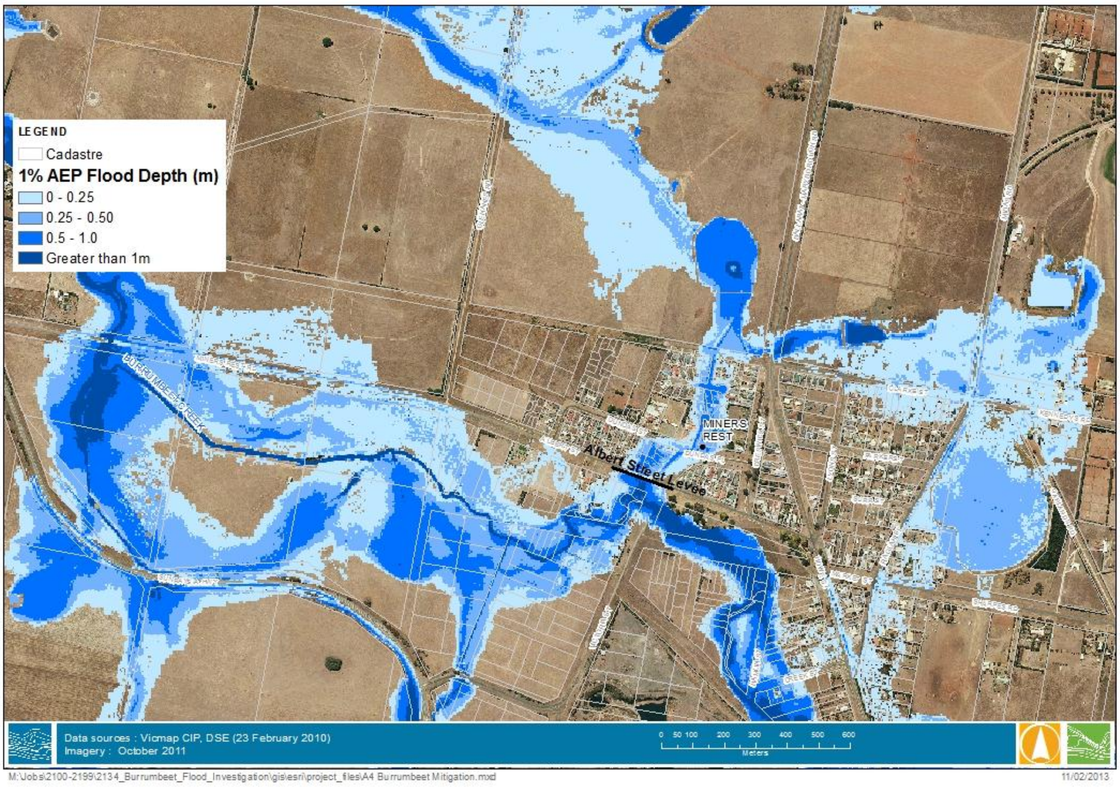

Figure 6-1 Location of Miners Rest Albert Street Levee Option

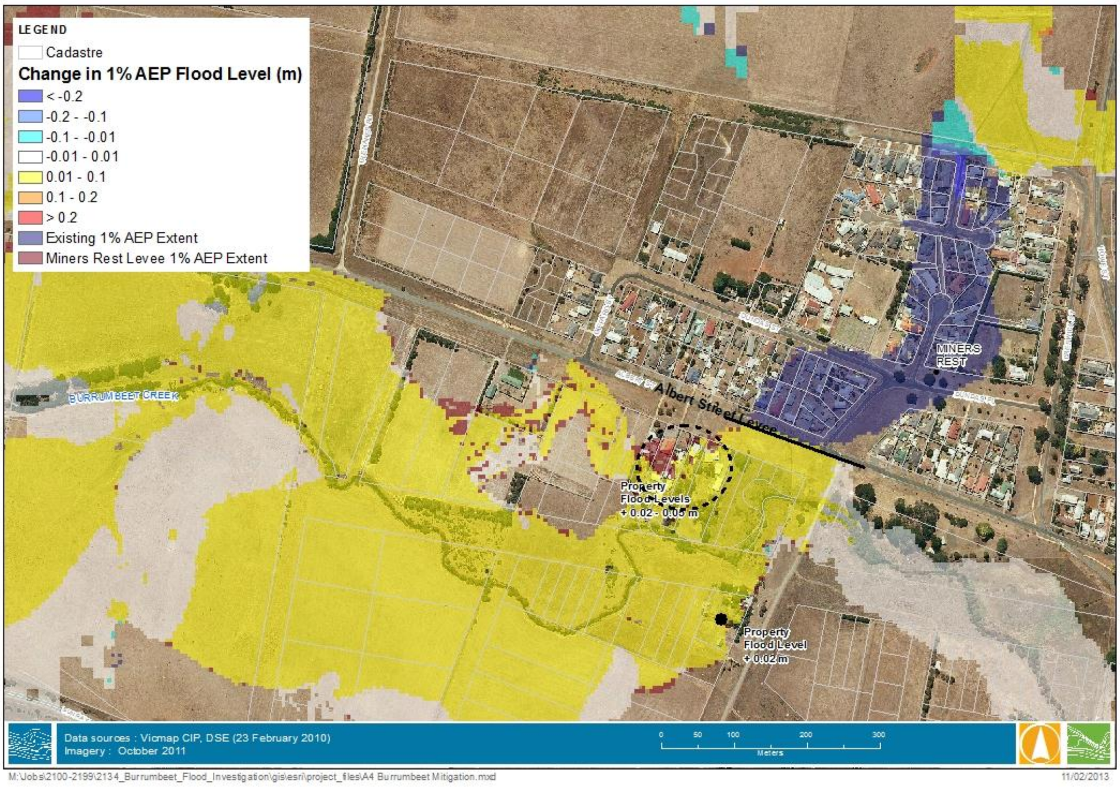

Figure 6-2 **Difference in 1% AEP flood extent and level that could be achieved as a result of Miners Rest Albert Street Levee**

6.2.5 Retarding Basin Upstream of Miners Rest

Overtopping of Albert Street in Miners Rest is initiated at a flow rate of approximately 60 m^3/s in Burrumbeet Creek. If the peak flow above this can be reduced, then significant reductions in flood damages in Miners Rest can be achieved.

Two locations have been identified as candidates for a retarding basin – upstream of Cummins Road and upstream of Gillies Road.

The Cummins Road Retarding Basin could reduce the 1% AEP peak flow at Miners Rest from 118 to 95 m^3/s, and lower flood levels at Miners Rest by up to 0.25 m. The Gillies Road Retarding Basin could reduce the 1% AEP peak flow at Miners Rest to 106 m^3/s, and lower flood levels in Miners Rest by up to 0.1 m.

The change in 1% AEP flood level and extent that could be achieved by each of the retarding basin option is shown in Figure 6-3 and Figure 6-4.

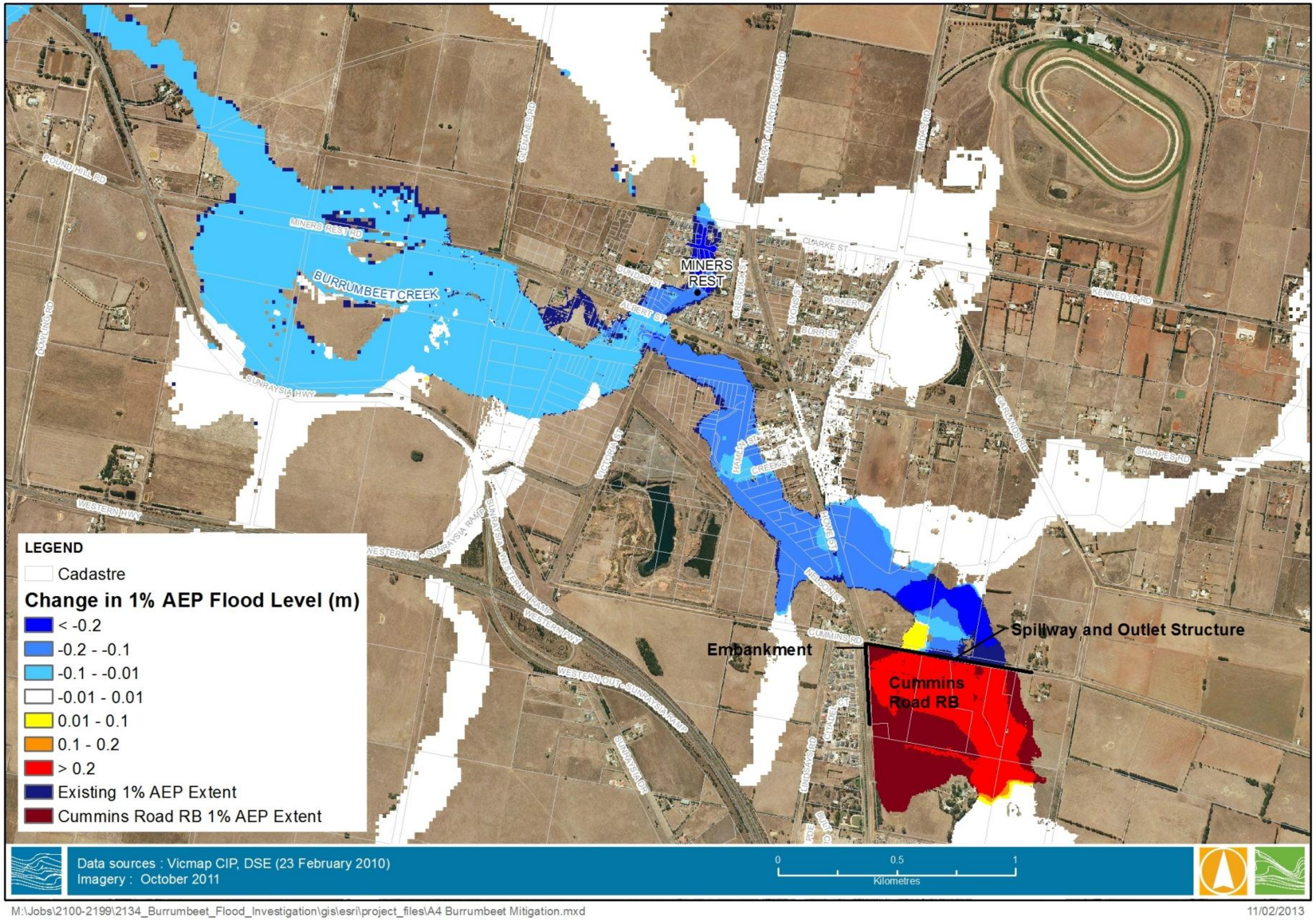

Figure 6-3 Difference in 1% AEP flood extent and level as a result of Cummins Road Retarding Basin

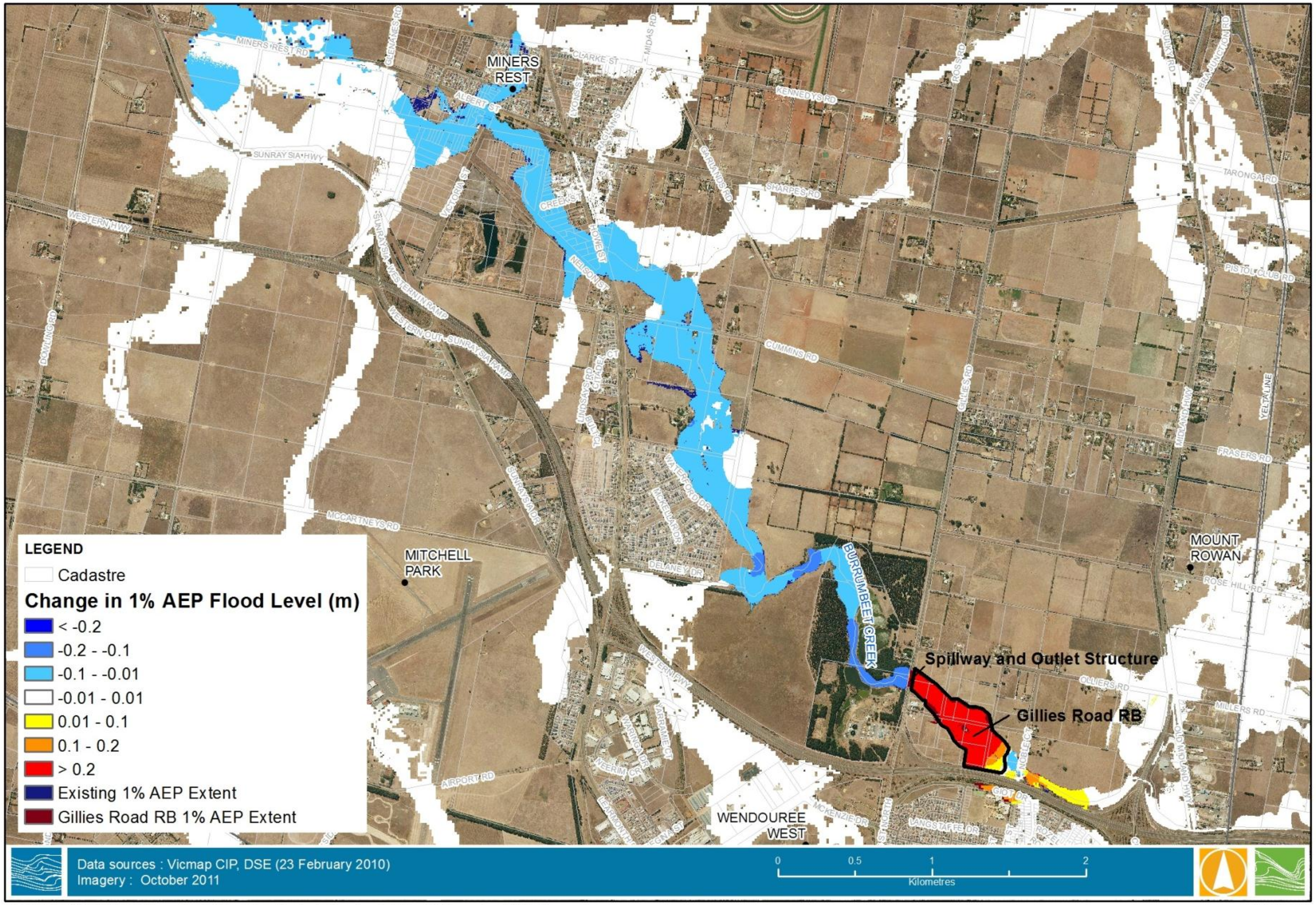

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Figure 6-4 Difference in 1% AEP flood extent and level as a result of Gillies Road Retarding Basin

6.2.6 High Flow Bypass Channel South of Miners Rest

A bypass channel to the south of Miners Rest was proposed to decrease the flow and water level through the Miners Rest section of Burrumbeet Creek and stop flooding across Albert Street into residential areas. The location of the bypass channel option is shown in Figure 6-5. This option has not been specifically modelled, however a preliminary feasibility assessment indicates that such a channel is feasible and could significantly mitigate flooding at Miners Rest.

The channel could reduce the 1% AEP flow at Miners Rest from 116 to 80 m^3/s, and could eliminate overtopping of Albert St in the 2% AEP.

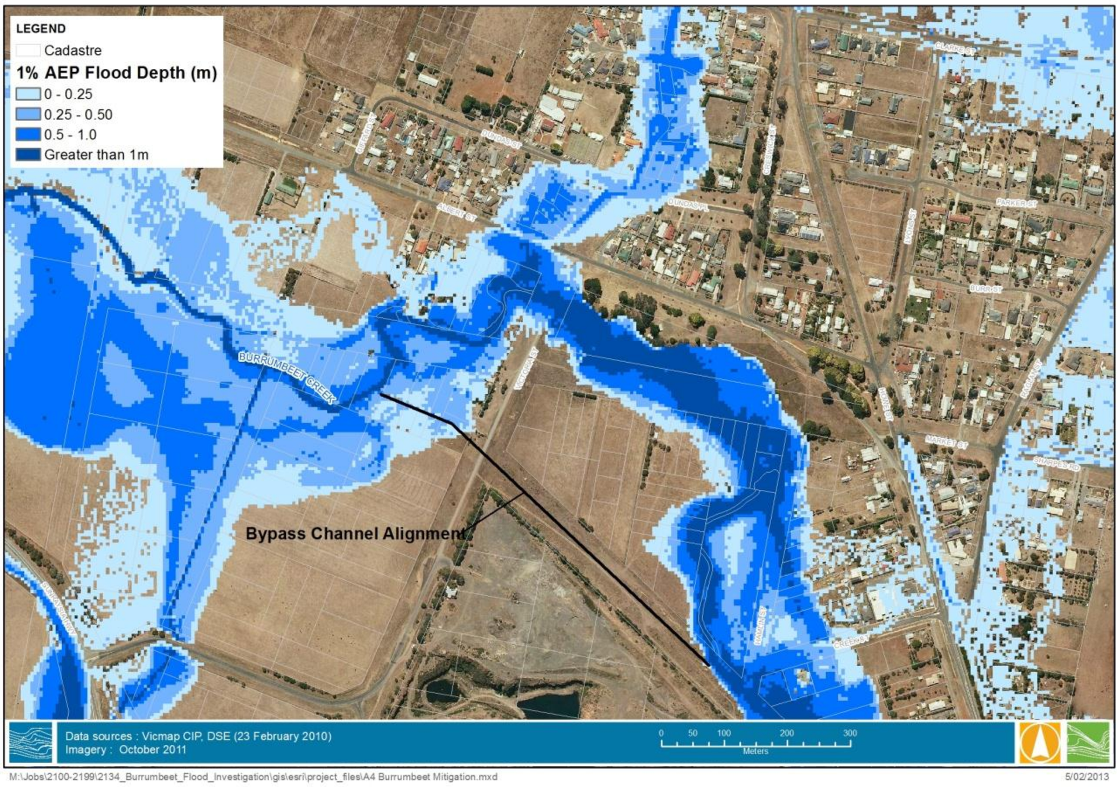

Figure 6-5 Alignment of Miners Rest bypass channel option

6.2.7 Flood Channel to the North of Miners Rest

A flood channel was proposed for the area to the north of Miners Rest in the Dowling Forest Precinct to mitigate an area of shallow inundation of land to the north of Clarke Street, Miners Rest. This option involved the provision of a flood drainage channel along the existing road reserve, as shown in Figure 6-6.

A feasibility assessment of this option included preliminary modelling of the proposed channel in the hydraulic model for the 1% AEP flood event. The results indicated that such a channel was feasible and could eliminate shallow inundation to the north of Clarke Street (east) in Miners Rest (Figure 6-7) but could also increase flood impacts on properties located between Albert Street and Clarke Street (Figure 6-8). To be most effective and eliminate any increase in flood impacts on existing properties this option would need to be combined with the Albert Street levee option.

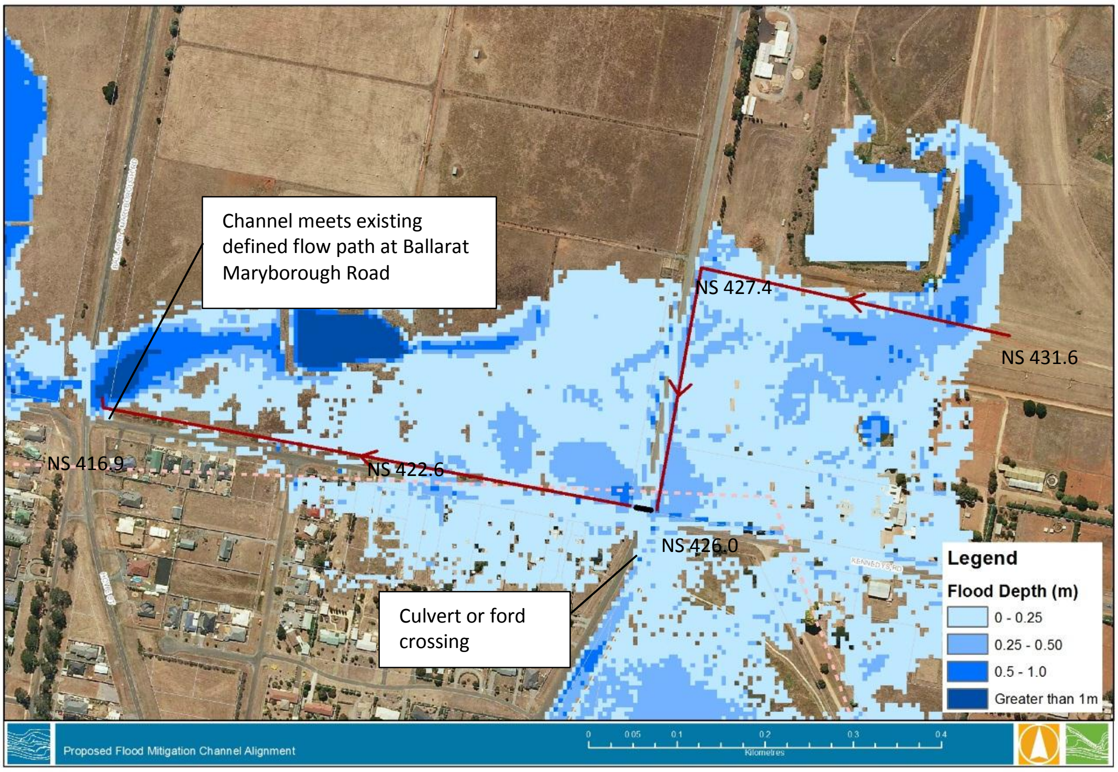

Figure 6-6 Proposed northern flood channel alignment (with existing conditions 1% AEP flood extent)

Figure 6-7 1% AEP flood extent with northern flood channel

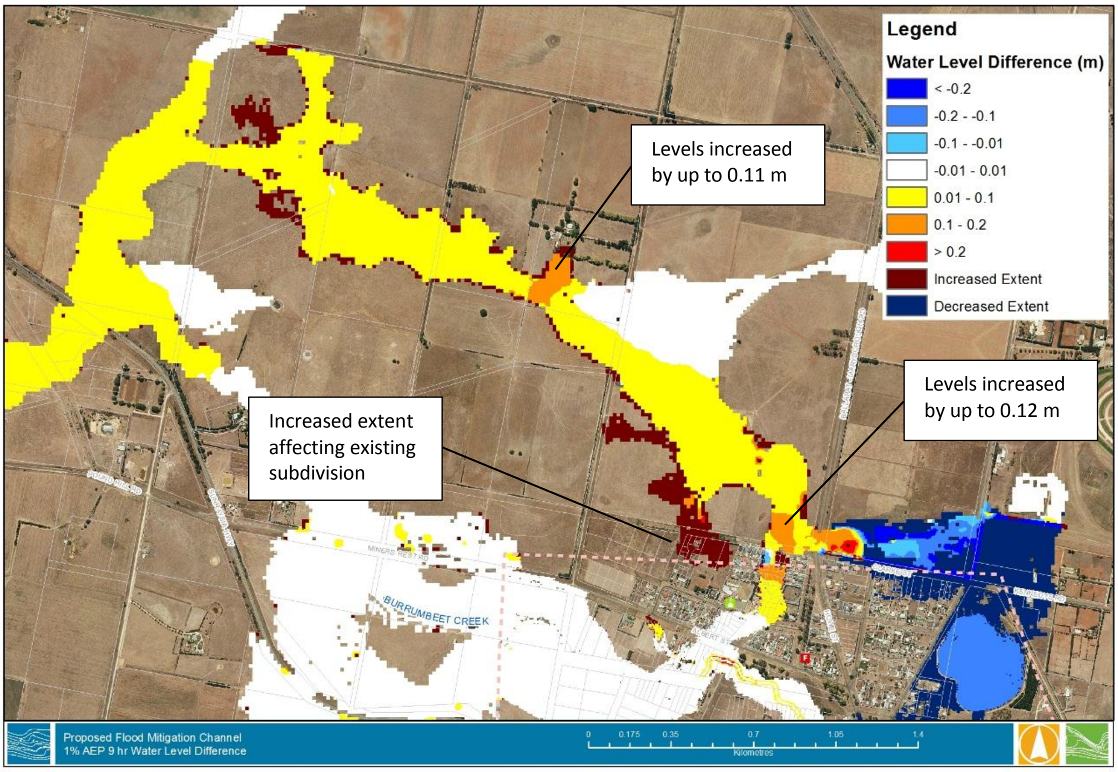

Figure 6-8 **Difference in 1% AEP flood extent and level that could be achieved as a result of the northern flood channel**

6.3 Non-Structural Mitigation Measures

6.3.1 Overview

Non-structural measures are floodplain management activities aimed at reducing future flood damages. Non-structural measures aim to reduce existing flood risk by lowering flood damages (consequences) at a given location (as opposed to structural measures which tend to reduce frequency or likelihood of flooding). Non-structural measures include:

- Catchment management
- Flood awareness, preparedness, warning and response
- Land use planning

Catchment management activities in the upstream catchment can influence the existing catchment runoff characteristics (flood peaks and volumes). Flood volumes and peaks are a function of the vegetation cover and land use within a catchment (in addition to topography). Land clearing and drainage works have significantly altered flood response in the catchment. Further drainage works may increase flood peaks and flood volumes resulting from significant rainfall events. Increases in peak flows and flood volumes in turn result in a higher flooding likelihood and flood risk. Catchment revegetation, over the longer term may reduce flood volumes. However, in major floods reductions in peak flow would be expected to be minimal.

Flood awareness, preparedness, warning and response aims to reduce the growth in future flood damages by improving community awareness of flooding and emergency services response. Flood awareness within a community reflects the frequency of significant flooding i.e. infrequent insignificant flooding leads to lower community flood awareness. The most recent significant flooding events occurred in the 2010/2011 flood events. Given the recent occurrence of significant flooding with associated damages to property, the community awareness of flooding in the Burrumbeet Creek catchment is expected to be at a medium level. This level of awareness has been demonstrated to diminish over time if community flood awareness programs are not ongoing.

Further discussion of flood warning and response arrangements, and community flood awareness is provided in Section 7.

Land use planning aims to reduce flood damages by providing appropriate guidelines/controls for land use and development. The Victorian Planning Provisions (VPPs) allow for zoning of land and the application of controls on the type of land use and permitted activities in areas prone to flooding. The VPPs provide for the following flood related zone and overlays:

- Land Subject to Inundation Overlay (LSIO)
- Floodway Overlay (FO)
- Urban Floodway Zones (UFZ)

The VPPs provide guidelines for the appropriate uses and/or development of land in LSIO, UFZ and FO areas. Further discussion of proposed land use planning mapping developed by this study for the Burrumbeet Creek catchment is provided in Section 8.

7. EMERGENCY MANAGEMENT

7.1 Overview

The 2010-11 flood events confirmed that a formal flood forecasting and warning system does not exist for Burrumbeet Creek or for any of the communities within the catchment. Further, the events highlighted critical deficiencies in existing arrangements and demonstrated that they failed to meet community and emergency agency expectations regarding the provision of accurate and timely information aimed at facilitating appropriate response actions. These issues were discussed in the Glenelg Hopkins CMA submission (Water Technology, 2011) to the Comrie Review (Comrie, 2011). While a range of matters were covered in that submission, it was noted in particular that:

- The "total" flood warning system is limited and that most of the deficiencies arise from the lack of data and related flood intelligence.
- The rain and river level data collection network is sparse and is inadequate, it is not sufficiently dense or accessible:
  - There is a clear need for a more dense network of rain and stream[1] gauges;
  - Rain and stream gauges need to be automated and to report in real-time;
  - Resulting data needs to be uploaded to the Bureau of Meteorology website so that it is accessible to communities and response and related agencies and available to assist their maintenance of an up-to-date appreciation of event development.
- At-risk communities within the Burrumbeet Creek catchment are not provided with any guidance on likely future flood conditions (i.e. a flood forecast or other information about the time to rise above predetermined critical levels, time to peak, likely peak level, etc.), with the result that appropriate damage reducing actions are not implemented with sufficient lead time:
  - There is need for an improved flood forecast capacity based on robust models that use rainfall data to predict stream flows and levels at key locations;
  - Flood class levels need to be established for all at-risk/forecast locations.
- The intelligence that enables a predicted flood height or rainfall depth to be interpreted in terms of flood inundation extents, depths and likely impacts is not available.
- Other elements of the total flood warning system need to be fully established and/or strengthened.

With the above comments in mind and the benefit of the flood intelligence (particularly the City of Ballarat Flood Emergency Plan Appendices for Burrumbeet Creek) and flood mapping delivered by the Burrumbeet Flood Investigation, existing flood warning arrangements have been examined in the context of the Total Flood Warning System (TFWS) model (EMA, 2009). Following consideration of available remedies and local flooding characteristics, actions aimed at addressing deficiencies in each of the eight TFWS building blocks have been recommended, refer to Report 7 of this study. Approximate cost estimates were also provided.

The detailed flood warning/emergency response report is provided in Report 7 while a summary of the recommendations is provided in the following sections.

[1] Also referred to as river gauging stations. Both terms are used throughout this report.

7.2 Suggested Actions

A staged approach to the development of a flood warning system for the Burrumbeet Creek catchment 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 Report 7. While it may be tempting to immediately move to install additional rain and river gauges and to develop/strengthen forecast capability, there are other more fundamental matters that experience tells us need to be addressed first.

Thus early attention is directed at ensuring that all involved entities agree on the scope of the proposed flash flood warning system and that the roles and responsibilities are agreed, understood and accepted. This will establish a firm foundation from which to develop an effective flash flood warning system: one that does not fail when it is needed most.

Attention is then directed to establishing a robust framework for communicating and disseminating flood related information so that immediate and maximum use can be made of available information as the ability to detect and predict flooding within the Burrumbeet catchment improves. It is at this stage that a decision on the scope of the flash flood warning system is required: simple, best possible or somewhere in between.

A tiered approach based around that decision is proposed wherein attention moves either to other TFWS elements or is focussed on securing the funding needed to buy, install and operate field equipment as well as other services needed to build elements of the TFWS.

The installation of data collection equipment follows, with a two tiered approach in the event that funding is not available or is delayed. Development of other technical elements and the build and delivery of on-going flood awareness activities can then occur in the knowledge that required data is/will be available and that robust and sustainable arrangements are in place that will enable maximum benefit to be derived from any information or programs delivered to the community.

Table 7-1 Suggested Flood Warning/Emergency Management Actions for Burrumbeet Creek

Stage	Suggested Actions
1	1. Council in conjunction with other agencies and communities as considered appropriate by Council, to review and either endorse or modify the proposition that: ▪ The proposed flash flood warning system (FFWS) for the Burrumbeet Creek catchment shall be concentrated, for the time being, on Miners Rest; ▪ The FFWS shall only be expanded to other areas within the catchment at Council's discretion, in a manner that is acceptable to Council and the responsible entities, and with due regard for need, benefit and opportunity; ▪ The FFWS will initially rely on rainfall data from the Ballarat Aerodrome AWS and the indicative quick look 'flood/no-flood' tool contained in the City of Ballarat MFEP and that development shall concentrate on the other TFWS elements; ▪ Work to establish a more sophisticated data collection network and/or flash flood forecasting model shall occur at Council's discretion, in a manner that is acceptable to Council and the responsible entities, and with due regard for need, benefit and opportunity. 2. Council, GHCMA, VICSES, BoM, DSE and other entities to determine and agree the responsible entity in relation to "ownership" of <u>each element of the flash flood warning system</u> for the Burrumbeet catchment. Note that ownership is considered to denote overall responsibility for funding as well as the functioning

Stage	Suggested Actions
	of the system element and, in the event of failure, responsibility for either fault-fix or the organisation of appropriate fault-fix actions along with any associated payments. VFWCC (2001) provides guidance on data collection network aspects although recommendation 5 from the Comrie Review Report (Comrie, 2011) suggests that some clarifications may be required[2]. 3. Council to: ▪ Monitor, possibly through DEPI, progress with the automation and telemetering of existing rain gauges in the general vicinity of the Burrumbeet Creek catchment as well as progress with the installation of new rain gauges near the top end of McCallum Creek and in the Baillie Creek catchment; ▪ Encourage BoM to add all new telemetered rain gauge data to the web data tables so that data is available to communities within the Burrumbeet catchment (and others) at (ideally) hourly intervals or more frequently.
2	A. Council to champion and in conjunction with VICSES oversee the establishment of a flood action or flood warden group for Miners Rest. Clearly establish the role and function for this group along with its authority and structure with due regard for liability issues. Essentially the group would: ▪ Monitor rain and creek information via the BoM website. ▪ If and when manual rain and river gauges are installed, collect and collate rain and water level/flow data. ▪ Make initial assessments of the likelihood and scale of flooding at Miners Rest within the catchment based on available rainfall data (and water levels and trends if available), and the indicative quick look 'flood/no-flood' tool developed for Miners Rest and included in the City of Ballarat MFEP. ▪ In the event of likely flooding, call VICSES to advise of likely flooding and, subject to discussion with the RDO or IC, call the City of Ballarat MERO and initiate flood response actions within Miners Rest/the Burrumbeet catchment consistent with the MFEP. This may include door knocking and through the MFEP, identification of roads and properties likely to be impacted. Thereafter work closely with VICSES, CFA and Council. ▪ Maintain a watching brief on flood response arrangements within the catchment/at Miners Rest and provide feedback to Council on the adequacy and efficacy of arrangements in place at the time. B. Council with the support of VICSES, GHCMA and communities in the Burrumbeet catchment to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements of a FFWS for Burrumbeet Creek to Miners Rest. C. Council to establish arrangements for the timely supply of sandbags and sand within Miners Rest. D. Council to champion and in conjunction with VICSES oversee the establishment of a flood action group.

[2] VFWCC (2001) provides guidance on responsibilities for funding the capital and on-going costs associated with rain and river gauges for flood warning purposes (essentially this advocates application of a beneficiary pays principle). Comrie (2011) suggests that some clarifications may be required.

Stage	Suggested Actions
3	A. Council to develop a schema for weighting rainfall data obtained from recently telemetered rain gauges so that the data can be used to better inform the indicative 'flood/no-flood' tool for Miners Rest. B. VICSES to share the MFEP, indicative 'flood/no-flood' tool, and the mapping arising from the Burrumbeet Creek Flood Investigation with communities in the Burrumbeet catchment. C. VICSES to load and maintain flood related material (including the MFEP) to its website. D. VICSES and Council to encourage and assist residents and businesses to develop individual flood response plans.
4	A. VICSES to develop and distribute a Local Flood Guide for Miners Rest and the Burrumbeet Creek catchment. B. VICSES with assistance from Council to initiate a community engagement program to communicate how the FFWS will work. It is likely that this program will need to be repeated as the system matures.
5	A. Council to oversee the development, printing and distribution of property-specific flood depth charts for properties within Miners Rest at risk of over-floor flooding. B. Council to consider installing flood depth indicator boards at key locations within the Burrumbeet Creek catchment (e.g. high hazard areas, where flood waters routinely cross roads at depth / speed, etc).
6	**but only if required** 1. Council to determine the location of private rain gauges within or in close vicinity to the upper reaches of the Burrumbeet catchment and between Miners Rest and Creswick and establish arrangements for the provision of rainfall data to the flash flood action or flood warden group at frequent intervals during heavy rain events. Alternatively, Council to source two rain gauges and distribute to local residents willing to provide rainfall data at frequent intervals during heavy rain events in the general vicinity of: ▪ The upper reaches of the Burrumbeet catchment to the east of Miners Rest, ▪ The catchment boundary between Miners Rest and Creswick. 2. Council to develop a schema for weighting rainfall data obtained from the above manually read rain gauges so that the data can be used to inform the indicative 'flood/no-flood' tool for Miners Rest.
7	**but only if the FFWS is to be taken past the base case for Miners Rest** A. Install a set of staff gauges immediately upstream of (say) the Howe Street crossing at Miners Rest. Set to either AHD or local datum and survey to AHD. Establish on-going gauge reading and maintenance arrangements, the latter ideally through the Surface Water Monitoring Partnership. B. VICSES to update the MFEP with staff gauge datums and other relevant details.
8	**but only if a more sophisticated FFWS is to be developed** A. Council with the support of VICSES, GHCMA and communities in the Burrumbeet catchment to submit an application for funding under the Australian Government

Stage	Suggested Actions
	Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements of a sophisticated FFWS for the Burrumbeet Creek catchment.
9	**following receipt of funding** A. Install an ERTS - ALERT flood monitoring system comprising: ▪ An ERTS rain - river installation immediately upstream of (say) Howe Street at Miners Rest; ▪ Additional ERTS rain - river installations at other key locations, as required, complete with staff gauges. Same configuration as at Howe Street; ▪ A local base station. B. Establish on-going maintenance arrangements for all installed equipment, ideally through the Surface Water Monitoring Partnership. C. If appropriate and following achievement of full operational status of each ERTS site providing additional rain and river data, retire the manual readers in the general vicinity who have previously provided manually read data. D. Approach BoM to add all telemetered sites to appropriate rainfall and river level bulletins accessible via the BoM website. E. In conjunction with VICSES, GHCMA, BoM and the Miners Rest based flood action or flood warden group, Council to determine appropriate alarm criteria for the ERTS rain and creek sites. These would be used to initiate local alerting of potential flooding. These could lead to the establishment of flood class levels if desired. F. Implement a community flash flood alerting and the new ERTS base station to alert communities in the Burrumbeet Creek catchment to the exceedance of alarm criteria at the ERTS rain and/or creek sites and the likelihood of flooding. G. Consider the need to expand or replicate the flood action or flood warden group concept established for Miners Rest to other areas within the Burrumbeet catchment. H. VICSES to rerun the community engagement program in order to communicate how the expanded FFWS will work. This will need to be repeated as the system continues to mature.
10	**Longer term actions that will depend on the identification of a willing responsible entity** A. Develop, run and maintain a rainfall-runoff based flash flood forecast model for the Burrumbeet Creek catchment.

8. DATASETS AND MAPPING

8.1 Overview

The flood mapping and datasets developed as part of the Burrumbeet Flood Investigation are described in this section. Details are provided regarding the input data, methodology and outputs for the emergency response inundation and land use planning mapping.

8.2 Flood Inundation Mapping

8.2.1 Overview

Flood inundation maps have been provided in pdf format for each flood event at 1:5,000 and 1:15,000 scales. The map base is cadastre as supplied in 2011 and is subject to change.

The following map components were generated:

- Flood extent and flood depth
- Flood elevation contours
- Flood affected properties
- Emergency service locations

8.2.2 Flood Extent and Flood Depth Zones

The hydraulic analysis provides regular grid of flood elevations across the hydraulic model study area. The flood extent was defined by intersecting the modelled flood elevations with a 3 m grid of the LiDAR. Following the intersection, all grid cells with a depth > 0.05 were selected and this was then converted to an extent polygon. The extent was smoothed to remove the sharp edges of the grid cells for cartographic/presentation purposes.

Flood depths were classified for mapping using the following classifications:

- 0 m to 0.25 m
- 0.25 m to 0.5 m
- 0.5 m to 1.0 m
- Greater than 1.0 m

8.2.3 Flood Elevation Contours

The flood elevations were contoured at 0.2 m intervals. The automatic contouring procedures can create erroneous flood elevation contours, therefore manual refinement of the flood contours was undertaken to improve their interpretability.

8.2.4 Flood Affected Properties

As detailed in Section 2.4.1 a survey was carried out of building floor heights identified within the study area that were within the likely 1% AEP flood extent. The building flood status was indicated with the following colouring:

- Below floor flooding:- green shading
- Above floor flooding:- orange shading

8.2.5 Emergency Service Locations

The location of the following emergency services was included on the flood response maps:

- Fire Station
- Police Station
- SES Unit

8.3 Flood Mapping for Land Use Planning

8.3.1 Overview

Land use planning controls and building regulations provide mechanisms for ensuring appropriate use of land and building construction, given the flooding risks to a particular area. Land use planning controls are aimed at reducing the growth in flood damages over time. The controls balance the likelihood of flooding with the consequences (flood risk).

As part of ongoing municipal reform, the State Government introduced a consistent planning scheme format for application across the State. The Victorian Planning Provisions (VPPs) are employed by all Victorian municipalities.

Victorian Building Regulations specify that floor levels should be at least 300 mm above a nominated flood level. If land is subject to flooding, the municipal council may set conditions that require particular types of construction or particular types of construction materials.

This section details the input data, methodology and outputs for the land use planning flood mapping. The following are discussed:

- Victorian Planning Provisions – outlines the flood related Victoria Planning Provisions (VPPs).
- Flood related planning zones and overlay – details the available flood related planning zone and overlays.
- Flood related planning zone and overlays delineation – details the delineation of the flood related planning zone and overlays for the study area.

8.3.2 Victorian Planning Provisions

The Victoria Planning Provisions (VPPs) aim to achieve consistency in the application of planning controls for areas subject to flooding throughout the State. The stated objectives are to protect life, property and community infrastructure from flood hazard, and to preserve flood conveyance capacity, floodplain storage and natural areas of environmental significance.

The VPPs provide for two overlays and one zone associated with mainstream flooding as follows:

- Land Subject to Inundation Overlay (LSIO),
- Floodway Overlay (FO),
- Urban Floodway Zone (UFZ).

Only the LSIO and FO overlays were considered relevant to the present study. Details of the definition of these overlays are provided in the following sections.

For each of the overlays, the VPPs specify the appropriate types of land uses and developments which are to be regulated through a system of permits. These are intended to achieve consistency throughout the State, but local variations to these guidelines are allowed in planning permit exemptions through a schedule to a flood overlay and/or performance-based criteria through a local floodplain development plan that has been incorporated into the planning scheme.

8.3.3 Flood Related Planning Overlays

Land Subject to Inundation Overlay (LSIO)

The LSIO identifies land liable to inundation by overland flow, in flood storage or in flood fringe areas affected by the 1% AEP flood.

The permit requirements of LSIO are intended to:

- ensure that development maintains the free passage and temporary storage of floodwaters,
- minimise flood damage,
- be compatible with the flood hazard and local drainage conditions,
- not cause any significant rise in flood level or flow velocity,
- protect water quality in accordance with relevant State Environment Protection Policies (SEPPs).

In general, emergency facilities (hospitals, schools and police stations etc.) must be excluded from this area (refer Clause 15.02). Similarly, developments or land uses which involve the storage or disposal of environmentally hazardous chemicals or wastes, and other dangerous goods should not be located within LSIO.

Permit requirements as well as performance based controls can be specified. The final extent of the LSIO proposed for the Burrumbeet Creek study area is discussed in the following section.

Floodway Overlay (FO)

The FO identifies waterways, main flood paths, drainage depressions and high hazard areas. The identification of floodways can be based on NRE's "Advisory Notes for Delineating Floodways" (Edwards, 1998) or more recently on the approach described in Cox et al. (2010) as part of the Australian Rainfall and Runoff update Project 10. GHCMA has developed a comprehensive approach to delineation of floodways and the flood fringe, based on these references, which is described in the following section.

In general, development is excluded from floodway overlay areas, except in exception circumstances where specific controlled activities have been defined within the planning scheme.

GHCMA Approach

GHCMA has adopted the following definitions for floodways and the flood fringe area which have then been used to delineate the LSIO and FO overlays.

Based on the definition of floodway by Edwards (1998):

- Generally the high hazard[3] portion of the floodplain.
- Water is likely to be deep and fast moving in these areas during large floods.
- Generally areas where major discharge or storage of water occurs during large floods.
- Often aligned with naturally defined channels and include areas which, if filled or even partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels[4].

[3] In the context of floodway hazard, hazard is defined as the potential source of harm or adverse health and wellbeing effects on people.

[4] The extent and behaviour of floodways can change with flood severity. Floodway areas that are benign for small floods may cater for much greater or more hazardous flows during larger floods. Floodways are not always aligned with well-defined channels.

The following definition has been adopted for the flood fringe:

- Generally the low hazard portion of the floodplain.
- Water is likely to be relatively shallow and slow moving in these areas during large floods.
- This land is often (but not always) on the fringe of the floodplain.

8.3.4 Flood Related Planning Zone and Overlay Delineation

The final extent of the floodway and land subject to inundation overlays proposed for the Burrumbeet Creek study area was based on consideration of the floodway and flood fringe definitions developed by GHCMA.

The following specific delineation criteria were applied:

Floodway

As a minimum[5], any land where best practice floodplain modelling indicates:

- The 1 % AEP flood depth is likely to reach or exceed 0.5 m; and/or
- The estimated 1 % AEP flood hazard factor (velocity x depth) can be expected to reach or exceed $0.4m^2/s$,

The land is delineated as floodway for the purpose of land use and development planning.

Flood frequency (e.g. the 10 %. AEP flood extent) is an additional criterion that may be applied as per Edwards (1998). However the implications of this need careful consideration. Significantly larger areas of land may be delineated as floodway. Whilst the subject land may flood more frequently, the relationship of the floodway delineation to hazard becomes weaker. This may not be appropriate from socio economic viewpoints. In general, stronger emphasis should be placed on flood frequency when considering flood controls for greenfield areas.

Flood Fringe

Any land that is outside the floodway, but inside the 1 % AEP flood extent is delineated as within the flood fringe by default.

Additional Notes

Flood hazard factor is derived from the product of velocity and depth of water likely to inundate the land during a 1 % AEP flood. A factor of 0.4 m^2/s is recommended by the Australian Rainfall and Runoff (ARR) guidelines (I.E.Aust, 1987) which states that 'to prevent pedestrians being swept along streets and other drainage paths during major storm events, the product of velocities and depths in streets and major flow paths generally should not exceed 0.4 m^2/s'.

Where depth is likely to be 0.5 m or more during a 1 % AEP flood it is assumed that the land is of major importance for the storage and conveyance of floodwater (Edwards, 1998). In addition, contemporary research indicates that flooding to this depth represents a significant risk to people in and of itself (ARR revision project 10, Stage 1 and 2 reports P10/S1/006, P10/S2/020).

8.3.5 Planning Map Development Principals

Model outputs (flood extents, flood depth and flow velocity) from the hydraulic analysis were employed to provide information on the flooding characteristics over the study area. Flood related planning maps (at the same scale as the flood inundation mapping) were produced showing areas of potential FO and LSIO based on flooding characteristics.

The following principals were developed by GHCMA to create the draft flood related planning maps:

[5] The criteria are subject to change pending advancements in flood hazard research.

- Raw flood data boundaries are smoothed to create plausible representation of the floodway and flood fringe boundaries.
- Irregularities in the floodway and flood fringe boundaries, such as small "tongues" of flood-prone land extending out from the bulk of the identified flood extent, may be smoothed when accurate reflection of this data is of no value in terms of a planning permit trigger. Underlying Planning Scheme Zone is a consideration in doing this.
- Flood-prone areas shown on raw flood mapping that are less than 1000 m^2 (0.1 Ha); and not directly connected to riverine flow path (i.e. outside the riverine floodplain) have been excluded from the planning maps. This needs careful consideration in relation to the scale and purpose of planning maps and the underlying planning scheme zone. A permit trigger for such areas within the Farming Zone may not be warranted.
- Islands (high ground) within the floodway (i.e. marooned by high hazard flooding) are in general covered by the floodway overly due to access being cut. A planning permit application is therefore triggered on such land which ensures flooded access hazards are accounted for
- Small "holes" in the floodway mapping have been filled in to create the floodway overlay map. The land is still flood-prone and such "holes" represent land where the depth and hazard factor (vxD) of floodwater is lower than the adopted floodway criteria. In general there is no value from a planning perspective in identifying small patches of land as subject to the Land Subject to Inundation Overlay when these patches will be marooned by high hazard flooding.
- Flood extents on planning maps may sometimes be pulled back to property boundaries in instances where the area of identified floodway or flood fringe land within the property boundary is minor as to render a planning permit trigger impractical.

The flood related planning maps were revised and amended in consultation with the City of Ballarat Council and Glenelg Hopkins CMA. Through this consultation, due consideration was given to local social, economic and environmental issues.

The Ballarat Airport and Ballarat West Employment Zone areas have been removed from the potential FO and LSIO overlay extent and will be processed as part of a separate flood control amendment in the future, once ongoing planning work in these areas is completed, to ensure that the most accurate flood planning controls are implemented.

The Wendouree area, to the south of the Western Highway, has also been removed from the potential FO and LSIO overlay extent as further local scale flood modelling work is required to resolve and refine the impacts of the local stormwater system on flooding in this area.

8.3.6 Planning Scheme Controls

Draft planning scheme controls were developed for the LSIO and FO for the Burrumbeet study area, which seek to:

1. Minimise risks to life, health and wellbeing associated with flooding of the township;
2. Maintain to the maximum possible extent, the free passage and temporary storage of floodwaters;
3. Require new development to use materials, design and construction techniques to minimise likely damage by floodwater;
4. Ensure new development will not cause any significant rise in flood level or flow velocity to the detriment of other land holders or property;
5. Ensure flood damage costs are not compounded unduly;

6. Ensure existing development that is affected by flooding is maintained in a manner commensurate with the likely impacts from future flood events.

Further information is provided in the Planning Scheme Amendment documentation currently being prepared by City of Ballarat Council.

9. STUDY DELIVERABLES

9.1 Overview

The study deliverables provide a comprehensive set of data that support the study outcomes. The deliverables were supplied on a study DVD and consist of background data and outputs as listed below:

- Digital copies of study reports in PDF format.
- Study survey data (LIDAR, structures, cross-sections and floor levels)
- Other input data including rainfall and flow data
- A property database including flood information
- Digital copies of the maps (PDF format)
- GIS datasets for the model results (Mapinfo and ArcGIS format)
- The hydrologic and hydraulic model input files

There was a readme.txt file on the disk that describes the directory structure of the data contained on the disk.

9.2 Mapping Outputs

Details are provided of the study outputs for emergency response, and land use planning mapping including:

- Data sets: grids and shapefiles/tabfiles
- Planning layers
- Flood response inundation maps
- VFD layer updates

9.2.1 Datasets

The following datasets were provided. All GIS files were provided in ESRI and MapInfo format.

Grids

Gridded datasets of model results were provided for the following:

- PMF – maximum hazard and water surface elevation,
- Climate change sensitivity (10%, 1% and 0.5% AEP events) – maximum depth, hazard and water surface elevation,
- Design events (10%, 20%, 5%, 2% 1% & 0.5% AEP events) – maximum depth, hazard, velocity and water surface elevation.

Shapefiles/Tabfiles

ERSI shapefiles and MapInfo Tab files were provided for the following:

- Flood depth contours
- Flood extents
- Floor levels
- Mapping limits
- Water surface elevation (flood level) contours

9.2.2 Maps

The flood response inundation maps were produced for the following design flood events:

- PMF – maximum depth and hazard,
- Climate change sensitivity – maximum depth and hazard for the 10%, 1% and 0.5% AEP events,
- Flood Hazard - 20%, 10%, 5%, 2% 1% & 0.5% AEP events,
- Flood Depth - 20%, 10%, 5%, 2% 1% & 0.5% AEP events,
- Flood Velocity - 20%, 10%, 5%, 2% 1% & 0.5% AEP events.

Each map includes:

- Flood extent,
- Flood level contour at 0.2 m and 1m intervals,
- Depth of inundation,
- Identification of essential services,
- Road/street names
- Cadastral base
- Land marks, including all physical man-made features particularly those affecting flood flows and distribution.

Soft copies were provided as PDFs. Related GIS files were provided in ESRI and Mapinfo format.

9.2.3 Flood Extent Mapping (VFD Compliant)

All flood mapping data was prepared to the VFD metadata specifications.

9.2.4 Land Use Planning Maps

A draft LSIO/FO map was produced as part of the Planning Scheme Amendment documentation. A copy of this map is included on the study DVD.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Overview

The Burrumbeet Flood Investigation provides a comprehensive analysis and review of existing and future potential flood risk in the township and surrounding area. The study involved:

- Collection and review of a range of data relevant to the definition of flooding within the study area.
- A survey analysis to develop a detailed description of the study area topography as a basis for analysis and mapping.
- A rigorous hydrologic analysis to develop robust design flood estimates for the study.
- Development of a detailed hydraulic model that is capable of predicting flood impacts in the Burrumbeet Creek Catchment under a range of conditions.
- Quantification of flood risk in terms of flood damages.
- Thorough sensitivity testing of the hydraulic results under both existing conditions and for a potential climate change scenario (a 20% increase in rainfall intensity).
- Examination of a range of potential flood mitigation options for different areas within the catchment.
- Review of flood warning and emergency management for the catchment including recommendations for development of a total flood warning system,
- Planning Scheme Amendment documentation for the Burrumbeet Creek catchment.

10.2 Key Outcomes

In undertaking this study a number of important aspects of flood risk relevant to the Burrumbeet Creek catchment became apparent. These are summarised as follows.

Burrumbeet Hydrology & Hydraulic Characteristics - The study area covers the whole of the Burrumbeet Creek catchment, including steep headwater streams, upland swamps and wetlands, broad floodplains and gorges. Flooding of these diverse flood-prone areas in the Burrumbeet Creek catchment can occur from a number of sources including:

1. Flooding in Burrumbeet Creek floodplain due to widespread and prolonged rainfall;
2. Flash flooding in tributaries due to intense local rainfall; and

Flooding in tributaries and upper catchment floodplains due to the filling of swamps and wetlands and extended ponding due to poor drainage.

The tributary catchments have shorter critical storm durations than the main Burrumbeet Creek floodplain, meaning that they are responsive to short, high intensity storms, whereas the Burrumbeet Creek flows are more responsive to sustained long duration rainfall.

Climate Change Risk Profile – In general, the impacts of climate change on flood level are relatively minor in the tributaries, and are greater in the main Burrumbeet floodplain. Across all events, increases in flood level are generally limited to less than 0.5 m, except in small isolated areas. Changes in flood extent are generally minor.

Flood Mitigation – Mitigation of flood risk in the Miners Rest area through the inclusion of levees along Albert Street and a flood channel to the north of Clarke Street amongst a number of options investigated provide the most benefit in terms of reduction in flood impacts and damages to the community relative to the cost of implementation. Due to the flash flooding nature of flooding within the Burrumbeet Creek catchment flood warning, emergency management and planning controls for reducing flood risk are also appropriate mitigation measures for reducing flood risk in the catchment.

Planning Controls –The most appropriate planning controls for the Burrumbeet Creek catchment are Land Subject to Inundation (LSIO) and Flood Overlay (FO). Draft overlays have been produced along with draft planning documentation to accompany a Planning Scheme Amendment.

10.3 Recommendations

Following the investigations undertaken for the study and the conclusions reached it is recommended that:

- The GHCMA and City of Ballarat Council adopt the determined design flood levels and proceed with the planning scheme amendment process.
- In conjunction with VICSES, the City of Ballarat Council and GHCMA continue to engage the community in the treatment of flood risks through regular flood awareness programs such as the VICSES FloodSafe program, starting with the development of a local flood guide.
- In consultation with VICSES, the City of Ballarat Council and GHCMA explore further the recommendations for enhanced flood response through co-operation with SES and Police, utilising the flood inundation maps and flood intelligence tools included in the Municipal Flood Emergency Plan (MFEP). Consideration should be given to the use of the MFEP during an emergency.
- The City of Ballarat Council and GHCMA explore further the recommendations for the development of the proposed total flood warning system for the Burrumbeet Creek catchment in conjunction with the BoM and SES.

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