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Heathcote Flood Study: Final Report

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Heathcote Flood Study: Final Report

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Executive Summary

This Executive Summary outlines the objectives, methodology and key outcomes of the Heathcote Flood Study. Detailed reporting and mapping undertaken as part of the Study are contained within the main report (Heathcote Flood Study: Draft Final, BMT WBM 2015).

Introduction

In July 2014 the Minister for Water announced funding for the Heathcote Flood Study (the Study) as part of the 2014 investment in flood related projects. In partnership with the Department of Environment, Land, Water and Planning (DELWP) and the City of Greater Bendigo Council (CoGB), the North Central Catchment Management Authority (NCCMA) has commissioned this investigation.

Heathcote was not significantly affected by flooding from McIvor Creek during the January 2011 event; however the existing best available information on flooding in Heathcote indicates there is a significant risk to a number of properties and dwellings in the town. Further, given Heathcote's proximity to both Bendigo (40km) and Melbourne (110km) it is expected to face increasing development pressure. As there have been no previous flood studies for Heathcote, this Study addresses this information gap and provide valuable planning and flood intelligence information as well as investigating options to reduce flood risk.

Key Objectives

The Key Objectives of the Study were:

(1) To engage with the community and stakeholders through the Community Consultation Process to incorporate their knowledge into the Study outcomes.

(2) To produce calibrated hydrologic and hydraulic flood models to characterise the flooding in the Study area for a range of AEP events.

(3) To provide recommendations for the update of the flood-related zones and overlays of the CoGB's planning scheme.

(4) To prepare flood intelligence and consequence information for input into the CoGB Municipal Flood Emergency Response Plan for Heathcote.

(5) Recommend measures to reduce the impact of flooding in Heathcote.

Flood modelling

A flood model of Heathcote was developed using standard industry practice and models and was calibrated to a number of events. The flood model provided base case or existing conditions flood information (including flood maps) for the catchment for the 20%, 10%, 5%, 2%, 1%, and 0.5% AEP flood events. The 1% AEP flood extent and depth is shown in Figure 1.

The modelling showed while flooding is extensive in many of the developed areas of the town, it is generally shallow. Velocities are highest in the main stream channel (greater than 2m/sec) and somewhat lower (between about 0.5m/sec and 2m/sec) along the main flow paths and roads. Flow velocity through properties is typically low at less than 0.5m/s. Hazard is low away from the main flow paths.

During the 20% AEP event, the Northern Highway (High Street) is wetted to a depth of around 250mm to the north west (towards Bendigo) of Mitchell Street from creek breakouts near Clouston Court and opposite Boomerang Place. The initial section of the McIvor Highway is also wetted to a similar depth.

As flood severity increases, breakout flooding occurs along Beauchamp Street, upstream of Chauncey Street and downstream to Mitchell Street.

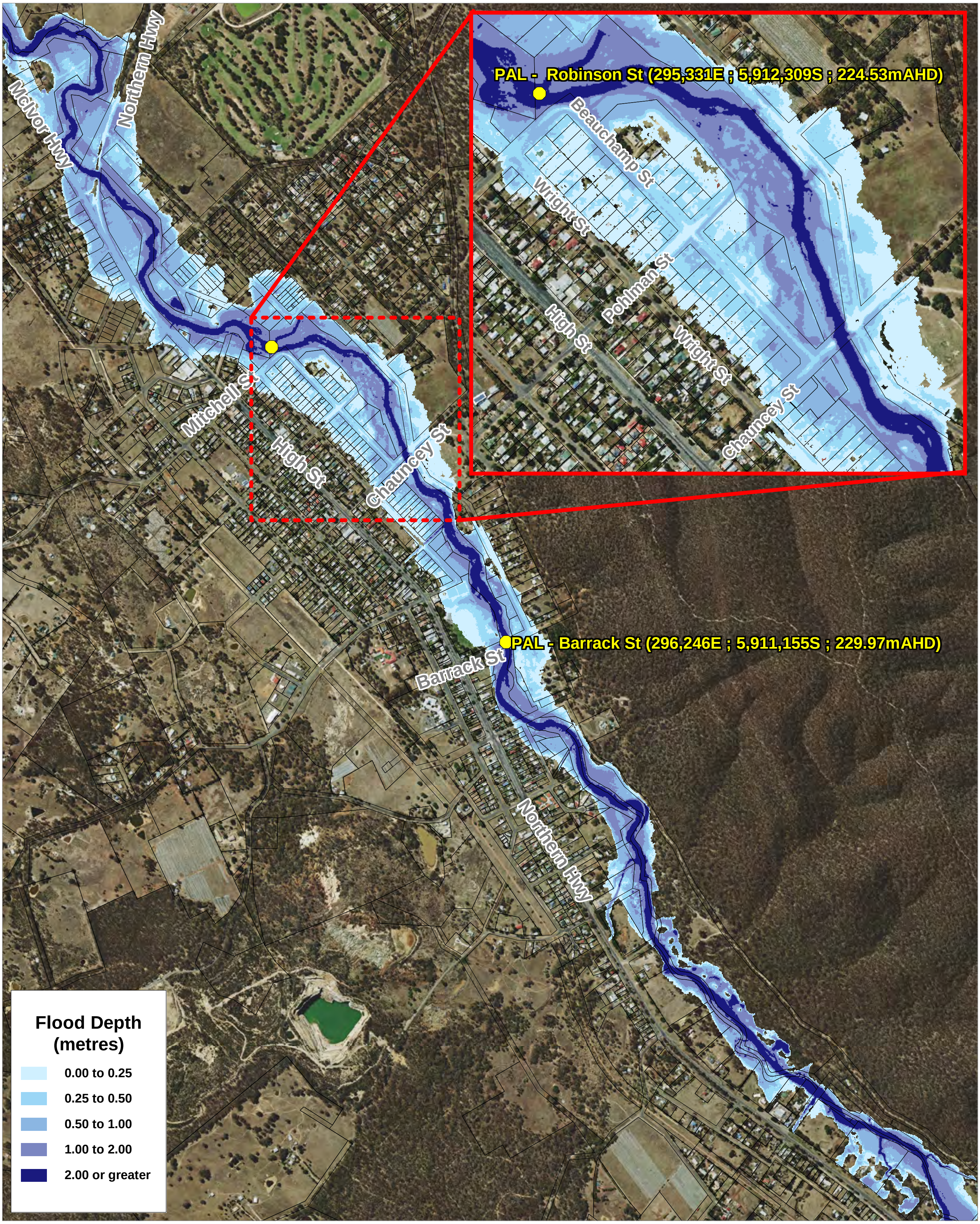
Flooding across both Highways to the north west of Mitchell Street is more established and deeper during a 10% AEP event with the result that both would probably need to be closed due to excessive depth (see January 2011 photo in Table 6-4). Travel to the north west (e.g. Bendigo) and north (e.g. Elmore) would still be possible but would need to be initially via the Heathcote – Kyneton Road and the Heathcote – Nagambie Road respectively.

While flood water does sit alongside the northern edge of the Northern Highway from near the town side of the Heathcote – Nagambie Road intersection from a little below the 2% AEP event, for all events up to and including the 0.5% AEP event, flood water only crosses the Highway to the north west (towards Bendigo) of Mitchell Street.

In Heathcote, 14 properties are flooded close to the buildings by the 10% AEP event with the first property flooded in Thomas Street. There are also 3 houses within 100mm of flooding over-floor: 2 in Thomas Street and 1 in Pohlman Street.

The VICSES depot is within 100mm of being flooded during a 2% AEP event. In the 1% AEP event most of the area downstream (to the north west) of Barrack Street between Wright Street (initially and then High Street) and McIvor Creek is flooded. This area has 109 properties, including the VICSES depot building. Of these 109 properties, 24 are flooded over-floor and a further 17 floors are within 100mm of being wetted.

Essential community infrastructure, such as the McIvor Medical Centre, the CFA, Ambulance and Police stations, Council offices, the Community Centre and the Primary School are not affected by flooding up to at least the 0.5% AEP event. While the swimming pool is similarly unaffected, facilities at the Tennis, Bowls, Angling and Football clubs are affected from around the 2% AEP event. Parts of the Queens Meadow Caravan Park are inundated from a little above the 10% AEP event. In the 5% AEP event, there is a breakaway flow through the park towards the portable cabins on Barrack Street with approximately half the site inundated to some extent in the 2% AEP (50-year ARI) event with one property flooded over-floor. Additional over-floor flooding occurs as flood severity increases.



Title:

Heathcote Flood Study
1% AEP Flood Depth and PAL Locations

Figure: 1

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Approx. Scale

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Flood Damages Assessment

A flood damages assessment was completed for the 20%, 10%, 5%, 2%, 1%, and 0.5% AEP flood events to ascertain the economic damage from flooding to the Heathcote community annually. The damages included damage to residential, commercial, public buildings as well as external property and indirect damages. A loss probability curve was produced to enable the calculation of annual flood damages. Large damages from low probability events are combined with lower damages from more frequent flood events and annual average damage (AAD) is calculated. A summary of the damages is provided in Table 1.

Table 1 Summary of Flood Damages for Heathcote

Likelihood of flooding	Number of Flood Affected Buildings	Number of Buildings Flooded above Floor level	Estimated Potential Damages ($ million)
0.5% AEP	129	49	$5,259,000
1% AEP	109	24	$3,602,000
2% AEP	70	12	$2,236,000
5% AEP	34	6	$957,000
10% AEP	14	0	$275,000
5% AEP	0	0	$0
AAD (potential)			$170,000
AAD (actual)			$153,000

Total Flood Warning System

A Total Flood Warning System (TFWS) provide a means of gathering information about impending floods, communicating that information to those who need it (those at risk) and facilitating an effective and timely response. Thus their development involves far more than the installation of a data collection network, implementation of a forecast tool and the forwarding of predicted flood levels and times to key agencies and / or the at-risk communities.

Following the assessment of the various TFWS investigated for this study, if it is assumed that a benefit cost ratio (BCR) of greater than one is required in order to secure support for TFWS development, the only economically feasible options is the “essential” case. While it is simple and requires active engagement by an informed and resilient local community, the “essential” case TFWS configuration delivers a BCR of 1.3 and is therefore preferred.

The ‘essential ‘case TFWS is based around Community owned and operated rain gauges with data shared through an open source cloud based system in near real-time will meet the needs of the Heathcote community in a cost effective manner although messaging (in “community friendly what does this mean for me” terms) remains to be resolved. A key element of the TFWS will be the building and maintenance of flood awareness across the Heathcote community.

Planning Controls

The study proposes planning scheme amendments for the catchment. The recommended approach is to assign areas identified as Extreme Hazard to Children (depth greater than 500 mm and/or velocity x depth greater than 0.6 m^2/s) to the more restrictive Floodway Overlay. Areas identified as lower hazard should be subjected to the less restrictive Land Subject to Inundation Overlay. The flood levels determined by the flood modelling should be used to assign floor levels at a minimum 300mm above the 1% AEP flood level for all future development within Heathcote.

Flood Response Plan

A Municipal Emergency Management Plan (MEMP) has been completed as part of the Study and has been delivered to Council as a separate document.

Community Consultation

Throughout the Study the local community was engaged indirectly through the Community Reference Group as well as directly via the Heathcote Bush Market as well one-on-one engagements with NCCMA. The feedback from the community was instrumental in the validation of the models ensuring the robustness and acceptance of the Study.

Summary and Recommendations

This report has documented the methodology and findings of the Heathcote Flood Study. The study has defined the flood behaviour for the catchment through the development of flood model and the determination of flood extents for a range of flood events. This model was used to determine the flood damages within the catchment. A number of measures have been documented and recommended for adoption within the catchment with the aim of reducing flood risk to Heathcote. These recommendations include:

- Declaring Designated Flood Levels (Section 13)
- Implementation of Planning Scheme Controls (Section 12.1)
- Implementation of a Total Flood Warning System (Section 11.6)
- Implementation of Building controls (Section 12.1.1)
- Consideration of Planning For Climate Change (Section 12.3)
- Implementation of Flood Response Plan (Section 13)
- Dissemination of Flood Intelligence and Consequence Information (Section 13.1.1)

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

- Undertake Community Awareness Programs (Section 14)

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Glossary

AEMI	Australian Emergency Management Institute
Annual Exceedance Probability (AEP)	The likelihood of occurrence of a flood of a given size or greater occurring in any one year. AEP is expressed as a percentage (%). For example, if a peak flood discharge of 300 m^3/s has an AEP of 1% there is a 1% chance of a flood with a peak of 300 m^3/s or greater occurring in a given year. The convention of AEP has been adopted for this study.
Average Annual Damages (AAD)	The average annual damage is the average cost in dollars per year that would occur in a particular area from flooding over a very long period of time.
Australian Height Datum (AHD)	The national height datum that approximately corresponds to mean sea level. Elevation is in meters.
AWS	Automatic Weather Station
Average Recurrence Interval (ARI)	An estimate of the average period in years between floods of a given magnitude or greater. For example the 50 year ARI flood will occur on average once every 50 years.
BoM	Bureau of Meteorology.
BTRE	Bureau of Transport and Regional Economics
Catchment	The area of land draining to a particular location and may include the catchments of tributary streams as well as the main stream.
CoGB	City of Greater Bendigo.
CRG	Community Reference Group.
DEM	Digital Elevation Model – Three dimensional computer representation of terrain.
DELWP	Department of Environment, Land, Water and Planning. Formally the Department of Environment and Primary Industries (DEPI).
Design Flood Event	A hypothetical flood representing a given probability.
Design Rainfall	The hypothetical rainfall event representing a given probability.
DoTARS	Department of Transport and Regional Services
FFA	Flood Frequency Analysis.
FI	Fraction Imperviousness – The fraction of the catchment that is impervious, that is, land which does not allow infiltration of water.
EA	Emergency Alert

EMA	Emergency Management Australia
EMMV	Emergency Management Manual Victoria
ERTS	Event Report Radio Telemetry System
Flood Model	A computer model developed to represent the flood behaviour within the study area, including both the hydrologic and hydraulic models.
FAG	Flood Action Guide
FO	Flood Overlay.
Floodplain	Area of land subject to inundation by floods up to and including the probable maximum flood (PMF) event.
GIS	Geographical Information System
GMW	Goulburn Murray Water
ICSM	Intergovernmental Committee on Surveying and Mapping's.
LiDAR	Light Detection and Ranging – Ground survey taken from an aeroplane typically using a laser. Using the laser pulse properties the ranging and reflectivity is used to determine properties of the laser strike, soil type/tree/building/road/etc. It is usual to filter non-ground strikes (trees/buildings/etc.) from the LiDAR before it is used to generate a DEM.
LSIO	Land Subject to Inundation Overlay
MEMPC	Municipal Emergency Management Planning Committee
MFEP	Municipal Flood Emergency Plan
ML	Mega-Litres (1,000,000 L).
NCCMA	North Central Catchment Management Authority.
Hydraulic Model	A computer model developed to extent, depth and velocity of surface water based on the Shallow Wave equations. The TUFLOW modelling package was adopted for this study.
Hydrologic Model	A computer model that converts rainfall into runoff. The URBS modelling package was adopted for this study.
Hydrograph	A graph showing discharge versus time at a particular location.
Hyetograph	A graph showing rainfall versus time at a particular location.
Manning's n	Hydraulic roughness due to ground conditions, typically averaged over an area of relative homogeneity, e.g. it's harder for water to flow through an area of heavy brush and trees than maintained grass.

Pluviograph	A rain gauge measuring the depth of rainfall over a small period of time (much less than a day). Often use to produce a graph of rainfall over time (hyetograph).
PMF	Probable Maximum Flood – the flood resulting from the PMP (see below).
PMP	Probable Maximum Precipitation - The probable greatest depth of precipitation meteorologically possible for a given duration, size storm area, and location with no allowance made for long-term climatic trends.
PSM	Permanent Survey Mark.
QA	Quality Assure / Assurance
Rapid Appraisal Method (RAM)	A methodology for the determination of flood damages in dollars.
Rating Curve	The relationship defining discharge for a given stage (water level) at a particular recording location.
RCBC	Reinforced Concrete Box Culvert (also referred to as a Rectangular Culvert).
RCP	Reinforce Concrete Pipe (also referred to as a Circular Culvert).
Runoff	The amount of rainfall from a catchment that is converted to flowing water.
SLS	Service Level Specification
Stage	Refers to the water level, often to a local datum, at a particular location typically at stream gauges.
TFWS	Total Flood Warning System
TUFLOW	A 1D / 2D finite difference numerical model that simulates hydrodynamic behaviour in rivers, floodplain and urban drainage environments. This is the hydraulic modelling package adopted for this study.
URBS	A hydrologic modelling software package used to simulate a catchments runoff response to rainfall. This is the hydrologic modelling package adopted for this study.
VFD	Victorian Flood Database
VicPol	**Victoria Police**
VICSES	**Victoria State Emergency Service**

1 Introduction

1.1 Study Background

In July 2014 the Minister for Water announced funding for the Heathcote Flood Study (the Study) as part of the 2014 investment in flood related projects. In partnership with the Department of Environment, Land, Water and Planning (DELWP) and the City of Greater Bendigo Council (CoGB), the North Central Catchment Management Authority (NCCMA) commissioned this investigation.

Heathcote was not significantly affected by flooding from McIvor Creek during the January 2011 event; however the existing best available information on flooding in Heathcote indicates there is a significant risk to a number of properties and dwellings in the town. Further, given Heathcote's proximity to both Bendigo (40km) and Melbourne (110km) (Figure 1-1) it is expected to face increasing development pressure. As there have been no previous flood studies for Heathcote, this Study addresses this information gap and provide valuable planning and flood intelligence information as well as investigating options to reduce flood risk.

In order to ensure the best outcomes for the community of Heathcote, the work undertaken by BMT WBM (this Study), was overseen and guided by the Community Reference Group (CRG), which was established for the Study.

This report documents the method, findings and conclusions of the Heathcote Flood Study

1.2 Previous Reports

Whilst no detailed flood studies of Heathcote itself have been undertaken, the catchment has been investigated as part of several previous studies. The focus of these previous studies was to assess the hydrologic risk of the Goulburn Murray Water's (GWM) storages including Lake Eppalock (to which Mt Ida Creek discharges). These include:

- Inflow Forecasting for Storages – Goulburn-Murray Water (SKM[1] 2012); and
- Conversion of RORB to URBS Models for implementation of Delft-FEWS – Goulburn-Murray Water (SKM 2013).

These studies have been made available by GMW. Heathcote was not the focus of these studies; however, the reports provide some detailed background information into the available flood history and behaviour of the system.

The Rural Water Commission in the late 1980's developed a preliminary HEC2 hydraulic model based on historic events of Heathcote. The outputs of this model, including flood levels, forms the basis of the existing flood risk knowledge of the catchment. Whilst the model itself was not used in this study this historic information was used to verify the accuracy of this study.

[1] Now trading as Jacobs

1.3 Catchment Description

The Study Catchment (the Catchment) is located in North-Central Victoria (refer to Figure 1-1). The catchment area upstream of the Mt Ida Creek stream gauge at Derrinal is approximately 173 km^2. The Catchment's primary waterway through Heathcote is McIvor Creek, which discharges to Mt Ida Creek downstream as shown in Figure 1-2. In addition to the main waterway, there are a number of tributaries feeding from the local gullies, including Golden Gully, Possum Gully, Long Gully, Caledonia Gully and Parsons Gully. The majority of the catchment is used for agricultural purposes, predominately grazing.

The Catchment originates in the mountainous areas of The Great Dividing Range. From there the McIvor Creek and its tributaries flow in a generally northerly direction towards Heathcote. The catchment is relatively steep with numerous well defined flow paths.

McIvor Creek discharges to Mt Ida Creek, which in turn discharges to Lake Eppalock and ultimately to the Campaspe River. This study focuses on the township of Heathcote.

1.4 Study Area

The Study Area, or the area to be hydraulically modelled and therefore flood mapped, extends from upstream of the Nagambie-Heathcote Road to the Mount Ida Creek streamflow gauge at Derrinal. The study area will be modelled in detail using a dynamically linked 1D/2D hydraulic models to simulate the flood behaviour within the study area using, inputs from the hydrologic model of the Catchment.

1.5 Historical Flooding

Throughout the flood events in Northern Victoria during 2010 and 2011 the township of Heathcote was not significantly affected. The largest flood in recent memory in Heathcote was in 1974, and this event falls outside of the instrumental record. Additionally, a number of larger events have been recorded in the area dating back to 1870. Due to the lack of detailed flood modelling there is significant uncertainty in existing planning controls in Heathcote and there may be a significant risk to a number of properties and dwellings within the township. This Study will address this uncertainty.

1.6 Key Objectives

The key objectives of the Study are:

(1) To engage with the community and stakeholders through the Community Consultation Process to incorporate their knowledge into the Study outcomes.

(2) To produce calibrated hydrologic and hydraulic flood models to characterise the flooding in the Study area for a range of AEP events.

(3) To provide recommendations for the update of the flood-related zones and overlays of the CoGB's planning scheme.

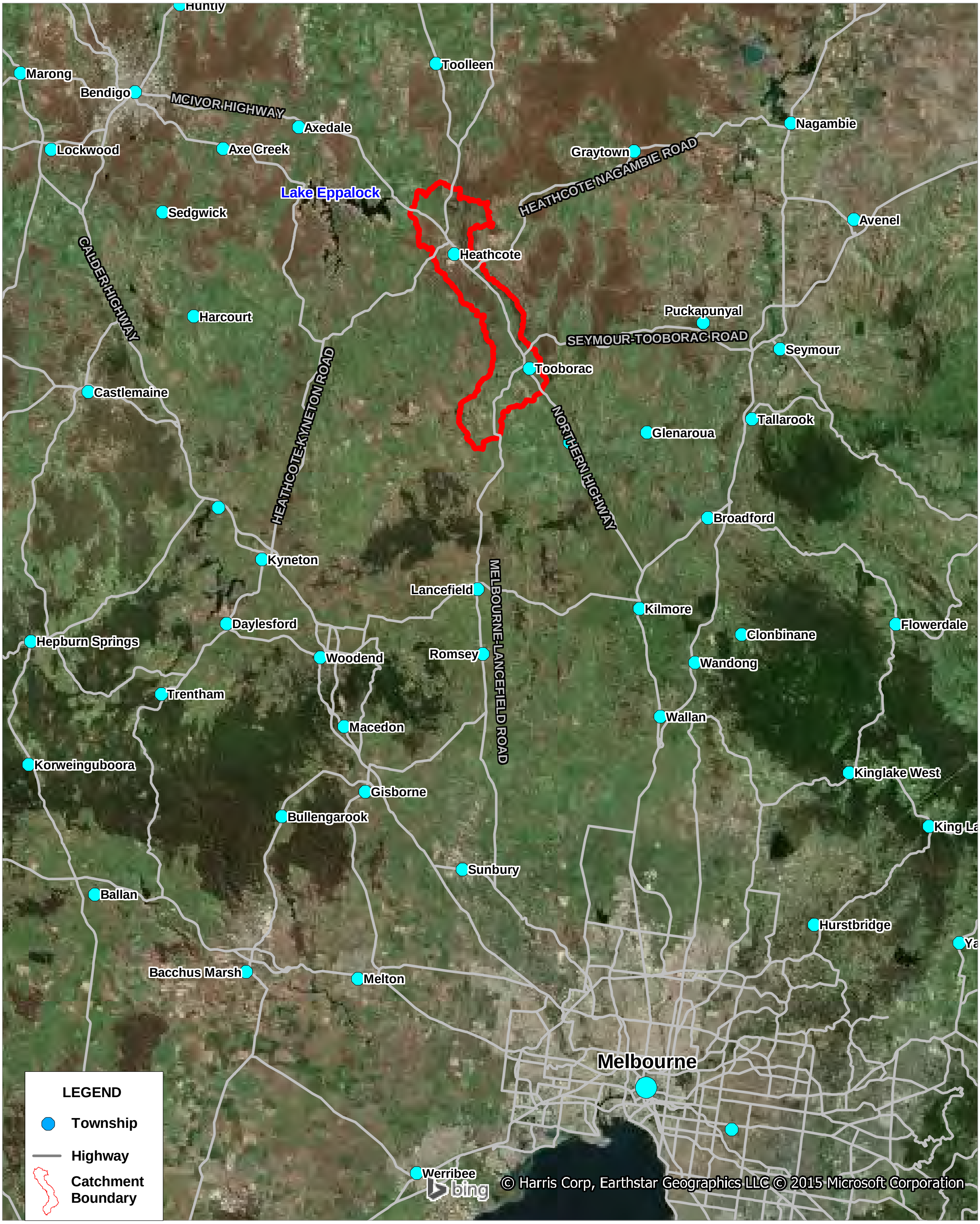
(4) To prepare flood intelligence and consequence information for input into the CoGB Municipal Flood Emergency Response Plan for Heathcote.

(5) Recommend measures to reduce the impact of flooding in Heathcote.

1.7 Structure of the Report

This report is presented in two parts, Sections 2 through 9 details the technical works undertaken to address Key Objectives 1 and 2. Sections 10 through 15 details the floodplain management plan for Heathcote which address Key Objectives 3, 4 and 5.

In addition to this report a flood atlas presenting all flood mapping outputs has been produced.



Title:

Heathcote Flood Study
Catchment Locality

Figure: 1-1

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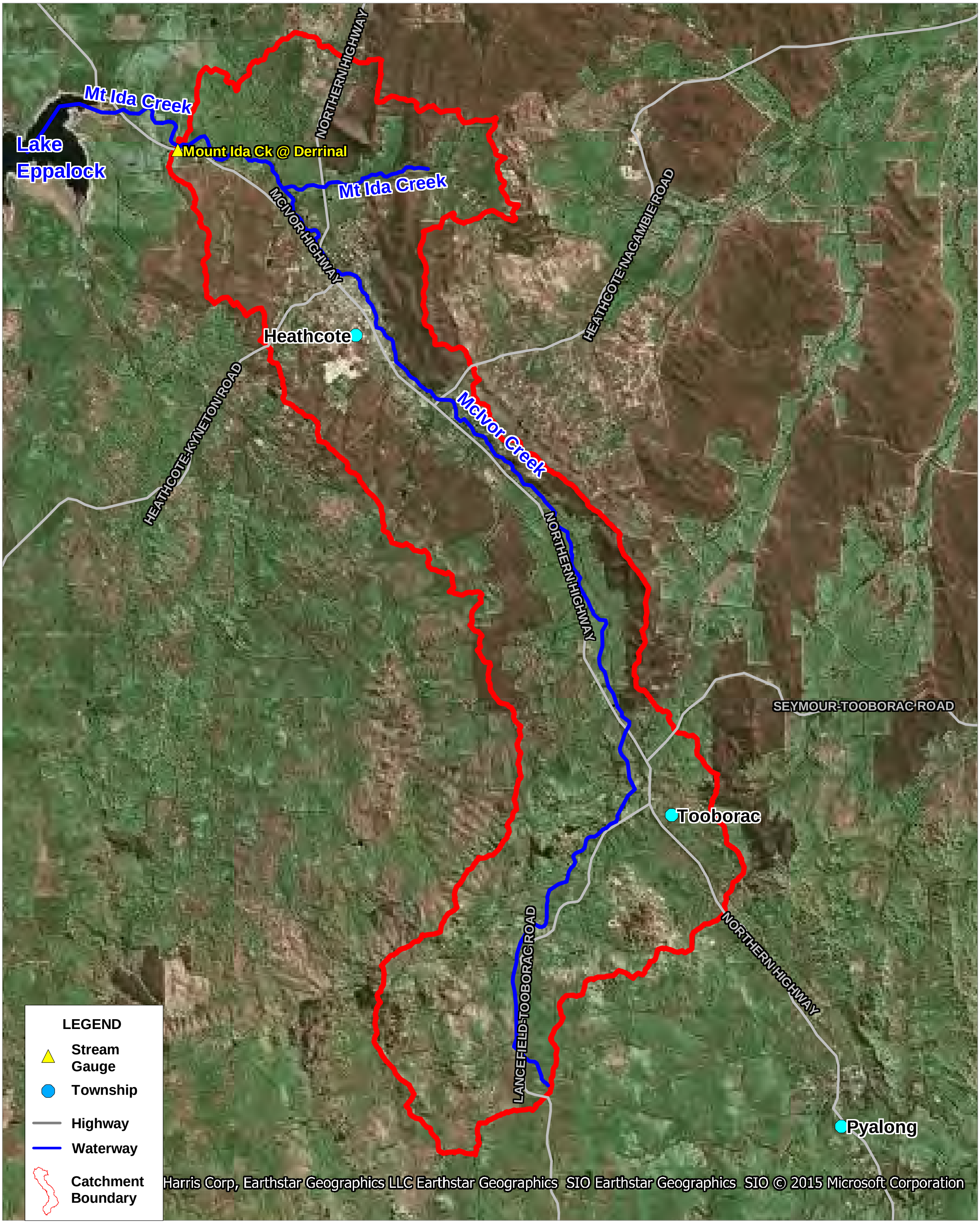

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Heathcote Flood Study
Study Catchment

Figure: **1-2**

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2 Data Collation

This section documents the data that was collated by BMT WBM for the Study. BMT WBM sourced information from a number of agencies and sources, including:

- North Central Catchment Management Authority (NCCMA);
- Bureau of Meteorology (BoM);
- Department of Environment, Land, Water and Planning (DELWP);
- VicRoads; and
- Members of the local Heathcote community.

2.1 Topographic Data

Topographic data, including LiDAR and ground contours, were used to generate the Digital Elevation Model (DEM) which forms the basis of both the hydrologic and hydraulic modelling components of the Study. A number of datasets were provided to BMT WBM as listed below. These were reviewed as detailed in Section 4.1. The extent of each dataset is shown in Figure 2-1.

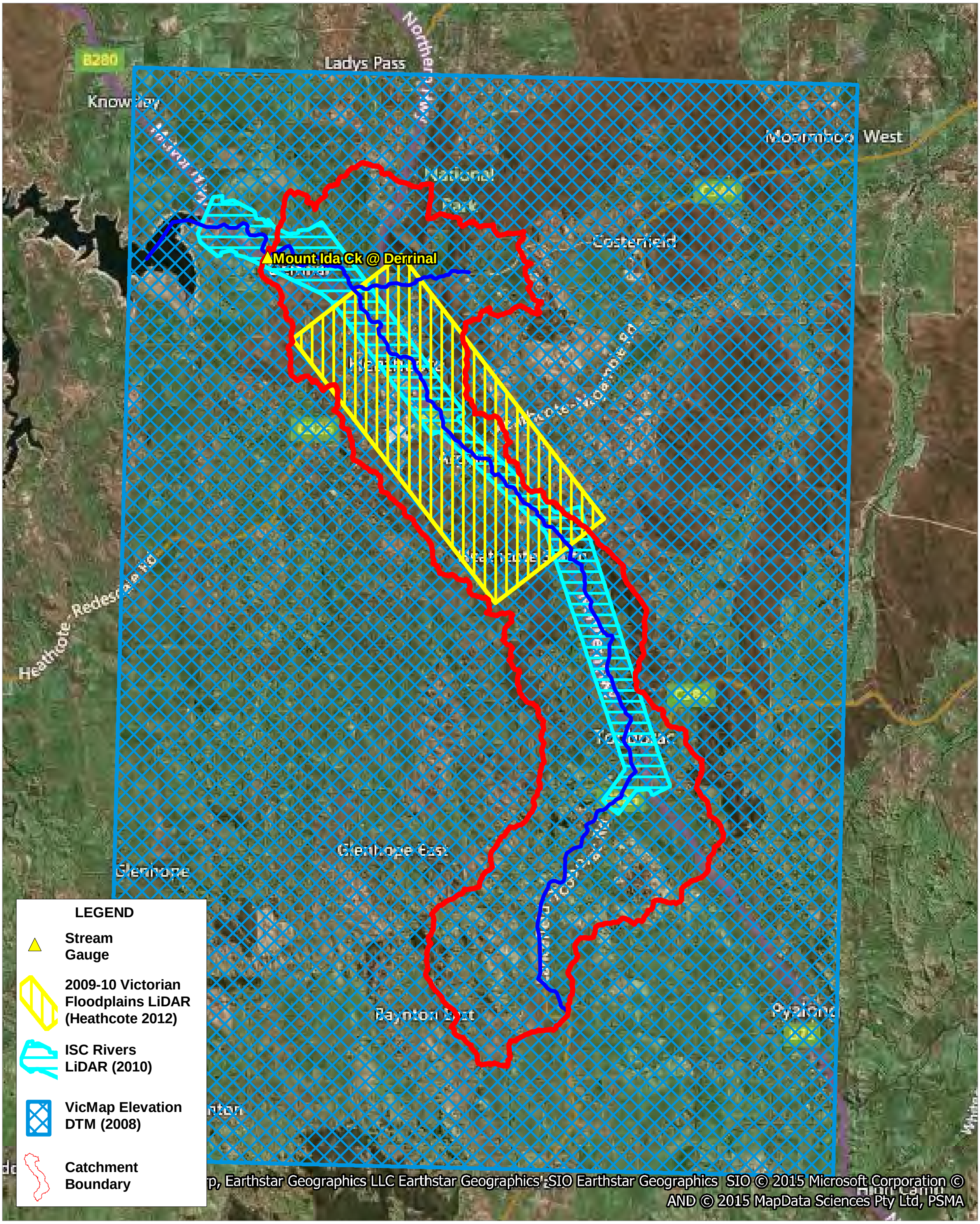
Table 2-1 Topographic Data Collected

Dataset	Resolution	Supplier	Comment
ISC Rivers LiDAR (2010)	1 m	NCCMA	
State-wide DEM	25m	NCCMA	Trimmed to Heathcote
2009-10 Victorian State Wide Floodplains LiDAR Project	1m	DELWP	Heathcote (April 2012)
VicMap Elevation DTM 2008	20m	DELWP	
Permanent Survey Marks (PSM)	N/A	DELWP	
Ground Survey (2014)	N/A	ThinkSpatial	Commissioned as part of the Study

2.1.1 Discussion

The provided LiDAR data sets have been checked to ensure they are suitable for use in the Study. Section 4 details the data validation process that has been undertaken to ensure the accuracy and suitability of the provided topographic information.

The 2008 VicMap elevation DTM and the 25 metre State-wide DEM datasets are sufficient for catchment delineation. The two LiDAR datasets, Heathcote 2012 and ISC River 2010, provide sufficient detail within the Study area to undertake the hydraulic modelling.



Title:

Heathcote Flood Study
LiDAR Dataset Extents

Figure: **2-1**

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

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2.2 Aerial Photography

Aerial Photography of the catchment is an important tool for verifying catchment characteristics such as land use, building footprints and other structures. During the hydrologic modelling stage this information was used, along with the planning scheme overlays, to estimate the fraction imperviousness of the catchment. Similarly, when developing the hydraulic model this information was used to assign the Manning's values (roughness) to the catchment and any blockages caused by buildings. The aerial photography can also be used to verify the model results by comparing relative extents and breakaway flows.

For the Study one geo-referenced tile covering the Heathcote Township - 2013 Bendigo, Shepparton & Wodonga Photography was available from DELWP.

2.3 Planning Scheme

The planning scheme layers were used in conjunction with the aerial photography and on-ground photography to define the current land use of the catchment. The planning scheme layers were used in both the hydrologic and hydraulic model to define factors such as fraction impervious and Manning's values (roughness). This was supplied by NCCMA and covers the study area.

2.4 Infrastructure (Culverts and Bridges)

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

CoGB provided GIS layers of Councils drainage network, these include pit and pipe information. The provided layers were reasonably complete with pipe dimension and pit depths provided. However pit/pipe inverts were generally missing from the data set. As pit depths have been provided inverts can be assumed by subtracting these depths from the ground surface DEMs.

The initial phase of the study identified a number of data gaps in the infrastructure data. These gaps were predominantly bridges' details, specifically those listed in Table 2-2. To address this, topographic survey was commissioned as part of the Study.

Table 2-2 Bridge Details

Bridge Location	Deck Level	Bridge Thickness	Soffit Level	Pier Configuration	Pier Width	Guard Rail Height
Heathcote-North Costerfield Road	229.43	0.64	228.79	inline square piers, 4 per line	0.46	0.75
Warrowitue Forest Rd - Milhaven Ln	246.36	0.7 (est.)	245.66	inline square piers, 4 per line	0.5 (est.)	1.06
Heathcote-Nagambie Rd	243.94	0.86	243.08	inline square piers, 2 per line	0.84	0.7
Northern Hwy	224.3	1.2	223.1	inline square piers, 4 per line	0.5 (est.)	0.7 (est.)
Barack St Pedestrian Bridge	232.9	0.2	232.7	N/A suspension bridge	N/A	1.25

2.5 Streamflow Data

Streamflow data is used for all stages of the investigation. Historic data can be used to calibrate or verify the hydrologic and hydraulic models. Additionally, the annual maximum series is used to undertake flood frequency analysis.

Many streamflow gauges in Victoria have rating curves that have been developed using in-banks manual streamflow gaugings. When out-of-bank flooding occurs, the flow determined from rating curve may be incorrect as the floodplain becomes activated. For this reason it is necessary to review the rating curve as well as the streamflow data. The stream gauge data is presented below in Table 2-3 and presented spatially in Figure 2-2.

Table 2-3 Stream Gauge Data Collected

Station No.	Station Name	Data Type	Start Date	End Date
406226A[2]	Mount Ida Creek @ Derrinal	Instantaneous Flow (ML/Day)	27/06/1978	29/04/2014
		Station Height (m)	27/06/1978	29/04/2014
		Rating Curve	14/01/2011	Current

[2] http://data.water.vic.gov.au/monitoring.htm (accessed 7/8/2014)

2.6 Rainfall Data

Rainfall data is used to calibrate the hydrologic model and provide information for the development of flood intelligence information. Both daily and pluviograph rainfall data was obtained from the Bureau of Meteorology. The obtained rainfall gauges details are tabulated in Table 2-4 and presented spatially in Figure 2-2.

Table 2-4 Rainfall Data Collected

Station No.	Station Name	Station Type	Start Date	End Date
81025	Knowsley Post Office	Daily	1/01/1905	31/12/1983
81083	Eppalock Reservoir	Daily	1/01/1965	26/08/2014
81118	Knowsley	Daily	1/01/1984	31/01/2014
81123	Bendigo Airport	Pluviograph	11/11/1993	15/10/2014
87029	Lancefield	Pluviograph	4/01/1929	31/07/1975
88029	Heathcote	Daily	1/01/1882	26/08/2014
		Pluviograph	17/04/1968	30/11/2013
88049	Puckapunyal	Daily	1/1/1899	11/06/1987
		Pluviograph	30/04/1968	31/01/1989
88050	Pyalong West (Caravan Park)	Daily	1/01/1900	30/06/2014
88051	Redesdale	Daily	1/01/1903	26/08/2014
		Pluviograph	7/11/1994	15/10/2014
88064	Mollisons Ck At Pyalong	Daily	1/01/2003	26/08/2014
88073	Baynton	Daily	1/03/1953	31/07/2014
88109	Mangalore Airport	Pluviograph	11/11/1993	15/10/2014

2.7 Historic Flooding

As part of the study, historic flood information from outside of the instrumental period of record was sought from a variety of sources. This information can be extremely valuable in hydrologic analysis and can assist in calibrating or verifying the hydraulic model results.

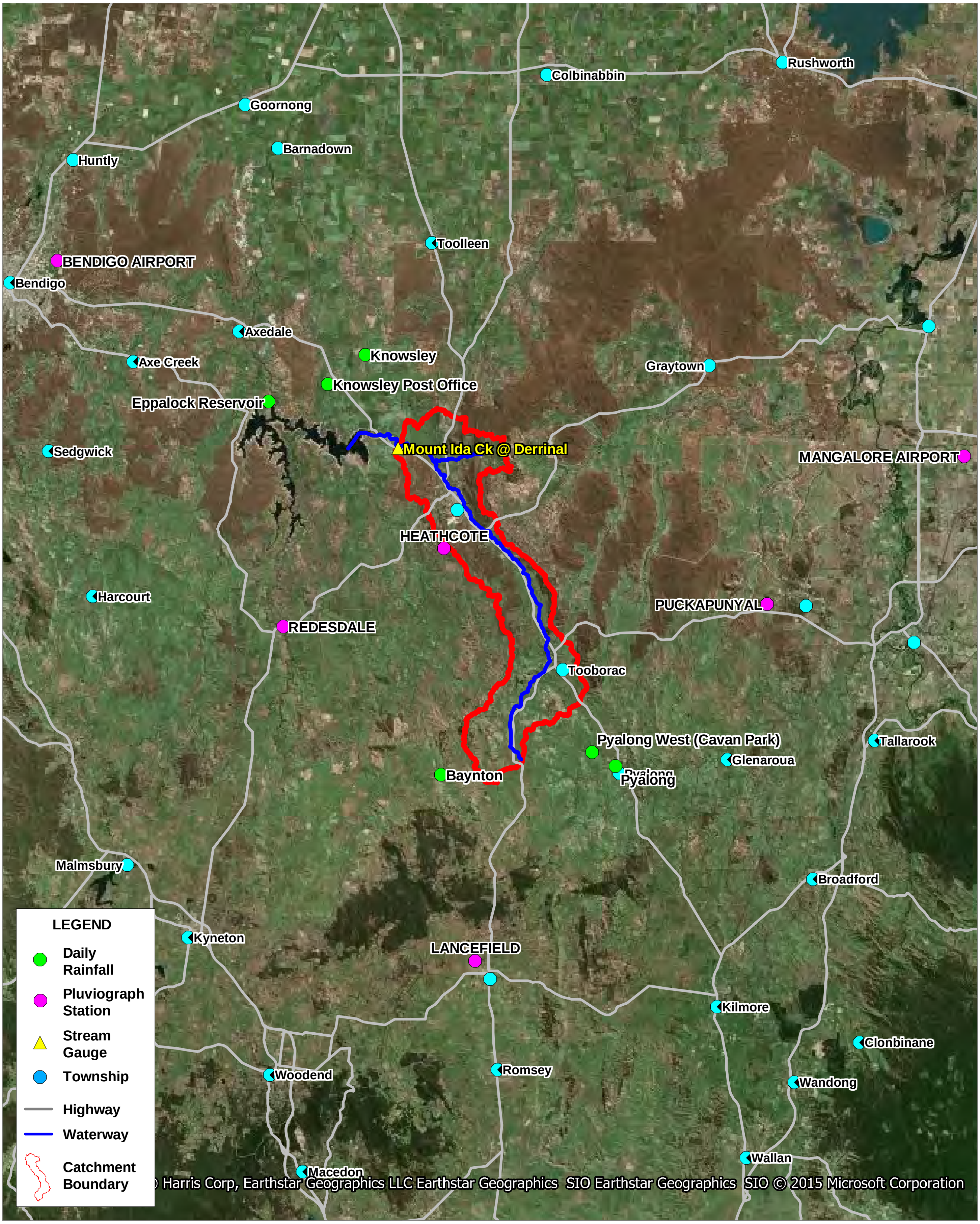
For the study, a search of newspaper databases was undertaken for reports of flooding within the study area. In total 25 articles were captured that provided additional information outside of the gauged record, these are listed in Appendix A.

In addition to the newspaper articles, ten plans were provided by NCCMA that had been created by the Rural Water Commission of Victoria. These plans documented flood history within the study area between 1916 and 1983. These plans included spot flood height for a number of historic flood events as well as an approximate flood extent for the 1974 flood event. In particular the plan titled *History of Flooding 1916-1983* provided invaluable information on flooding in Heathcote and a copy of this is enclosed in Appendix B.

The gathered historic flooding information is presented in Table 2-5.

Table 2-5 Historic Flood Events

Event	Source	Comments	Sufficient Information to include
1867	*The Argus* 29/10/1867	Newspaper Article	No
1870	*The Mercury* 20/09/1870 *Bendigo Advertiser* 09/09/1870	Newspaper Articles	No
1883	*Newcastle Morning Herald and Miners Advocate* 15/02/1883	Newspaper Articles	No
1899	*Ian Hollingsworth*	Highest flood in creek since 1887	No
1906	*Ian Hollingsworth*	Biggest flood since 1870	No
1906	*Bendigo Advertiser* 11/09/1906 The Argus 11/09/1906	Newspaper Articles	No
1916	*McIvor Creek Adopted 1% Flood Profile – Plan 201261* (Rural Water Commission, 1988) *McIvor Creek History of Flooding 1916-1983 – Plan 201275* (Rural Water Commission, 1988)	Plans with survey flood heights. Deemed by RWC engineers to be of low reliability.	No, however noted as largest event to have occurred within the catchment since settlement.
1930	*The Argus* 17/12/1930	Newspaper Article	No
1939	*McIvor Creek Adopted 1% Flood Profile – Plan 201261* (Rural Water Commission, 1988) *McIvor Creek History of Flooding 1916-1983 – Plan 201275* (Rural Water Commission, 1988 *Kilmore Free Press* 25/05/1939 *Daily Advertiser* 10/04/1939 *News* 8/04/1939	Longitudinal plot showing adopted 1% flood extent that was based on the 1939 flood event. Newspaper Articles, reported worst event in 20 years	Yes
1954	*The Argus* 4/12/1954	Newspaper Article	No
1974	*McIvor Creek Adopted 1% Flood Profile – Plan 201261* (Rural Water Commission, 1988) McIvor Creek History of Flooding 1916-1983 – Plan 201275 (Rural Water Commission, 1988)	Longitudinal plot showing survey of flood heights and approximate flood profile Plan shows survey of flood heights and approximate flood extent	Yes



Title:

Heathcote Flood Study
Streamflow and Rainfall Gauges

Figure: 2-2

Rev: A

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

N

0 7.5 15km

Approx. Scale

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3 Community Engagement

This section documents the community engagement undertaken by BMT WBM for the Study. Ultimately the study outcomes need the support and acceptance of the community if they are to be effective in managing flood risk within Heathcote. Therefore their engagement is of utmost importance to the outcomes of the study.

Community engagement was undertaken in a variety of formats including:

- The Community Reference Group (CRG);
- Direct community consultation;
- One-of-one meeting with community members with knowledge of flooding in Heathcote;
- Informal and ad-hoc consultation by CRG members.

Further details of these are provided by below under the appropriate heading. This section addresses Key Objective 1.

3.1 Community Reference Group

For this Study a Community Reference Group (CRG) was established to provide local knowledge and aid in establishing communication between the various stakeholders in the Study. These stakeholders include a number of government agencies as well as local residents and community representatives. These agencies and representatives are listed in Table 3-1 below.

Table 3-1 Community Reference Group Representatives

Agency or Group	Representative
North Central Catchment Management Authority	Colin Smith (Chair) Leila Macadam Jolene Goulton
City of Greater Bendigo	Cr Helen Leach Cr Mark Weragoda George Buchhorn Noel Shanahan
Department of Environment, Land, Water and Planning	Simone Wilkinson
Victorian State Emergency Service (VicSES)	Jemma Nesbit-Sacville
Victoria Police	John Olver
Heathcote Community Plan Committee	Stephen Trompp
Community Representatives	Dick Duncan (also VicSES volunteer) Grant Baker Greg Speirs Ray Bastock (also VicSES volunteer)

During the study the CRG met once per month to provide information and feedback as well as to discuss project progress. Members of the CRG would liaise directly within their organisation as well as with other members of the community on project progress together with aiding and disseminating information in between meetings.

In addition, the CRG provides input to the study direction and key decisions and are responsible for the formal sign-off and acceptance of the outcomes of the study.

3.2 Direct Community Engagement

The last time Heathcote experienced a large disruptive flood was during the 1970’s. So, the township has not experienced significant floods (from McIvor Creek) for nearly 40 years and the perception in Heathcote was that there is not a significant flood risk. For these reasons, it was decided that a town hall style meeting may not receive sufficient participation and it was decided to take a more proactive approach to community engagement. It was decided by the CRG that the best approach was to take advantage of existing community events. Local knowledge indicated that the monthly Heathcote Bush Market was the most popular event and a stall was organised through the SES.

At the stall community members were able to engage with the study team and were updated on the progress of the study in an informal manner. The community members were asked to provide feedback on the preliminary results as well as any additional local knowledge and any documentation (photos, notes and the like) of historic flood events in their possession.

The first community engagement was held at the Heathcote Bush Market on Saturday 1st November 2014. Approximately 15 to 20 members of the community visited the stall. These community members were shown preliminary flood mapping of the January 2011 and May 1974 flood extents. In addition, 80 information flyers were distributed detailing the purpose of the study and the progress to date.

As well as the notes taken from the various community members on the day a number of the community took the opportunity to provide photos, notes and other information they had personally collected during and following flood events within the catchment. This information allows increased confidence and certainty in the outcomes of the study.

A register of the information provided by the community is presented in Appendix C.

Figure 3-1 Community Engagement - Heathcote Bush Market Stall (1/11/2014)

3.3 One-on-one Meetings

Individual were sought in the community who had been identified as being informal custodians of the flood history of Heathcote. The NCCMA organised on-on-one meeting with these community members to record the flood information. The individuals identified, were:

- Ian Hollingsworth

The notes gathered / provided by Ian Hollingsworth are presented in Appendix C.

3.4 Informal Consultation by CRG Members

An important aspect of the CRG is its ability to disseminate information to the community through informal and ad-hoc consultation. While this function of the CRG is difficult to measure it is an essential part of any successful study.

The CRG provides not only a conduit to pass information to the community, but also a mechanism for the community to provide feedback and information to the Study team.

3.5 Community consultation following completion of flood modelling

Following the completion of the flood modelling, North Central CMA sent to all properties that were identified as being subject to flooding a flyer that explained the background and recommendations of the study. Accompanying the flyer was a property specific flood report that detailed the floor level of the property and associated flood levels for the full range of flood events. Residents were given the opportunity to attend one-on-one meetings with North Central CMA to find out more information about the results of the study and provide feedback. Approximately 15 residents attended these one-on-one meetings.

4 Data Verification

This section documents the data verification process that was undertaken by BMT WBM for the study. Specifically, this section documents the quality assurance checks that have been performed to ensure that the supplied data is fit for purpose.

4.1 LiDAR Verification

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

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

For each LiDAR dataset a Digital Elevation Model (DEM) was developed.

4.1.1 Vertical Accuracy

The vertical accuracy of a LiDAR dataset can be demonstrated through the comparison of the LiDAR elevations to the elevation of known points within the study area. BMT WBM was provided with details of all Permanent Survey Marks (PSM) within the study catchment by DELWP and pit lid levels from the CoGB. In addition, topographic survey commissioned as part of the study captured road centre lines for the purposes of verifying the vertical accuracy of the LiDAR. The LiDAR was compared to both of these datasets, as outlined below.

As well as investigating the LiDAR, the other DEMs obtained were investigated, namely the 25m grid – State-wide and the 20m grid – VicMap 2008 datasets.

4.1.2 Permanent Survey Marks

Only the third order PSMs (the most accurate PSMs) was used in the analysis and there were 35 of these within the extents of the catchment. Each PSM was then inspected using information from the four constructed LiDAR DEM's.

The results from the statistical assessment of the vertical accuracy of the DEM when compared to PSMs are detailed in Table 4-1.

Note that the due to the poor results for the 25m grid – State-wide dataset this was not compared to the other ground level datasets.

Table 4-1 Comparison of LiDAR to PSMs

Statistical Measure of Difference (m)	25m grid -State-wide	20m grid - VicMap 2008	1m grid – Heathcote 2012	1m grid – ISC Rivers 2010
Mean	1.28	0.63	-0.66	-0.55
Median	3.27	0.44	-0.11	-0.01
Standard Deviation	4.54	3.85	1.38	1.32
Lower Quartile	-1.11	-2.09	-0.58	-0.28
Upper Quartile	4.16	2.70	0.10	0.13

4.1.3 Pit lids

For the Study, CoGB supplied BMT WBM with a GIS layer containing local pipe and pit drainage network. The GIS layer contained information of the ground surface level of a number of the pit lids which could be used to verify the LiDAR. In total there were 89 data points for comparison.

The results from the statistical assessment of the vertical accuracy of the DEM when compared to PSMs are detailed in Table 4-2.

Table 4-2 Comparison of LiDAR to Pit Lids

Statistical Measure of Difference (m)	20m grid - VicMap 2008	1m grid – Heathcote 2012	1m grid – ISC Rivers 2010
Mean	0.51	0.04	0.09
Median	0.55	0.02	0.07
Standard Deviation	1.79	0.34	0.30
Lower Quartile	-0.40	-0.06	-0.05
Upper Quartile	1.80	0.15	0.22

4.1.4 Topographic survey

Topographic survey was undertaken by ThinkSpatial at a number of locations in and around Heathcote. These surveyed points were compared to the three LiDAR DEM's. In total 172 points of comparison were available.

The results from the statistical assessment of the vertical accuracy of the DEM when compared to ground survey are detailed in Table 4-3.

Table 4-3 Comparison of LiDAR to Ground Survey

Statistical Measure of Difference (m)	20m grid - VicMap 2008	1m grid – Heathcote 2012	1m grid – ISC Rivers 2010
Mean	2.56	-0.05	0.01
Median	2.50	-0.04	0.01
Standard Deviation	0.52	0.06	0.05
Lower Quartile	2.05	-0.09	-0.02
Upper Quartile	3.06	0.00	0.04

4.1.5 Cross sections

A number of cross-sections were extracted throughout the catchment of each DEM to check the overall match between the datasets, an example is shown in Figure 4-1. Inspection of Figure 4-1 demonstrates a close agreement between the two 1m grid LiDAR DEM's. Typically, the Heathcote LiDAR within McIvor Creek has a base level on average 0.5m lower than the ISC Rivers data. This difference could be due to different water levels in the watercourse at the time the respective datasets were captured or due to filtering of vegetation; it is not possible to determine which from the data provided. Figure 4-1 is consistent with the information in Table 4-1 confirming the close agreement between the two LiDAR datasets.

The 20m VicMap DEM includes a representation of the waterway. The 25m state-wide DEM is consistently higher than the LiDAR datasets, and does not represent features such as McIvor Creek well. For this reason the 25m state-wide DEM was not used for this Study.

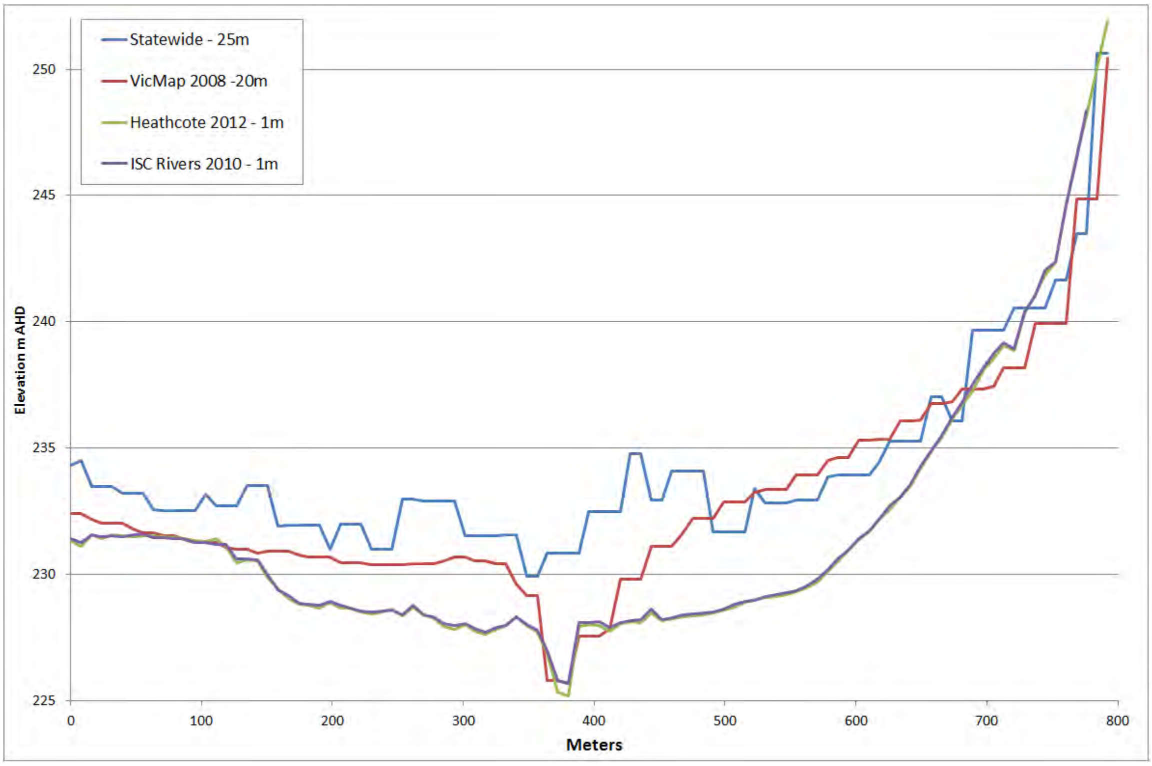


Figure 4-1 Cross-Section Comparison of LiDAR

4.1.6 Discussion on Vertical Accuracy

The supplied LiDAR DEMs have been checked for vertical accuracy against three independent sources. In general, the two LiDAR datasets had similar fits to the ground level datasets, significantly differing from the 20m grid - VicMap 2008 dataset. This general observation is confirmed in Figure 4-1. This figure also highlights that the 25m grid –State-wide dataset does not represent the McIvor Creek, and why it was not used in the study.

The comparison of the LiDAR DEM's to the PSMs suggests resulted in poor fit when compared to the other two ground truthing datasets available. The Heathcote catchment is relatively steep, with ground levels that can change elevation significantly over a relatively short area. This makes the vertical accuracy checks highly dependent on the horizontal location of the PSMs being correct. All of the PSMs available within the study area have only approximate horizontal coordinates. These coordinates were generally scaled from a 1:100,000 map and were sufficient to plot an approximate location only. For this reason, the PSM dataset is not considered to be as accurate as the pit lid or topographic survey datasets.

Overall, both 1m grid datasets showed close agreement with the provided pit lid data. There was a slight bias (0.04 – 0.09m) of the LIDAR datasets overestimating ground levels; however, there was a smaller standard deviation of 0.30 - 0.35m compared to the PSM analysis. This indicates there was less spread in the differences between the pit lids and the LiDAR datasets with the LiDAR datasets provided a better matched the pit lid datasets compared to the PSMs. The comparison to the 20m VicMap 2008 DEM similarly showed much greater agreement than to the PSMs.

When compared to the topographic survey data, both 1m grid data sets showed close agreement with the survey data. The ISC Rivers LiDAR had a better fit survey and the Heathcote 2012 dataset showing a slight bias to underestimating ground levels. It is of note that the mean difference between the two LiDAR datasets and the survey are similar each other, a student t-test indicated that there was no significant difference between these mean values ($t = 9.469$, $df = 326.38$, $p\text{-value} < 2.2e\text{-}16$). This suggests that both samples could have been drawn from the same population. The comparison to the 20m VicMap 2008 DEM showed poor agreement to the ground survey.

Further, the ISC Rivers LiDAR appeared to have been captured with higher base flow than the Heathcote 2012 LiDAR which will affect conveyance within the channel. This can be seen in Figure 4-1. For this reason, the preference was for the use of the Heathcote 2012 LiDAR to the ISC Rivers LiDAR.

The LiDAR datasets are considered to be suitable for the purposes of flood modelling and mapping Heathcote.

Whilst the 20m VicMap DEM did not capture the finer detailed, it did represent the significant hydrologic features. This DEM was considered suitable for catchment delineation; however, it is not suitable for hydraulic modelling within the study area.

The 25m state-wide DEM showed overall a poor agreement with the other DEMs and will not be used in this project.

4.1.7 Horizontal Accuracy

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

The horizontal accuracy of the LiDAR was checked through the comparison of the alignments of identifiable features (roads, farm dams, ovals, etc.) within the terrain, the aerial photography and cadastre throughout the catchment. Visual inspection of the DEMs to the property boundaries indicated some discrepancies particularly in relation to McIvor Creek; however, these are not considered to be significant. The aerial photography was compared to the DEMs at a number of locations where topographic features could be identified, typically waterways and farm dams. From the visual inspections a close agreement was noted which confirms the validity of the horizontal accuracy of the DEMs.

Figure 4-2 shows an example of horizontal accuracy check undertaken. From the figure the road embankments, stream location, as well as minor details such as the bales in the paddock in the DEM align with the aerial photography.

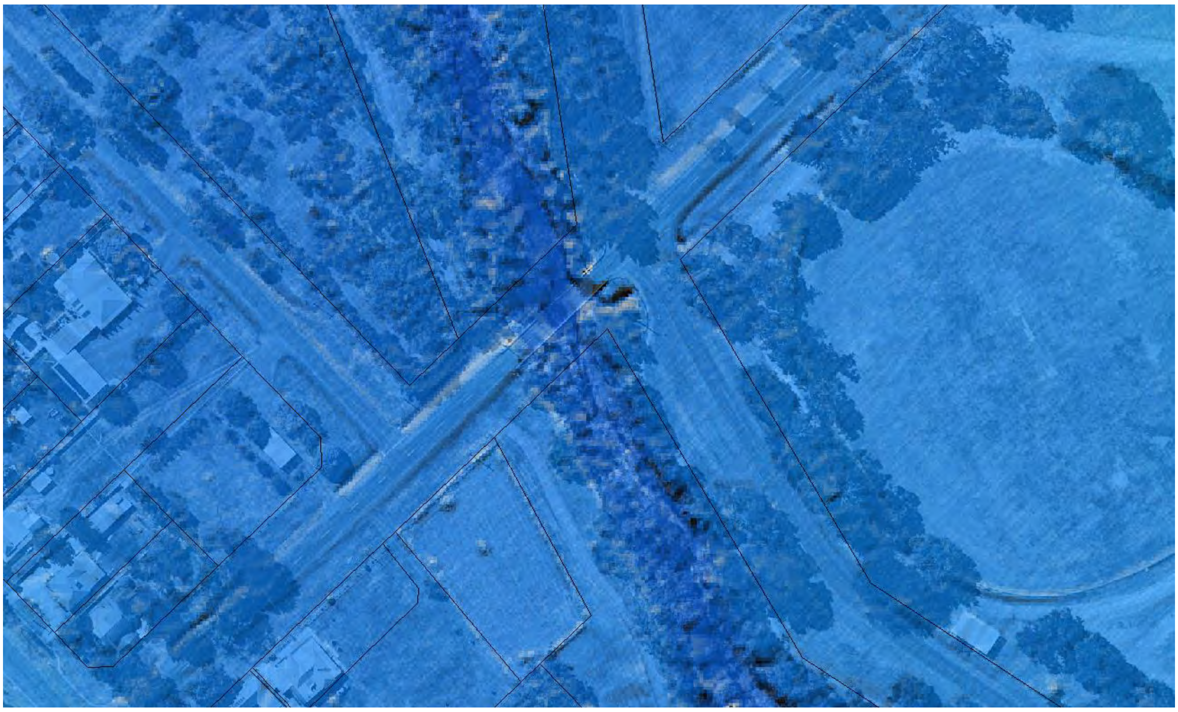


Figure 4-2 LiDAR Feature Check

4.1.8 Summary

Review of the LiDAR DEMs indicates that the two 1m LiDAR datasets provide an accurate representation of the Study area's topography. This review indicated that the VicMap DEM was suitable for the delineation of the Catchment and sub-catchment areas. The state 25m State-wide DEM was deemed not to be suitable for use.

A summary of the review of the various LiDAR datasets is presented in Table 4-4. As only the coarser 20m VicMap DEM covers the entire catchment, Table 4-4 also specifies the end use of the datasets as well as the order of preference in their use. The Heathcote LiDAR dataset was preferred (where available) given its better representation of the McIvor Creek channel.

Table 4-4 LiDAR Summary and Comments

Dataset	Resolution	Comments and Planned Use
2009-10 Victorian State Wide Floodplains LiDAR Project (Heathcote 2012)	1m	Primary LiDAR used in hydraulic model. Does not cover the whole of the hydraulic model domain.
ISC Rivers LiDAR (2010)	1m	Secondary LiDAR used in hydraulic model. Primarily used downstream of the Heathcote 2012 extent.
VicMap Elevation DTM 2008	20m	Covers whole of catchment, used for hydrologic delineation, also used for downstream of mapping limit in hydraulic model
State-wide DEM	25m	Deemed unreliable. Not used for this Study.

4.2 Verification of Other Data

4.2.1 Rating Curve

The rating curve for Mount Ida Creek at Derrinal was obtained from the Victorian Water Monitoring site[3] together with details of manual gaugings (as a static image only) which are presented in in Figure 4-3. This information indicates that there have been 158 gaugings between 31/05/1978 and 26/08/2013.

As part of the topographic survey commissioned as part of the study, survey of the gauging station was undertaken. This survey captured the details of the gauges boards, weir and channel cross sections.

[3] http://data.water.vic.gov.au/monitoring.htm

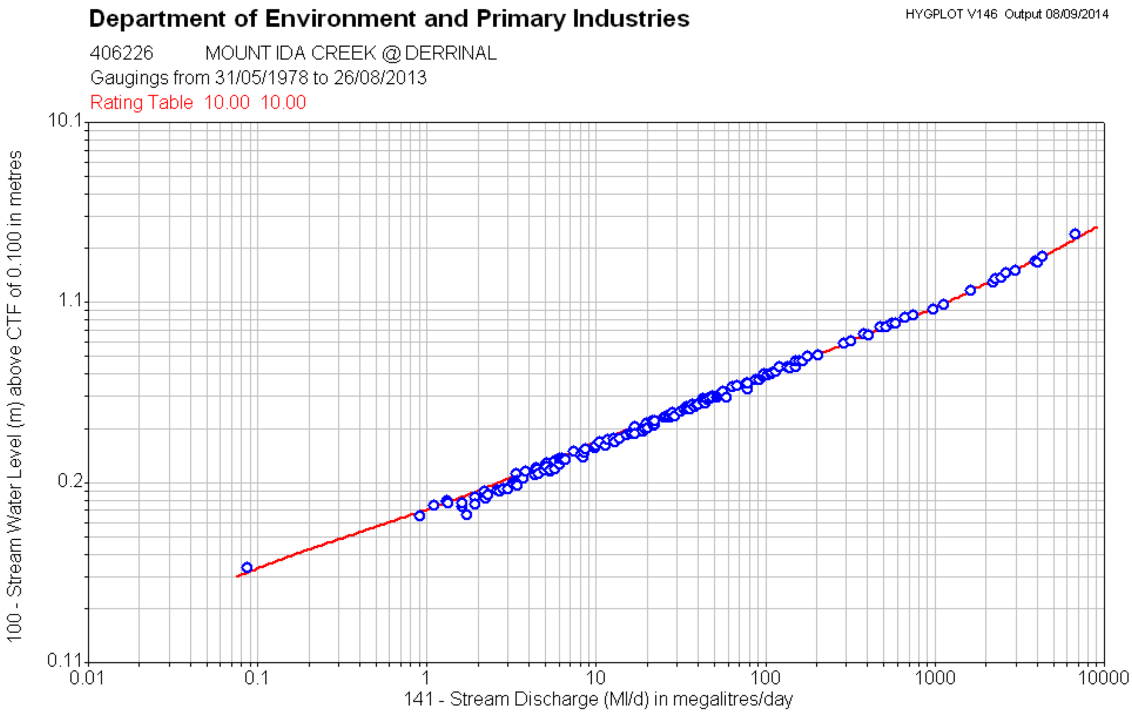


Figure 4-3 Mount Ida Creek at Derrinal manual gaugings.

The rating curve at Mount Ida Creek, the only gauge within the catchment, was checked by SKM (SKM, 2013) against historic gauging's, this is replicated below in Figure 4-4. SKM did not provide any commentary on the reliability of the rating curve.

The gauge was inspected during a site visit. Photographs of the gauge station are shown in Figure 4-5 through Figure 4-7.

The highest gauged discharge has a stage of 2.51m (200.82 m AHD) which was in-bank (see the gauge staff in Figure 4-7). It is generally considered that, when rating curves are developed using in-bank gauging, extending the rating to the top-of-banks is reasonable. However, in these circumstances extending the rating curve beyond the top-of-banks is likely to introduce significant error.

As all recorded stages at the gauge are in-bank it is considered the determined flows should be reliable for the purposes of the FFA and calibration of the hydrologic and hydraulic models.

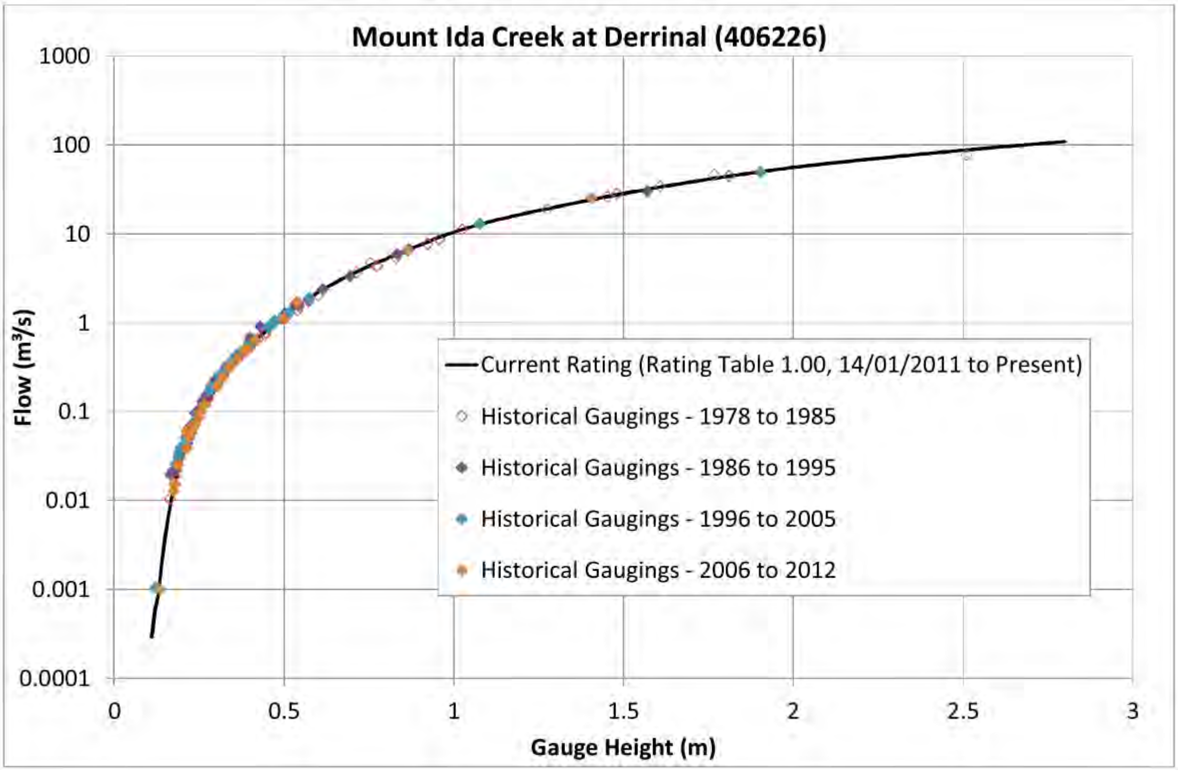


Figure 4-4 Mount Ida Creek Rating Curve Comparison (SKM 2013)

Figure 4-5 Mount Ida Creek Gauge – Facing Upstream

Figure 4-6 Mount Ida Creek Gauge – Facing Downstream

Figure 4-7 Mount Ida Creek Gauge – Gauge Staffs

5 Hydrologic Modelling

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

Rainfall-runoff modelling or hydrologic modelling, of the Catchment was undertaken with the URBS hydrological modelling package. The output from the URBS model provided inputs into the TUFLOW hydraulic model. Hydrologic models of the catchment have previously been developed as part of flow modelling studies focussed on inflows to Lake Eppalock. A RORB model had been previously developed for Lake Eppalock as part of the Inflow Forecasting for Storages (SKM, 2012) on behalf of Goulburn-Murray Water. This was subsequently updated and converted to an URBS model as part of the Conversion of RORB to URBS Models for Implementation of Delft-FEWS project (SKM, 2013). Whilst these models were appropriate for the generation of inflows to Lake Eppalock they were deemed to lack the required definition (there was not the recommended 3 to 5 sub-catchments upstream of Heathcote) of the catchment for the purposes of hydrologic modelling for the town of Heathcote. Therefore, a new URBS model was developed to meet the requirements of this study.

Flood Frequency Analysis involves the use of historic flow conditions at a river gauging site to aid the prediction of design flow rates. This is achieved by the analysis and fitting of statistical distributions to the gauged streamflow data. Once a statistical distribution has been fitted to the streamflow data, estimates of the rarity of flood events can be made in terms of probability, that is, an estimate of the return period of an event can be made. Whilst the catchment has a long history of settlement, stream gauging within the catchment only began in 1978.

This chapter addresses Key Objective 2 and is presented in the following format:

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

5.1 Regional Flood Frequency Analysis

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

The results from the ARR RFFE Model 2012 (test version) for the reporting locations are presented in Table 5-1. It should be noted that ARR RFFE Model 2012 (test version) is based on ARR 1987 IFD data. It is not expected that the updated RFFE model and IFD data will be available before completion of the Study.

Table 5-1 RFFE Results: 406226 Mount Ida Creek at Derrinal

AEP	Expected Quantile (m^3/s)	90% Quantile Probability Limits	
20%	57	24	137
10%	83	34	201
5%	109	44	269
2%	145	58	364
1%	172	67	436
0.5%*	200	-	-
0.2%*	235	-	-
0.1%*	261	-	-

* These quantiles were estimated using the LP3 distribution parameters from the RFFE and using the quantile estimation technique outlined in Roa & Hamid (2000) and the Wilson-Hilferty Transform. No estimate of the uncertainty was made as there was not enough information to construct these from the RFFE results.

It should be note that the RFFE flows were only used for comparison purposes with the other techniques. However, the resulting Log Person Type III parameters were used as prior information in the Bayesian Flood Frequency analysis.

5.2 At-site Flood Frequency Analysis

5.2.1 Introduction

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

The fitting of flood frequency distributions using Flike was undertaken with the following steps:

- Prepare data:
    - Collect gauged streamflow data
    - Undertake standard data checks on the stream flow data including checking error codes, cataloguing data gaps and undertaking visual inspections;
    - Extract the annual maxima series and check peaks for independence; and

    - Collect historic data

- At-site FFA: Fit an extreme value distribution using Flike, this involves:
    - Incorporating historic data;
    - Censoring low flows: low flows were systematically removed using a multiple Grubbs Beck test from the data to ensure that the distributions are 'aware' of the full length of record as opposed to block censoring the data; and
    - Prior Parameters Information: Distribution parameter estimates from the RFFE model were applied to Flike as prior information.

Background on Approach

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

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

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

5.2.2 Data

Collect the data

Streamflow data was available at only one location in the catchment as shown in Figure 1-2, namely Mount Ida Creek at Derrinal approximately 7km downstream of the centre of Heathcote. As outlined in Section 2.5, this data was obtained from the Victorian Water Monitoring site.

There are 36 complete years (1978 to 2013) of instantaneous flow record length for the gauge. No average daily flows beyond this period have been recorded which could have been used to extend the stream gauging record.

Standard Data Checks

The quality control code in the stream gauge data was checked for the largest event in each calendar year. These were inspected for any anomalies or indications of errors such as instrument failure and the like. These are summarised in Appendix D along with the annual maximums.

Of the 36 events, all bar five years reported good quality data. Of the remaining five years, two (2011 & 2010) warned of extrapolated flows, however, the peak flood levels recorded for these events is within bank and as discussed above in Section 4.2.1 should be reasonably accurate. Two of the years (1983 & 2002) indicate that the peak level was manually estimated and the remaining year (2013) indicates the data was manually estimated. All of these records were reviewed and were considered to be suitable for inclusion in the analysis.

Annual Maximum Data

The annual maximum data for the Mt Ida Creek gauging station was extracted from the streamflow data collected and is listed in Appendix D. A plot of this data is presented in Figure 5-1.

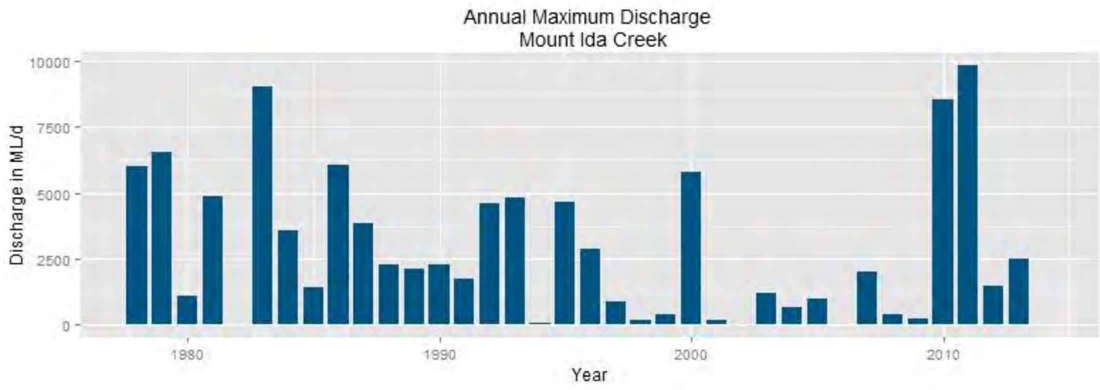


Figure 5-1 Annual Maximum Series Mount Ida Creek

Collect Historic Data

In addition to the data recorded by the stream gauge, a number of historic events were included in the flood frequency analysis. The catchment has a long history of settlement, however, only a relatively short stream gauge history. Whilst the January 2011 event was the largest recorded at the gauge there have been at least four larger flood events that are understood to have occurred (see Section 2.7), these were the 1870, 1906, 1939 and 1974 events. The available information for each of these events is discussed below. The Bayesian framework allows the incorporation of historic events into the FFA.

During the data collation a number of plans were provided that document in detail the 1974 flood event as well as anecdotal information about 1939 and 1906 flood levels. These are enclosed in Appendix B. The plans provided included a significant number of surveyed flood levels of the 1974 flood event as well as an approximate flood extent. Using the calibrated hydraulic model and temporal patterns from the Heathcote rainfall station (Station No. 88029) the peak flow at the gauge was estimated to be 220 m^3/s. Details of this, including a comparison of flood marks to the modelled flood levels are presented in Section 6.7.4.

The comparison to the 23 flood marks found 2 flood marks were outside of the mapping limit and 13 out of the remaining 21 (62%) were within +/-0.2m of the modelled flood surface with a mean difference of -0.05m. This information was included in the gauged flow record directly.

The details of the 1939 and 1906 flood levels are less certain. According to a note on one of the plans the existing 1% flood extent within the township was based on 1939 flood using information available to the Rural Water Commission engineers in 1988 who undertook the original work. To generate a flood extent similar to the existing 1% mapping a peak flow of around 350 m^3/s was required in the preliminary flood hydraulic model. The single recorded flood mark for this event was higher than the modelled flood surface, so this event was included as an event exceeding 350m^3/s in the FFA.

On these plans two data points exist for the 1906 event. These flood marks place the event significantly above the 1939 event, however these were deemed to be of low reliability by the Rural Water Commission engineers. Given this, it was not considered feasible to reconstruct the flow rate in the same way as the 1939 or 1974 flood events. The 1906 was, however, included as an event exceeding 350m^3/s in the FFA.

Similarly, the specific details of the 1870 event were not considered detailed enough to assign a flow magnitude. Further from the available information it was not possible to determine the rank of this event compared to the other events. For these reasons, the 1870 event was not included in the FFA.

From the above analysis there was enough certainty to incorporate three historic events in the FFA using the details outlined in Table 5-2.

Table 5-2 Details of historic events to be incorporated into FFA

Event	Estimated Peak Flow	Source of information (refer to Appendix B)
1974	220 m^3/s	For 1974 event see Section 6.7.4 & McIvor Creek Adopted 1% Flood Profile – Plan 201261 (Rural Water Commission, 1988) & McIvor Creek History of Flooding 1916-1983 – Plan 201275 (Rural Water Commission, 1988)
1939	Greater than 350 m^3/s	
1906	Greater than 350 m^3/s	

5.2.3 At-site FFA Results

The FFA was undertaken using the Flike software program which uses either a Bayesian inference framework or LH moments. The software uses global search to determine the most probable values of the parameters and calculates a second-order approximation of the posterior distribution. Confidence limits are then calculated together with flood quantiles and expected probability flood distributions.

Historic Information

The historic events outlined in Table 5-2 were incorporated in to Flike. The 1974 event was directly incorporated as a peak flow of 220m^3/s. The earlier events were incorporated as a historic period with two events greater than 350m^3/s between 1973 and 1906. Note that care was taken to ensure that the frequency information was preserved, that is, the period from 1974 to 1978 was accounted for.

Removal of Probable Influential Low Flows

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

A discharge to censor below of 23.1 m^3/s was determined by using the multiple Beck Grubbs test which resulted in 18 events being censored. These events are less than the average annual flood and therefore are not considered important in the context of rarer flood events.

Prior Parameters Information

The higher order Log Pearson Type III parameters derived from the RFFE analysis were used as prior information to the Bayesian framework in Flike. That is, the standard deviation (log flow) and skew (log flow) parameters. As well as the parameter values the standard deviations of the determined parameters, were used as prior information. The mean (log flow) parameter was determined from the streamflow data. The parameters used are shown in Table 5-3.

Table 5-3 RFFE parameters for Mount Ida Creek

Parameter	Mean	St Dev	Correlation		
Mean (loge flow)	3.067	0.539	1.000		
St dev (loge flow)	1.133	0.205	-0.210	1.000	
Skew (loge flow)	-0.665	0.167	-0.040	-0.410	1.000

FFA Results

The results for the FFA are shown in Table 5-4 and Figure 5-2. This table lists the 1% AEP peak discharge as 321 m^3/s. The January 2011 flood was determined to be approximately the 10% AEP (10 year ARI) event.

Table 5-4 FFA Results: 406226 Mount Ida Creek at Derrinal

AEP	Expected Quantile (m^3/s)	90% Quantile Probability Limits	
20%	80	58	109
10%	126	94	173
5%	180	133	249
2%	257	188	363
1%	321	232	462
0.5%	387	276	571
0.2%	477	334	729
0.1%	547	376	859

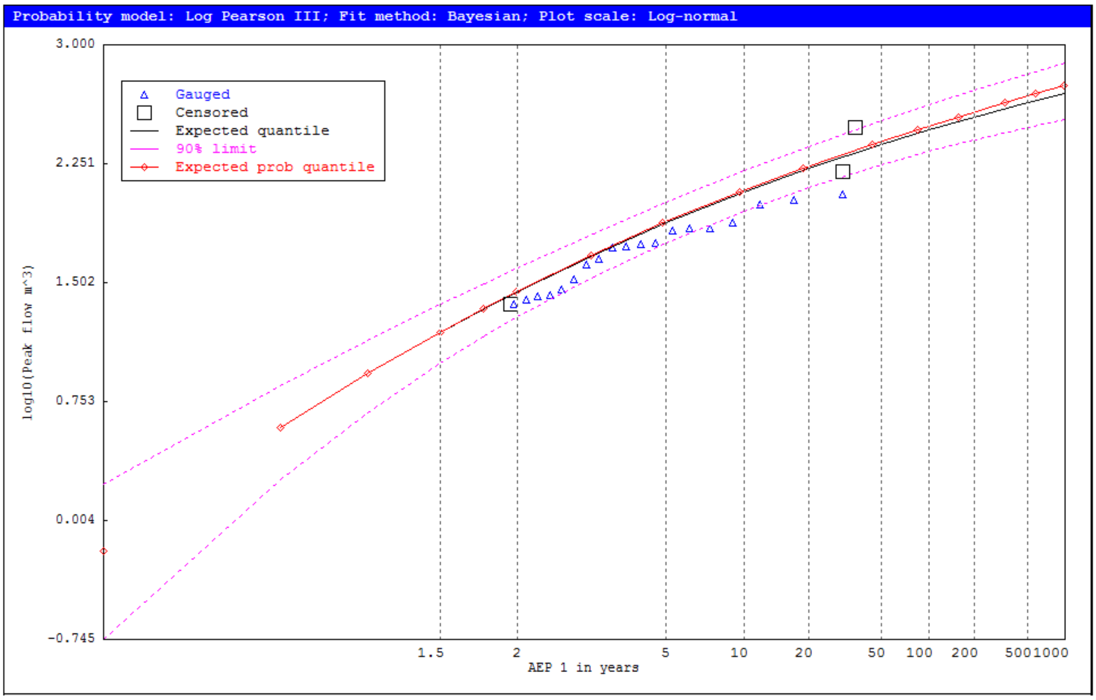


Figure 5-2 FFA Results: 406226 Mount Ida Creek at Derrinal - Log Pearson Type III

5.3 Peak Flow Discussion

The results from the regional flood frequency estimate analysis and the at-site flood frequency analysis have been compared and are presented in Table 5-1 and Table 5-4. The RFFE values are lower than those derived from the at-site FFA for all calculated AEPs. Whilst the expected flood quantiles differ, it is of note that flood quantiles calculated by these two techniques are not expected to be identical. The calculated quantiles from FFA analysis fell within the 90% confidence limits of the RFFE; however, the RFFE quantiles did not fall within 90% confidence limits of the FFA. These results are considered to be acceptable as the more certain results (at-site FFA) fell with the confidence limits of the less certain results (RFFE).

For the purpose of the Study the at-site FFA methodology is recommended over the RFFE method.

5.4 URBS Model

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

5.4.1 Model Description

The URBS model covers an area of approximately 173 km^2. To ensure accurate representation of the hydrological response of the overall catchment, the model was divided into 11 individual sub-catchments. Conceptual reaches (approximate overland flow paths) were defined.

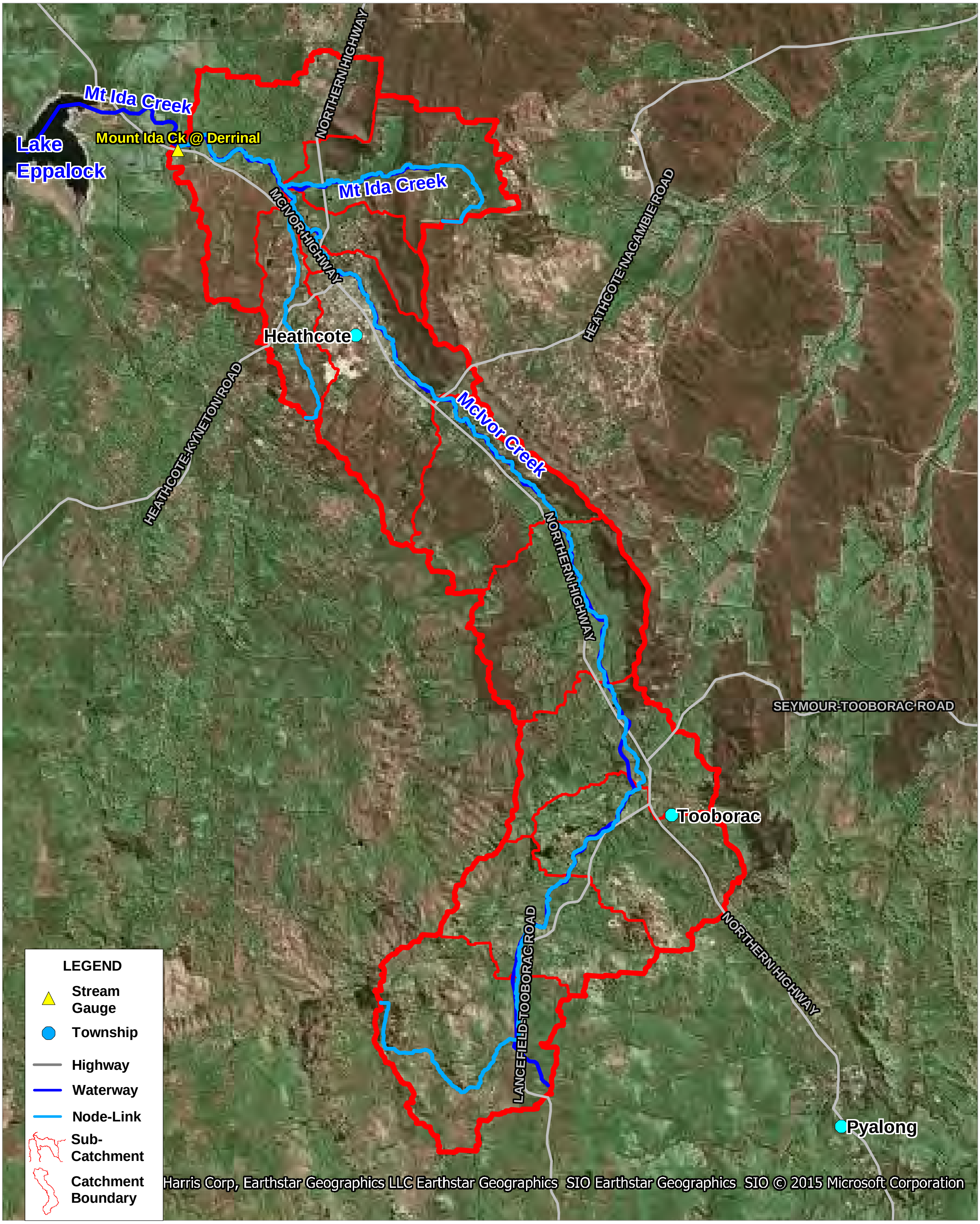
There are a number of storages within the catchment. These include Caledonia Gully Reservoir and the Heathcote Landfill. Neither of these storages has substantial catchments upstream of them and are typically small in the context of the study catchment. In addition to the formal storages a number of small, informal farm dams exist within the catchment. For the purposes of the hydrologic model these storages were assumed to be full and thus were not included in the model explicitly. Whilst these have not been incorporated into the model explicitly they will be inherently modelled during the calibration of the models with the adopted initial loss parameter.

5.4.2 Sub-Catchment Definition

The catchment and sub-catchment boundaries were initially determined using the software package CatchmentSIM, based on the provided digital elevation datasets. The catchment breakup was then refined to ensure that consistency in sub-catchment size and shape was achieved as best as the catchment topology would allow with a final total of 11 individual sub-catchments. To ensure sufficient routing upstream of the hydraulic model extent a total of 6 sub-catchment areas were delineated. The sub-catchment breakdown is shown in Figure 5-3.

5.4.3 Fraction Impervious

The catchment is predominately a rural catchment with the township of Heathcote the only area of substantial impervious surfaces. However, unlike a more heavily urbanised area, the drainage of many of these impervious surfaces is via natural channels and gullies opposed to piped drainage assets. For the Study the fraction imperviousness of the catchment was primarily determined from the planning layer with the cadastral and aerial photography used to validate the adopted values. The fraction imperviousness was assigned to each sub-catchment individually. Values varied from 0.5% to 6.3%.



Title:
Heathcote Flood Study
URBS Model Layout

Figure:
5-3

Rev:
A

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

N

0 2.5 5km
Approx. Scale

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Filepath : T:\M20448.PP.HeathcoteFloodStudy\MapInfo\Drawings\R.M20448.008.00.Final\HC_Final_Fig5-3_URBS_RevA.WOR

5.5 Calibration and Validation

To establish that the hydrologic modelling is suitably representing runoff behaviour of the catchment the model underwent a calibration and validation to actual flood events. This is important to ensure that the hydrologic model is providing reasonable inputs for the hydraulic modelling process. The hydrologic model was first calibrated to five events, from the individual parameter sets a representative parameter set was generated which was then validated against the same five events whilst only varying the loss parameters. The calibration and validation process is described in detail below. The calibration and validation results were assessed visually, combined with comparisons of peak flow and total volume at each gauge in combination with the Nash-Sutcliffe Efficiency (NSE) value.

5.5.1 Calibration and Validation Process

The hydrologic modelling calibration process involves the following steps:

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

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

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

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

(5) From the individual parameter sets determine the final parameter set for validation and design events.

(6) Validate the model parameters against an original storm events, using final parameter set.

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

5.5.2 Stream Gauge Information

The same stream gauge used in the FFA was used in the URBS calibration; Mount Ida Creek at Derrinal.

5.5.3 Rainfall Selection and Distribution

There are a number of pluviograph stations in and around the catchment as well as 6 daily rainfall stations as shown in Figure 2-2.

For all the calibration and validation events modelled, the Heathcote (station no. 88029) pluviograph was used to distribute the temporal rainfall within the model. Whilst other pluviograph gauges exist, they are located outside of the study catchment. However, these other pluviograph stations were used to verify the Heathcote gauge. The purpose of the verification was to check for consistency in the rainfall patterns across the catchment. For the selected events, it was observed that rainfall fell with a similar temporal pattern at each of the stations, although the magnitudes did vary. That is, the temporal pattern of rainfall across the catchment was consistent.

Similarly the daily rainfall gauges were used to validate the Heathcote pluviograph station to ensure data consistency.

5.5.4 Calibration and Validation Event Selection

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

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

Both rainfall and streamflow data at a resolution commensurate with the hydrological response of the study catchment are required to calibrate a hydrological model. The hydrological response of the catchment to the gauge is of the order of 0.5 - 2 days. It was therefore necessary to have data at a sub-daily scale to adequately model the catchment's response.

As discussed in Section 1.5 there is a long history of flood events in the catchment which have impacted upon the township. Since the construction of the gauging station on Mt Ida Creek there has not been a flood event that has caused significant flooding within the township. The event with the greatest amount of information for calibrating the hydraulic model is the 1974 event which predates the stream gauge which was installed in 1978. Following the 1974 event, survey was undertaken of flood marks throughout Heathcote. In the absence of a stream gauge this event cannot be used to calibrate the hydrologic model but was used for verification of the hydraulic model.

For the calibration of the URBS model five events were selected. These events represent the largest event as well as a range of flow rates than should ensure that the model is representative over a range of flood frequencies. The events selected were:

- August 1978;
- September 1993;
- September 2010;
- December 2010; and
- January 2011.

5.5.5 Calibration Parameters

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

The URBS program provides the facility to manually adjust the calibration parameters until an acceptable fit is found. URBS also provided a number of summary statistics including difference in observed and calculated hydrograph volumes, differences in peak flow and differences in the time to peak. In addition, the Nash-Sutcliffe Efficiency (NSE) (Nash and Sutcliffe, 1970) was also calculated. This is a statistical measure to evaluate a model's performance against observed data.

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

$$NSE = 1 - \frac{var(Res)}{var(hyd)} \qquad \text{Equation 2}$$

where *var(Res)* is the variance of the model residuals or the difference between the observed and calculated flows, and *var(hyd)* is the variance of the observed hydrograph. Additional summary statistics are presented on the calibration and validation plots and a description of these is presented below under the heading *Summary Statistics.*

Guidance on interpreting NSE values has been published by Chiew and McMahon (1993) and is reproduced below (Table 5-5) to aid the interpretation of the calibration and validation results.

Table 5-5 Guide to interpret NSE values after Chiew and McMahon (1993)

Classification	NSE value Calibration	NSE value Validation
Excellent	NSE >= 0.93	NSE >= 0.93
Good	0.8 <= NSE < 0.93	0.8 <= NSE < 0.93
Satisfactory	0.7 <= NSE < 0.8	0.6 <= NSE < 0.8
Passable	0.6 <= NSE < 0.7	0.3 <= NSE < 0.6
Poor	NSE < 0.6	NSE < 0.3

Summary Statistics

On each of the plots comparing the observed to the modelled events a number of summary statistics are reported. A description of these is provided below.

Percent Bias (PBIAS): Measures the average tendency of the simulated values to be larger or smaller than their observed ones as a percentage. Smaller percentages indicate less bias.

Nash Sutcliffe Efficiency (NSE): Provides the proportion of variance explained by the modelled response (Nash and Sutcliffe, 1970).

R^2 (Coefficient of Determination): This is the well-known R^2 (R squared) value that describes a statistical model's fit to the data, a value of 1 indicates a perfect fit and values of less than 1 indicate less than perfect fits.

VE (Volumetric Efficiency): This is an analogue to the NSE that uses volume as opposed to flow. It represents the proportion of water delivered (Criss and Winston, 2008).

5.5.6 August 1978 Calibration Results

The best fit for the calibration parameters are listed in Table 5-6 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-4.

The calibration resulted in a good fit to the observed record. The modelled initial catchment response was slightly quicker than the observed record with a longer receding curve, however an NSE of 0.89 indicates an overall good fit.

Table 5-6 Calibrated Parameters and Values for August 1978

Station	*A*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.18	0.80	1.5	15	0.2	0.89	11%	0%

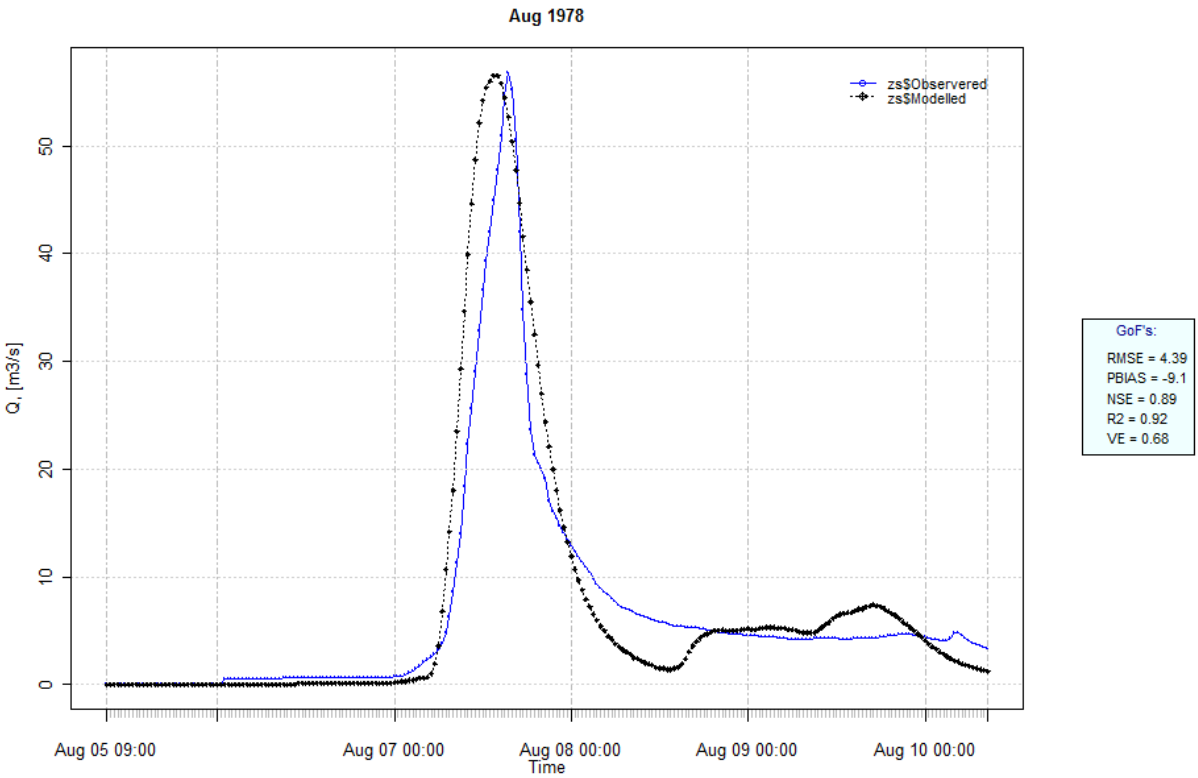


Figure 5-4 Calibrated Hydrograph Comparison for August 1978

5.5.7 September 1993 Calibration Results

The best fit for the calibration parameters are listed in Table 5-7 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-5.

The calibration resulted in generally a poor fit to the observed record. Primarily the poor timing of the peaks resulted in a poor NSE of 0.59 with the peaks offset by approximately 6 hours. The peak flow and general shape of the hydrograph are a reasonable approximation of the observed record.

A significantly better NSE of 0.84 could be achieved at the sacrifice of the peak flow (34 versus 56 m^3/s) and considerably greater volumes. It was considered that it was more important to match the general shape, peak flow and total volume rather than a stronger NSE value.

Table 5-7 Calibrated Parameters and Values for September 1993

Station	*α*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.10	0.80	2.0	13	0.0	0.59	0%	3%

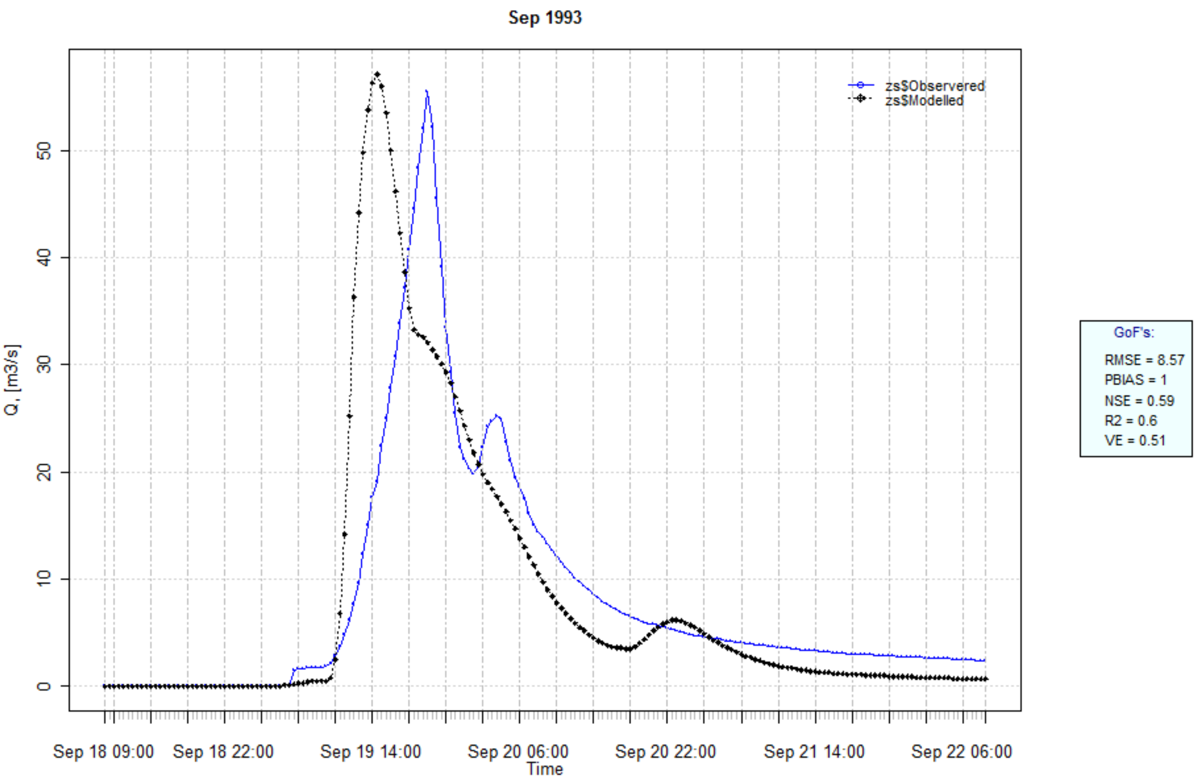


Figure 5-5 Calibrated Hydrograph Comparison for September 1993

5.5.8 September 2010 Calibration Results

The best fit for the calibration parameters are listed in Table 5-8 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-6.

The calibration resulted in a good fit to the observed record. This is confirmed by an NSE of 0.94, a peak flow rate and total volume difference of 1%.

Table 5-8 Calibrated Parameters and Values for September 2010

Station	*α*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.25	0.80	2.0	15	1.0	0.94	1%	-1%

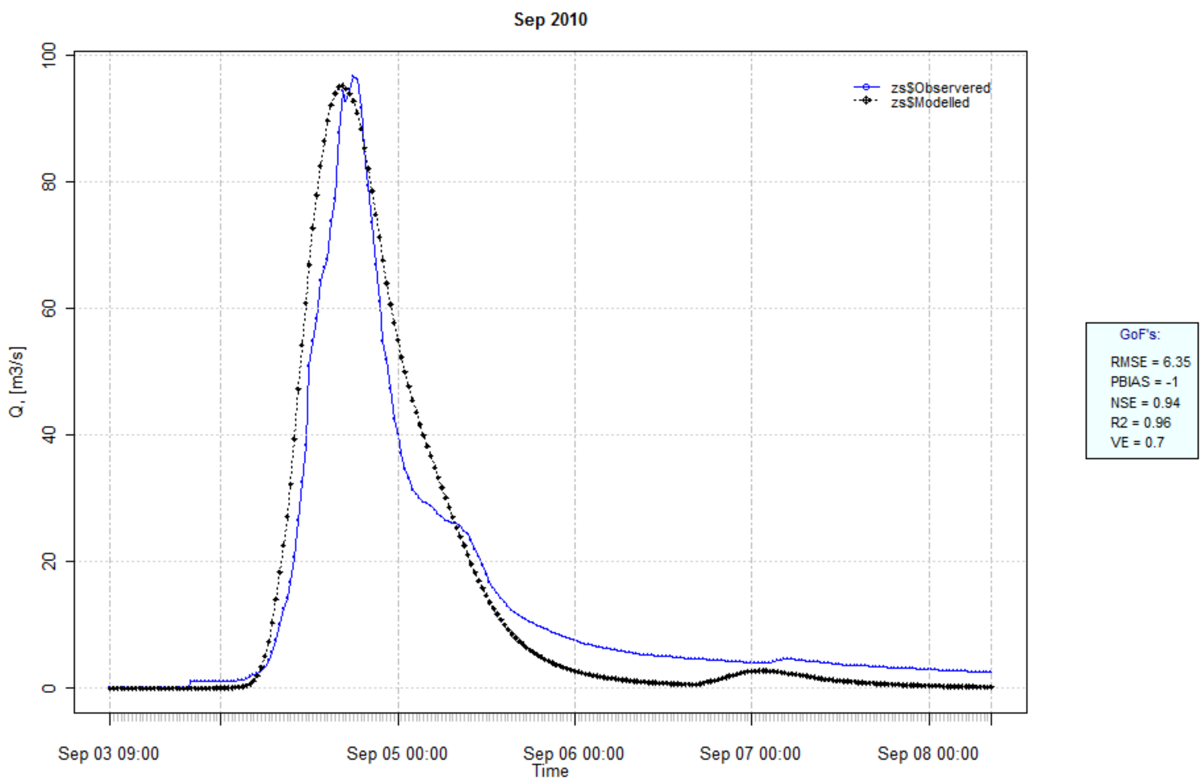


Figure 5-6 Calibrated Hydrograph Comparison for September 2010

5.5.9 December 2010 Calibration Results

The best fit for the calibration parameters are listed in Table 5-9 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-7.

The calibration resulted in an excellent fit to the observed record. Whilst the timing of the peaks were offset by approximately 1.5 hours the overall shape, magnitude and volume were very good and within 2% of the observed record. This resulted in an excellent NSE value of 0.96.

Table 5-9 Calibrated Parameters and Values for December 2010

Station	*α*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.30	0.80	3.5	21	2.5	0.96	2%	2%

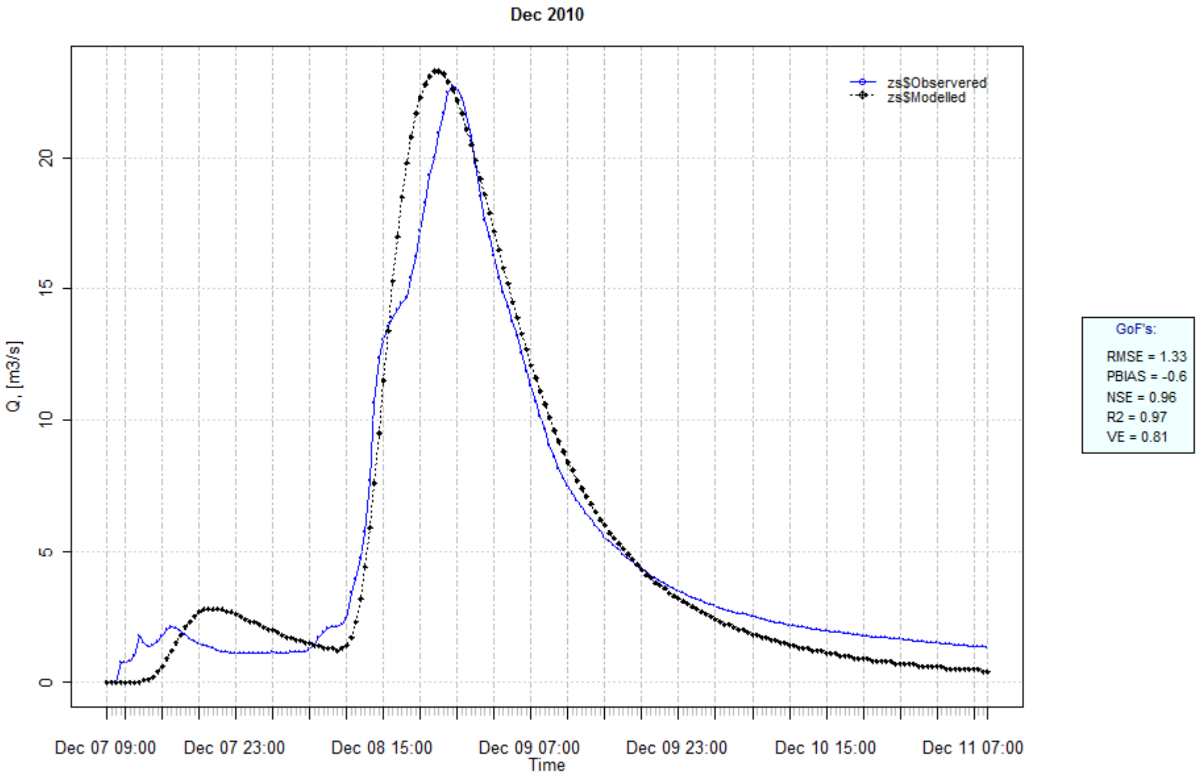


Figure 5-7 Calibrated Hydrograph Comparison for December 2010

5.5.10 January 2011 Calibration Results

The best fit for the calibration parameters are listed in Table 5-10 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-8.

The calibration resulted in generally a good fit to the observed record. It should be noted that this is a double peaked hydrograph, which are often difficult fit to rainfall runoff models. Whilst the timing of the peaks were offset by approximately 5 hours the overall shape, magnitude and volume were very good. This resulted in a good NSE value of 0.87, with approximately 2% greater volume and a peak flow rate matching the recorded flow. We consider this to be an excellent fit to a double peaked hydrograph.

Table 5-10 Calibrated Parameters and Values for January 2011

Station	*α*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.17	0.80	2.5	101	0.9	0.87	2%	0%

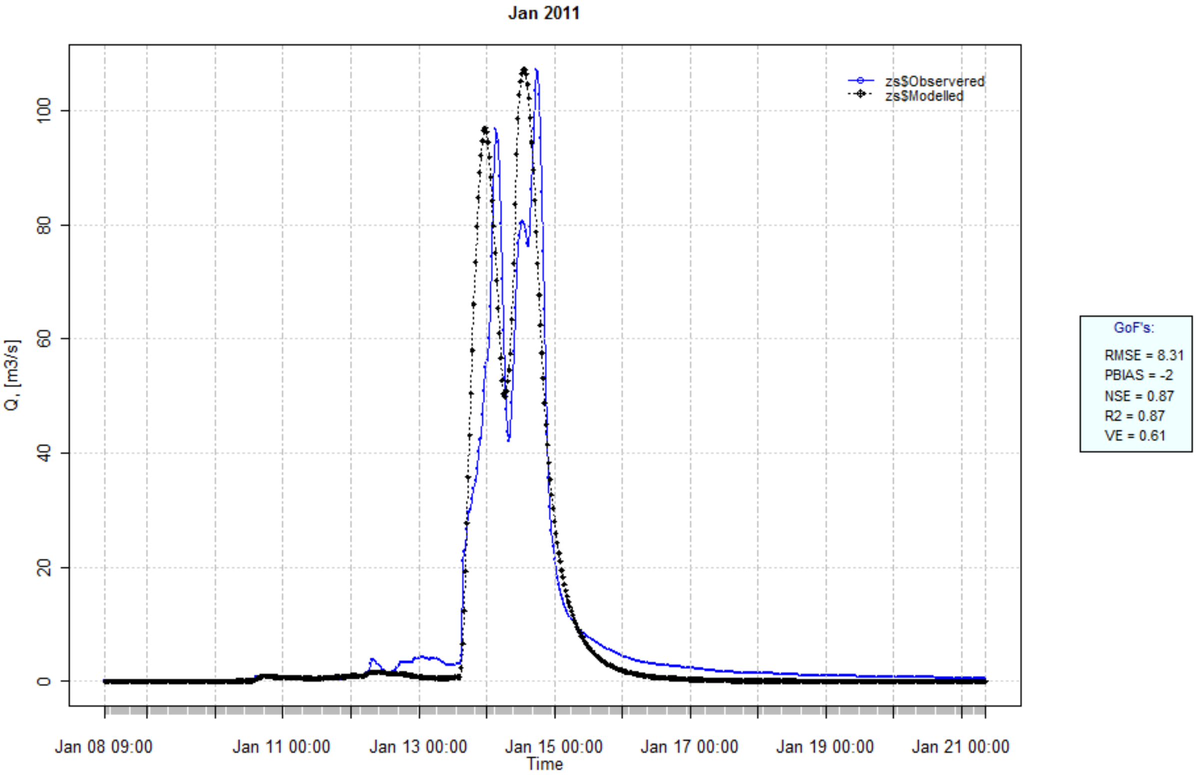


Figure 5-8 Calibrated Hydrograph Comparison for January 2011

The initial loss parameter for the January 2011 event was deemed to be unusually high, particularly with relation to the relatively low continuing loss value. The reasons for this were investigated to ensure confidence in the parameters. Daily rainfall and evapotranspiration data was obtained from the SILO climate data for Heathcote. Average month rainfall and evapotranspiration figures were calculated as presented in Table 5-11. The total rainfall and evapotranspiration from 10th December 2010 to 10th January 2011 were also calculated and found to be 15.2 mm and 126.3 mm respectively. Comparing the rainfall total to the monthly averages for January and December indicates that this less than half that could be expected in that period, further the evapotranspiration during that period was higher than average. This indicates that the period preceding the January 2011 flood event was unusually dry, resulting in the higher loss parameters for the January 2011 flood event. For these reason the resulting loss parameters are considered acceptable.

Table 5-11 Average Monthly Rainfall and Evapotranspiration from 1970-2014

Month	Rainfall (mm/month)	Evapotranspiration (mm/month)
January	39.2	110.2
February	36.0	86.0
March	31.1	64.4
April	39.2	38.5
May	49.5	24.0
June	52.2	18.9
July	55.6	21.3
August	56.8	35.9
September	52.6	58.9
October	50.6	88.7
November	46.9	102.3
December	38.5	112.2

5.5.11 Calibration Summary

The URBS model parameters for the catchment from the individual calibration of each event are summarised in Table 5-12 below.

The calibration of the catchment produced a wide range of potential parameter sets and did not converge on a single range. The α varied from 0.10 to 0.30 with the β varying between 1.5 and 3.5 whilst there was generally less variability in the loss parameters. The losses recording the best fit for each event typically favoured higher initial losses and lower continuing losses.

A plot of the calibrated URBS parameters is presented in Figure 5-9. This plot shows a cluster of four points and a fifth point in the top right hand corner. Table 5-12 shows that the point in the top right hand corner is the calibrated parameters from the December 2010 event. This point appears to be an outlier and the December 2010 event had the smallest discharge of all the calibration events, in fact, this event has an AEP of less than the mean annual flood. For these reasons the December 2010 was removed from the determination of the final parameter set.

Table 5-12 Calibrated Parameters and Values Summary

Event	α	m	β	IL (mm)	CL (mm/hr)	NSE	Observed Peak Flow (m^3/s)	Observed Volume (m^3)	Approx. AEP
Aug '78	0.18	0.8	1.5	15	0.2	0.89 – good	57	2912	< 20% AEP
Sep '93	0.10	0.8	2.0	13	0.0	0.59 – poor	56	2866	< 20% AEP
Sep '10	0.25	0.8	2.0	15	1	0.96 – good	97	6081	< 10% AEP
Dec '10	0.30	0.8	3.5	21	2.5	0.96 – excellent	23	1823	< 2% AEP
Jan '11	0.17	0.8	2.5	101	0.9	0.87 – good	107	9094	< 10% AEP

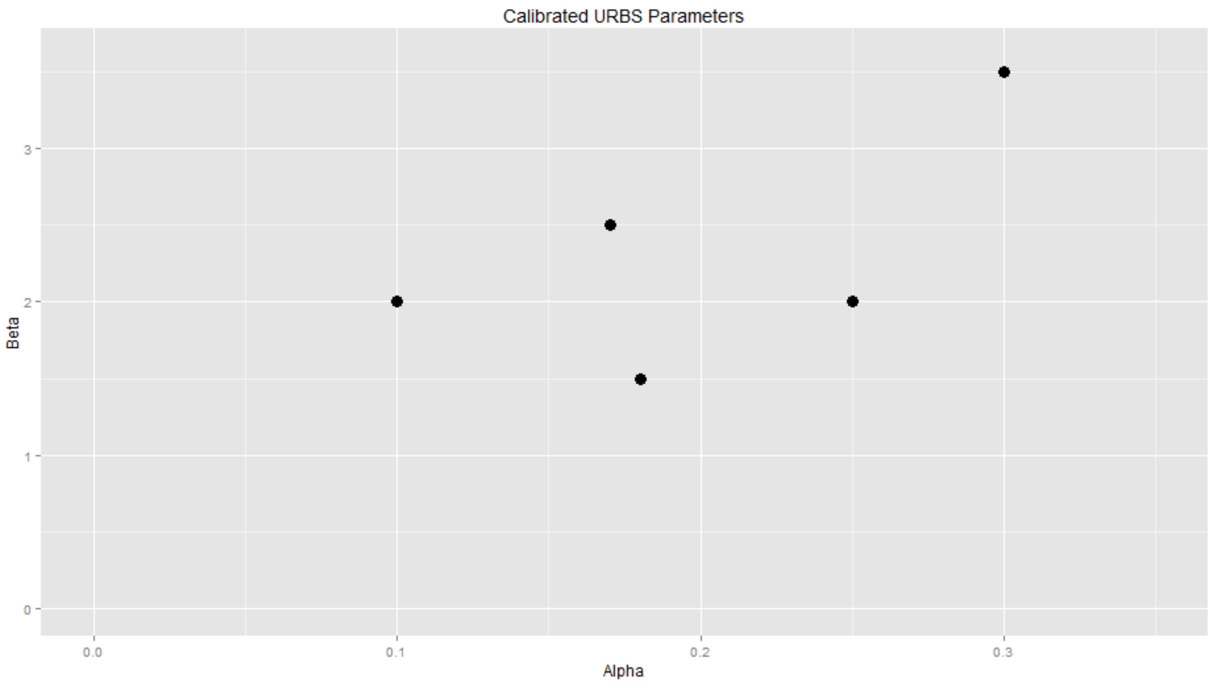


Figure 5-9 Calibrated URBS Parameters

5.5.12 Final Calibration Parameters

The final parameter set was determined by taking the weighted mean and standard deviation of each parameter presented in Table 5-12. The parameters were weighted by the NSE values.

The adopted parameters together with their upper and lower 95% confidence limits are displayed in Table 5-13. Note it has been assumed that α and β are normally distributed and IL and CL are log-normally distributed in calculating confidence limits.

Table 5-13 Adopted Calibrated Parameters Set

Parameter	Weighted mean	Weighted standard deviation	Upper CL	Lower CL
α	0.19	0.06	0.31	0.071.96*
β	2.0	0.4	2.76	1.22
IL	24.6	1.00#	174	3.4
CL	0.4	1.07#	3.5	0.05

standard deviation of log transform

5.5.13 August 1978 Validation Results

The best fit for the validation parameters are listed in Table 5-14 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-10.

The validation resulted in a good fit to the observed record. Compared to the calibration the validation has significantly greater volume (up 21%) and faster rising and slower falling limbs. The peak flow rate was 4% lower than the observed record. Despite this the overall fit is still good for a validation and this is shown with an NSE of 0.89.

Table 5-14 Validation Parameters and Values for August 1978

Station	*α*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.19	0.80	2.0	13	0.2	0.89	21%	-4%

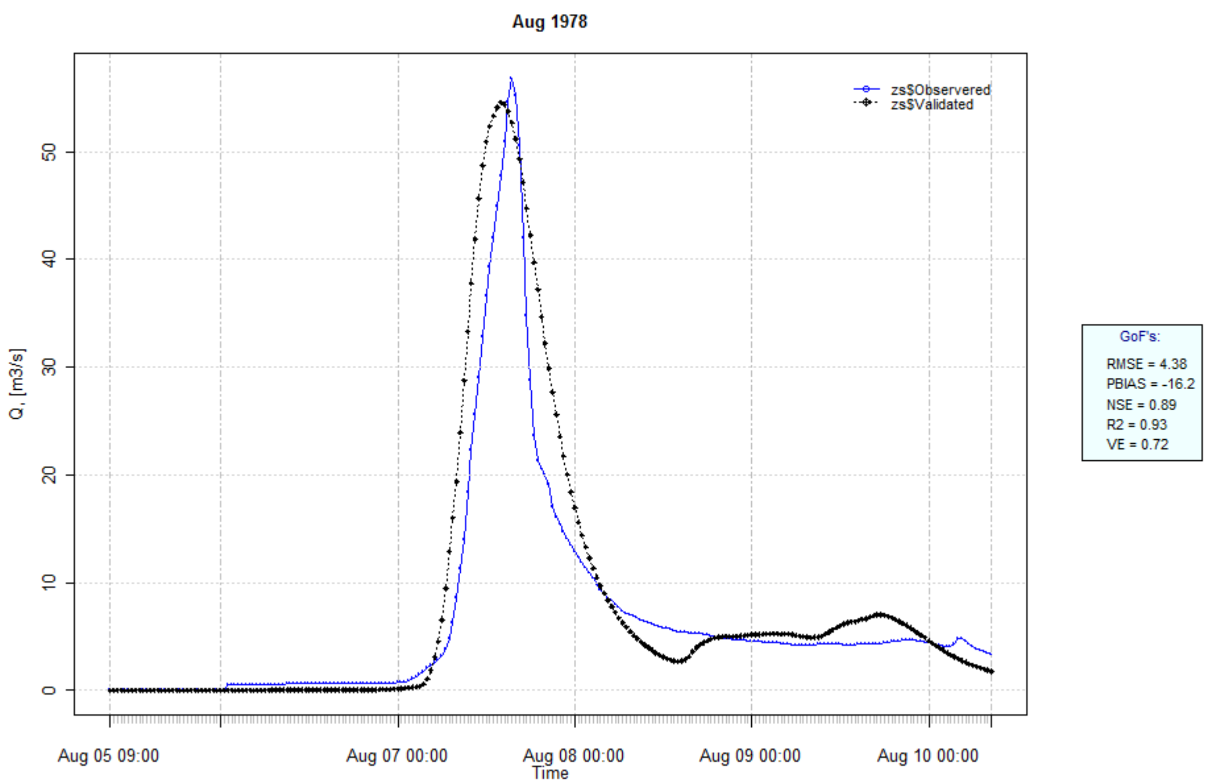


Figure 5-10 Validation Hydrograph Comparison for August 1978

5.5.14 September 1993 Validation Results

The best fit for the validation parameters are listed in Table 5-15 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-11.

Whilst the validation resulted in a superior NSE of 0.77 (satisfactory) compared to the calibration model the overall visual fit of the model is not as good. As was found with the August 1978 validation, the rising and falling limb are not a great fit being too fast and slow respectively. This results in a volume 17% greater and a peak flow 3% lower than observed.

Overall for a validation event the September 1993 model was deemed as passable.

Table 5-15 Validation Parameters and Values for September 1993

Station	*α*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.19	0.80	2.0	10	0.0	0.77	17%	-3%

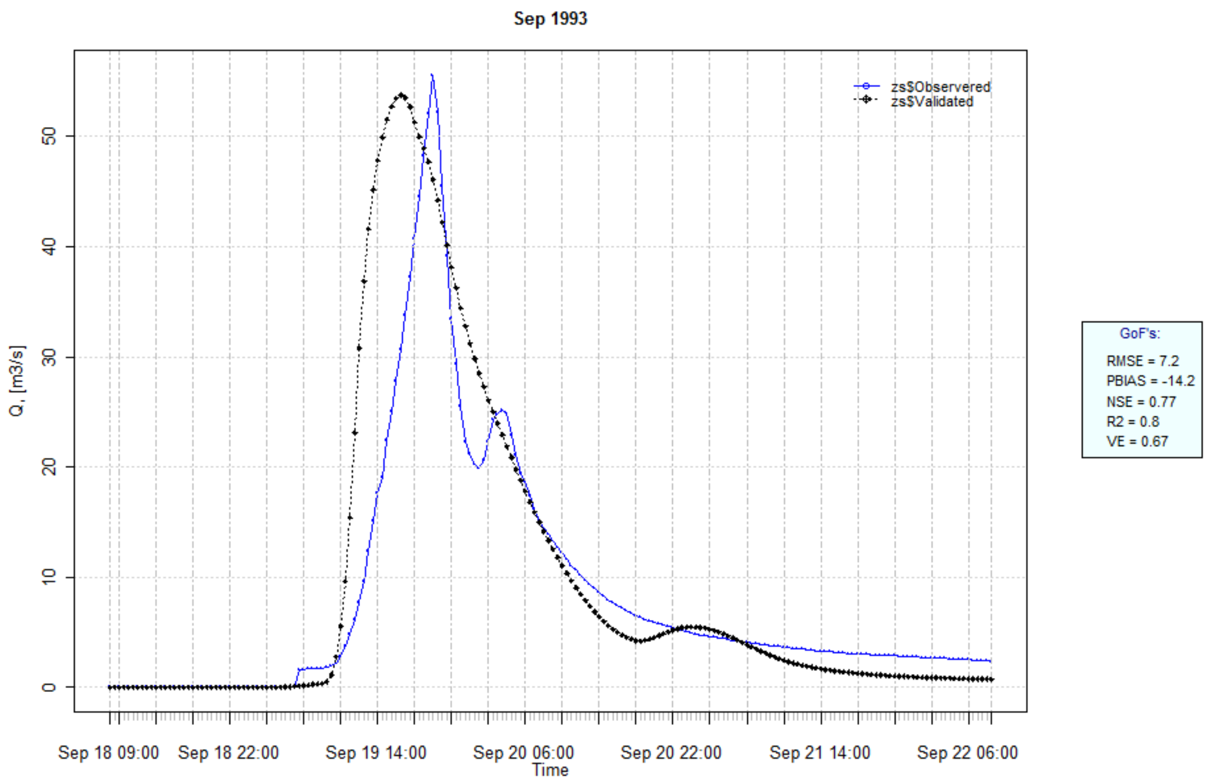


Figure 5-11 Validation Hydrograph Comparison for September 1993

5.5.15 September 2010 Validation Results

The best fit for the validation parameters are listed in Table 5-16 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-12.

The validation resulted in an excellent fit to the observed record. This is confirmed by an NSE of 0.95. A peak flow matching the observed record and a difference in volume of only -1% are good for a validation event.

Table 5-16 Validation Parameters and Values for September 2010

Station	*α*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.19	0.80	2.0	27	0.5	0.95	-7%	-1%

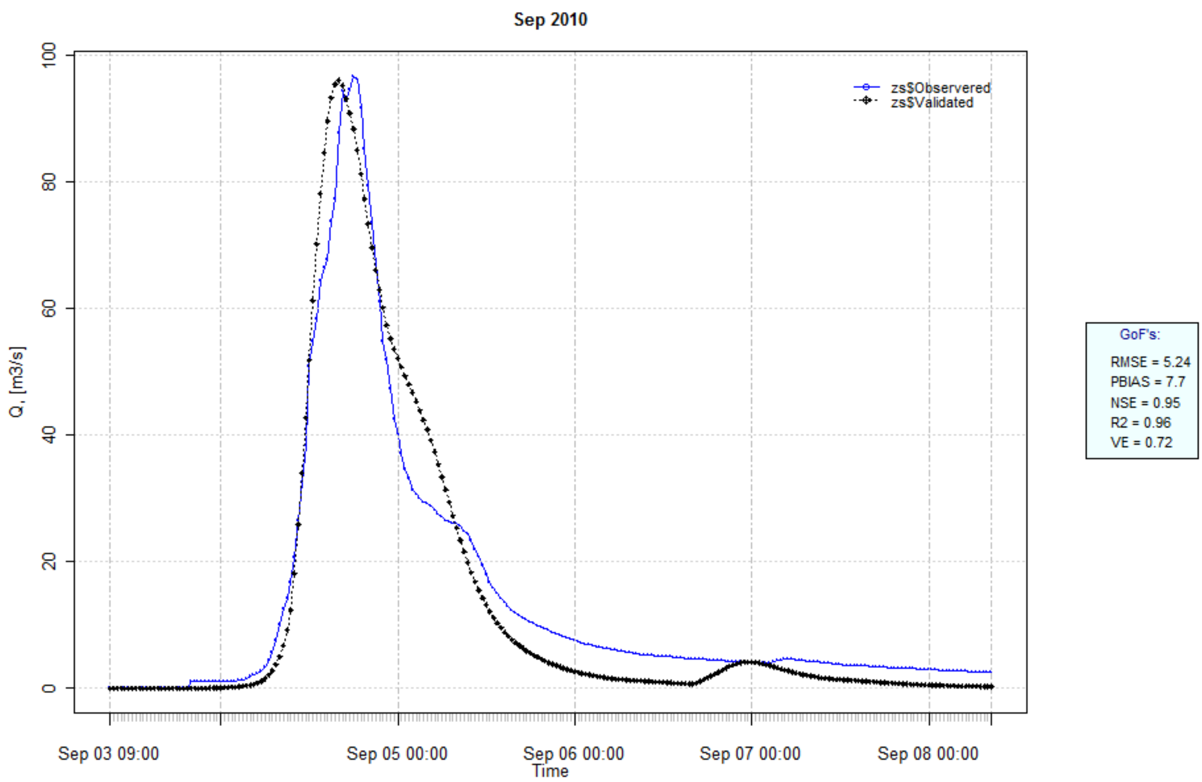


Figure 5-12 Validation Hydrograph Comparison for September 2010

5.5.16 December 2010 Validation Results

The best fit for the validation parameters are listed in Table 5-17 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-13.

The validation of the December 2010 event was overall satisfactory, with an NSE of 0.77 but not as good as the excellent result achieved during the calibration of the model. This is not surprising as the parameter sets differ considerably between the calibration and validation.

Table 5-17 Validation Parameters and Values for December 2010

Station	α	m	β	IL (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.19	0.80	2.0	39	0.1	0.77	-30%	2%

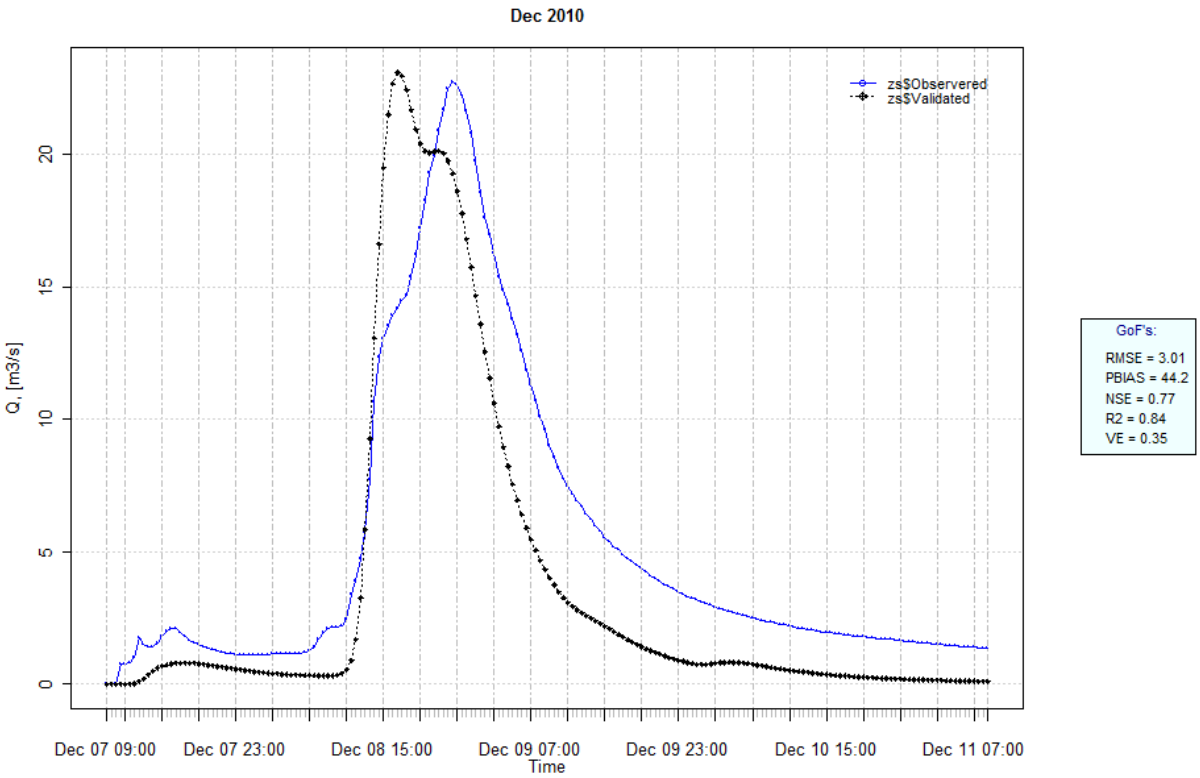


Figure 5-13 Validation Hydrograph Comparison for December 2010

5.5.17 January 2011 Validation Results

The best fit for the validation parameters are listed in Table 5-18 together with the NSE and Volume difference values. The resulting fit is illustrated in Figure 5-14.

The validation resulted in a good fit to the observed record. The validation result is similar to that achieved for the calibration. The parameter set was not as dissimilar as other events and as such only minimal changes were made to the initial loss to achieve the best fit. This resulted in a good NSE value of 0.86, with both the volume and peak flow rate matching the recorded flow.

Table 5-18 Validation Parameters and Values for January 2011

Station	*α*	*m*	*β*	*IL* (mm)	CL (mm/hr)	NSE	Vol (diff)	Peak Flow (diff)
Mt Ida Creek at Derrinal	0.19	0.80	2.0	102	0.9	0.86	0%	0%

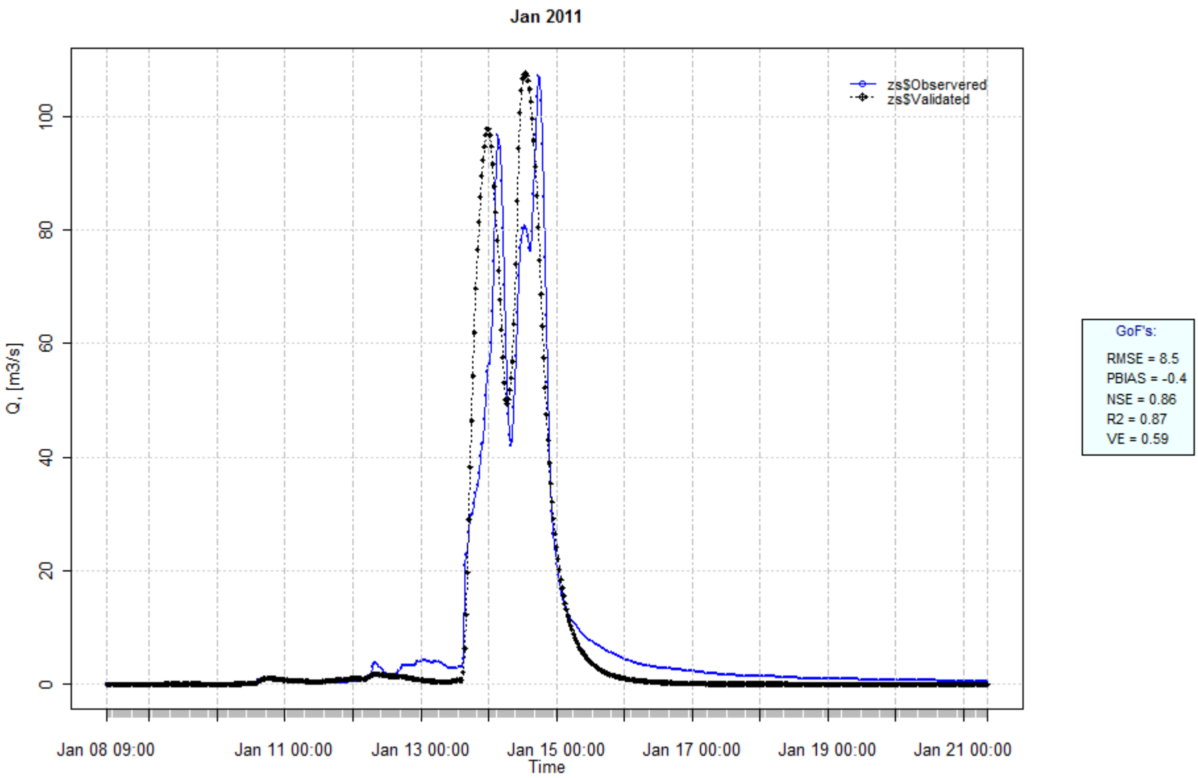


Figure 5-14 Validation Hydrograph Comparison for January 2011

5.5.18 Validation Summary

The URBS model parameters for the catchment from the individual validation of each event are summarised in Table 5-19 below.

The validation process produced results similar to the calibration results. The exception being December 2010 which produced an NSE of 0.77 down from 0.96, however this is considered a satisfactory result for a validation event given the discrepancy in parameter sets between the calibration and validation. With the exception of this event and the September 1993 event all other events had an NSE greater the 0.86 indicating good fits with the observed record.

During the validation process it was found that the best fits were achieved using higher initial losses and low to zero continuing losses.

Table 5-19 Validation Parameters and Values Summary

Event	*α*	*m*	*β*	IL (mm)	CL (mm/hr)	NSE	Observed Peak Flow (m^3/s)	Observed Volume (m^3)
Aug '78	0.19	0.8	2.0	13	0.2	0.89 – good	57	2912
Sep '93				10	0.0	0.77 – satisfactory	56	2866
Sep '10				27	0.5	0.95 – excellent	97	6081
Dec '10				39	0.1	0.77 – satisfactory	23	1823
Jan '11				102	0.9	0.86 – good	107	9094

5.5.19 Calibration and Validation Conclusions

The URBS model of catchment has been calibrated to the five events including the largest on record, the January 2011 flood event, resulting in five parameter sets. The weighted averages of these parameters sets, excluding the December 2010 parameter, were taken as the final parameter set. The December 2010 parameter set was removed as an outlier. The model was then validated to the same events using the final parameter set.

Overall the calibration and validation of the model produced good to excellent results with the exception of the September 1993 event. Whilst there was some variability in the *α* and *β* during the calibration process, a good fit to the same events using a common parameter set was found during the validation process. During both the calibration, and particularly the validation, it was found that the catchment favours a higher initial loss and relatively low continuing loss.

5.6 Design Event Modelling

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

5.6.1 Global Parameters

The URBS model parameters for design event modelling are summarised in Table 5-20. The parameters *α, m* and *β* were adopted from the calibration process.

The loss model adopted was the "initial loss/continuing loss" model.

Table 5-20 URBS design parameters

Parameter	Value
Catchment Area	173 km^2
Latitude	36.975S
Longitude	144.750E
Initial Loss	Variable - event specific (See section 5.6.6 for details)
Continuing Loss	0.3
α	0.19
m	0.8
β	2.0
Fraction Impervious	Variable by subcatchment

5.6.2 Design Event Probabilities

Hydrologic analysis was undertaken for the 0.1%, 0.2%, 0.5%, 1%, 2%, 5%, 10% and 20% Average Exceedance Probability (AEP) design storm events. In addition, an approximate estimate of the Probable Maximum Precipitation (PMP) was generated to determine the Probable Maximum Flood (PMF) event for the catchment.

5.6.3 Design Rainfall

In order to define the design rainfall for ARI events, Intensity Frequency Duration (IFD) parameters for the Catchment were generated by the Bureau of Meteorology (http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml accessed 19/09/2014) using a method based on the maps from Volume 2 of Australia Rainfall and Runoff (ARR87) - A Guide to Flood Estimation. These IFD parameters were used to generate design rainfall intensities and depths using standard AR&R procedures. Storm data was sourced from the Bureau of Meteorology, which are based on Figures 1.8 to 6.8 and 7d to 9 of Australian Rainfall and Runoff (AR&R) Volume 2. The adopted values for the catchments are presented in Table 5-21.

The adopted IFD parameters to define the climate change scenario are also displayed in Table 5-21. These adjusted parameters allow for a 20% increase in rainfall intensity, as documented below in Section 0 below.

Table 5-21 IFD Parameters

IFD Parameter		Adopted Value	Climate Change
Rainfall Intensity (mm/hr)	2 Year ARI, 1 Hour Duration	22.02	26.42
	2 Year ARI, 12 Hour Duration	4.08	4.90
	2 Year ARI, 72 Hour Duration	1.06	1.27
	50 Year ARI, 1 Hour Duration	43.42	52.10
	50 Year ARI, 12 Hour Duration	7.11	8.53
	50 Year ARI, 72 Hour Duration	2.09	2.51
Skew Coefficient		0.23	
Geographical Factor F2		4.32	
Geographical Factor F50		14.99	
Zone		2	

For rainfall estimates of AEP events rarer than the 1% AEP event the ARR87 methods are not recommended. For estimates of rainfall for these extreme events the CRC-Forge method is recommended (Nandakuma, et al., 1997). The CRC-Forge method has been applied to Heathcote catchment to produce the rainfall depth estimates in Table 5-22.

Table 5-22 CRC-Forge Rainfall Estimates in mm

Duration in Hours	0.5% AEP Event	0.2% AEP Event	0.1% AEP Event
9	105.8	123.8	138.7
12	114.2	133.6	149.6
18	132.2	154.6	173.2
24	145.4	170.1	190.6

To estimate the Probable Maximum Precipitation (PMP) within the catchment the Generalised Southeast Australia Method (GSAM) was adopted.

5.6.4 Increase Rainfall Intensity - Climate Change

The assessment of the increase in flood risk due to increasing rainfall intensity associated with climate change was undertaken in line with the latest ARR guidance. At the time of the Study the ARR guidance had not been finalised and as such is based on the Discussion Paper on an Interim Guideline for Considering Climate Change in Rainfall and Runoff – November 2014.

In line with the interim guidance an increase in rainfall intensity of 5% per degree change in temperature was adopted. The 'Climate Futures Tool' has not been released to industry use at this time. However, projection summaries at a regional and sub-regional scale have been published. The summary for the Murray Basin indicated a temperature increase of between 2.7 to 4.5°C for 2090 using a high emissions scenario (RCP8.5) and between 1.3 to 2.4°C using a medium emissions scenario (RCP 4.5). The ARR guidance recommends that emissions scenario RCP6 is used; however, these results are not currently available.

Given the above, a 4ºC temperature increase was adopted for the study. Therefore, an increased rainfall sensitivity of 20% was adopted. This value is at the higher end of the expected temperature range and is considered a conservative estimate selected to test the sensitivity of increased rainfall intensity due to climate change on the Heathcote catchment.

A summary of the IFD parameters used for the rainfall sensitivity modelling calculation are contained in Table 5-21. For events greater than the 1% AEP event, the CRC-Forge totals were multiplied by 20%.

5.6.5 Temporal Patterns and Aerial Reduction Factors

Temporal patterns derived as per Australian Rainfall and Runoff 1987 were used for this study. Aerial reduction factors were not adopted for this Study. As the peak model discharge was adjusted to match the flows from the FFA aerial reduction factors are not required.

5.6.6 Design Event Losses and Results

With a suitably calibrated hydraulic model the URBS design events were calibrated to the peak flow estimates from the FFA as described in Section 5.2. This was undertaken by holding the CL constant at 0.3 mm/hour and the IL varied to match the peak flows from the FFA.

The URBS hydrology parameters are presented in Table 5-23 below.

Table 5-23 URBS Hydrology: Design Event Calibration Values

AEP	α	m	β	IL (mm)	CL (mm/hr)
20%	0.19	0.80	2.0	35	0.3
10%				25	
5%				20	
2%				15	
1%				10	
0.5%				5	
0.2%					
0.1%					
PMP					

Peak flows for each design event probability modelled were extracted from the hydrologic model at the gauge location, and are presented in Table 5-24. Hydrographs of the peak flow for each AEP events are shown in Figure 5-15.

Table 5-24 URBS Hydrology: Design Peak Flow Values (m^3/s)

AEP	20%	10%	5%	2%	1%	0.5%	0.2%	0.1%	PMF
Peak Flow (m^3/s)	81	134	186	260	318	395	472	535	3901

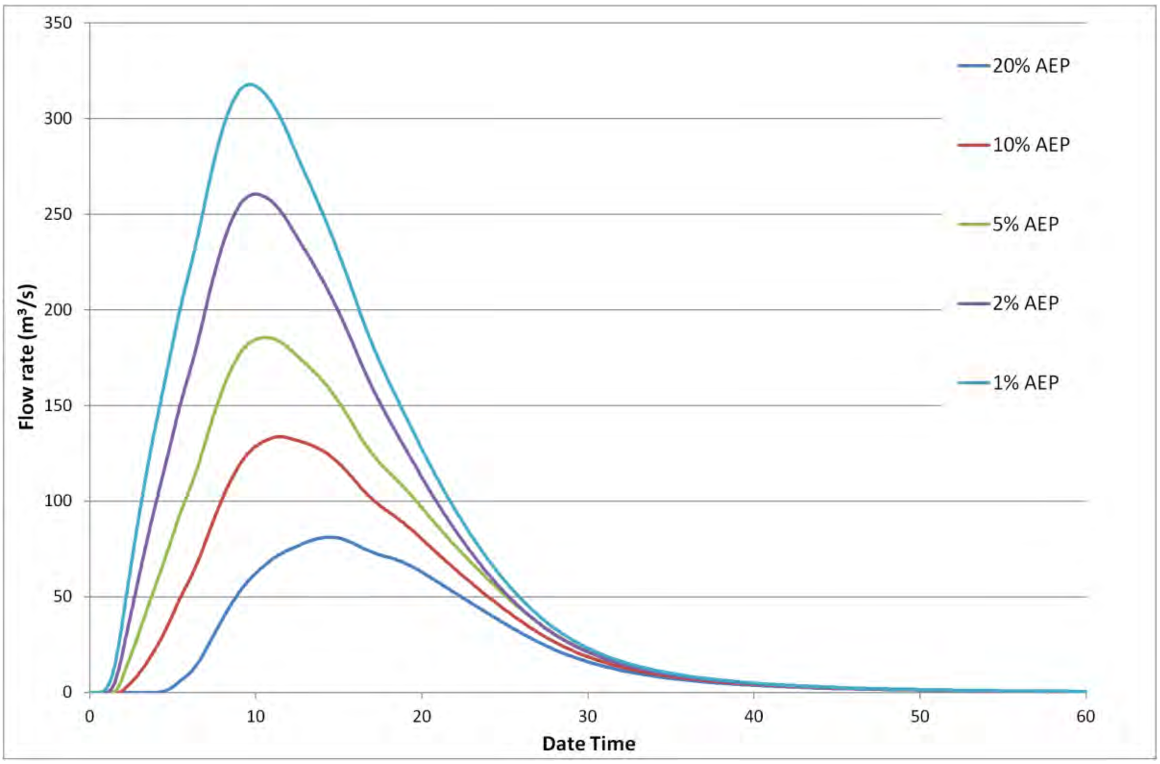


Figure 5-15 URBS Hydrology: Design Hydrographs

5.6.7 Critical Event Derivation

Initial results indicated that the 48 and 72 hour events were critical, however this is considered unrealistic and a function of the standard temporal patterns. For this reason they were discarded from the analysis. Following this, the critical duration for each design AEP was found to be the 18 hour event. For the PMP event the 72 hour event was retained for the analysis. A summary of the critical duration is presented in Table 5-25.

Table 5-25 URBS Design Event – Critical Duration

AEP	20%	10%	5%	2%	1%	0.5%	0.2%	0.1%	PMP
Duration	18h	18h	18h	18h	18h	18h	18h	18h	72h

5.6.8 Sensitivity Analysis - Climate Change

The rainfall intensities were factored by 20% to account for the expected increases in rainfall intensity due to climate change. No allowance has been made for changed temporal patterns or changed rainfall losses due to the impact of climate change. This analysis has tested a single variable that will be impacted by climate change and a more detailed assessment may be required as the understanding of the impacts of climate change on hydrology and stream flow improves.

For the sensitivity only the 1% AEP event was investigated as the short-term outcomes of this Study focus on planning which typically is based on the 1% AEP flood extent. The peak discharge at the gauge increased by 24% from 318 m^3/s in the base case to 395 m^3/s for the climate change sensitivity. Figure 5-16 shows the change the flood hydrograph for the 1% AEP flood events.

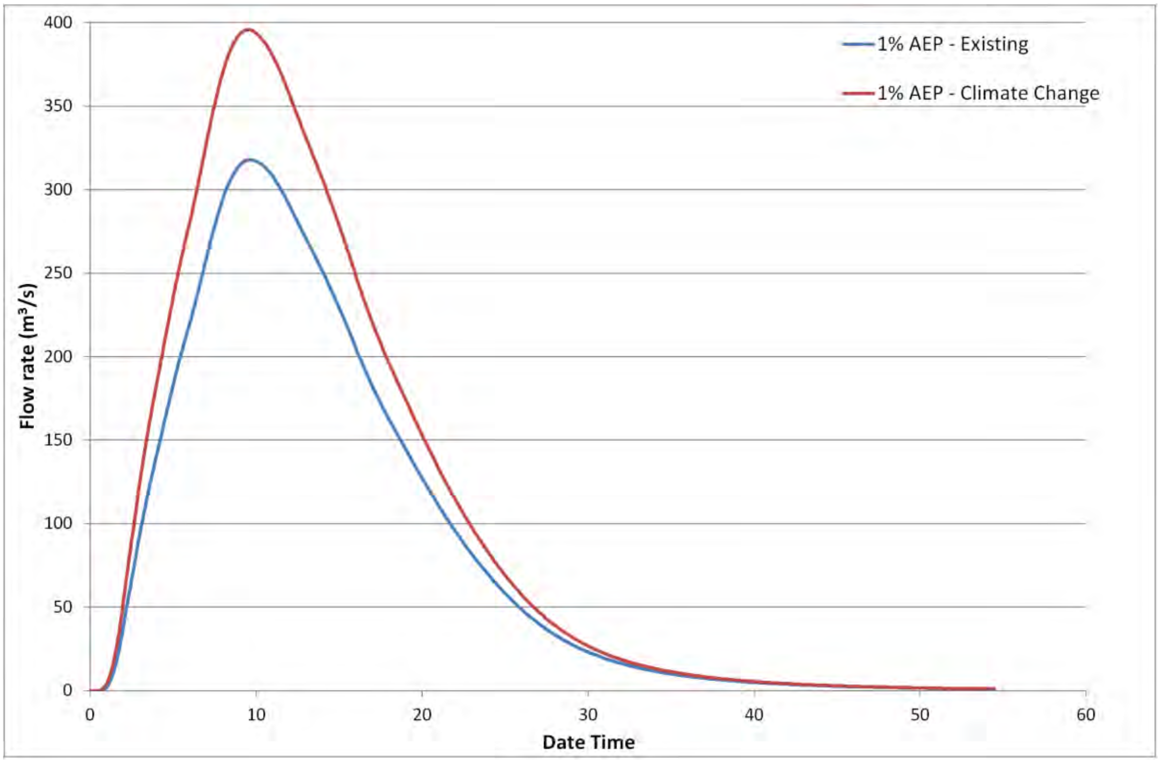


Figure 5-16 URBS Hydrology: Climate Change Sensitivity Hydrograph

5.7 Discussion

An analysis of the design flows derived from the URBS model was undertaken to compare the peak flows determined with those determined from the site flood frequency analysis and regional flood frequency analysis. This analysis (Table 5-26) has shown that the URBS derived design flows are consistently with the flood frequency analysis as expected. The URBS model was adopted to provide inflows to the hydraulic model documented in the following sections.

Table 5-26 Comparison of Peak Design Flows at Mt Ida Creek Gauge @ Derrinal

Location	Peak Flow at Mt Ida Creek Gauge @ Derrinal (m^3/s)		
	URBS Model (Adopted)	Site FFA	RFFE
0.1% AEP	535	550	261
0.2% AEP	471	480	235
0.5% AEP	394	390	200
1% AEP	318	321	172
2% AEP	261	258	145
5% AEP	186	180	109
10% AEP	134	127	83
20% AEP	81	80	57

6 Hydraulic Modelling

This section provides a description of the TUFLOW modelling process undertaken for the catchment. A TUFLOW hydraulic model was developed as part of this study with the aim of flood mapping the catchment for the calibration and design flood events. Specifically this Section addresses Key Objective 2.

The following sections detail the development of the hydraulic model used to produce the flood maps. This chapter is presented in the following format:

- TUFLOW model development
- Calibration and Validation of the TUFLOW model
- Design event modelling

6.1 Model Description

In order to produce flood extents, depths, velocities and other hydraulic properties for the study area a 1D/2D linked hydraulic model was developed using TUFLOW. The McIvor Creek and Mt Ida Creek, including their floodplains and the town of Heathcote, were represented in the 2D domain with the drainage network modelled as connected 1D elements. The model extended from upstream of the Heathcote-Nagambie Road to downstream of the Derrinal stream gauge covering an area of approximately 4.5 square kilometres of the catchment and floodplain, as shown in Figure 6-2.

6.1.1 Model Schematisation

As noted above, the model was schematised a 2D model with embedded 1D elements that represented the underground drainage system. The model was designed to flood map the risk of flooding from McIvor Creek and Mt Ida Creek to the town of Heathcote.

The floodplain topography and other significant hydraulic features, such as roads and embankments, were represented within the 2D domains. A 2D domain with a 3m grid resolution was used to represent the floodplain. The major watercourses, McIvor Creek and Mt Ida Creek, in the study area were represented in the 2D domain of the hydraulic model. Modelling the floodplain and channel in 2D has a number of advantages over modelling watercourses in 1D. These advantages include:

- Explicitly accounting for form and bend losses;
- Calculating contraction and expansion losses through constrictions (see Leister and Jempson, (2011));
- Explicitly calculates the momentum across channel banks; and
- Calculates the in channel velocity on a cell by cell basis rather than horizontal averaged velocity across the channel.

Heathcote's underground drainage network and selected drainage culverts along the creek alignment were also represented as a 1D network.

External inflows boundaries were applied to the model to represent flow in the McIvor Creek and Mt Ida Creek as well as minor inflows from Parsons Gully. The downstream boundary was downstream of the Mt Ida Creek streamflow gauge. Internal inflow boundaries were distributed throughout the model domain to ensure a 'realistic' distribution of runoff across the study area.

Details of the model setup and application are described below and shown in Figure 6-2.

6.2 Hydraulic Modelling Overview

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

6.2.1 TUFLOW Model Version

Model runs were performed with the 2013-12-AD-iDP-w64 build of TUFLOW.

6.2.2 Design Event Modelling

The hydraulic model was run for a number of design events as well as the calibration and validation events discussed below. The following events were run in the hydraulic model:

- 20% AEP (5 year ARI) event;
- 10% AEP (10 year ARI) event;
- 5% AEP (20 year ARI) event;
- 2% AEP (50 year ARI) event;
- 1% AEP (100 year ARI) event; and
- 0.5% AEP (200 year ARI) event.

6.2.3 Model Extent

The model domain extends from approximately 700 meters upstream of the Heathcote-Nagambie Road to approximately 700 meters downstream of the Mt Ida Creek at Derrinal stream gauge, covering 4.5 km^2 of the catchment and floodplain, as shown in Figure 6-2. This model extent allows for the flood behaviour within the study area to be reliably represented without the influence of boundary effects.

6.3 2D Domain

6.3.1 Topography

The geometry of the 2D floodplain and watercourses were established by constructing a uniform grid of square elements from the DEM. This TUFLOW grid (or zpt layer) provides the topography for the hydraulic model. The DEM used in the hydraulic model was based on three digital elevation datasets. The hierarchy of the DEMs was the same as with the development of the hydrologic model, that is, from highest to lowest priority as shown in Table 6-1.

Given the high resolution of the TUFLOW grid, 3m as discussed below, floodplain features such as such as roads and embankments were well represented. Given this, it was not necessary to reinforce features through the use of breaklines and the like.

Table 6-1 Digital Elevation Datasets Summary and Comments

Dataset	Resolution	Comments and Planned Use
2009-10 Victorian State Wide Floodplains LiDAR Project (Heathcote 2012)	1m	Primary LiDAR used in hydraulic model. Does not cover whole of hydraulic model domain.
ISC Rivers LiDAR (2010)	1m	Secondary LiDAR used in hydraulic model. Primarily used downstream of the Heathcote 2012 extent.

6.3.2 Grid Resolution

One of the key considerations in establishing a 2D hydraulic model relates to the selection of an appropriate grid element size. Element size affects the resolution, or degree of accuracy, of the representation of the physical properties of the study area as well as the size of the computer model and its resulting run times. Selecting a very small grid element size will result in both higher resolution and longer model run times.

In adopting the grid size for the model, the above issues were considered in conjunction with the final objectives of the study. To ensure accurate representation of flooding within the catchment a grid size of 3 metres was adopted for model. Each square grid element contains information on ground topography, sampled from the DEM and surface resistance to flow (Manning's 'n' value).

Watercourses

The McIvor Creek and Mt Ida Creek were represented in the 2D domain for the reasons outlined above. The watercourses within the model extent were typically 3-5 grid cells wide in the channel and 7-10 grid cells bank-to-bank, more than recommended by the TUFLOW manual. Further the conveyance and resulting water level elevations of the at the gauge were compared to the rating table as presented in Section 6.6 to check consistency in conveyance between modelled and the observed system.

6.3.3 2D Hydraulic Structures

It is important to ensure that large (2D grid size or larger) impediments and constrictions to flow are properly incorporated in the TUFLOW model. The 2D structures included in this model include the three bridges, namely; Northern Hwy, Heathcote-Nagambie Road, and Chauncey Street (Heathcote-North Costerfield Road). The location of these structures is shown in Figure 6-2.

Bridge structures were modelled as 2D flow constrictions with the appropriate losses derived from *Waterway Design: A Guide to the Hydraulic Design of Bridges, Culverts and Floodways* (Austroads, 1994). The losses applied were confirmed during the calibration and validation process (Refer to Section 6.7). The layered flow constriction also allows for typical bridge characteristics such as bridge deck height and thickness as well as any blockages associated with guard or hand rails to be incorporated directly in the 2D domain.

6.3.4 Surface Roughness

The roughness layer, or Manning's 'n' layer, for the floodplain were based on areas of different land-use type determined from the planning scheme, aerial photography and site inspections. Initially these values were based on standard texts such as *Open Channel Hydraulics* (Chow 1959) and were refined during the calibration and validation process (Refer to Section 6.7). The adopted Manning's 'n' coefficients are summarised in Table 6-2 and the layer is shown in Figure 6-3.

The Manning's values for the watercourses varied throughout the model, with two approaches adopted. These were; a fixed value; or a depth varying value. Fixed values were typically used where wooded vegetation was noted within the waterway. The depth varying approach was used where the waterway was clear of wooded vegetation. In the depth varying approach a higher value is used for shallower depths to account for the resistance caused by bed material, in channel vegetation, etc. Whereas a lower Manning's value is used for deeper depths where there is less resistance from vegetation and none from the channel. The depth varying technique is particularly suitable for deep flow in confined channels such as in the McIvor Creek and Mt Ida Creek.

Table 6-2 2D Domain Manning's 'n' Coefficients

Land Use	Manning's 'n'
Roads – pavement	0.020
Roads – reserve	0.040
Residential	0.100
Low Density & Rural Living	0.060
Mixed Use	0.060
Commercial & Industrial	0.200
Parks & Recreational Zone	0.050
Public Use Zone	0.060
Unmaintained grass/crops	depth variable - 0.040 to 0.013
Waterway - Mt Ida/McIvor Creek channel	depth variable - 0.040 to 0.013 Or fixed 0.060 to 0.080
Waterway or Parks with scattered vegetation	0.060
Waterway or Parks with moderate vegetation	0.080
Waterway or Parks with dense vegetation	0.100

6.4 1D Network

6.4.1 Drainage Network

Key features of the township drainage system, including pipes and pits, were modelled in 1D. A Manning's 'n' of 0.013 was adopted for the stormwater pipes. All supplied council pipes that were in the study area were modelled.

Where possible invert levels were adopted from the supplied council GIS pipe data set. For those pipes where invert level information was not available, inverts were derived from adjacent pipes, reference to plans, by interpolation or by using the ground level on the DEM and an assumed minimum cover depth.

All entry pits that connected to the included pipe network were modelled as boundaries between the 1D network and the 2D domain. Entry pits were assumed to be 900mm wide and 150mm high kerb inlets.

The 1D domain of the model was run on a 0.5 second timestep. This timestep is within the range recommended by the TUFLOW manual. It is half of the timestep required by the 2D domain which is running at 1.0 seconds.

6.4.2 Drainage Network Losses

Pipe junction losses were modelled using the Engelhund manhole feature of TUFLOW. Additional losses were applied as appropriate to account for entrance and exit losses at the first and final pipes respectively, which are not assigned by the Engelhund method.

6.5 Boundary Conditions

A hydraulic model requires inflow boundaries and outlet boundaries to allow water into and out of the model in a realistic manner. Often 2D hydraulic models will have external and internal inflow boundaries. The external inflow boundaries accounts for flow generated from outside of the model extents (external boundaries) whereas internal boundaries account for the runoff generated from within the model extents. Flow is removed from the model through downstream boundaries, which are generally a fixed water level or a stage discharge relationship.

The Heathcote TUFLOW model has external inflow boundaries for the McIvor Creek, Mt Ida Creek and other minor inflows, internal inflow boundaries and a downstream stage discharge relationship. The external and internal inflow boundaries were obtained from the URBS hydrological modelling described in Section 0. The location and distribution of boundaries are shown in Figure 6-2.

6.5.1 External Boundaries

The upstream boundary is usually a flow-time series (or hydrograph) and the downstream boundary is often a level-time series or a rating curve (when there is data available). This is the approach that has been taken with the Heathcote TUFLOW model with an automatically generated height-flow relationship was derived within TUFLOW as the downstream boundary.

The McIvor Creek, Mt Ida Creek and other minor inflows derived from the URBS model were applied as flow versus time boundaries directly to the watercourse in the 2D domain.

The downstream boundary was located approximately 700 metres downstream of the Mt Ida Creek gauging station at Derrinal. This boundary was represented as a head versus flow (stage-discharge) relationship. The head versus flow relationship was generated by TUFLOW based on the topography and the catchment slope at the outlet. The location of the downstream boundary was far enough downstream to ensure that there are no boundary effects on water levels at the gauge.

6.5.2 Internal Boundaries

The internal inflow boundaries account for runoff generated within the model domain. The location of these boundaries is shown in Figure 6-2. In total, three internal inflow boundaries were applied. In the Heathcote model, internal flow was applied directly to the 2D domain.

The internal inflow boundaries used were “excess rainfall” boundaries. These boundaries are the runoff after the initial and continuous losses have been deducted. The internal inflow boundaries were applied as source over area boundaries (SA) allowing flow to be distributed along Mt Ida Creek. This was appropriate as the aim of the Study was to map flood risk from the main watercourses.

6.5.3 1D / 2D Linking

The 1D network was dynamically linked to the 2D domain through boundary cells. These boundary cells pass water from one domain to the other. In the Heathcote model 1D/2D linking occurred at the 1D pipe network and the 2D domain at the pits. Accordingly, boundaries were set at these locations in the model.

Culverts or pipes that have headwalls, or similar, such as their entrance/exit structures were connected directly to the 2D domain with the appropriate entry and exit losses applied to the 1D elements.

6.6 Rating Curve

As part of the hydraulic model development the height-flow relationship within the hydraulic model was compared to the published rating table at the gauge. Initial results indicated that there was a poor fit to the rating curve.

When this was investigated, the ISC Rivers (2010) LiDAR was found not to represent the channel in the vicinity of the gauge well. The channel in this area was replaced by topography derived from the topographic survey. It is of note that the Heathcote (2012) LiDAR was found to better represent the channel and this was the LiDAR that was used in the vicinity of Heathcote.

The results of updating the topography in the vicinity of the gauge on the rating curve are shown in Figure 6-1. Overall a good match was noted between the rating table and the model flow at the gauge. It is, therefore, considered that the model was replicating the recorded flow at the gauge and suitable for the purposes of the study.

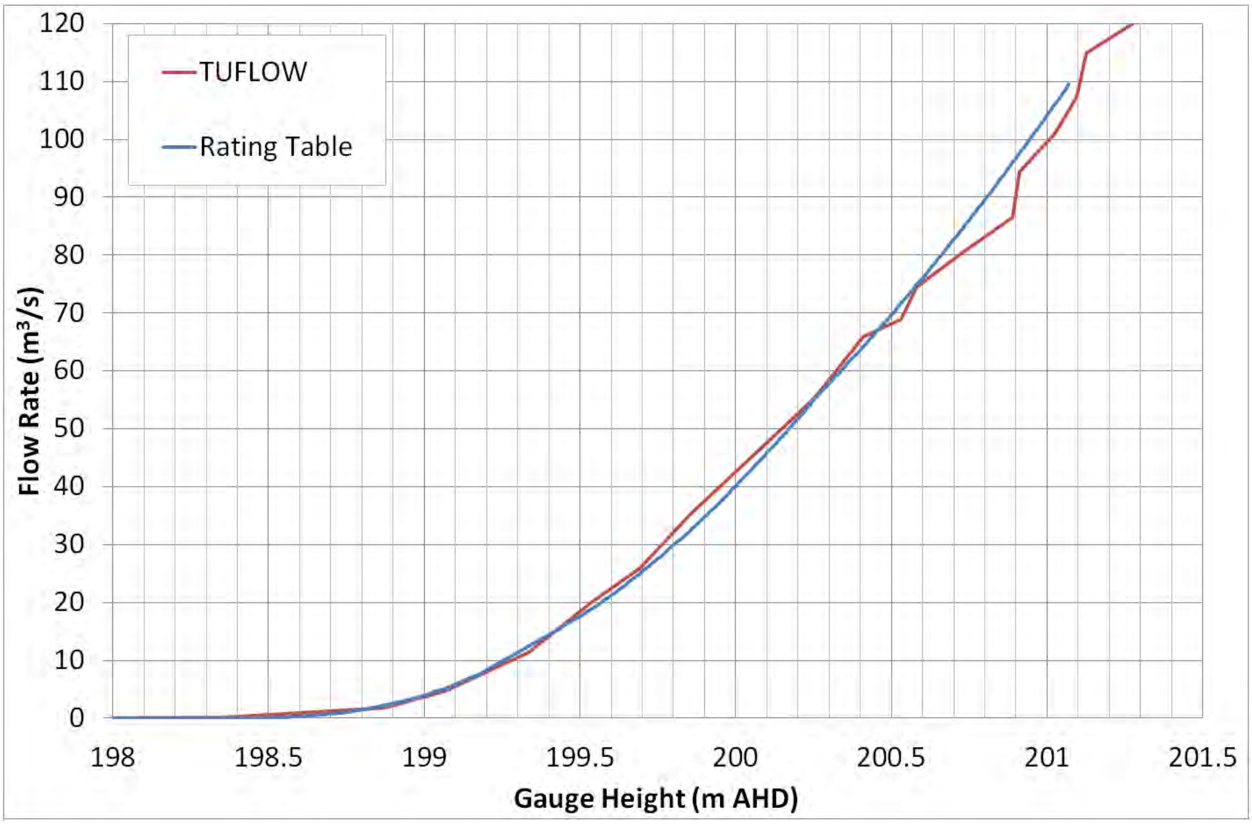
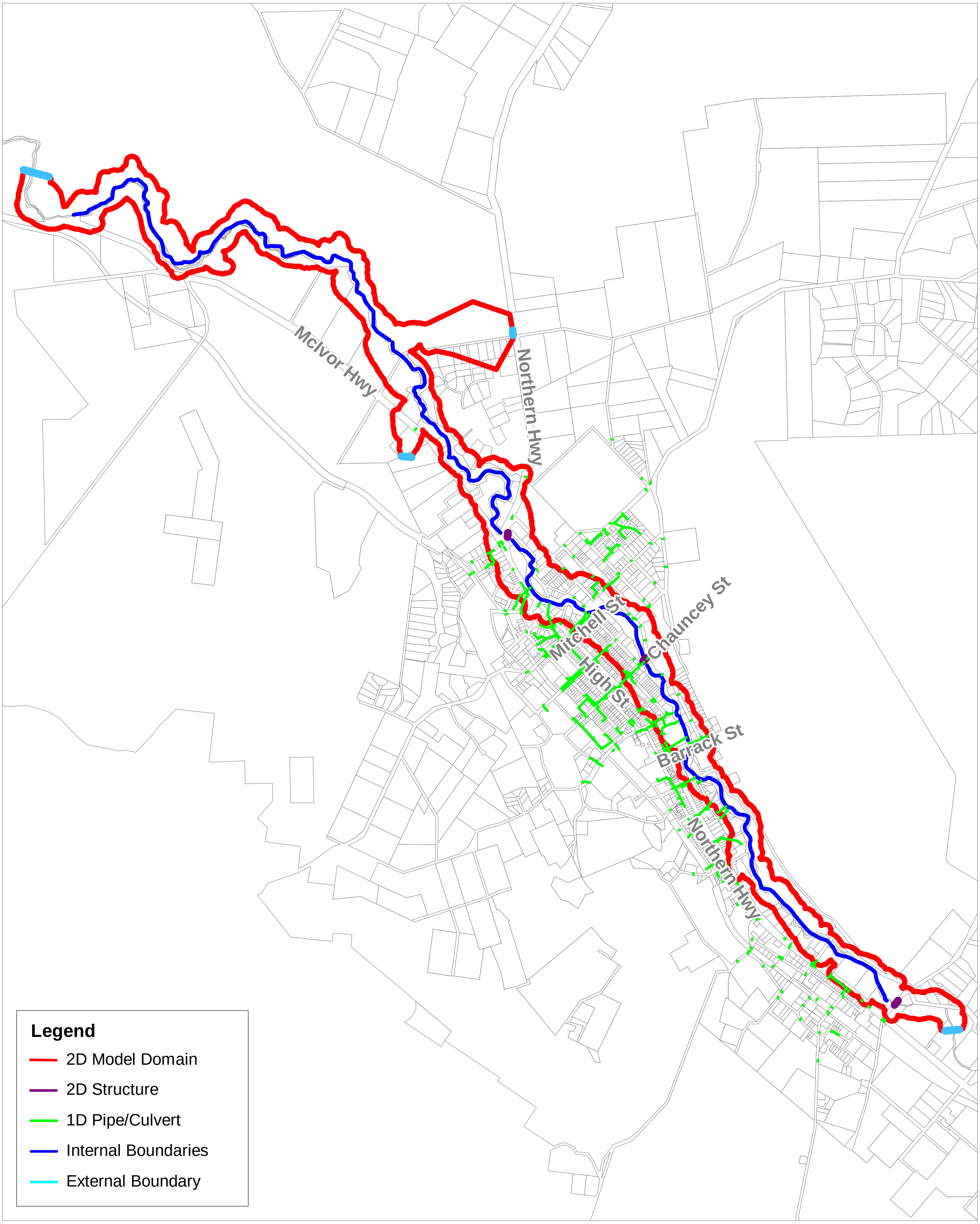


Figure 6-1 TUFLOW to Rating Table Comparison



Title:
Heathcote Flood Study
TUFLOW Schematisation

Figure: **6-2**

Rev: **A**

N

0 0.75 1.5km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

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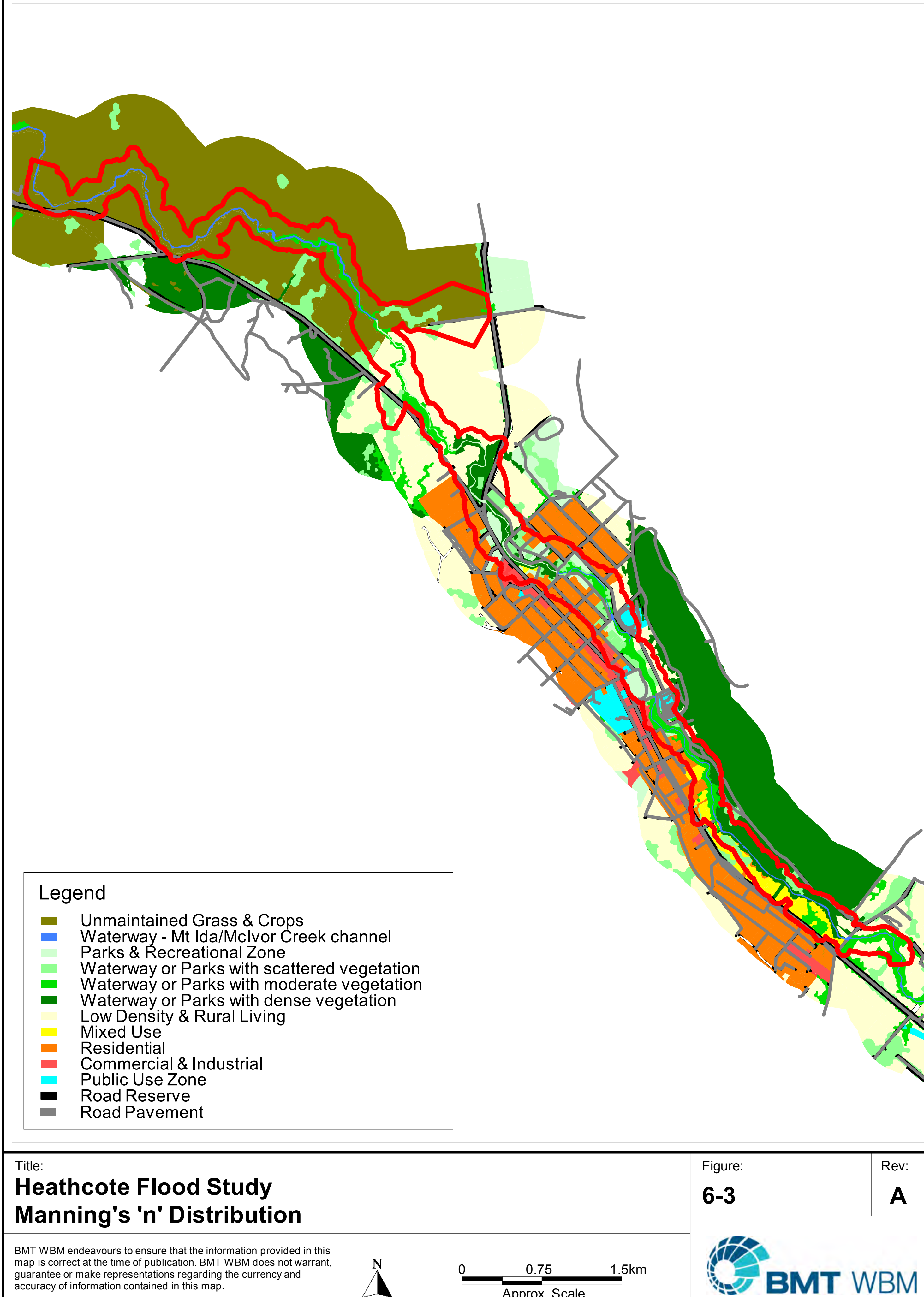

Title:

Heathcote Flood Study
Manning's 'n' Distribution

Figure: **6-3**

Rev: **A**

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6.7 Model Calibration and Validation

The calibration of hydraulic model is a critical stage of the model development process, and it is considered good practice to calibrate hydraulic models where there is sufficient data. According to the draft chapter on 2D modelling in the Australian Rainfall and Runoff revision (ARR, 2012), model calibration:

- Demonstrates that the hydraulic model is capable of reproducing flood behaviour within acceptable parameter bounds; and
- Demonstrates the model is capable of adequately representing the physical system and, in doing so, producing reliable results.

This was the case for the Heathcote hydraulic model.

Model calibration involves the adjustment of model parameters until an acceptable fit to the recorded flood data is achieved. Model validation on the other hand, uses the parameters determined in the calibration process and applies them to a different flood event. The validation results are then checked to ensure that an acceptable fit to the data has been achieved. Model verification involves the comparison of modelled results to collected data, but is not as rigorous as model calibrations. Model verification can be a valuable tool in circumstances where the data does not support full model calibration or there are insufficient resources to undertake a full model calibration.

The Heathcote TUFLOW model underwent a calibration process to fit the model to the observed data. The TUFLOW model was calibrated to the January 2011 flood event and validated and verified against four other flood events. The TUFLOW model was calibrated by varying the model parameters (Manning's n) within acceptable tolerances and, if required, model schematisation. Summary statistics were reviewed in addition to an assessment of model fit to ensure the best fit was obtained. For a discussion on the summary statistics see Section 5.5.5 and Table 5-5 for a classification system for NSE.

6.7.1 Calibration and Validation Process

The hydraulic modelling calibration process involves the following steps:

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

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

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

(4) Apply the calibration storm event (January 2011) to the TUFLOW model and optimise the model parameters to achieve model calibration.

(5) Validate the model parameters against the other four events.

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

6.7.2 Event Selection

As discussed in 5.2 the largest event in the stream gauge record was the January 2011 flood event. However, larger events are known to have occurred outside of the instrumental record, including the 1974 flood event. Typically, the calibration of a hydraulic model to a flood event requires streamflow information and surveyed flood marks from that flood event. Unfortunately, for all of the historic events there exists only streamflow data or surveyed flood mark data, for no event were both data types available for calibration purposes (see Table 6-3). The data available for the January 2011 event was considered to provide the best dataset for calibration for the reasons outlined below. All other flood events were validated using the streamflow records for Mt Ida Creek at Derrinal with the exception of the May 1974 event. The May 1974 had surveyed flood levels and this event was verified against this data.

The January 2011 flood event was relatively minor, with an AEP of less than 10%, and as such no survey of flood marks was collected. Fortunately the event occurred recently enough that anecdotal evidence of flood behaviour and heights were able to be obtained from the community. This evidence was considered reliable enough to be used in the hydraulic model calibration.

For the other events investigated during the hydrologic modelling (not the May 1974 event) there were no flood marks or sufficient anecdotal evidence to aid the calibration. For this reason, these events were verified against the stream gauge.

In addition, the 1974 flood event was also investigated. The stream gauge at Mt Ida Creek at Derrinal was not installed at this time, hence there was no recorded streamflow data. However, numerous flood marks were surveyed by the Rural Water Commission (see Appendix B).

Table 6-3 Summary of Hydraulic Calibration and Validation Events

Event	Observed Peak Flow (m^3/s)	Modelled Peak Flow (m^3/s)	NSE	Type	Calibration data
May '74	-	220	-	Verification	Flood marks
Aug '78	57	54	0.87 – Good	Validation	Streamflow record
Sep '93	56	52	0.61 – Satisfactory	Validation	Streamflow record
Sep '10	97	95	0.91 – Good	Validation	Streamflow record
Dec '10	23	24	0.87 – Good	Validation	Streamflow record
Jan '11	107	100	0.76 – Satisfactory	Calibration	Streamflow record & Anecdotal evidence

6.7.3 Calibration Event

January 2011

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

For the January 2011 flood event the following data was available:

- Recorded streamflow from the Mt Ida Creek at Derrinal gauge;
- Pluviograph data from the Heathcote gauge; and
- Anecdotal evidence supported by photographs.

Manning's n was the primary variable used to calibrate the hydraulic model. These values, for each identified material, were varied until a suitable match with the observed record was reached. The resulting Manning's values are listed in Table 6-2.

The flows at the Derrinal streamgauge are plotted in Figure 6-4. The flow at the stream gauge from the TUFLOW hydraulic model shows a good fit with respect to the observed record. The summary statistics indicate that the modelled results can be considered good.

The peak flow depths for the January 2011 flood event are presented in Figure 6-5. The extents of this event have been compared to the anecdotal evidence provided by the Heathcote community, which includes extents marked up on maps, photos and other recollections. A number of locations were identified highly reliable in terms of extents as they had been identified by multiple individuals, had photos to support the extents or were distinctive features. These locations are compared in Table 6-4 to the results of the hydraulic model calibration.

Overall this is considered to be good calibration. The comparison of the modelled results with the streamflow data indicates the modelled data is a good fit with the recorded data. It is of note that double peaked events, such as January 2011, are usually difficult to match. The comparison of the modelled extents with the anecdotal data demonstrates that the modelled extents are able to replicate the observed.

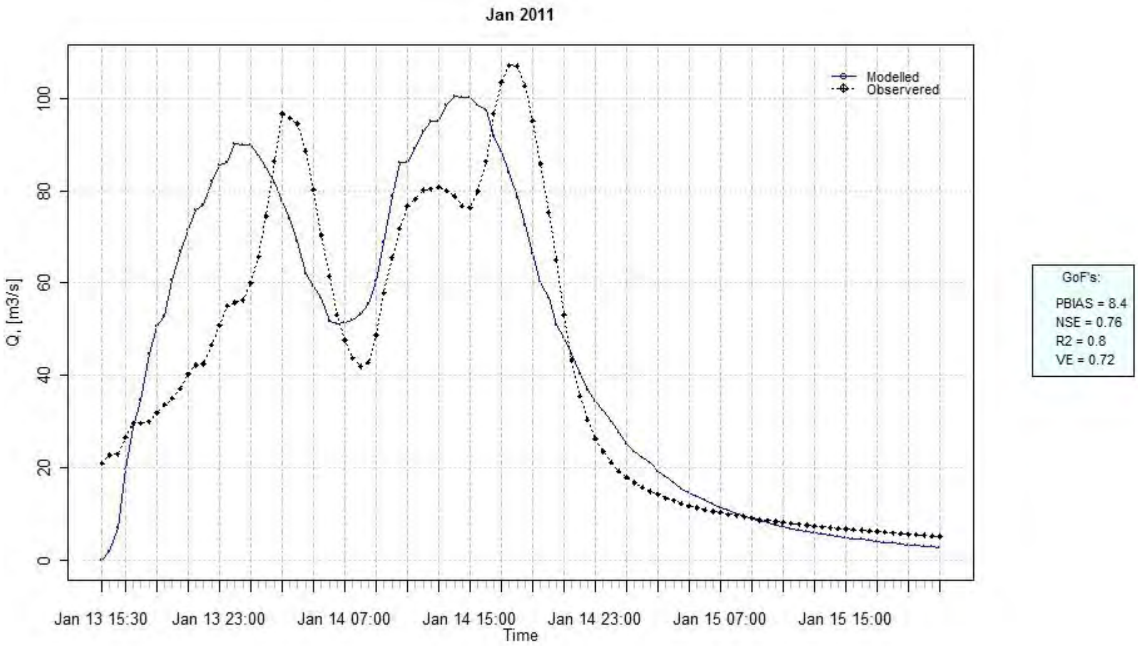
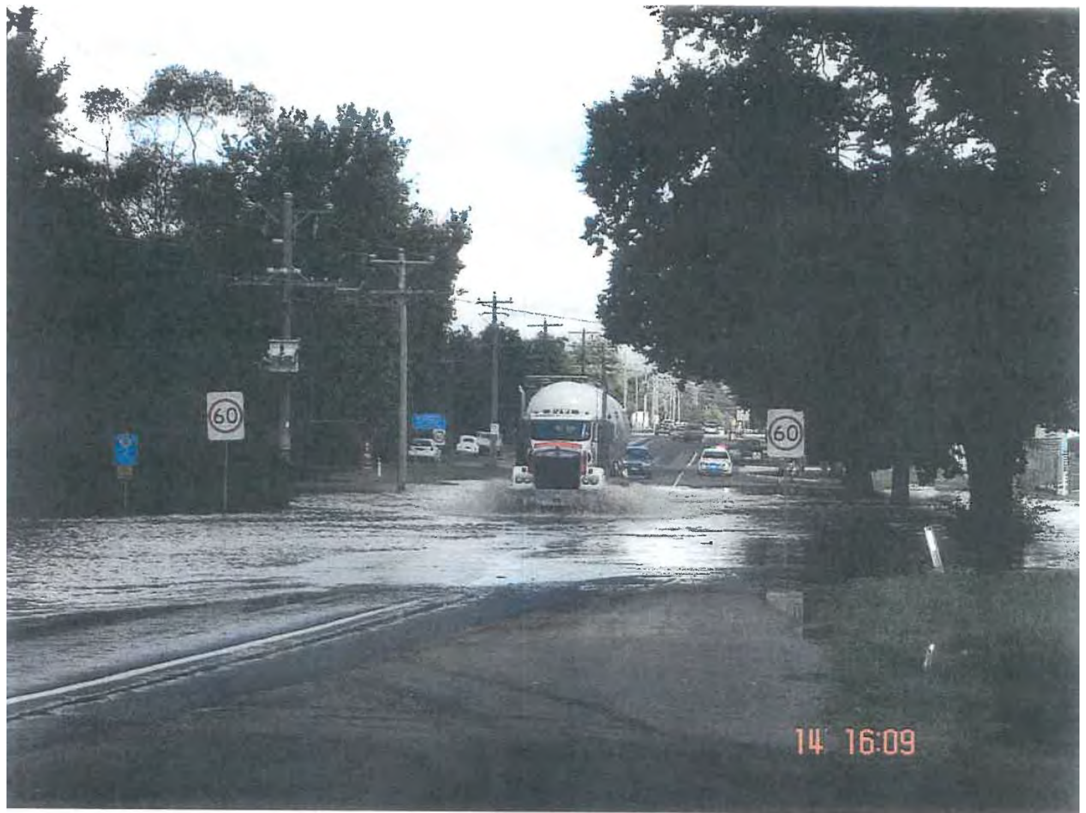
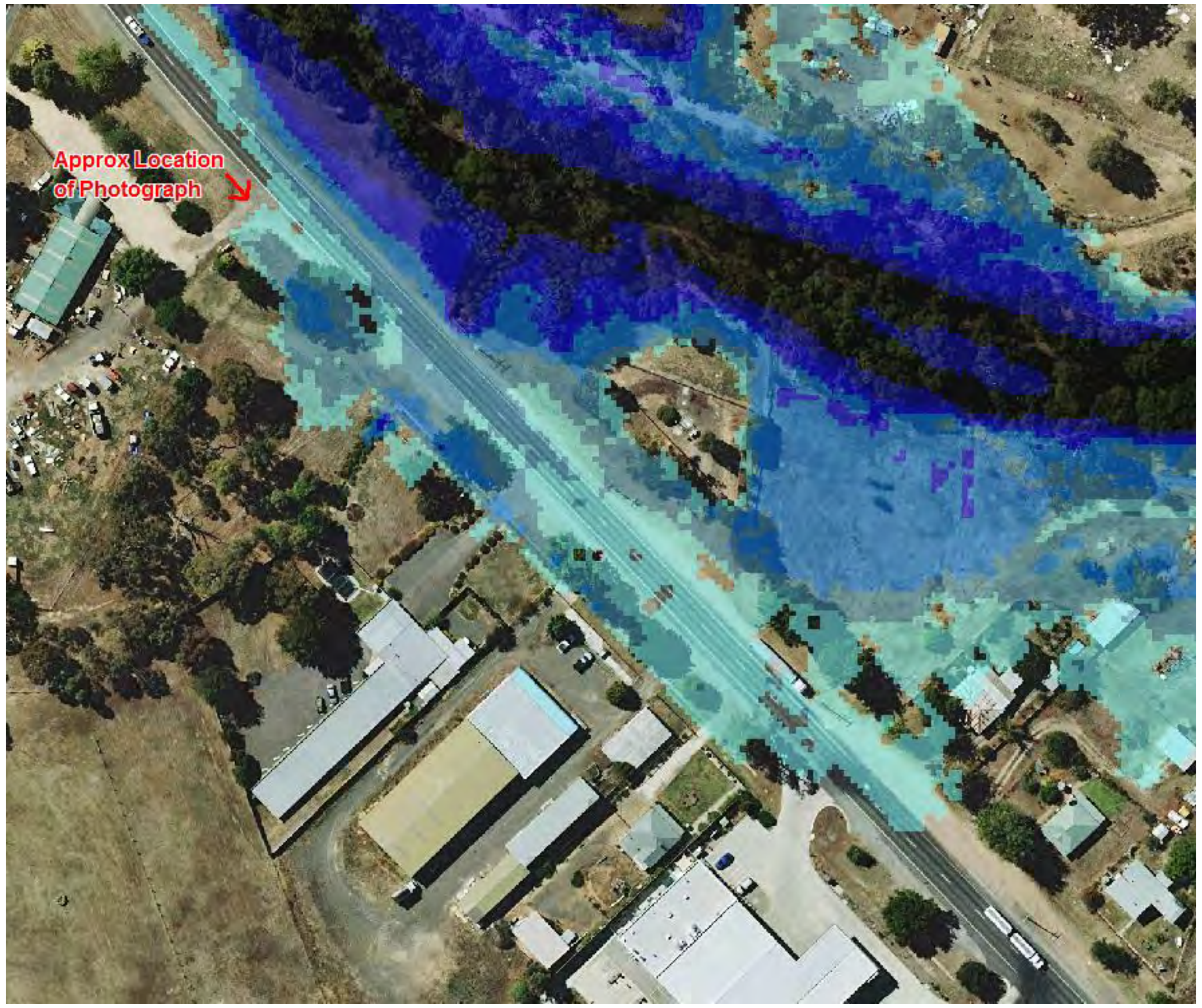
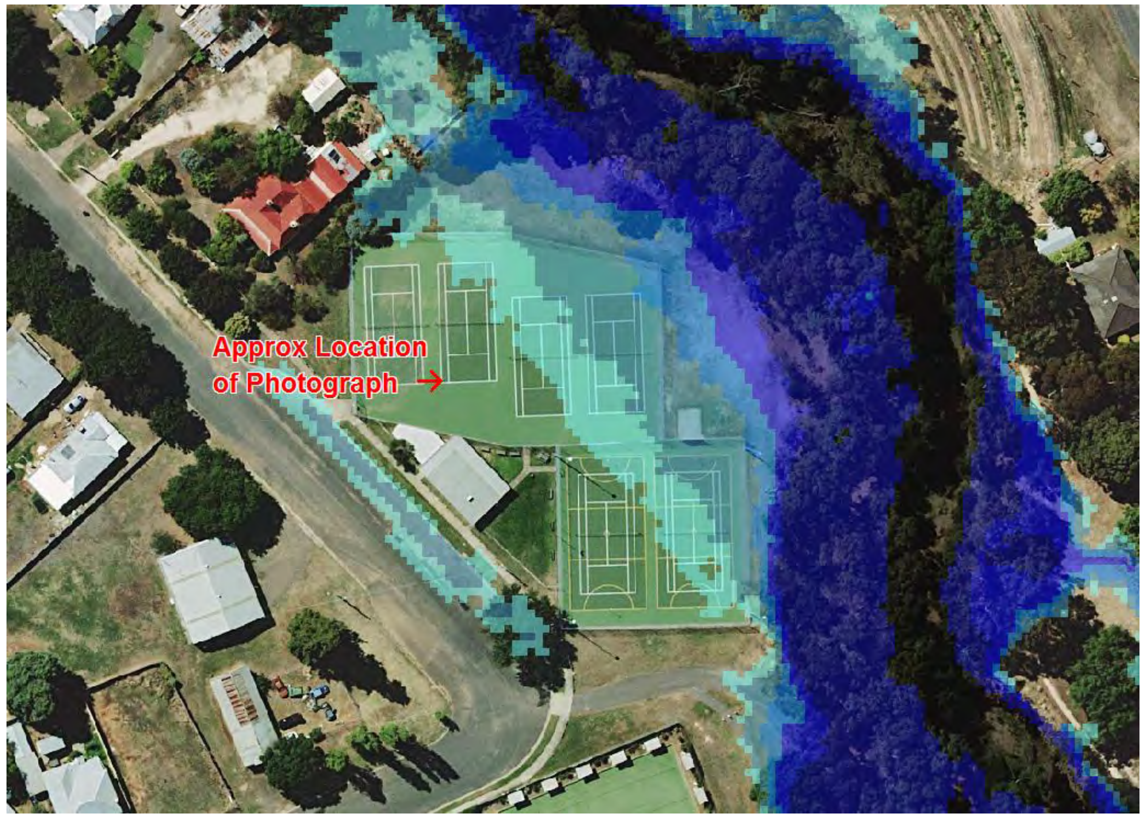
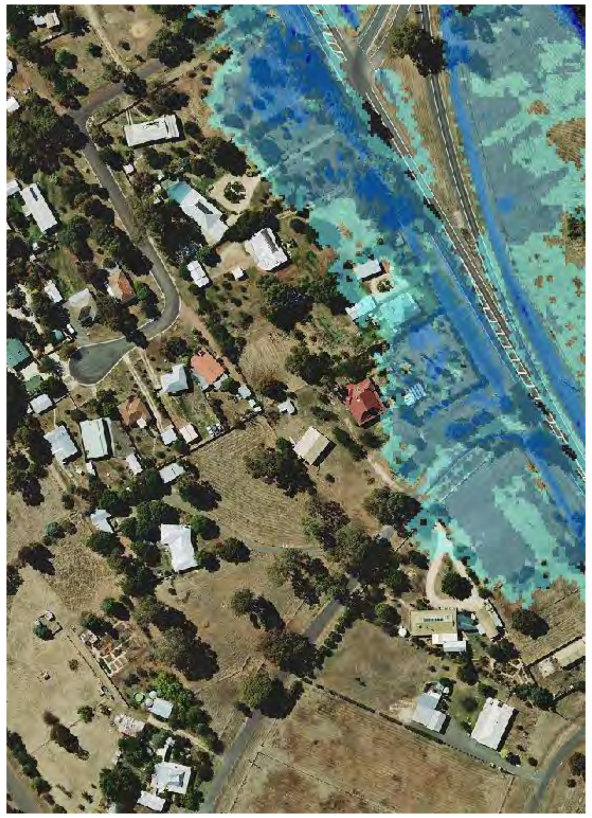
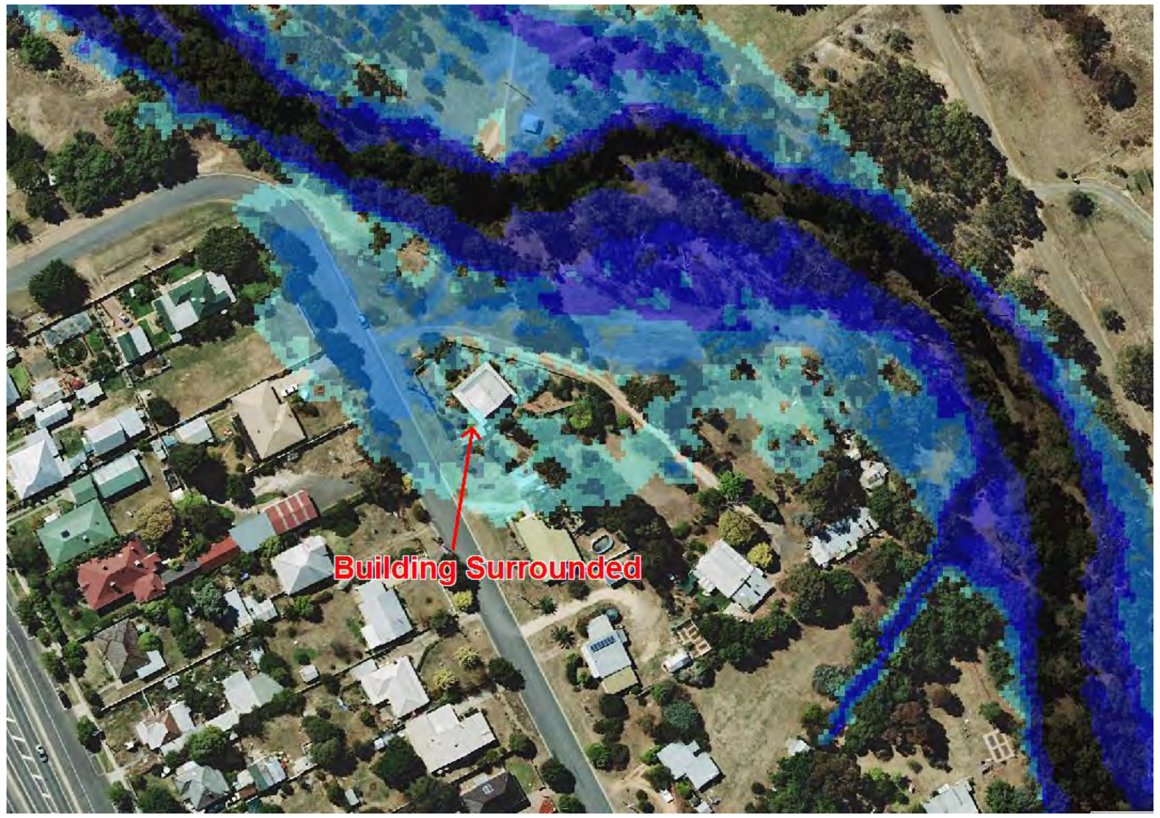
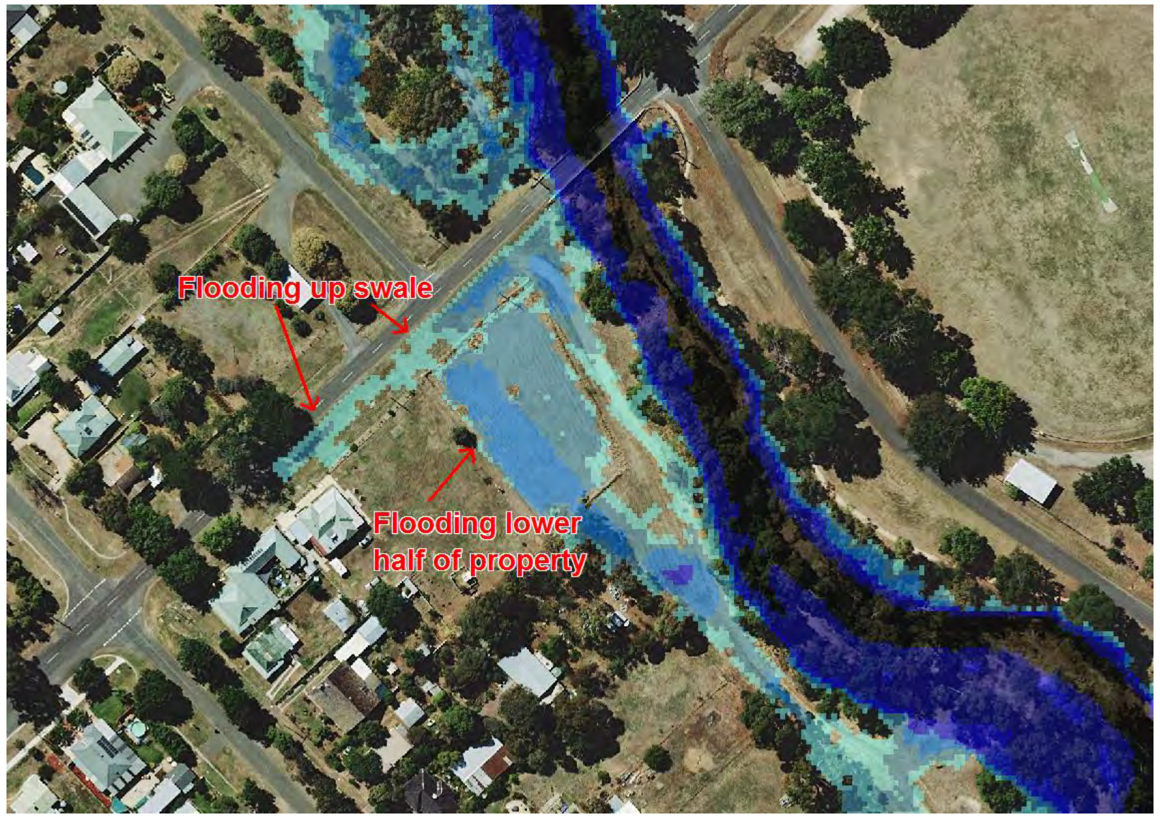


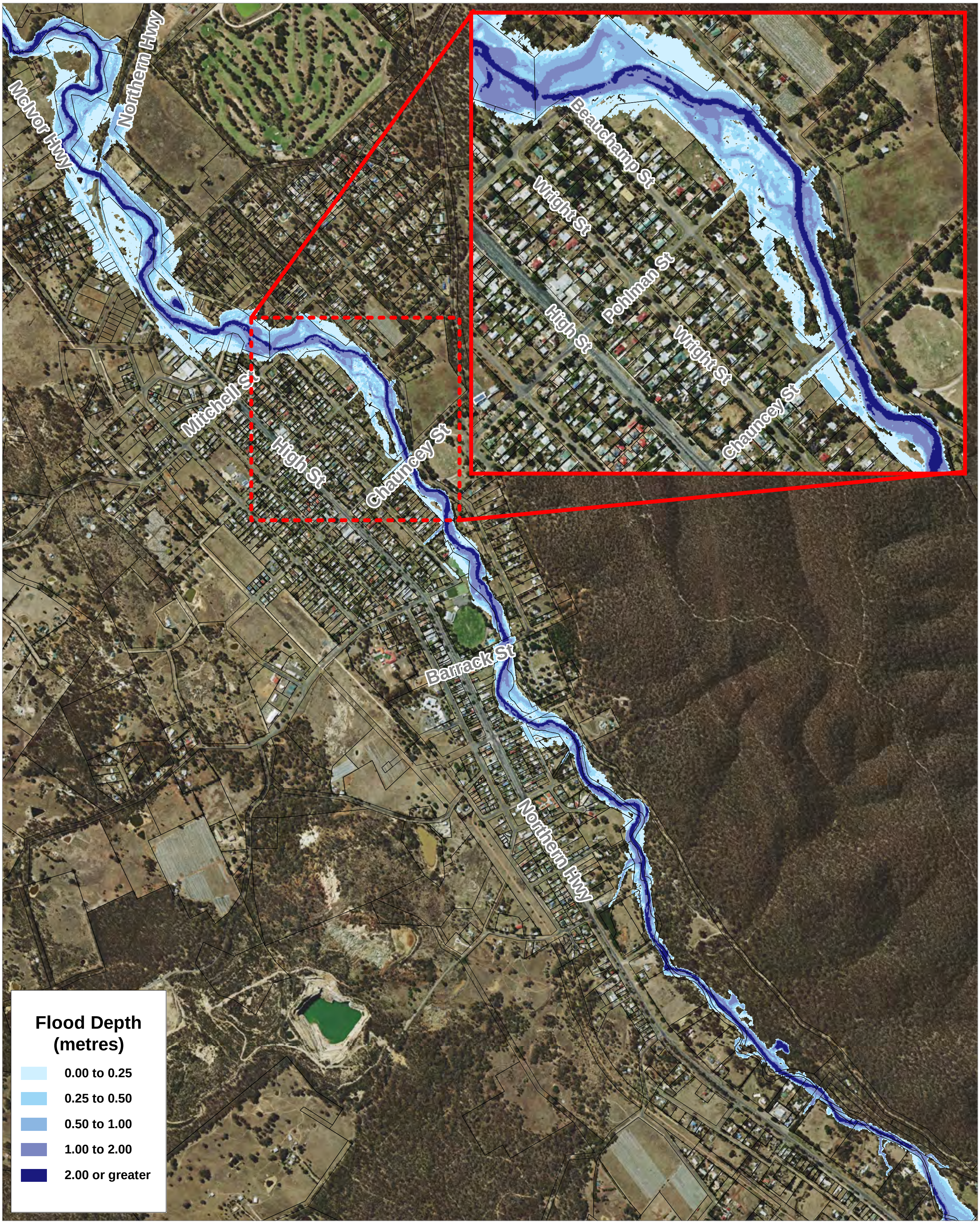
Figure 6-4 January 2011 Calibration Event Flow Rate Comparison

Table 6-4 January 2011 Calibration Anecdotal Information

Anecdotal Point & Comments	Supplied Information	TUFLOW Calibration Model
1 – Northern Highway Flooding shown from north of large tree to approximately 3rd visible power pole in photograph	 	

<table>
<tr><th>Anecdotal Point & Comments</th><th>Supplied Information</th><th>TUFLOW Calibration Model</th></tr>
<tr><td>2 – Tennis Courts
Flooding shown to be along the ‘singles’ lines on the 3rd court and appears to be increasing inundation to the left of photo.</td><td></td><td></td></tr>
<tr><td>3 – Local resident comment between Speed St and Craven Cres.
Notes from Bushmarket: Preliminary mapping (shown on the left) too low in area, increase to approx. red lines</td><td></td><td></td></tr>
</table>

Anecdotal Point & Comments	Supplied Information	TUFLOW Calibration Model
4 – SES member comments	Notes from Bushmarket: Building surrounded, however no inundation of building	
4 – Local resident	Notes from Bushmarket: Flooding backwatering up local drainage (swale), inundation of lower portion of property from the creek to approximate extent shown.	



Title:

Heathcote Flood Study
January 2011 Flood Depth

Figure: **6-5**

Rev: **A**

N

0 375 750m
Approx. Scale

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6.7.4 Validation Events

August 1978

The results of the August 1978 validation are presented in Figure 6-6. The results in this figure and the summary statistics indicate that the validation event is a good fit to the recorded data.

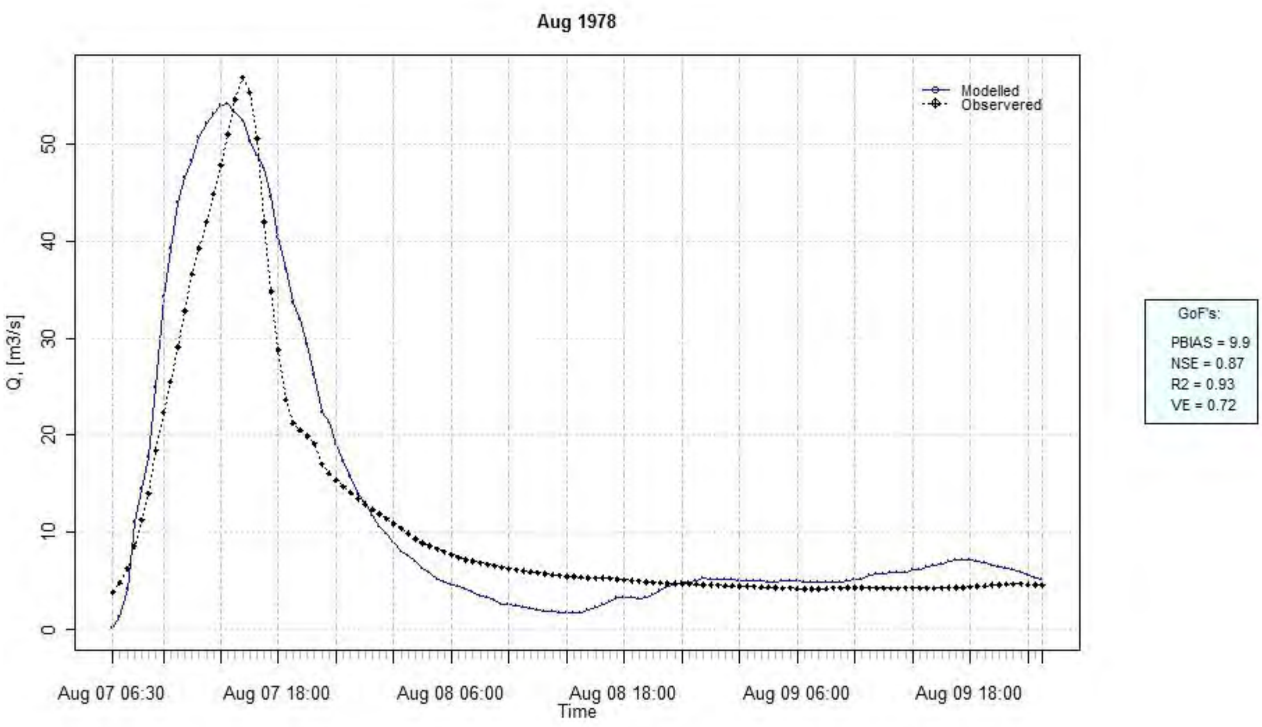


Figure 6-6 August 1978 Validation Event Flow Comparison

September 1993

The results of the August 1978 validation are presented in Figure 6-7. The results in this figure and the summary statistics indicate that the validation event is a satisfactory fit to the recorded data.

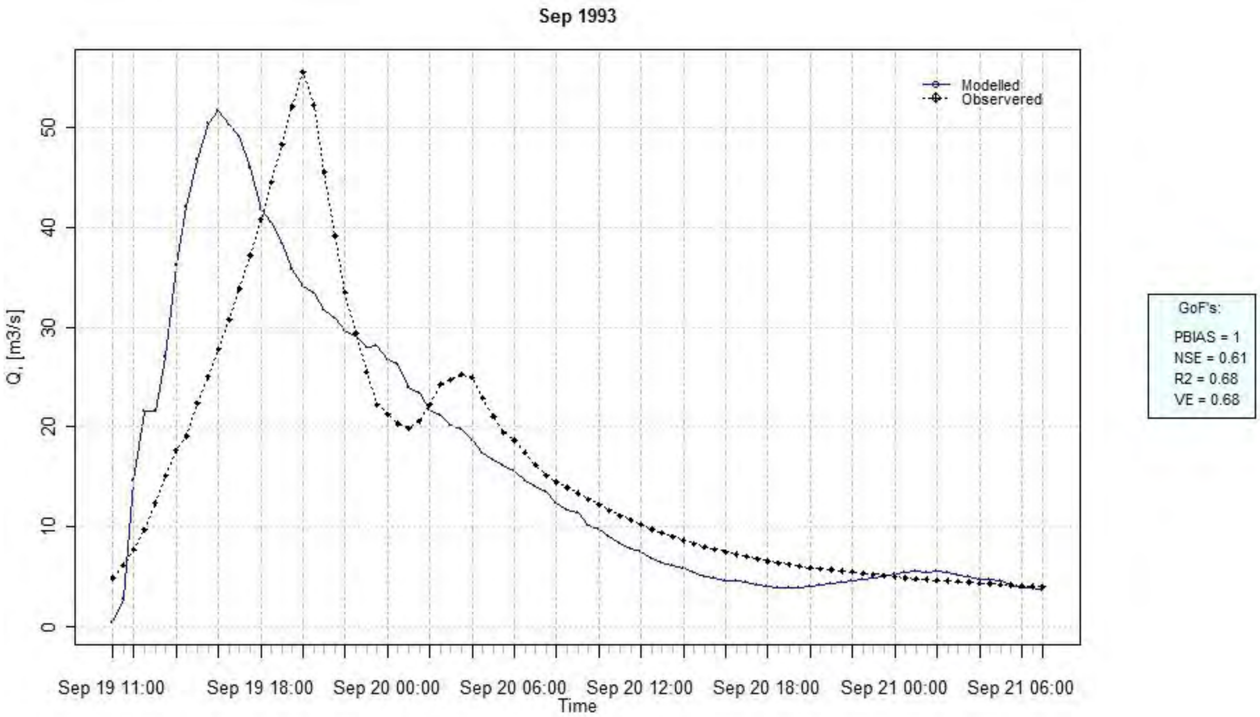


Figure 6-7 September 1993 Validation Event Flow Comparison

September 2010

The results of the September 2010 validation are presented in Figure 6-8. The results in this figure and the summary statistics indicate that the validation event is a good fit to the recorded data.

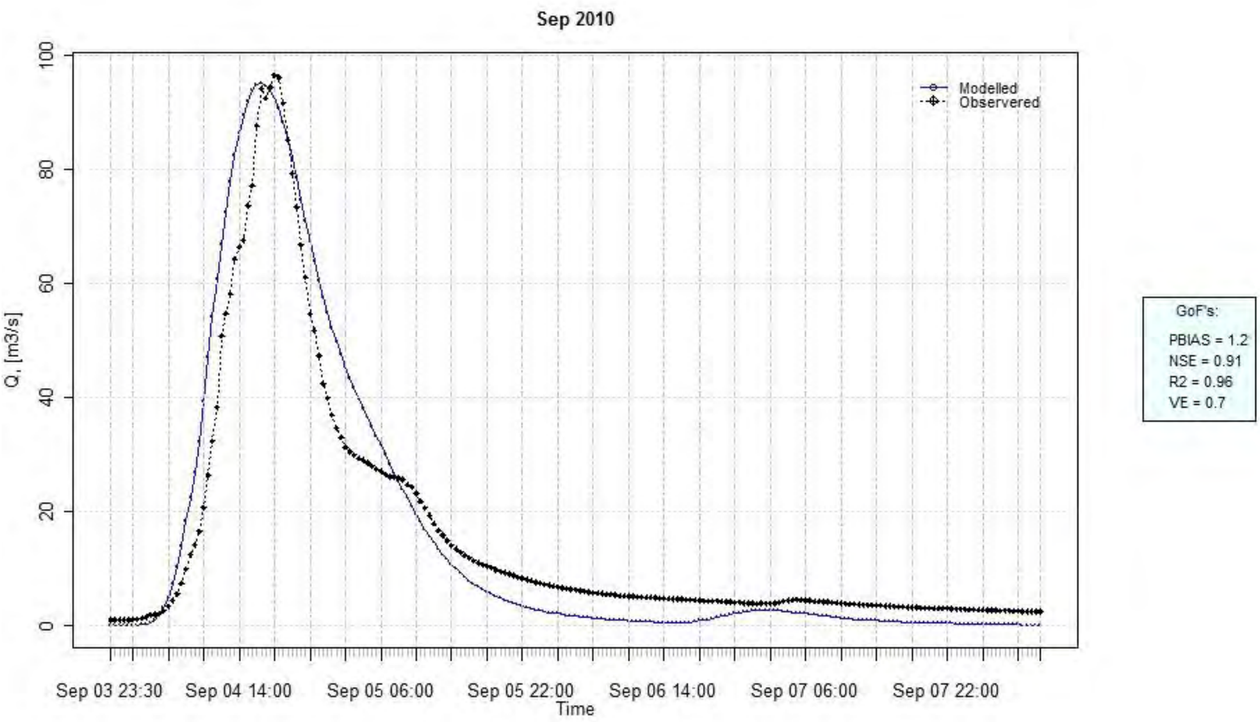


Figure 6-8 September 2010 Validation Event Flow Comparison

December 2010

The results of the December 2010 validation are presented in Figure 6-9. The results in this figure and the summary statistics indicate that the validation event is a good fit to the recorded data.

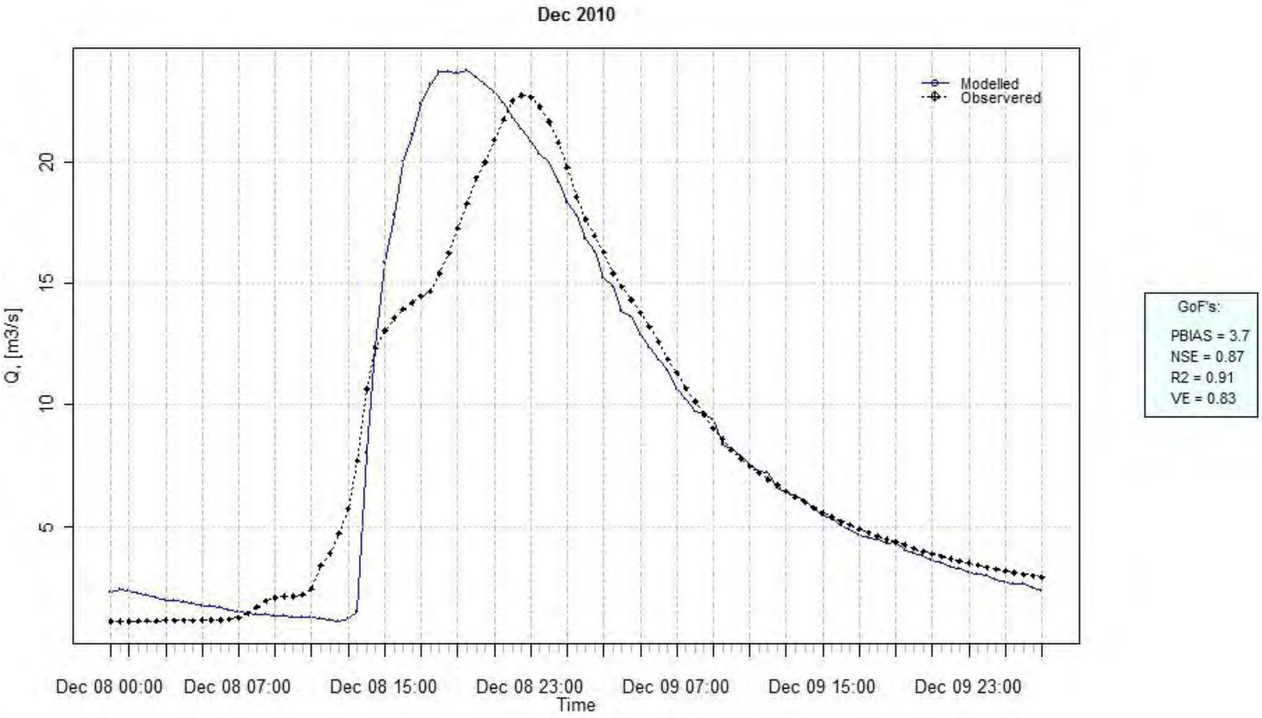


Figure 6-9 December 2010 Validation Event Flow Comparison

Verification Event

6.7.5 Verification Event

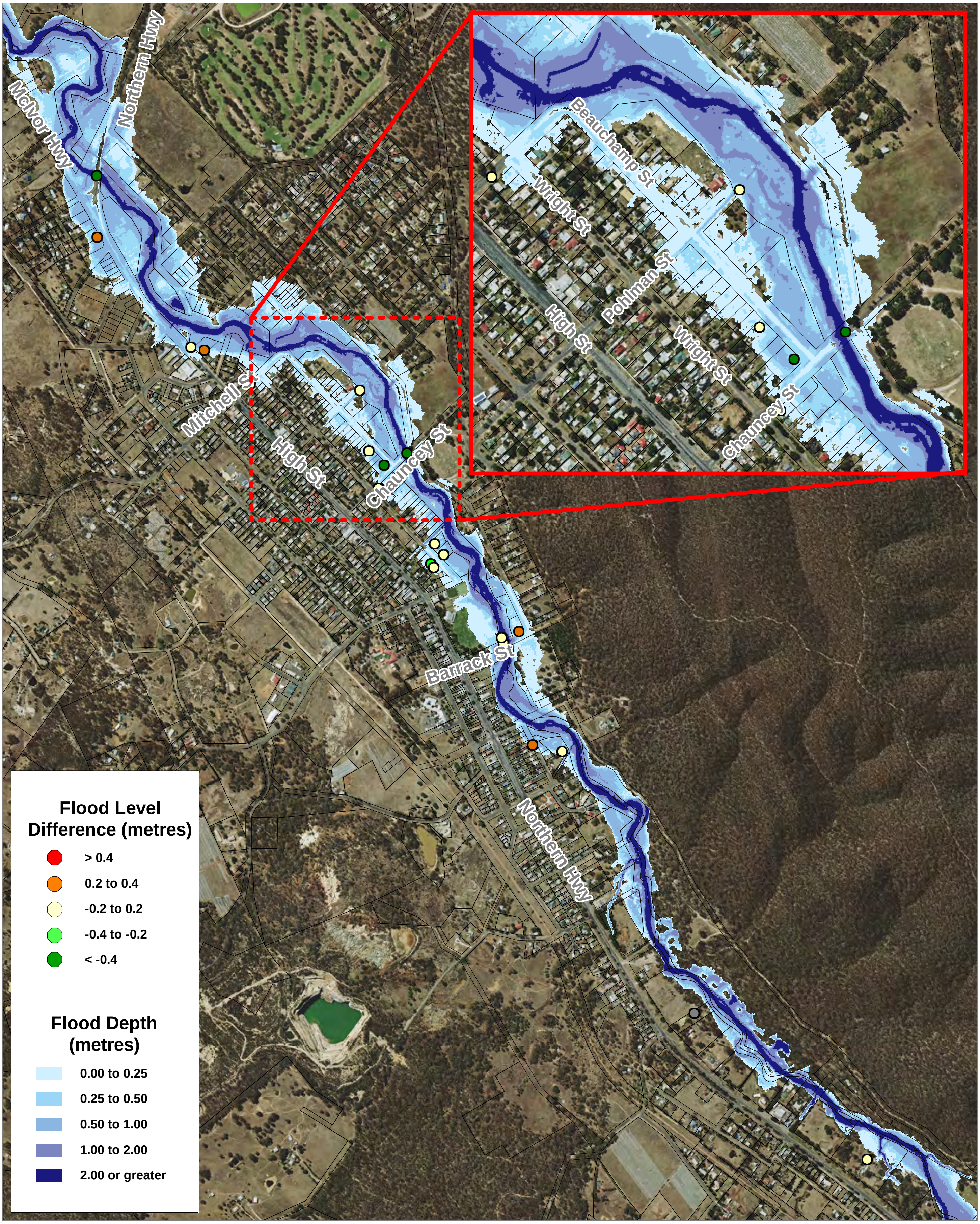
May 1974

As discussed in Section 2.7 in May 1974 the catchment experienced a flood significantly larger than any during the stream gauge instrumental period. While the available data did not support model calibration or validation it was considered to be important (potentially the most important) event for consideration. To differentiate the process undertaken for the May 1974 from the process undertaken for the validation events above it has been referred to as a verification event.

To undertake this verification event, the URBS was run with the calibrated parameters and the resulting hydrographs applied to the hydraulic model. For the verification of the 1974 event recorded pluviograph and daily rainfall records were used with no changes to either the hydrologic or hydraulic models. These results are presented in Figure 6-10 along with the flood height difference for each flood mark. Overall, given the information available a good outcome was achieved with the majority (13 out of 21) of modelled flood levels within ±0.2 m of the surveyed flood marks.

Table 6-5 Comparison of Floodmarks to Modelled Flood Level

Statistical Measure of Difference (m)	Difference between Floodmarks and Hydraulic model results
Mean	-0.05
Median	-0.09
Standard Deviation	0.26
Lower Quartile	-0.15
Upper Quartile	0.16



Title:
Heathcote Flood Study
May 1974 Flood Depth

Figure: 6-10

Rev: A

N

0 375 750m

Approx. Scale

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Filepath : T:\M20448.PP.HeathcoteFloodStudy\MapInfo\Drawings\R.M20448.008.00.Final\HC_Final_Fig6-10_May1974_dMax_RevA.WOR

6.7.6 Calibration and Validation Discussion and Summary

The flooding dataset available for each individual event would not be considered sufficient to reliably calibrate a model; however, when considered in total the diverse set of information provides a strong basis to calibrate the Heathcote TUFLOW model. To make best use of this diverse set of information, the model was calibrated to the January 2011 event, validated against four additional flood events and verified against a further flood event (May 1974).

Overall the validation events can be considered as a good fit to the observed, with three events achieving a good fit, with only the September 1993 event resulting in a satisfactory fit. It is of note that the recorded data form the 14:00 to 22:00 19/09/1993 appears to be linear, which could be the result of interpolation; however, the data has been classified as *Good quality data - minimal editing required. Drift correction*. If the data was in fact interpolated data the fit to this event could significantly improve the fit of the data.

In addition, the verification event provided a good fit to the survey flood marks. It is of note that the 1974 flood marks were surveyed in 1987. Considering this, the good fit to survey flood marks is an excellent result.

This indicates, that the model setup, the parameters and assumptions used in the model are appropriate for use in the design event modelling required for the study. That is, these results taken together, demonstrate that the Heathcote TUFLOW model is well calibrated and suitable of the purposes of this study.

6.8 Sensitivity Analysis

As part of the modelling process a number of parameters were varied as part of a sensitivity analysis. This involved varying the Manning's n values ±20% from those derived during the calibration. Due to the potential for blocked and damaged structures such as culverts and bridges a sensitivity analysis was undertaken where all bridge and culvert structures were blocked by 50%.

The difference between the peak modelled flood level and the levels at the gauge are presented in Table 6-6 for the 1% AEP flood event.

Under the 50% blockage of all structures within the model there were negligible increases in flood levels at the gauge or within the catchment, with an average increase in water levels of less than ±0.01 m.

Raising or lowering the Manning's n within the catchment by 20% resulted in peak flood levels changing by ±0.09 m.

Table 6-6 1% AEP Flood Event Sensitivity Analysis Comparison

	Manning's n -20%	Manning's n +20%	50% Blockage
Gauge height (dif in m)	-0.03	0.04	0.00
Gauge flow rate (diff in m^3/s)	3.52	-4.55	-0.28
Average water level (diff in m)	-0.09	0.09	0.01

6.9 Design Event Modelling

Hydraulic modelling was undertaken for the 0.5%, 1%, 2%, 5%, 10% and 20% Average Exceedance Probability (AEP) design storm events. These design events were used to undertake existing conditions flood mapping and the damages assessments for the study.

Climate change sensitivity has been undertaken for rainfall intensity increases of 20% for the 1% AEP flood event. Refer to Section 5.6.3 for further details on climate change sensitivity.

7 Modelling Quality Assurance

To ensure that results of the modelling undertaken as part of the Study and can be used for any future assessments or works within the Catchment, an extensive Quality Assurance (QA) program has been undertaken. This includes independent review of all modelling and reporting outputs.

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

7.1 Hydrologic (URBS) Model Review

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

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

7.2 Hydraulic (TUFLOW) Model Review

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

- The methodology of the model development and calibration and validation process was checked for suitability and agreed upon. The process is described in detail in Section 6.7.
- That the TUFLOW model was developed correctly to ensure that input data appropriately represented in the model.
- That the topography, surface roughness and hydraulic structures were appropriately represented with the hydraulic model.
- The boundary conditions were correctly modelled ensuring that flow is entering and leaving the model appropriately and not influencing the model results, i.e. imposing boundary effects within the study area. The model extent is a significant distance from mapping limit so as not to create boundary effects.
- The model was checked for negative depth warnings that could indicate instability within the model. The model was healthy with no 1D or 2D negative depths generated for any modelled flood event.

- That mass balance errors present within the TUFLOW model were within acceptable limits as to not influence results. At the time of maximum total model volume, peak flow out the model and at the final model timestep the mass error did not exceed ±0.22%, indicating a healthy model.

8 Flood Mapping and Results

This section provides an overview of the floodplain mapping process used in the study and presents a selection of the existing conditions mapping outputs.

TUFLOW produces a geo-referenced datasets defining peak water levels, depth, velocities and hazard throughout the model domain at the corners of its computational cells. This data is imported into GIS to generate a digital model of the flood properties and produce the required flood mapping outputs. This Section addresses Key Objective 2.

8.1 Flood Depth Mapping and Description

Flooding within the Heathcote township is generally very well contained within the banks of McIvor Creek. Flood depths throughout the catchment are presented in Figure 8-1 to Figure 8-6.

The 5% AEP event is largely contained within the creek and the immediate floodplain with little in the way of breakaway flows between the top of the model and Mitchell St. Between Mitchell St and the Northern Highway minor breakaways were noted however these are typically shallow and confined to drainage channels along the Northern Highway. The causeway crossings are submerged and unsafe to traffic.

Up to the 10% AEP event the flood waters are largely contained within the channel and the existing designated floodway with increased flood depths. The modelling shows flood waters backing up behind the Chauncey St bridge resulting in minor flooding immediately upstream and causing floodwaters to breakaway along Beauchamp St. The intersection of Thomas and Jennings St closest to the creek are inundated from the breakaway from the creek. Flooding of the Northern Highway and McIvor Highway as well as the causeway crossings are likely to cause minor disruption to the town.

For rarer events than the 10% AEP event results in incrementally increases in the flood extent with the most significant increases in the vicinity from the breakout flooding between Chauncey St and Mitchell St along Beauchamp St. During the 1% AEP event almost the entire area between Wright St and McIvor Creek are inundated.

8.2 Flood Hazard Mapping

Existing conditions peak flood hazard is mapped for events up to and including the 1% AEP event. The flood hazard for each event is shown in Figure 8-7 through Figure 8-11.

Hazard mapping was undertaken using a methodology from the draft ARR revision project (ARR 2010) based on flow hazard regimes Hazardous to Children. Hazard is defined in terms of the depth and velocity-depth product as follows:

- Safe - velocity x depth equal to 0.0 m^2/s;
- Low Hazard - velocity x depth less than 0.4 m^2/s;
- Significant Hazard - velocity x depth less than 0.6 m^2/s; and
- Extreme Hazard - depth greater than 500 mm and/or velocity x depth greater than 0.6 m^2/s.

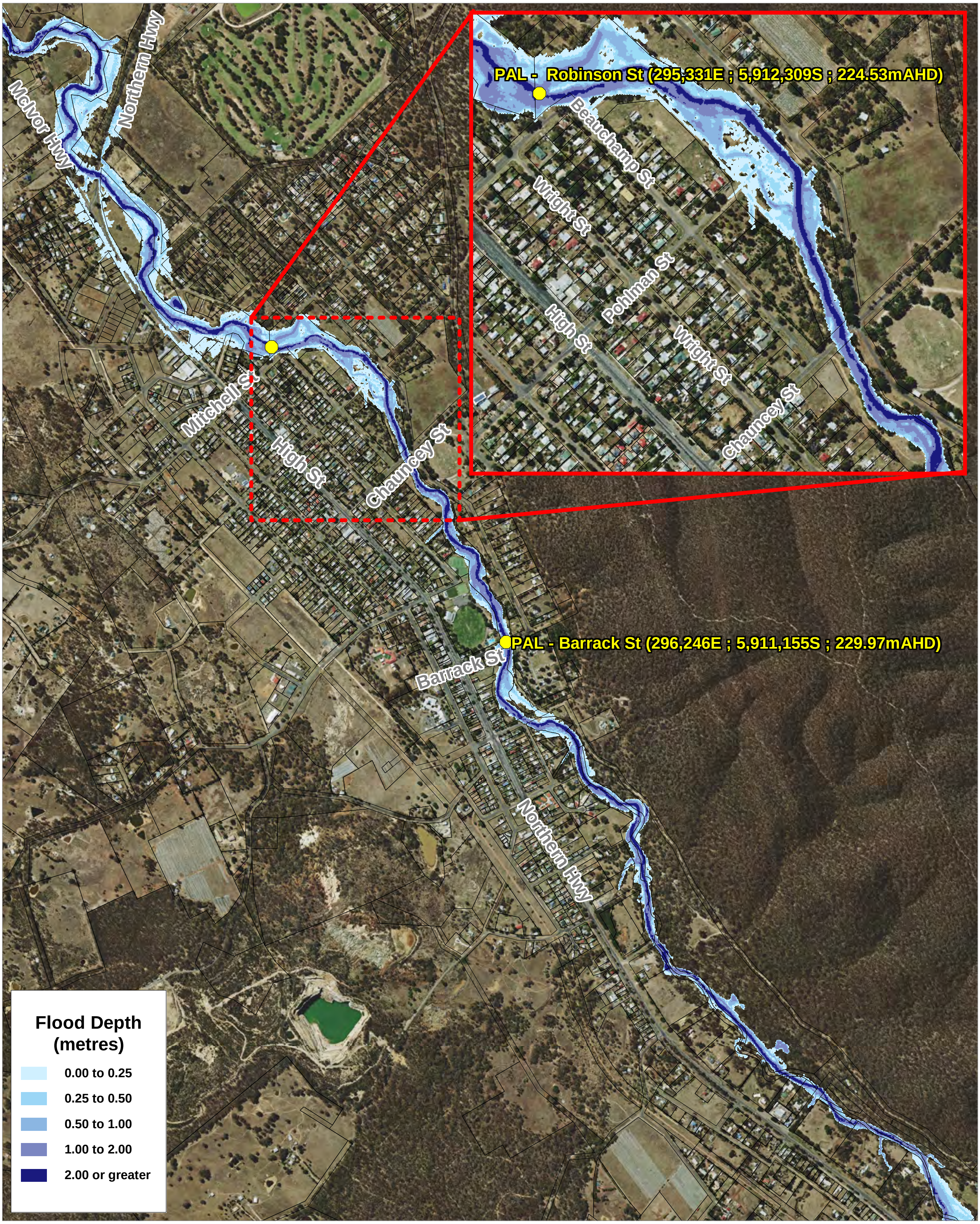
Generally, the areas inundated out-of-banks and on the broader floodplain are categorised as low hazard. Whilst there is flooding in many developed areas, it is generally shallow. Areas of high hazard are usually confined to the waterways and the designated floodway.

In the 2% and rarer events, flood risk will likely impact traffic from leaving Heathcote along both the Northern Highway and McIvor Highway.

8.3 Flood Velocity Mapping

Existing conditions flood velocity is mapped for the 1% AEP event at peak flood level. The flood velocity mapping is designed to depict both the magnitude and direction of the flow velocities. The 1% AEP flood velocity is shown in Figure 8-12.

Typically velocities exceed 2 m/s within the banks of the channel and between 0.5 and 2 m/s through the floodplain and along roads. Where flow is through properties the velocity is typically low below 0.5 m/s.



Title:

Heathcote Flood Study
20% AEP Flood Depth

Figure: **8-1**

Rev: **A**

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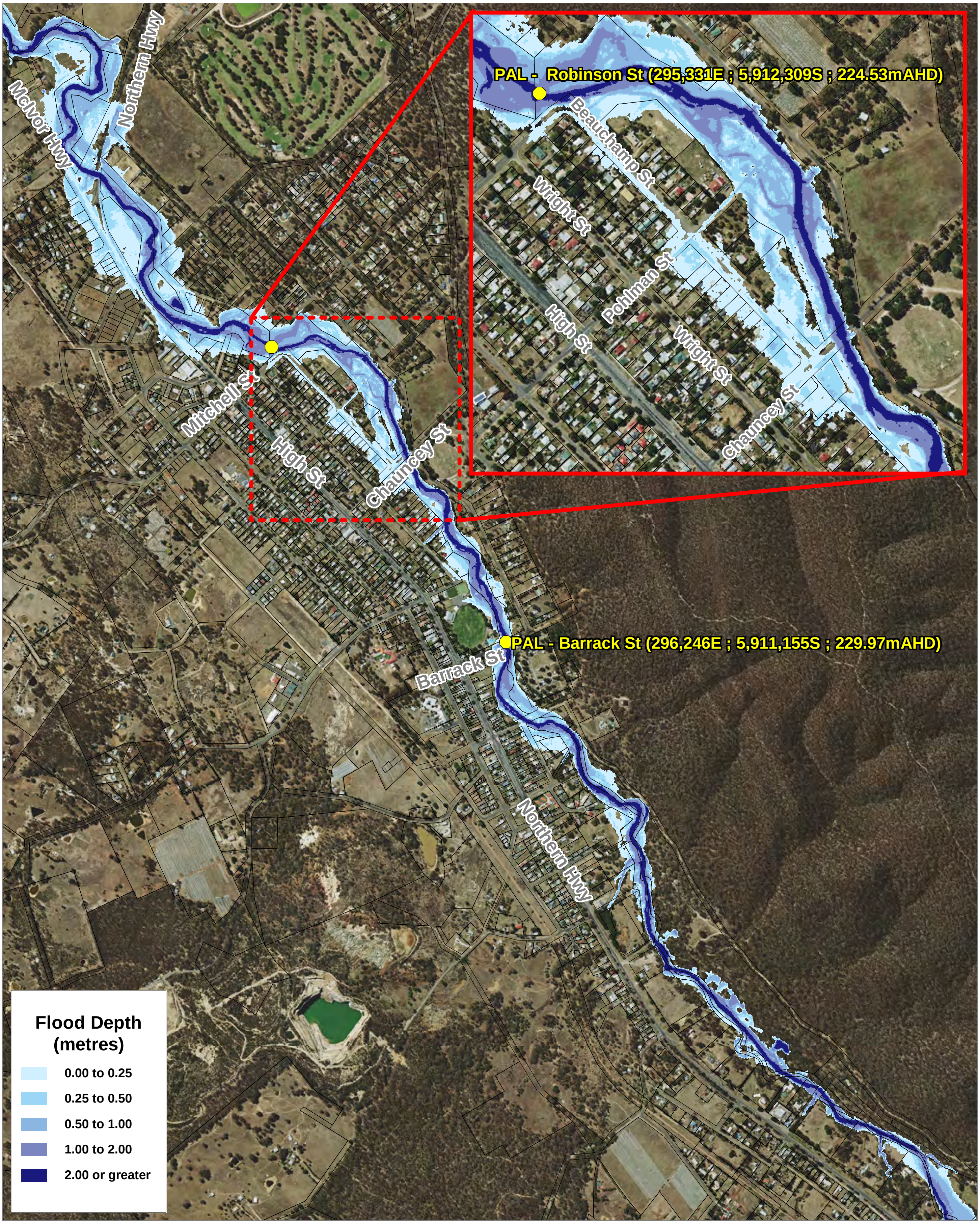

Title:
Heathcote Flood Study
10% AEP Flood Depth

Figure: **8-2**

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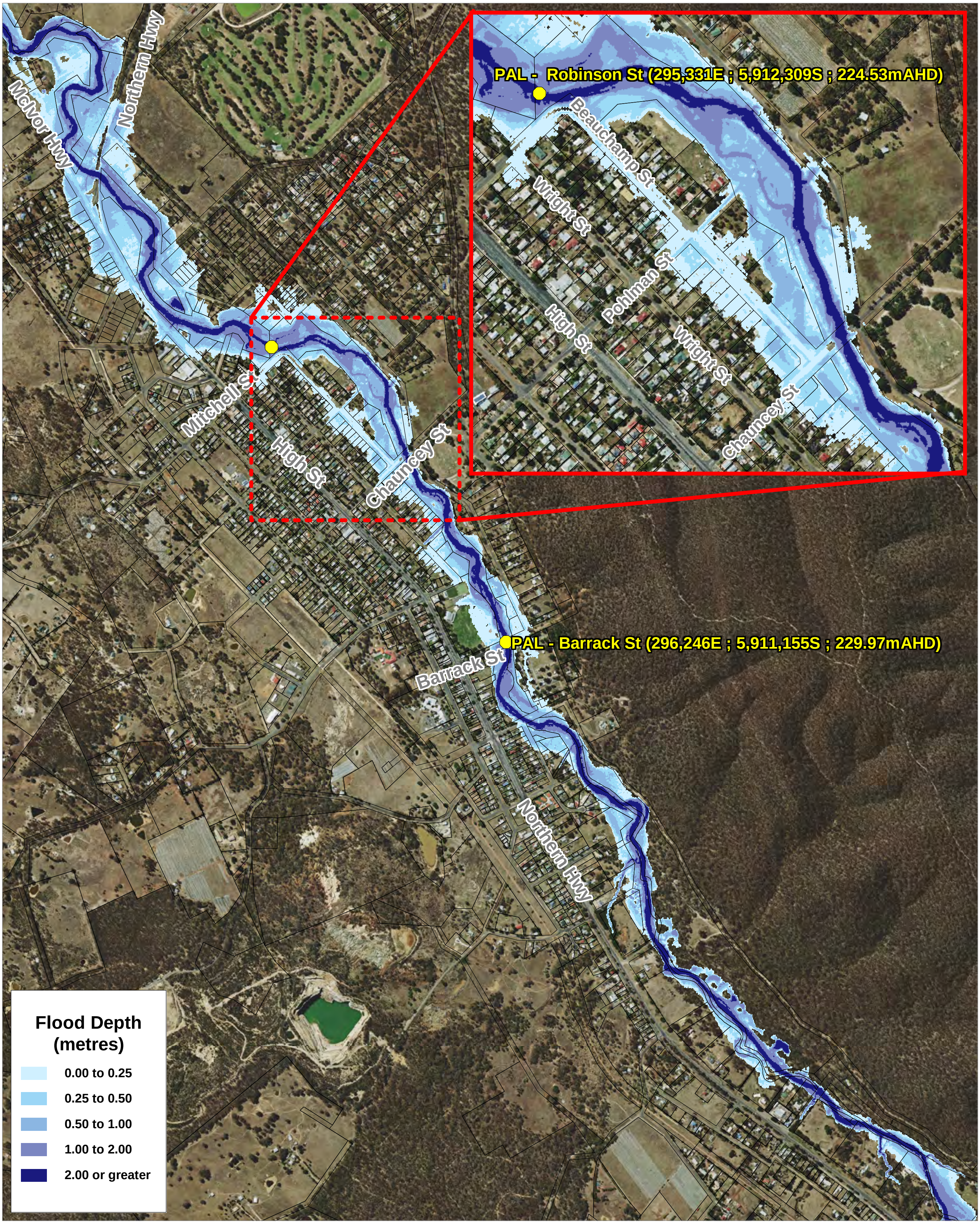

Title:

Heathcote Flood Study
5% AEP Flood Depth

Figure: 8-3

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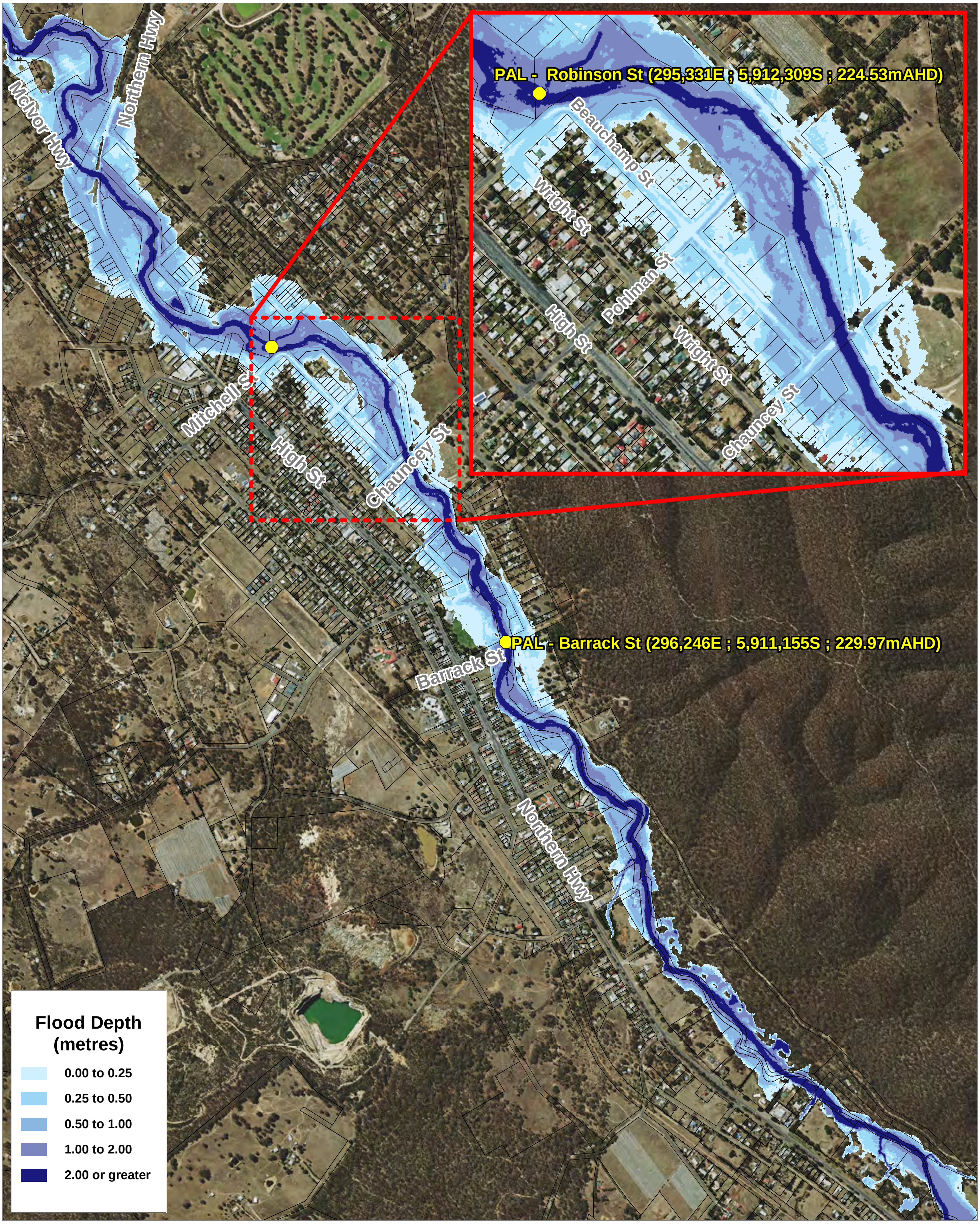

Title:

Heathcote Flood Study
2% AEP Flood Depth

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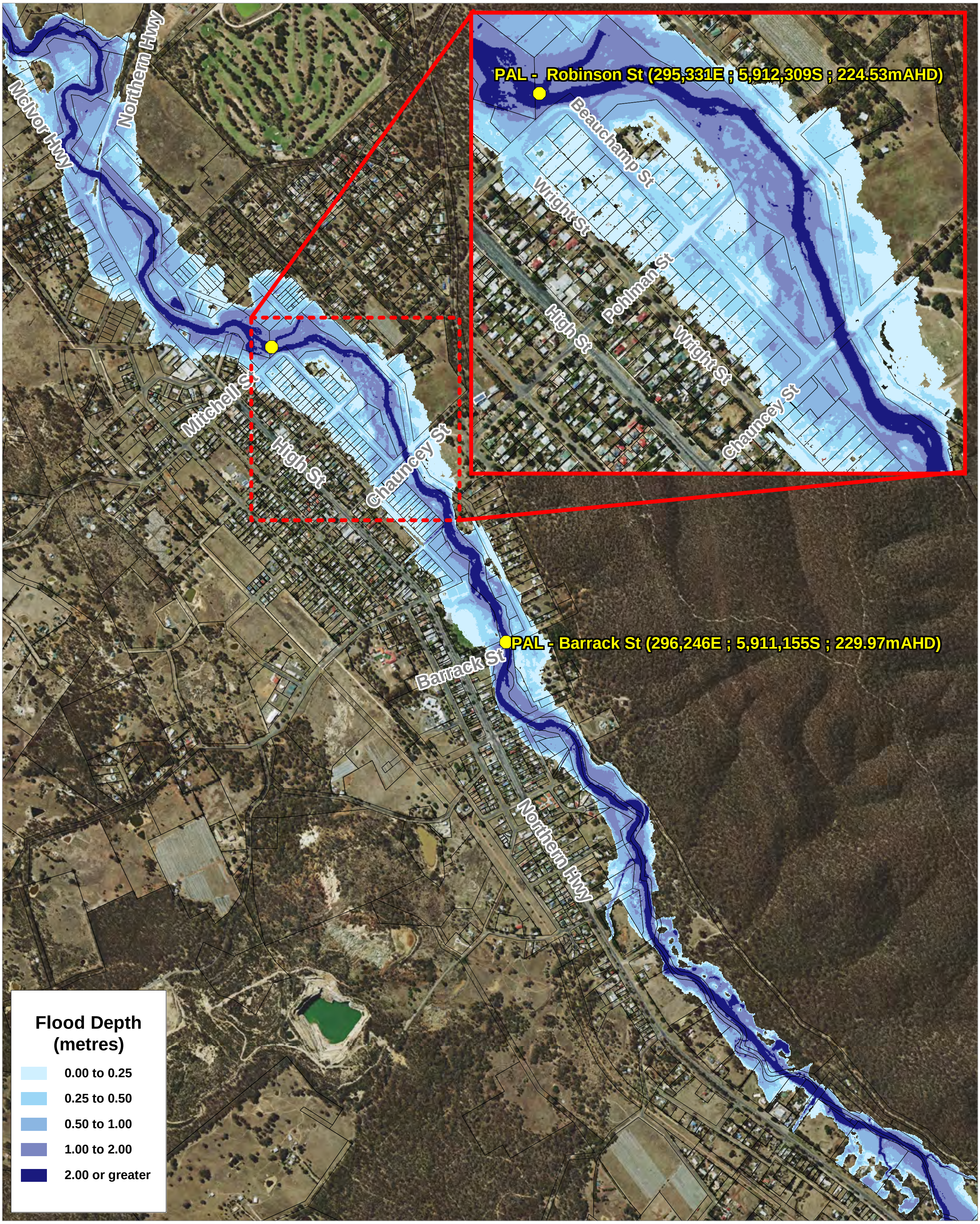

Title:

Heathcote Flood Study
1% AEP Flood Depth

Figure: 8-5

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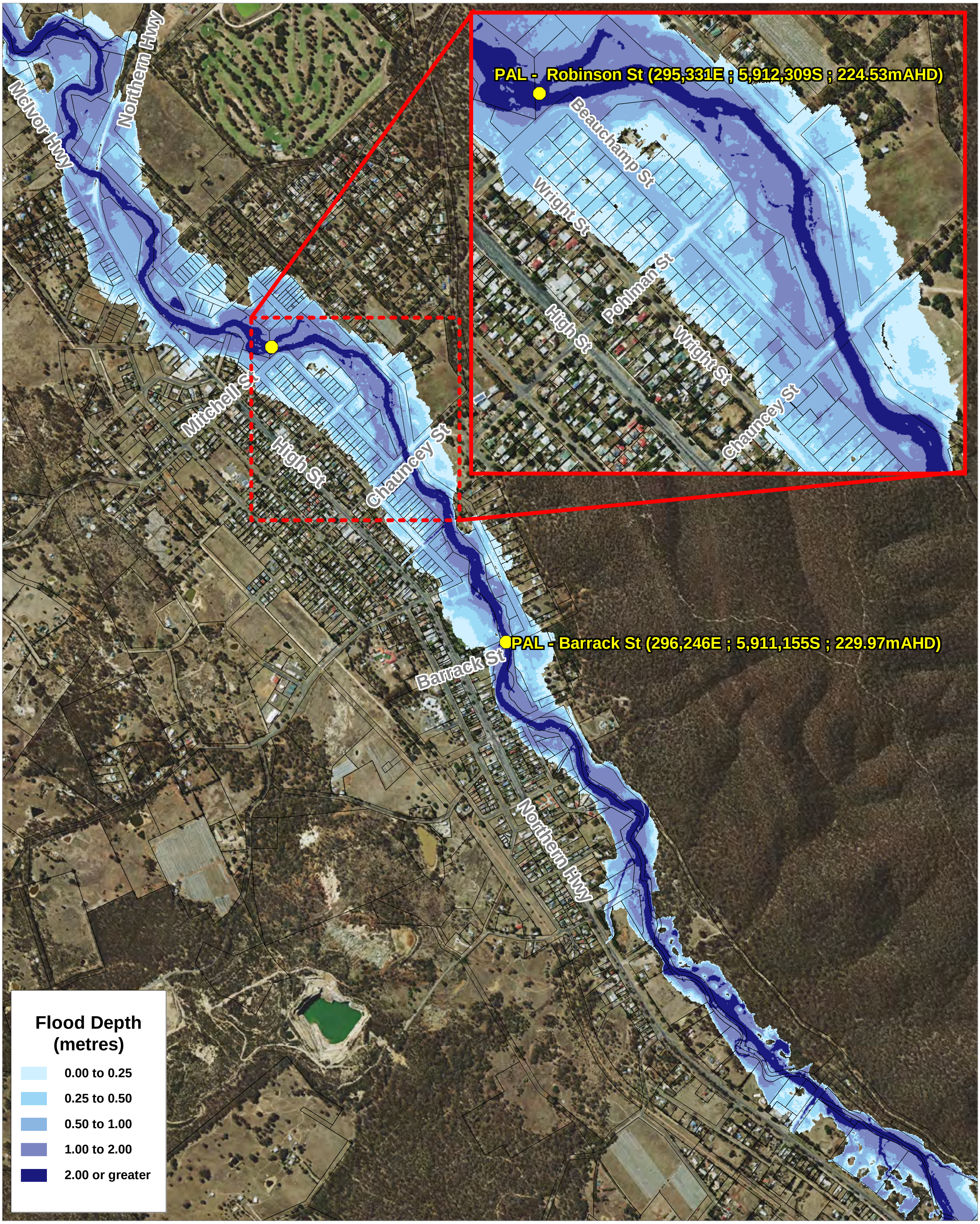

Title:

Heathcote Flood Study
0.5% AEP Flood Depth

Figure: **8-6**

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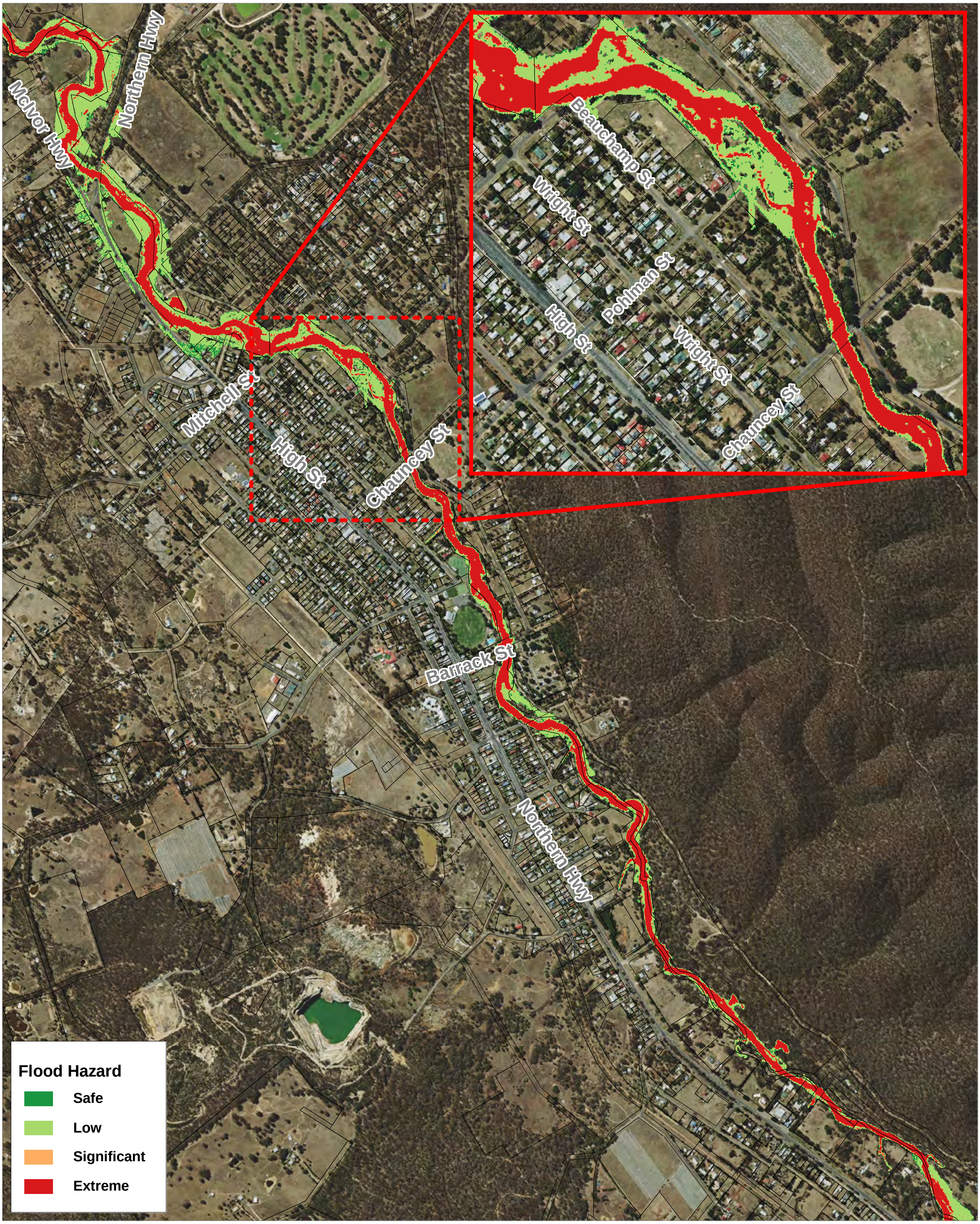

Title:

Heathcote Flood Study
20% AEP Flood Hazard

Figure: **8-7**

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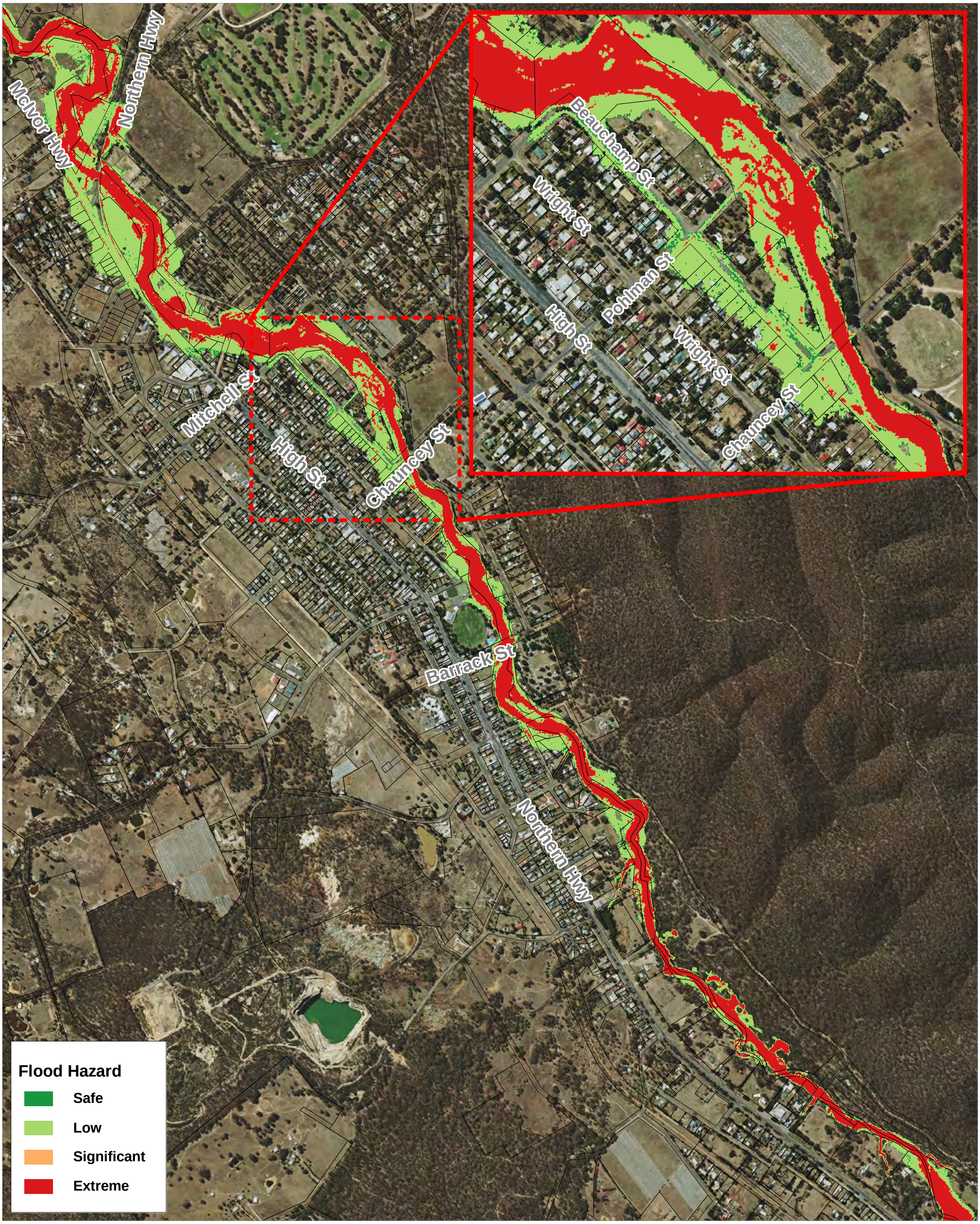

Title:

Heathcote Flood Study
10% AEP Flood Hazard

Figure: **8-8**

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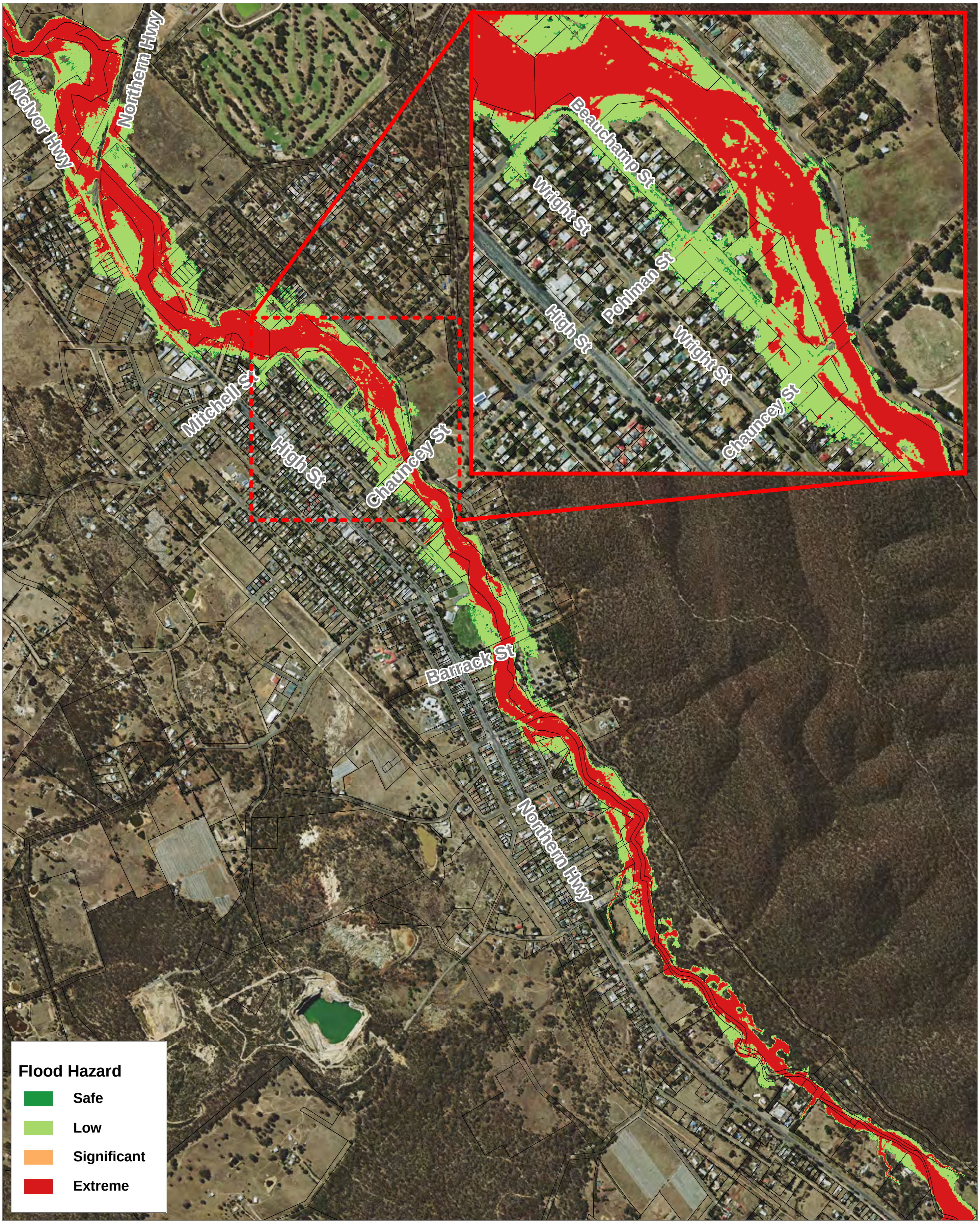

Title:

Heathcote Flood Study
5% AEP Flood Hazard

Figure:
8-9

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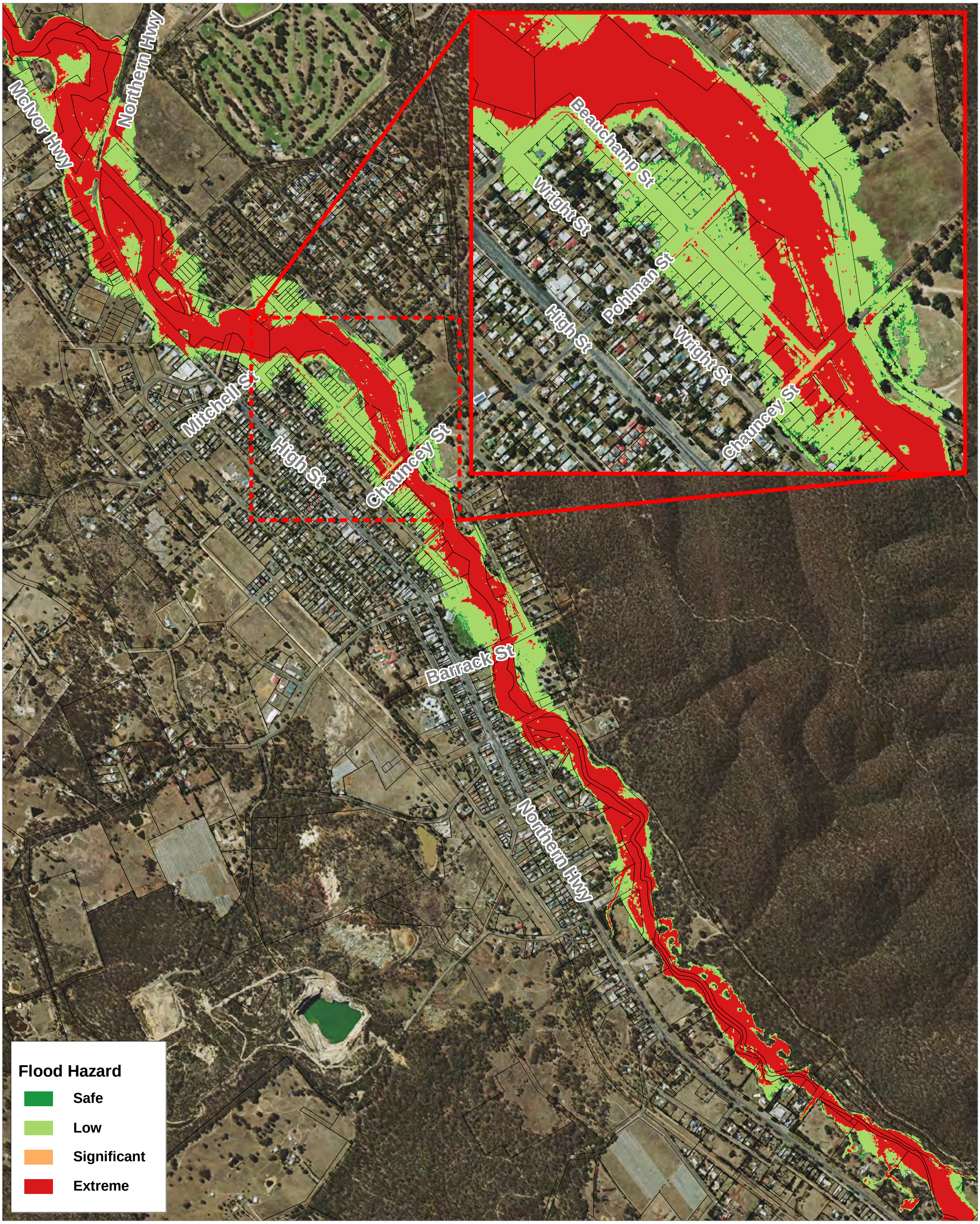

Title:

Heathcote Flood Study
2% AEP Flood Hazard

Figure: 8-10

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Approx. Scale

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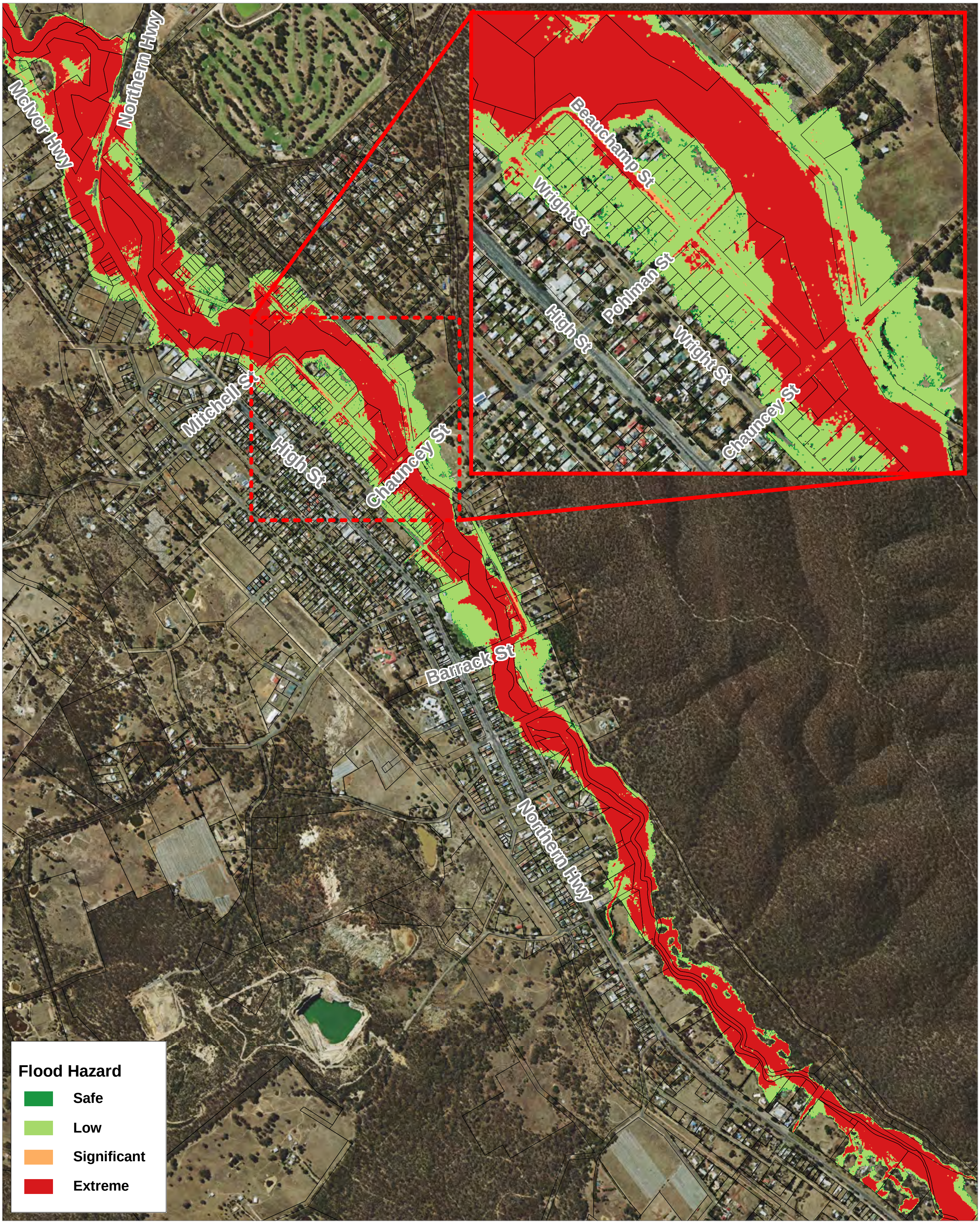

Title:

Heathcote Flood Study
1% AEP Flood Hazard

Figure: **8-11**

Rev: **A**

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

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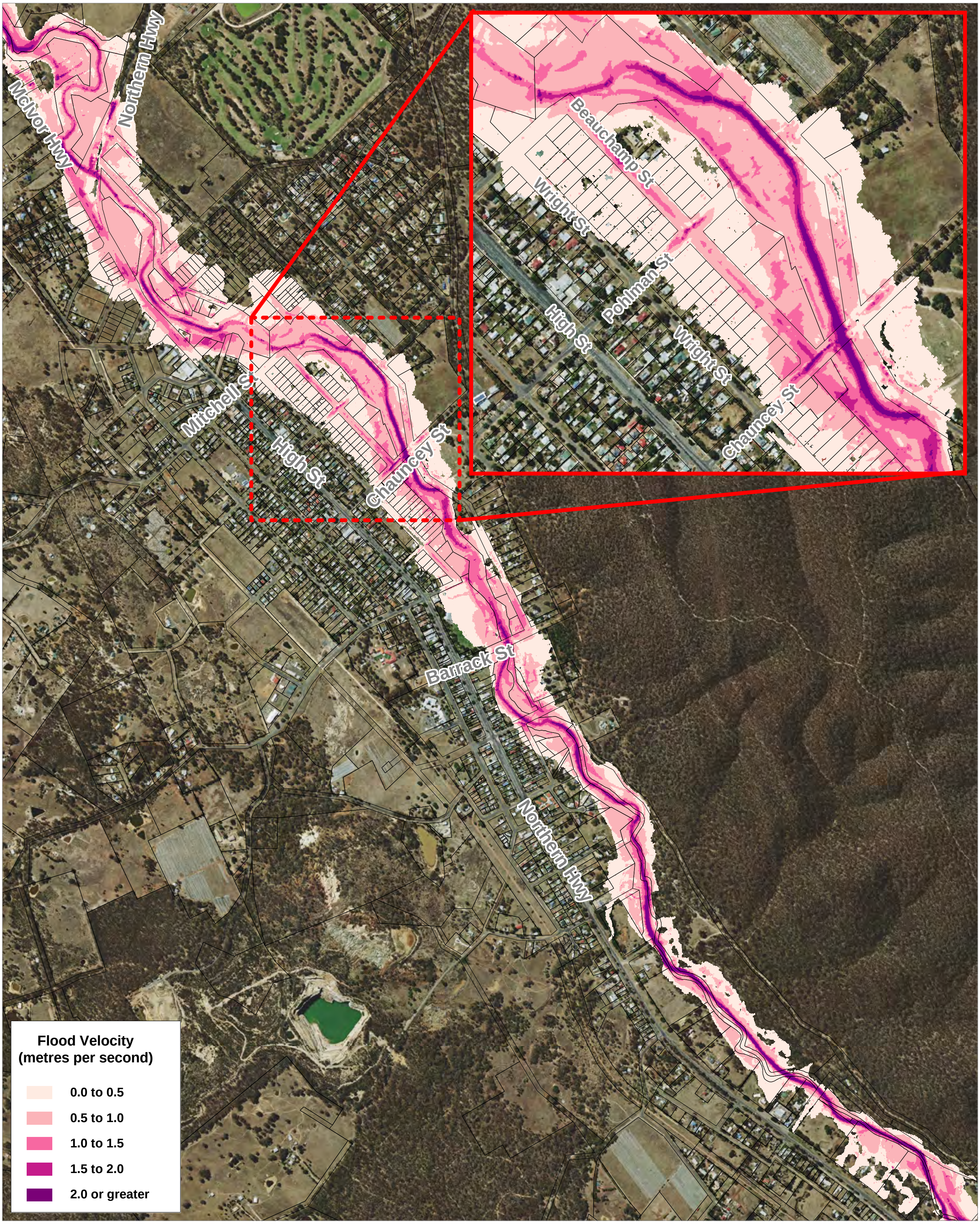

Title:

Heathcote Flood Study
1% AEP Flood Velocity

Figure: 8-12

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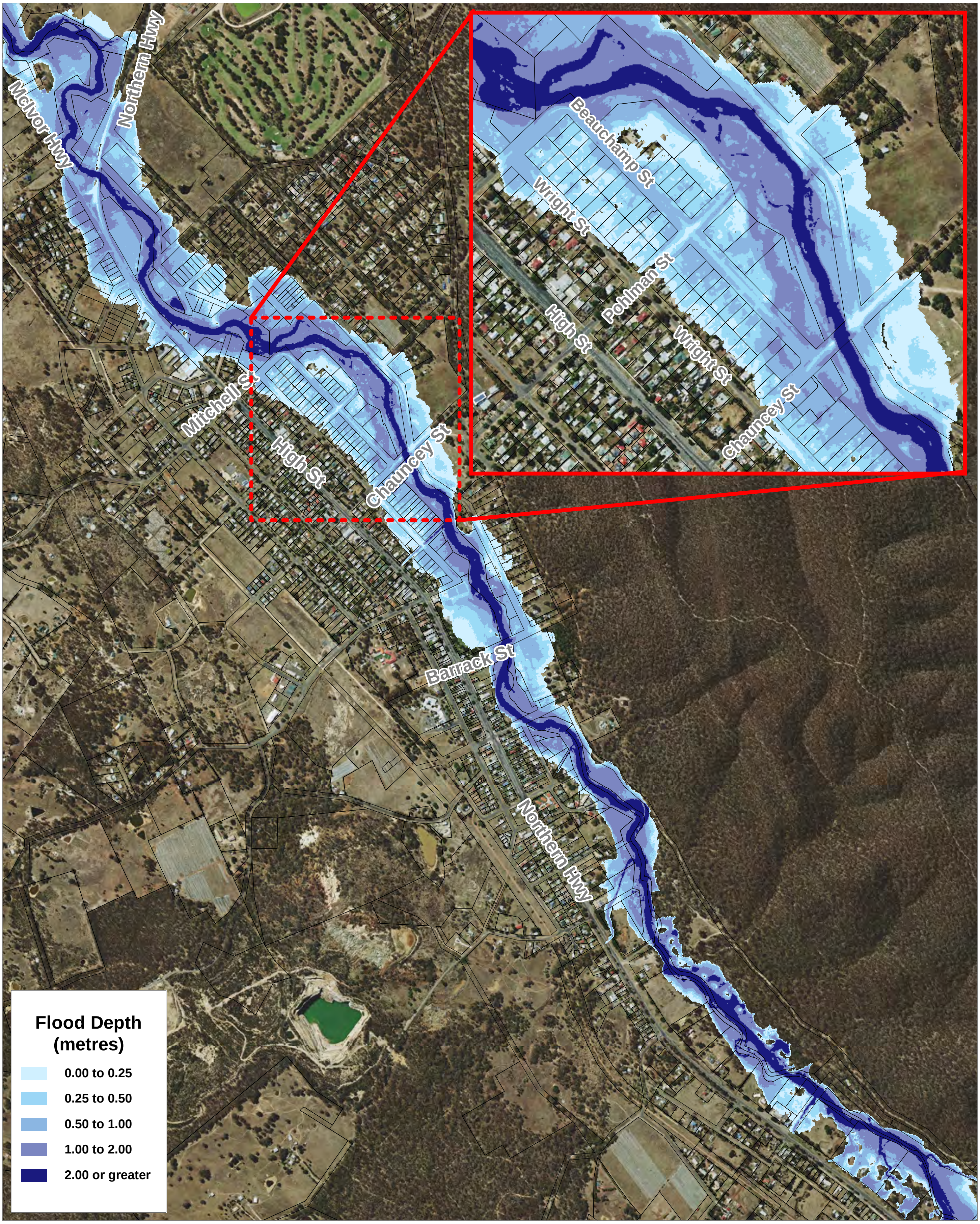
8.4 Climate Change Sensitivity

Climate change sensitivity modelling was undertaken for the catchment for increased rainfall intensities of 20% for the 1% AEP flood event, the results of which are presented in Figure 8-13. For details on the adjusted parameters refer to Section 5.6.3.

The purpose of this analysis will allow planners to gain an understanding of the potential impact that climate change could have on the study area and make future decisions accordingly. In general, the scenario shows similar flood extents to the 0.5% AEP existing condition, however, the depths are slightly greater.



Title:
Heathcote Flood Study
1% AEP Flood Depth - Climate Change

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9 Flood Damages Assessment

This Section addresses Key Objective 2 of the Study, specifically the characterisation of the existing flood risk and hazard to Heathcote.

9.1 The nature of flooding

At Heathcote, there are a good number of residential and commercial properties located on the well-defined floodplain of McIvor Creek. While flooding is extensive in many of the developed areas of the town, it is generally shallow. Velocities are highest in the main stream channel (greater than 2m/sec) and somewhat lower (between about 0.5m/sec and 2m/sec) along the main flow paths and roads. Flow velocity through properties is typically low at less than 0.5m/s. Hazard is low away from the main flow paths.

During the 20% AEP event, the Northern Highway (High Street) is wetted to a depth of around 250mm to the north west (towards Bendigo) of Mitchell Street from creek breakouts near Clouston Court and opposite Boomerang Place. The initial section of the McIvor Highway is also wetted to a similar depth.

As flood severity increases, breakout flooding occurs along Beauchamp Street, upstream of Chauncey Street and downstream to Mitchell Street.

Flooding across both Highways to the north west of Mitchell Street is more established and deeper during a 10% AEP event with the result that both would probably need to be closed due to excessive depth (see January 2011 photo in Table 6-4). Travel to the north west (e.g. Bendigo) and north (e.g. Elmore) would still be possible but would need to be initially via the Heathcote – Kyneton Road and the Heathcote – Nagambie Road respectively.

While flood water does sit alongside the northern edge of the Northern Highway from near the town side of the Heathcote – Nagambie Road intersection from a little below the 2% AEP event, for all events up to and including the 0.5% AEP event, flood water only crosses the Highway to the north west (towards Bendigo) of Mitchell Street.

In Heathcote, 14 properties are flooded close to the buildings by the 10% AEP event with the first property flooded in Thomas Street. There are also 3 houses within 100mm of flooding over-floor: 2 in Thomas Street and 1 in Pohlman Street.

The VICSES depot is within 100mm of being flooded during a 2% AEP event. In the 1% AEP event most of the area downstream (to the north west) of Barrack Street between Wright Street (initially and then High Street) and McIvor Creek is flooded. This area has 109 properties, including the VICSES depot building. Of these 109 properties, 24 are flooded over-floor and a further 17 floors are within 100mm of being wetted.

Essential community infrastructure, such as the McIvor Medical Centre, the CFA, Ambulance and Police stations, Council offices, the Community Centre and the Primary School are not affected by flooding up to at least the 0.5% AEP event. While the swimming pool is similarly unaffected, facilities at the Tennis, Bowls, Angling and Football clubs are affected from around the 2% AEP event. Parts of the Queens Meadow Caravan Park are inundated from a little above the 10% AEP event. In the 5% AEP event, there is a breakaway flow through the park towards the portable cabins on Barrack Street with approximately half the site inundated to some extent in the 2% AEP (50-year ARI) event with one property flooded over-floor. Additional over-floor flooding occurs as flood severity increases.

While there are a number of creek crossings, the study has shown that partial blockage of culverts and bridge openings (up to 50%) generally have little impact on adjacent flood levels. For example, partially blocking the Northern Highway Bridge increases upstream levels by up to about 120mm whereas blocking the Chauncey Street Bridge increases upstream levels by up to around 200mm across the reserve and at a number of nearby properties.

The fords at Barrack Street and Robinson Street are inundated by quite frequent floods with depth of greater than 1m experienced in the 20% AEP (5-year ARI) event. During larger floods, access to the properties on the northern side of the creek becomes difficult as:

- The Northern Highway is likely to be impassable from between the 10% (10 year ARI) and 5% (20-year ARI) AEP events;
- Chauncey Street is likely to be impassable from between the 10% (10 year ARI) and 5% (20-year ARI) AEP events; and
- While access via the Heathcote - Nagambie Road and then Forest Drive may be possible up to somewhere between the 2% (50 year ARI) and 1% (100-year ARI) AEP events; and via fire tracks through reserve land up to and including the 0.5% AEP (200-year ARI) event, local drainage may make local roads and tracks impassable[4].

9.2 Damages caused by flooding

The damages caused by flooding can involve both the direct and indirect impacts. These impacts are further considered tangible (easily quantified) or intangible (difficult to quantify). Within this assessment of flood damages, we have only considered tangible direct and indirect impacts, which is appropriate for this feasibility level of assessment.

9.2.1 Approach

Damages have been assessed for the 20%, 10%, 5%, 2%, 1%, and 0.5% AEP flood events. The damages assessed are:

- Damage to residential buildings (structure and contents)
- Damage to commercial and public buildings (structure and contents)
- External property damage
- Indirect damages (e.g. evacuation, clean-up, and production losses).

A loss probability curve was produced to enable the calculation of annual flood damages (Figure 9-1). Large damages from low probability events are combined with lower damages from more frequent flood events and annual average damage (AAD) is calculated.

[4] Local drainage issues were not modelled as part of this project.

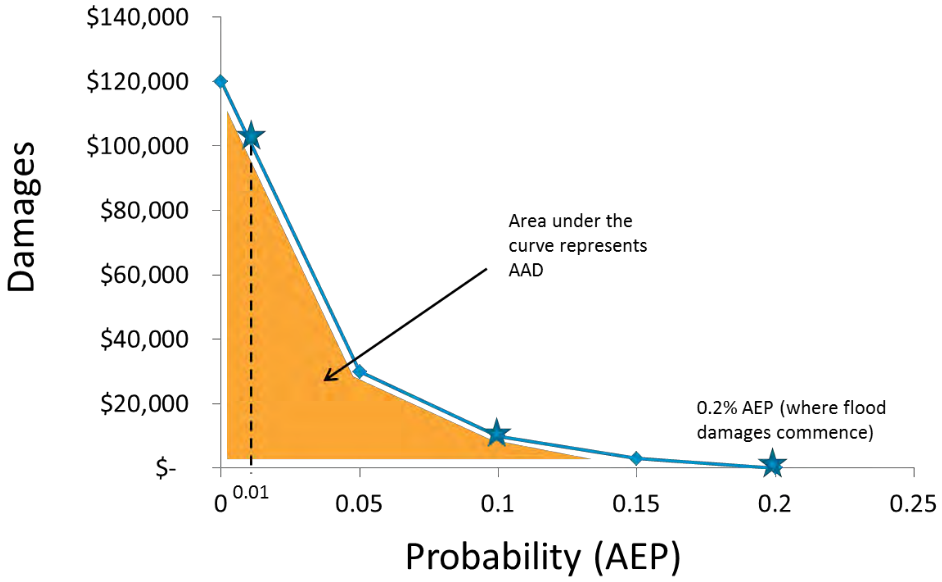


Figure 9-1 Loss probability curve used for calculating AAD

9.2.2 Assumptions

The damage assessment included the following assumptions:

- Residential damages were calculated using the OEH depth damage curve for single story low set buildings and single story high set buildings.
- Commercial and community building damages were calculated using US Federal Emergency Management Agency (FEMA) depth damage curves. These depth damage curves plot damage as a percentage of building replacement value (BRV).
- The building replacement value for commercial and community buildings was calculated at $200,000 based on an assumed building footprint of 200 m^2 and average building costs of $1,000/$m^2$ (Rawlinsons Construction Handbook).
- Indirect damages were included at 25% of direct damage to buildings.
- The ratio of actual to potential damages was estimated at 0.9, which assumes <2 hours of flood warning time.

9.3 Findings

These assumptions were used to estimate the costs of flooding in Heathcote shown in Table 9-1.

Table 9-1 Summary of flood damages in Heathcote

Likelihood of flooding	Number of Flood Affected Buildings	Number of Buildings Flooded above Floor level	Estimated Potential Damages ($ million)
0.5% AEP	129	49	$5,259,000
1% AEP	109	24	$3,602,000
2% AEP	70	12	$2,236,000
5% AEP	34	6	$957,000
10% AEP	14	0	$275,000
5% AEP	0	0	$0
AAD (potential)			$170,000
AAD (actual)			$153,000

10 Floodplain Management for Heathcote

This Section and the following Sections of the report document the Floodplain Management Plan for Heathcote and presents the tasks undertaken to meet Key Objective numbers 3, 4 and 5 outlined in Section 1.6. These Sections are outlined in Section 10.2. The Heathcote Study Process is presented in Figure 10-1.

10.1 Floodplain Management Plan Process

The process adopted for the Heathcote Flood Study to manage the risk of flooding is shown in Figure 10-1. This floodplain management process has been adapted from *The Victoria Flood Management* Strategy (DNRE 1998) and is consistent with the approaches adopted throughout Australia as documented in *Floodplain Management in Australia Best Practice Principles and Guidelines* (CSIRO 2000).

10.2 Floodplain Management Section Layout

The following Sections have the following structure:

- Section 10 - Floodplain Management for Heathcote (this Section)
- Section 11 – Flood Warning Systems
- Section 12 – Planning Controls
- Section 13 – Flood Response Plan
- Section 14 – Community Awareness
- Section 15 – Floodplain Management Plan

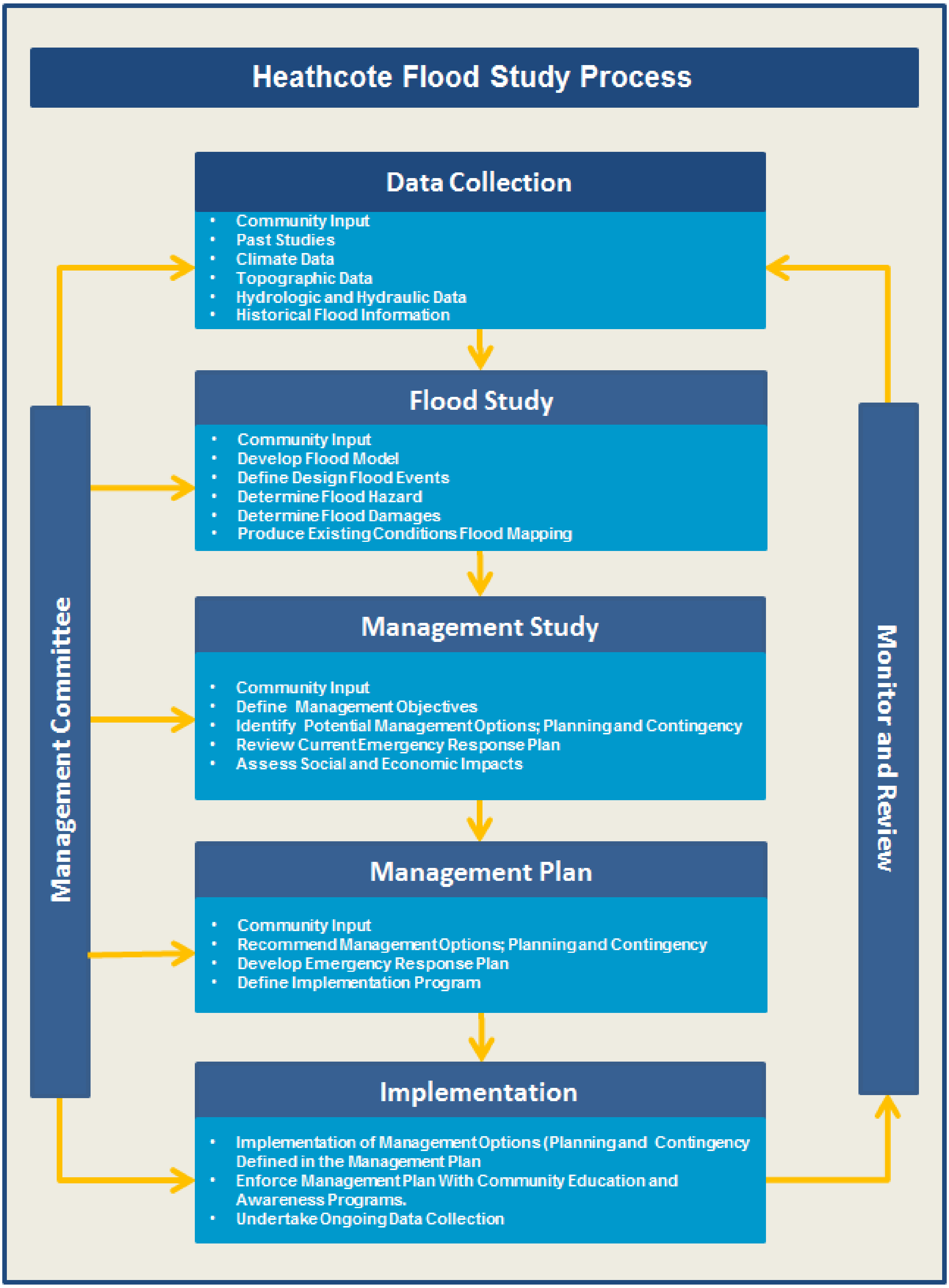


Figure 10-1 Flood Management Plan Process

11 Flood Warning Systems

Heathcote has a population of around 4,000 and is situated approximately 40km south-east of Bendigo. The town straddles McIvor Creek (see Figure 1-2) and currently there is no flood warning systems or arrangements in place for the McIvor Creek catchment or for Heathcote.

The McIvor Creek catchment is described in more detail in Section 1.3 of the study report. A brief history of past floods is also provided in those volumes.

11.1 Flood Risk in and Around Heathcote

Heathcote has a long history of flooding as described in Section 1.5; however, the largest flood in recent memory (assessed as being around a 3% AEP (30-year ARI) event occurred at Heathcote in May 1974[5].

Floods generally occur at Heathcote during the spring and summer months as a result of local heavy rain. Rises usually begin between 3 and 6 hours from the start of rain but can be delayed by up to 10 hours. Rises are rapid with the peak generally occurring between 10 and 12 hours after the start of rise. The size of the flood does not appear to drive the rate of rise but a second flood on a wet catchment does rise a little quicker. Timing can be as short as 8 hours from start of rise to peak.

There are a number of differing views on what constitutes flash flooding; from temporary exceedance of urban stormwater drainage system capacity through to large and very rapid rises in both rural and urban streams, sometimes as a result of urban stormwater being discharged to the stream. The trigger for flooding is considered to be essentially the same – high intensity short duration rainfall emanating from severe thunderstorms or rain bearing weather systems that are locally intense and slow moving.

A flash flood is defined in Australia as a flood that occurs within about 6 hours of the start of the rain that causes it (BoM, 1996). The source of flooding, whether the result of urban stormwater system capacity constraints or overflow from a watercourse, is not addressed by the definition: the key issue is time between cause and effect.

In view of the above definition and typical response times as determined by the Heathcote Flood Study, it is suggested that Heathcote probably falls within, or certainly very close to, the flash flood category.

11.2 Opportunities to Mitigate Flood Risk

With the shift to a risk based approach to floodplain management within Australia, emphasis has moved from the implementation of structural solutions for flooding to 'softer' non-structural solutions. These solutions recognise the value of floodplains and their processes as well as the economic and social benefits that flow from their development. The emphasis now is on modifying how floodplains are developed (i.e. the human interface) rather than on modifying the floodplain so that it can be developed.

5 The stream gauge at Derrinal (406226) was installed in 1978, sometime after the May 1974 flood.

The value of floodplains to the community and to State and National economies is well recognised in Australia (e.g. DNRE, 1998; EMA, 2009; ARMCANZ, 2000). It is also recognised that the benefits that flow from the use and habitation of floodplains come at some costs. The challenge is to reduce those costs while maintaining the benefits: in effect to make it easier for communities to live with flooding.

Effective flood warning systems in conjunction with (perhaps) physical mitigation measures, a regime of appropriate land use management practices and instruments and the necessary emergency management measures are increasingly being recognised as representing good practice. It is the totality and proper mix and balance of measures that effectively contain the negative consequences of flooding. Appropriate flood warning practices are a vital ingredient within that mix.

A review of the floodplain in Heathcote indicates that opportunities to reduce the risk of flooding at Heathcote through the implementation of structural measures are limited. Flood warning, however, offers opportunities to reduce flood related damages and flood related risk to personal safety.

The five key flood related issues for the town:

- The speed with which floods develop and propagate within the McIvor Creek catchment, particularly when the area is wet;
- The hazard associated with deep fast flowing water over the low level creek crossings with the town from quite frequent flood events;
- Flooding of properties within Heathcote;
- Over-floor flooding of buildings; and
- The hazard caused by floodwater flowing at depth over the Northern and McIvor Highways.

A formal flood warning system does not currently exist for Heathcote. There are no stream gauge records (past or present) available for the town or upstream. The nearest (and only) downstream gauge is located at Derrinal (406226), a short distance upstream from Lake Eppalock on Mt Ida Creek and downstream of the confluence of Mt Ida Creek and McIvor Creek. Further, there are no telemetered rain gauges operated by the BoM or other agencies, within the general vicinity of Heathcote

A Municipal Flood Emergency Plan (MFEP) that includes intelligence on flood impacts within the Heathcote study area (i.e. from upstream of the Heathcote - Nagambie Road to the Mt Ida Creek streamflow gauge at Derrinal) has been prepared for the City of Greater Bendigo as part of this study.

11.3 Flood Warning Systems

11.3.1 Aim and Function

Flood warning systems provide a means of gathering information about impending floods, communicating that information to those who need it (those at risk) and facilitating an effective and timely response. Thus their development involves far more than the installation of a data collection network, implementation of a forecast tool and the forwarding of predicted flood levels and times to key agencies and / or the at-risk communities. Well-developed mechanisms for establishing and maintaining flood awareness are also required so that the at-risk communities appreciate the likely impact of flooding and are capable of an appropriate response. Key to that aspect is the availability of authoritive flood risk and inundation information / mapping together with a clear understanding of the likely impacts of flooding across the full range of possible events. They aim to enable and persuade people and organisations to take action to increase personal safety and reduce the damage caused by flooding[6].

The 'flood warning coupled with flood awareness and preparedness' theme is reiterated in BTRE (2002) where it is stated (p. 69) that "*Community awareness and preparedness together with reliable and timely flood warning systems play an important role in the success of (flood) mitigation (activities)*." The theme is also present in the list of principles for the application of early warning at national and local levels introduced and discussed in UN (1997).

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

11.3.2 The Total Flood Warning System Concept

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

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

cooperation and coordination of a range of agencies, organisations and the community" (DoTARS, 2002).

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

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

11.3.3 Total Flood Warning System Building Blocks

An effective flood warning system is made up of several building blocks. Each building block represents an element of the TFWS. The blocks (derived from EMA, 2009) along with the basic tools to facilitate delivery against each of the TFWS elements are presented in Table 11-5.

It is essential that the basic tools against each of the building blocks are appropriately developed and integrated. Such a system considers not only the production of a timely alert to a potential flood but also the efficient dissemination of that alert to those, particularly the threatened community, who need to respond in an appropriate manner. A community that is informed and flood aware is more likely to receive the full benefits of a warning system.

It follows therefore that, actions to improve flood response and community flood awareness using technically sound data (such as produced by this study) will by themselves result in some reduction in flood losses.

11.4 Developing a Total Flood Warning System for Heathcote

If an effective flood warning system is to be established for Heathcote, attention will need to be given to each of the TFWS building blocks. Installing rain and / or river gauges will not be sufficient. Practical information on what to do in response to rapidly developing flooding is critical (Environment Agency, 2009). It is important that attention is paid to issues of risk communication including:

- Building local awareness of flood risk along with knowledge of what can be done to minimise that risk;
- Determining what information is required by the at-risk community and with what lead times;
- How warnings and required information will be distributed to and within the at-risk communities;
- Ensuring that recipients of warning messages understand what the message is telling them and what it means for their property and individual circumstances in terms of the damage reducing actions they need to take.

The following sections outline how each of the TFWS elements could be addressed in order to implement a cost-effective, functional and sustainable flood warning system for McIvor Creek at Heathcote.

A summary of roles and responsibilities against each of the TFWS building blocks is provided as Appendix E.

11.4.1 Limitations

Flood warning systems are, by their very nature, complex. They are a combination of technical, organisational and social arrangements. To function effectively they must be able to alert the at-risk communities to coming floods and their severity in ways that are understood and which result in appropriate flood damage reducing behaviours (for example, to protect assets or to evacuate out of the path of the floodwater).

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

- To building a local awareness of flood risk along with knowledge of what can be done to minimise that risk;
- Determining what information is required by the at-risk community and with what lead times;
- How warnings and required information will be distributed to and within the target communities; and
- Ensuring that recipients of warning messages understand what the message is telling them and what it means for their property and individual circumstances in terms of the damage reducing actions they need to take.

The lessons from the above are that:

- Many flood warning systems have an inbuilt likelihood of failure, most often due to inadequate conceptualisation and an imbalance in the attention given to each of the TFWS elements;
- All elements of the system must be given appropriate attention (and resourcing) if the system is to be made capable of functioning effectively;
- People in flood liable areas need to be helped to build an understanding of flood risk and what the data is telling them in the lead up to and during a flood event (i.e. the gap between the information provided and what is understood needs to be minimised);
- There is no single or suite of off-the shelf solutions (each system needs to be appropriate to the circumstances);
- Systems (and investments in their implementation) that over-emphasise the collection of input data (i.e. flood detection) and / or the production of flood forecasts relative to the attention given to other elements (such as warning dissemination, the information provided in the warning

messages, local interpretation and response, and the education of flood prone communities about floods and flood warnings) will fail to fully meet the needs of the at-risk communities they have been set up to serve.

11.4.2 Data Collection and Collation

There is a variety of equipment available that will “collect” rain and river level data and make it available to a single entity or to a group of entities, either from the site, through a post box, via the cloud or delivered to a predetermined address. There are a number, but fewer, systems that collect the data, make it available in the desired format at the desired location(s), provide an alert of likely flooding (i.e. detect or predict the likelihood of flooding) after checking the data against pre-determined criteria and that also quality check and collate the data so that it is ready for use. Some of these systems are “turn-key” [7] while others are user built. All are modular in that fault-fix maintenance is generally via component plug-out / plug-in and expansion easy to achieve. There are costs (e.g. capital, installation and on-going) associated with all approaches.

An alternative approach is evident in open source systems such as “Weather Underground” or “WeatherLink”. These cloud based open systems allow registered users to load weather information, including rainfall data, in real-time. The data is then displayed for any internet users to see. This provides a very cheap and easy means of collecting, collating and sharing rainfall data albeit without the rigour or quality assurance that is attached to more mainstream data collection systems.

Existing Data Collection Network

There are no telemetered creek level or rainfall monitoring stations within or near the McIvor Creek catchment at or upstream of Heathcote. The nearest telemetered rain gauge (a BoM AWS) is at Redesdale.

Possible New Data Collection Sites

Ideally, up to three (3) rain gauges would be installed or providing data. While exact locations have not been determined, it is suggested that gauges in the general vicinity of:

- The first 5km of the Heathcote – Nagambie Road and the Heathcote – Costerfield Road (Rainfall Location 1 Figure 11-1);
- 5km kilometres either side of the Northern Highway between Tooborac and Heathcote (Rainfall Location 2 Figure 11-1); and
- Tooborac / Yellow Hammer Hill / Mt Koala (Rainfall Location 3 Figure 11-1).

This distribution of rain gauges would give adequate coverage of the spatial and temporal distribution of flood producing rain.

If installed, only one (1) stream gauge would be required. Ideally, this would be located immediately upstream of the Barrack Street ford or perhaps on the upstream side of the Chauncey

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

Street Bridge. An alternative but less desirable location would be on the upstream side of the Northern Highway Bridge at the downstream (Bendigo) end of town.

It is noted that a staff gauge (0 to 2m) is located on the downstream edge of the ford at Barrack Street and at Robinson Street.

It is also noted that a rain gauge, located about 3km along the Heathcote – Nagambie Road, is already registered on Weather Underground.

Favoured Approach

A variety of equipment and systems have been considered for Heathcote. A summary of these considerations is provided in Appendix F.

While not the most robust solution, the favoured approach for Heathcote is a number of registered local rain gauges with data uploaded to Weather Underground. Rain gauge owners will need to be recruited to the flood warning system. Guidance on how to register as a data provider and how to access the data will need to be developed and made available to the community along with guidance on how to translate the raw rainfall data provided into flood potential, in terms of likelihood and severity. The latter will need to be easy to understand, but be sufficiently technically rigorous to enable the interpretation and use of available data[8] to determine a consistent appreciation of the event.

Council will also need to consider whether rain gauge readers would be formally engaged or whether their involvement is left as an informal arrangement. The former would impose obligations on both parties while the latter would need to have regard for potential legal issues.

A PALS site has also been identified (and its position identified on the flood inundation maps for Heathcote as well as in the MFEP). This site could be either instrumented with a PALS ahead of an expected severe event or Council could install either a set of staff gauges to be read by (say) VICSES during flood events or a DipStik gauge (see Appendix F) reporting to Council, local VICSES and a small number of key local persons[9]. DipStik rainfall data could also be loaded to Weather Underground if the site(s) was / were registered and a person assigned to upload data as it became available.

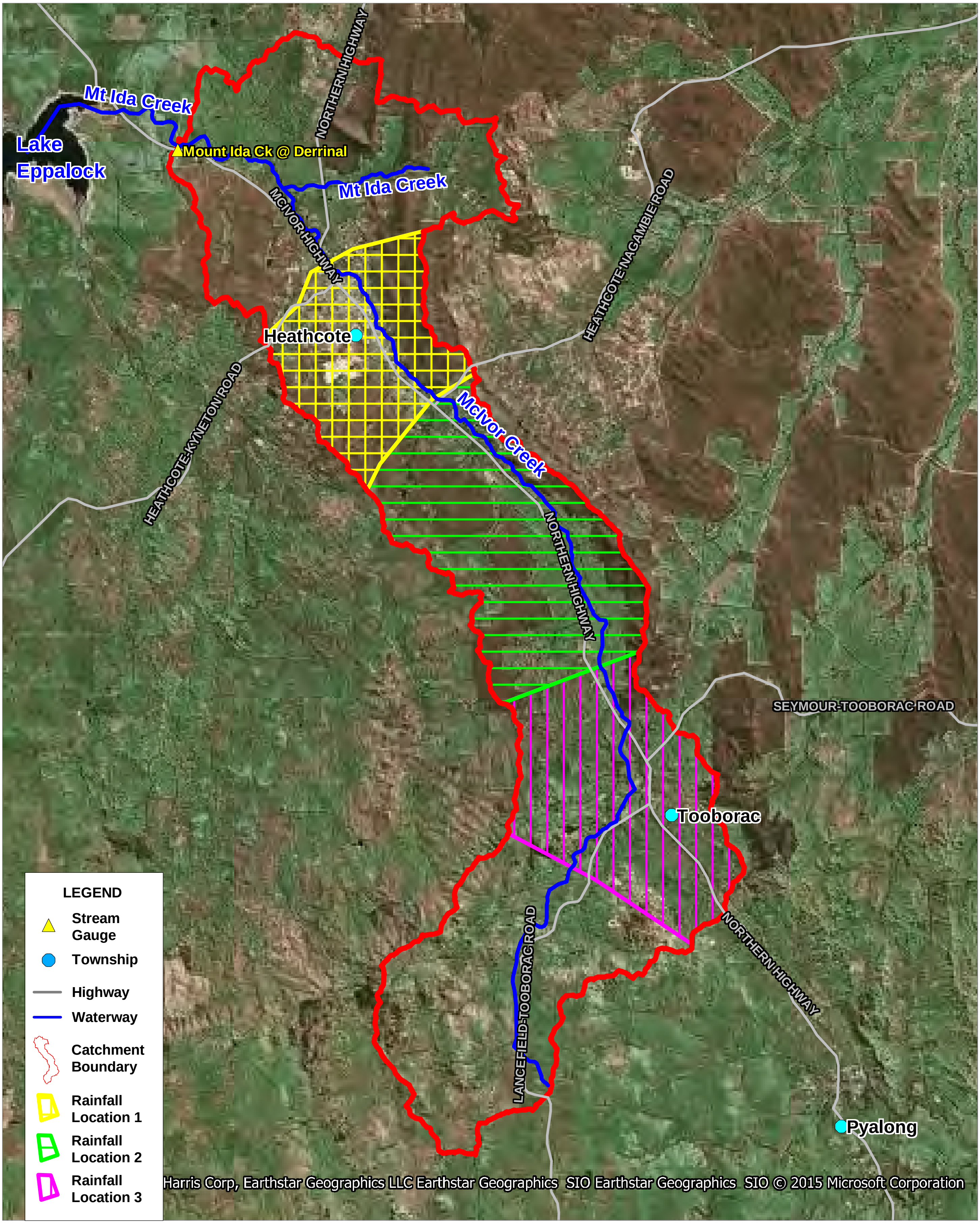
The existing staff gauges (0 to 2m) at the fords at Barrack Street and Robinson Street should be retained and read during flood events. Levels should be related to consequences in and around Heathcote as the event progresses and loaded to the MFEP post-event. Data from these two sites would also aid post-event analyses[10].

Note that even without the initiation of the proposed rain gauges, the indicative quick look "flood / no flood" tool developed as part of this project (refer to Appendix C2 of the MFEP) will be able to be used during general rain events. The Redesdale AWS (see Figure 2-2) provides data, available on a 3-hourly basis from the BoM website, that when used with the tool will provide an initial heads-up with some lead time of the likelihood and scale of possible flooding within the catchment.

8 Guidance will need to address use of data recorded at each of the rain gauges over different time periods.

9 A DipStik gauge installed at each of the fords across McIvor Creek within Heathcote could be set to initiate (say) a flashing light (or boom gate?) either side of each ford whenever flows across the ford reached levels considered unsafe for a crossing vehicle. This would reduce risk to life within Heathcote and substantially reduce Council's risk and liability profile.

10 Post-event ground survey of flood extents also informs post-event and other analyses.



Title:

Heathcote Flood Study
Indicative Rain Gauge Locations

Figure: 11-1

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11.4.3 Flood Detection and Prediction

An overview of flood warming services provided within Victoria by the BoM is available at Appendix G.

As discussed in Section 11, there are currently no flood warning systems or arrangements in place for the McIvor Creek catchment or for Heathcote. While it could be argued that the catchment is not subject to flash flooding, it is suggested that there are benefits in approaching the development of a TFWS for Heathcote as if it is (see Section 11.1). This effectively gives Council a lead role in the development, operation and maintenance of the TFWS. This includes flood prediction.

Normally and as part of a comprehensive forecasting capability, a rainfall – runoff model that makes use of rain and river data telemetered from each of the proposed data collection sites would be proposed[11]. However, opportunities to run a rainfall-runoff model to predict future levels within McIvor Creek are limited without access to telemetered (i.e. near real-time) data.

Other approaches to flood forecasting have used measured and predicted rainfall to determine an input field (in terms of IFD) and then matched the rainfall to a flood profile (e.g. extent, depth, velocity, hazard) determined from the predetermined design event flood mapping.

A GIS based forecasting approach[12] might have application for Heathcote, if telemetered rainfall data was available.

It is noted that DELWP is currently working on the development of a flood mapping access and enquiry tool, FloodZoom. It is possible that FloodZoom may offer some scope for the City of Greater Bendigo to utilise it to assist flood prediction capacity.

Favoured Approach

Regardless of the above, as a first step it is suggested that the indicative quick look 'flood / no flood' tool located in Appendix C2 of the MFEP should be made available to the Heathcote community. The tool provides some guidance on the likelihood and possible severity of flooding at Heathcote using near real-time rainfall data obtained from the Weather Underground (or WeatherLink) website[13]. Rainfall depths from across the catchment are used in the tool to determine the likelihood and approximate severity of flooding through a link to the flood inundation maps delivered as part of the Heathcote Flood Study. It is suggested that the inundation maps, quick look tool and associated instructions for their use should be loaded to the City of Greater Bendigo website where they can be accessed and used by the area's residents.

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11 Rainfall – runoff models use measured and / or predicted rainfall to provide a prediction of flow and gauge height at one or more key locations. A stream gauge is generally required at each forecast location so that initial conditions can be fed into the model and the forecast hydrograph (or levels) can be tracked against the actual stream response in terms of timing and levels. Forecast levels then need to be translated into areas affected. This can be done through a linked hydraulic model or through reference to comprehensive flood inundation maps.

12 Rainfall data from each gauge would need to be assessed in real-time against IFD criteria (i.e. looking at the intensity and return period of recorded rainfall over a range of durations around the critical durations as determined by the study) and then matched up against the inundation mapping. Using the areal extent as a trigger, the GIS could then extract the addresses of properties and / or other assets likely to be flooded over-floor along with the names / locations of streets likely to experience high hazard flooding (i.e. where the velocity – depth product is (say) greater than 0.3). There are many commercial systems that can provide this kind of real-time hydrological analysis, flood risk assessment, visualisation of results and message dissemination.

13 While an alternative approach could be to use predicted rainfalls obtained from the BoM website, the uncertainty associated with those predictions would substantially decrease the confidence that could be attached to the results from the tool.

Flood class levels, determined against standard definitions[14], are used to establish a degree of consistency in the categorisation of floods. In order to assist the flood warning process and increase awareness of flooding within the community, particularly if a stream gauge is installed at Heathcote (perhaps at the PALS site) or the staff gauges at the Barrack Street and Robinson Street fords are included more formally into the TFWS, consideration should be given to establishing flood class levels for these sites.

11.4.4 Interpretation

The flood inundation maps and MFEP Appendices developed as part of the Heathcote Flood Study provide the base information to enable the community (and stakeholder agencies) to determine the likely effects of a potential flood. This means, however that the flood inundation maps and relevant MFEP Appendices would need to be readily available to the Heathcote community. A lack of ready availability would severely compromise the proposed TFWS.

Flood intelligence gained from staff gauge levels at the fords at Barrack Street and Robinson Street linked to local consequences and available within the MFEP, will assist local interpretation and the determination of likely flood impacts during future events.

11.4.5 Message Construction and Dissemination

There are a number of alerting and notification tools, technologies and service providers available, some of which both alert (make people aware of an imminent hazard) and notify (provide a warning message). A summary of those considered as part of this project has not been included as the proposed approach does not include the construction and / or dissemination of formal messages.

It is likely that for most Heathcote residents, the initial alert of likely flooding will come from environmental indicators (i.e. heavy rain) and from application of the quick look “flood / no flood” tool (i.e. likely severity and impact of expected flooding). The message in relation to likely consequences and required actions will be as derived by the individual as a result of their consideration of information provided by the tool, the MFEP and the flood inundation maps.

There may however be a need to alert the Heathcote community to the likely on-set of flooding and to then back this up with information about the likely consequences. This will encourage individuals to initiate appropriate damage reducing actions. Initially this could be done via social media, perhaps via a Twitter and / or Facebook account[15] established for the Heathcote TFWS.

It is generally recognised that a critical issue in developing and maintaining locally based flood warning system is the active and continued involvement of the flood-liable community in the design and development of the total system so that their warning needs are satisfied. It is therefore suggested that the City of Greater Bendigo give strong consideration to championing the formation of a Heathcote community flood action group (or similar).

Members of this group could play a key role in local flood warning operations and review. In particular, through a telephone tree, Facebook and / or Twitter account (i.e. social media), they

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

15 A UK firm, Shoothill, has developed a tool called GaugeMap, that presents river level data tweeted from water level sensors at set time intervals. Further, people are able to subscribe to tweets from specific gauges. While the concept could not be applied at Heathcote in the short term, the concept could be considered for a later upgrade.

could share information initiated within the community and by VICSES on likely flood severity, impacts and appropriate actions.

11.4.6 Response

The Bendigo MFEP Appendices have been populated for the McIvor Creek catchment at Heathcote as part of the Heathcote Flood Study. Information in the MFEP includes all available intelligence relating to flooding in the catchment along with an indicative quick look “flood / no flood” tool based on rainfall depths across the catchment. Instructions for the tool’s use have also been included. Flood inundation extent and depth maps have been added together with a list of areas and roads likely to be flooded. A table of properties and key infrastructure likely to be flooded along with the expected depth of flooding (over-ground and over-floor) at each property is also included along with a flood intelligence card for the town.

11.4.7 Community Flood Awareness

Activities that emphasise personal safety and that provide information on how the TFWS works, where data is available, how that data can be used, what people can do what any alerts mean and what individuals should do to stay safe and protect their property should be initiated to develop, maintain and renew flood awareness within the Heathcote community.

11.5 Evaluation of TFWS Options

With increasing focus on non-structural flood mitigation measures and increasing calls for assistance in establishing flood warning systems, there has been a shift to a more rigorous assessment of the need and level of development required for such systems. This is aimed at matching the flood warning system to the level of risk in essentially the same way that the utility of any proposed structural works in reducing flood related damages is assessed. The costs and benefits of options are compared to determine whether options are economically justified, and the justification for cost sharing by beneficiaries.

Within this section we discuss and evaluate five options that are proposed for Heathcote. From this evaluation, a preferred option is identified.

11.5.1 The “Do Nothing” Case

As discussed in Section 11, there is currently no flood warning systems or arrangements in place for the McIvor Creek catchment or for Heathcote. Further, the last flood of any significance (see Section 11.1) occurred in January 2011 and had an estimated AEP of around 14% (approx. 7-year ARI). The largest flood in recent memory occurred in May 1974 and was assessed as being around a 3% AEP (30-year ARI) event. Flood experience in Heathcote is not high. It would be reasonable, therefore, to suggest that flood awareness and preparedness are similarly not high. Coupled with the relatively short catchment response time and the speed with which floods develop and propagate through Heathcote, response is likely to be largely reactionary with limited preparation ahead of damage occurring.

There are no specific TFWS costs associated with the “do nothing” case. Benefits of any preparatory work are likely to be minimal.

11.5.2 The "Essential" Case

The essential case is a system that has regard for each of the TFWS elements and is heavily biased towards local involvement at minimum cost. Local community resilience[16] is an essential ingredient to such a system. Council has a lead role in championing and driving system development.

The "base" case essentially comprises the "favoured approaches" detailed in Section 11.4 above: community owned and operated rain gauges with data shared through an open source cloud based system in near real-time. It also includes a rain – river DipStik gauge. Other TFWS elements are addressed at a similar community level. Capital costs are low and the need for involvement by agencies outside the immediate area is also low.

The "base" case TFWS will provide Heathcote area residents with access to local rainfall data which will be able to be used to determine the likelihood and scale of possible flooding within the town. Using the inundation maps delivered by the Heathcote Flood Study together with the Flood Information Card and property inundation tables available from the Bendigo MFEP, residents will also be able to determine likely impacts and consequences at the property level and more generally across the area. While for most floods there will be no mass alerting or public issue warnings, benefit for residents over the "do nothing" case will be:

- Easy access to relevant rainfall data;
- An ability to estimate the likelihood and scale of possible flooding;
- Easy access to guidance on likely impacts and consequences;
- Opportunity for a more timely and targeted response to likely flooding; and
- A heighted awareness of local flood risk.

Estimated costs associated with getting the proposed system installed and operational are provided below and have been extracted from Appendix H. The majority of the capital costs (around 70%) are associated with the preparation of material needed to establish and support the system. Equipment costs are minimal.

The all up capital cost is estimated at $31K with a further $28.5K of in-kind contributions from Council, VICSES and NCCMA. Annual recurrent costs for Council are conservatively estimated at $3.6K. An evaluation of the costs and benefits of each option is presented in Table 11-1.

16 Resilience is the ability to anticipate risk, limit impact and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change. That change may have been caused by a flood, another type of natural disaster or some other event. Resilient communities are not only prepared to help prevent or minimize the loss or damage to life, property and the environment, but they also have the ability to quickly return citizens to work, reopen businesses, and restore other essential services needed for a full and timely economic recovery (CRRI website).

Table 11-1 Evaluation of costs and benefits for the "Essential" Case

	Do Nothing	Essential Case	Difference
Ratio of Actual to Potential Damages	0.9	0.84	0.061
AAD	$153,000	$143,000	$10,000
PV Benefits			$140,000
PV Costs	$0	$100	$109,000
NPV			$31,000
BCR			1.3

Note (1) This difference is consistent with behavioural research findings for TFWS in the United Kingdom (DEFRA 2006). (2) PV = present value, NPV = net present value, BCR = benefit cost ratio.

11.5.3 The "Essential Plus" Case

The "base plus" case is based on a more technically advanced approach to data monitoring and flood event detection coupled with automated alerting. The backbone of the "base" case, the manually read rain gauges and the sharing of data via Weather Underground, is strengthened by the installation of (say) up to three DipStik rain gauges that alert to the exceedance of pre-determined thresholds to opted-in mobile phones. Other elements of the TFWS would be essentially as for the "base" case, including the rain –river DipStik gauge.

The "better" case TFWS will provide Heathcote area residents with automated alerting of the likelihood of flooding in near real-time. Data available via Weather Underground will be able to be used to determine (and verify) the likelihood and scale of possible flooding within the town. As for the "base" case, residents will be able to use inundation maps delivered by the Heathcote Flood Study together with the Flood Information Card and property inundation tables available from the Bendigo MFEP to determine likely impacts and consequences at the property level and more generally across the area. Benefit for residents over the "base" case will be:

- Automated alerting to opted-in mobile phones of likely flooding;
- Improved lead time on awareness of likely flooding, especially if at night;
- A reduced need to be environmentally aware and self-starting when it rains, and
- No need for a local presence to be aware that flooding is likely.

The all up capital cost is estimated at $49K with a further $35K of in-kind contributions from Council, VICSES and NCCMA. Annual recurrent costs for Council are estimated at $15K. An evaluation of the costs and benefits of each option is presented in Table 11-2.

Table 11-2 Evaluation of costs and benefits for the "Essential Plus" Case

	Do Nothing	Essential Case	Difference
Ratio of Actual to Potential Damages	0.9	0.82	0.081
AAD	$153,000	$139,000	$14,000
PV Benefits			$187,000
PV Costs	$0	$100	$206,000
NPV			-$19,000
BCR			0.9

Note (1) PV = present value, NPV = net present value, BCR = benefit cost ratio.

11.5.4 The “Better” Case

The “better” case is based on a much greater involvement from Council and the establishment of an ERTS-based network of 1 x combined rain and river station and 2 x rain only stations reporting to a base station in Bendigo and to the BoM in Melbourne. Flood alerts / warnings would be issued by Council via SMS to stakeholder agencies and to selected key community representatives on the exceedance of rain and river level alarm criteria. Data would be available in near real-time from the BoM website. Other elements of the TFWS would be essentially as for the “base” case.

The “better” case TFWS will provide Heathcote area residents with easier and more structured access to regularly recorded local rainfall and creek level data in near real-time. There will also be opportunities for residents to receive alerts of likely flooding: the need for environmental awareness and self-starting will be reduced. They will also be able to use the data to determine (and verify) the likelihood and scale of possible flooding within the town. As for the “base” case, residents will be able to use inundation maps delivered by the Heathcote Flood Study together with the Flood Information Card and property inundation tables available from the Bendigo MFEP to determine likely impacts and consequences at the property level and more generally across the area. Benefit for residents over the “base” case will be:

- Easier access to more structured and regularly recorded rainfall and creek level data;
- A reduced need to be environmentally awareness and self-starting when it rains; and
- Opportunity to obtain archived rain and creek level data.

The all up capital cost is estimated at $90K with a further $35K of in-kind contributions from Council, VICSES and NCCMA. Annual recurrent costs for Council are estimated at $12K. An evaluation of the costs and benefits of each option is presented in Table 11-3.

Table 11-3 Evaluation of costs and benefits for the “Better” Case

	Do Nothing	Better Case	Difference
Ratio of Actual to Potential Damages	0.9	0.8	0.1
AAD	$153,000	$136,000	$17,000
PV Benefits			$234,000
PV Costs	$0	$100	$290,000
NPV			-$56,000
BCR			0.8

Note: (1) PV = present value, NPV = net present value, BCR = benefit cost ratio.

11.5.5 The "Better-Plus" Case

The "better-plus" case is based on active involvement of BoM in delivery of a quantitative flood warning service for Heathcote. This will involve the establishment of an ERTS-based network of 1 x combined rain and river station and 2 x rain only stations reporting to a base station in Bendigo and to the BoM in Melbourne (same as for the "better" case). Data would be available in near real-time from the BoM website. A flood prediction model would be developed by BoM at cost and flood forecasts and warnings provided to VICSES, Council, other agencies and the media through the BoM's normal warning dissemination system. These warnings would be available from the BoM and VICSES websites. Other elements of the TFWS would be essentially as for the "base" case.

The "better-plus" TFWS will provide Heathcote area residents with the same access to local rainfall and creek level data as the "better" case. However, quantitative flood forecasts and warnings (i.e. formal predictions of flood behaviour, the scale of flooding and the expected time and height of the flood peak) will be broadcast via local and national media and be available from the BoM and VICSES websites. While alerts will, in general, not be delivered to individuals, residents are expected to be more aware of the likelihood and scale of expected flooding. In turn, that is expected to inform a more uniform community response. While other aspects of the system will be as for the "better" case, benefits for residents will include:

- Access to public issue flood forecasts that provide detailed information on current and expected future conditions; and
- A more uniform, though not necessarily more targeted or timely, response to expected flooding.

The all up capital cost is estimated at $130K with a further $28K of in-kind contributions from Council, VICSES and NCCMA. Annual recurrent costs for Council are estimated at $12K. An evaluation of the costs and benefits of each option is presented in Table 11-4.

Table 11-4 Evaluation of costs and benefits for the "Better-Plus" Case

	Do Nothing	Better Plus Case	Difference
Ratio of Actual to Potential Damages	0.9	0.78	0.12
AAD	$153,000	$133,000	$20,000
PV Benefits			$281,000
PV Costs	$0	$100	$309,000
NPV			-$28,000
BCR			0.9

Note: (1) PV = present value, NPV = net present value, BCR = benefit cost ratio.

11.5.6 Summary

Assuming that a benefit cost ratio (BCR) of greater than one is required in order to secure support for TFWS development, the only economically feasible options is the “essential” case. The “essential-plus”, “better” or the “better-plus” configurations cannot be justified by the estimation of avoided damages. However, the analysis has not included the avoided loss of life, which is plausible given the limited warning time available in Heathcote. In fact there has been one loss of life in 1946 and near miss in 1939 with two men narrowly avoiding drowning in flood waters. Where such life estimates were made, it is possible that all options would be feasible.

While it is simple and requires active engagement by an informed and resilient local community, the “essential” case TFWS configuration delivers a BCR of 1.3 and is therefore preferred.

The preferred TFWS for Heathcote is explored in Section 11.6.

11.6 The Preferred TFWS for Heathcote

Community owned and operated rain gauges with data shared through an open source cloud based system in near real-time will meet the needs identified in Section 11.6.2 in a cost effective manner although messaging (in “community friendly what does this mean for me” terms) remains to be resolved. A key element of the TFWS will be the building and maintenance of flood awareness across the Heathcote community.

Table 11-5 provides a brief description of the basic tools needed to be delivered against each TFWS building block together with an outline of a suggested system for McIvor Creek at Heathcote. The system has regard for:

- The reasonably rapid development and progress of floods within the catchment and the limited lead time available between heavy rain and stream rises;
- The character of the flood risk (i.e. rapid onset, over-floor flooding of buildings from quite low levels, depth hazards along part of the Northern Highway within the town boundaries, isolation of the northern part of town, etc.); and
- Economic metrics (i.e. likely cost – benefit based on consideration of the contribution of avoidable damages to the value of average annual damages).

Indicative costs associated with the implementation and on-going operation of each of the elements proposed for the Heathcote TFWS are provided in Appendix H and as part of Section 11.6.1.

Table 11-5 Total Flood Warning System Building Blocks and Possible Solution for the McIvor Creek catchment to Heathcote.

This table considers the EMMV and Commonwealth-State arrangements for flood warning service provision (BoM, 1987; VFWCC, 2001; EMA, 2009)

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Heathcote
DATA COLLECTION & COLLATION	Data collection network (e.g. rain and stream gauges) System to convey data from field to central location and / or forecast centre (e.g. radio or phone telemetry).	Recruit a minimum of 3 community rain gauge readers and secure site registration on Weather Underground. May need to provide rain gauges and assist with siting. Consider adding a DipStik river (or rain-river) gauge at Heathcote (refer PALS location). Establish protocols for reading the staff gauges at the Barrack Street and Robinson Street fords. No staff gauges proposed although could add gauge boards to the upstream side of road bridges. Prepare instructions for readers and for community use of available data.
	Data management system to check, store, display data.	Weather Underground – including for the DipStik data (if installed).
	Arrangements and facilities for system / equipment maintenance and calibration. For example, the Regional Surface Water Monitoring Partnership, data QA'ing and warehousing, etc.	Maintenance not required for manually read gauges Davis Instruments weather stations may require routine maintenance Staff gauges and DipStik require annual health checks and associated preventative maintenance. Data is not QA'ed and is not available for archive (or to FloodZoom) unless protocols established with individual readers outside Weather Underground or scripts written to access data from Weather Underground. The Surface Water Monitoring Partnership may be able to assist with protocols.
DETECTION & PREDICTION (i.e. Forecasting)	Rainfall rates and depths likely to cause flooding together with information on critical levels / effects at key and other locations.	INITIALLY: Using the tools described below together with data from nearby rainfall stations, individuals and agencies determine the likelihood and scale of possible flooding at key locations.
	Appropriately representative flood class levels at key locations plus information on critical levels / effects.	Establish flood class levels for stream gauge sites within the catchment. LATER: In order to initiate local alerting of potential flooding, use rainfall rates and depths from the MFEP tools to set rainfall gauge alarm criteria. This will necessitate consideration of how alerting should be achieved, who should do it, who should be alerted and what they should do

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Heathcote
		following the alert.
	Flood forecast techniques (e.g. hydrologic rainfall - runoff model, stream flow and / or height correlations, simple nomograms based on rainfall).	The indicative quick look "flood / no flood" tool developed for Heathcote and included in the Bendigo MFEP provides guidance on the likelihood and scale of possible flooding. Council responsible for maintaining the tool. Decide how the tool is to be used and who by – VICSES? community?, etc. GIS based forecasting approach may have application for Heathcote. Could involve assessing real-time rainfall against IFD criteria and matching up against inundation mapping for the creek. Using the areal extent as a trigger, GIS could identify properties and other assets likely to be inundated or experience high hazard flooding. Will need to be developed.
INTERPRETATION (i.e. an ability to answer the question "*what does this mean for me - will I be flooded and to what depth*".	Interpretative tools (i.e. flood inundation maps, flood information cards, flood histories, local knowledge, flood response plans that have tapped community knowledge and experience, flood related studies and other sources, etc.).	Deliverables and intelligence arising from the Heathcote Flood Study have been captured to the Bendigo MFEP. This includes flood extent, depth and hazard mapping together with a table of properties flooded over-ground and over-floor, and information about areas / roads likely to be affected along with guidance on the expected depth of flooding. The quick look tool (see above) together with the MFEP enable those at risk to determine, with some lead time, whether they are likely to be flooded. In order to enable community members to determine the likely effects of a potential flood, Council to provide the Heathcote community with ready access to flood inundation maps and relevant Appendices of the MFEP. This will also inform development of individual flood response plans (see below). Council too periodically (and after each major flood event) review the quick look tool and update / refine as necessary as part of maintaining a strong awareness of and engagement in the TFWS and its continuous improvement.
MESSAGE CONSTRUCTION	Warning messages / products and message dissemination system.	Reasonably short hydrologic response time, hence simple automated messaging is likely to work best, if required. Confirm audience and determine what messages will be provided.

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Heathcote
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	Formal media channels17 – TV, radio and print. Fax / faxstream, phone / pager (e.g. SMS, voice), voice messaging systems (e.g. Xpedite), tape message services, community radio, internet (e.g. BoM & VICSES websites, email, social media), national Emergency Alert system. Flood wardens Door knocking Informal local message / information dissemination systems or "trees". Opportunity for at-risk communities to confirm warning.	If considered beneficial, Council to establish and champion a community flood action group and ensure that terms of reference are appropriate and agreed. Environmental indicators (i.e. heavy rain) and awareness following application of the quick look "flood / no flood" tool (i.e. likely severity and impact of expected flooding) will alert individuals to likely flooding. This alert could be shared within the community, either informally or more formally through the flood action group. Establish a Heathcote TFWS Twitter and / or Facebook account and direct alerting and information messages to those accounts. In severe flood situations, the Emergency Alert would be used by VICSES to disseminate critical information and key messages. Likely consequences and required actions will be as determined by the individual and VICSES as a result of consideration of local information and as augmented by the quick look tool, MFEP and flood inundation maps. VICSES as the Control Agency for flood also issue flood warning messages that include more detailed information including flood consequences to the media and to a wider audience via the electronic media, websites and social media. LATER - consider each of the following and action if and as appropriate: a) Establish threshold criteria for each automated rain and river gauge and initiate an SMS (or similar) alert to key personnel (and perhaps members of the at-risk community) in order to achieve more lead time on possible flooding. b) Adopt a GIS based system and develop a publically available web portal to display areas likely to experience hazardous flood conditions within Heathcote in real-time. Alternative alerting mechanisms could include use of a siren or similar
RESPONSE	Flood management tools (e.g. MFEP complete with inundation maps and	Evacuation arrangements / planning (Appendix E of the MFEP) remain to

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

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Heathcote
	"intelligence", effective public dissemination of flood information, local flood awareness, individual and business flood action plans, etc.). Flood response guidelines and related information (e.g. Standing Operating Procedures). Comprehensive use of available experience, local knowledge and information.	be completed. The MFEP remains to be reviewed and signed-off by Council MEMPC after the "required actions" column of the Flood Intelligence Card has been fully populated. Initiate a community engagement program to communicate how the TFWS will work. Environmental indicators (i.e. heavy rain) and awareness following application of MFEP tools will alert individuals to the need for response. Likely consequences and required actions will be as determined by those individuals. Following (or perhaps in concert with) acceptance of the MFEP, encourage and assist residents and businesses to develop individual flood response plans. A package that assists businesses and individuals is available from VICSES and provides an excellent model for community use.
REVIEW	Post-event debriefs (agency, community), etc. Data from Rapid Impact Assessments. Flood "intelligence" and flood damage data from the event collected by residents, Council, NCCMA, VICSES, etc. Review and update of personal, business and other flood action plans.	Review and update of alarm criteria (if established), local flood intelligence (i.e. flood characteristics, impacts, etc.), local alerting arrangements, response plans, local flood awareness material, etc. (initially) after every (severe) flood. Best done by Council with input from VICSES, NCCMA and (if established) the Council championed community flood action group. Council to develop review and update protocols => who does what when and process to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP. Ensure that as part of the above, information contained in Rapid Impact Assessments is captured to the MFEP. Council to develop and implement a TFWS monitoring and evaluation plan to review and improve the flood warning system as required.
AWARENESS	Identification of vulnerable communities and properties (i.e. flood inundation maps, information on flood levels / depths and extents, etc.).	Flood intelligence delivered by the Heathcote Flood Study has been captured to the MFEP. VICSES and Council to engage with the community during the development of the TFWS, perhaps through a flood action group or

Flood Warning System Building Blocks	Basic Tools	Possible Solution for Heathcote
	Activities and tools (e.g. participative community flood education, flood awareness raising, flood risk communication) that aim to build flood resilient communities (i.e. communities that can anticipate, prepare for, respond to and recover quickly from floods while also learning from and improving after flood events).	
	Community education and flood awareness raising including VICSES FloodSafe and StormSafe programs.	
	Local flood education plans – developed, implemented and evaluated locally (e.g. Cities of Maroondah, Whitehorse, Wodonga, Benalla, Greater Geelong and Warrnambool).	
	Flood response guidelines, residents' kits, flood markers, flood depth indicators, flood inundation maps and property listings, property specific flood depth charts, flood levels in meter boxes and on rate notices, etc. for properties identified as being subject to flooding.	

11.6.1 Implementing the Preferred Option

Staged implementation of the preferred option is recommended. The stages have been ordered and the tasks within each stage grouped to facilitate incremental growth of the TFWS elements in a balanced manner and with full regard for matters discussed in this report.

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

While it may be tempting to immediately move to “install” rain (and stream) gauges and to perhaps also implement a predictive or forecast capability, there are other more fundamental matters that experience tells us need to be addressed first. Thus early attention is directed at ensuring roles and responsibilities are agreed, understood and accepted and that there is a firm foundation for the development of an effective flood warning system: one that does not fail when it is needed most. Consideration is then given 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 at Heathcote improves. Attention is then directed to sharing available flood intelligence with the at-risk community. Next, attention is focussed on securing the funding needed to buy, install and operate equipment as well as other services needed to build elements of the TFWS. 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.

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

Stage 1

(1) Council, NCCMA, VICSES and other entities to determine the responsible entity in relation to “ownership” of each element of the total flood warning system for Heathcote, where ownership is considered to denote overall responsibility for funding as well as the establishment and functioning 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 associated payments. VFWCC (2001) provides guidance on this matter although recommendations 1 and 5 from the Victorian Floods Review Report (Comrie, 2011) suggest that some clarifications may be required. DELWP have initiated a project to review the arrangements and deliver clarity where required and may be able to offer guidance on resolving any uncertainties.

Stage 2

(1) Council and VICSES with input from others as required, to populate the “required actions” column of the Flood Intelligence Cards within the Heathcote Appendices of the Bendigo MFEP.

(2) VICSES, VicPol and Council to complete the documentation / planning of evacuation arrangements for the Heathcote community (Appendix E of the MFEP).

(3) Council, VICSES and NCCMA (and community?) to determine how the indicative quick look “flood / no flood” tool should be used and who by.

	Incremental	Cumulative
Capital cost		
Recurrent cost		
In-kind	$6,000	$6,000

Stage 3

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

(2) VICSES and Council to encourage and assist residents and businesses to develop individual flood response plans.

(3) Council to load and maintain flood related material (including the MFEP) to its website.

	Incremental	Cumulative
Capital cost		
Recurrent cost	$500	$500
In-kind	$5,000	$11,000

Stage 4

(1) Council and VICSES (possibly in conjunction with other agencies) to consider how all elements of the TFWS will be developed and how they will work. This will result in the preparation of a document that will form the basis of a community engagement program to advise the Heathcote community of the TFWS and how it will work.

	Incremental	Cumulative
Capital cost	$5,000	$5,000
Recurrent cost		$500
In-kind	$3,000	$14,000

Stage 5

(1) Council with the support of VICSES, NCCMA and the Bendigo community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements (i.e. field equipment, awareness and other materials, etc.) of the proposed TFWS for Heathcote.

Stage 6

(1) If considered appropriate, Council to champion and in conjunction with VICSES oversee the establishment of a flood action group for Heathcote. Clearly establish the role for the group along with its authority and structure (i.e. terms of reference) with due regard for possible liability and related issues.

	Incremental	Cumulative
Capital cost		$5,000
Recurrent cost	$500	$1,000
In-kind	$5,000	$19,000

Stage 7

(1) Council to recruit and equip a minimum of three (3) community rain gauge readers and secure site registration on Weather Underground. As part of this prepare instructions for rain gauge readers and for community use of available data.

(2) Establish protocols for reading the staff gauges at the Barrack Street and Robinson Street fords.

(3) VICSES to repeat the community engagement program at Heathcote in order to reinforce how the flood warning system will work along with evacuation arrangements. This will need to be repeated as the TFWS matures.

(4) VICSES to develop and distribute a Flood Action Guide for Heathcote.

	Incremental	Cumulative
Capital cost	$13,000	$18,000
Recurrent cost		$1,000
In-kind	$5,000	$24,000

Stage 8

(1) After rain gauges have been installed, Council to review the quick look tool to ensure that the tool is making best use of available data.

(2) Council in conjunction with VICSES and with input from NCCMA and other stakeholders as required, to lead the preparation of protocols for the development, review and update of TFWS elements => the who does what when and processes to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP, quick look tool and personal / business flood action plans. This should include the capture of information contained in Rapid Impact Assessment reports.

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

	Incremental	Cumulative
Capital cost	$7,000	$25,000
Recurrent cost		$1,000
In-kind	$3,000	$27,000

Stage 9

(1) Council to contract for the supply, installation, commissioning and warranty / maintenance (and other deliverables) of a rain – river DipStik gauge at Heathcote. Note that while the addition of gauge boards on the upstream side of road bridges would be useful, their supply and installation has not been included at this stage.

(2) Council to establish on-going maintenance arrangements for the new data collection network sites, ideally through the Surface Water Monitoring Partnership.

(3) When appropriate, VICSES to formally request BoM to establish flood class levels for stream gauge sites in the McIvor Creek catchment (assume 2). Flood class levels will need to be proposed by Council consistent with BoM definitions and local impacts / consequences.

	Incremental	Cumulative
Capital cost	$6,000	$31,000
Recurrent cost	$2,600	$3,600
In-kind	$1,500	$28,500

Possible further augmentation

(1) Council to arrange for the supply and installation of gauge boards on the upstream side of road bridges within and in close proximity to Heathcote. This could include a gauge on the bridge at Tooborac.

(2) Council to decide whether to alert residents and visitors to the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at strategic locations along local roads where there is appreciable danger to human life due to flood depth and / or velocity as indicated by the deliverables from the Heathcote Flood Study.

(3) Council to consider the preparation and distribution of property specific flood depth charts and / or meter box flood level stickers for each property within Heathcote subject to over-floor flooding up to and including the 200-year ARI event. The data to inform the charts is already available within the Bendigo MFEP.

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

(5) Council to consider loading and maintaining other flood related material on their websites with appropriate links to relevant useful sites (e.g. the GBCMA website).

(6) Longer term and as part of a "best possible" system, Council to consider establishing a GIS based forecasting capability with web portal.

These activities are possible but have not been costed in this report.

11.6.2 Roles and Responsibilities

The aim and function of flood warning systems are discussed in Section 11.3.1. However, the question of who pays and who would be responsible for the various elements of a TFWS for Heathcote remains to be addressed.

The division of responsibilities associated with the establishment, maintenance and operation of flood warning systems was formalised in working arrangements approved by the Commonwealth Government in 1987 (BoM, 1987) and agreed to in-principle by the Victorian Government through the State Disaster Council in early 1988. The arrangements were reiterated and aspects clarified in *Arrangements for Flood Warning Services in Victoria* (VFWCC, 2001)[18] and then endorsed by the relevant Ministers at both State and Federal level. A summary of roles and responsibilities against each of the TFWS building blocks is provided as Appendix E.

More recent developments have seen the BoM establish a Service Level Specification (SLS) that identifies the flood forecast and warning service it will provide for specific locations across the State. In addition, BoM is moving to establish a fee for service approach to the development of flood forecasting tools for locations not currently included in the SLS.

The current arrangements for riverine and flash flood warning systems, in terms of roles, responsibilities and who pays, are different. Local government has a more prominent role in flash flood warning systems while the role of the BoM is substantially diminished[19]. Further, while the BoM will continue to provide generalised warnings of weather conditions likely to lead to flash flooding, it will not provide flash flood warnings for specific creeks and locations[20].

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18 Comrie (2011) noted that the arrangements described by VFWCC (2001) are not couched in TFWS terms and fail to address system elements that do not have a technical basis.

19 A flood warning system established for a stream or location considered to be subject to flash flooding is, in general terms, the responsibility of the local council. While the technical elements will need to be installed, operated and maintained by council, BoM will provide advice aimed at assisting council establish and develop these elements. Responsibility for message construction and dissemination also resides with council. BoM will, however, assist through the supply of operational software for data management and alerting and continue delivery of existing severe weather and riverine flood warning related services. While it is not specifically stated where responsibilities for other elements of the TFWS reside, it is apparent that arrangements in place for non-flash flood warning systems apply. Thus delivery on a number of TFWS elements, including the development and application of flood response plans as well as (flash) flood education and awareness programs, is a shared state and local government responsibility.

20 A detailed description of flash flood warning related service provided by the BoM is provided in BoM (1996). The service comprises four components, depending on the sophistication of available monitoring and forecast capabilities, as follows:

While there are a number of decisions required in relation to how each of the TFWS elements will be developed and implemented, the key issue for Heathcote and McIvor Creek is how a potential flood will be detected and how the at-risk community will be alerted. A range of systems, equipment and approaches is available. The dilemma is "what is sufficient"? That then begs the question "what are we trying to achieve"?

Answering the second question first and having regard for first level achievements only, gives rise to the following:

- Monitoring of rainfall (and creek level), possibly for exceedance of triggers that indicate that flooding may occur.
- Ready public access to raw data.
- Alerting the community to potential flooding as quickly as possible.
- Alerting VICSES (and the City of Greater Bendigo) to potential flooding.
- Ready public access to flood intelligence so that the community can determine likely impacts and individual consequences and initiate appropriate response actions.
- Low setup and operating costs with a positive benefit – cost ratio (a key consideration).

- Generalised warnings (issued to the general public and emergency management organisations, generally as a regional severe weather warning) associated with the onset of heavy rainfall. The threshold in Victoria is 25mm in an hour which is around the average 10-year 1-hour rainfall for Victoria.
- Radar based warnings of rainfall (issued to identified agencies and user groups as a severe thunderstorm warning at a space scale, where feasible according to BoM, of a typical local government area) that could lead to flash flooding within specific areas, but only where those areas are covered by suitable weather watch radar and where a threshold intensity, chosen such that its exceedance will produce flash flooding irrespective of existing antecedent catchment conditions, is expected to be equalled or exceeded. In Victoria the current threshold is 20mm in half an hour.
- Area specific predictions of rainfall intensities (issued to local flash flood warning groups where a local warning system has been established) but only in areas covered by suitable weather watch radar.
- Support and advice to local authorities in the establishment of automated flash flood warning systems (for example, ALERT systems) and related matters.

12 Planning Controls

In the long term, one of the most effective means of flood mitigation is the establishment and enforcement of appropriate planning scheme controls in areas identified as at risk of flooding. Planning controls are effective over time as buildings are renewed they can be built in areas outside the floodplain, or if in an area of low flood risk, can be built above the declared flood level. This Section specifically relates to addressing Key Objectives 3 & 5 of the Study.

12.1 Overlays

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

- Environmental Significance Overlay (ESO);
- Floodway Overlay (FO);
- Land Subject to Inundation Overlay (LSIO);
- Special Building Overlay (SBO); and
- Urban Flood Zone (UFZ).

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

The proposed planning scheme for the catchment is to assign areas identified as Extreme Hazard to Children (depth greater than 500 mm and/or velocity x depth greater than 0.6 m^2/s) to the more restrictive Floodway Overlay. Areas identified as lower hazard should be subjected to the less restrictive Land Subject to Inundation Overlay. The proposed planning scheme overlays are presented in Figure 12-1.

12.1.1 Building Controls

Building controls consistent with the advice provided by NCCMA have been developed. It is recommended that:

- Finished floor levels of all properties within the 1% AEP flood extent are set at a minimum of 300mm above the declared flood levels.
- Finished floor levels of all properties adjacent the 1% AEP flood event extents are set at a minimum of 300mm above the declared flood levels nearest the site.
- There is no development within the UFZ and FO.

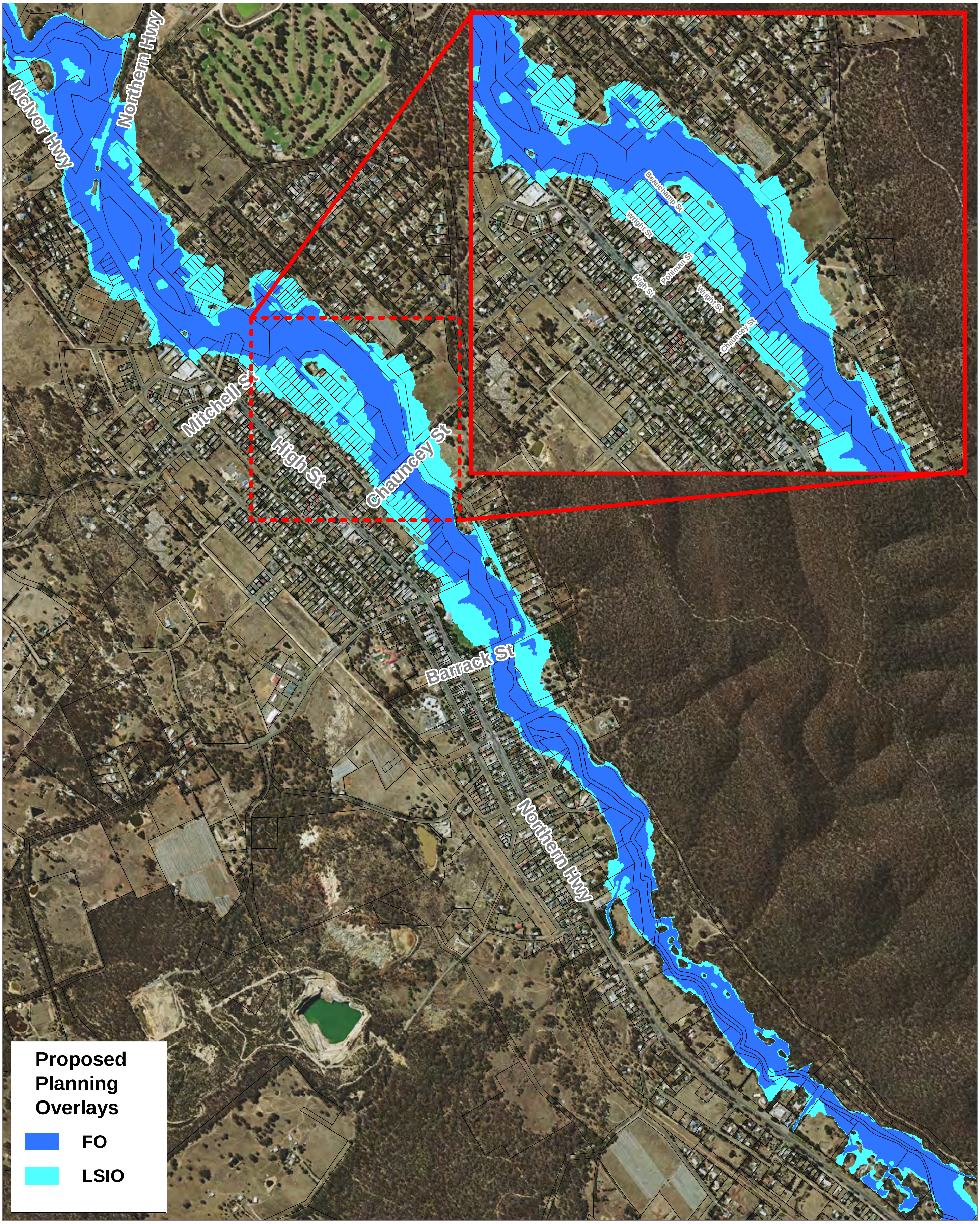
12.2 Declared Flood Levels

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

12.3 Planning For Climate Change

The DELWP have recommended that the impact of climate change on flooding is assessed by increasing the rainfall intensity of design events. To ascertain the likely impact of climate change, an increased rainfall intensities (and therefore total depth of rainfall) was modelled as described in Section 6.9. The scenario had the rainfall intensity increased by 20% for the 1% AEP design event. The resulting flood depth map is shown in Figure 8-13.

At present there is no requirement from State Government for the incorporation of climate change into floodplain management decisions. The incorporation of climate change information into floodplain management decisions is undertaken on a Council by Council basis. These decisions may take the form of setting building controls at the climate change flood levels, for instance.



Title:
Heathcote Flood Study
Draft Planning Overlays

Figure: **12-1**

Rev: **A**

N

0 375 750m
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : T:\M20448.PP.HeathcoteFloodStudy\MapInfo\Drawings\R.M20448.008.00.Final\HC_Final_Fig12-1_PlanningOverlays_RevA.WOR

13 Flood Response Plan

13.1 Flood Response Plan

A Municipal Emergency Management Plan (MEMP) has been completed as part of the Study and has been delivered to Council as a separate document. This Section specifically relates to addressing Key Objective 4 of the Study. Further details are available in Table 11-5.

13.1.1 Flood Intelligence and Consequence Information

Intelligence and consequence information about flood risk has been prepared as part of the Study. The City of Greater Bendigo MFEP contains this intelligence and consequences information for Heathcote. While all required actions at various flooding depths remain to be completed on the Heathcote Flood Intelligence Card, the MFEP provides a strong base to initiate a timely and considered response to (forecast) flooding at Heathcote.

A relationship that links the flood inundation maps produced by the Study and flood levels at the two PALS locations (Barracks St Ford and Robinson St Ford) as shown on the flood depth maps has been developed and is also included in the MFEP.

Further details on the MFEP and flood intelligence consequence information are provided Table 11-5.

13.1.2 MEMP Appendices

The VICSES MFEP Appendices templates have been updated with flood intelligence extracted from the flood modelling and community consultation sessions undertaken as part of the Study. These include:

- Appendix A – Flood Threats for City of Greater Bendigo
- Appendix B – Typical Flood Rise, Recession and Peak travel times
- Appendix C – Flood Emergency Plans for the study area “communities” containing information on:
    - A flood consequence table (tied to the two PALS gauges correlated to design rainfall depths),
    - Lists of roads impacted / flooded relative to flood severity,
    - Details of essential and other community infrastructure impacted again relative to flood severity,
    - A table of properties (by address) affected (with depth of likely flooding) for each of the design flood events modelled,
    - A table of properties flooded count by gauge height / design flood AEP
    - A quick look indicative flood prediction tool

14 Community Awareness

Community awareness regarding flooding and their flood risk is a fundamental component of the TFWS and critical to its success. While this topic is covered in Section 11, it has been elevated to its own Section given importance and the value that can be gained through its implementation. Further, community awareness of flood risk can be carried out independently as well as in conjunction with the TFWS. In fact, it is recommended that community awareness programs are carried out periodically to provide opportunities new residents and to manage ‘flood amnesia’ in established residents.

This section outlines materials that could be used for community education purposes such as the SES Flood Safe Guides and during community events.

Supported by materials and information developed as part of the Study, include:

- Flood History – see Section 2.7
- Description of Flooding – see Section 9.1
- Flood Mapping products – in particular the flood depth maps
    - Historic Events
        - Figure 6-5 January 2011 Calibration Event Peak Flood Depths
        - Figure 6-9 December 2010 Validation Event Flow Comparison
        - Figure 6-8 September 2010 Validation Event Flow Comparison
        - Figure 6-7 September 1993 Validation Event Flow Comparison
        - Figure 6-6 August 1978 Validation Event Flow Comparison
        - Figure 6-10 May 1974 Verification Event Peak Flood Depths
    - Design Events
        - Figure 8-1 Existing Conditions 20% AEP Peak Flood Depth
        - Figure 8-2 Existing Conditions 10% AEP Peak Flood Depth
        - Figure 8-3 Existing Conditions 5% AEP Peak Flood Depth
        - Figure 8-4 Existing Conditions 2% AEP Peak Flood Depth
        - Figure 8-5 Existing Conditions 1% AEP Peak Flood Depth
        - Figure 8-6 Existing Conditions 0.5% AEP Peak Flood Depth
- Flood Animations – Provided as one of the Study deliverables
- Quick look tool – Enclosed at part of the MEFP

15 Floodplain Management Plan

The preceding Sections of this report document the first three steps in the floodplain management plan process adopted for the Study (refer to Section 10.1 and Figure 10-1), namely:

- data collection;
- flood study; and
- management study.

The next step is the development of a management plan. The flood management plan presents the recommended management options to be implemented in order to reduce the risk of flooding in Heathcote. This Section presents that plan.

This process incorporated extensive input from the community along with the Community Reference Group, both of which are made up of community members, technical experts and representatives from government agencies.

The following sections provide an overview of the management options adopted in the Study followed by a description of each individual management option.

15.1 Overview of the Flood Management Plan

Table 15-1 summarises the recommended non-structural options adopted in the MFEP for implementation.

Table 15-1 Summary of the Heathcote Floodplain Management Plan

Management Measure	Description of Works	Section
Declared Flood Levels	The 1% AEP flood levels determined by the Study will be adopted as the Declared Flood Levels as prescribed by Section 204 of the Water Act 1989.	Section 12.2
Amendments to Planning Schemes	Flood planning GIS data for Heathcote, indicating the extent of Urban Floodway Zone (UFZ), Land Subject to Inundation (LSIO) and Floodway Overlays (FO) has been provided to Council for inclusion into the planning scheme.	Section 12.1
Building control	Building control recommendations consistent with the current recommendations issued by the NCCMA have been provided. NCCMA require a minimum of 300mm freeboard above the declared flood levels.	Section 12.1.1
Planning For Climate Change	Climate change sensitivity modelling has been undertaken as part of the MFEP and the results have been made available to Council.	Section 12.3
Flood Response Plan	A MFEP has been completed as part of this study and is available from City of Greater Bendigo.	Section 13
Flood Intelligence and Consequence Information	Flood intelligence and consequence information has been prepared as part of the MFEP. This information is presented in the City of Greater Bendigo MFEP.	Section 13.1.1
Flood Warning System	A review of the total flood warning system for Heathcote has been undertaken as part of the Study. This review has made a number of recommendations which are listed in Section 11.6.	Section 11
Community Awareness	Materials and information developed as part of the Study useful for community awareness are outlined in Section 14.	Section 14

16 Summary and Recommendations

This report has documented the methodology and findings of the Heathcote Flood Study. The study has defined the flood behaviour for the catchment through the development of calibrated hydrologic and hydraulics models and the determination of flood extents for a range of flood events. These models have been used to determine the flood damages within the catchment. A number of mitigation measures have been documented and recommended for adoption within the catchment with the aim of reducing flood risk to Heathcote. These recommendations include:

- Declaring Designated Flood Levels (Section 13)
- Implementation of Planning Scheme Controls (Section 12.1)
- Implementation of a Total Flood Warning System (Section 11.6)
- Implementation of Building controls (Section 12.1.1)
- Consideration of Planning For Climate Change (Section 12.3)
- Implementation of Flood Response Plan (Section 13)
- Dissemination of Flood Intelligence and Consequence Information (Section 13.1.1)
- Undertake Community Awareness Programs (Section 14)

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

17 References

Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000), Standing Committee on Agriculture and Resource Management (SCARM) Report No 73: Floodplain Management in Australia, Best Practice Principles and Guidelines.

Australian Emergency Management Institute (AEMI) (1995): Flood Warning: An Australian Guide.

Austroads, 1994. *Waterway Design: A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*

Bureau of Meteorology (1987): Flood Warning Arrangements - Papers prepared for discussions with Victorian Agencies, December 1987.

Bureau of Meteorology (1996): Bureau of Meteorology Policy on the Provision of the Flash Flood Warning Service. May 1996.

Bureau of Transport and Regional Economics (BTRE) (2002): Benefits of Flood Mitigation in Australia: BTRE Report No 106. Canberra, May 2002.

Community and Regional Resilience Institute (CRRI) website: http://www.resilientus.org/

Comrie, N. (2011): Review of the 2010-11 Flood Warnings and Response: Final Report. 1 December 2011.

Chow, V. T., 1973. *Open-Channel Hydraulics*, McGraw Hill International, Sydney.

Chiew, F. H. S., and Mcmahon, T. A. 1993. *Assessing the adequacy of catchment streamflow yield estimates*, Australian Journal of Soil Research 31(5) 665 - 680

Criss, R. E. and Winston, W. E. 2008, Do Nash values have value? Discussion and alternate proposals. Hydrological Processes, 22: 2723-2725. doi: 10.1002/hyp.7072

Engineers Australia, 2010, *Australia Rainfall & Runoff Revision Projects – Project 10 Appropriate Safety Criteria for People,* Australian Rainfall and Runoff ARR April 2010

Department of Natural Resources and Environment (DNRE) (1998): Victoria Flood Management Strategy.

Department of Transport and Regional Services (DoTARS) on behalf of the Council of Australian Governments (CoAG) (2002): Natural Disasters in Australia. Reforming Mitigation, Relief and Recovery Arrangements: A report to the Council of Australian Governments by a high level officials' group. August 2002 published 2004.

Emergency Management Australia (EMA) (2009): Manual 21: Flood Warning.

Engineers Australia, 2014, *Discussion Paper: An Interim Guideline for Considering Climate Change in Rainfall and Runoff*, Australian Rainfall and Runoff ARR D3 – 25th November 2014

Environment Agency (2009): Understanding of and response to flash flooding. June, 2009.

Handmer, J.W. (1997): Flood Warnings: Issues and Practices in Total System Design. Flood Hazard Research Centre, Middlesex University.

Handmer, J.W. (2000): Are Flood Warnings Futile? Risk Communication in Emergencies. The Australasian Journal of Disaster and Trauma Studies. Volume: 2000-2.

Handmer, J.W. (2001): Improving Flood Warnings in Europe: A Research and Policy Agenda. Environmental Hazards. Volume 3:2001.

Handmer, J.W. (2002): Flood Warning Reviews in North America and Europe: Statements and Silence. The Australian Journal of Emergency Management, Volume 17, No 3, November 2002.

Intergovernmental Committee on Surveying and Mapping (ICSM) 2010, *ICSM LiDAR Acquisition Specifications and Tender Te*mplate, Intergovernmental Committee on Surveying and Mapping, Canberra, viewed 11 November, 2011, <http://www.icsm.gov.au/elevation/LiDAR_Specifications_and_Tender_Template.pdf >

Leister, J.G. and Jempson, M.A., (2011), Backwater Effects of Bridge Piers and Abutments in 2D – *Replication of Physical Model Tests in a 2D Hydrodynamic Model*, 34th International Association of Hydraulic Research (IAHR) World Congress, Brisbane, Australia, June 2011.

Nash J. E. and Sutcliffe, J.V. 1970, River flow forecasting through conceptual models. Part 1: a discussion of principles, J. Hydrol. 10, pp. 282–290

SKM 2012, *Inflow Forecasting for Storages,* prepared for Goulburn-Murray Water

SKM 2013, *Conversion of RORB to URBS Models for implementation of Delft-FEWS,* prepared for Goulburn-Murray Water

Steel, R. G. D.; Torrie, J. H. 1960. Principles and Procedures of Statistics with Special Reference to the Biological Sciences.McGraw Hill.

United Nations (UN) (1997): Guiding Principles for Effective Early Warning. Prepared by the Convenors of the International Expert Groups on Early Warning of the Secretariat of the International Decade for Natural Disaster Reduction, IDNDR Early Warning Programme, October 1997, Geneva, Switzerland.

Victorian Flood Warning Consultative Committee (VFWCC) (2001): Arrangements for Flood Warning Services in Victoria. February 2001.

Appendix A Data Log

BMT WBM	Subject: Heathcote Flood Study	Job No: M20448	Date: 26/08/2014
		By: DR	Rev:
		Ckd:	Date:

Category	Sub-Category	File Name	File Path	Supplied	Format	Date Received	Received From	Comments	Licence Valid Until	Superceded
1. Rainfall (daily)										
	KNOWSLEY POST OFFICE	IDCJAC0009_081025_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_081025_1800\IDCJAC0009_081025_1800_Data.csv	YES	csv	26/08/2014	BoM			
	EPPALOCK RESERVOIR	IDCJAC0009_081083_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_081083_1800\IDCJAC0009_081083_1800_Data.csv	YES	csv	26/08/2014	BoM			
	KNOWSLEY	IDCJAC0009_081118_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_081118_1800\IDCJAC0009_081118_1800_Data.csv	YES	csv	26/08/2014	BoM			
	HEATHCOTE	IDCJAC0009_088029_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_088029_1800\IDCJAC0009_088029_1800_Data.csv	YES	csv	26/08/2014	BoM			
	PUCKAPUNYAL	IDCJAC0009_088049_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_088049_1800\IDCJAC0009_088049_1800_Data.csv	YES	csv	26/08/2014	BoM			
	PYALONG WEST (CAVAN PARK)	IDCJAC0009_088050_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_088050_1800\IDCJAC0009_088050_1800_Data.csv	YES	csv	26/08/2014	BoM			
	REDESDALE	IDCJAC0009_088051_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_088051_1800\IDCJAC0009_088051_1800_Data.csv	YES	csv	26/08/2014	BoM			
	MOLLISONS CK AT PYALONG	IDCJAC0009_088064_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_088064_1800\IDCJAC0009_088064_1800_Data.csv	YES	csv	26/08/2014	BoM			
	BAYNTON	IDCJAC0009_088073_1800_Data.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\BOM\Daily\IDCJAC0009_088073_1800\IDCJAC0009_088073_1800_Data.csv	YES	csv	26/08/2014	BoM			
2. Rainfall (pluvi)										
	HEATHCOTE			YES	txt	15/10/2014	BoM			
	WANALTA RECORDER TWO			YES	txt	15/10/2014	BoM			
	REDESDALE			YES	txt	15/10/2014	BoM			
3. Stream Gauge										
	MOUNT IDA CREEK @ DERRINAL - Level/Discharge	406226.csv	T:\M20448.PP.HeathcoteFloodStudy\Data\DEPI\406226.csv	YES	csv	18/07/2014	DEPI	Daily back to 1945 - check		
	MOUNT IDA CREEK @ DERRINAL - Rating Table	406226.ratingtable.txt	T:\M20448.PP.HeathcoteFloodStudy\Data\DEPI\406226.ratingtable.txt	YES	txt	26/08/2014	DEPI			
4. GIS Misc.										
	CoGB Planning Overlays	CoGB_Planning_Overlays.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\CoGB_Planning_Overlays.shp	YES	Esri Shp	15/08/2014	NCCMA			
	Crown Land	Crown_Land.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\Crown_Land.shp	YES	Esri Shp	15/08/2014	NCCMA			
5. Existing Flood Info.										
	NCCMA 100Y ARI Flood Extent	NCCMA_100Y_ARI_FloodExtent.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\NCCMA_100Y_ARI_FloodExtent.shp	YES	Esri Shp	15/08/2014	NCCMA			
	VFD 100Y ARI Flood Extent	VFD_100Y_ARI_FloodExtent.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\VFD_100Y_ARI_FloodExtent.shp	YES	Esri Shp	15/08/2014	NCCMA			
	VFD Contour 100Y ARI	VFD_Contour_100Y_ARI.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\VFD_Contour_100Y_ARI.shp	YES	Esri Shp	15/08/2014	NCCMA			
	VFD Floodway	VFD_Floodway.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\VFD_Floodway.shp	YES	Esri Shp	15/08/2014	NCCMA			
	VFD HistoricContour	VFD_HistoricContour.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\VFD_HistoricContour.shp	YES	Esri Shp	15/08/2014	NCCMA			
	VFD RiverRunningDistance	VFD_RiverRunningDistance.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\VFD_RiverRunningDistance.shp	YES	Esri Shp	15/08/2014	NCCMA			
6. LiDAR										
	1m grid - 2010 ISC Rivers LiDAR	riverslidar_heathcote.txt	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\riverslidar_heathcote.txt.zip	YES	ascii	15/08/2014	NCCMA			
	25m grid - trimmed to Heathcote statewide DEM	statewide_dem_heathcote.asc	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\20140813 For BMT WBM\20140813 For BMT WBM\statewide_dem_heathcote.asc	YES	ascii	15/08/2014	NCCMA			
6. Existing Models										
	Conversion of RORB to URBS Models for implementation of Delft-FEWS - SKM 2013	Final URBS Models from SKM	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\Models for Mark B and CMA\Models for Mark B and CMA\Final URBS Models from SKM	YES	URBS	15/08/2014	NCCMA			
	SKM RORB model project 2012	SKM RORB model project 2012	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\20140813\Models for Mark B and CMA\Models for Mark B and CMA\SKM RORB model project 2012	YES	RORB	15/08/2014	NCCMA			
7. Drainage										
	Box-culverts - Side Gully near Pianta St	Heathcote plans_001.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_001.pdf	YES	PDF	12/09/2014	CoGB			
	Bridge - Warrowitue-Forest Rd	Heathcote plans_002.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_002.pdf	YES	PDF	12/09/2014	CoGB			
	Box-culverts - Side Gully near Pianta St	Heathcote plans_003.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_003.pdf	YES	PDF	12/09/2014	CoGB			
	Box-culverts - Side Gully near Pianta St	Heathcote plans_004.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_004.pdf	YES	PDF	12/09/2014	CoGB			
	Box-culverts - Side Gully near Pianta St	Heathcote plans_005.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_005.pdf	YES	PDF	12/09/2014	CoGB			
	Box-culverts - Side Gully near Pianta St	Heathcote plans_006.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_006.pdf	YES	PDF	12/09/2014	CoGB			
	Box-culverts - Side Gully near Pianta St	Heathcote plans_007.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_007.pdf	YES	PDF	12/09/2014	CoGB			
	Box-culverts - Side Gully near Pianta St	Heathcote plans_008.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_008.pdf	YES	PDF	12/09/2014	CoGB			
	Bridge - Chauncey St(?)	Heathcote plans_009.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\Heathcote plans_009.pdf	YES	PDF	12/09/2014	CoGB			
	Bridge/road culvert - Existing Bridge over un-named creek - believe to be side gully under High St	SN0455General Arrangemen.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\VicRoads\SN0455General Arrangemen.pdf	YES	PDF	23/10/2014	VicRoads			
	Bridge - Northern Hwy - Mt Ida Creek	SN0456General Arrangement.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\VicRoads\SN0456General Arrangement.pdf	YES	PDF	23/10/2014	VicRoads			
	Box-culverts - Caledonia Gully (under High St)	SN0457General Arrangemen.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\VicRoads\SN0457General Arrangemen.pdf	YES	PDF	23/10/2014	VicRoads			
	Box-culverts - Mt Ida Creek - next to existing bridge	SN0459General Arrangement.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\VicRoads\SN0459General Arrangement.pdf	YES	PDF	23/10/2014	VicRoads			
	Bridge - Heathcote-Nagambie Rd - Mt Ida Creek	SN4887General Arrangemen.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\VicRoads\SN4887General Arrangemen.pdf	YES	PDF	23/10/2014	VicRoads			
	Heathcote town drainage network - Pipes and Pits	Pits_HeathcoteClip.shp Pipes_HeathcoteClip.shp	T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\CoGB_HeathcoteDrainage_20141010\Pits_HeathcoteClip.shp T:\M20448.PP.HeathcoteFloodStudy\Data\CoGB\CoGB_HeathcoteDrainage_20141010\Pipes_HeathcoteClip.shp	YES	ESRI Shape	10/10/2014	CoGB			
8. Historic Flood Information										
	Plan map of Heathcote - potentially flood extent of 1974 (unsure) - possibly VFD lines	Heathcote flood plans_0001.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0001.p	YES	PDF					
	Plan map of Heathcote - flood extent of 1974 and 1939 (refered to as 1%) - possibly VFD lines	Heathcote flood plans_0002.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0002.p	YES	PDF					
	Contour map of Heathcote with some flood behavour notes of 1974 (unsure but presumably)	Heathcote flood plans_0003.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0003.p	YES	PDF					
	Contour map of Heathcote with some flood behavour notes of 1974 (unsure but presumably)	Heathcote flood plans_0004.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0004.p	YES	PDF					
	Contour map of Heathcote with some flood behavour notes of 1974 (unsure but presumably)	Heathcote flood plans_0005.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0005.p	YES	PDF					
	Contour map of Heathcote with some flood behavour notes of 1974 (unsure but presumably)	Heathcote flood plans_0006.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0006.p	YES	PDF					
	Contour map of Heathcote with some flood behavour notes of 1974 (unsure but presumably)	Heathcote flood plans_0007.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0007.p	YES	PDF					
	Long section plot with spot heights for various flood events through heathcote	Heathcote flood plans_0008.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0008.p	YES	PDF					
	Plan map of Heathcote showing spot flood marks along with the survey details	Heathcote flood plans_0009.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0009.p	YES	PDF					
	Flood contours - unsure of event	Heathcote flood plans_0010.pdf	T:\M20448.PP.HeathcoteFloodStudy\Data\NCCMA\CoGB_HeathcoteFloodHistoric_20141103\CoGB_HeathcoteFloodHistoric_20141103\Heathcote flood plans_0010.p	YES	PDF					
	Newspaper Article	The Argus 29/10/1867		YES	PDF					
	Flood Victoria - Flood History	http://www.floodvictoria.vic.gov.au/centric/learn_about_flooding/flood_history/pre_1900_floods.jsp		YES	Website					
	Newspaper Article	Bendigo Advertiser 09/09/1870		YES	PDF					
	Newspaper Article	The Mercury 20/09/1870		YES	PDF					
	Newspaper Article	Newcastle Morning Herald and Miners Advocate 15/02/1883		YES	PDF					
	Newspaper Article	SouthAustralian Register 13/02/1883		YES	PDF					
	Newspaper Article	The Argus 13/02/1883		YES	PDF					
	Newspaper Article	The Capricornian 17/02/1883		YES	PDF					
	Newspaper Article	Bendigo Advertiser 14/10/1903		YES	PDF					
	Newspaper Article	Bendigo Advertiser 11/09/1906		YES	PDF					
	Newspaper Article	The Argus 11/09/1906		YES	PDF					

Newspaper Article	Bendigo Advertiser 21/08/1909	YES	PDF
Newspaper Article	The McIvor and Rodney Advertiser 28/09/1916	YES	PDF
Newspaper Article	The Argus 17/12/1930	YES	PDF
Newspaper Article	Kilmore Free Press 25/05/1939	YES	PDF
Newspaper Article	Daily Advertiser 10/04/1939	YES	PDF
Newspaper Article	News 8/04/1939	YES	PDF
Newspaper Article	Kilmore Free Press 24/01/1946	YES	PDF
Newspaper Article	The Argus 4/12/1954	YES	PDF
Flood Victoria - Flood History	http://www.floodvictoria.vic.gov.au/centric/learn_about_flooding/flood_history/1900_to_1970_floods.jsp	YES	Website
Flood Victoria - Flood History	http://www.floodvictoria.vic.gov.au/centric/learn_about_flooding/flood_history/1971_to_2000_floods.jsp	YES	Website
Flood Victoria - Flood History	http://www.floodvictoria.vic.gov.au/centric/learn_about_flooding/flood_history/1971_to_2000_floods.jsp	YES	Website
Flood Victoria - Flood History	http://www.floodvictoria.vic.gov.au/centric/learn_about_flooding/flood_history/1971_to_2000_floods.jsp	YES	Website
Emergency Management Australia	http://pandora.nla.gov.au/pan/12572/20080911-0930/www.ema.gov.au/ema/emadisasters.nsf/c85916e930b93d50ca256d050020cb1f/9823fd8c1c66bb3bca256d330005aea1f30d.html	YES	Website

Appendix B Historic Flood Plans

NOTES:

1. The land shown hachured is the area ~~proclaimed as being~~ liable to flooding. This area is bounded by the limits of the "1% probability flood", which is the flood prescribed by Sec, 37B of the Drainage of Land Act, 1975 for floodplain management purposes. The 1% flood is regarded as having a probability of occurrence of 1% in any one year, i.e., on average it will occur once in 100 years.

2. The 1% flood relevant to this location has been derived from known historical flood and flow information.

3. The limits of the 1 % flood were defined by using the best available contours of the region ~~during .... 19 .... using the data contained on the Designated Flood Levels plan (Plan No ....)~~ for conditions existing at that time.

4. The hachured area represents the land which is subject to special controls. Either the Rural Water Commission or the local municipality should be consulted for details on special requirements in this area.

5. Although there may be buildings within the area shown as liable to flooding it should not be assumed that the floor of any individual building is below flood level. Buildings should be surveyed to determine whether their floors are above or below the 1% flood level.

EXTENT OF INUNDATION IN A 1% FLOOD

(Reference flood 1939) 12.10.87

WORKING PLAN

100 50 0 100 200 300 400 M

TOWNSHIP OF HEATHCOTE

NOTES:

AREA INUNDATED IN 1974

AREA INUNDATED IN A 1% FLOOD.

NOTES:-

1. The 1% flood (Annual Exceedance Probability of 1 in 100) is prescribed by Sec. 37B of the Drainage of Land Act, 1975 for floodplain management purposes. The 1% flood is regarded as having a probability of occurrence of 1% in any one year, i.e., on average it will occur once in 100 years.

2. Flood level information was obtained from the following sources:-

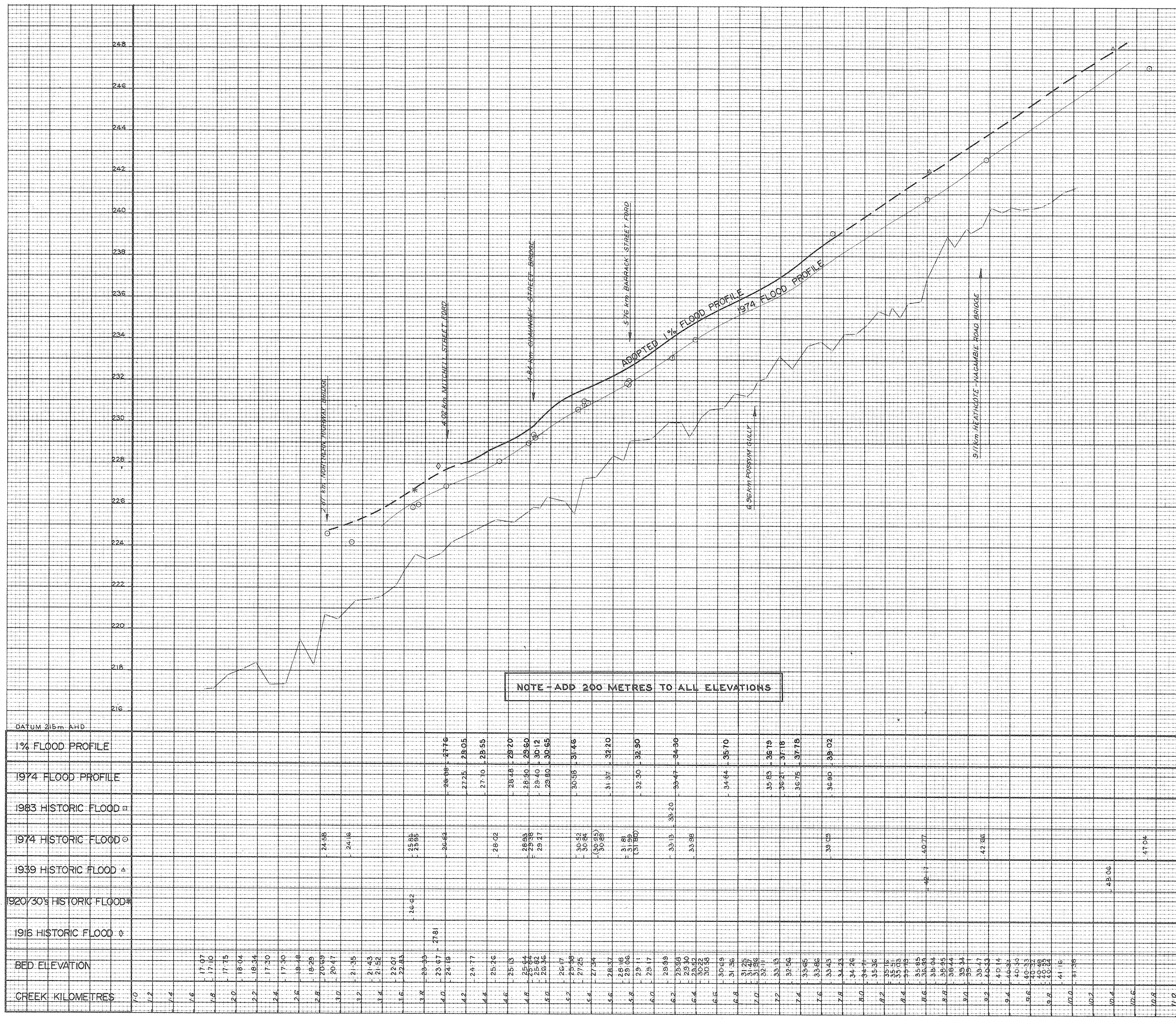
   (a) History of flooding 1916-1983 and Creek longitudinal Section - R.W.C. Plan No. 201075.

   (b) Back water analysis HEC2 computer model was used to produce the adopted 1% flood profile.

3. Between Creek Running Distances 4 to 8 km the R.W.C. Plan No. 201260 provides Designated 1% flood level information.

4. The confluence with Mount Ida Creek is used as zero (km) for determining Creek Running Distances.

5. All levels are shown in metres to Australian Height Datum.



SCALES

10 (METRES) VERTICAL

20 (KILOMETRES) HORIZONTAL

LOCALITY PLAN

SCALE OF METRES (APPROX)

150 0 250 500 750 1000 1250 1500

ZONE 55 SW E 292700 N 5906000 NE E 300000 N 5914400

REV	DATE	DESCRIPTION	CHKD	DOC CAT	FILMED
	AUG 1988	ORIGINAL CREATED			

REVISIONS

TITLE	PLAN NO
DESIGNATED FLOOD LEVEL LINES	201260
HISTORY OF FLOODING	201075

REFERENCES

DRAWN | CHECKED | G Tierney 19.10.88 DESIGNING ENGINEER

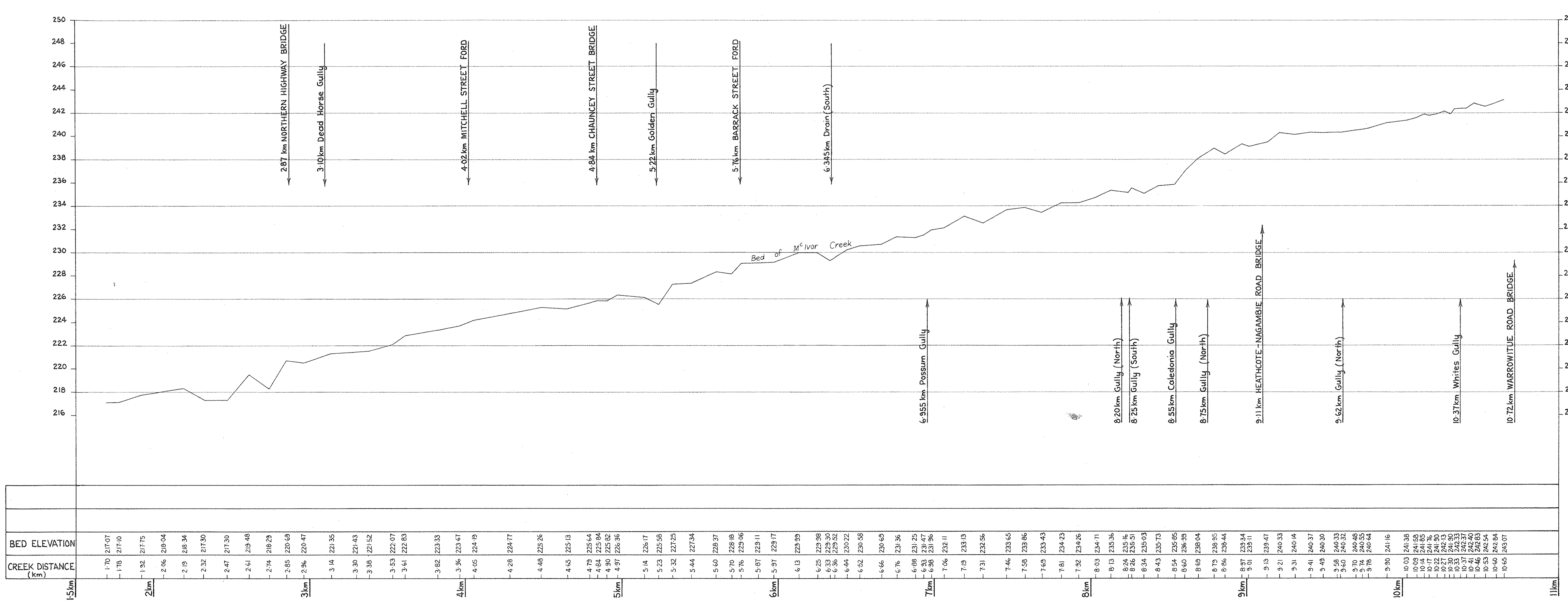
CHIEF DRAUGHTING OFFICER 19.8.88 | 20-10-88 SENIOR EXECUTIVE ENGINEER

P. J. CHIEF SURVEYOR 19.8.88

McIVOR CREEK – HEATHCOTE
ADOPTED 1% FLOOD PROFILE

CORR. NO.		PLAN NUMBER	SHEET NUMBER	REVISION
84/0911	Rural Water Commission of Victoria, SURVEY AND HYDROGRAPHIC BRANCH	201261	1 of 1	

SHEET SIZE A1



Mc IVOR CREEK LONGITUDINAL SECTION

HORIZ. 150 0 500 1000 1500 m
VERT. 1 0 5 10 15 20 m

SITE	YEAR	FLOOD LEVEL Elev.	FLOOD LEVEL Rel. %	L11425 Page	PHOTO	Description of peak flood levels
* 1	1974	224·58		17		Flood level up to underside of bridge decking.
2	1974	224·16		17		Flood level 0·1m above concrete floor of verandah 224·06. Floor of house 224·41.
3	1974	225·95		16	1,2,3, 4&6	Nail in lawn near B·B·Q. Floor of J. Halls house 226·64.
3A	1974	225·86		16	5	Dumpy at base of second Plane tree from J. Halls wood yard gate.
* 4	1974	226·82		15		Flood flowed 0·1m over road. Nail in bitumen road 226·72.
4A	Late '20s / Early '30s	226·62		15	A	At F. McDonald's old house.
4B	1916?	227·81		15		Nail at natural surface in old gateway to T. Hall's old house. This level is the highest Mr. Hall can remember, possibly 1916.
5	1974	228·02	85	13, 14		Dumpy at base of second post south of old corner post.
* 6	1974	228·93	95	13, 14		Flood 0·3m below floor level of house 229·23
7	1974	229·38	95	13, 14		Bottom of concrete pad of refrigerating unit of brick diary.
* 7A	1974	229·33	95	13, 14		Flood flowed over bridge decking 229·33 (Centre of road and bridge) Top of gravel beam 229·56 Underside of stringers 228·92
8	1974	229·27	95	13, 14		Top of concrete floor of verandah of Nº 44 Wright Street. Floor level of house 229·49.
* 9	1974	230·84		9		Flood level 0·2m above floor level (highest) of Nº 12 Wright Street 230·64.
* 9A	1974	230·52		9		Flood level 0·1m above floor level of Nº 16 Wright Street 230·42.
* 9B	1974	230·95		9		Flood level 0·3 below floor level of Nº 11 Wright Street 231·25.
* 9C	1974	230·89		9		Flood level 0·3 below floor level of Nº 9 Wright Street 231·19.
* 10	1974	231·99		10		Flood flowed 2·0m over ford. Top of road at ford 229·99. Invert of culverts under ford 229·11.
* 10A	1974	231·81		10		Flood level 0·5m± below top of decking of footbridge 232·31.
10B	1974	231·80		10		Top of brick step of gate to Nº 2 Barrack Street. (indicated by owner)
11	1974	233·13	65	8		Flood level 0·3m above nail in bitumen road in front of Nº 12 Thomas Street 232·83.
11A	1983	233·20	85	8		Flood level 0·1m above floor slab of Nº 12 Thomas Street 233·10.
12	1974	233·98		8		Nail at natural surface between small gateway in creek fence at rear of Nº 4 Thomas Street 233·73.
13	1974	239·08	75	7		Dumpy and red stake below old small G.I. Shed at Mr Ellis property.
14	1974	240·77	65	4		Nail at natural surface 3m N.E. of Silky Oak tree between house and creek.
14A	1939	242·17	60	4		Nail in angle post of Post, rail & cyclone fence in front of house.
15	1974	242·66		3		Nail in round corner post S.E. side of bridge Top of timber decking and centre of bridge and road 243·60. Underside of stringers 242·54.
16	1974	247·04	65	1, 2		Bottom of upstream side Armco rail. Centre of road and bridge 246·35. Top of gravel beam 246·51. Natural surface at site of B. Manton's house (now non-existant) 246·62 - Refer 1939 McIvor Times, copy attached to Corr. Nº 84/0911.
17	1939	248·06	50	1		Nail in edge of bitumen highway

* Denotes Flood Level indicated by Mr. T. Rowe, Ass. Shire Engineer 1974 now Shire Engineer.

NOTE - FOR PHOTOGRAPH DETAILS, SEE NOTE 2D. BELOW.

Creek Flooding

(a) Most people interviewed, particularly the older generation, were of the opinion high creek flows and levels were of a much more frequent nature now than in the past and claimed that the heavy reed growth (i.e., cumbungi and phragmites) is restricting flow and causing the creek to overflow even in moderate rainfall. It was also stated that since part of the creek bed at the northern end from near the Northern Highway bridge to approx. Coulston Court was cleared out (possibly illegally) by the sewerage construction contractor. The high flows have been less evident.

(b) To support these statements, I was informed that prior to the 1950s, the creek reserve was used as the town common with people grazing their house cows along or in the creek, thus keeping the weed and reed growth down. Floods and very high creek levels occurred only in extreme rainfall, conditions as in Easter 1939.

Creek Topography - General

The creek in the area of survey is generally of the following nature:

(a) Channel

i. Channel pattern - regular meanders.

ii. Channel shape - Trapezoidal

(b) Bank

i. Bank shape - upper (south) end of survey - steep (50°-70°) Town and lower (north) end - moderate (30° - 50°) Generally stable with very little stock damage.

ii. Bank growth - Heavy native and exotic shrub growth.

(c) Bed

Generally a series of holes and sand bars with 60% reed/weed surface cover.

i. Bed material -

Granitic sands intermixed with fine clay particles	80%
Bare clay	15%
Bed rock	5%

ii. Consolidation - fair, some packing, can be dislodged by foot.

iii. Aggradation - Minor sand build up at weed growth areas.

iv. Degradation - Nil in area of survey.

NOTES FROM SURVEYOR-IN-CHARGE
B.J. CHIRGWIN MARCH 1987.

ZONE | SW E 292700 N 5906600 | NE E 300000 N 5914400

ELEVATIONS .... TO AUSTRALIAN HEIGHT DATUM
SURVEY .... DATE - FEBRUARY 1987 CLASSIFICATION - 03 & 04 BOOKS - L 11425* (see note 1.)
PHOTOGRAPHY .... HEATHCOTE MAPSHEET 1:25 000 FLOWN OCTOBER 1982. PLAN BASE IS AN UNCONTROLLED MOSAIC.
NOTES ....*1. CREEK SURVEY WAS COMPLETED IN PART USING A NIKON DMT. THIS DATA IS STORED ON MAGNETIC TAPE T1006. (FILE MCIVORRN)

2. FLOOD LEVELS SURVEYED WERE OBTAINED BY :
A. INTERVIEW WITH ALL CURRENT AND SOME PREVIOUS LANDHOLDERS ALONG BOTH SIDES OF McIVOR CREEK.
B. INTERVIEW WITH RESIDENTS AS LISTED BY THE SHIRE ENGINEER. REFER CORR. Nº 84/0911.
C. INFORMATION SUPPLIED BY SHIRE ENGINEER SHOWN ON COPY OF SHIRE OF McIVOR 1974 FLOOD LEVEL PLANS. (SHEETS 1-4)
D. PHOTOGRAPHS SUPPLIED BY MR F. McDONALD SNR. (LATE 20'S OR EARLY 30'S FLOOD) & MRS J. HALL (1974 FLOOD). REFER 84/0911.

3. FOR ADDITIONAL INFORMATION, REFER TO
A. HEATHCOTE SEWERAGE AUTHORITY RETICULATION SEWERAGE PLANS (SHEETS 1-23)
B. SHIRE OF McIVOR, McIVOR CREEK ALIGNMENT PLANS. (SHEETS 1-15 OF 18)

CONTINUED OVER →

4. CREEK DISTANCES (km) HAVE BEEN DERIVED BY SCALING FROM THIS PLAN. ZERO (km) ADOPTED AT THE CONFLUENCE WITH MOUNT IDA CREEK.
5. FLOOD LEVEL SITE SHOWN THUS ○ (15)
6. FOR DETAILS OF SURVEY MARKS SHOWN THUS ⊚ RWC/86/Y13, REFER SURVEY BRANCH.

SCALE OF METRES
80 0 100 200 400 600 800 (APPROX.)

REVISIONS

REV	DATE	DESCRIPTION	CHKD	DOC CAT	FILMED
	MAY 1987	ORIGINAL CREATED		4	

REFERENCES

TITLE	PLAN NO.

DRAWN Mark Boyce	SURVEYED B.J. CHIRGWIN	
CHECKED G. Fountain	SUPERINTENDING SURVEYOR M.J. RANKIN	
CHIEF DRAUGHTING OFFICER 27·5·87	CHIEF SURVEYOR P.J. Ramm 27.5.87	

HEATHCOTE FLOOD STUDY (Mc IVOR CREEK)
HISTORY OF FLOODING 1916 - 1983 AND CREEK LONGITUDINAL SECTION

CORR. NO.		PLAN NUMBER	SHEET NUMBER	REVISION
84/0911	Rural Water Commission of Victoria SURVEY AND HYDROGRAPHIC BRANCH	201075	- of -	

SHEET SIZE B1

Appendix C Community Information

Table C-1 Summary of Information Collected from Community

Community Notes:	File
Comments from resident (near Craven Cres) indicating preliminary 2011 mapping less than what occurred near Craven Cres. Separate community member - 1970s flooded paddock near Craven Cres between High St and Mt Ida Creek	CommentedMaps1.pdf
Comments from SES member - indicating preliminary 2011 mapping less than what occurred in the area of Jennings and Thomas St Comments - Bill - 20 Wright St - claims property doesn't flood Comments - Ellis Knight - local drainage in gully drain causes flooding from Pohlman St Comments - Wright St community member - indicating preliminary 2011 mapping less than what occurred near 34-36 Wright St.	CommentedMaps2.pdf
Comments - indicating preliminary 2011 mapping less than what occurred near 44 Wright St Comments - local drainage flooding from gully's from the west Comments - 2001 tennis courts flooded Comments - local drainage causing flooding from gully's	CommentedMaps3.pdf
Comments - 2001 flooding from western hill gully's Comments - Tim (?) L - Mitchell St bridge floods frequently - Shakespeare St. Every time it rains a lot. Comments - sports oval flooded in 1974	CommentedMaps4.pdf
Newspaper article on flooding - part 1/3 - 22/11/2000	Scan1_PEichhorn.BMP
Newspaper article on flooding - part 2/3 - 22/11/2000	Scan2_PEichhorn.BMP
Newspaper article on flooding - part 3/3 - 22/11/2000	Scan3_PEichhorn.BMP
Photos of January 14th 2011 event and 8/9/1983 event	SpearsG_FloodPhotos.pdf
Comment - 2011 - Stockyards surrounded - preliminary mapping look okay Comment - 2011 - Wright St ok(ish) Comment - Heathcote Historical Society Comment - 1974 - over oval & Northern Hwy - picture of person rowing down High St (Nth Hwy) - Barry (note: some uncertainty over which event) Comment - Barry - knows of a 1974 flood mark Comment - Flash floods - 2001 - tennis court flooded ruining surface Comment - Wright St flooding around tennis court in 80's Comment - 32 Wright St - Janet McCharthy - has a photo of creek in flood - possibly 1934 Comment - mitigation - clean creek out at Shakespeare St	Misc. notes taken from the community bush market
Ian Hollingsworth - Notes from meeting 20140930.docx	Ian Hollingsworth - Notes from meeting 20140930.docx
Photo provided by Ian Hollingsworth	JohnFarley_2011 FloodMarker.JPG

Community Notes:	File
Old township map	P9300850.JPG
Old township map	P9300851.JPG
Old township map	P9300852.JPG
Old township map	P9300853.JPG
Old township map	P9300854.JPG
Old township map	P9300855.JPG
Old township map	P9300856.JPG
Details of photo below	P9300858.JPG
14-1-2011 at 13-50PM McIvor Hwy Bridge at Mt Ida Creek. Lake Eppalock backed up to near its highest level recorded since it was built in 1960-1962	P9300859.JPG
Details of photo below	P9300860.JPG
14-1-2011 19:39 PM. Traffic going through Lake Eppalock water at Mt Ida Creek - west end	P9300861.JPG
14-1-2011 19:39 PM. Traffic going through Lake Eppalock water at Mt Ida Creek - west end	P9300862.JPG
14-1-2011 19:39 PM. Traffic going through Lake Eppalock water at Mt Ida Creek - west end	P9300863.JPG
Photo of notes of September 1906 showing rainfall - amount is unclear 336 points	P9300864.JPG
Photo of gauge station (?)	P9300866.JPG
Photo of stream crossing (downstream of gauge?)	P9300867.JPG
Photo of stream crossing (downstream of gauge?)	P9300868.JPG

Table C-2 Notes from meeting with Ian Hollingsworth, 30 September 2014

Year	Day	Comment from Ian's family	Comments from John
1891	15 May	Heavy rain all day, creek running at bank	
1895	10 Dec	Heavy rain all day, creek running at bank	
1899	22 June	**Highest flood in creek since 1887**	
1887	**5 Nov**	**3 days of big rain leading to flood**	
1906	**9 Sept**	**336 points of rain in 12 hours. Biggest flood since 1870. One yearling steer washed away.**	
1909	May/Jun/Jul/Aug	All very wet, floods in August. 2212 points of rain that year. Flood did not do so much damage.	
1920	April	Got some 16". Nearly 2 ft. deep at Robinsons Garden. See photos with 4 bushel bags.	
1932	March	347 points and floods	
1932	April	493 points and floods	
1930	6 Dec	330 points in a day. 719 for the month total.	
1934	April good Friday	8 inches	
1939		**Hay bales were taken downstream, water was across old railway line.**	
1951	11/12/13 Jun	422 points, heavy rain	
1954		Floods	
1955	**24 Sept**	**Biggest flood since 1939. 329 points last night.**	
1956		Also wet.	
1972	Feb	6 inches in Feb, washed everything away	
1974		41 inches of rain for the year.	About 1 metre deep either side of the creek on the flat in the flood.
1979	Sept	Wet year, 4.5 inches in Sept	
1981	Jun & Jul	5 inches in Jun, 5 inches in Jul	
1984		McIvor Creek flooded a bit	

Appendix D Annual Maximum Series

Table D-3 Annual Maximum Series: 406226 Mount Ida Creek at Derrinal

Rank	Year	Discharge m^3/s	QC Code	Comment
1	2011	114.0	150	Rating extrapolated due to insufficient gaugings
2	1983	104.7	104	Records manually estimated.
3	2010	99.2	150	Rating extrapolated due to insufficient gaugings
4	1979	75.9	2	Good quality data - minimal editing required. Drift correction
5	1986	70.3	2	Good quality data - minimal editing required. Drift correction
6	1978	69.4	2	Good quality data - minimal editing required. Drift correction
7	2000	67.3	2	Good quality data - minimal editing required. Drift correction
8	1981	56.3	2	Good quality data - minimal editing required. Drift correction
9	1993	55.6	2	Good quality data - minimal editing required. Drift correction
10	1995	53.8	2	Good quality data - minimal editing required. Drift correction
11	1992	53.3	2	Good quality data - minimal editing required. Drift correction
12	1987	44.5	2	Good quality data - minimal editing required. Drift correction
13	1984	41.7	2	Good quality data - minimal editing required. Drift correction
14	1996	33.2	2	Good quality data - minimal editing required. Drift correction
15	2013	28.8	100	Irregular data, Use with caution. Beyond QC=50 or unexplained
16	1988	26.5	2	Good quality data - minimal editing required. Drift correction
17	1990	26.0	2	Good quality data - minimal editing required. Drift correction
18	1989	24.7	2	Good quality data - minimal editing required. Drift correction
19	2007	23.1	2	Good quality data - minimal editing required. Drift correction
20	1991	20.3	2	Good quality data - minimal editing required. Drift correction
21	2012	16.9	2	Good quality data - minimal editing required. Drift correction
22	1985	16.1	2	Good quality data - minimal editing required. Drift correction
23	2003	14.0	2	Good quality data - minimal editing required. Drift correction
24	1980	12.8	2	Good quality data - minimal editing required. Drift correction
25	2005	11.4	2	Good quality data - minimal editing required. Drift correction
26	1997	10.1	2	Good quality data - minimal editing required. Drift correction
27	2004	7.7	2	Good quality data - minimal editing required. Drift correction
28	2008	4.6	2	Good quality data - minimal editing required. Drift correction
29	1999	4.2	2	Good quality data - minimal editing required. Drift correction
30	2009	2.8	2	Good quality data - minimal editing required. Drift correction
31	1998	1.9	2	Good quality data - minimal editing required. Drift correction
32	2001	1.8	2	Good quality data - minimal editing required. Drift correction
33	1994	0.6	2	Good quality data - minimal editing required. Drift correction
34	1982	0.1	2	Good quality data - minimal editing required. Drift correction
35	2002	0.0	104	Records manually estimated.
36	2006	0.0	2	Good quality data - minimal editing required. Drift correction

Appendix E Flash Flood Warning Systems Roles and Responsibilities

The institutional arrangements supporting the establishment, operation and maintenance of flash flood warning systems are generally similar to those applying to riverine flood warning systems except in relation to the role of Local Government and the BoM. See Table below.

TFWS Element	Description	Responsibility (decision maker / funds)	Support (guidance only)
DATA COLLECTION & COLLATION	Site selection and, if ERTS, radio path testing	LG Thiess offer a commercial service while BoM operate on a cost recovery basis	BoM CMA DELWP
	Purchase equipment and necessary software Install and maintain for life of system	LG Opportunity to seek grant funding for capital, installation, commissioning and warranty / maintenance period costs Thiess offer a commercial service	BoM CMA DELWP
	Maintain any base station hardware and software	LG Base station will require a local system manager Support available at a cost	BoM
DETECTION & PREDICTION (i.e. Forecasting)	Establish and maintain triggers for alerts with due regard for lead time and consequence	LG Refer to WBM report and quick look indicative flood / no flood tool	BoM CMA
INTERPRETATION (i.e. an ability to answer the question "what does this mean for me - will I be flooded and to what depth".	Decide what information to make publically available (i.e. flood inundation maps, flood information cards, flood histories, etc.)	LG with VICSES	CMA
	Develop post-works flood inundation mapping and intelligence	LG	CMA DELWP
MESSAGE CONSTRUCTION	Determine audience and what message(s) will be provided	LG with VICSES Critical issue is lead time If available, simple automated messaging direct to affected community likely to work best	CMA
	Use of Emergency Alert in critical events	VICSES	
MESSAGE DISSEMINATION	SMS direct to community, LG and	LG with VICSES	CMA

TFWS Element	Description	Responsibility (decision maker / funds)	Support (guidance only)
(i.e. Communication and Alerting)	VICSES from field site or base station when alert triggers tripped		
	Wider dissemination of message (e.g. OSOM)	VICSES	
	Local flash flood Action Group	LG to champion	CMA VICSES
	Social media – Heathcote Facebook?	VICSES	LG
RESPONSE	Evacuation plan – part of MFEP	VICSES with VICPOL	LG
	Community engagement program	VICSES with LG	
	Champion the development of individual flood response plans	VICSES	LG
REVIEW	System review and update protocols	LG with VICSES	CMA
AWARENESS	Develop and implement an on-going flood awareness program	VICSES with LG	CMA

In summary, the principles applying to the provision of flash flood warning services are as follows:

- The BoM has a responsibility to provide predictions of weather conditions likely to lead to flash flooding.
- Local government has prime responsibility for flash flood warnings extending from system establishment and operation through to the provision of predictions (if required) of stream levels.
- The BoM will provide specialist technical assistance and advice to local government to assist in system establishment[21] and in relation to flood prediction techniques.

Arrangements for the delivery on other TFWS elements, including the development and application of flood response plans along with (flash) flood education and awareness programs[22], is a shared state and local government responsibility, the same as for non-flash flood warning systems.

21 It is understood that BoM will soon introduce “cost recovery” charges for installing, configuring and maintaining Enviromon software.

22 Due to the relatively short warning lead times for flash floods, it is critical that people are aware of the potential consequences prior to an event. It is therefore important that in areas with a history of flash flooding, VICSES and councils adopt flash flood education and awareness programs.

Appendix F Summary Consideration of Data Collection and Flood Detection Equipment/Systems

F.1 Prospect Environmental

Prospect Environmental is an Australia supplier of turn-key flood and other disaster warning systems. Customised solutions are offered that are designed to meet a client's needs from initial investigation through to system design, installation, testing and operation. A number of systems have been installed for Queensland Councils over the past year including for the Lockyer Valley and Somerset Regional Councils.

A flood warning system from Prospect Environmental suitable for Heathcote could include the following components:

- Two rain gauges located in the upper and middle reaches of the catchment;
- A water level / rain gauge station within Heathcote;
- A flood forecasting algorithm that will determine when to trigger the warning system;
- A means of pushing the data into the flood algorithm;
- A means of triggering the warning system based on the output from the flood algorithm;
- A warning system which could be:
    - SMS based – one SMS would trigger bulk SMS from a provider; or
    - A mass notification system that calls the community to attention via an ALERT and then gives clear instructions via pre-recorded messages: the system broadcasts:
        - An ALERT (warning tone);
        - INFORMATION and DIRECTION (via pre-recorded messages).

Software to transfer data collected by the system to other locations (e.g. BoM, State Data Warehouse) would need to be developed. Further, site and equipment maintenance arrangements would need to be established although Prospect would provide assistance on scoping out the requirement.

F.2 Smart Data Logger

A variety of smart data loggers are readily available within Australia, mostly off-the-shelf. The Campbell data logger provides a level of functionality and reliability that has seen them installed at many water resources and flood warning sites across Victoria over the past 10 years or so. They generally collect data at a combination of predetermined frequencies and exceedance criteria. When paired with a modem, they can be interrogated by computer via the telephone system (fixed and mobile) and can also be set to send an SMS to up to five (5) pre-determined telephone numbers or to email to one or more addresses when alarm criteria (either single or multi-parameter with simple or conditional rules) are exceeded. The alarm rules are user-specified and can be used (say) to alert to the likelihood of flooding and the detection of flooding. While the writer is not aware of any operational installations, it would be technically feasible to design a simple algorithm to run on the loggers and for the loggers to alarm based on the results of that algorithm. Developing and adding the algorithm would add additional cost.

A commercial SMS service provider would need to be engaged to distribute SMS alerts to multiple recipients.

Quality control of data accessed direct from site is an end-user responsibility although any data loaded to the State Data Warehouse for long-term archive would be subject to rigorous quality control and correction as part of the loading process.

F.3 Event-Reporting Radio Telemetry System, Enviromon and TARDIS

Event-Reporting Radio Telemetry System (ERTS) equipment has been installed at a large number of sites across Australia, including Victoria. Base stations are operational at a number of local offices and at the Bureau of Meteorology's office in Melbourne. All base stations host BoM supplied and maintained Enviromon software. This software manages the data checking, collation and initial alerting functions as well as the "push" of data to BoM.

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

Quality and other checks are performed automatically against pre-determined parameters (threshold checking and alerting) on the data as it is received in real-time at each base station. These checks include a comparison of rainfall and river level data received from each of the stations against a pre-set rainfall amount in a specified time period and / or against a pre-set river level threshold. The values selected reflect typical catchment response times as well as catchment and stream characteristics and can be adjusted (e.g. based on experience) so that alarms do not trigger unnecessarily or too often but do provide sufficient lead time on a potential flood event.

The local base station can be programmed to initiate an SMS message to the mobile phone (or pager) of up to five (5) key personnel[23] as soon as any of the trigger rates / values is exceeded[24.] In cases where there are multiple recipients (e.g. South Australia), BoM use a commercial service provider (currently StreetData) to distribute the SMS alerts.

Up to ten (10) registered users are able to interrogate Enviromon to look at raw and processed data. Recognising that display functionality is limited, a trio of Queensland councils developed additional software (TARDIS - Torrent And Rainfall Distribution Information System) that extends the capability of Enviromon. TARDIS is a free but licenced user-friendly web-based interface that allows rapid production of graphs and reports[25] containing both current and historical data obtained from Enviromon. Importantly TARDIS also enables, through web publishing / HTMP scripts, these data and reports to be made available to the community via the web[26.]

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

24 The SMS alert provides a 'heads up' to a possible flood event. It is aimed at flagging the need for people to more closely monitor rainfall and other flood indicators (e.g. continuing heavy rain and other local indicators of a developing flood, including radar imagery and rainfall data available from the BoM website, etc), and at enabling early activation of flood response and related plans in order to minimise the risk to life and property.

25 Graphs and reports include rainfall / water level maps overlayed on Google Maps, rainfall contour maps, rainfall / water level graphs for various time frames and time steps as well as IFD charts. TARDIS also facilitates the export of data in a number of common formats (e.g. CSV, HYDSYS, Word, Excel, PDF).

26 This can act to increase community engagement and understanding of both likely flooding and of the flood monitoring and warning system.

In its current state of development, Enviromon is not able to accommodate a real-time flood prediction algorithm.

Data is pushed from Enviromon via the web to BoM where it could be made available to the community, subject to BoM editing the web-based maps and tables to accommodate it.

While there are no purchase costs associated with either Enviromon or TARDIS, there are setup fees currently estimated to be of order $5,000 and $10,000 respectively.

F.4 DipStik

DipStik is a simple, robust, autonomous, solar powered, flood level monitoring and alarm device[27]. It samples water levels at regular intervals and compares these measurements to alarm rules that have been previously configured in the unit. When alarm rules are exceeded (e.g. water level too high or rate of water rise too great), DipStik will send SMS alert messages[28] to a number of pre-programmed recipients (up to 10) via the national mobile phone network. The unit can be remotely interrogated over the mobile phone network using simple text messages by using the device's network address (phone number) and access password. This provides current information back to the individual making the request. Such individuals do not need to be one of the (maximum of) 10 pre-programmed alert message recipients.

The DipStik unit can also be configured with a flashing warning beacon that begins to flash when a pre-set water level is exceeded. That level can be different from the alarm level. In addition, as DipStik units can be configured to communicate with up to two other units, an upstream unit that exceeds alarm criteria can "advise" a downstream unit to initiate the flashing beacon.

Set-up and control is also achieved via SMS over the mobile phone network. Additional backend infrastructure is not required.

Key event data such as maximum water level, maximum rate of rise, etc., can be obtained from DipStik after each event. A continuous record of the event is not however available.

The control module is housed securely at the top of a 3m mounting pole so in some respects it is similar to an ERTS installation.

DipStik will automatically send essential four (4) types of text / SMS message. These include:

- Periodic system heart beat test message;
- Flood alarm message;
- Flood warning message; and
- End of event message.

A DipStik rain gauge is under development as are options for achieving mass distribution of alarm messages via SMS. As with other equipment, a commercial SMS service provider (or similar) would need to be engaged to distribute SMS alerts to multiple recipients. Similarly, as with manually read gauges, data from a DipStik gauge could be uploaded to an open source cloud based website and shared in near real-time.

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[27] DipStik is not designed to continuously monitor water level (it detects and reports event / alarm situations) and can be installed out of the stream channel on what is normally dry land.

[28] DipStik will also email alert / alarm messages.

F.5 Open Source Sharing Of Community Data

Informal community open source cloud based systems (e.g. such as WeatherLink as provided by Davis Instruments, or Weather Underground) offer a no-cost opportunity to share weather data across communities. Data (e.g. rainfall data) is loaded to the cloud by registered users and within 5 to 10 minutes becomes available via the internet or a SmartPhone App to anyone looking at the WeatherLink or Weather Underground website. As it does require a user to look for and retrieve the data (i.e. there are no alerting functions for casual users[29]), its use in a flood warning context, particularly in a reasonably rapid responding catchment such as McIvor Creek, does require a flood aware community. That data then has to be translated into flood potential. If this approach was to be adopted for data collection for the McIvor Creek catchment, guidance on how to register as a data provider and how to access the data would need to be developed and made available to the community along with guidance on how to translate the raw rainfall data provided into flood potential, in terms of likelihood and severity.

The need for high quality rain gauges is minimal. Davis Instruments manufacture and supply a relatively cheap base model solar charged battery powered weather station that includes a rain gauge. The station will upload data to WeatherLink automatically according to criteria programmed into the unit by the owner. Weather Underground does not appear to have any particular requirements in relation to gauge types or quality. In both cases data is accepted “as is”: quality control is minimal and there are no minimum site, equipment maintenance or other requirements. While that may be an issue from the long term climate record and trend point of view, it is very unlikely, for a whole host of reasons, to have any detrimental impacts on the utility of the data for flood warning purposes.

While there are no long term guarantees that the websites will remain active and that data loaded to the sites will remain available to the community at large, it is suggested that if one site did fold, alternative sites would rise to fill the gap. Further, as it is recent and current data that are of real interest for flood warning for Heathcote, the loss of the website along with the long term rainfall record would not threaten or jeopardise the flood warning system.

The rainfall data would not be available from the BoM website. In addition, unlike the data available from the BoM website, the period between data updates is unlikely to be regular or for all sites to be updated around the same time. This could present some event appreciation and interpretation issues. These issues could be addressed through the guidance provided to the community as part of the flood warning system awareness element. The challenge will be to provide sufficient technical rigour within easy to understand guidance and explanations.

Whether rain gauge readers would be formally engaged or whether their involvement was left as an informal arrangement would need to be considered. The former would impose obligations on both parties to the formal engagement while the latter would need to have regard for potential liability issues.

29 There is an option that allows data to be pulled periodically from Weather Underground. The ingested data could then be processed through a flooding algorithm and linked to a messaging service. This would require some software development with the resulting system hosted either by Council, an external service provider (e.g. WBM) or perhaps NCCMA or VICSES.

Summary Consideration of Data Collection and Flood Detection Equipment/Systems

	Data Collection	Monitoring against alarm criteria	Data available via web to community	Alerting			Approx. capital, install and setup costs (notes 4 & 5)	Approx. annual on-going costs
				Mass	SMS to key personnel	SMS to community (note 7)		
Prospect Environmental	Yes Data stored at site for download	Alarm raised based on outcome of flood prediction algorithm	See note 3	Yes	Yes	Is an additional cost	$100K – field equipment $60K – algorithm $80K – mass alerting $TBA – SMS alerting	$1.8K – software $10K – field equipment (note 6)
ERTS & Enviromon	Yes	Yes – rain and river (note 2)	Via BoM website	No	Via service provider	Via service provider	$5K – radio path testing $45K – field equipment $10K – base station $5K – Enviromon	$5K – field equipment $1K – software support
ERTS, Enviromon & TARDIS	Yes	Yes – rain, river and other criteria	Via BoM website	No	Via service provider	Via service provider	As above plus $10K - TARDIS	$1K – software support
DipStik (notes 1 & 8)	Only key event data is retained for download	Yes (note 2)	Note 3	No	Yes Up to 10	Note 1	$33K – field equipment $5K – to establish alert trigger	$6K – field equipment (note 6)
Open source cloud based systems utilising community data	Data is entered to the website by registered users as data becomes available	No	Yes	No	No	No	Allow either $10K for Davis weather stations or $2K for other rain gauges	$3K for communications costs if use Davis weather stations else allow $1K float

Notes:

(7) Further development required to complete rain gauge component and establish capability to deliver an SMS to opted-in community members via a commercial service provider.

(8) Alarm criteria would be set based on consideration of rainfall amounts over set times (i.e. more than Xmm in Y hours) and exceedance of creek levels.

(9) Data can be pushed from both the DipStik and Prospect Environmental system to BoM so that it can be displayed on the BoM website. Additional cost of around $10,000.

(10) Council will need to manage land (permissive occupancy) matters.

(11) Based on 1 x combined rain and river station and 2 x rain only stations but rain only installations for the *open source cloud based systems* option.

(12) Thiess or Surface Monitoring Partnership would be cheaper.

(13) StreetData, QITPlus and other commercial service providers are able to provide a service (mostly SMS) that will result in the Heathcote community receiving an alert when the alarm trigger levels have been exceeded at the field sites. The key issues include:

- The format of the triggering message and the ability of the service provider to ingest that message;
- Whether that triggering message can initiate distribution of a pre-scripted pre-loaded community friendly SMS message;
- How opt-in / opt-out and community contact details are managed (e.g. by Council, by individuals using a service provider hosted App, etc.); and
- Costs – although note that QITPlus (mass SMS delivery) have indicated that costs could be minimal as they are keen to establish a “proof of concept” presence in Victoria.

(14) A SIM and annual plan can be provided as part of site establishment or a SIM provided by the Corporate mobile phone service provider can be used.

Appendix G Overview of Flood Warning Services Provided by BOM

G.1 Flood Warning Products

Flood Warning products and Flood Class Levels can be found on the BoM website. Flood Warning products include Severe Thunderstorm Warnings, Severe Weather Warnings, Flood Watches and Flood Warnings.

G.2 Severe Thunderstorm and Severe Weather Warnings

The BoM can forecast the environment in which severe thunderstorms or small scale weather systems that are locally intense and slow moving may occur and provides a generalised service to that effect. However, it is not yet scientifically possible to predict individual flash flooding events except on time scales of tens of minutes at the very best.

The BoM issues warnings of flash flooding when it becomes apparent that an event has commenced which may lead to flash flooding or when flash flooding has commenced. However, the BoM does not provide warnings for flash flooding for specific creeks and locations.

G.3 Flood Watches

Flood watches are issued by the BoM to notify communities and other stakeholders within broad areas (rather than specific catchments) of the potential flood threat from a developing weather situation. They provide a “heads up” of likely flooding.

Flood watches are based on an assessment of the developing weather situation and indicators of current catchment wetness. They provide generalised statements about expected forecast rainfall totals, the current state of the catchments within the target area and the streams at risk from flooding. Instructions for obtaining rain and stream level observations and access to updated Watches and Warnings are also included.

Normally, the BoM would issue a Flood Watch 24 to 36 hours in advance of any likely flooding and issue updates as required. If at any time during that period there was an imminent threat of floods occurring within an area covered by the formal flood forecast and warning service, the Flood Watch would be upgraded to a Flood Warning.

G.4 Flood Warnings

Flood Warnings are firm predictions of flooding based on actual rainfall and river height information as well as the results of stream flow based models of catchment behaviour that take account of antecedent conditions (i.e. the "wetness" of the catchment, storage levels within dams, etc.) and likely future rainfall. Releases from dams are an essential input to such models.

To assist the description of the flood warning service it provides; BoM has categorised the locations where river height data is obtained into three types as follows.

- **Forecast locations:** BoM provides a forecast of future water level as the class of predicted flooding ('minor', 'moderate' or 'major' - see BoM website for an explanation of these terms and current flood class levels) or as a predicted level and associated class of flooding for these locations.
- **Information locations:** BoM does not provide a forecast for these locations but as flood class levels are defined, does provide current water levels and trends.
- **Data locations:** BoM only provides data for these locations: no forecasts and no indication of the class (or severity) of flooding.

These locations will be further designated as either "key" or "secondary" in relation to flood forecasting activities.

- **Key locations:** may be a forecast location and the real-time data collected at site are critical to the provision of a flood forecasting service to a downstream site.
- **Secondary locations:** data from these sites are used to support hydrological modelling and flood prediction activities although their loss during an event is considered unlikely to affect BoM ability to provide a flood forecasting service.

Flood forecasts provided by the BoM are categorised as either:

- **Qualitative:** the forecast includes information about the expected class of flooding ('minor', 'moderate' or 'major' - see BoM website for an explanation of these terms and current flood class levels) and the timing of expected flooding at the location. The forecast may also include information about the expected class of flooding during the peak.
- **Quantitative:** the forecast includes the expected class of flooding ('minor', 'moderate' or 'major' - see BoM website for an explanation of these terms and current flood class levels) together with more specific information about the height and time of future water levels at the location.
- **Generalised:** the forecast comprises generalised statements advising that flooding is expected and are usually issued for areas where no locations exist for which quantitative or qualitative forecasts are provided, in the developing stages of a flood and / or when there is insufficient data available to make a specific prediction.

Not all sites for which flood class levels exist will automatically be provided with a quantitative flood forecast. It is understood that sites will be classified on the basis of flood risk and consequence. The lower rated sites will receive a qualitative warning service only. For these sites, BoM will issue warnings that advise only of the exceedance (or likely exceedance) of flood class levels along with the class of flooding expected: a detailed flood forecast will not be provided.

Generally flood warnings are issued by the BoM to the media, VICSES, Council and other stakeholder agencies and organisations. VICSES promptly alerts and disseminates such warnings to other agencies and organisations. Stakeholder agencies and organisations, including Council, are responsible for onward dissemination of the warning details.

Flood warnings usually include:

- Rainfall amounts for selected locations within and adjacent to the subject catchment;
- River heights and trends (rising, steady, falling) at key locations within the subject catchment;
- Outflows (in ML/d) from any major storages within the catchment;
- Forecasts of the height and time of flood peaks at key locations;
- A weather outlook and the likely impact of expected rainfall on flooding; and
- A warning re-issue date and time.

Note 1: The term “local flooding” and “flash flooding” may be used for localised flooding resulting from intense rainfall over a small area.

Note 2: The term “significant rises” may be used in the early stages of an event when it is clear that river levels will rise but it is too early to say whether they will reach flood level.

Additional information (e.g. weather radar and satellite images as well as updated rain and river level information, details of current watches and warnings) can be obtained from the BoM website (www.bom.gov.au/hydro/flood/vic) and the VICSES website (www.ses.vic.gov.au) or for the cost of a local call on ☎ 1300 659 217.

G.5 Flood Class Levels

The occurrence of a certain class of flooding at one point in a catchment will not necessarily lead to the same class of flooding at other points – for example along the main river and its tributary creeks or along a drainage network’s overland flow paths. This is because the floodplain physiography and use (and thus flood impact) varies along the river or flow path and also because antecedent conditions combined with where and how rainfall occurs (both in time and space) will drive how a flood develops and progresses.

It is emphasised that the flood class levels refer to that part of the watercourse where the flood effects can be related to the gauge reading.

It is important to remember that flood impact is dependent on more than the peak height or flow. The rate of rise, duration, extent and season of flooding are also important. For this reason, flood class levels can only be considered as a guide to flood severity.

Note that in the future it is likely that not all sites for which flood class levels exist will automatically be provided with a quantitative flood forecast by the BoM. It is understood that sites will be classified on the basis of flood risk and consequence. The lower rated sites will receive a quantitative warning service only. For these sites, BoM will issue warnings that advise only of the exceedance (or likely exceedance) of flood class levels along with the class of flooding expected: a detailed flood forecast will not be provided.

Appendix H Estimated Costs Flood Warning System

The following table provides indicative costs associated with the implementation and on-going operation of each of the elements proposed for the Heathcote TFWS as discussed in Section 6 of this report.

Item	Estimated cost as at April 2015 (excl GST)	Comments
In-kind estimates developed using at-cost (not commercial) rates for time, consumables, etc.		
1. Data Collection and Collation		
Recruit a minimum of 3 community rain gauge readers and secure site registration on Weather Underground. May need to provide rain gauges and assist with siting	Capital $2,000 In-kind ~$2,000 total	Will need to be led by Council. Assume manually read rain gauges, not Davis Instruments weather stations. Contractual, liability and related may need to be considered and resolved.
Prepare instructions for rain gauge readers and for community use of available data.	Capital $5,000 In-kind ~$2,000	Will need to be led by Council with input from VICSES and NCCMA. Consultant to assist.
Install DipStik rain-river gauge at Heathcote.	Capital $6,000 per site Recurrent $1,000 /year /site	Will need to be led by Council. Cost covers supply, installation, commissioning and maintenance of equipment for the first 12-months. Does not include allowances for cultural heritage assessment and service checks and markings at site.
Establish protocols for reading the staff gauges at the Barrack Street and Robinson Street fords.	In-kind ~$1,000 total	Will need to be led by Council with input from VICSES and NCCMA. Timing subject to operational and other workloads.
Add gauge boards to the upstream side of road bridges.	Capital $2,500 / set / site Recurrent $800 / year / site	Will need to be led by Council. Cost includes supply and installation as well as survey to AHD. Recurrent cost estimate is indicative only and dependent on the work scope and whether the sites are brought into the Surface Water Monitoring Partnership.
2. Flood Detection and Prediction		
Council (perhaps with input from VICSES, NCCMA and communities) to determine how the indicative quick look “flood / no flood” tool is to be used and who by.	In-kind~$2,000 total across all agencies	Expenditures relate to time costs. Timing subject to operational and other workloads.
The indicative quick look “flood / no flood” tool together with the MFEP enable those at risk to determine the likelihood and scale of possible flooding	In-kind ~$3,000 / flood	Council to maintain the tool. This could be done by plotting flood producing rainfall events and resulting flooding on the chart along with the event date. This may allow some refinement of

Item	Estimated cost as at April 2015 (excl GST)	Comments
with some lead time.		the tool over time. MFEP intelligence will also need to be updated by Council and VICSES with input from NCCMA, following flooding in the McIvor Creek catchment.
Establish flood class levels for (say) 2 x stream gauging sites.	In-kind ~$1,500 total across all agencies	Will need to be led by Council with input from VICSES and NCCMA. Expenditures relate to time costs. Timing subject to operational and other workloads.
Longer term and as part of a “best possible” system, establish a GIS based forecasting capability with web portal.	Capital ~$50,000 to setup. Operational and ongoing costs not included.	Will need to be led by Council. No indication of likely timetable for this as will depend on identification of responsible entity to develop, run and maintain the model / system.
3. Interpretation		
Make relevant parts of the MFEP and flood inundation and related mapping available to the Heathcote community.	In-kind ~$3,000	Council to work with communities on how best to achieve access.
The indicative quick look “flood / no flood” tool together with the MFEP enable those at risk to determine whether they are likely to be flooded with some lead time.	Costed above	MFEP intelligence will need to be updated by Council and VICSES with input from NCCMA, following flooding at Heathcote.
4. Message Construction and Dissemination		
Council to champion and oversee the establishment of a flood action group.	In-kind ~$5,000 to set up Recurrent ~$500 / year	Will need to clearly establish the role for the group(s) along with authority and structure. VICSES should be invited to be involved in setting up the group. Liability issues may need to be considered and resolved.
Longer term and as part of a “best possible” system, establish a web portal.	Costed above	Will need to be led by Council.
5. Response		
VICSES, VicPol and Council to complete the documentation / planning of evacuation arrangements for the Heathcote community (Appendix E of the MFEP)	In-kind ~$2,000	A required element of the MFEP.
Council and VICSES, with input from	In-kind	A required element of the MFEP.

Item	Estimated cost as at April 2015 (excl GST)	Comments
others as required, to populate the "required actions" column of the Flood Intelligence Card within the MFEP.	~$2,000	
MEMPC to sign-off on the MFEP.	Part of normal business	Will allow the MFEP to be operationalised.
Council and / or VICSES to share relevant parts of the MFEP with the McIvor Creek communities.	In-kind ~$500 to set up	Will assist the implementation of an informed local response when it next floods.
Initiate a community engagement program to communicate how the TFWS will work.	Capital $5,000 In-kind ~$3,000 to start ~$1,000 to repeat	VICSES with assistance from Council. Consultant to assist. Will need to be repeated as the system matures.
Encourage and assist residents and businesses to develop individual flood response plans.	In-kind ~$500 to promote	VICSES and Council.
6. Review and Keeping the System Alive		
Review and update protocols => who does what when and process to be followed to update material consistently across all parts of the flood warning and response system, including all parts of the MFEP.	In-kind ~$3,000	Could be led by Council in conjunction with VICSES. Consultant could assist.
Post-event review and on-going maintenance of the TFWS in order to keep it alive within the community (e.g. exercises to test procedures, website maintenance, asset replacement, operational costs, involvement with a community flood action group and so on). Includes capture of intel to the MFEP. Replacement spares if required are considered to be included in site recurrent costs.	In-kind ~$2,000 / year for activities. Operational costs are assumed absorbed into incident management activities.	Costs will vary year to year and will depend on seasonal conditions (e.g. rainfall and flooding).
7. Community Flood Awareness		
Develop and distribute a Flood Action Guide for Heathcote.	Capital up to $6,000 but expected to be covered by other funding through VICSES	Cost will depend on how much of the work is out-sourced and how much is done by VICSES as an in-kind contribution.

Item	Estimated cost as at April 2015 (excl GST)	Comments
Load and maintain flood related material (including the MFEP) on Council's (and perhaps also VICSES') website.	In-kind ~$1,000 to cover initial load Recurrent ~$500 / year	
Council to develop, review and update protocols in conjunction with VICSES and with input from NCCMA and other stakeholders as required => who does what when and the process to be followed to update material consistently across all parts of the flood warning and response system, including the MFEP, quick look tool and personal / business flood action plans. This should include the capture of information contained in Rapid Impact Assessment reports.	Capital $5,000 In-kind ~$5,000	Cost will depend on how much of the work is out-sourced. Consultant to assist.
Develop, print and distribute property-specific flood depth charts for Heathcote properties.	Capital ~$5,000	Cost will depend on how much of chart preparation is out-sourced. Does not include allowance for further floor level survey or for further processing of hydraulic model results.
Install flood depth indicator boards / markers at strategic locations within the McIvor Creek catchment and Heathcote.	Capital ~$700 / board	Locations to be determined from inundation and hazard maps.

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