# Carisbrook Flood and Drainage Management Plan

## Final Study Report

June 2013

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# PROJECT DETAILS

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|---|---|
| Project Name | Carisbrook Flood and Drainage Management Plan |
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**Cover Photo:** Aerial image of January 2011 flood (photo courtesy of The Courier).



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# GLOSSARY OF TERMS

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

| | |
|---|---|
| **Flood storages** | Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood. |
| **Freeboard** | A factor of safety above design flood levels typically used in relation to the setting of floor levels or crest heights of flood levees. It is usually expressed as a height above the level of the design flood event. |
| **Geographical information systems (GIS)** | A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data. |
| **Hydraulics** | The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity. |
| **Hydrograph** | A graph that shows how the discharge changes with time at any particular location. |
| **Hydrology** | The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods. |
| **Intensity frequency duration (IFD) analysis** | Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates. |
| **MIKE FLOOD** | A hydraulic modelling tool used in this study to simulate the flow of flood water through the floodplain. The model uses numerical equations to describe the water movement. |
| **Ortho-photography** | Aerial photography which has been adjusted to account for topography. Distance measures on the ortho-photography are true distances on the ground. |
| **Peak flow** | The maximum discharge occurring during a flood event. |
| **Probability** | A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval. |
| **Risk** | Chance of something happening that will have an impact. It is measured in terms of consequence and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment. |
| **RORB** | A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events. |
| **Runoff** | The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess. |
| **Stage** | Equivalent to 'water level'. Both are measured with reference to a specified datum. |
| **Stage hydrograph** | A graph that shows how the water level changes with time. It must be referenced to a particular location and datum. |
| **Topography** | A surface which defines the ground level of a chosen area. |

# EXECUTIVE SUMMARY

***Overview***

Central Victoria was subject to a number of widespread heavy rainfall and flood events in late 2010 and early 2011. Carisbrook was one of the towns hit hardest during this period, and was flooded in September 2010, and again in January 2011 with the majority of the township inundated in the 2011 event. The North Central CMA estimates that over 250 properties were inundated during the floods. A number of dwellings required demolition and reconstruction. The flood in January 2011 exceeded the existing mapped extent, encompassing the whole central portion of the town.

The Victorian Minister for Water, Peter Walsh, announced funding to undertake the Carisbrook Flood and Drainage Management Plan on 8th September 2011. The North Central CMA, in conjunction with the Central Goldfields Shire and the community, has developed the Carisbrook Flood and Drainage Management Plan.

***Community Consultation and Feedback***

A key objective of the Plan was to ensure strong community engagement and to demonstrate strong community support for the final Plan. A key aspect of all community engagement was to provide information to ensure community understanding and then to seek feedback verbally at meetings and through more formal feedback methods such as surveys. Three public meetings held at various stages of the Plan development were all strongly attended with over 100 community members present. Feedback from these meetings guided the development of the Plan.

Key findings of the Draft Carisbrook Flood Mitigation and Drainage Management Plan were presented to the community at a public meeting held on 15th February 2013. A summary brochure outlining the mitigation packages and preferred option along with a feedback form was provided to all meeting attendees and a three week consultation period then ensued.

During the public consultation the community provided a total of 113 submissions were received from the community, with 100 submissions supporting the preferred option and 13 not supporting the preferred option or unsure.

As a result of the extensive community consultation, and public feedback, it is clear that the Steering Committee's proposed scheme for Carisbrook has strong community support.

***Plan Recommendations***

A range of mitigation options have been assessed in detail (Section 6). Each mitigation option was assessed against a number of criteria including potential reduction in flood damage, cost of construction, feasibility of construction, environmental impact and community support.

After significant consultation with the community and stakeholders the Plan recommends a package of works that will provide protection for the vast majority of the township up to and including a 1% AEP event at a total estimated cost of $1.651 million (note: excludes social costs).

The works proposed include:

- A Western Floodway and Levee to divert overland flows to the west of the township
- A smaller levee near Williams Road to divert additional overland flow into McCallums Creek
- A non-return valve on culverts under Landrigan Road near Camp Street
- Vegetation works on Tullaroop and McCallums Creek extending from Camp Street to a point 500 m downstream of the railway bridge
- A long-term recommendation that the highway bridge be replaced with a clear-span structure when the bridge is due for replacement (or when funding becomes available).

***Next Steps***

The Carisbrook Flood and Drainage Management Plan will seek endorsement from both the North Central Catchment Management Authority Board and the Central Goldfields Shire Council prior to sending to the Victorian Government for consideration for funding. Initial funding requests will comprise implementation of the vegetation management works along McCallums and Tullaroop Creeks and detailed design of the Western Floodway and Levee Option. Other actions will include updating of the Emergency Response Plan, implementation of updated planning scheme layers, and investigation into a flood warning system.

***Acknowledgements***

The Carisbrook Flood and Drainage Management Plan was led by the Carisbrook Flood and Drainage Management Plan Steering Committee and supported by the Technical Working Group.

The study team would like to thank the Steering Committee, Technical Working Group and all others concerned for their diligence in delivering a quality study in a timely manner.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# 1. INTRODUCTION

## 1.1 Background

Following the recent flood events in Carisbrook including the large events of September 2010 and January 2011, Water Technology was commissioned by the North Central CMA to undertake the Carisbrook Flood and Drainage Management Plan. This study will include detailed hydrological and hydraulic modelling of the waterways around Carisbrook, flood mapping of the Carisbrook area and also provide recommendations for flood mitigation.

As part of the initial scoping work, the data required for modelling and mapping was collated and reviewed. This report documents the data review findings and identifies gaps in the data. It also outlines the proposed hydrological and hydraulic modelling scope and methodology.

## 1.2 Study Area

Carisbrook is a small township of 713 residents (2006 Census) 66 km north of Ballarat in Central Victoria. The township lies at the confluence of McCallum Creek and Tullaroop Creek within the wider Loddon River catchment. The combined catchment area of the two creeks at Carisbrook is approximately 1,240 $km^2$. The smaller McCallum Creek catchment encompasses the towns of Waubra, Talbot and Majorca, whilst Tullaroop Creek catchment includes Clunes, Creswick, Learmonth and Springmount to the south.

Tullaroop Reservoir is situated on Tullaroop Creek, approximately 7km upstream from Carisbrook. The reservoir has the closest flow gauge station and the potential to attenuate peak flows on Tullaroop Creek. Tullaroop Reservoir has a capacity of just under 73 GL and covers an area of 550 Ha. It is used primarily to store water for supplies to irrigated properties along Tullaroop Creek and the Loddon River and to supply water to Maryborough.

Tullaroop Creek is referred to locally as Deep Creek from the Pyrenees Highway Bridge to somewhere downstream of town, where it is again called Tullaroop Creek. For the purposes of this study and for simplification we will refer to the creek through Carisbrook as Tullaroop Creek. On the west bank of Tullaroop Creek the township of Carisbrook is of low relief and much of the town is situated on a floodplain. There is a small flood levee to the south of the town adjoining a drainage line and the Pyrenees Highway is also elevated slightly. It is unclear from the field investigations completed by Water Technology to date whether the levee is a formal piece of Council infrastructure. A number of open channels drain local runoff through Carisbrook and ultimately into Deep Creek. Flooding in Carisbrook can be caused by overland flooding from the local catchment between Carisbrook and Maryborough, as well as riverine flooding from Tullaroop Creek, McCallum Creek or a combination of each.

Apart from the populated areas of Carisbrook, land use across the catchment is primarily agricultural. It is believed that the majority of the watercourses in the area are used for stock and domestic purposes.

The study area boundaries for the hydrological and hydraulic models are described in detail under the model schematisation section. Figure 1-1 below shows the location of the main waterways around Carisbrook.

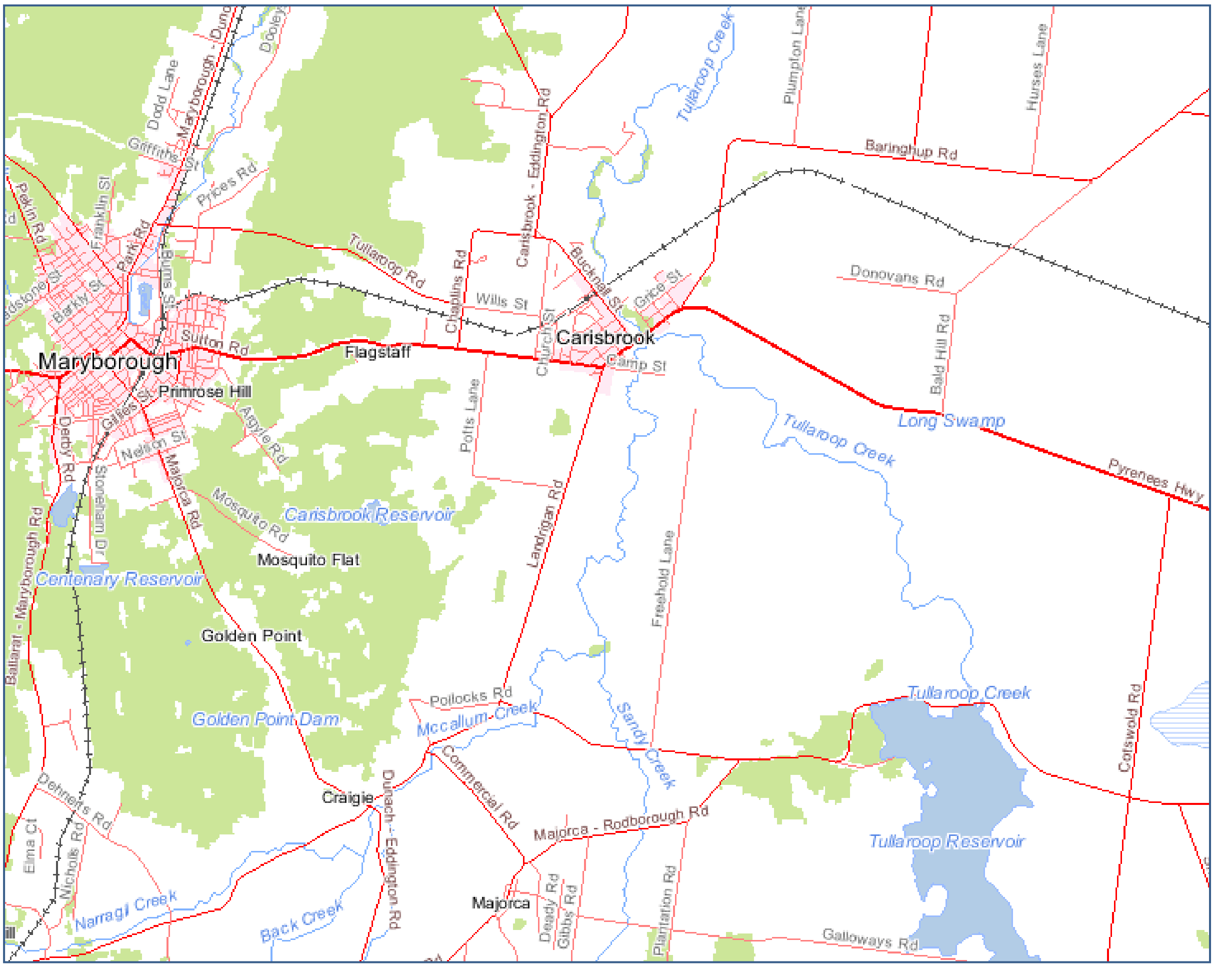



**Figure 1-1** **Major waterways surrounding Carisbrook (Victorian Data Warehouse)**

## 1.3 Flood Related Studies

Currently a Land Subject to Inundation Overlay exists along Tullaroop Creek and covers approximately 25% of the township. This overlay is thought to have been developed following the 1999 flood event and based on the estimated flood extent of that event. The event of January 2011 was of a significantly greater extent than the current LSIO. It is likely the existing 100 year extent will change considerably when re-modelled and mapped using the latest LiDAR information and design hydrology and hydraulic modelling.

**Figure 1-2 Existing Land Subject to Inundation Overlay for Carisbrook (VFD)**

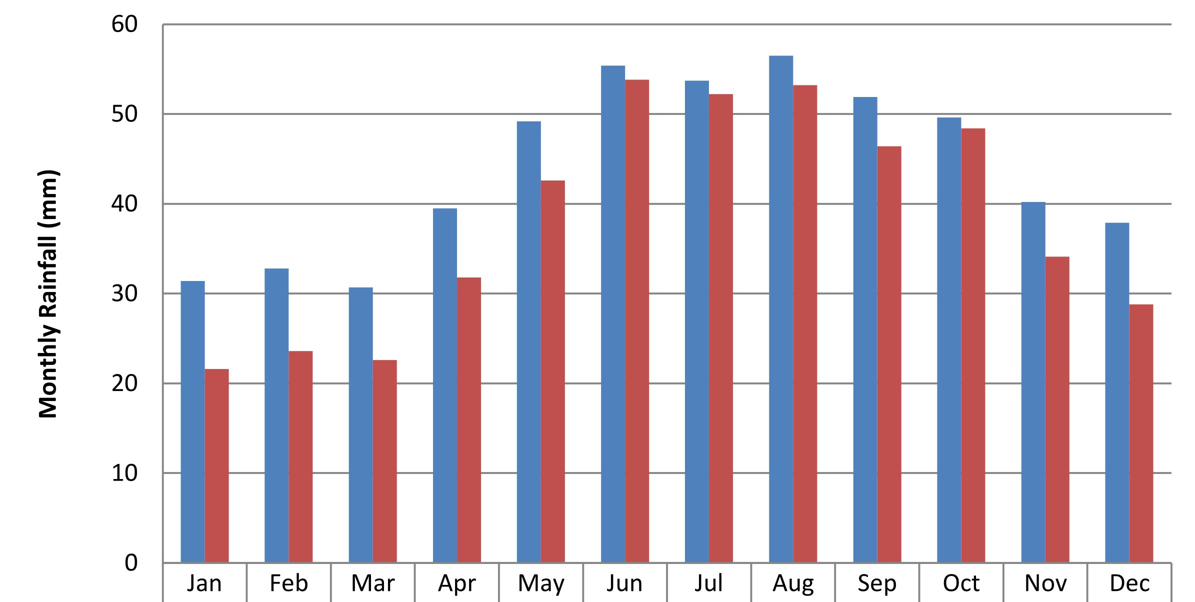
A reported entitled "Water Study for Carisbrook" was provided by NCCMA (Streets and Creek Consulting 2006). This study was completed on behalf of the Central Goldfields Shire Council and involved a review of the existing street drainage in Carisbrook. The report makes some recommendations with an emphasis on water quality as opposed to flood management.

A number of flood assessments have been carried out in Carisbrook since the 2010-11 floods. Reports were available from both Water Technology and AECOM (February 2011), with both sources acknowledging the likelihood of overland flooding from the local catchment but suggesting that the major cause of flooding in the 2010-11 floods was a result of heavy rainfall in the Tullaroop Creek and McCallum Creek catchments, resulting in the creeks overtopping the banks and flooding the township.

## 1.4 Historical Flooding

Carisbrook lies on a natural floodplain and has a history of regular flooding. Prior to the floods of 2010/2011 the next previous flood was in 1999 which resulted in significant inundation around the township. Prior to 1999 major flood events are also reported to have occurred in 1900, 1964, 1975, 1981 and 1993. More anecdotal information will be sought on these historical floods but is currently unavailable.

The January 2011 flood event is thought to be the largest flood event in Carisbrook on record. Records indicate that flooding historically occurs between the months of August and November, partially corresponding to those months which receive greater rainfall as indicated by the Bureau of Meteorology (BOM) records (Figure 1-3).




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 31.4 | 32.8 | 30.7 | 39.5 | 49.2 | 55.4 | 53.7 | 56.5 | 51.9 | 49.6 | 40.2 | 37.9 |
| Median | 21.6 | 23.6 | 22.6 | 31.8 | 42.6 | 53.8 | 52.2 | 53.2 | 46.4 | 48.4 | 34.1 | 28.8 |

**Figure 1-3 BOM historical rainfall records for Maryborough (BOM, 2011)**

## 1.5 Recent Flood Events

Central Victoria was subject to a number of widespread heavy rainfall and flood events between late 2010 and early 2011. Carisbrook was one of the towns hit hardest during this period, and was flooded in September 2010, and again in January 2011 with the majority of the township impacted by inundation. The North Central CMA estimates that over 250 properties were inundated during the floods. A number of dwellings required demolition and reconstruction. The flood in January 2011 exceeded the existing mapped extent, encompassing the whole western portion of the town, see Figure 1-4. The 90.4 mm of rainfall recorded at the nearby Maryborough rainfall gauge over the 24 hour period up till 9 am on the Friday 14$^{th}$ January was the highest daily total recorded in 131 years (BOM). Tullaroop Reservoir filled very quickly towards the end of 2010 after heavy rainfall and flooding. The storage has remained relatively full since these flooding events.

Carisbrook received very little warning during the September 2010 and January 2011 flood events. Water Technology has been involved in a number of site-specific flood inspections following the

January event and reports from residents detailed a rapid rise in the floodwater within the town from 8 am on Friday 14th January 2011. By this time, the levee and drainage infrastructure to the south of the town had breached and floodwaters had entered the main town, inundating properties. The peak within the town was estimated to be at approximately 11.15 am Friday, though there is no water level gauge in Carisbrook and this is based on anecdotal reports only.

Water Technology also received reports of floodwater emanating from the west of the town, from the local catchment not the creek. A field inspection revealed that the drainage channel to the south and west of Carisbrook, designed to convey local runoff through the town to the Creek, may have been overtopped exacerbating the flooding in the west of the town. This is believed to have contributed to the flooding in town, and is likely to have responded prior to Tullaroop Creek given the smaller catchment size.

**Figure 1-4 Flooding at Carisbrook during the January 2011 event (NCCMA)**

Discussions with residents, site observations and a review of hydrological data have been used to provide an understanding of the key flooding issues in Carisbrook. These flooding issues/spots will help guide the model schematisation. The following is a list of the key observations/theories regarding flood mechanisms during a major flood event in Carisbrook:

- Carisbrook lies on a floodplain at the confluence of Tullaroop and McCallum Creeks which are significant waterways and together have an upstream catchment area of approximately 1,200 $km^2$.
- The town of Carisbrook has a local catchment to the west and south-west of the town which is thought can play a significant role in local flooding. The size of this local catchment is approximately 21 $km^2$
- The township has a number of bluestone channels which drain local runoff through the town to the creek. In events where the capacity of these drains is exceeded water from the drains

may cause flooding, particularly in the west and south of the town. Given the smaller catchment size it is likely that these drains will respond quicker than Tullaroop Creek and McCallum Creek, but in a long duration event with in-built thunderstorms the two may coincide.

- There are several structures around Carisbrook which are thought to play a significant role in flood behaviour around the town. These structures include the Pyrenees Highway Road Bridge and VicTrack Railway Bridge across Tullaroop Creek, Council drains and informal levees.

Rough flood extents and flood levels for the January 2011 event have been supplied by the North Central CMA. The flood levels and extents will form the basis of the hydraulic model calibration process. The approximate flood extent for the January 2011 event is shown in Figure 1-5.

**Figure 1-5 Approximate flood extent in Carisbrook for the January 2011 event (NCCMA)**

# 2. SITE VISIT

A site visit was undertaken by Water Technology on 21st December 2011 with representatives from the North Central CMA and local community present for the initial part of the visit. The purpose of the site visit was to gain a better understanding of the flood issues in Carisbrook and to identify key structures for the hydraulic modelling. Information gathered from the site visit including photos has been documented in a separate report which is presented in Appendix 1.

# 3. AVAILABLE INFORMATION

## 3.1 Topographic and Physical Survey

Three sources of topographic/survey data have been obtained to prepare the hydrological and hydraulic models. These include:

- Light detection and ranging (LiDAR) data (NCCMA);
- 20 m grid topography (VicMap); and
- Field survey (CGS, VicTrack, Vicroads)

### 3.1.1 LiDAR Data

LiDAR data for the region was made available from the North Central and consisted of 2 datasets – a floodplain dataset dated 11th February 2011 and a rivers dataset dated 7$^{th}$ December 2011. A comparison of both datasets was undertaken in ARCGIS. Both datasets have the same grid resolutions (1 metre) and are recorded to have the same vertical accuracy of 0.1m with a 67% confidence interval. Upon inspection a mean elevation difference was observed where the two datasets overlap, with the Floodplain LiDAR being generally lower than the Rivers LiDAR with a mean difference across Carisbrook of approximately 15 cm. Further inspection and comparison against field survey revealed the Rivers LiDAR to be significantly more accurate and better processed than the Floodplain LiDAR.

The River LiDAR dataset was adopted in preference to the Floodplain LiDAR for this study due to its higher accuracy however it did not cover the full study extent. Sections of the Floodplain LiDAR were used to create a mosaic digital elevation model (DEM). Where the different LiDAR intersected interpolation was used between the two datasets so as to provide a smooth joining of the two datasets. The extents of the LiDAR data sets are shown in Figure 3-1 below.

A source of uncertainty was the accuracy of the 1m LiDAR in representing the smaller bluestone channels around the township. To check this, a series of cross sections (Figure 3-3) were extracted along the channel centreline and compared back to the observed channel sections.

The extracted cross sections (Figure 3-4) show that:

- The channel has a fairly consistent capacity through the town which concurs with observations and measurements taken during the site visit;
- In some places the cross-section provides a good estimate while in others it can over and underestimate the channel capacity.
- It has been concluded that the LiDAR data generally does not sufficiently represent the capacity of the Bluestone channel. Water Technology has deemed that it will be more accurate to represent the channel from measurements taken on-site and using the Rivers LiDAR to determine the channel invert levels.

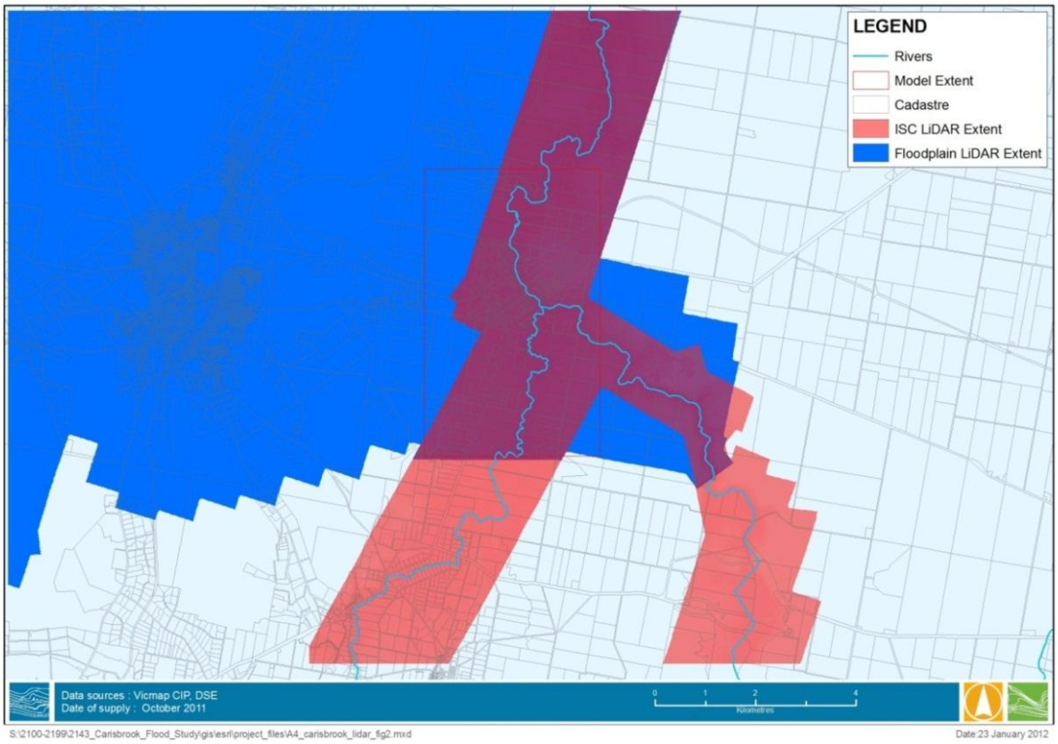



**Figure 3-1 1m LiDAR extents for Carisbrook (DSE, 2011)**

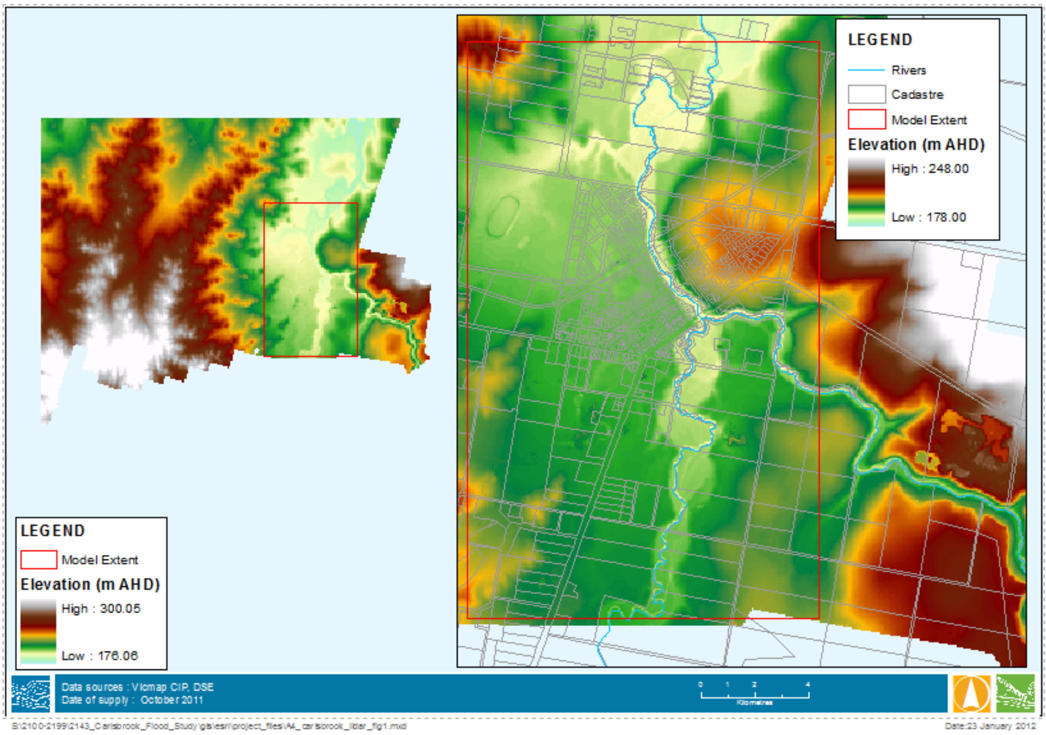



**Figure 3-2 1m Floodplain LiDAR around Carisbrook (DSE, 2011)**

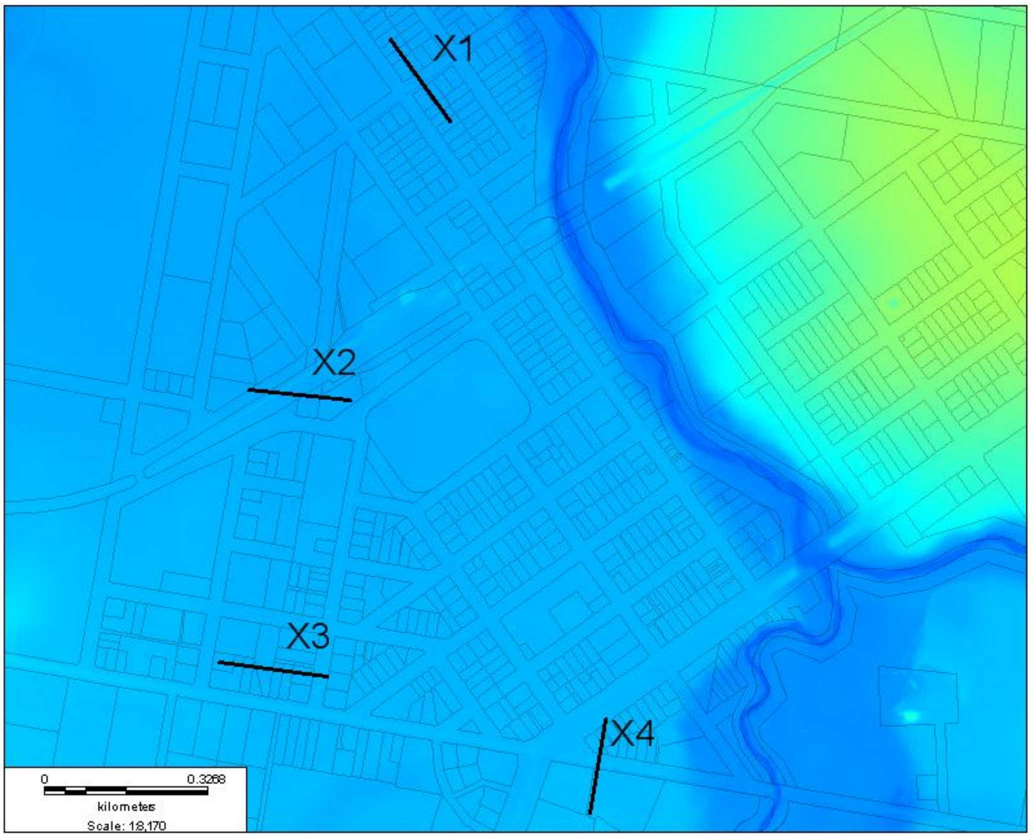
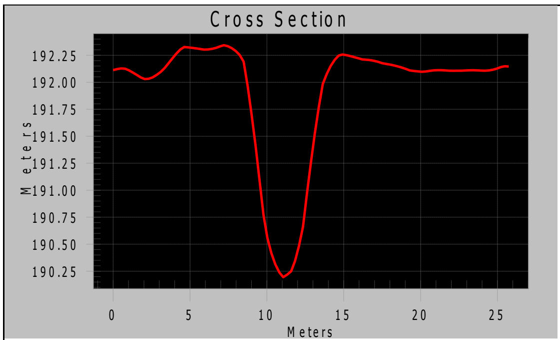
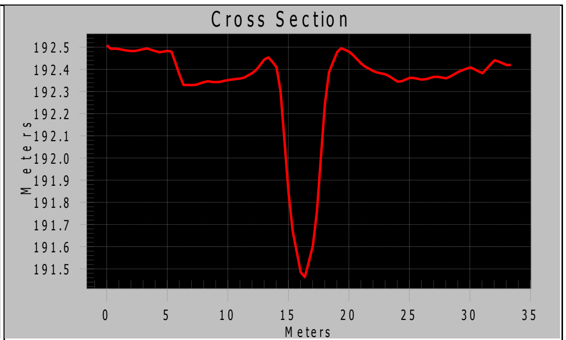


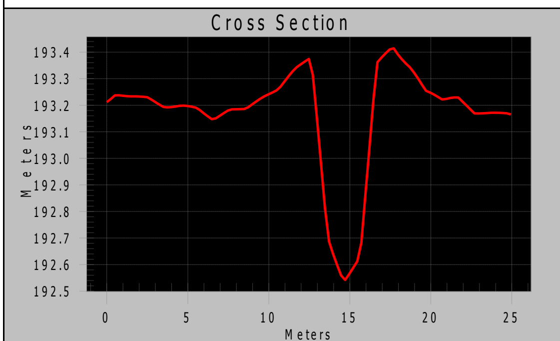

**Figure 3-3 Location of cross sections along bluestone channels around Carisbrook**



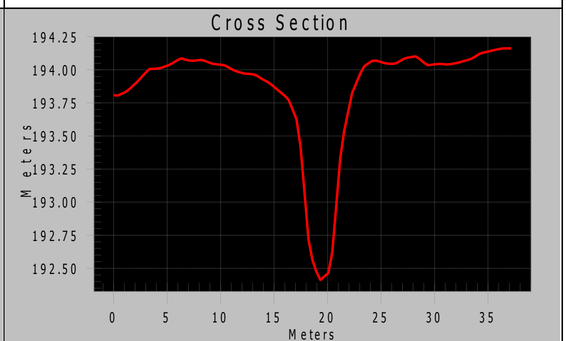

**Cross Section X 1**




**Cross Section X 2**




**Cross Section X 3**




**Cross Section X 4**

**Figure 3-4 Extracted cross sections around Carisbrook**

### 3.1.2 Field Survey

Information (dimensions, inverts) of the key hydraulic structures along Tullaroop Creek and other small waterways and drains around the township are required for input into the hydraulic model.

Some information on these structures has been provided by VicRoads and the Central Goldfields Shire. Water Technology has also made some measurements of structures during the field visit.

Figure 3-5 shows the location of the key waterway structures around the Carisbrook township while Table 3-1 details the location and characteristics of the structures. It has been identified that there is insufficient survey available for some of the major structures and so survey will be required to enable an accurate hydraulic model to be developed. Photos of these structures are also provided below.

Cross section details, dimensions and obverts of the remaining hydraulic structures were estimated during the site visit. The pipe obvert was tied back into the LiDAR data to estimate the invert level. It is expected that this method of estimating the structure inverts will be accurate to +/-150 mm and as such will not have a significant impact on the model accuracy.

**Table 3-1 Details of key hydraulic structures in Carisbrook**

| Waterway | Crossings | Structure Details | Construction Information Available | Structure Number |
|---|---|---|---|---|
| Tullaroop Creek | Pyrenees Highway Road Bridge | Eight pier road bridge | Yes | 1 |
| | Pedestrian Bridge | Two pier pedestrian bridge | Yes | 2 |
| | Railway Bridge | Nine pier railway bridge | Yes | 3 |
| McCallum Creek | Camp Street culvert | TBC | No, measured | - |
| Small waterways and drains | Railway culverts (primary) | Single Culvert | No, measured | 4 |
| | Railway culverts (secondary) | Single Culvert | No, measured | 5 |
| | Railway Bridge (Chaplins Rd) | Two pier railway bridge | No, measured | 6 |
| | Pyrenees Highway culverts (Victoria St) | Single culvert road | No, measured | 7 |

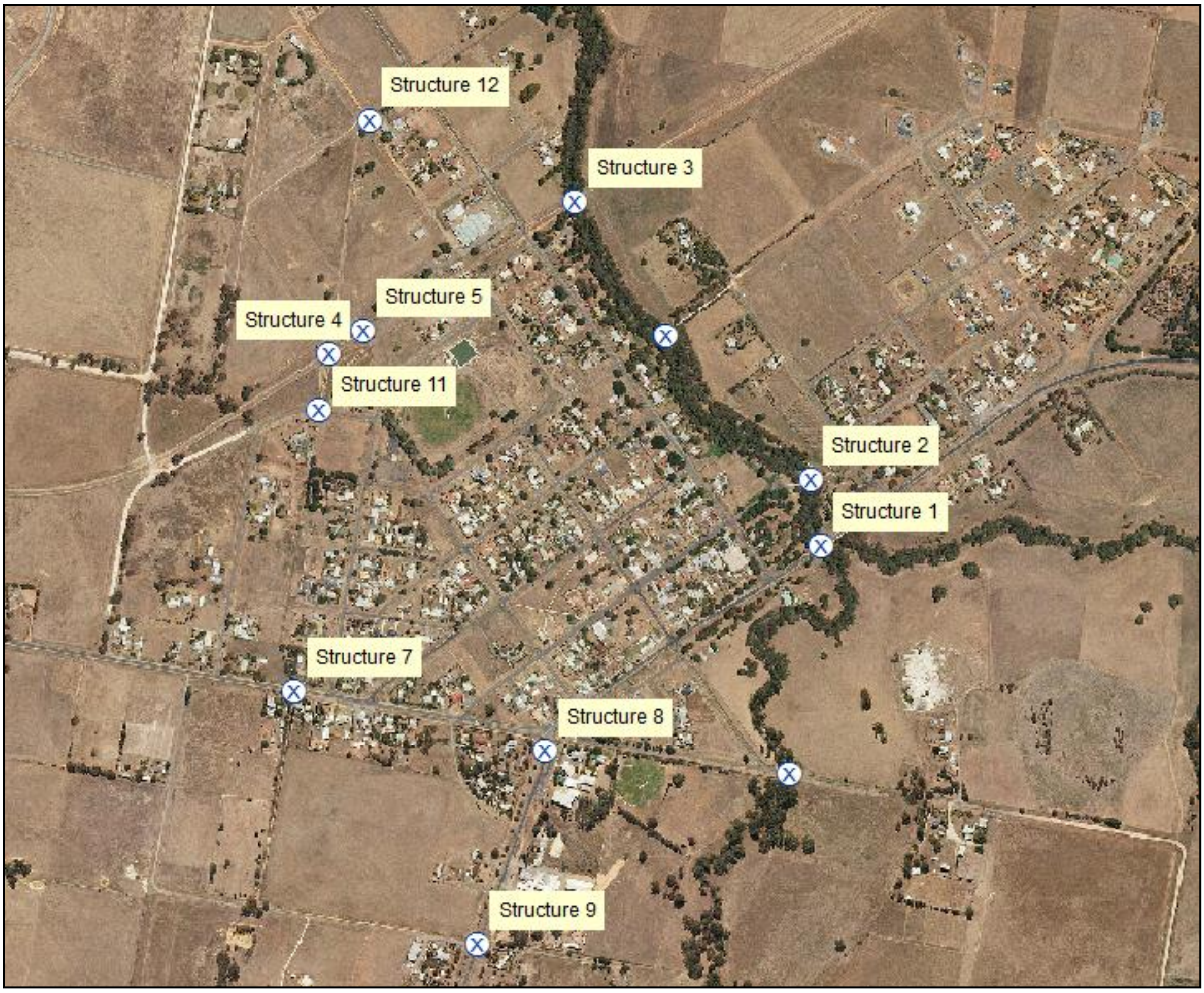



**Figure 3-5 Location of key hydraulic structures within Carisbrook**

| | |
|---|---|
|  Structure 1 Pyrenees Highway Bridge |  Structure 2 Pedestrian Bridge at Bland Reserve |
|  Structure 3 Railway Bridge |   Structure 4 Railway Culvert (primary) |
|   Structure 5 Railway Culvert (secondary) |  Structure 6 Railway Culvert (Chaplins Rd) |


**Structure 7 Victoria Street Culvert**


**Structure 8 Landrigan Rd Culvert (at school)**


**Structure 9 Landrigan/Belfast Rd Culvert**

**Structure 10 Landrigan/Williams Rd Culvert**


**Structure 11 High St Culvert**


**Structure 12 Annesly/Hood St Culvert**

### 3.1.3 Carisbrook Drainage Network

Details of the underground drainage network are important for the establishment of the hydraulic model and identification of flood related drainage issues. It should be noted however that this study is not to consider the entire stormwater system, and will be concentrating on larger flood events.

The Central Goldfield Shire provided Water Technology with GIS data of the Carisbrook drainage network and representations of kerbs, footpaths, bridges and major culverts. The pipe network layout has been received in ESRI Shapefile format. The date of these plans is unknown.

The Shapefiles indicates conduit/pit locations and conduit sizes for installed pipes in Carisbrook. The drainage network consists of 104 conduits all of which have recorded dimensions including invert levels and pipe diameters. The electronic file is missing a number of pipe branches as well as the bluestone channels which traverse the town. The missing sections have been added from the watercourses layer and marked up on Figure 3-6 below. The remainder of the drainage network in Carisbrook consists of grass swales. Most of the pipes in Carisbrook outfall into open grassed drains or swales which then flow into Tullaroop Creek (Figure 3-7).

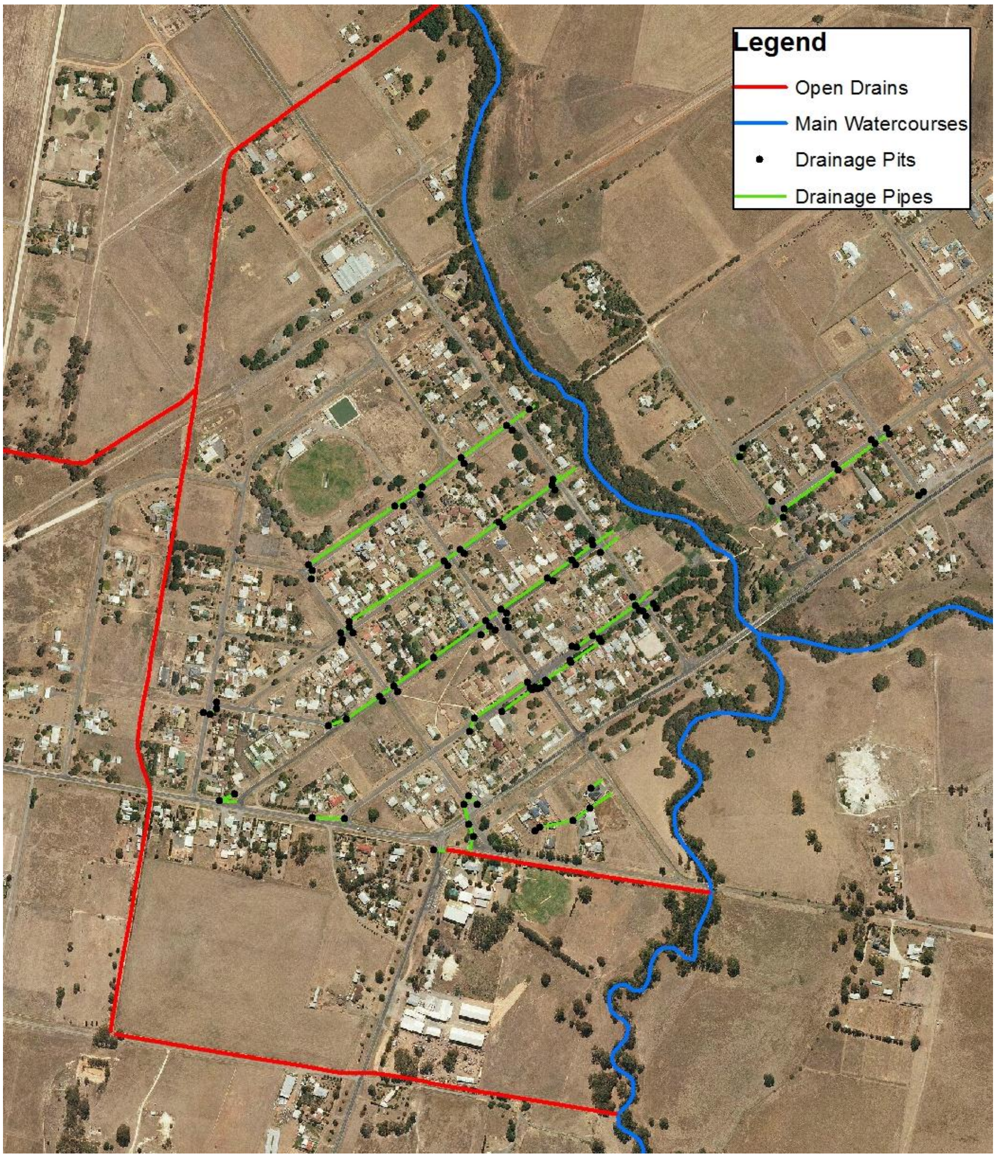



**Figure 3-6 Carisbrook Drainage Network (Central Goldfield Shire)**

**Figure 3-7 Typical swale drain at corner of Pyrenees Highway and Landrigan Road**

## 3.2 Available Hydrological Data

### 3.2.1 Streamflow Data

Streamflow data is required for the hydrological analysis. The nearest active streamflow gauges are at 'Tullaroop Creek @ Tullaroop Reservoir (Head Gauge)', located 7 km upstream of Carisbrook, and 'McCallums Creek at Carisbrook' Gauge, located approximately 5km upstream. Streamflow data records for the September 2010 and January 2011 flood events were sourced from the DSE. Additional detail regarding the availability and quality of data at these gauges is provided in Section 4.5.2 of the Hydrological Analysis.

Several other active gauges also exist upstream of Carisbrook. Two gauges are located close to Clunes and provide instantaneous data for both the January 2011 and September 2010 events and will be used in the calibration process. Gauges also exists on Birch Creek at Smeaton and at Newlyn Reservoir however records at these gauges show large gaps in data during flood events so this data is of limited use. No streamflow gauge exists in Carisbrook itself.

**Table 3-2 Streamflow gauge details**

| Station Name | Station No. | Status | Data Type | Period of record |
|---|---|---|---|---|
| Tullaroop Creek @ Tullaroop Reservoir (Head Gauge) | 407244 | Active | Instantaneous flow, station level and average daily flow | May 1960 - Present |
| McCallum Creek @ Carisbrook | 407213 | Active | Instantaneous flow, station level and average daily flow | November 1972 - Present |
| Tullaroop Creek @ Clunes | 407222 | Active | Instantaneous flow, station level and average daily flow | February 1973 - Present |
| Creswick Creek @ Clunes | 407214 | Active | Instantaneous flow, station level and average daily flow | August 1943 – Present |
| Birch Creek @ Smeaton | 407277 | Active | Instantaneous flow, station level and average daily flow | July 1975 - Present |
| Birch Creek @ Newlyn Reservoir | 407249 | Active | Instantaneous flow, station level and average daily flow | June 2006 - Present |

### 3.2.2 Rainfall Data

Both pluviograph and daily rainfall records are required for the hydrological analysis. Pluviographs record rainfall data at short time increments, indicating the temporal distribution pattern while the more common daily rainfall data provides the spatial variation over the catchment. Figure 3-8 and Figure 3-10 show the locations of rainfall stations and stream gauges in the region.

Pluviograph records (half hourly or hourly rainfall data) were available at Maryborough, Clunes, Ballarat and Bendigo stations, whereas daily rainfall records were obtained from a number of stations spread out across the catchment.

**Table 3-3 Daily rainfall station details**

| Station Name | Station Number | Period of Record |
|---|---|---|
| AVOCA (POST OFFICE) | 81000 | 1884 to present |
| NATTE YALLOCK | 81038 | 1898 to present |
| TARNAGULLA | 81047 | 1888 to present |
| DUNOLLY | 81085 | 1882 to present |
| EASTVILLE (BONNIE BANKS) | 81092 | 1968 to present |
| CAIRN CURRAN RESERVOIR | 88009 | 1949 to present |
| CAMPBELLTOWN | 88011 | 1889 to present |
| CLUNES | 88015 | 1878 to present |
| CRESWICK | 88019 | 1881 to present |
| EBERYS | 88021 | 1813 to present |
| JOYCES CREEK | 88032 | 1907 to present |
| MARYBOROUGH | 88043 | 1878 to present |
| TULLAROOP RESERVOIR | 88052 | 1881 to present |
| TALBOT (POST OFFICE) | 88056 | 1898 to present |
| YANDOIT | 88066 | 1801 to present |
| MAJORCA | 88160 | 1887 to present |
| MALDON (STUMP ST) | 88161 | 2003 to present |
| LILLICUR | 88137 | 2002 to present |
| AVOCA (HOMEBUSH) | 81122 | 1988 to present |
| BEAUFORT | 89005 | 1922 to present |
| ADDINGTON | 89106 | 1991 to present |
| BALLARAT AERODROME | 89002 | 1908 to present |
| WHITE SWAN RESERVOIR | 89048 | 1953 to present |
| SMEATON (BARDIA) | 88113 | 1968 to present |
| MOORABOOL RESERVOIR | 87045 | 1912 to present |
| BENDIGO AIRPORT | 81123 | 1991 to present |

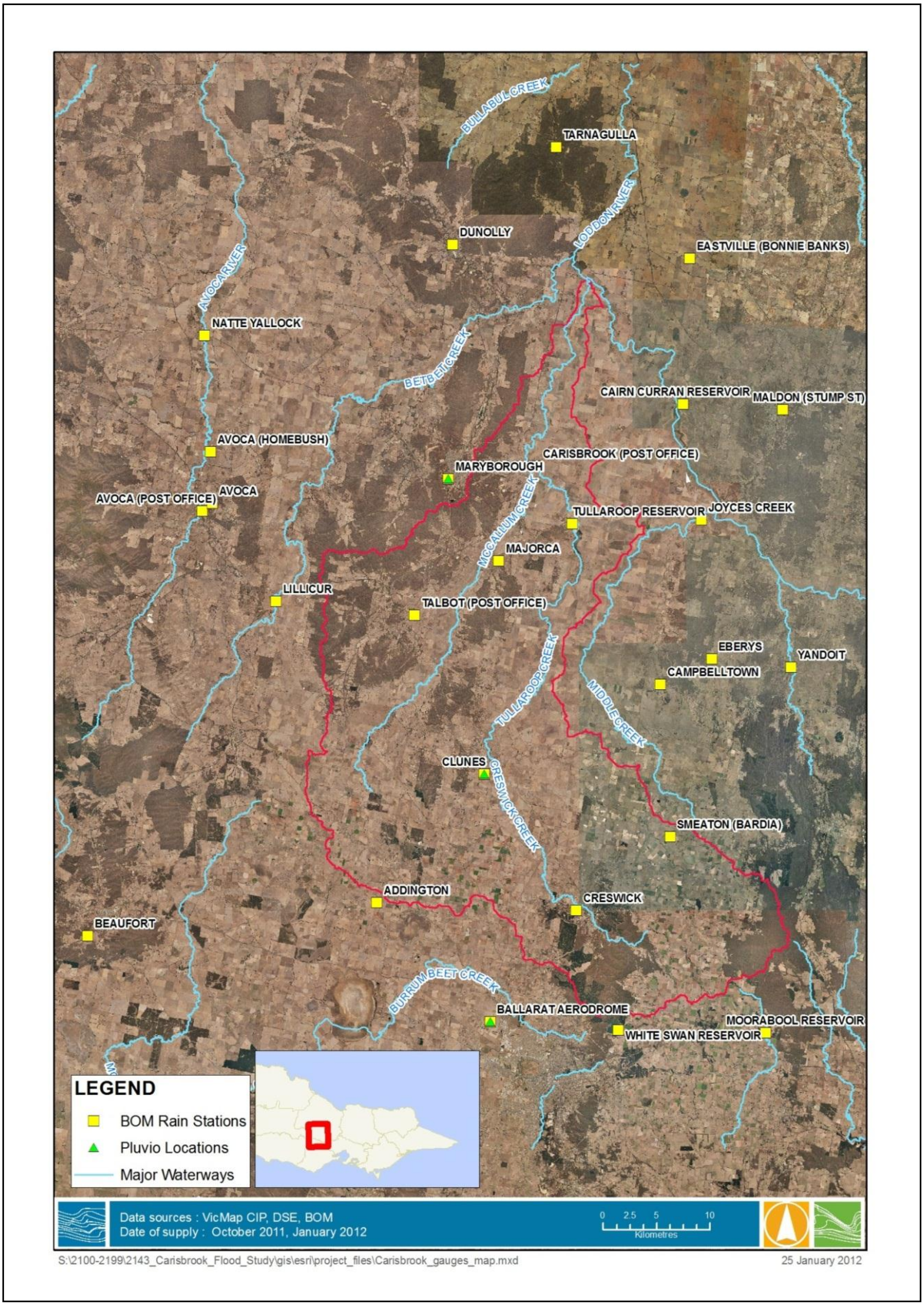



**Figure 3-8 Location of daily rainfall and pluviograph stations and streamflow gauges for this study**

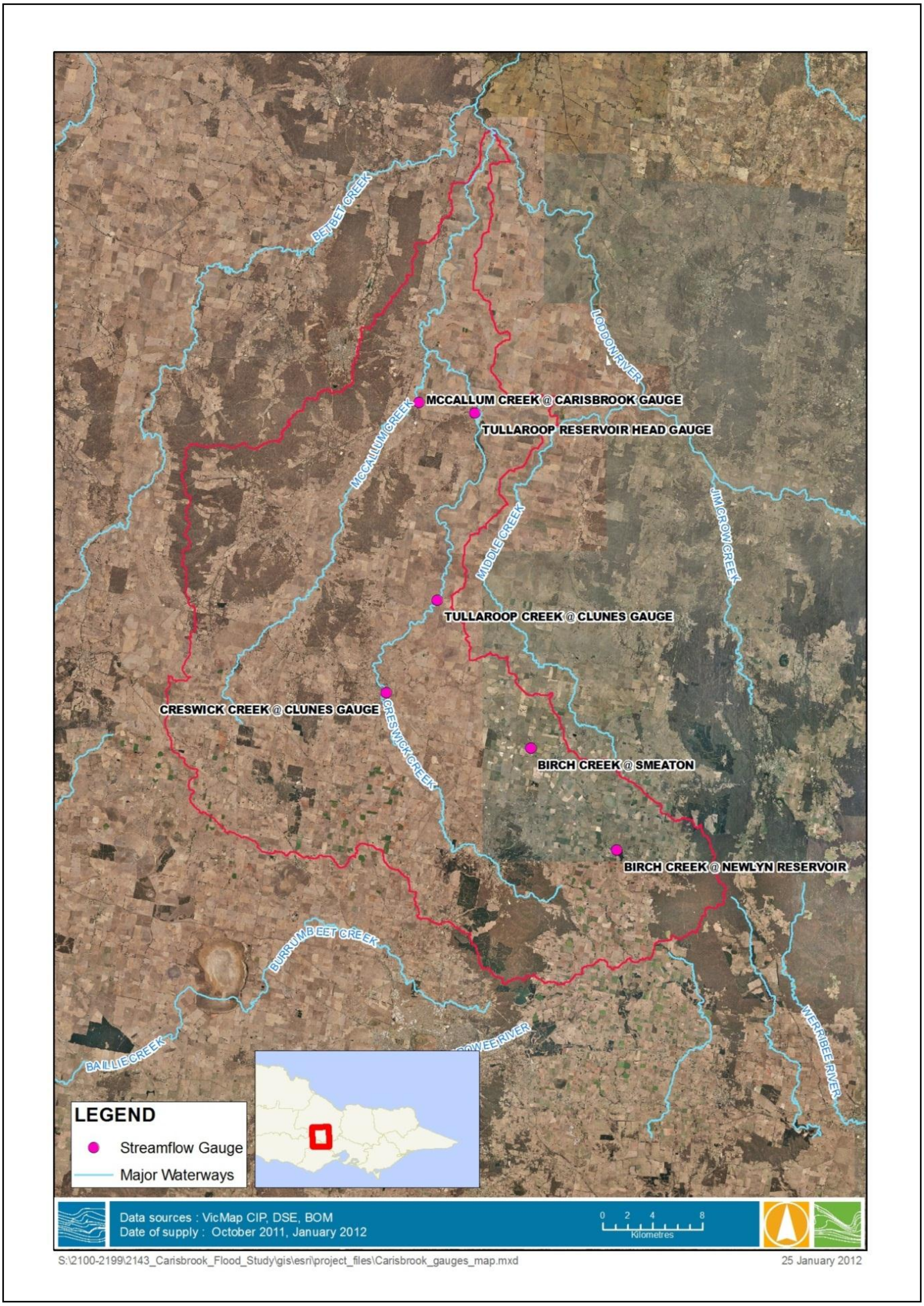



**Figure 3-9 Location of streamflow gauges for this study**

### 3.2.3 Storages

The main water storage with potential to impact flooding at Carisbrook is Tullaroop Reservoir, situated on Tullaroop Creek. The reservoir is located approximately 7 km upstream from Carisbrook and is a Goulburn-Murray Water asset. The reservoir has the closest flow gauge station and the potential to attenuate peak flows on Tullaroop Creek.

Tullaroop Reservoir has a capacity of just under 73 GL and covers an area of 550 Ha. It is used primarily to store water for supplies to irrigated properties along Tullaroop Creek and the Loddon River and to supply water to Maryborough. Historic level and volume records and rating tables were provided by Goulburn-Murray Water. Gauge data indicates that at the time of the September 2010 event the reservoir was at approximately 60% capacity while following a wet few months the reservoir was close to full capacity at the time of the January 2011 event.

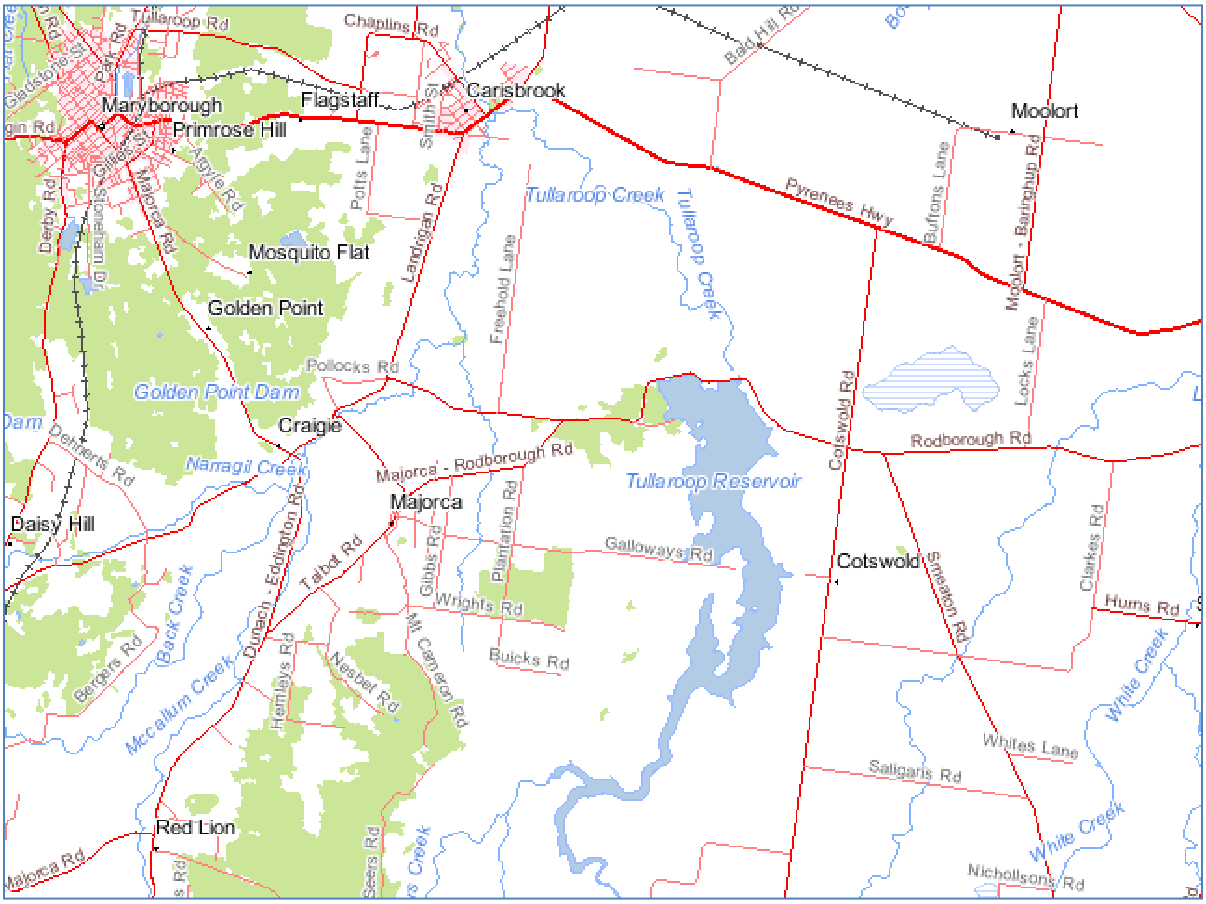



**Figure 3-10 Location of Tullaroop Reservoir upstream of Carisbrook (DSE, 2011)**

There are also a number of other smaller water bodies located along tributary reaches within the study area. These storages are too small to have a significant impact on the flows in Tullaroop and McCallum Creeks and will not be considered in the hydrological modelling.

It is important to include the main storages within the hydrological model as they can have a significant impact on the downstream hydrographs. Stage-storage relationships, spillway rating curves and gauged water levels within the storages were provided for Tullaroop Reservoir.

A report entitled "Review into the operation of storages during flooding" (SKM 2011) was provided by Goulburn-Murray Water. This report formed part of the review of the 2010-11 floods and examined the operation of a number of storages including Tullaroop Reservoir during the large events of 2010-2011. It reported that the reservoir provided some flood mitigation benefit and "did not contribute to increasing the frequency, magnitude or impact of the floods". It also found that the reservoir had a greater contribution to mitigate floods from September to November 2010 when the reservoir was at a lower volume. By December 2010 it was close to capacity and had less of an ability to mitigate flows, however during the January 2011 event the flow was still attenuated by approximately 20,000 ML/d.

## 3.3 Other Background Data

High resolution (1m) aerial images of Carisbrook were sourced from Vicmap data sets. For flood mapping, the most recent aerial imagery (20$^{th}$ January 2011) will be used as a background overlay.

Other background data available for the study includes:

- Numerous photos of the flood events including aerial imagery of the September 2010 and January 2011 floods;
- Video of the September 2010 and January 2011 flood events;
- Approximate flood extent of the January 2011 event undertaken by the CFA and provided by the Central Goldfield Shire;
- List of flood affected properties in Carisbrook for the January 2011 event supplied by Central Goldfields Shire
- Field survey of two properties in Carisbrook supplied by Central Goldfields Shire
- 0.5 m contour GIS data supplied by Central Goldfields Shire
- A report by geologist David Choy entitled "A proposal for flood prevention by recharging aquifers in the Loddon and Murray-Darling basins". This report proposed the diverting of flood water during large flow events into storage basins which lie above aquifers. It is proposed the flood water will then drain into and recharge the aquifer.
- A reported entitled "Water Study for Carisbrook" completed by Streets and Creeks Consulting on behalf of Central Goldfields Shire Council. This report involved a review of the existing street drainage in Carisbrook and made some recommendations with an emphasis on water quality as opposed to flood management.
- Asset and cadastral information sourced from the NCCMA.

# 4. HYDROLOGICAL ANALYSIS

## 4.1 Introduction

This report details the hydrological modelling component of the Carisbrook Flood and Drainage Management Plan.

## 4.2 Hydrological Study Area

The township of Carisbrook lies at the confluence of McCallum Creek and Tullaroop Creek within the wider Loddon River catchment. The combined catchment area of the two creeks at Carisbrook is approximately 1,240 $km^2$. The smaller McCallum Creek catchment encompasses the towns of Waubra, Talbot and Majorca, whilst Tullaroop Creek catchment includes Clunes, Creswick, Learmonth and Springmount to the south.

To the west and south-west of Carisbrook lie a number of smaller catchments which feed several small waterways and drains that pass through and around the township. These local catchments have a combined area of approximately 25 $km^2$.

Tullaroop Reservoir is situated on Tullaroop Creek, approximately 7 km upstream from Carisbrook. The reservoir has the closest flow gauging station to Carisbrook and has the potential to attenuate peak flows on Tullaroop Creek. Tullaroop Reservoir has a capacity of just under 73 GL and covers an area of 550 Ha. It is used primarily to store water for supplies to irrigated properties along Tullaroop Creek and the Loddon River and to supply water to Maryborough.

The catchment area upstream of Creswick consists largely of cleared agricultural land with some pockets of forested areas located mainly in the upper catchment close to Creswick. A number of rural towns are located within the catchment area including Creswick and Clunes. Since European settlement in the region the land has been cleared however an accurate assessment of land use changes in that time has not been made.

The topography consists of relatively low relief areas in the lower catchment and more undulating topography in the upper catchment. Evaporation charts of the region indicate a mean annual potential evaporation (PET) of approximately 1,100 mm. The mean annual rainfall across the study area varies from 755 mm at Creswick in the upper catchment to 481 mm at Tullaroop Reservoir located 7 km from Carisbrook in the lower catchment.

## 4.3 Hydrological Modelling

### 4.3.1 Overview

A hydrological model of the catchment was developed for the purpose of extracting design flows to be used as boundary conditions in the hydraulic model. The rainfall-runoff program, RORB (Version 6) was used for this study.

RORB is a non-linear rainfall runoff and streamflow routing model for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reach storages. Rainfall is input to the centroid of each subarea. Specific losses are then deducted, and the excess routed through the reach network.

A RORB hydrological model was developed using MiRORB (Mapinfo RORB tools).

The following methodology was applied to construct the RORB model:

- Tullaroop, McCallum Creek and the local catchments were delineated upstream of Eddington;
- The catchments were divided into subareas based on the site's topography and required hydrograph print (result) locations;
- A RORB model was constructed using appropriately selected reach types and fraction impervious values and rainfall information specific to the catchment;
- For the ease of future use a naming convention was applied to each sub-area node based on the location in the catchment and the catchment the sub-area lies in. Sub-areas were prefixed with the initial 3 letters of the catchment named followed by A-Z with A being the sub-area being at the very top of the catchment. For example the two sub-areas at the top of Tullaroop Creek catchment were named Tul_A, Tul_B and so forth.
- The model parameters were calibrated to selected historical flood events (September 2010 and January 2011). The calibration involved matching the modelled hydrograph to the observed hydrograph at the 3 active streamflow gauges along Tullaroop Creek. Unfortunately no gauge data existed for McCallum Creek for the historic calibration events;
- Hydrographs calculated by the September 2010 and January 2011 model runs were extracted for use as inflow boundaries for the hydraulic model calibration;
- Using the model parameters from calibration and other appropriate inputs, the RORB model was run in design mode for the 5, 10, 20, 50, 100 and 200 year ARI events. Calculated flows for these events were extracted for input into the hydraulic model; and
- The RORB model was used to test the performance of Tullaroop Reservoir as a flow retarding basin by comparing the downstream modelled hydrograph using the 100yr ARI design event, with various initial drawdown levels in the reservoir. This option was considered as it was something that the community wished to be investigated, however it is clearly understood that Tullaroop Reservoir is not designed to be operated as flood mitigation and has an important water supply role for the region.

## 4.4 RORB Model Construction

### 4.4.1 Subarea and Reach Delineation

The RORB model was constructed from the upper reaches of both McCallum and Tullaroop Creek catchments, extending downstream to Eddington. The outer catchment boundary for the hydrological assessment is shown in Figure 4-2, covering an area of 1,344 km$^2$. The total size of the McCallum Creek and Tullaroop Creek catchments upstream of Carisbrook is 1,237 km$^2$. The area of the smaller local catchment to the west and south-west of Carisbrook is 25 km$^2$. The catchment boundary was delineated using Vicmap 20 m contour dataset and the watercourses layer.

The RORB model was constructed using MapInfo RORB tools (MiRORB), the RORB Graphical User Interface (RORB GUI) and RORBWIN V6.0. Initially a catchment boundary was delineated from the available 20 m contours of the area. Sub-area boundaries were then delineated using ARCHydro and revised as necessary to allow flows to be extracted at the points of interest.

RORB requires a minimum of 3 to 5 sub-areas upstream of a location to extract a hydrograph that is considered accurate. For this reason the local catchment around Carisbrook was delineated into smaller sub-areas than the upstream catchments. To account for this difference in sub-area size and reaches, two interstation areas are modelled was placed at the confluence of McCallum and Tullaroop Creeks. This enabled different parameters to be applied to the upper and lower catchments.

The final RORB model included 421 sub-areas. It is acknowledged that this is a considerably larger number of sub-areas than in a typical RORB model. Traditionally, RORB models have been constructed by first manually delineating catchments into approximately 20 sub-areas. With modern GIS tools it is now much faster to delineate a catchment and construct a RORB catchment file and so a relatively fine delineation can occur with relative ease.

In this instance a finer delineation was necessary to enable flows from the small local catchments around Carisbrook to be properly modelled. The complex local catchment around Carisbrook involves a number of small tributaries flowing through the area. Most of these tributaries will be an inflow into the hydraulic model and so required the minimum number of upstream catchments above each inflow location to ensure appropriate routing of flows and smoothing of the hydrograph. This necessitated a finer delineation than a traditional RORB model would require. Larger sub-areas were used in the upper catchment so the model did not become too unwieldy however to ensure the discrepancy in size between the upper catchment and lower sub-areas was not too great a relatively fine delineation was used in the upper catchment as well.

In addition, a large number of sub-areas ensures that for future use flows can be extracted at almost any location along the major waterways and smaller tributaries around Carisbrook with the confidence that there is adequate routing of flows above that location.

We acknowledge that many of the regional parameter prediction equations are based on a RORB model layout that includes a smaller number of subareas and therefore may not be directly comparable. The RORB model being used in the Carisbrook study has been calibrated to two large events at two streamflow gauges to obtain the parameters used in design which is considered to be a superior method of parameter selection. Comparison to prediction equations has been carried out for completeness only.

A summary of the RORB model characteristics is shown in Table 4-1 below while Figure 4-3 demonstrates the sub area delineation around the Carisbrook township. $D_{av}$ is a measure of the average flow distance in the channel network of sub area inflows and with catchment area gives an indication of the shape of the catchment.

**Table 4-1 Summary of RORB Model Characteristics**

| Catchment | Number of sub areas | Mean sub area size ($km^2$) | $d_{Av}$ (km) |
|---|---|---|---|
| Upper | 314 | 3.94 | 44.69 |
| Lower | 103 | 1.02 | 20.48 |

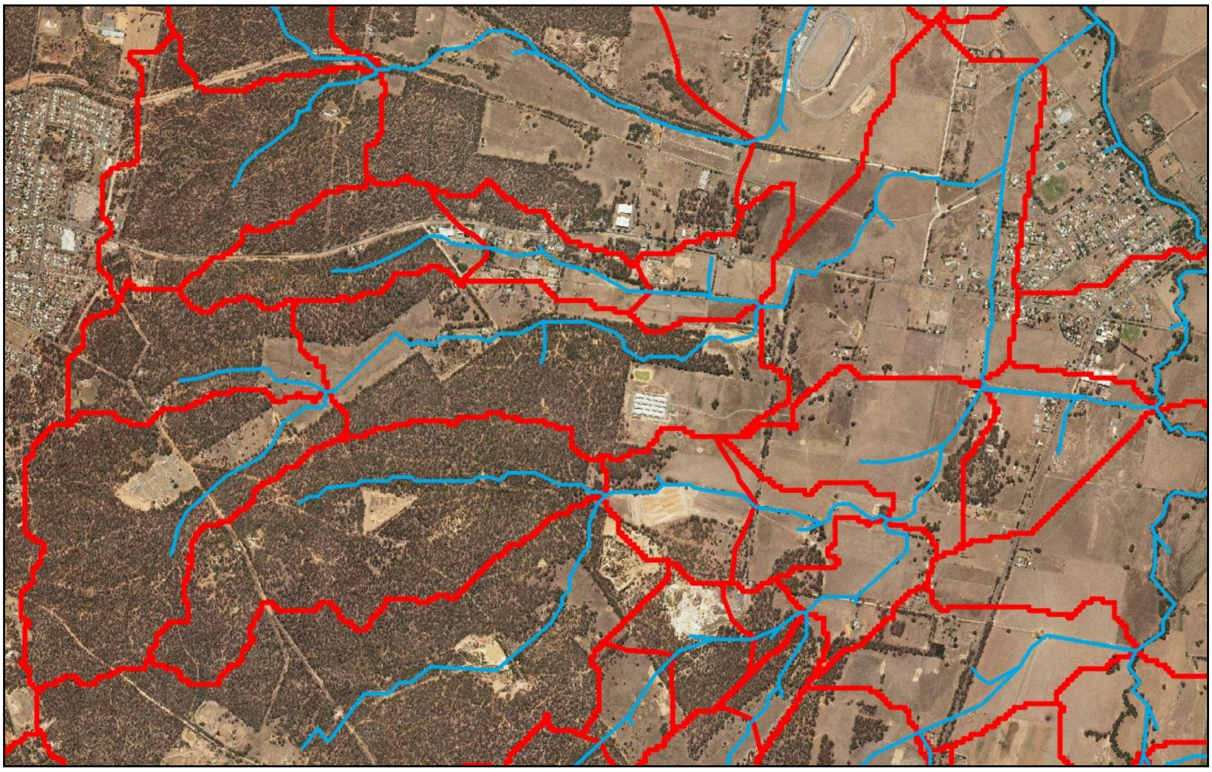


**Figure 4-1 RORB sub area delineation around Carisbrook township**

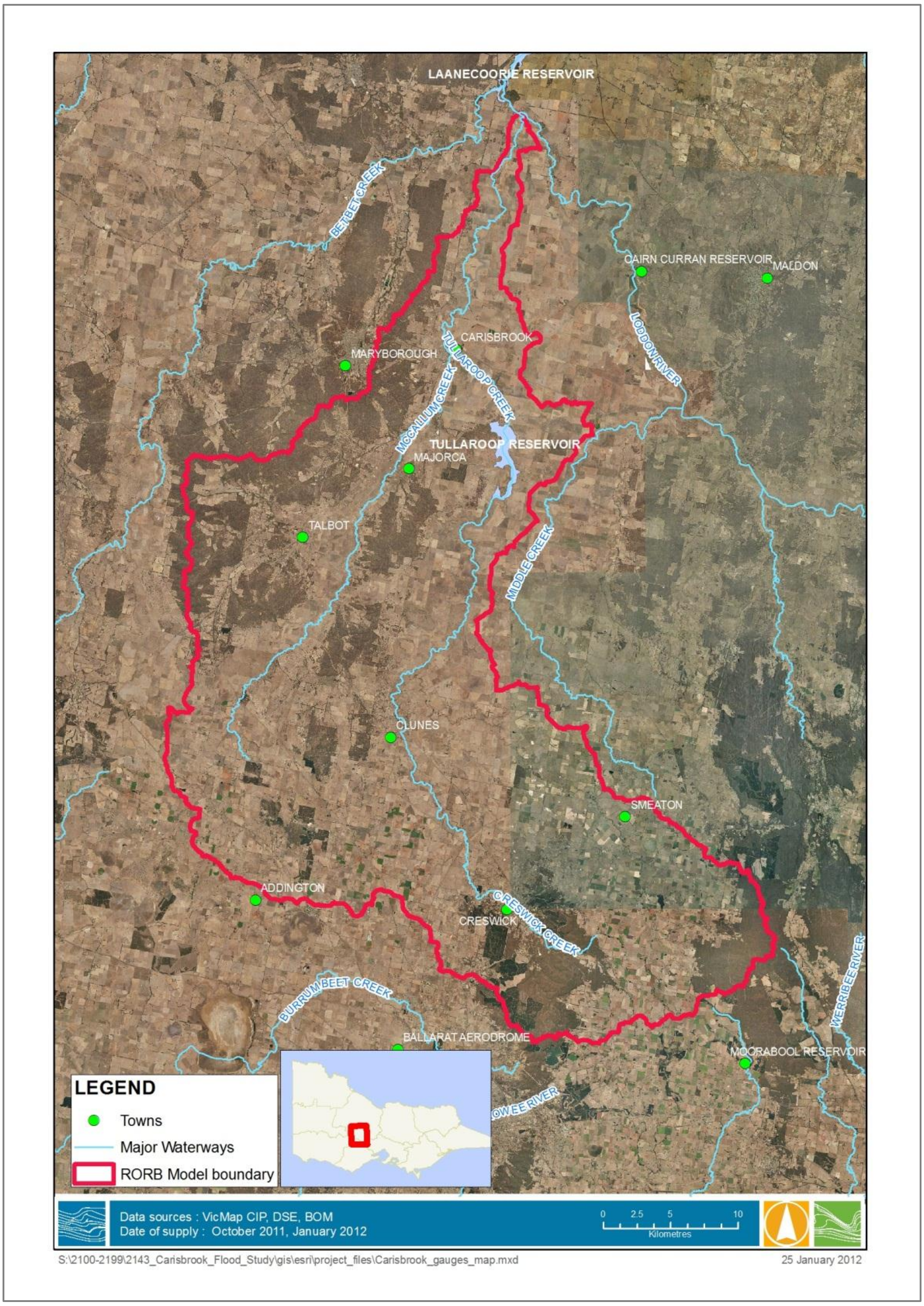



**Figure 4-2 RORB model boundary**

***Model Structure***

### Sub-area nodes

Nodes were placed at areas of interest such as flow gauging sites, the confluence of McCallum and Tullaroop Creeks and the junctions of any two reaches. Nodes were then connected by RORB reaches, each representing the length, slope and reach type.

### Reach types

Reach types in the model were set to be consistent with the land use across the catchment. Five different reach types are available in RORB (1 = natural, 2= excavated & unlined, 3= lined channel or pipe, 4= drowned reach, 5= dummy reach). Drowned reaches were used within storages. Each reach type was determined from site visits and aerial photography. Given the rural nature of the catchment, the reaches were set to natural. Reach slopes were calculated using the Vicmap 20m DEM dataset, but are not used within RORB for natural reaches.

### Model print locations

Design hydrographs were extracted at the following locations:

- Tullaroop Creek branch, at a location approximately 2 km upstream of the confluence with McCallums Creek;
- McCallums Creek at a location approximately 3km upstream of the confluence with Tullaroop Creek.
- 9 unnamed tributaries to the west, south and east of Carisbrook

The locations of these points are shown in Figure 4-3. There were also numerous other print locations throughout the model to assist in calibration and understanding of model behaviour. These included points of interest such as downstream of the confluence of Tullaroop and McCallum Creeks and Tullaroop Creek immediately downstream of the railway bridge. Print locations were also placed at all stream gauge locations within the catchment to assist with calibration.

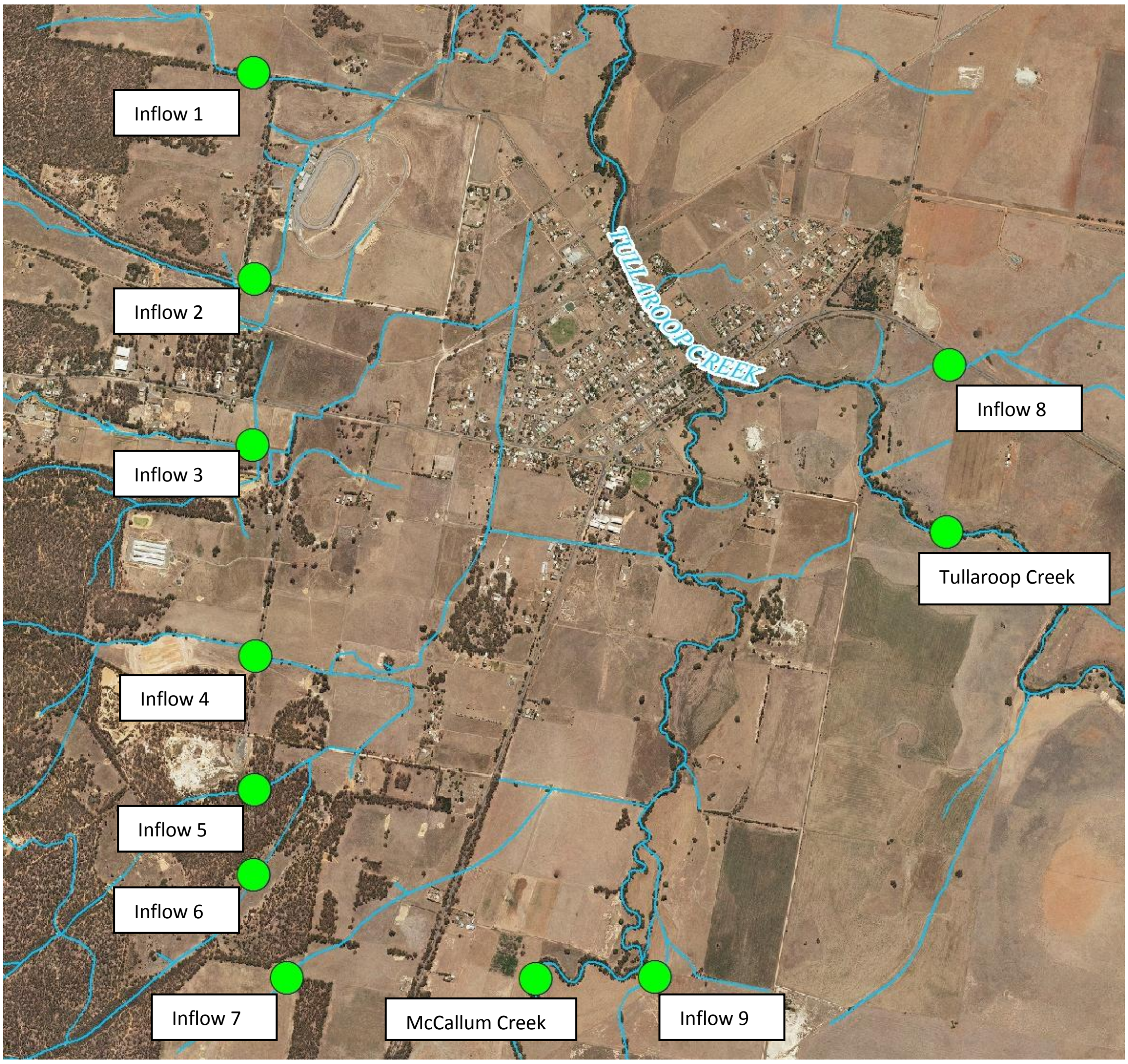



**Figure 4-3 Location of RORB extracted hydrographs around Carisbrook**

### 4.4.2 Storages

The main water storage with potential to impact flooding at Carisbrook is Tullaroop Reservoir, situated on Tullaroop Creek. The reservoir is located approximately 7 km upstream from Carisbrook and is a Goulburn-Murray Water asset. The reservoir has the closest flow gauge station to the town of Carisbrook. Tullaroop Reservoir has a capacity of just under 73 GL and covers an area of 550 Ha and has the potential to attenuate peak flows on Tullaroop Creek.

Tullaroop Reservoir was defined in RORB using a stage-storage (H-S) relationship and a storage-discharge (S-Q) relationship. Historic level and volume records and rating tables were provided by Goulburn-Murray Water. An analysis of the reservoir data indicates that at the time of the September 2010 event the reservoir was at approximately 60% capacity. Following a few wet months the reservoir was close to full capacity at the time of the January 2011 event. During the RORB model calibration the initial drawdown level was set to that recorded in the reservoir data.

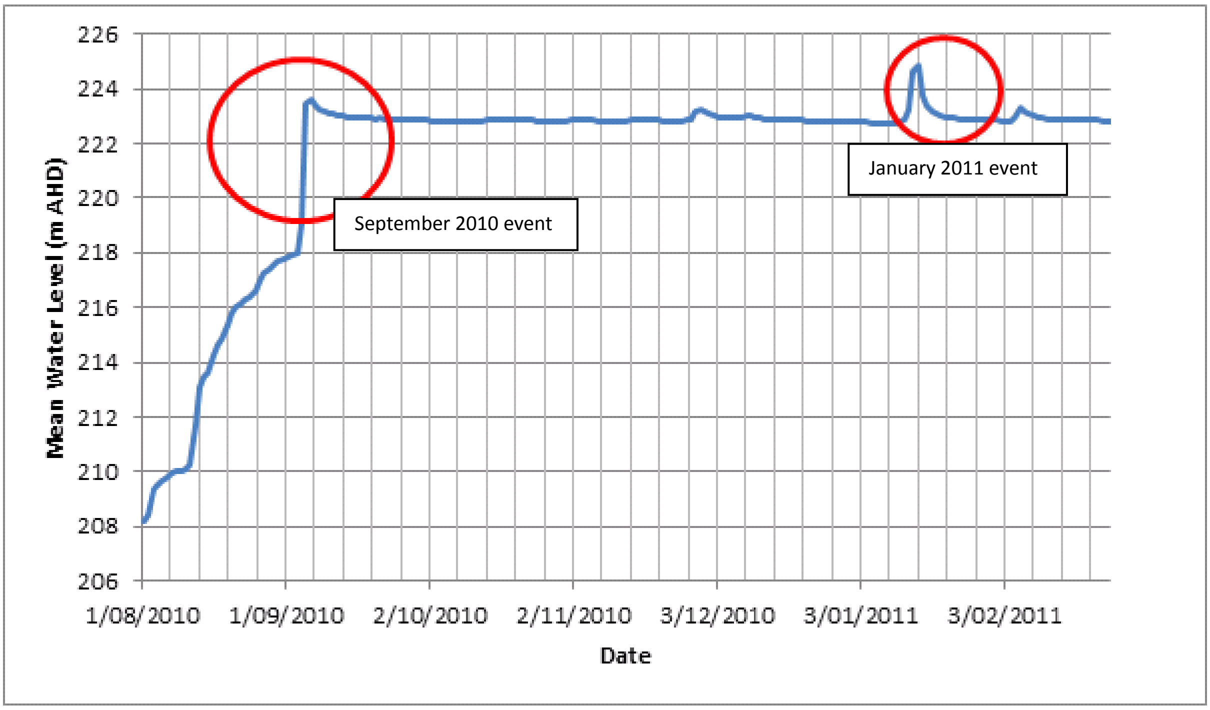



**Figure 4-4 Tullaroop Reservoir water levels**

A hydrologic study of Tullaroop Reservoir was completed in 2002 by SKM[1] and involved dambreak scenario modelling as well as flood frequency analysis of the reservoir inflows and outflows. The results of this study have been utilised in this hydrological analysis and are discussed in later sections.

## 4.5 RORB Model calibration

### 4.5.1 Overview

The RORB model was calibrated to the September 2010 and January 2011 flood events. Calibration was based on comparing modelled hydrographs to recorded information at the 'Tullaroop Creek @ Tullaroop Reservoir (Head Gauge)' , 'Creswick Creek @ Clunes' and 'Tullaroop Creek @ Clunes' streamflow gauges.

The focus of the RORB model calibration was the determination of RORB parameters: kc, initial loss and continuing loss values for the entire catchment.

### 4.5.2 RORB Model calibration event data

***Observed stream flow data***

Streamflow data was required for the hydrological analysis. The closest active streamflow gauges to Carisbrook are at 'Tullaroop Creek @ Tullaroop Reservoir (Head Gauge)', located 7 km upstream of

[1] Sinclair Knight Merz, (2002) *Tullaroop Dam: Review of Hydrology and Dambreak Modelling*, Melbourne

Carisbrook, and 'McCallums Creek at Carisbrook' gauge located approximately 5km upstream, see Figure 3-9. Streamflow data records for the September 2010 and January 2011 flood events were sourced from DSE. The records at the McCallums Creek gauge show extended period of missing or poor quality data during significant flood events including the September 2010 and January 2011 events. Thiess was contacted regarding the lack of available data and advised that the gauge was damaged and offline for much of that period due to the flood events. The gauge has since been upgraded and relocated to a higher position. Thiess are in the process of updating the rating curves for the gauge and upon completion are hopeful of providing estimated peak flows for the calibration events based on flood marks and the new rating curve sometime in 2013.

The data record at the Tullaroop Creek @ Tullaroop Reservoir (Head Gauge) provides good quality instantaneous data for the January 2011 event however during the September 2010 event only daily data was available. On investigation it was discovered that both the GMW and Thiess loggers at this gauge failed during the September 2010 event. Manual log sheets were provided by GMW which recorded four hourly reservoir and spillway measurements during this period. Thiess have also been contacted and advised that high quality data should be available for this period from backup loggers. This data was requested but is currently not available.

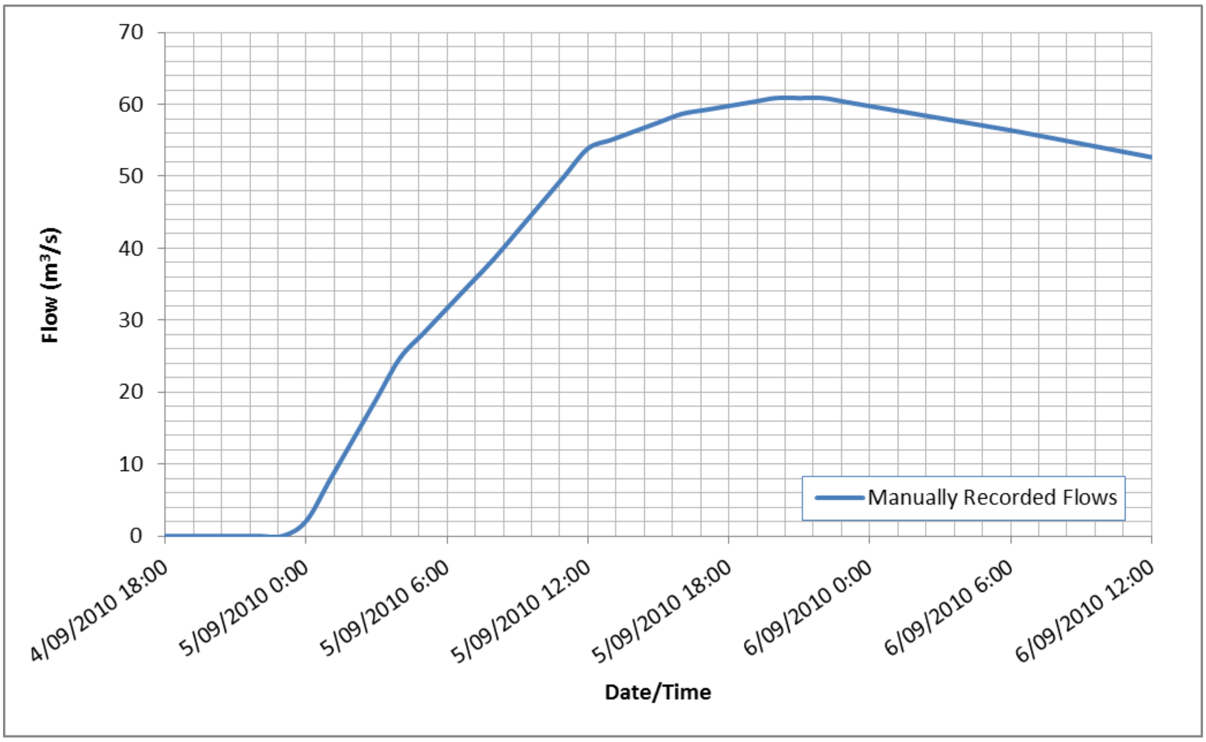



**Figure 4-5 Tullaroop Creek @ Tullaroop Reservoir flow hydrograph – September 2010**

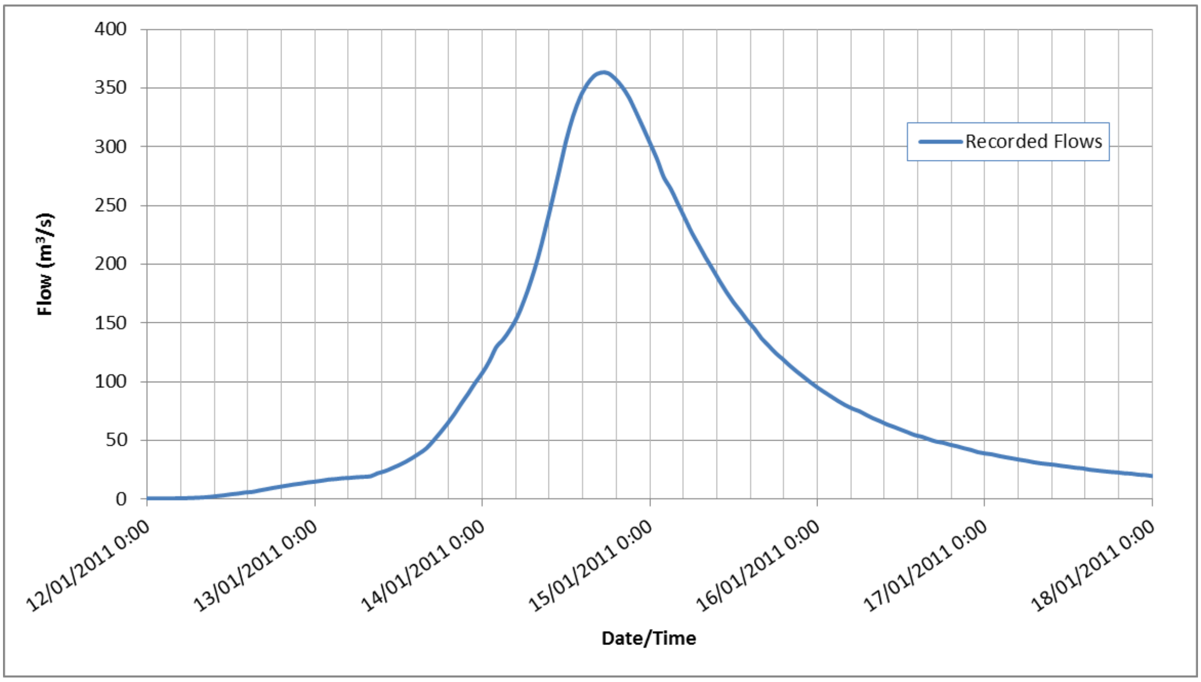



**Figure 4-6 Tullaroop Creek @ Tullaroop Reservoir flow hydrograph – January 2011**

The other two gauges used in the calibration. 'Creswick Creek at Clunes' and 'Tullaroop Creek at Clunes' are located close to the township of Clunes, upstream of Carisbrook, and provide instantaneous data for both the January 2011 and September 2010 events. The 'Tullaroop Creek at Clunes' gauge shows poor quality data and data gaps during the peak of the flood events. For this reason it is unlikely that the peak flow was accurately recorded during these events. The gauge was still used in the calibration process, however, only the general shape of the rising and falling limbs of the hydrograph was utilised.

Rating curves are used to relate measured water levels at a gauge to a streamflow rate. During the September 2010 and January 2011 flood events, the gauge at Creswick Creek @ Clunes recorded water levels at a regular interval of 15 minutes, however no flows were derived at the peak of either flood event as the maximum water level (4.5 m) on the rating curve was exceeded. In the completion of the Creswick Flood Mitigation and Urban Drainage Plan[2] these gaps in flows were infilled using an extrapolated rating curve sourced from Thiess. This infilled data was utilised in the calibration of the Carisbrook RORB calibration. The recorded hydrographs at Clunes for September and January events are shown in Figure 4-7 and Figure 4-8 respectively.

[2] Water Technology (2012) *Creswick Flood Mitigation and Urban Drainage Plan*, North Central CMA.

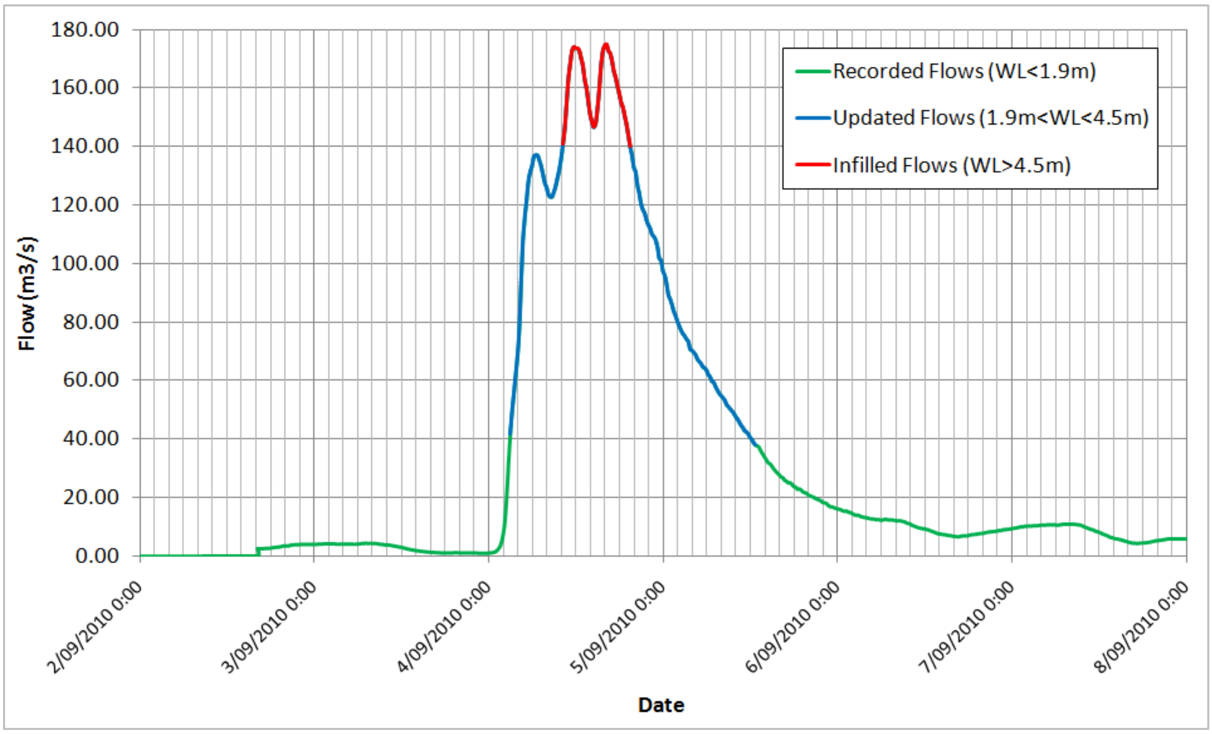



**Figure 4-7** **Creswick Creek @ Clunes flow hydrograph – September 2010**

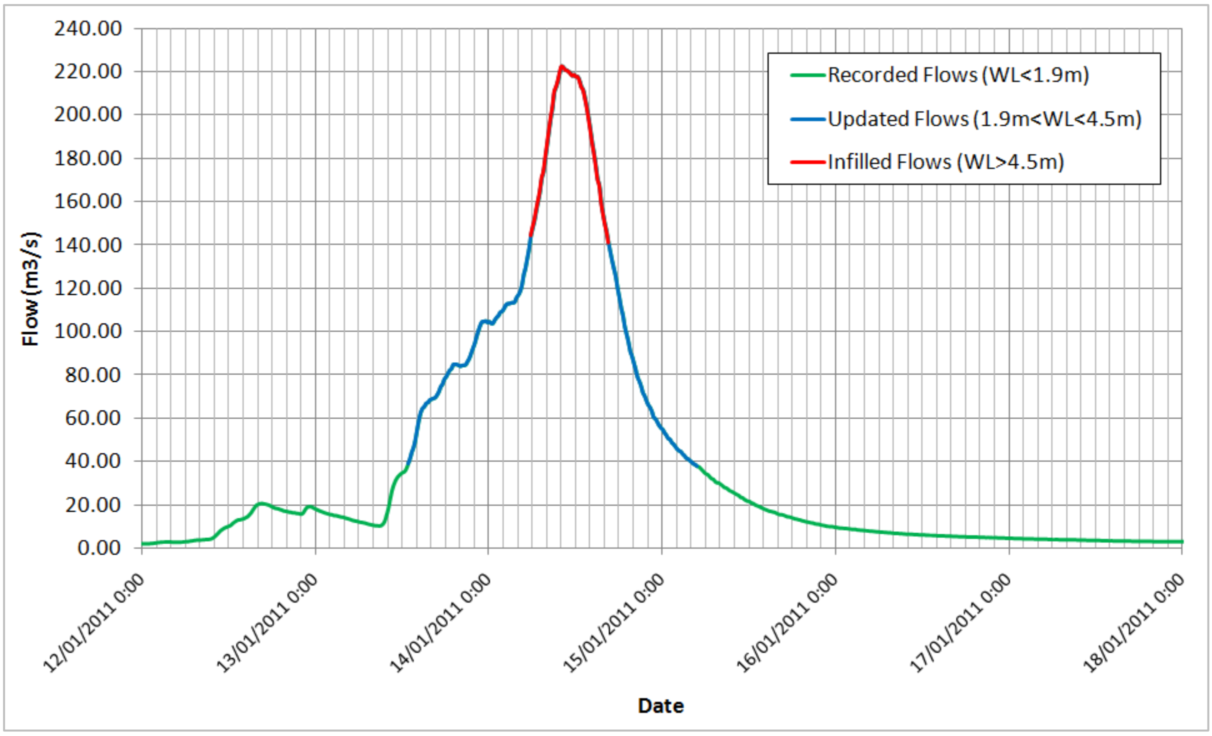



**Figure 4-8** **Creswick Creek @ Clunes flow hydrograph – January 2011**

***Observed rainfall data***

Both pluviograph and daily rainfall records were required for the hydrological analysis. Pluviographs record rainfall data at short time increments, indicating the temporal distribution of rainfall, while the more common daily rainfall data provides the spatial variation over the catchment. Pluviograph records (half hourly or hourly rainfall data) were available at Clunes, Ballarat and Bendigo stations, whereas daily rainfall records were obtained from a number of stations spread out across the catchment.

RORB can treat a storm event either as a single storm or as multiple bursts within the storm. Using separate bursts allows the loss parameters to vary across each burst. For both the September 2010 and January 2011 event, a multi burst approach was adopted. The following points summarise the rationale behind adopting a multi burst approach:

- The January rainfall event ran over four days, with daily rainfall totals across the catchment varying over the event;
- Both the Clunes and Ballarat pluviographs (Figure 4-11 and Figure 4-12) show two separate rainfall events during the January flood event. The first event contains two peaks of rainfall with approximately an 8 hour period between these peaks. The events were separated by a 16 hour period of no rainfall;
- The September rainfall event ran over two days. Both the Clunes and Ballarat pluviographs (Figure 4-11 and Figure 4-12) show two noticeable peaks during the September flood event. The first peak occurs at around midnight on the 3rd September 2010 while a second peak occurs around ten hours later at 10am on 4th September 2010; and
- The hydrographs recorded at Clunes show a multi-peaked hydrograph for both events. Multi-peaked hydrographs are often easier to replicate using a multi burst approach.

The rainfall depth for each subarea was estimated using storm event rainfall isohyets. Five rainfall isohyets were created, two for the double burst in September 2010 and three for the triple bursts in January 2011.

The temporal rainfall distribution was determined using the rainfall pattern from the Ballarat and Clunes pluviographs. Figure 4-9 and Figure 4-11 display the pluviographs for the September 2010 and January 2011 events at Ballarat. Sub-areas across the catchment utilise a temporal pattern from one of these gauges depending on their proximity to each of them. As the Ballarat gauge is on the other side of the Great Dividing Range, there is some uncertainty in the appropriateness of this temporal pattern for use in the upper Tullaroop Creek catchment, however this is the nearest to parts of the catchment and along with the Clunes gauge is considered the best available data for the study area.

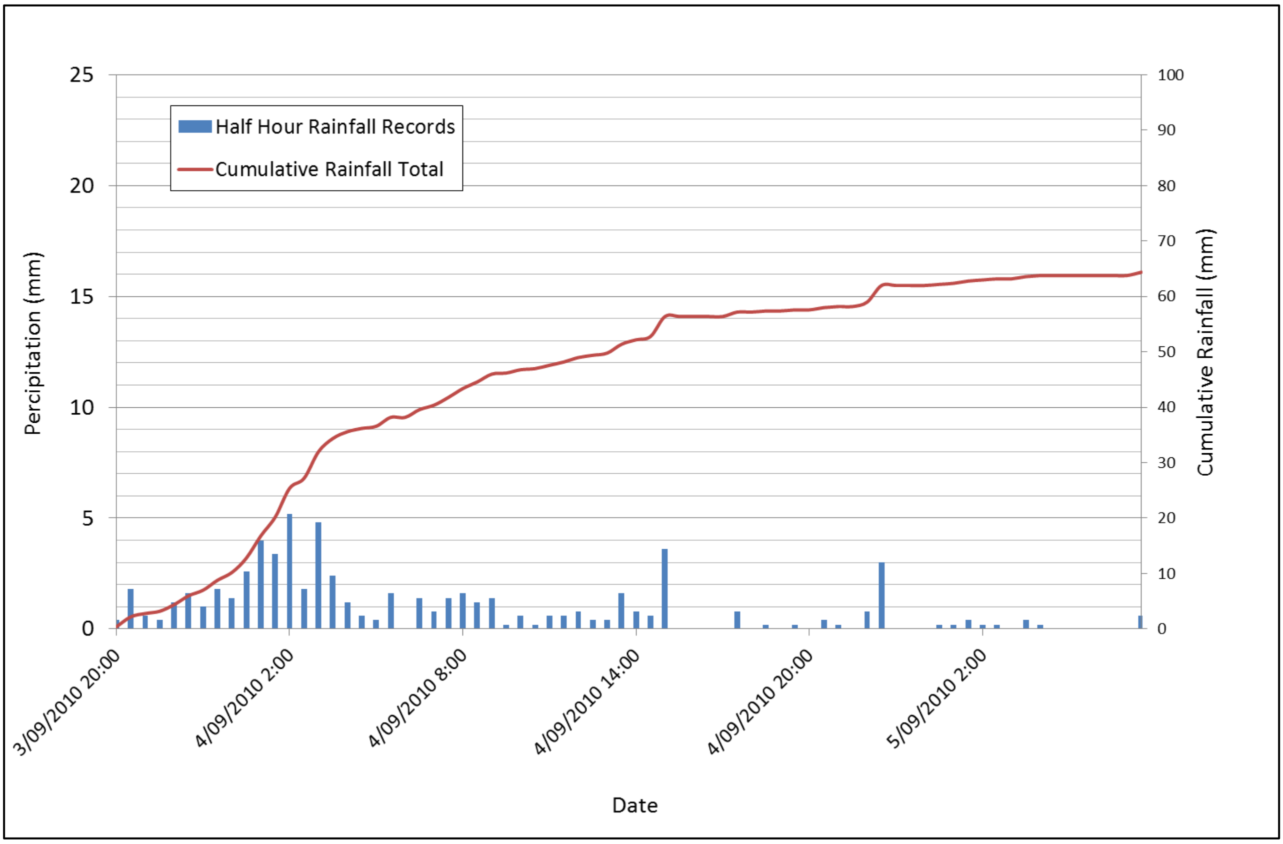



**Figure 4-9 Ballarat Aerodrome pluviograph – September 2010**

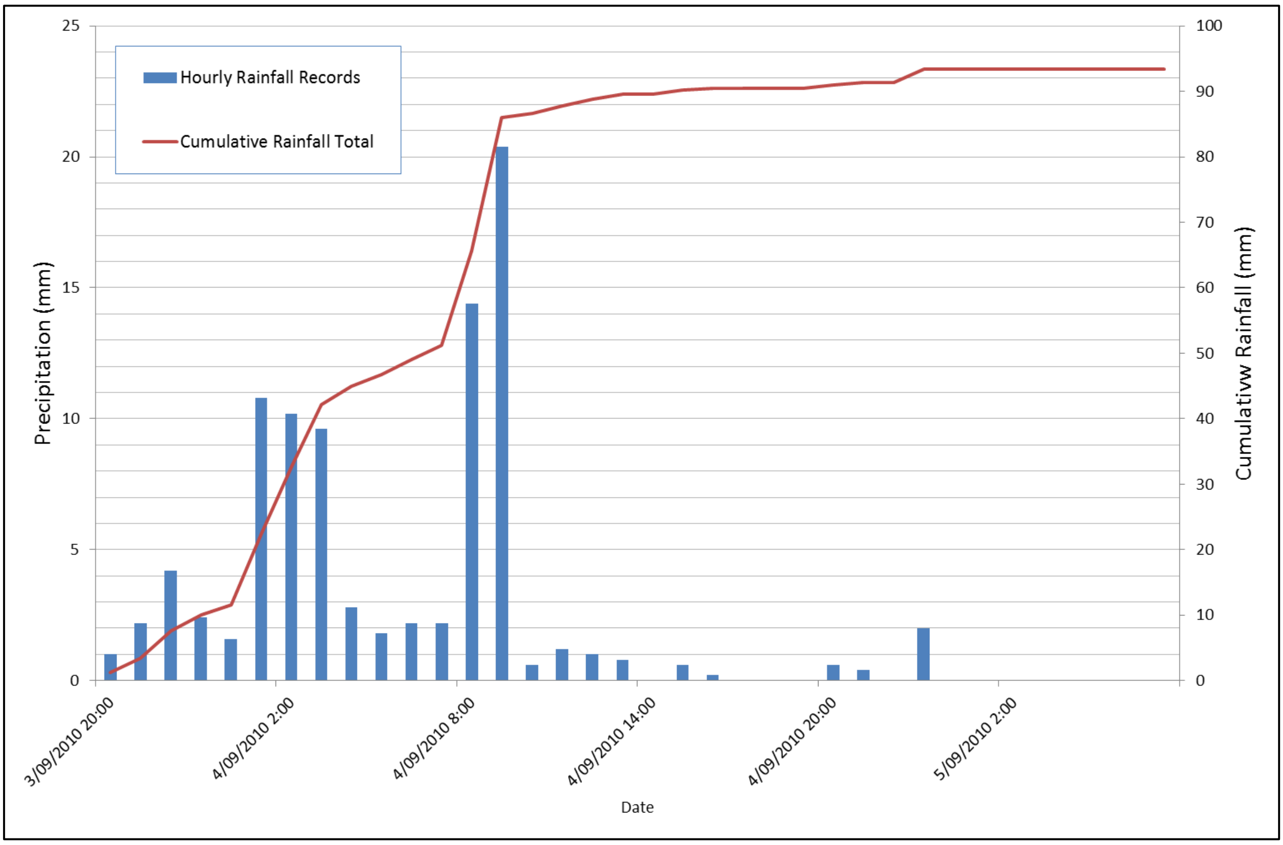



**Figure 4-10 Clunes pluviograph – September 2010**

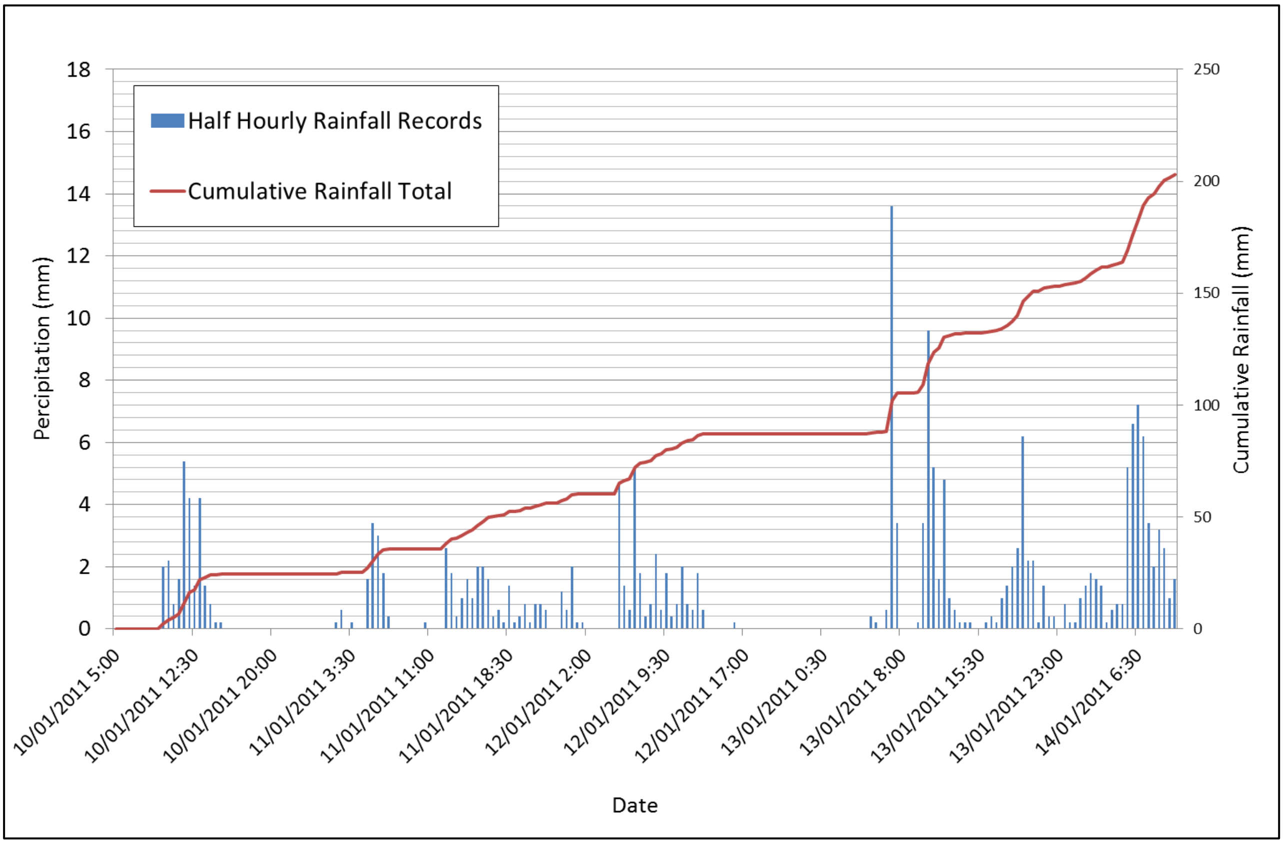



**Figure 4-11 Ballarat Aerodrome pluviograph – January 2011**

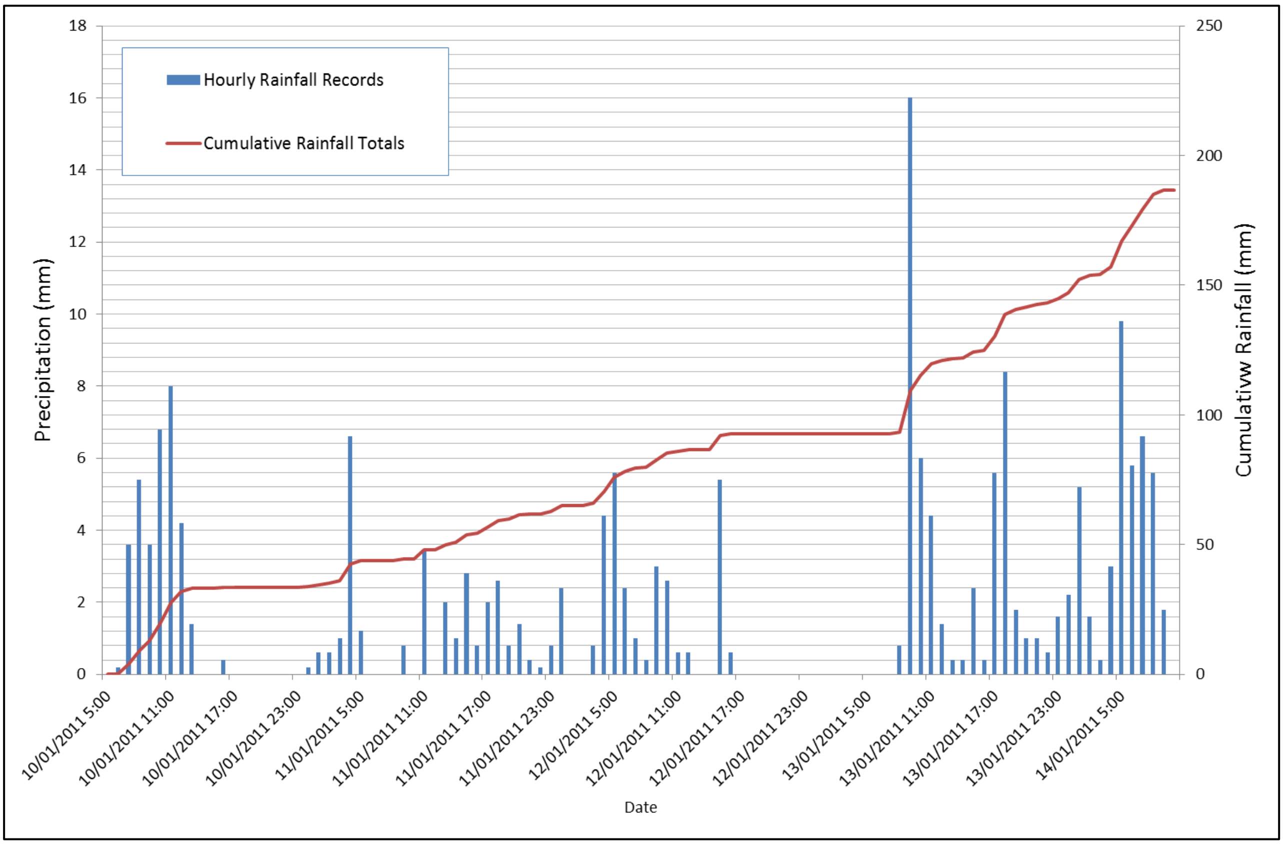



**Figure 4-12 Clunes pluviograph – January 2011**

### 4.5.3 RORB Model Calibration Parameters

By calibrating the RORB model to historic events, model parameters for the catchment are determined and can be then applied with added confidence in design, principally the main parameter kc. The process involves comparison of modelled flood hydrographs with the observed flood hydrographs at the selected stream flow gauges and adjusting the value of kc to reproduce both the peak and volume. RORB also requires calibration of the initial loss and continuing loss for these events. The initial loss / continuing loss model was found to provide a better fit of observed and modelled flood hydrographs and was adopted for this study. The calibration involves matching the modelled hydrograph to the observed hydrographs at the 'Tullaroop Creek at Tullaroop Reservoir', 'Creswick Creek at Clunes' and 'Tullaroop Creek at Clunes' streamflow gauge by adjusting the available parameters, kc and losses.

The calibration approach adopted for this study was as follows:

- Set m = 0.80. This value is an acceptable value for the degree of non-linearity of catchment response (Australian Rainfall and Runoff, 1987).
- The initial loss parameter (IL) was determined by finding a reasonable match between the modelled and observed rising limbs of the flood hydrograph. The initial losses in both January and September vary with time, decreasing from the first to the final burst.
- A continuing loss (CL) was selected to achieve a reasonable fit between the modelled and observed hydrograph volumes. The CL also decreased from the first to the final burst.
- The RORB kc parameter was initially calculated within RORB using a catchment area relationship (equation 2-5 in version 5 of RORB User Manual). This kc value was then varied to achieve a reasonable fit of the peak flow and general hydrograph shape.

Details of the selected calibration events are provided in Table 4-2 below.

**Table 4-2 RORB model calibration event summary**

| Event | Event Start & Finish Date | Average Catchment Rainfall (mm) |
|---|---|---|
| September 2010 | 03/09/2010 8:00pm - 06/09/2010 12:00am | 83.5 mm (over a 36 hour period) |
| January 2011 | 11/01/2011 10:30am - 15/01/2011 23:30pm | 201 mm (over a 3 day period) |

The average catchment rainfall show in Table 4-2 was determined by creating a Triangular Irregular Network (TIN) of rainfall depths from the daily rainfall data. A mean depth for the catchment area was then extracted from the TIN.

**Table 4-3 RORB model calibration event peak flows**

| Event | Recorded Peak Flow at Creswick Creek @ Clunes Gauge ($m^3/s$) | Recorded Peak Flow at Tullaroop Creek @ Clunes Gauge ($m^3/s$) | Recorded Peak Flow at Tullaroop Reservoir Gauge ($m^3/s$) |
|---|---|---|---|
| September 2010 | 175 | 405 | 60 |
| January 2011 | 262 | 401 | 363 |

The RORB model parameters and how they were determined are described below:

### kc value

A range of prediction equations for kc are available, some of which are built into RORB. These prediction equations were used to determine an initial Kc value at the commencement of calibration. These equations use different inputs such as catchment area and $D_{av}$ (the average flow distance in the channel network of sub area inflows), and have been developed using different data sets. The RORB model kc value was then adjusted to match the modelled hydrograph to the observed hydrograph at the 'Tullaroop Creek at Tullaroop Reservoir', 'Creswick Creek at Clunes' and 'Tullaroop Creek at Clunes' streamflow gauges.

As previously stated the catchment downstream of the confluence of McCallum and Tullaroop Creeks was delineated to a finer level than the upstream catchment so that flows could be extracted from a number of smaller tributaries around Carisbrook. Routing parameters were varied upstream and downstream of the confluence allowing a different kc value to account for differences in routing. Use of interstation areas is generally avoided unless there are particular circumstances that require it and there is available gauge data to allow for a detailed calibration. Due to the requirement for different sub area sizes, separation into two interstation areas is justified in this case. The different sub area size required a different kc. The challenge in this instance was to choose a kc that was reasonable for the smaller local catchment given that there was no gauged data. It was decided to scale the kc using the relative difference in $D_{av}$ between the upper and lower catchments. The kc for the local catchment was then checked against Rational Method estimates of peak flows from the local catchment. The observed timing of flows off the local catchment was also used to verify the choice of Kc for the local catchment.

**Table 4-4 Method of kc value calculation**

| Method | Equation | Upper Catchment | Lower Catchment |
|---|---|---|---|
| Default RORB | $kc = 2.2*A^{0.5}$ | 77.6 | 21.9 |
| Vic MAR>800 mm - Eq 3.21 ARR (BkV) | $kc=2.57*A^{0.45}$ | 63.5 | 20.3 |
| Victoria data (Pearse et al, 2002) | $kc=1.25*D_{av}$ | 55.9 | 25.5 |
| Aust wide Dyer (1994) (Pearse et al 2002) | $kc=1.14*D_{av}$ | 50.9 | 23.2 |
| Aust wide Yu (1989) (Pearse et al 2002) | $kc=0.96*D_{av}$ | 42.9 | 19.6 |

### m Value

m is a measure of a catchment's non-linearity. The value is rarely set as greater than 1 or less than 0.6 and a value of 0.8 is recommended in the RORB manual as an initial starting value. During the calibration process there was no justification to vary this value and it remained at 0.8.

There are methods for determining an appropriate value of m and one such method is Weeks (1980) which uses multiple calibration event to select kc and m. However, given the extrapolation of selected parameters to larger events and the goodness of fit obtained using the recommended value of 0.80, there appears no significant reason to vary it for the Carisbrook catchment.

This value is considered an acceptable value for the degree of non-linearity of catchment response and is consistent with other flood studies in the region. (Australian Rainfall and Runoff, 1987).

### Temporal patterns

Calibration temporal patterns used in the RORB model were extracted from the Ballarat and Clunes pluviographs as these were the closest weather stations to the Carisbrook catchment to record instantaneous rainfall data. Figure 4-13 and Figure 4-14 below show the observed temporal pattern at Ballarat Aerodrome and Clunes for the January 2011 and September 2010 events. The temporal patterns were applied to subareas according to locality with the temporal pattern from the nearest weather station applied to each individual subarea.

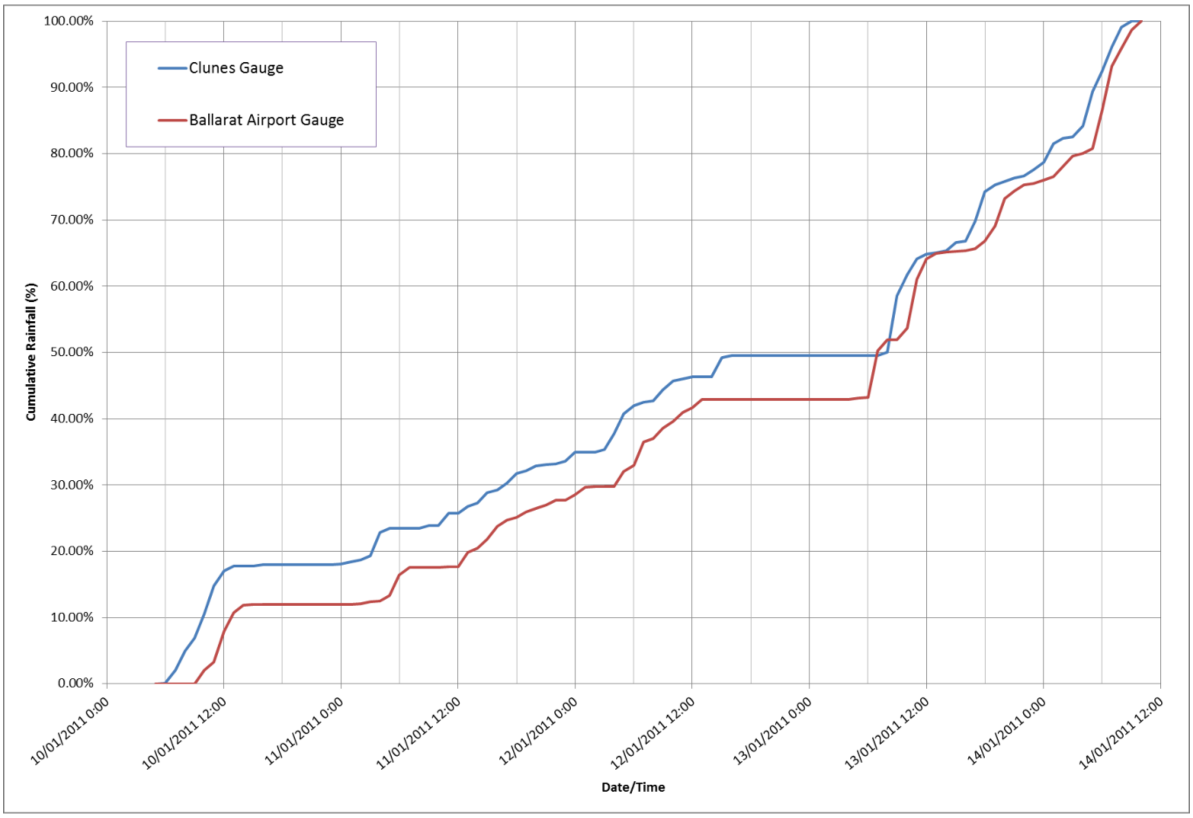



**Figure 4-13 Observed temporal pattern at Ballarat Aerodrome and Clunes for January 2011**

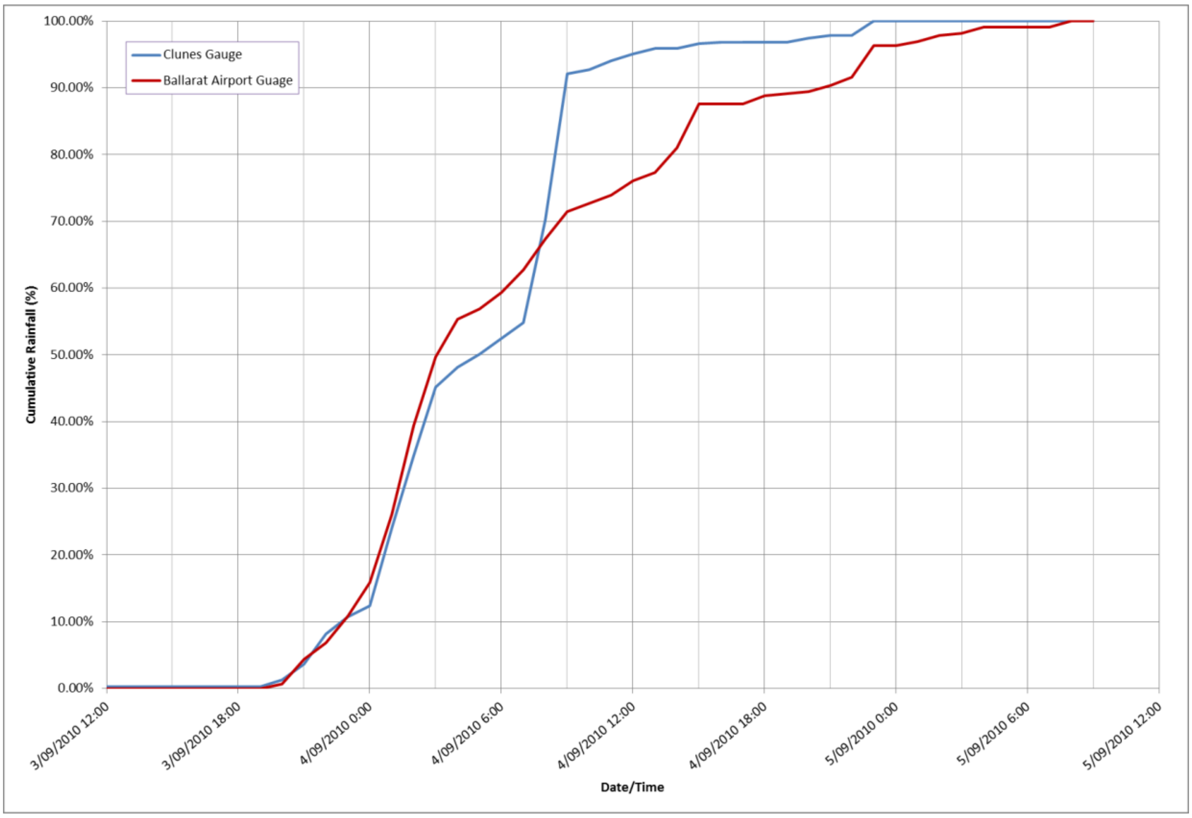



**Figure 4-14 Observed temporal pattern at Ballarat Aerodrome and Clunes for September 2010**

### Fraction Impervious

Fraction impervious values were allocated for each of the RORB model subareas. These were an approximation of the land use based on Land Use Zoning. Aerial imagery was also reviewed to ensure appropriate values were used.

The zones and fraction impervious values used are shown in Table 4-5.

**Table 4-5 Land use zones and fraction impervious values**

| Land Use Zone | Description | Fraction Impervious |
|---|---|---|
| Residential Zone | Normal range of densities | 0.45 |
| Low Density Residential | 0.4 ha min. | 0.2 |
| Rural Zone | Rural areas | 0.0-0.1 |
| Public Park and Recreation Zone | Open public space | 0.01 |
| Road Zone | Secondary and local roads | 0.6 |

### Spatial Patterns

Spatial patterns for calibration were based on the spatial distribution of rainfall observed during each of the events. The gauges used in determining the spatial pattern are discussed in Section 3.2.2 and are shown in Figure 3-8. Each gauge's rainfall total over the duration of the event is used to create a rainfall isohyet, creating a spatial distribution of rainfall covering the Carisbrook catchment. The rainfall depth for each subarea can then be estimated from the isohyets. Five rainfall isohyets were created, two for the double burst in September 2010 and three for January 2011, one for each of the three bursts.

### Losses

An initial and continuing loss model was adopted for the Carisbrook catchment as it is largely an agricultural area with minor built up areas.

### 4.5.4 RORB Model Flood Event Calibration

The calibration results are summarised in Table 4-6 to

Table 4-8. Figure 4-15 through to Figure 4-21 display the modelled and observed flood hydrographs for the calibration events at the three gauges. Data at the Tullaroop Creek at Clunes gauge was found to be missing for much of the September 2010 event so this gauge was excluded from the calibration for that event. The upstream and downstream kc refers to the separate kc values used for the upper and lower catchments as explained earlier.

**Table 4-6 RORB model calibration parameters – September 2010 event**

| September 2010 | U/S kc | D/S kc | Burst 1 | | Burst 2 | |
|---|---|---|---|---|---|---|
| | | | IL | CL | IL | CL |
| | 10.5 | 4.79 | 35 | 1.5 | 5 | 0.55 |

**Table 4-7 RORB model calibration peak flows – September 2010 event**

| January 2011 | Tullaroop Reservoir Head Gauge Peak Flow ($m^3/s$) | | Creswick Creek at Clunes Peak flow ($m^3/s$) | |
|---|---|---|---|---|
| | Observed | Calculated | Observed | Calculated |
| | 60 | 50 | 175 | 198 |

**Table 4-8 RORB model calibration parameters – January 2011 event**

| January 2011 | U/S kc | D/S kc | Burst 1 | | Burst 2 | | Burst 3 | |
|---|---|---|---|---|---|---|---|---|
| | | | IL | CL | IL | CL | IL | CL |
| | 10.5 | 4.79 | 30 | 2.9 | 15 | 2.9 | 12 | 1.8 |

**Table 4-9 RORB model calibration peak flows – January 2011 event**

| January 2011 | Tullaroop Reservoir Head Gauge Peak Flow ($m^3/s$) | | Tullaroop Creek at Clunes Peak Flow ($m^3/s$) | | Creswick Creek at Clunes Peak flow ($m^3/s$) | |
|---|---|---|---|---|---|---|
| | Observed | Calculated | Observed | Calculated | Observed | Calculated |
| | 363 | 399 | 401 | 726 | 262 | 462 |

It is acknowledged that the adopted kc of 10.5 is considerably lower than the regional estimates shown in Table 4-4 which is a direct result of the small sub areas used in the RORB model as described earlier. A kc value of 4.79 was adopted for the lower catchment which includes the local catchments around Carisbrook. These catchments are ungauged and so calibration within RORB was not possible. This value of 4.79 was determined by scaling the upper catchment kc using the relative $D_{av}$ values between the catchments (20.38 and 44.69 km). $D_{av}$ is a measure of the average flow distance in the channel network and is linearly related to kc. Methods to verify this value are discussed in later sections.

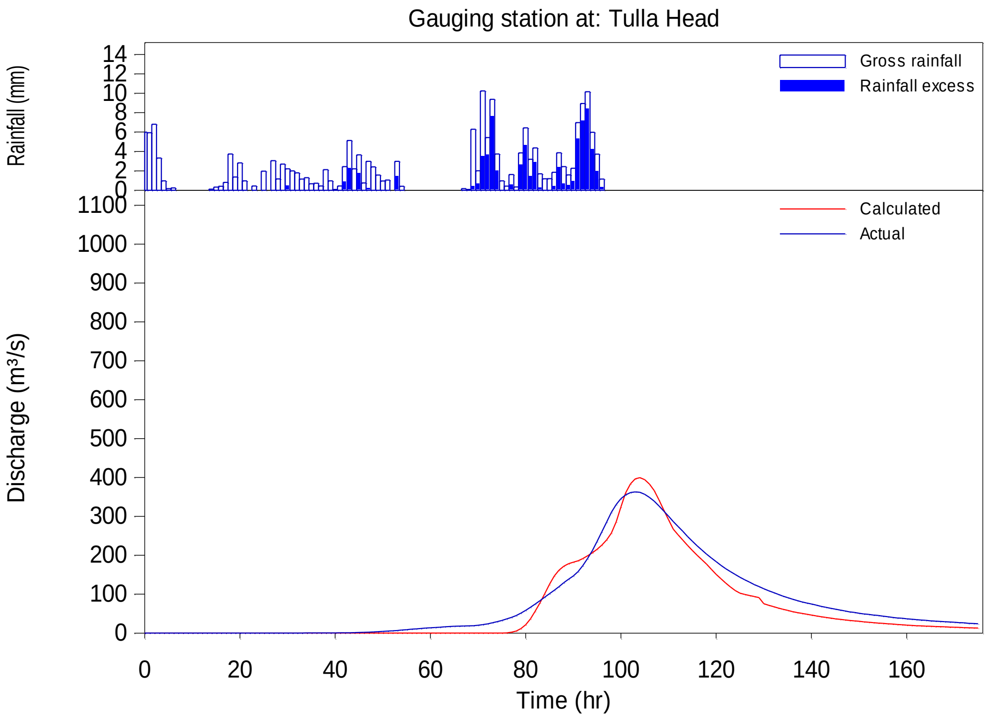



**Figure 4-15 RORB model calibration hydrograph – January 2011 at Tullaroop Head Gauge**

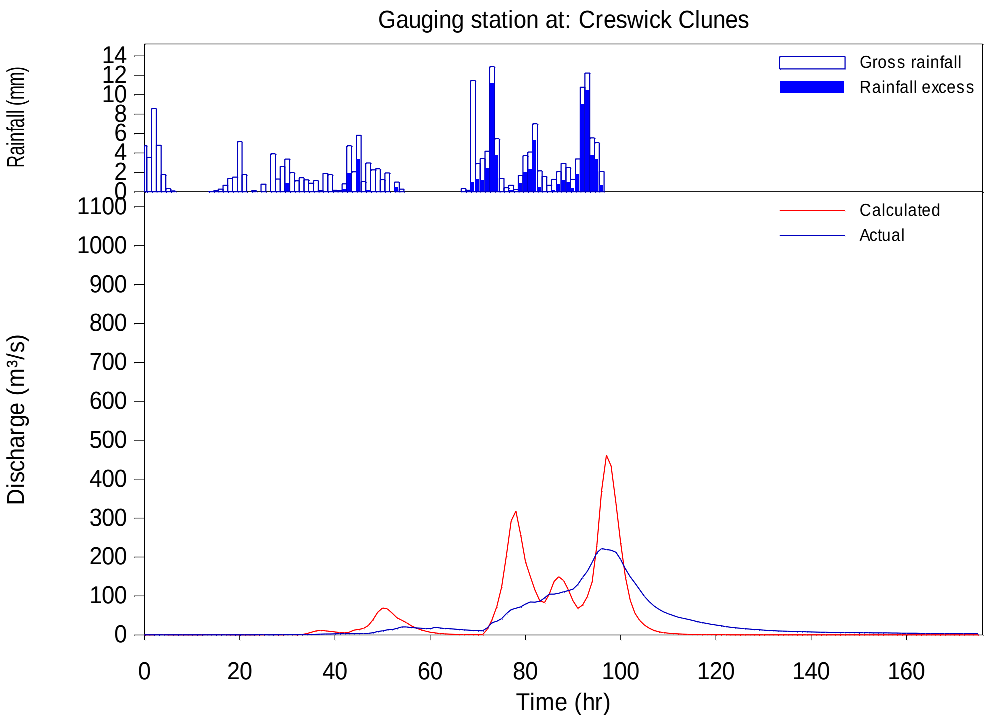



**Figure 4-16 RORB model calibration hydrograph – January 2011 at Creswick Creek at Clunes Gauge**

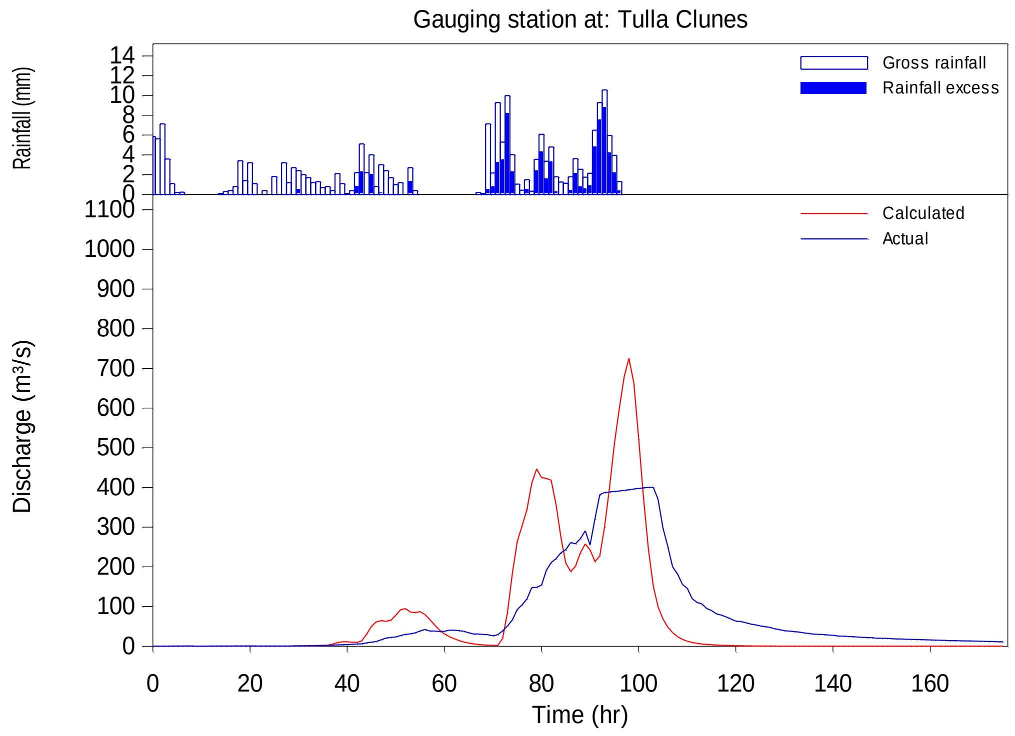



**Figure 4-17** **RORB model calibration hydrograph – January 2011 at Tullaroop Creek at Clunes Gauge**

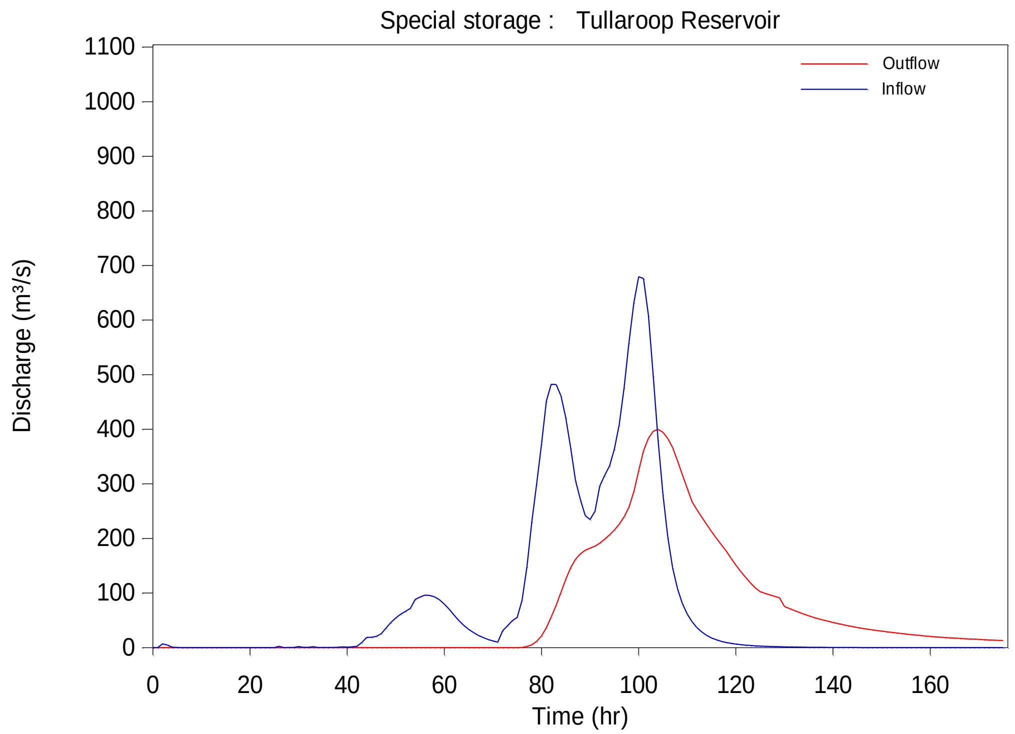



**Figure 4-18** **RORB model calibration hydrograph – Inflow/Outflows at Tullaroop Reservoir during January 2011 event**

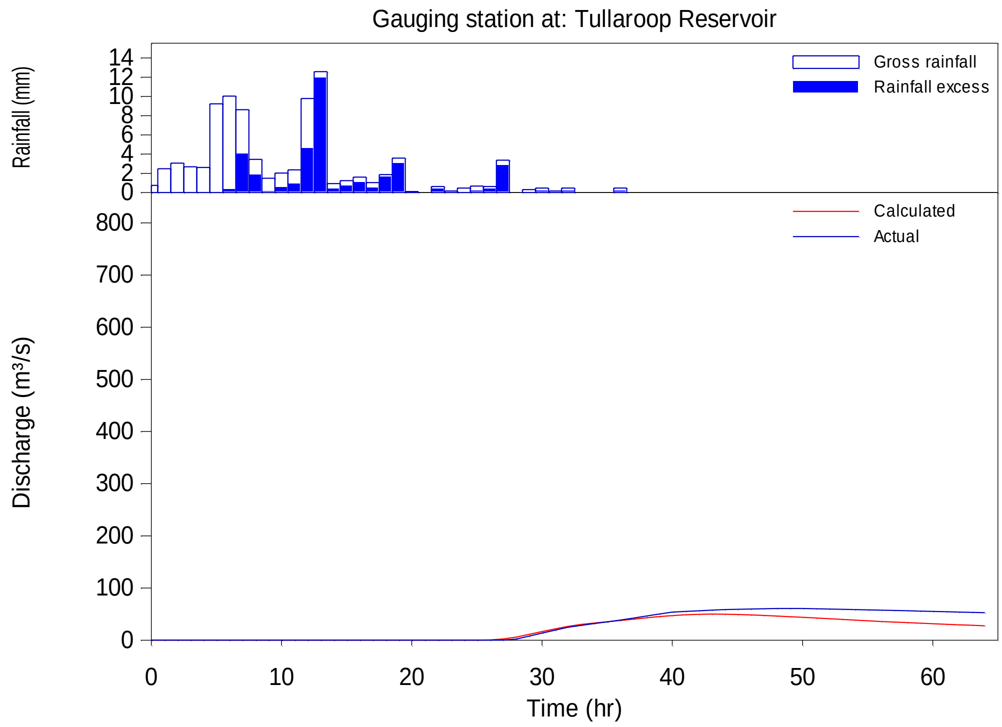



**Figure 4-19 RORB model calibration hydrograph – September 2010 at Tullaroop Head Gauge**

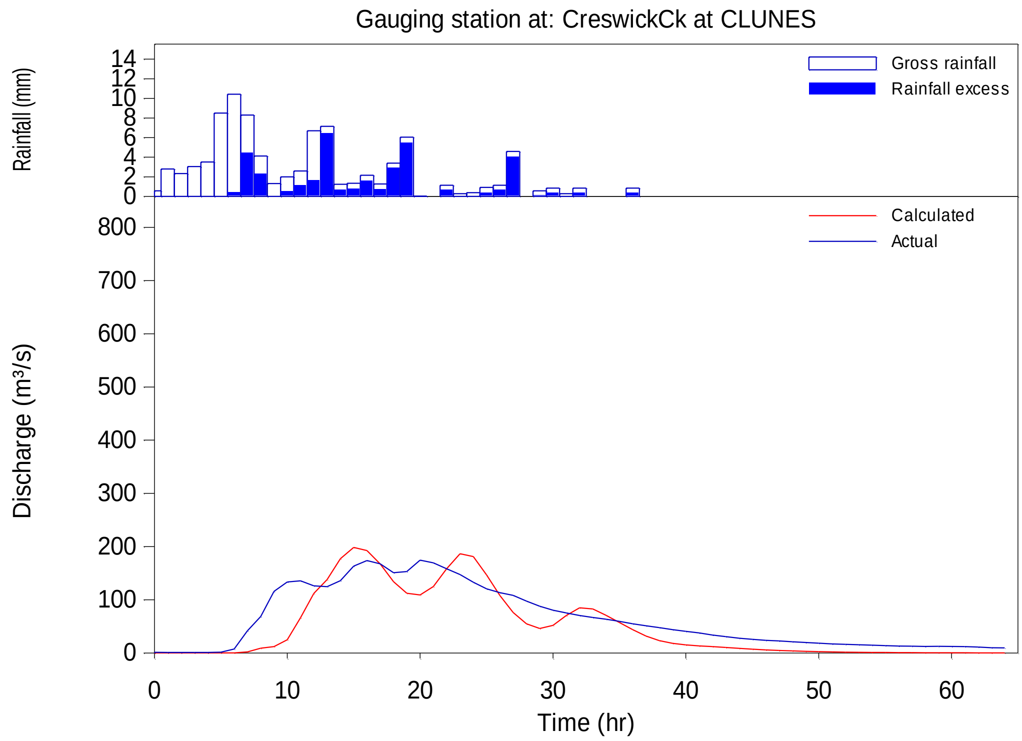



**Figure 4-20 RORB model calibration hydrograph – September 2010 at Creswick Creek at Clunes Gauge**

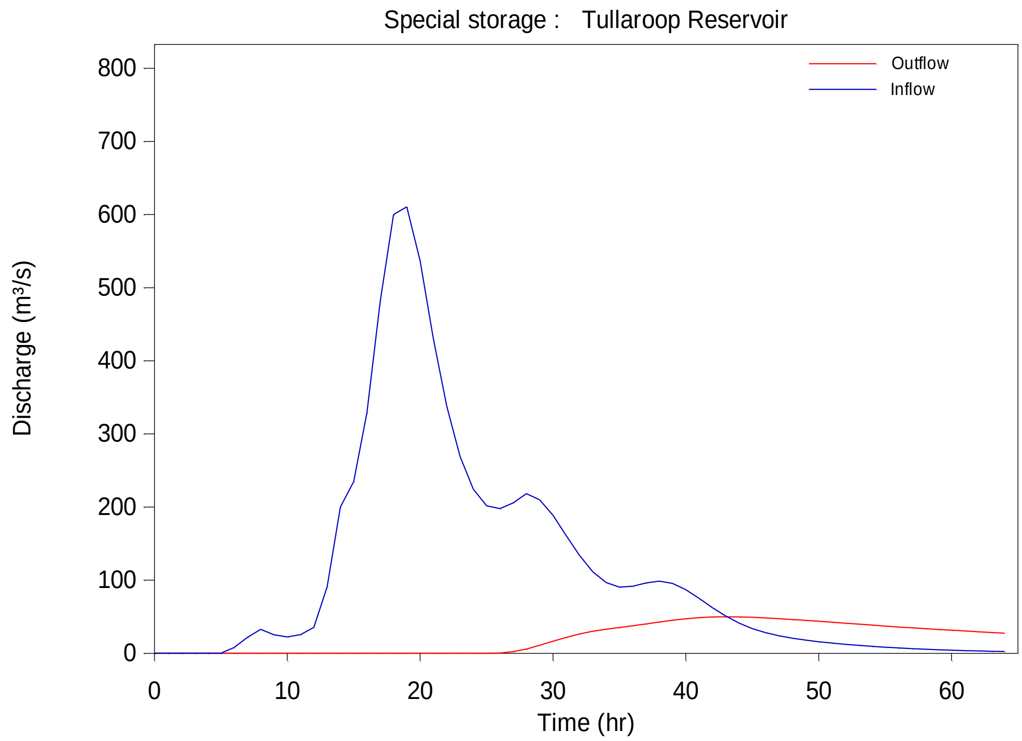



**Figure 4-21** **RORB model calibration hydrograph – Inflow/Outflows at Tullaroop Reservoir during September 2010 event**

## 4.6 Discussion

### 4.6.1 January 2011 Flood Event Calibration

For the January 2011 event, the modelled hydrograph at the Tullaroop Reservoir Gauge reproduced the peak flow and general hydrograph shape very well. The fit at the Tullaroop Creek at Clunes gauge was not as close however the data at that gauge shows very poor data quality at the height of the event. It has been estimated by Thiess using revised rating tables that the peak flow at the Tullaroop Creek at Clunes Gauge during the January 2011 event was 778 $m^3/s$ which correlates fairly closely with the modelled peak flow of 729 $m^3/s$. The fit at the Creswick Creek at Clunes gauge matched the general shape of the hydrograph moderately well however the multiple peaks in the modelled hydrograph were not present in the observed data.

The fit at both Clunes gauges could not be improved any further as it was found that an improvement in fit at Clunes resulted in a poorer fit at Tullaroop Reservoir and it was deemed that the fit at Tullaroop Reservoir is of higher priority due to its proximity to Carisbrook. As an additional check the peak inflow at Tullaroop Reservoir was checked against the calculated peak inflow from GMW records. This demonstrated that the modelled inflow of 679 $m^3/s$ correlates fairly well with the calculated inflow of 630$m^3/2$ from GMW.

The timing of the peak flow through the Carisbrook township correlates very closely with anecdotal reports from the event. The modelled peak flow through the township occurs at 1 pm on 14th January with anecdotal reports indicating a peak time of around 1-2 pm.

It can be seen that an initial peak in the modelled hydrograph at both Clunes gauges is not present in the observed data. Without spatial and temporal rainfall data inside the catchment it can be difficult to accurately represent multiple peaks in an event however the event peak flows, volume and general hydrograph shape still match fairly well resulting in a good fit at these locations. These differences could also be due to differences in the timing of the rainfall between the Ballarat Aerodrome pluviograph and the rainfall falling in the catchment upstream of Creswick.

The hydrographs of the Tullaroop Reservoir inflow and outflow as show in Figure 4-18 demonstrate that despite Tullaroop Reservoir being at close to capacity it still played a role in attenuating the peak flow with the peak outflow being approximately 45% lower than the inflow.

### 4.6.2 September 2010 Flood Event Calibration

For the September 2010 event, the calibration of the modelled hydrograph to the observed hydrograph at Tullaroop Creek at Tullaroop Reservoir provided a very good match in terms of the peak flow, shape and timing of the hydrograph.

At the Creswick Creek at Clunes gauge the calibration of the modelled hydrograph to the observed hydrograph produced the general shape of the hydrograph and peak flow reasonably well however there is some discrepancies in the timing of the multiple peaks observed at Clunes. The multiple peaks at Clunes are most likely associated with isolated thunderstorms across the catchment, which may not be well reflected in the available pluviograph at Ballarat.

Despite difficulty in matching the peaks at the Clunes gauge the model provides an excellent fit at the Tullaroop Reservoir gauge and as stated above the fit at the Tullaroop Reservoir Gauge is considered a higher priority due to its close proximity to Carisbrook township.

The hydrographs of the Tullaroop Reservoir inflow and outflow as show in Figure 4-21 demonstrate that Tullaroop Reservoir had a significant role in attenuating peak flows in Tullaroop Creek during the September event. The reservoir was at approximately 60% capacity at the beginning of the event which resulted in significant attenuation with the peak outflow being approximately 80% lower than the inflow.

### 4.6.3 Inflow Hydrographs at Carisbrook

Hydrographs were extracted from the calibrated models at various points of interest around Carisbrook. This includes locations where inflows will be required for the hydraulic model. The extracted hydrographs from September 2010 and January 2011 are shown in Figure 4-22 and Figure 4-23 below for the two main waterways and the combined flows of the local tributaries flowing into the south-west of Carisbrook. A hydrograph of the combined flow of Tullaroop and McCallum Creeks extracted downstream from where they converge is also shown.

At Carisbrook, it can be seen that generally greater flows were recorded during the January 2011 event as compared to the September 2010 event. The peak flow in January 2011 in the township was approximately 30% higher than in September 2010, consistent with the heavier rainfall recorded in January and the fact that Tullaroop Reservoir was close to capacity.

During both flood events, the local tributaries around Carisbrook peaked several hours before the Tullaroop and McCallum Creeks. It can also be seen that in the September 2010 event Tullaroop Reservoir caused significant attenuation of the flood peak with the peak in Tullaroop Creek occurring 24 hours later and at 90% lower magnitude than the McCallum Creek peak flow, despite Tullaroop having the larger catchment. In the January 2011 event the peak in Tullaroop Creek occurred approximately 6 hours after the peak in McCallums Creek.

**Table 4-10 Modelled peak flows in Carisbrook during the recent flood events**

| Location | 4th of September 2010 Modelled Peak Flow ($m^3/s$) | 4th of September 2010 Modelled Peak Time | 14th of January 2011 Modelled Peak Flow ($m^3/s$) | 14th of January 2011 Modelled Peak Time |
|---|---|---|---|---|
| Combined local catchments | **74** | ≈10:00 am | **47** | ≈7:00 am |
| McCallums Creek above confluence | **716** | 2:00 pm | **757** | 12:00 pm |
| Tullaroop Creek below confluence (township) | **779** | 2:00 pm | **1,000** | 12:00 pm |
| Tullaroop Creek above confluence | **92** | 1:00 pm | **399** | 7:00 pm |

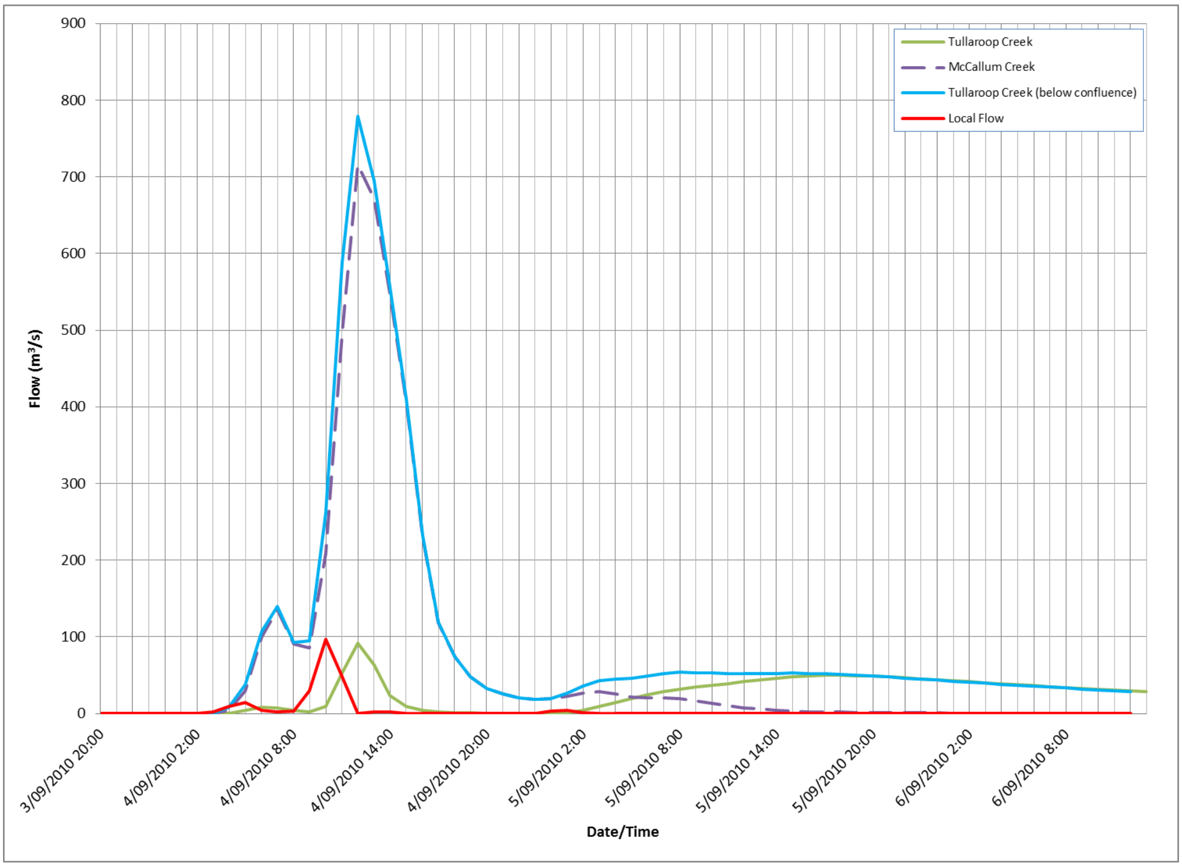



**Figure 4-22 Flood hydrographs in Carisbrook – September 2010**

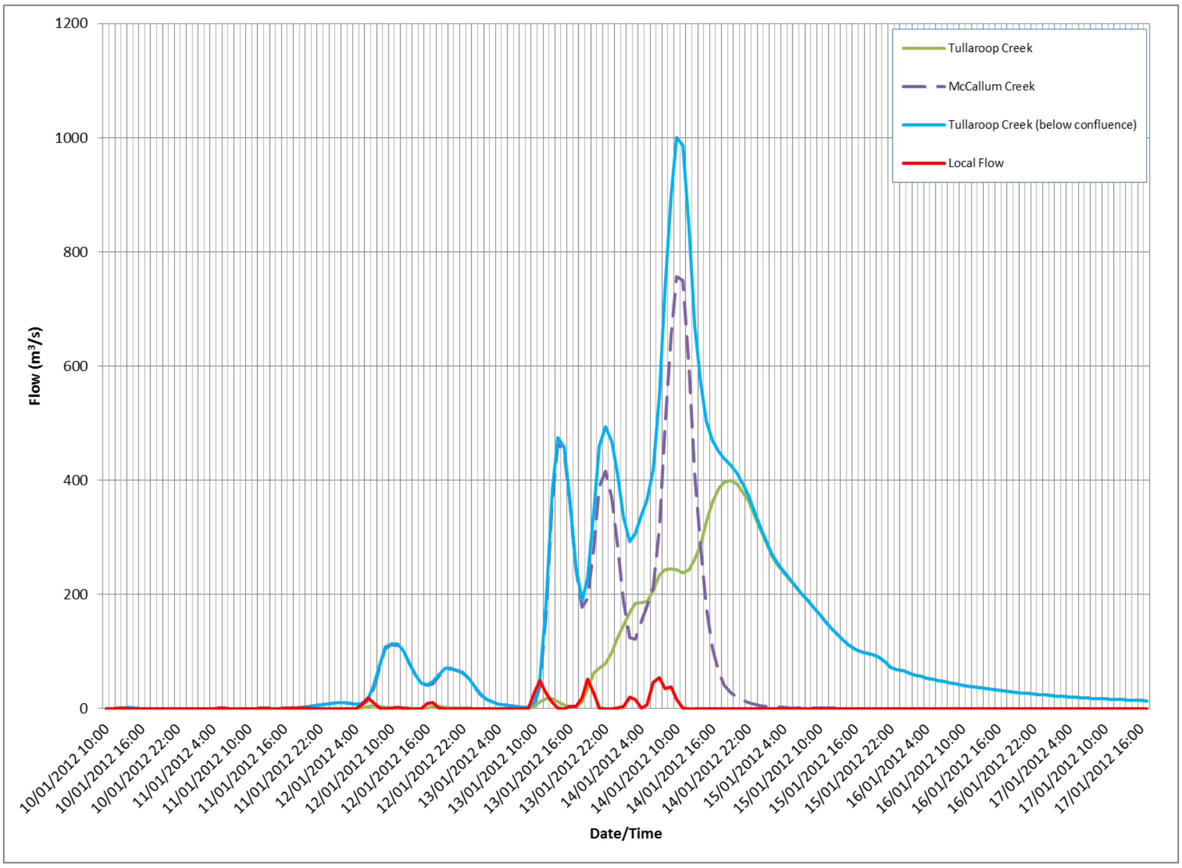



**Figure 4-23 Flood hydrographs in Carisbrook – January 2011**

### 4.6.4 Local Catchments around Carisbrook

It has been reported anecdotally that flows from the smaller local catchments around Carisbrook are a significant contributor to inundation around the township. For this reason it is important that these modelled flows are verified against other methods. These local tributaries are ungauged and so in the first instance modelled flows for the calibration events were compared against flows from 100 year peak flows calculated using the Rational Method. These results are shown in Table 4-11 below for the January 2011 event and indicate a similar order of magnitude. Further verification was completed once design events were run and is detailed in the design modelling section. The timing of the modelled hydrographs at these locations also correlates well with anecdotal reports of flows observed around Carisbrook during the January 2011 event.

**Table 4-11 Comparison of January 2011 modelled flows with Rational Method**

| Inflow | Area ($km^2$) | Rational Method Q100 ($m^3/s$) | January 2011 event modelled flow ($m^3/s$) | Time/Date of modelled peak |
|---|---|---|---|---|
| 1 | 3.8 | 8.9 | 9.8 | 13/01/2011 19:00 |
| 2 | 4.7 | 10.5 | 13.8 | 13/01/2011 19:00 |
| 3 | 4.9 | 10.9 | 12.4 | 14/01/2011 07:00 |
| 4 | 5.4 | 11.6 | 13.3 | 14/01/2011 07:00 |
| 5 | 1.1 | 3.5 | 2.6 | 13/01/2011 19:00 |
| 6 | 1.2 | 3.7 | 2.9 | 14/01/2011 07:00 |
| 7 | 1.6 | 4.8 | 3.1 | 14/01/2011 07:00 |
| 8 | 1.5 | 4.5 | 2.9 | 14/01/2011 07:00 |
| 9 | 4.3 | 9.8 | 6.0 | 14/01/2011 07:00 |
| McCallum Creek | 477 | 328 | 757 | 14/01/2011 10:00 |
| Tullaroop Creek (U/S of Reservoir) | 722 | 465 | 680 | 14/01/2011 14:00 |

## 4.7 Design Event modelling

The goal of the RORB design modelling was to provide design flow hydrographs over a range of ARI's for input into the hydraulic model. For this study the 5, 10, 20, 50, 100 and 200 year ARI events were run. The design runs were modelled conservatively with Tullaroop Reservoir set at full capacity, consistent with conditions during the January 2011 event. The inputs for design flood estimation are described below.

### 4.7.1 Design Rainfall

***Design rainfall depths***

Design rainfall depths were determined using the Intensity-Frequency-Duration (IFD) methodology outlined in AR&R Volume 2, 1987. The IFD parameters were generated for the centroid of the Carisbrook catchment (143.85E, -37. 24S) and are shown in Table 4-12 below.

**Table 4-12 Catchment IFD parameters**

| $2I_1$ (mm/hr) | $2I_{12}$ (mm/hr) | $2I_{72}$ (mm/hr) | $50I_1$ (mm/hr) | $50I_{12}$ (mm/hr) | $50I_{72}$ (mm/hr) | G | F2 | F50 | Zone |
|---|---|---|---|---|---|---|---|---|---|
| 19.64 | 3.51 | 0.94 | 39.86 | 6.96 | 1.81 | 0.28 | 4.34 | 14.89 | 2 |

IFD parameters were taken from the Bureau of Meteorology's online IFD tool. Table 4-13 and Figure 4-24 show preliminary values extracted from the BOM online IFD extraction tool at the centroid of the catchment upstream of Carisbrook.

**Table 4-13 IFD parameters extracted from the online BoM IFD tool at Carisbrook**

| DURATION | 1 Year | 2 years | 5 years | 10 years | 20 years | 50 years | 100 years |
|---|---|---|---|---|---|---|---|
| 5 Mins | 50.1 | 66.3 | 89.9 | 106.0 | 126.0 | 156.0 | 180.0 |
| 6 Mins | 46.7 | 61.8 | 83.6 | 98.2 | 117.0 | 145.0 | 167.0 |
| 10 Mins | 37.9 | 50.0 | 67.4 | 78.9 | 94.2 | 116.0 | 133.0 |
| 20 Mins | 27.4 | 36.1 | 48.2 | 56.2 | 66.8 | 81.7 | 93.8 |
| 30 Mins | 22.0 | 29.0 | 38.6 | 44.9 | 53.2 | 64.9 | 74.4 |
| 1 Hr | 14.6 | 19.1 | 25.3 | 29.3 | 34.6 | 42.1 | 48.1 |
| 2 Hrs | 9.2 | 12.1 | 15.9 | 18.3 | 21.6 | 26.2 | 30.0 |
| 3 Hrs | 7.0 | 9.1 | 12.0 | 13.8 | 16.3 | 19.7 | 22.5 |
| 6 Hrs | 4.3 | 5.6 | 7.3 | 8.5 | 10.0 | 12.0 | 13.7 |
| 12 Hrs | 2.6 | 3.4 | 4.5 | 5.2 | 6.1 | 7.4 | 8.4 |
| 24 Hrs | 1.6 | 2.1 | 2.8 | 3.2 | 3.7 | 4.5 | 5.2 |
| 48 Hrs | 1.0 | 1.3 | 1.7 | 1.9 | 2.2 | 2.7 | 3.0 |
| 72 Hrs | 0.7 | 0.9 | 1.2 | 1.4 | 1.6 | 1.9 | 2.2 |

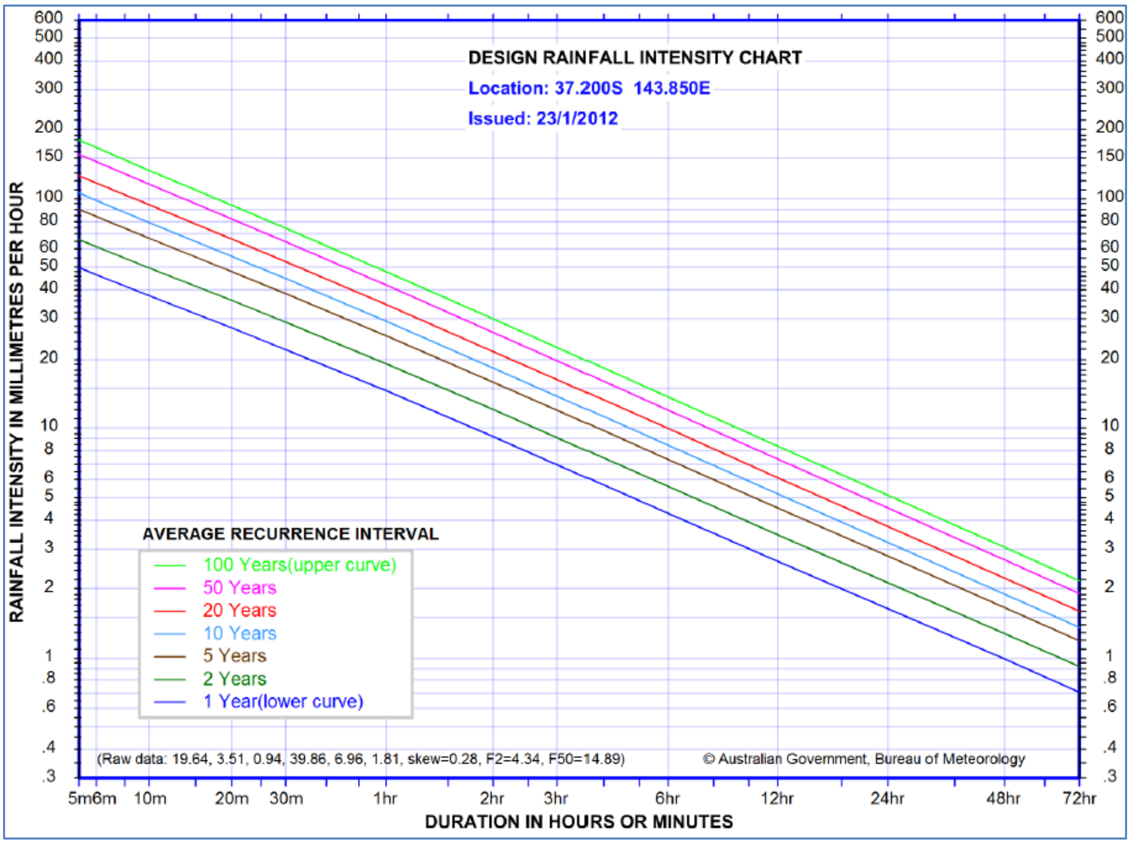



**Figure 4-24 IFD curves extracted from the BoM online IFD tool for Carisbrook Catchment**

***Design temporal pattern***

Design temporal patterns were taken from the Generalised South East Australia Method (GSAM) patterns for long duration events up to the 100 year ARI event and either Generalised Short Duration Method (GSDM) or GSAM temporal patterns for the 200 year ARI and PMF events, depending on the catchment's critical duration.

Short duration events up to the 100 year ARI event used temporal patterns obtained from ARR 1987. The catchment is located within Zone 2 of the temporal pattern map as defined in AR&R 1987. The temporal patterns are filtered to remove embedded intensities of higher ARI. The chosen design temporal patterns described above are consistent with recommendations made in the revised Australian Rainfall and Runoff (1998)

***Design spatial pattern***

A uniform spatial rainfall pattern (i.e. same rainfall depths applied to the entire catchment) was adopted for the generation of design flood hydrographs for events up to 100 year ARI. GSAM patterns were used for events beyond a 100 year ARI. The chosen design spatial patterns described above are consistent with recommendations made in the revised Australian Rainfall and Runoff (1998)

As part of the process of selecting the design spatial pattern parameters a sensitivity analysis was conducted and is described in Section 4.8.2.

***Areal reduction factor***

Areal reduction factors convert point rainfall to areal estimates and are used to account for the variation of rainfall intensities over a large catchment. Siriwardena and Weinmann reduction factors were applied to the catchment area of 1,244 $km^2$.

**Table 4-14 Summary of design inputs**

| Design Consideration | AEP | |
|---|---|---|
| | Large (to 1 in 100 AEP) | Rare (beyond 1 in 100 AEP) |
| Point rainfall depths | IFD information | |
| Areal reduction factors | Siriwardena and Weinmann (1996) | |
| Temporal patterns | Short duration: ARR (1987)<br>Long duration: unsmoothed GSAM | Short duration: GSDM<br>Long duration: unsmoothed GSAM |
| Spatial patterns | Uniform | GSAM |

### 4.7.2 Design Model Parameters

***Routing Parameters***

Various regional kc estimation equations were trialled for the calibration process and a value of 10.5 was found to provide a good fit of the observed and modelled hydrographs. Table 4-15 and Table 4-16 show a comparison between this studies' proposed kc values and regional kc estimates. A kc value of 10.5 for the upper catchment and 4.79 for the lower catchment is proposed for the design flood estimation.

**Table 4-15 Comparison of adopted kc and regional kc estimates for upper catchment**

| Source | kc value (upper catchment) |
|---|---|
| Adopted kc | 10.5 |
| Regional Equation For Areas where Annual Rainfall <800mm ($kc = 0.49*A^{0.65}$ Catchment area = 1245 $km^2$) | 50.4 |
| MMBW ($kc = 1.19*A^{0.56}$ Catchment area = 1245 $km^2$) | 64.4 |
| DVA ($kc = 1.53*A^{0.55}$ Catchment area = 1245 $km^2$) | 77.1 |

**Table 4-16 Comparison of adopted kc and regional kc estimates for lower catchment**

| Source | kc value (lower catchment) |
|---|---|
| Adopted kc | 4.79 |
| Regional Equation For Areas where Annual Rainfall <800mm ($kc = 0.49*A^{0.65}$ Catchment area = 99 $km^2$) | 9.7 |
| MMBW ($kc = 1.19*A^{0.56}$ Catchment area = 99 $km^2$) | 15.5 |
| DVA ($kc = 1.53*A^{0.55}$ Catchment area = 99 $km^2$) | 19.2 |

It is recognised that the adopted kc values for both the upper and lower are considerably lower than the estimates as shown in Table 4-15 and Table 4-16. As previously discussed this was a direct result of the small subareas used in the RORB model which was necessary in this study. Traditional RORB models have typically consisted of approximately 20 sub-areas. This study necessitated a much larger number of sub-areas so that flows could be accurately extracted from a number of local tributaries which flow into Carisbrook. The high number of sub-areas is also a result of modern GIS tools which allow a quicker and more detailed model construction compared with traditional manual methods. The result of this finer delineation is lower kc values in both the upper and lower catchments which do not correlate well with kc estimates based on traditional RORB models. Despite this discrepancy the calibration process was robust and the results demonstrate that the model provides an excellent representation of the catchment behaviour in the study area. It is encouraged that this be discussed with a number of experts in the field (i.e. the DSE review Panel) and that guidance be provided relating to this point for future studies.

***Design Losses***

It is proposed that this study adopt an initial loss of 25 mm and a continuing loss of 2.5 mm/hour as the design loss parameters. The loss parameters are to be applied across all ARI events and durations. The loss parameters proposed are consistent with design loss parameters set out in AR&R 1987. As part of the process of selecting the design loss parameters a sensitivity analysis was conducted and is described in Section 4.8.1.

The proposed loss parameters were verified against other methods including those described by Hill, Mein and Siriwardena (1998). This method, using a baseflow index of 30%, resulted in an initial loss of 26 mm and a continuing loss of 3.7 mm/hour which correlates well with the proposed losses. In this method the calculated initial loss is entirely a function of baseflow index (BFI) as shown in Equation 4-1. Regional maps indicate a base flow of approximately 30% for the region. Baseflow in the region varies considerably, however, so as part of the sensitivity analysis a number of baseflow values were trialled.

**Equation 4-1 Loss Equations as described by Hill, Mein and Siriwardena (1998)**

$$Initial\ Loss = (-25.8 \times BFI) + 33.8$$

$$Continuing\ Loss = (7.97 \times BFI) + (0.00659 \times PET) - 6$$

Where: BFI is the baseflow index

PET is the mean annual potential evaporation (mm)

It should be noted that the design losses were not based on the losses adopted in the calibration events. Losses applied for the September 2010 and January 2011 are highly dependent on antecedent catchment conditions and are not suitable for design flood estimation.

An alternative method to determine design losses is to fit the design flows to the results of flood frequency analysis. This was not possible in this study due to the following reasons:

a) the flood frequency analysis at the Tullaroop Reservoir Head Gauge is dependent on initial water levels in the reservoir and so is not suitable to use in determining losses across the catchment;
b) As previously discussed there were significant problems with data quality in the gauge records at the McCallums Creek and Tullaroop Creek Clunes gauges particularly in high flow events. It was decided that there is too much uncertainly in the resulting flood frequency analysis at these locations for use in determining design losses; and
c) The gauge at Creswick Creek at Clunes has a relatively good data record however its location in the upper half of the catchment introduces uncertainty in using the flood frequency analysis at this location to determine losses across the whole study area. Some initial testing was done on fitting the design flows to the flood frequency analysis at this location however it was discovered that excessively high losses were required to achieve a good fit. It was deemed that using alternative methods as described above to determine design losses was preferable than using the flood frequency analysis at this gauge.

***Storages***

As a conservative measure the initial storage level of Tullaroop Reservoir was set at full supply level for design event modelling. Sensitivity testing, as detailed in Section 4.8.5, demonstrated that the initial water level in the reservoir has a relatively small impact on peak flows experienced through Carisbrook in large events, with McCallum Creek being the dominant waterway in such events. Having the initial water level at full supply level is a conservative approach, consistent with the upstream Creswick and Clunes studies[3&4] and is equivalent to the conditions present during the January 2011 event in Carisbrook.

[3] Water Technology (2012) *Creswick Flood Mitigation and Urban Drainage Plan*, North Central CMA.

[4] Water Technology (2012) *Clunes Flood Mitigation and Urban Drainage Plan*, North Central CMA.

### 4.7.3 Design Flood Hydrographs

Using the proposed RORB parameters, design flood hydrographs were determined for input locations into the hydraulic model. A range of storm durations were run (10min – 72hrs) to ensure the critical storm durations of the large branches and smaller tributaries were determined. Table 4-17 displays the calculated design peak flows and critical storm durations for various ARI events.

**Table 4-17 RORB model design peak flows and critical storm durations at selected locations**

| | McCallum Creek (above confluence) | | Tullaroop Creek (above confluence) | | Tullaroop Creek (below confluence) | | Local Tributary D/S of Carisbrook Reservoir | |
|---|---|---|---|---|---|---|---|---|
| ARI | Peak flow ($m^3/s$) | Duration (hrs) | Peak flow ($m^3/s$) | Duration (hrs) | Peak flow ($m^3/s$) | Duration (hrs) | Peak flow ($m^3/s$) | Duration (hrs) |
| **5** | 123 | 9h | 22.3 | 9h | 129 | 9h | 3.8 | 9h |
| **10** | 204 | 18h | 39 | 18h | 220 | 18h | 4.9 | 9h |
| **20** | 315 | 18h | 109 | 72h | 352 | 18h | 7.1 | 3h |
| **50** | 573 | 6h | 181 | 18h | 617 | 6h | 12.0 | 2h |
| **100** | 817 | 6h | 272 | 6h | 882 | 6h | 16.4 | 2h |
| **200** | 1285 | 6h | 428 | 6h | 1230 | 9h | 26.6 | 2h |

The design flows indicate that the September 2010 and January 2011 flood events were approximately 75 and 135 year ARI events respectively in Tullaroop Creek at Carisbrook. It also indicates that in McCallums Creek the flood events were approximately 80 and 90 year ARI events respectively while in Tullaroop Creek above the confluence they were approximately 15 and 180 year ARI events respectively.

Based on the results shown in Table 4-17 it is proposed that the 2, 6, 9, 12, 48 and 72 hour durations will be run in the hydraulic model. This will ensure that the critical durations of both the local and broader catchments are modelled. The resulting flood extents from all durations will be enveloped to form a single ARI event extent.

It is also proposed that simplified joint probability scenarios be run to represent the impact of local catchment flows combined with larger flows from McCallums and Tullaroop Creeks. The 100 year ARI event of critical duration for the local catchment will be run with a lower ARI event in the McCallums and Tullaroop Creek catchments. The reverse will also be modelled with a 100 year ARI critical duration event in the Tullaroop and McCallums Creek catchments combined with a smaller ARI event in the local catchment.

### 4.7.4 Design Flow Verification

The design flows are largely dependent on the adopted RORB model design parameters. A number of checks were undertaken to verify the generated design flows.

***Flood Frequency Analysis***

A flood frequency analysis (FFA) utilises the available historic flood peak information and based on a statistical approach fits a probability distribution, providing an estimate of flow for various design probability events. FFA has previously been undertaken for the Creswick Creek at Clunes gauge as well as for Tullaroop Reservoir inflow and outflows. The results of the FFA provide an estimate of the 100 year ARI flow at these locations.

FLIKE was used to perform the existing FFA at Creswick Creek at Clunes. FLIKE uses a different fitting procedure to that outlined in AR&R (1987). AR&R recommends the 'methods of moments' fitting algorithm while FLIKE offers a choice of either the Global Probabilistic or Quasi-Newton fitting algorithms.

There are a number of probability distributions which can be used to undertake a FFA. The 'Log Pearson III' distribution was adopted as the best fit for the FFA. The 100 year ARI flow estimated from the 'Log Pearson III' FFA (208.5 $m^3/s$) was much lower than the 100 year ARI design flow at Clunes (372 $m^3/s$) as estimated from the RORB modelling. This large difference is most likely due to a lack of significant flood events across the available streamflow record, resulting in a lower 100 year ARI peak flow calculated from the FFA. Larger floods are known to have occurred in the past but no record is available. The estimated 100 year ARI flow from the RORB modelling still fell well inside the large confidence limits of the FFA.

When the FFA was undertaken at Clunes it was acknowledged that across the 68 years of data, the 2011 and 2010 events were significantly higher than the next highest record (90 $m^3/s$) in 1975. Given that the two recent flood events are much larger than other flows on records, resulting in a poor fit, it is suggested that the FFA should not be used to scale the design flows. The FFA for Clunes is shown in Figure 4-25.

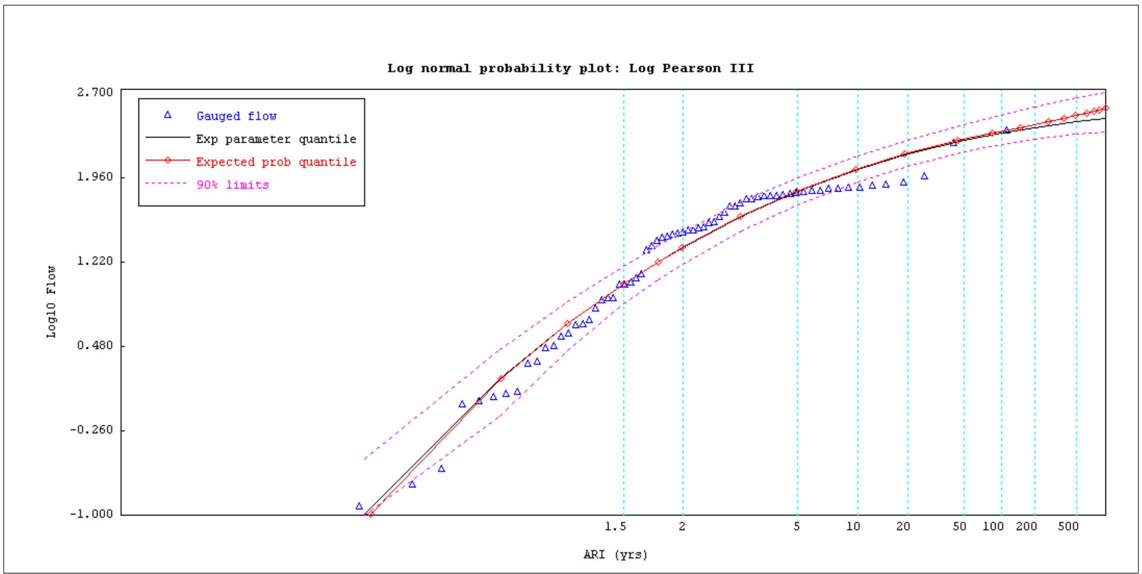



**Figure 4-25 Log Pearson III flood frequency analysis – Creswick Creek @ Clunes**

A FFA was also completed at McCallums Creek using the available data. The missing peak flows for the large events of 2010 and 2011 were included in the analysis by using a minimum flow approach for those events. The September and January peak flows were included in the analysis as greater than 600 and 700 $m^3/s$ flows respectively which is a reasonable assumption based on the hydrologic calibration results and initial hydraulic modelling. The 'Log Pearson III' distribution was also adopted as the best fit for this FFA.

The results of the FFA for McCallums Creek are shown in Figure 4-26 and indicate 50 and 100 year flows of 762 and 981 $m^3/s$ respectively. This would mean the September 2010 event on McCallums Creek was less than a 50 year event while January 2011 was approximately a 50 year event. This correlates reasonably well with the design modelling results which suggests the September and January were between 50 and 100 year events.

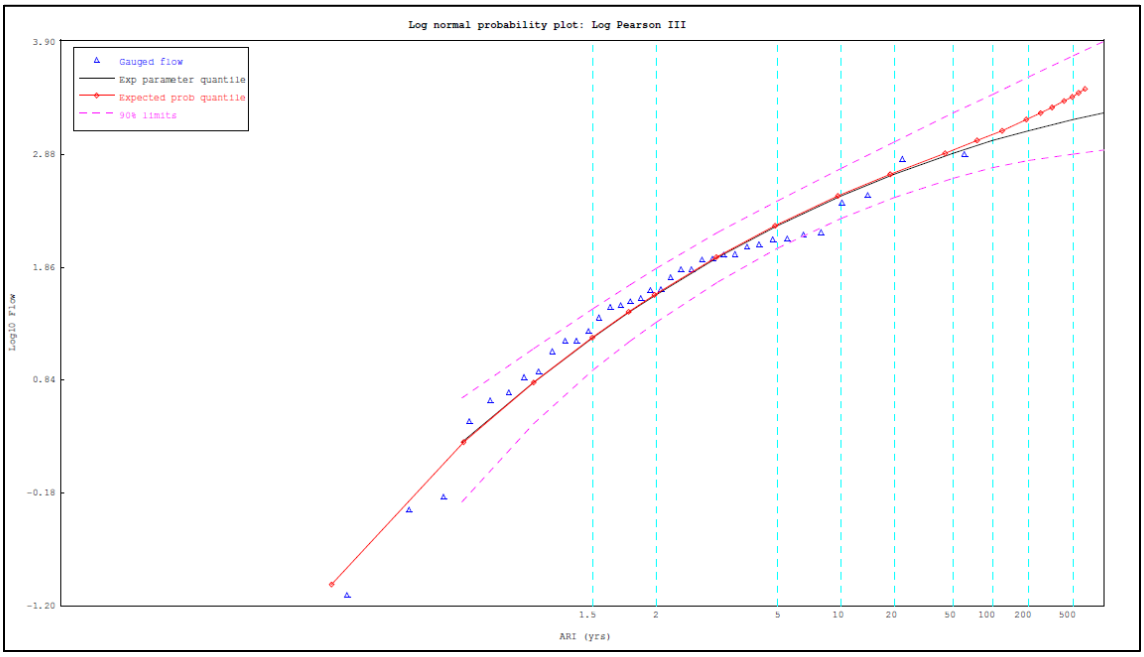



**Figure 4-26 Log Pearson III flood frequency analysis – McCallums Creek Gauge**

A FFA of Tullaroop Reservoir inflows and outflows was completed by SKM in 2002 assuming that the reservoir was full. The FFA indicates that the peak reservoir inflow of 612 $m^3/s$, as recorded by GMW during the January 2011 event, equates to approximately a 1 in 500 year event (0.2% AEP) which would seem an overestimate compared with the design flows and other checks detailed in this report. It should be noted that this analysis was completed using data up until 2002 and so does not include the large events of 2010 and 2011 which are likely alter the curve significantly.

The FFA at the Tullaroop Outflow was redone for this study with the inclusion of the additional 10 years of available data. The results of the FFA are shown in Figure 4-27. This FFA was completed using the historical annual record of peak flows without any assumption made on reservoir levels. 36 of the 74 years of data were censored due to no flow in those years. The results of the FFA indicate 50 and 100 year ARI flows of 705 $m^3/s$ and 1,050 $m^3/s$ respectively. These values are considerably higher than the design 50 and 100 year ARI flows of 181 $m^3/s$ and 272 $m^3/s$ along Tullaroop Creek above the confluence with McCallums Creek and which assumes a full reservoir level.

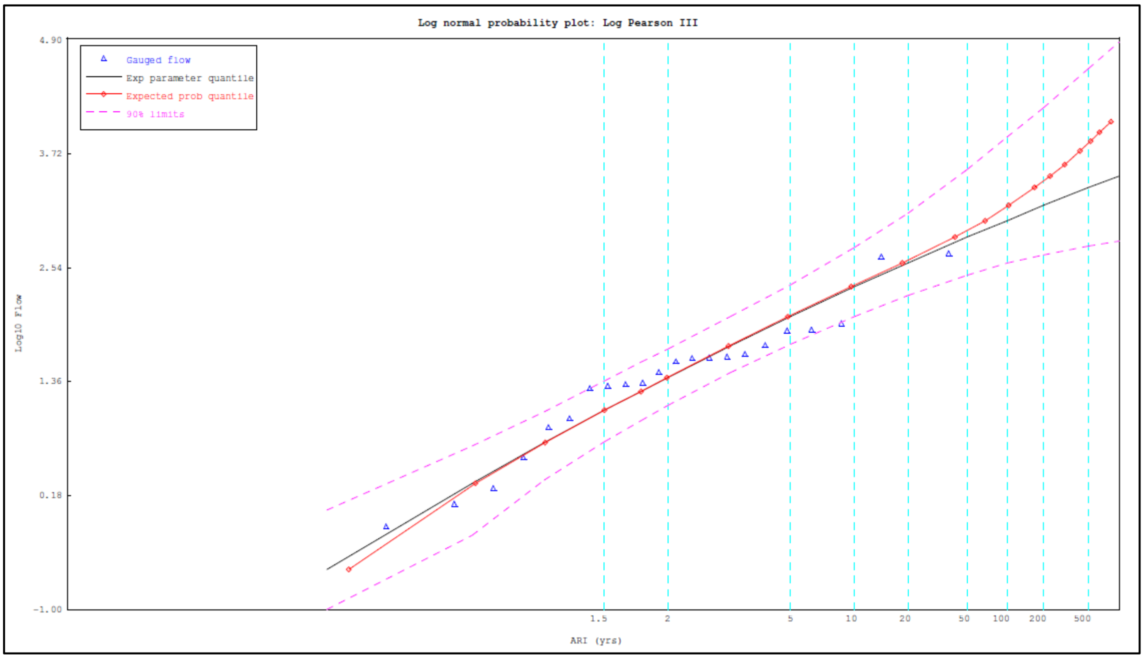



**Figure 4-27 Log Pearson III flood frequency analysis – Tullaroop Reservoir Head Gauge**

### *Rational Method*

Rational method calculations were performed as an additional check of the design flows at the lower end of McCallum Creek, Tullaroop Creek above the reservoir and in the nine local tributaries around Carisbrook. The results are shown in Table 4-18 and demonstrate the rational flows are generally around 25% lower in the local catchments and substantially lower in the broader catchments. The rational method is generally used for estimating peak flows from small catchments, and is not designed to be used for large rural catchments such as Tullaroop and McCallum Creeks hence the large discrepancies than can be seen for the larger McCallums and Tullaroop Creek catchments. The discrepancies in the local catchments could be due to a number of factors such as land use and the wide confidence limits of the Rational Method.

**Table 4-18 Comparison between Design Flows and Rational Method Calculations**

| Inflow | Rational Method 100yr flow ($m^3/s$) | Design 100yr flow ($m^3/s$) | Difference (%) |
|---|---|---|---|
| 1 | 8.91 | 17.9 | 100% |
| 2 | 10.53 | 13.3 | 26% |
| 3 | 10.92 | 16.4 | 50% |
| 4 | 11.59 | 16.0 | 38% |
| 5 | 3.45 | 4.2 | 22% |
| 6 | 3.68 | 4.1 | 11% |
| 7 | 4.78 | 6.3 | 32% |
| 8 | 4.5 | 5.6 | 24% |
| 9 | 9.8 | 11.9 | 21% |
| McCallum Creek | 328 | 817 | 149% |
| Tullaroop Creek (above reservoir) | 465 | 1,121 | 141% |

**Regional Method**

Design flows from the broader catchments were also verified against methods described in Hydrological Recipes – Estimation Techniques in Australian Hydrology (Grayson et al, 1996). This method utilises a regional equation for the 100 year ARI event in rural catchments. The peak 100 year ARI design flow at the lower end of McCallum Creek of 817 $m^3/s$ was higher than the regional method flow estimate which was found to be 516 $m^3/s$. In Tullaroop Creek above the reservoir the peak 100 year ARI design flow of 1,121 $m^3/s$ is somewhat higher than the regional method flow estimate which was found to be 708 $m^3/s$. This method uses the equation show below.

$$Q_{100} = 4.67 \times (Area^{0.763})$$

**IFD Analysis**

As an additional comparison an IFD analysis was completed at the Maryborough Rainfall Gauge so that the frequency of the rainfall events could be compared against the frequency of the flood events at Carisbrook determined from the calibration and design modelling. The results of the IFD analysis at Maryborough, as shown in Figure 4-28, indicate that the January 2011 rainfall event (72 hours) at Maryborough was a greater than a 100 year ARI event which correlates well with the design modelling which indicates a 135 year ARI for the January 2011 flood event. The IFD analysis also indicates that the September 2010 rainfall event (24 hour duration) was approximately a 10 to 20 year event which is significantly less than the 75 year flood event determined from design modelling. While the frequency of a rainfall event often correlates well with the frequency of the associated flood event it is not always the case due to a number of other factors such as losses and recent rainfall events.

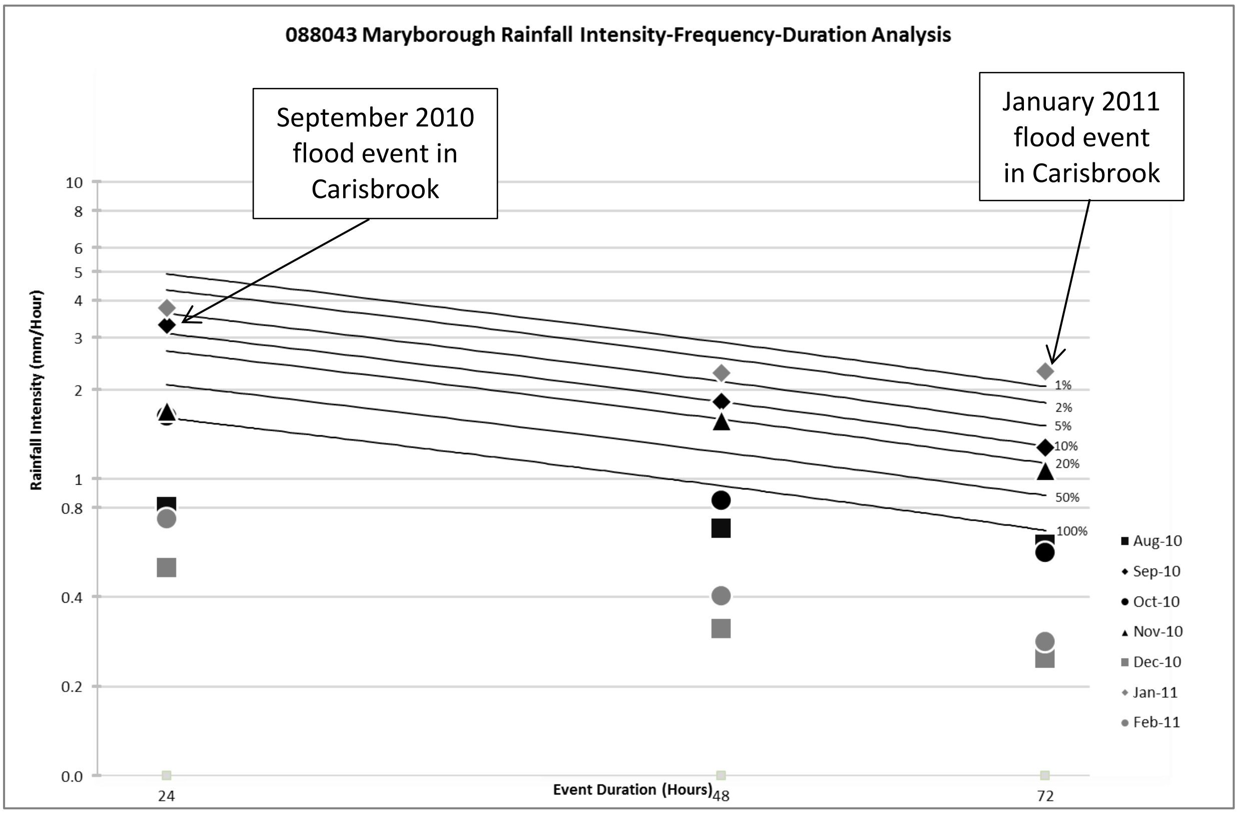



**Figure 4-28** IFD Analysis of recent rainfall events at Maryborough gauge with Carisbrook flood events indicated

**Summary**

Based on the above checks it is recommended that the proposed design flow parameters be adopted for this study. It has been demonstrated that they provide a good estimate of flows in both the local and broader catchments as demonstrated by a number of verification methods.

## 4.8 Sensitivity Analysis

### 4.8.1 Sensitivity Analysis of Design Losses

A sensitivity analysis was conducted on the design loss parameters and five combinations were trialled to assess their impact on peak flows in the major waterways and local catchments to Carisbrook. Changes in these parameters also impact the apparent frequency of historic events such as the January 2011 and September 2010 calibration events so this impact was also assessed. The combination of initial and continuing loss parameters that were trialled are detailed in Table 4-19 and the results of the analysis are shown in Table 4-20 and Table 4-21.

**Table 4-19 Design Loss Sensitivity Analysis –Parameter Details**

| Scenario | Loss Parameter Details | Initial Loss (mm) | Continuing Loss (mm/h) |
|---|---|---|---|
| 1 | AR&R design losses (upper end of range) | 25 | 2.5 |
| 2 | AR&R design losses (lower end of range) | 20 | 2.5 |
| 3 | Hill et al. losses using a Baseflow Index of 0.3 | 26.1 | 3.7 |
| 4 | Hill et al. losses using a Baseflow Index of 0.2 | 28.6 | 2.9 |
| 5 | Hill et al. losses using a Baseflow Index of 0.1 | 31.5 | 2.0 |

**Table 4-20 Design Loss Sensitivity Analysis – Impact on peak flows and calibration event frequency at McCallum and Tullaroop Creeks**

| Scenario | Initial Loss (mm) | Continuing Loss (mm/h) | Tullaroop Creek U/S of Carisbrook | | | McCallums Creek U/S of Carisbrook | | |
|---|---|---|---|---|---|---|---|---|
| | | | Q100 ($m^3/s$) | Jan 11 ARI (yrs) | Sept 10 ARI (yrs) | Q100 ($m^3/s$) | Jan 11 ARI (yrs) | Sept 10 ARI (yrs) |
| 1 | 25 | 2.5 | 272 | 181 | <50 | 817 | 88 | 79 |
| 2 | 20 | 2.5 | 386 | 113 | <50 | 880 | 74 | 42 |
| 3 | 26.1 | 3.7 | 257 | >200 | <50 | 595 | 150 | 137 |
| 4 | 28.6 | 2.9 | 266 | >200 | <50 | 656 | 138 | 123 |
| 5 | 31.5 | 2.0 | 305 | 178 | <50 | 711 | 120 | 102 |

**Table 4-21 Design Loss Sensitivity Analysis – Impacts on peak flows and calibration event frequency on Tullaroop Creek in Carisbrook and local catchment**

| Scenario | Initial Loss (mm) | Continuing Loss (mm/h) | Tullaroop Creek in Carisbrook | | | Local catchment (Inflow 3) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Q100 ($m^3/s$) | Jan 11 ARI (yrs) | Sept 10 ARI (yrs) | Q100 ($m^3/s$) | Jan 11 ARI (yrs) | Sept 10 ARI (yrs) |
| 1 | 25 | 2.5 | 882 | 134 | 76 | 16.4 | 55 | 139 |
| 2 | 20 | 2.5 | 1027 | 95 | <50 | 12.4 | 101 | >200 |
| 3 | 26.1 | 3.7 | 727 | >200 | 112 | 10.1 | 164 | >200 |
| 4 | 28.6 | 2.9 | 757 | 189 | 100 | 9.8 | 172 | >200 |
| 5 | 31.5 | 2.0 | 833 | 161 | 72 | 9.7 | 186 | >200 |

The results of the sensitivity analysis show that the design losses have a significant impact on flows at Carisbrook. Results using the Hill and Mein losses show considerably lower flows as a result of the higher losses used in the method. The reduction in flows causes the frequency of the calibration events to increase significantly with the January 2011 event becoming a greater than 200 year event in Scenario 3. The September 2010 event also becomes less frequent and becomes a greater than 200 year event in two of the scenarios. The September event was generally perceived as a moderate event by local residents and is unlikely to have been a 100 year event. The frequency of the calibration events resulting from using the upper range of the AR&R design losses are a 76 year ARI for the September 2010 event and 134 year ARI for the January 2011 event. This would seem to correlate much more closely with the perceived size of these events from local residents and stakeholders.

The results suggest that the losses determined using the Hill and Mein method are generally too high and that the AR&R loss parameters are more appropriate to adopt for this study.

### 4.8.2 Sensitivity Analysis of Spatial Patterns

A sensitivity analysis was conducted on spatial patterns using a design 100 year event. Two spatial patterns were trialled initially, a uniform pattern and the January 2011 event spatial pattern. These were tested on both 18 and 72 hour duration events. The impact on flows was observed at six locations as shown in Figure 4-22 and Figure 4-23. The spatial pattern for the January 2011 event was determined from rainfall isohyets constructed in the calibration phase of the hydrologic analysis. The spatial pattern of the third rainfall burst of the event was utilised as this was the dominant burst of the event with a high proportion of the rainfall. The sensitivity analysis was conducted assuming Tullaroop Reservoir was at full supply level which is consistent with the January 2011 event and the approach adopted for the design modelling.

**Table 4-22 Spatial Pattern Sensitivity Analysis – 100 year, 72 hour event**

| Spatial Pattern | Peak Flows ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|
| | Creswick Creek @ Clunes | Tullaroop Reservoir Inflow | McCallums Creek U/S of Carisbrook | Tullaroop Creek U/S of Carisbrook | Tullaroop Creek at Carisbrook | Local Catchment (Inflow 3) |
| Uniform | 497 | 1018 | 749 | 338 | 938 | 8.4 |
| Jan 11 Pattern | 479 | 966 | 874 | 299 | 1007 | 8.9 |
| *Difference (%) c/w uniform* | *-3.6%* | *-5.1%* | *+16.7%* | *-11.5%* | *+7.4%* | *+6.0%* |

**Table 4-23 Spatial Pattern Sensitivity Analysis – 100 year, 18 hour event**

| Spatial Pattern | Peak Flows ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|
| | Creswick Creek @ Clunes | Tullaroop Reservoir Inflow | McCallums Creek U/S of Carisbrook | Tullaroop Creek U/S of Carisbrook | Tullaroop Creek at Carisbrook | Local Catchment (Inflow 3) |
| Uniform | 152.0 | 253.6 | 204.1 | 39.0 | 220.0 | 3.6 |
| Jan 11 Pattern | 142.4 | 241.3 | 259 | 32.82 | 264.5 | 3.9 |
| *Difference (%) c/w uniform* | *-6.3%* | *-4.9%* | *+26.9%* | *-15.9%* | *+20.2%* | *+8.3%* |

The results indicate that the January 2011 spatial pattern has a greater proportion of rainfall over the McCallums Creek catchment with significantly larger flows observed in McCallums Creek and less flows in Tullaroop Creek.

The results also indicate slightly greater rainfall over the local catchments to Carisbrook in the January spatial pattern with larger flows observed from the local catchments.

While some differences in flow are observed with the January 2011 event it is difficult to justify using this pattern for design events. Without further detailed analysis of rainfall events in the region it cannot be concluded that the January spatial pattern is more representative of rainfall events than a uniform pattern in the catchments upstream of Carisbrook. This analysis is beyond the scope of this study and for these reasons a uniform pattern was adopted for design modelling in this study for events up to 100 year ARI. GSAM patterns will be for events greater than 100 year ARI. This is consistent with recommendations made in the revised Australian Rainfall and Runoff (1998).

### 4.8.3 Sensitivity Analysis of Spatially-Varied IFD parameters

In addition, sensitivity testing was conducted using differing IFD parameters for the upper and lower sections of the catchment. IFD parameters were extracted at the centroid of the upper and lower catchments and the resulting rainfall depth was applied to those catchments respectively. The centroid location and IFD depth for the catchments are shown in Table 4-22. These were compared against the Uniform spatial pattern results for a 100 year, 72 hour event as shown in Table 4-25.

**Table 4-24 Upper and Lower Spatial Pattern IFD Details**

| Catchment | Latitude | Longitude | Rainfall Depth (mm) |
|---|---|---|---|
| Upper | -37.370 | 143.852 | 143.9 |
| Lower | -37.075 | 143.770 | 128.9 |
| *Difference (%)* | | | *13.2%* |

**Table 4-25 Spatially-Varied IFD Parameters Sensitivity Analysis –100 year, 72 hour event**

| Spatial Pattern | Peak Flows ($m^3$/s) | | | | | |
|---|---|---|---|---|---|---|
| | Creswick Creek @ Clunes | Tullaroop Reservoir Inflow | McCallums Creek U/S of Carisbrook | Tullaroop Creek U/S of Carisbrook | Tullaroop Creek at Carisbrook | Local Catchment (Inflow 3) |
| Uniform | 497 | 1018 | 749 | 338 | 938 | 8.4 |
| Upper/ Lower | 534 | 1058 | 666 | 354 | 847 | 7.2 |
| *Difference (%) c/w uniform* | *+11.5%* | *+9.5%* | *-23.8%* | *+18.4%* | *-15.9%* | *-19.1%* |

The results when using the upper/lower catchment spatial pattern show more flow occurring in Tullaroop Creek and significantly less in McCallums Creek. This is the opposite result to what was observed with the January 2011 spatial pattern and indicates that using this spatial pattern is not appropriate for design modelling. As discussed above a uniform pattern was adopted for design modelling in this study for events up to 100 year ARI and GSAM patterns for events greater than the 100 year ARI event. This is consistent with recommendations made in the revised Australian Rainfall and Runoff (1998).

### 4.8.4 Climate Change Analysis

A number of climate change scenarios were run in the hydrologic model to investigate the impact climate change may have on flows in the catchment. The climate change scenarios were run with an increased rainfall intensity of 32% which is the value adopted by Melbourne Water and represents the upper range of CSIRO predictions regarding the impact of climate change on rainfall intensity by 2100[5].

Three scenarios were run and are detailed in Table 4-26 below. The results of the sensitivity analysis are also shown below in Table 4-27 to Table 4-29. ARR (1987) temporal patterns were used in the sensitivity analysis.

[5] CSIRO (2007). Climate change in Australia: Technical Report (http://www.climatechangeinaustralia.gov.au/technical_report.php)

**Table 4-26 Climate change scenarios**

| Scenario | Rainfall Design Event (ARI, Duration) | Mean Rainfall (existing conditions), mm | Mean Rainfall (climate change scenario), mm |
|---|---|---|---|
| 1 | 100yr, 6hr | 63.1 | 83.2 |
| 2 | 10yr, 18hr | 59.3 | 78.2 |
| 3 | 5yr, 9hr | 39.3 | 51.2 |

**Table 4-27 Results of Climate Change Analysis for 100 year event**

| Conditions | Peak Flows ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|
| | Creswick Creek @ Clunes | Tullaroop Reservoir Inflow | McCallums Creek U/S of Carisbrook | Tullaroop Creek U/S of Carisbrook | Tullaroop Creek at Carisbrook | Local Catchment (Inflow 3) |
| Existing Conditions | 608.5 | 1,121 | 817.4 | 216.1 | 882.5 | 11.91 |
| Climate Change | 1,086 | 2,001 | 1,453 | 438.1 | 1,567 | 26.03 |
| *Increase (%)* | *78%* | *79%* | *78%* | *103%* | *78%* | *119%* |

**Table 4-28 Results of Climate Change Analysis for 10yr event**

| Conditions | Peak Flows ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|
| | Creswick Creek @ Clunes | Tullaroop Reservoir Inflow | McCallums Creek U/S of Carisbrook | Tullaroop Creek U/S of Carisbrook | Tullaroop Creek at Carisbrook | Local Catchment (Inflow 3) |
| Existing Conditions | 152.0 | 253.6 | 204.1 | 39.0 | 220.0 | 3.58 |
| Climate Change | 269.5 | 516.8 | 398.6 | 120.3 | 453.8 | 5.719 |
| *Increase (%)* | *77%* | *104%* | *95%* | *208%* | *106%* | *60%* |

**Table 4-29 Results of Climate Change Analysis for 5yr event**

| Conditions | Peak Flows ($m^3/s$) | | | | | |
|---|---|---|---|---|---|---|
| | Creswick Creek @ Clunes | Tullaroop Reservoir Inflow | McCallums Creek U/S of Carisbrook | Tullaroop Creek U/S of Carisbrook | Tullaroop Creek at Carisbrook | Local Catchment (Inflow 3) |
| Existing Conditions | 106.4 | 154.7 | 123.2 | 22.3 | 129.4 | 2.71 |
| Climate Change | 223.4 | 367.9 | 284.9 | 57.4 | 312.0 | 4.67 |
| *Increase (%)* | *110%* | *138%* | *131%* | *157%* | *141%* | *72%* |

The results demonstrate a significant increase in peak flow rates across all three scenarios. It can be seen that the impact is greater the lower the ARI with a mean increase in peak flow rates of 125% in the 5 year event compared to a mean 89% increase in the 100 year event. It can be see that the 100 year ARI peak flow rate with climate change through the township is 1,567 $m^3/s$, which based on the current design modelling represents a greater than 500 year ARI event. With climate change, extreme events such as January 2011 would become considerably more frequent.

### 4.8.5 Initial Reservoir Water Level

Reservoir outflows can be significantly impacted by the initial reservoir level so for this reason sensitivity testing was conducted around what impact levels in Tullaroop Reservoir would have on flows at Carisbrook. A number of initial water levels were tested including a median drawdown level as described in the existing SKM (2002) study of Tullaroop Reservoir. This study determined that the median drawdown level of the reservoir is 22,000 ML which equates to 70% capacity. This was determined by deriving a storage frequency curve from the full record of weekly storage levels. The curve is shown in Figure 4-29 and demonstrates that the median storage volume is 55,000 ML which equates to a drawdown of 22,000 ML.

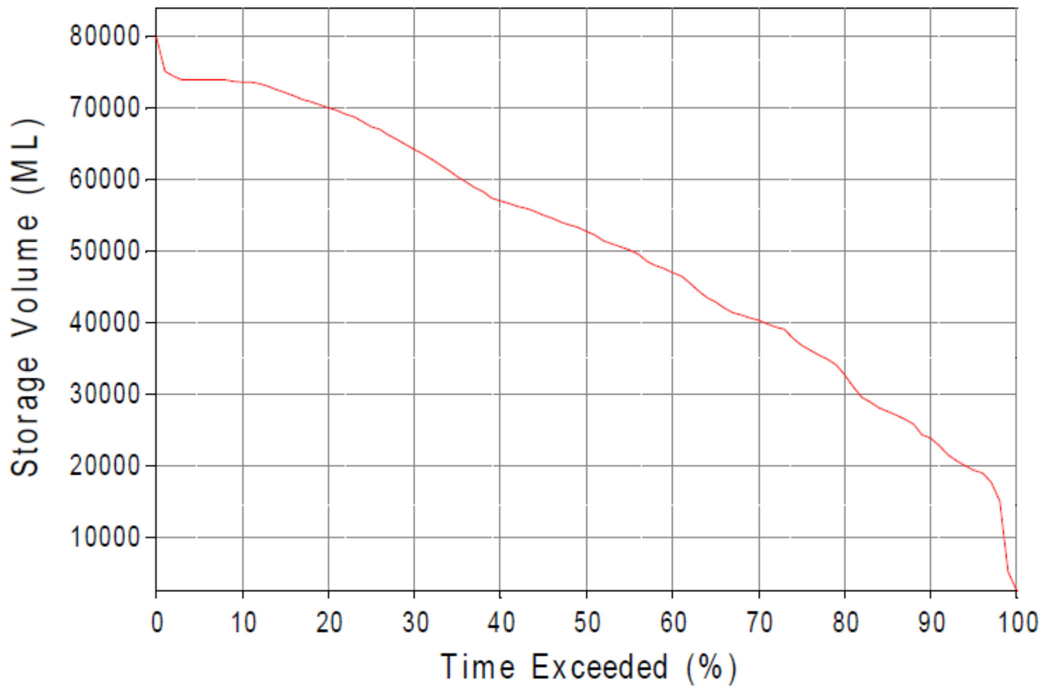



**Figure 4-29 Storage Behaviour for Tullaroop Reservoir (SKM 2002)**

The methodology of the sensitivity analysis is described below:

- An initial reservoir drawdown was set in the RORB catchment file for the following scenarios:
  - full capacity (no drawdown)
  - 90% capacity (drawdown of 7,000 ML)
  - median drawdown level of 22,000 ML (70% capacity)
  - 50% capacity (drawdown of 36,500 ML)
- 100 year ARI 6 hour duration and 100 year ARI 72 hour duration design events were run for each of the above scenarios
- Peak flows were observed at the reservoir outflow, Tullaroop Creek above the confluence with McCallum Creek and Tullaroop Creek through Carisbrook township

The results of the sensitivity testing are shown in Table 4-30 and Table 4-31.

**Table 4-30 Impact of Initial Tullaroop Reservoir Storage Level on flows – 100yr, 6hr event**

| Reservoir Initial Drawdown (ML) | Initial Reservoir Capacity (%) | Tullaroop Reservoir peak Outflow ($m^3/s$) | Tullaroop Creek U/S of confluence peak flow ($m^3/s$) | Tullaroop Creek at Carisbrook peak flow ($m^3/s$) |
|---|---|---|---|---|
| 0 | 100% | 216 | 216 | 882 |
| 7,000 | 90% | 110 | 110 | 870 |
| 22,000 (Median Drawdown) | 70% | 0 | 92 | 870 |
| 36,500 | 50% | 0 | 92 | 870 |

**Table 4-31 Impact of Initial Tullaroop Reservoir Storage Level on flows – 100yr, 72hr event**

| Reservoir Initial Drawdown (ML) | Initial Reservoir Capacity (%) | Tullaroop Reservoir peak Outflow ($m^3/s$) | Tullaroop Creek U/S of confluence peak flow ($m^3/s$) | Tullaroop Creek at Carisbrook peak flow ($m^3/s$) |
|---|---|---|---|---|
| 0 | 100% | 112 | 111 | 291 |
| 7,000 | 90% | 43.3 | 42.7 | 270 |
| 22,000 (Median Drawdown) | 70% | 0 | 22 | 270 |
| 36,500 | 50% | 0 | 22 | 270 |

It can be seen that the reservoir does not spill in a 100 year design event if the initial storage level is at 50% or 70% capacity for both duration events. Despite the reservoir not spilling in these conditions the peak flow through Carisbrook township is reduced by less than 2% in the 6 hour event and 7% in the 72 hour event. These results demonstrate that regardless of the initial water level in Tullaroop Reservoir peak flows through Carisbrook are dominated by flows in McCallums Creek.

The peak reservoir inflow for the 72 hour event was 340$m^3/s$ in each of the scenarios which demonstrates that even when at full capacity Tullaroop Reservoir causes significant attenuation of peak flows of around 70% in a 100 year 72 hour design event. The peak reservoir inflow for the 6 hour event was 1,121$m^3/s$ which again shows significant attenuation of approximately 80%. This correlates with modelling and GMW records from the January 2011 event which indicates peak flows through the reservoir were attenuated by approximately 45% despite the reservoir being at close to capacity at the beginning of the event.

Further joint probability analysis could be conducted on Tullaroop Reservoir but the results indicate that in major flood events peak flows through the town are dominated by McCallum Creek and that the initial storage level has a relatively minor impact. For this reason and as a conservative measure it is recommended that the reservoir be set at full capacity for the design events.

## 4.9 Summary

A RORB hydrological model was used to generate design flows for the study. The RORB model developed for the catchment was calibrated to the September 2010 and January 2011 flow hydrographs at three gauges located at Clunes and Tullaroop Reservoir. The model was then used to generate design flows for the 5, 10, 20, 50, 100 and 200 year ARI events. The choice of hydrological model parameters used to generate design flows was comprehensively checked using alternative design flow estimation techniques and sensitivity testing, and is recommended for adoption in this study. The design flows indicate that the September 2010 and January 2011 flood events were approximately 75 and 135 year ARI events respectively in Tullaroop Creek at Carisbrook.

# 5. HYDRAULIC ANALYSIS

## 5.1 Overview

A detailed combined 1D-2D hydraulic modelling approach was adopted for this study. The hydraulic modelling approach consisted of the following components:

- One dimensional (1D) hydraulic model of key drains, drainage lines and hydraulic structures;
- Two dimensional (2D) hydraulic model of the broader floodplain; and
- Links between the 1D and 2D hydraulic models to accurately model the interaction between in bank flows (1D) and overland floodplain flows (2D).

The hydraulic modelling software MIKE FLOOD developed by the Danish Hydraulic Institute (DHI) was used for this study. MIKE FLOOD is a state-of-the-art tool for floodplain modelling that combines the dynamic coupling of the 1D MIKE 11 river model and 2D MIKE 21 model systems. Through coupling of these two systems it is possible to accurately represent river and floodplain processes.

The hydraulic model was calibrated against observed flood levels and extents in the September 2010 and January 2011 flood events. This model calibration enables the assessment of the hydraulic model's ability to reproduce observed flood behaviour. For this model calibration, the condition of the waterways and floodplain represented the condition at the time of the September 2010, and January 2011 events respectively.

For the design flood events, adjustments to the model geometry was undertaken to reflect current waterway condition and works carried out since the recent floods. A number of design events were then modelled.

## 5.2 Hydraulic Model Development and Parameters

### 5.2.1 Model Schematisation

The hydraulic model of Carisbrook was constructed using a linked 1D-2D modelling approach. The 1D hydraulic model was used to represent the main constructed drains and culverts in the townships while the 2D model was used to model the larger waterways and broader floodplain as shown in Figure 5-1.

The two models were linked using a number of standard links at the upstream and downstream ends of the 1D drains and culverts as well as a series of lateral links running parallel to the 1D drains. Water flowed into the model through eleven 2D inflow boundaries which represented inflows from Tullaroop and McCallums Creeks as well as the nine local catchments which surround Carisbrook. Water flowed out of the 2D model using a standard link across the entire floodplain at the downstream end of the model. The standard link transitioned into a 1D floodplain branch which used a Q-H relationship on Tullaroop Creek as the downstream boundary of the 1D-2D linked model.

The approach detailed above allowed local flows to flow across the 2D grid, enter the 1D network and then re-enter the 2D grid at the bottom end of the drains. Further detail regarding the model schematisation can be found in the relevant sections below.

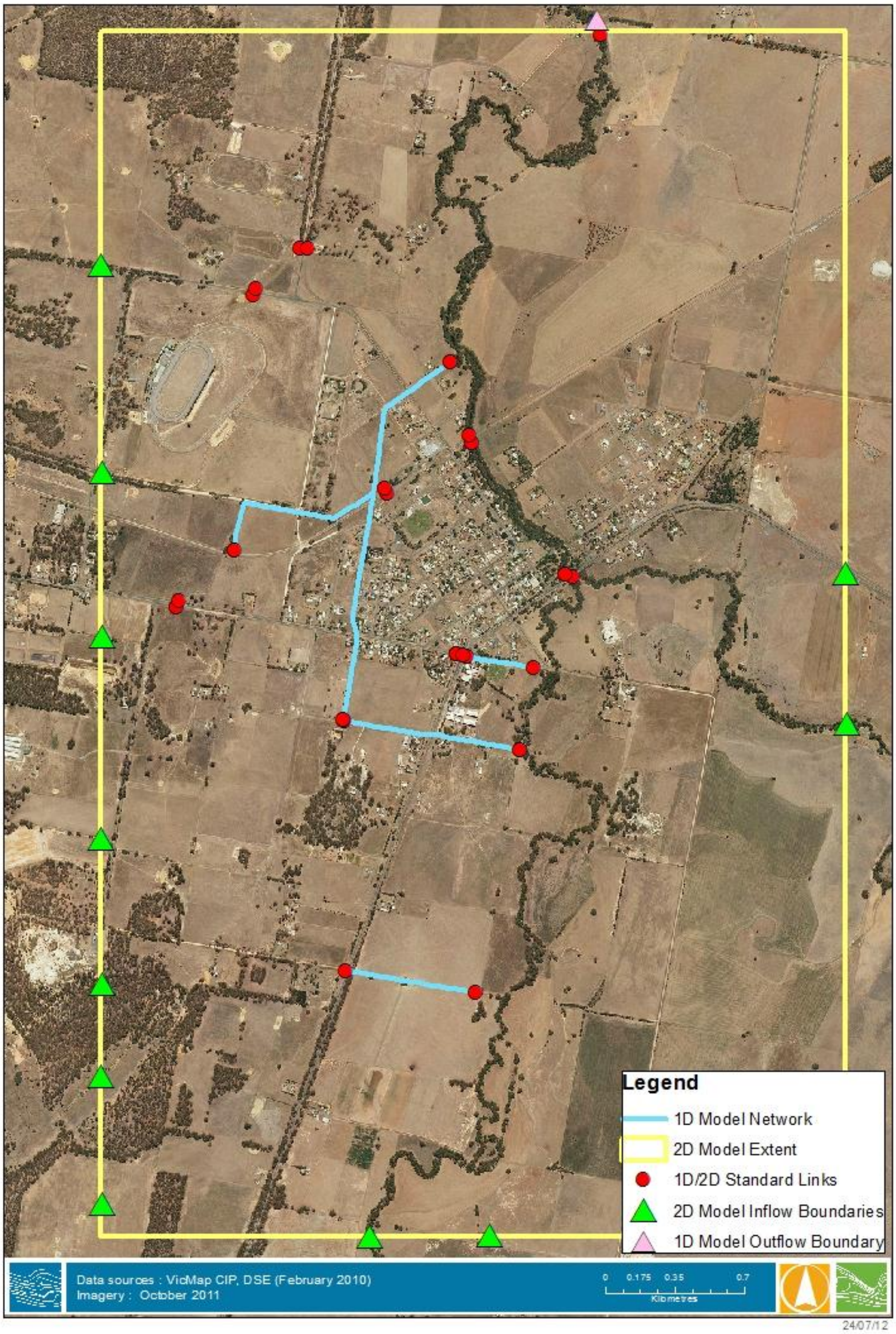



**Figure 5-1 1D/2D Hydraulic Model Schematization**

### 5.2.2 1D Model Component

***1D Network***

The MIKE11 model explicitly modelled the main drains and drainage lines in Carisbrook. The 1D model network consisted of five key drainage branches:

- **Main bluestone drain through township** - from Belfast Road, flowing from south to north through town, outflowing into Tullaroop Creek near Hood Street;
- **Drain along railway line flowing into main drain –** commencing near Wills Street, flowing east and outflowing into main bluestone drain adjacent to railway line;
- **Drain along Belfast Road –** commencing on Belfast Road at southern end of the main bluestone drain, flows east along Belfast Road, outflowing into McCallums Creek near Virginia Street;
- **Bluestone drain near cemetery** – from corner of Landrigan Road and Williams Road, flowing east and outflowing into McCallums Creek; and
- **Bluestone drain near school –** from corner of Landrigan Road and Pyrenees Highway, flowing east and outflowing into McCallums Creek near Camp Street.

Figure 5-1 shows in blue the above five drainage lines included in the 1D model. The Pyrenees Highway road bridge and main railway bridge across Tullaroop Creek were also modelled within the MIKE11 model as were a number of other culverts around the township. These structures were modelled using very short 1D branches extending out either side of the structure, and linked into the 2D model using standard links.

For the calibration model, the 1D branches were initially developed using regularly spaced cross-sections (at approximately 100 m intervals, closer around structures) generated from the LiDAR. The cross sections were extended out to the top of the drain or creek bank on either side. The cross-sections were then edited if necessary based on measurements of the drains taken during site visits.

***Structures***

Bridge and culvert crossings were modelled as MIKE11 structures. All structures were modelled with culvert and weir structures to simulate flow under the road and flow over the road during large events. The Pyrenees Highway and railway bridges over Tullaroop Creek were modelled using a 1D culvert to represent the waterway area under the bridge. Both the railway and road bridges are significant structures, with lengths of approximately 135 m and 90 m respectively and widths of approximately 5-10 m. Given the relatively small 2D grid size of 5 m, it was considered appropriate that the 2D model be used to represent the weir flow over both of these structures.

Original structure plans were used to model the Pyrenees Highway road bridge and railway bridge on Tullaroop. Further details of the key hydraulic structures are provided in Appendix A.

***Channel Roughness***

For the 1D network the following Manning's 'n' roughness coefficients were initially trialled:

- Bluestone drains - 0.02
- Earthen swale drains - 0.025

These roughness parameters were revised during calibration as discussed in Section 5.3.

### 5.2.3 2D Model Component

***2D Grid Size and Topography***

The 2D model was linked to the 1D model distributing the out of channel flows across the floodplain. A 2D model grid was created using the LiDAR supplied. A 5 m model grid resolution was adopted, achieving detailed representation of the 2D topography but allowing for reasonable model run times.

Tullaroop and McCallums Creeks were modelled in 2D as the grid size of 5 m allowed for a good representation of these creeks in the 2D.

The 2D grid cells were blocked out along the 1D channels so as not to double count any floodplain storage and conveyance.

***Floodplain Roughness***

The 2D model roughness was modelled using a roughness grid. Roughness values for a range of land use types were specified, including roads/carparks, buildings, open space with little vegetation, open space with dense vegetation and waterways. The hydraulic roughness grid (Figure 5-2) was based primarily on recent aerial imagery and adjusted as necessary based on observations during site visits. Table 5-1 outlines the initial roughness parameters trialled for each land use type. These roughness parameters were revised during calibration as discussed in Section 5.3, and were changed for design events to reflect current conditions with some works undertaken around the Pyrenees Highway Bridge after the January 2011 flood event.

**Table 5-1 Preliminary 2D hydraulic model roughness parameters**

| Floodplain Element | Manning's 'n' value |
|---|---|
| Road/Road Reserves/Car Parks | 0.035 |
| Buildings | 0.2 |
| Township backyards including fencing | 0.08 |
| Open Grassed Agricultural Areas | 0.04 |
| Dense Vegetation | 0.08 |
| Waterway (with woody debris) | 0.04 |

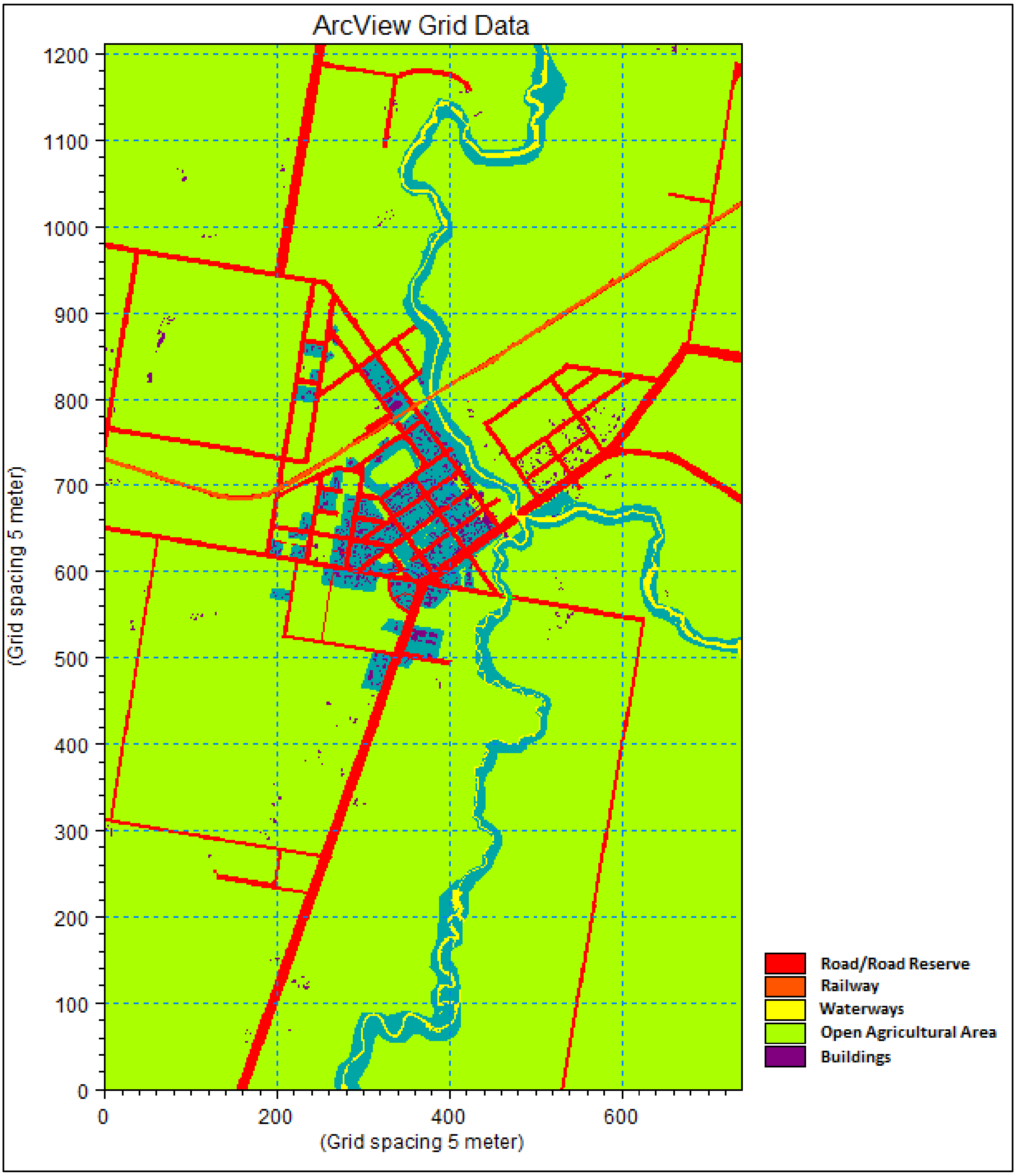



**Figure 5-2 2D hydraulic model roughness grid**

### 5.2.4 1D-2D Model Linking

Within MIKE FLOOD there are two main types of linking methods:

- Standard Links – linking a 1D branch to the 2D grid at the end of a branch
- Lateral Links – linking a 1D branch to the 2D grid along a reach of the branch

The 1D drains were all linked to the 2D grid using lateral links on both the left bank and right banks across the entirety of their length. Lateral links were broken across hydraulic structures and at stream junctions to ensure that there was no bypassing of these critical hydraulic points.

Standard links were used at each end of the drains to link the 1D sections of drain with the 2D model. This approach allowed the local flows to flow across the 2D grid, enter the 1D network and then re-enter the 2D grid at the bottom end of the drains.

The connection between the main bridges and culverts (modelled in 1D) and the 2D grid was set up using standard links at each end of the 1D branch.

A standard link was also used at the downstream end of the model to allow the use of a 1D Q-H downstream boundary on Tullaroop Creek, this is described further below.

### 5.2.5 Boundary Conditions

***Inflow Boundaries***

Inflow boundaries were created at a number of locations in the 2D MIKE21 model to allow water to flow into the model. There were a total of eleven inflow boundaries in the 2D model, located at the upstream end of Tullaroop and McCallums Creeks and nine local tributaries around Carisbrook as shown in Figure 5-3. The inflow hydrographs at these locations were extracted from the RORB model.

***Outflow Boundary***

The 2D model was linked at the downstream end across the entire floodplain using a standard link, transitioning into a 1D floodplain branch with the Q-H relationship on Tullaroop Creek as the downstream boundary.

The main reason for this approach was because a Q-H relationship allows a much more accurate representation of the flood levels at the downstream boundary rather than setting a constant water level representative of the water level expected at the peak of the flood. A constant water level is not representative of all flows or all points in time across a single event. With a Q-H relationship the boundary level is determined by a hydraulic relationship and requires no estimation of an appropriate water level for each event. It also allows the downstream area to fill and drain as it should during a flood rather than being constantly inundated by the backwater of the downstream boundary. This ensures the boundary condition does not have undue effect on the water levels further upstream.

The Q-H relationship was determined within the Mike 11 software by input of the waterway cross-section, roughness and slope at that location.

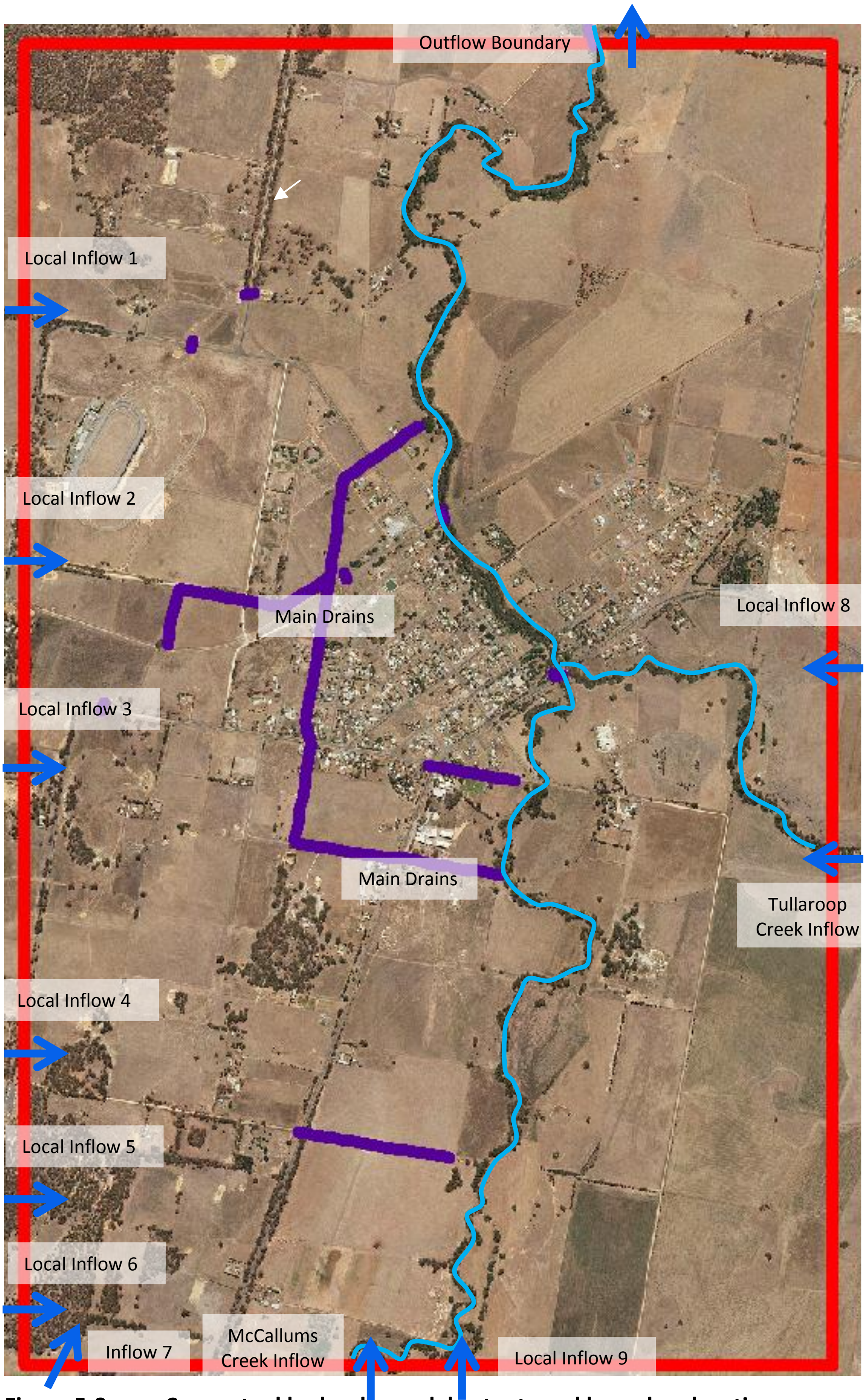



**Figure 5-3 Conceptual hydraulic model extents and boundary locations**

## 5.3 Hydraulic Model Calibration

### 5.3.1 Overview

This section discusses the fine-tuning of the hydraulic model parameters through calibration against observed flood data. The model was calibrated to two large flood events in September 2010 and January 2011. Surveyed flood marks (provided by the North Central CMA), general observations and aerial photographs of the floods were used in the calibration.

A number of sensitivity runs were undertaken with minor changes to the model parameters to get a better match to surveyed flood levels and observations, namely:

- Raising the crest elevation of both the railway and Pyrenees Highway in the model topography as in some locations the 5 m DEM had not accurately picked up the crest elevation determined from the 1m LiDAR (lost in the resampling of the data from a 1 metre to 5 metre grid)
- Increased the waterway roughness from 0.035 to 0.045 (reasonable given the dense vegetation and woody debris along the channel)
- Increased the open agricultural area roughness from 0.04 to 0.05 to better simulate flood depths around the town and along the major waterways (reasonable for pasture and long grass)
- Increased the 1D roughness along drains from 0.02 to 0.03 (reasonable given the gravel base at certain locations and irregular stonework)
- Modelling the flow under the railway and road bridge on Tullaroop Creek in 1D as opposed to 2D to better represent the conveyance through these structures.

The final roughness parameters determined from the calibration process are shown below in Table 5-2.

**Table 5-2 2D Hydraulic model roughness parameters**

| Floodplain Element | Manning's 'n' value |
|---|---|
| Road/Road Reserves/Car Parks | 0.038 |
| Buildings | 0.3 |
| Township backyards including fencing | 0.08 |
| Open Grassed Agricultural Areas | 0.05 |
| Dense Vegetation | 0.08 |
| Waterways (with woody debris) | 0.045 |
| Bluestone drains (1D Model) | 0.03 |

The increased roughness and changes to hydraulic structures resulted in an average water level increase of approximately 100-200 mm across the floodplain, giving a better calibration for both September 2010 and January 2011. The modelled results are discussed below.

It should be noted that while flood mark survey is available for the calibration events there is inherent inaccuracies in the collection of those levels. The levels are primarily based on flood debris marks which may be significantly higher or lower than the true peak due to a number of reasons such as debris piling up on the upstream side of an obstruction or debris collecting on the recession of a flood.

A certain degree of judgement is required in the collection of this data and inaccuracies in the data at some locations are likely.

### 5.3.2 September 2010 Calibration

A number of flood marks from the September 2010 flood event were collected by the North Central CMA. A list of flood affected properties, community feedback regarding the flood events and aerial imagery provided by the North Central CMA were also used to check the modelled flood extent. Calibration plots for the September 2010 flood event are shown in Figures 5-4 and 5-5 below.

Of the 11 survey flood marks located within the study area:

- 2 points are within +/- 100 mm
- 3 points are within +/- 200 mm
- 2 point are within +/- 300mm
- 1 points located a short distance downstream of the Pyrenees Highway road bridge fell slightly outside the flood extent but is within +/- 100mm
- 3 points were discarded from the calibration due to suspected errors in survey

The overall trend showed that the modelled flood levels were slightly higher than the surveyed flood levels. Three surveyed flood marks were suspected of being inaccurate as they do not correlate with adjacent flood marks. For instance a survey flood mark located immediately upstream of the Pyrenees Highway bridge shows a flood elevation 2.1 m higher than adjacent marks also located upstream of the bridge.

The modelled flood extent matches very well with observations, community feedback and aerial photographs, and is deemed an acceptable calibration result.

***Flood Behaviour***

The local catchments to the west and south-west of the township responded quicker than the larger McCallums and Tullaroop Creek catchments. Modelling shows that the local tributaries passed flow into the south and west of the township in the early hours of 4$^{th}$ September 2010, 10-12 hours prior to McCallums Creek peaking. Reports from local residents advised that at 8:42am on the 4$^{th}$ September the culvert under Landrigan Road which drains the Belfast Road drain had reached capacity and water had started to break out of the drain and flow north adjacent to Landrigan Road.

The modelling indicates that significant breakout flows from the local catchments occurred from approximately mid-morning at the confluence of the two major drains on Belfast Road. This breakout flowed down a natural drainage line to the north-east and inundated properties on the south side of Victoria Street. Breakouts also occurred from the main bluestone drain on the upstream side of the Pyrenees Highway culvert and further downstream near High Street. Local residents reported that by 12:50pm the Belfast Road drain had overtopped over Virginia Street and that at 2:14pm flood water was approximately 200-300 mm deep along Virginia Street.

The modelling demonstrates that flows in McCallums Creek and Tullaroop Creek had continued to rise through this time and downstream of the confluence Tullaroop Creek peaked between 12 and 1pm with a combined flow in the creeks of approximately 780 m$^3$/s. Flood water in Tullaroop Creek inundated the rear of properties along Bucknall Street but generally did not get above floor level and damage homes. By that time around 25 properties around the township had been inundated primarily along the south side of Victoria Street as a result of the flows from the local catchments. Levels in McCallums Creek receded over the following few hours. Tullaroop Creek continued to gradually rise through the afternoon and did not peak until that evening, however flows were minor in comparison with flows in McCallums Creek largely due to the attenuation of flows through Tullaroop Reservoir.

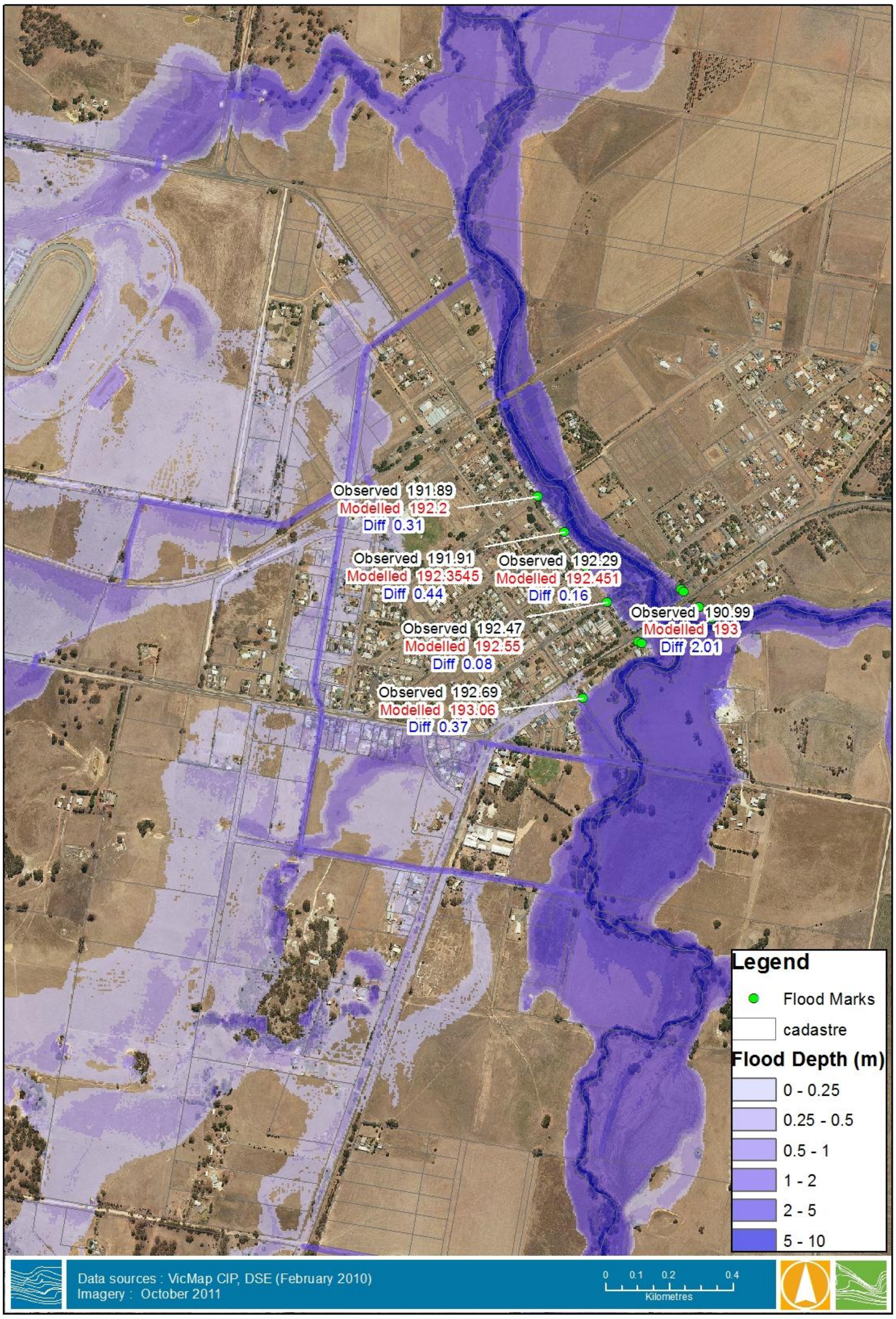



**Figure 5-4 Hydraulic model calibration plot – September 2010**

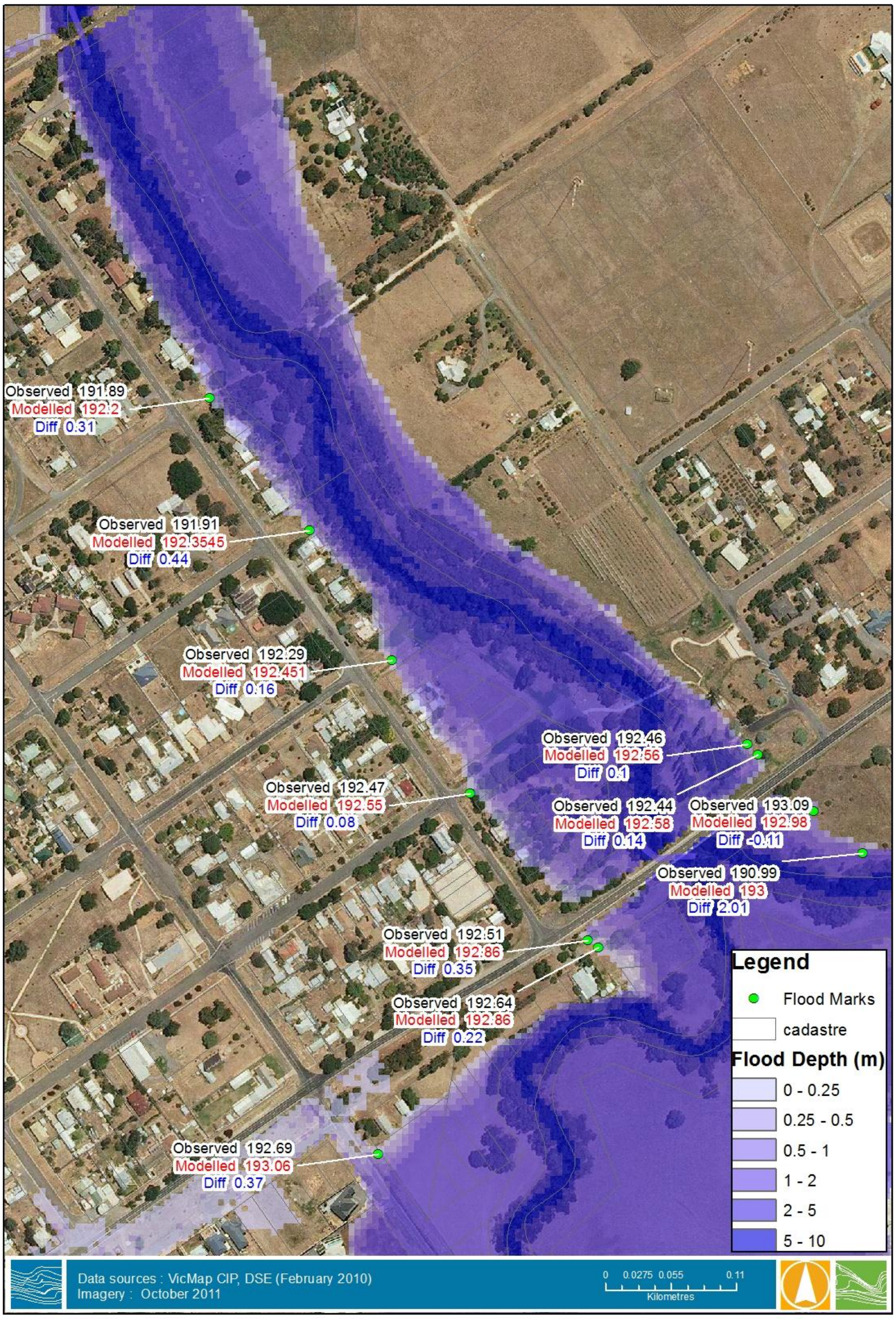



**Figure 5-5 Hydraulic model calibration plot – September 2010 (around Pyrenees Hwy bridge)**

### 5.3.3 January 2011 Calibration

A set of 10 survey flood marks were collected for the January 2011 flood event. Calibration plots of the January 2011 flood event are shown in Figure 5-6 and 5-7 below. Of the 10 survey flood marks located within the study area:

- 5 points are within +/- 100 mm
- 2 point are within +/- 150 mm
- 1 point is within +/- 250 mm
- 1 point is within +/- 400m but may also be a result of an error in survey
- 1 point was discarded due to suspected errors in survey

The overall trend showed that the modelled flood levels were slightly lower than the surveyed flood levels. Two surveyed flood marks were suspected of being inaccurate as they do not correlate with adjacent flood marks. A survey flood mark located immediately upstream of the Pyrenees Highway bridge showed a flood elevation 0.2 m lower than a mark located on the downstream of the bridge and was 0.53 m lower than the modelled peak, strongly suggesting inaccuracy in the survey level. Another surveyed level along Victoria Street was 0.4 m higher than the modelled flow and was also unlikely given surrounding surveyed levels, and again was thought to be an error.

The modelling results matched very well with observations, community feedback and aerial photographs.

***Flood Behaviour***

The January 2011 flood was considerably larger in terms of both flow and flood extent as compared to the September 2010 event. As with the September 2010 event the local catchments to the west and south-west of the township responded considerably quicker than the larger McCallums and Tullaroop Creek catchments. Both anecdotal reports and modelling indicate significant local runoff flowed into the south and west of the township more than 12 hours prior to the larger waterways breaking out through the township. CFA records indicate that significant local flows had been reported around the gun club and trotting track from 7-8pm on the 13th January with drains overflowing and minor roads in that area being closed. It was also reported that by 8:30pm the road between Carisbrook and Red Lion was impassable although the exact location of the blockage was not recorded (most likely at Craige as there was a significant amount of water over the road at this location, the evidence of which could still be observed on fences, etc. at the time of writing this report). By 10pm residents living along Bucknall Street were advised to evacuate due to concerns about rising levels in Tullaroop Creek.

The first significant flooding to impact buildings was a result of local runoff and occurred at the confluence of the two major drains on Belfast Road. The modelling demonstrates that this breakout flowed down the natural drainage line to the north-east and inundated properties on the south side of Victoria Street during the night. Records show that by 4:30am on the 14th a number of properties along Victoria Street had been inundated and flood water was almost overtopping Victoria Street. The modelling also shows that additional breakouts occurred during this time along the main bluestone drain between Victoria Street and High Street.

The modelling also indicates that significant inundation occurred in the drainage line north of the township which flows under Carisbrook-Eddington Road. Initially this was due to local flows from the small catchments to the west and then later as a result of high levels in Tullaroop Creek backing up the drainage line. CFA records report that cars were continuing to drive through the flood water at this location at 8am on the $14^{th}$ January, with one car driving into the water almost up to the windows and the driver evacuating on foot.

Levels in both McCallums and Tullaroop Creeks continued to rise through the night and the modelling indicates that once the combined flows in McCallums and Tullaroop Creek reached approximately 900 $m^3/s$ upstream of the Pyrenees Highway Bridge the flood waters overtopped the Pyrenees Highway between Chapel Street and the Pyrenees Highway bridge. Anecdotal reports and the modelling indicate that this occurred from around 9:30am on the $14^{th}$ of January 2011. CFA records show that by 10:10am water was flowing into the CFA fire station, located in central Carisbrook, and much of the town was inundated.

Flood water went on to inundate most of the township to significant depths. The breakout over the Pyrenees Highway flowed north-west across the town and overtopped the railway line in a number of locations. The modelling supports anecdotal reports that the railway line acted as a levee with some flood water banking up behind the railway embankment increasing flood depths on the upstream side. The modelling also indicates that flood depths in properties along the Pyrenees Highway which were already flooded from the local flows rose significantly as the breakout flooded the town. The rising creek levels at the time of the large breakout also caused a smaller breakout to occur to the south of Camp Street which flowed westwards, merged with the larger breakout and inundated the primary school at the corner of Landrigan Road and Camp Street.

The modelling and anecdotal reports indicate that flood water continued to flow through the central township for several more hours and peaked between 1pm and 2pm that afternoon, at which point the combined flow in the creeks was approximately 1,000 $m^3/s$. By that time approximately 250 commercial and residential buildings had been inundated. Flood water had receded from much of the township by late afternoon.

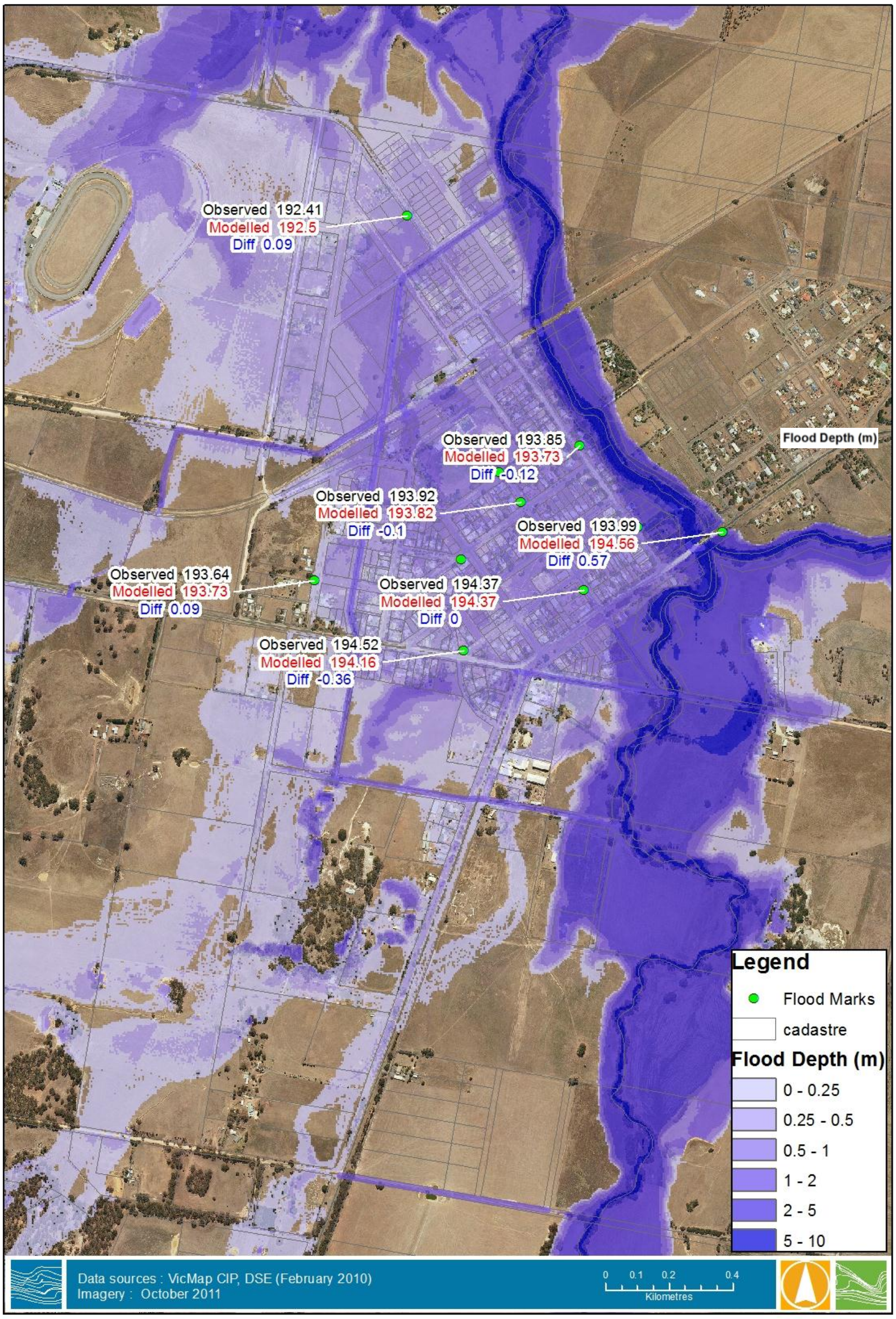



**Figure 5-6 Hydraulic model calibration plot – January 2011 event**

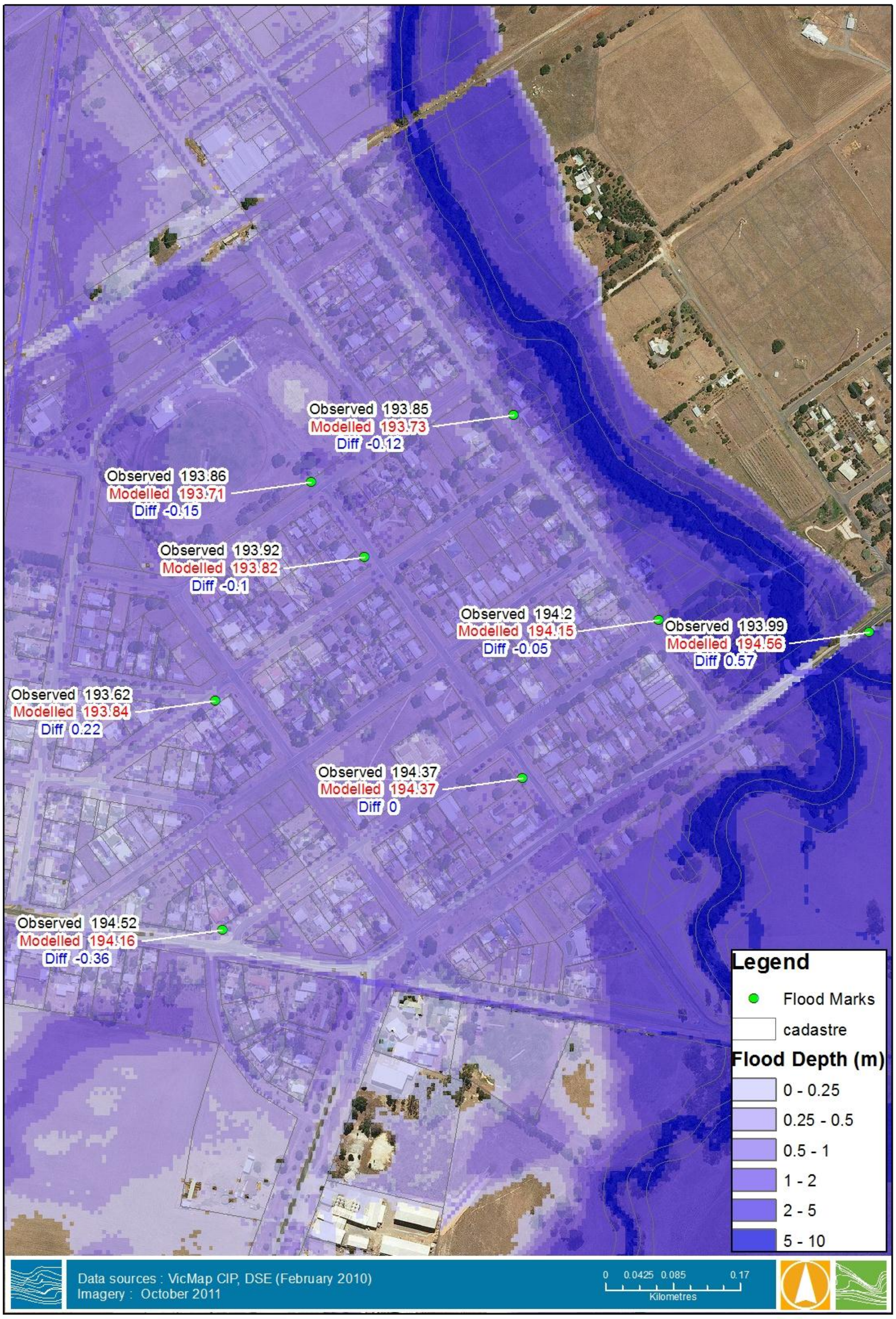



**Figure 5-7 Hydraulic model calibration plot – January 2011 event (central township)**

### 5.3.4 Hydraulic Model Calibration Summary

The hydraulic models have provided a very good representation of the January 2011 and September 2010 flood events which impacted Carisbrook. The modelling demonstrates that the events were quite different in nature which correlates with observation that the January 2011 was a much larger and more damaging event. The January event inundated approximately 250 residential and commercial buildings across the township. The modelling has demonstrated that initial inundation was a result of runoff from the local catchments and then later due to large breakouts from McCallum and Tullaroop Creeks. The September event resulted in inundation of approximately 25 buildings located mainly along the southern side of Victoria Street and modelling has confirmed that was primarily as a result of runoff from the local catchments.

Modelling has identified that the combined peak flow in McCallums and Tullaroop Creeks was approximately 1,000 $m^3/s$ during the January 2011 event and 780 $m^3/s$ during the September 2010 event. It was observed from the January model that the large breakout through the township occurred once the combined flow reached approximately 900 $m^3/s$.

The difference in flows resulted in the January 2011 peak flood level being approximately 1.6 m higher than the September event level upstream of the Pyrenees Highway Bridge. The higher flood level in the January event led to the large breakout occurring. Upstream of the railway bridge over Tullaroop Creek the January 2011 flood level was approximately 1.3 m higher than the September 2010 flood level. The difference in flood levels is reflected in the significantly greater flood extent and damage that occurred in the January 2011 event.

The modelling also confirmed that runoff from the local catchments had a significant role in both events with runoff accumulating to the south of the township well before levels in the creeks rose. In both events the small levee along Belfast Road near the upstream end of the main bluestone drain was breached resulting in inundation of properties to the south of Victoria Street. The bluestone drain also overtopped at other locations in both events leading to inundation of properties adjacent to the drain in the west of the township. The modelling has confirmed that both runoff from the local catchments and raised levels in McCallums and Tullaroop Creeks contributes to flooding in Carisbrook.

The model results for the January 2011 and September 2010 floods replicated the observed flood behaviour through the town quite accurately; this was confirmed by post flood level survey from debris marks, aerial images as well as community feedback during public consultation. The model is considered appropriate for use for design event modelling and mitigation options investigation.

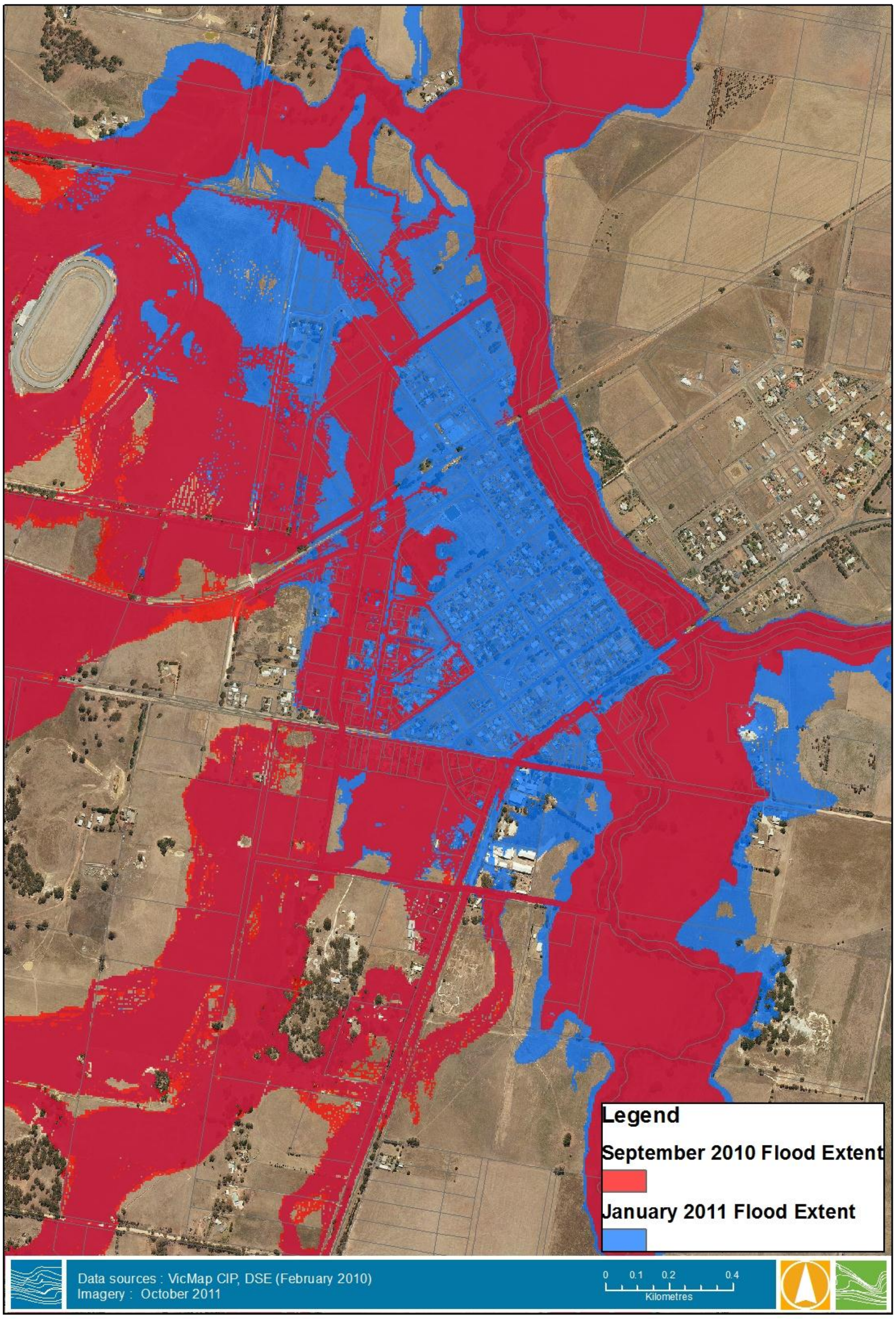



**Figure 5-8 September 2010 and January 2011 Flood Extents**

## 5.4 Design Flood Modelling

To prepare design flood maps for the 5, 10, 20, 50, 100 and 200 year ARI events, the calibrated hydraulic model was updated to reflect post flood conditions in Carisbrook. Between the September 2010 and January 2011 events the Central Goldfields Shire cleaned out a number of the bluestone drains of silt and weeds. The following modification was made to the model to represent post flood conditions:

- Manning's 'n' value in main bluestone drains was reduced from 0.03 to 0.025, representing the clearing of silt and weeds by Central Goldfields Shire.

Utilizing the updated hydraulic model, the design flood events were run for all six ARI events. Each design event was run for the 3hr, 6hr, 9hr, 12hr, 48hr and 72hr events and the results enveloped. A suite of flood maps was developed across the range of flood magnitudes (5, 10, 20, 50, 100 and 200 year ARI events), as shown in Appendix C. Figure 5-5 shows all design flood extents overlayed on the one figure for comparison.

Figure 5-9 shows the 100 year ARI design flood extent overlayed with the January 2011 event modelled extent and some observations can be made in comparing the extents of these events:

- The January 2011 event flood extent is larger than the 100 year ARI design event flood extent with greater depths of inundation through the central township. Inundation which occurred in the west of the central township around Smith, Powlett, Albert and McLachlan Streets is not present in the 100 year ARI design flood extent.
- Additional inundation is evident to the north and north-west of the township in the January 2011 extent as a result of the large breakout from McCallum Creek flowing north-west over the railway lines and through that area. Some properties along Pleasant and Rose Streets which were impacted in the January 2011 are not impacted in the 100 year ARI event extent.
- The inundation around Carisbrook Primary School which occurred in the January 2011 event is not shown as occurring in the 100 year ARI design extent.

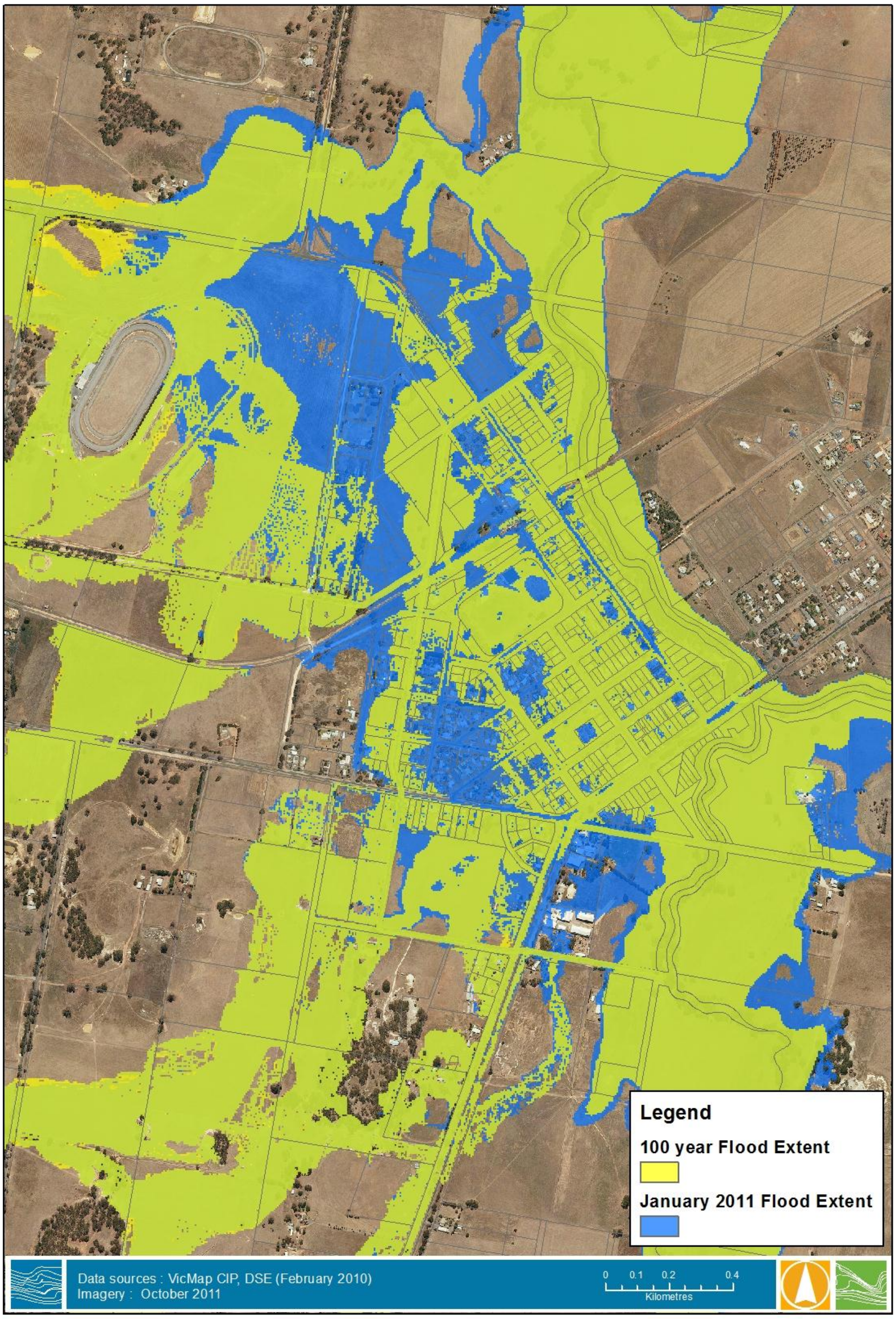



**Figure 5-9 Hydraulic Modelling January 2011 and 100 Year ARI Design Event Flood Extents**

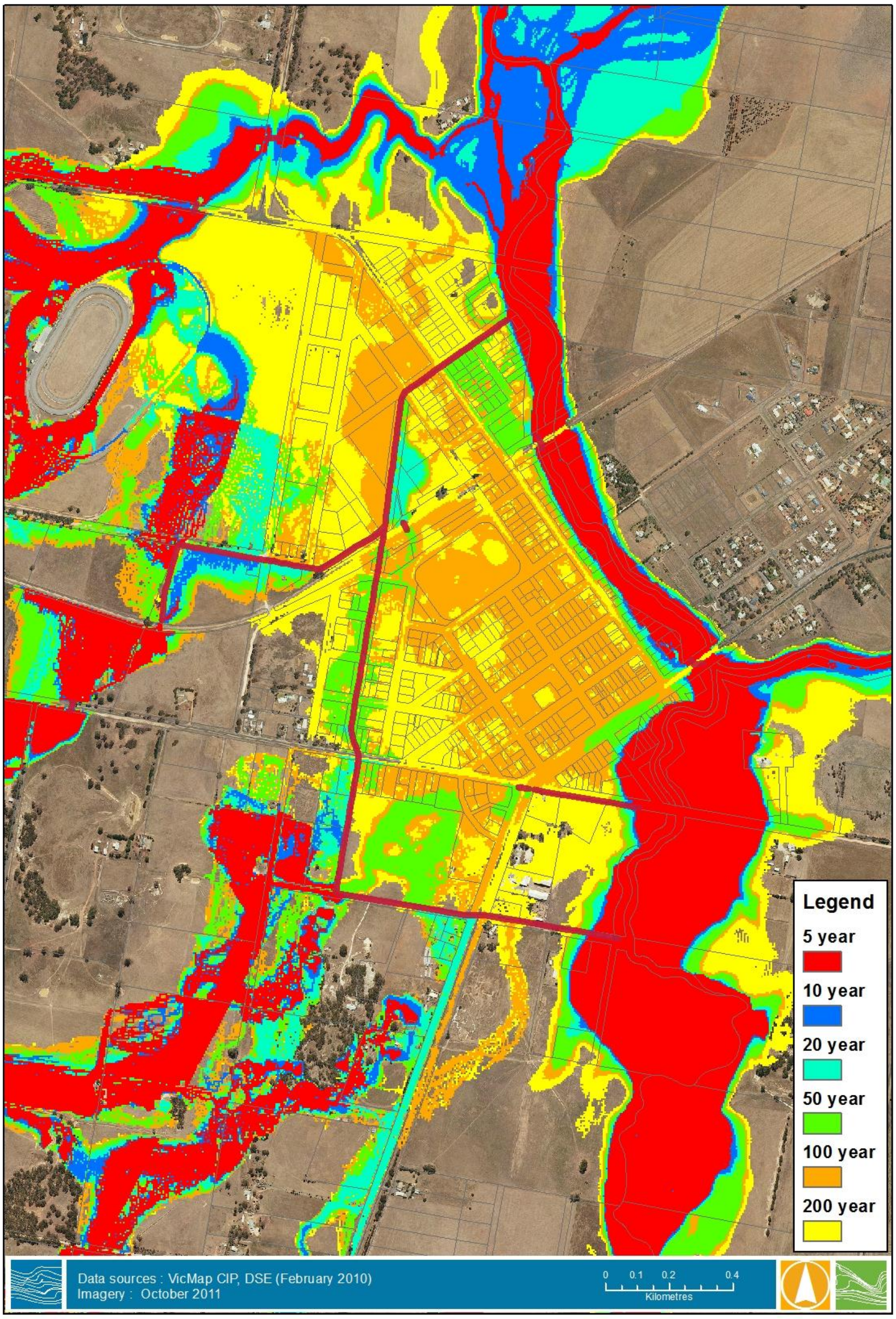



**Figure 5-10 Hydraulic modelling design flood extents**

## 5.5 Design Flood Behaviour

Broadly it can be seen from the design flood extents that flooding from Tullaroop Creek in the 5, 10, 20 and 50 year ARI events is generally well-confined within the creek, while the 100 and 200 year ARI events show a significant breakout over the Pyrenees Highway causing widespread inundation across the township. The 5, 10, 20 and 50 year ARI flood maps have a fairly similar inundation extent along the creek with some incremental changes as the flood magnitude increases.

With regards to inundation from the local catchments to the west and southwest of the township it can be seen that the 5, 10 and 20 year ARI events cause some shallow inundation in the agricultural areas around the town but have little impact on property other than around the trotting track. Through the township the 5 and 10 year ARI events are reasonably well–confined to the bluestone drain while events greater than 20 year ARI overtop the drains and impact property.

The following comments describe the key flood characteristics in Carisbrook for each design event.

***5 Year ARI Event***

- Flood well-confined along McCallums and Tullaroop Creeks and the bluestone channels through the township.
- Some shallow inundation in agricultural areas to the west and south-west of the township including parts of the trotting track.
- No buildings flooded above floor and 12 flooded below floor.

***10 Year ARI Event***

- Flow well-confined along McCallums and Tullaroop Creeks and the bluestone channels through the township.
- Some shallow inundation in agricultural areas to the west and south-west of the township including parts of the trotting track.
- No buildings flooded above floor and 12 flooded below floor.

***20 Year ARI Event***

- Flow well-confined along McCallums and Tullaroop Creeks and the bluestone channels through the township.
- Some shallow inundation in agricultural areas to the west and south-west of the township including parts of the trotting track and areas immediately to the south of the railway line and Pyrenees Highway where water is banking up.
- Water starting to accumulate adjacent to Landrigan Road
- 1 building flooded above floor and 25 flooded below floor.

***50 Year ARI Event***

- Along Tullaroop Creek some small breakouts occurring and impacting property on Bucknall, Hood and Brown Streets downstream of the Railway Bridge.
- A small breakout from McCallums Creek near Chapel Street impacting property at that location.
- Local flows from the south-west overtop the levee along Belfast Road causing some shallow inundation to properties along the south of Victoria Street
- Overtopping of the main north-south bluestone drain impacting several properties between Victoria and High Streets.
- Water surcharging up through the bluestone drain adjacent to the school causing some inundation of property at the corner of Victoria Street and Landrigan Road.
- 4 buildings flooded above floor and 50 flooded below floor.

***100 Year ARI Event***

- Significant inundation of properties through the central township as a large breakout from McCallums Creek overtops the Pyrenees Highway and flows through the township.
- Overtopping of the main north-south bluestone drain from local catchment flows impacts a number of properties between Victoria and High Streets and properties along the southern side of Victoria Street.
- 51 buildings flooded above floor and 192 flooded below floor.

***200 Year ARI Event***

- Widespread inundation through the township as a large breakout from McCallums Creek overtops the Pyrenees Highway and flows through the township.
- The break out is considerably deeper than in the 100 year event causing more inundation in the west and north of the central township.
- Properties in the west of the township adjacent to the main north-south drain and along the south side of Victoria Street are impacted first by local catchment flows overtopping the drain and then later from the main waterway breakout as it flows west across the township.
- 263 building flooded above floor and 43 flooded below floor.

# 6. FLOOD MITIGATION OPTIONS

This section provides an overview of the mitigation options available to reduce the flood risk and flood damages in Carisbrook. The options are divided into structural and non-structural mitigation options.

## 6.1 Structural Mitigation Options

### 6.1.1 Overview

This section provides a preliminary assessment of potential structural flood mitigation measures for the township of Carisbrook. These are made up of community suggested options as well as options suggested by the Steering Committee and Water Technology. Each option was assessed to determine its feasibility. The full list of suggested mitigation measures and the source of the suggestion is shown below in Table 6-1.

For flood protection purposes, Carisbrook can be separated into three basic divisions:

- 1 - Properties south of Victoria Street and west of Landrigan Road (impacted first by local flows and then flows from McCallum/Tullaroop Creek in major events);
- 2 - Properties on west of township close to the bluestone drain and north of Victoria Street (impacted first by local flows and then flows from McCallum/Tullaroop Creek in major events); and
- 3 – The remaining properties located in the central township (impacted primarily by flows from McCallum/Tullaroop Creek in major events.

These divisions are highlighted in Figure 6-1.

Each mitigation option was assessed against a number of criteria, potential reduction in flood damage, cost of construction, feasibility of construction and environmental impact. The score for each criterion was based on a ranking system of 1 to 5, with 1 being the worst score and 5 the best. Each criteria score was then weighted according to the weighting shown in Table 6-2 below. The reduction in flood damage was of course the most heavily weighted criteria as this is really the main objective for all flood mitigation. Table 6-3 reviews and scores each mitigation option against the four criteria and calculates a total score for each option. The options with the higher scores indicate the most appropriate mitigation solutions for Carisbrook. While these options were reviewed and recorded individually it is important to consider a combination of options when developing a complete flood mitigation scheme.

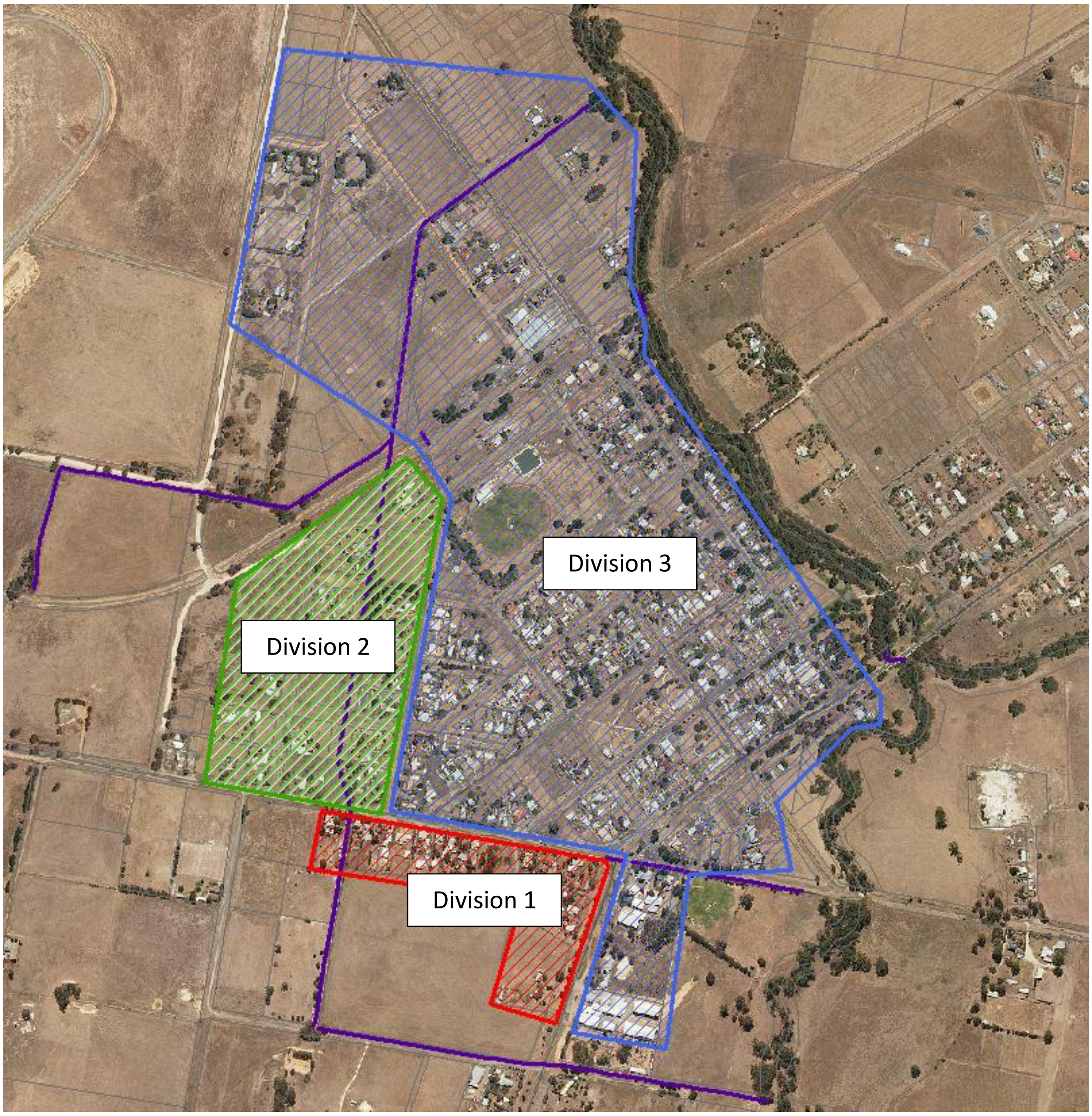



**Figure 6-1 Carisbrook township, showing mitigation divisions**

**Table 6-1 Suggested mitigation options**

| Option No. | Detail | Source |
|---|---|---|
| 1 | Clear Tullaroop Creek of woody debris and vegetation between rail and road bridge | Community Questionnaire/Steering Committee members |
| 2 | Increased Tullaroop Creek channel capacity between railway and road bridge | Community Questionnaire/ Steering Committee members |
| 3 | Increase capacity of Pyrenees Highway road bridge | Community Questionnaire/Steering Committee members |
| 4 | Upgrade of the levee along Belfast Road | Community Questionnaire |
| 5 | Increase capacity of main north/south bluestone drain | Community Questionnaire |
| 6 | Clear drains of weeds/silt | Community Questionnaire/Steering Committee members |
| 7 | Diversion of flows around west of town | Central Goldfields Shire/ Community Questionnaire/Steering Committee members |
| 8 | Increase railway line culvert capacity | Community Questionnaire/ Steering Committee members |
| 9 | Use of Tullaroop Reservoir for flood mitigation | Community Questionnaire/Steering Committee members |
| 10 | Additional storages on McCallums Creek | Community Questionnaire/Discussion at community meeting |
| 11 | Repair and reinstate Carisbrook Reservoir | Community Questionnaire/Steering Committee members |
| 12 | Build ring road to west of town which would also act as a levee | Community Questionnaire |
| 13 | Divert local flows from south into McCallums Creek using upgraded levee/drain along Belfast Rd | Community Questionnaire/Water Technology |

| | | |
|---|---|---|
| 14 | Divert local flows from south into McCallums Creek using upgraded levee/drain along Williams Road near cemetery | Water Technology/Central Goldfields Shire/ Steering Committee members |
| 15 | Extend Carisbrook-Eddington Road southwards to act as a levee and divert local flows from the west | Community Questionnaire/Steering Committee members |
| 16 | Diversion channel from McCallums Creek around west of town near racecourse and back into Tullaroop Creek | Community Questionnaire |
| 17 | Additional street drainage in town | Community Questionnaire |
| 18 | Additional strategic levees to protect township from large flows in McCallums/Tullaroop Creeks | Community Questionnaire/Water Technology |
| 19 | Installation of "Flood Gates" on Tullaroop Reservoir | Community Questionnaire/Steering Committee members |

**Table 6-2 Prefeasibility assessment criteria**

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

### 6.1.2 Prefeasibility Assessment

Each of the suggested mitigation options was assessed using the above outlined assessment criteria, with the results summarised below in Table 6-3.

**Table 6-3 Prefeasibility assessment scoring**

| No. | Works Location | Mitigation Option | Criteria | | | | | Score |
|---|---|---|---|---|---|---|---|---|
| | | | Reduction in Flood Damages | Cost ($) | Feasibility/ Constructability | Environmental Impact | Comments | |
| **1** | Tullaroop Creek between Pyrenees Highway Bridge and Rail Bridge | Clear Tullaroop Creek of woody debris and vegetation | 3 | 2 | 3 | 3 | Clearing Tullaroop Creek is likely to cause significant negative environmental impact, decrease the amenity and aesthetics of the township and has the potential for ongoing erosion issues. This may be minimised through appropriate thinning of vegetation without wholesale clearing.<br>The reduction in water levels in the township during large flood events is likely to be small. | 11 |
| **2** | Tullaroop Creek between Pyrenees Highway Bridge and Rail Bridge | Increase Tullaroop Creek channel capacity by deepening and/or widening the channel | 4 | 2 | 3 | 2 | Widening and deepening Tullaroop Creek may cause a small reduction in flood damage in major events. It will also have a significantly negative environmental impact, decrease the amenity and aesthetics of the township and has the potential for ongoing erosion issues. | 12.5 |
| **3** | Pyrenees Highway Bridge | Increase the capacity of Pyrenees Highway bridge by either widening the | 3 | 2 | 3 | 2 | Preliminary modelling has indicated that an increase in the width of the bridge or constructing additional culverts on Tullaroop Creek may have a moderate impact at mid-high range ARIs.<br>This would be a relatively costly option, causing closure or | 10.5 |

| | | | | | | | | |
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| | | bridge or by construction of additional culverts | | | | | partial closure of the Pyrenees Highway. | |
| **4** | Belfast Road | Upgrading of the levee along Belfast Road | 4 | 4 | 4 | 1 | Upgrading of the levee along Belfast Road would divert additional flow towards McCallums Creek and is likely to reduce flood levels at properties south of Victoria Street.<br>An assessment of the levee would be required using the hydraulic model to determine the overall change in flood levels. | 14.5 |
| **5** | Main north/south bluestone drain | Increase capacity of main north/south bluestone drain | 4 | 3 | 4 | 3 | Increasing the capacity of the main north-south bluestone drain by either widening or deepening the channel is likely to reduce flood levels in the south and west of the township where flooding is a result of local overland flow.<br>An assessment of this option would be required using the hydraulic model to determine the overall change in flood levels. | 14.5 |
| **6** | Bluestone drains around township | Clear drains of weeds/silt | 2 | 2 | 4 | 5 | Preliminary modelling has indicated that clearing the drains of weeds/silt would have minimal impact on flood levels particularly in medium-high ARI events. | 10.5 |
| **7** | Several locations to the west of the township | Diversion of flows around west of town using a combination of additional open drains and a levee | 4 | 3 | 3 | 3 | Diversion of local flows around the western side of the township is likely to reduce flood levels in the south and west of the township where flooding is a result of local overland flow. The construction of additional drains through private property increases the cost of this option.<br>An assessment of this option would be required using the | 14 |

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| | | | | | | | hydraulic model to determine the overall change in flood levels. | |
| **8** | Railway culverts near High Street | Increase railway line culvert capacity | 3 | 3 | 3 | 4 | Increasing the capacity of the railway line culverts may reduce flood levels in the township in high ARI events where flooding is a result if breakouts from the major waterways. Likely to be an expensive option.<br>An assessment of this option would be required using the hydraulic model to determine the overall change in flood levels. | 12.5 |
| **9** | Tullaroop Reservoir | Use of Tullaroop Reservoir for flood mitigation | 3 | 2 | 2 | 3 | The use of Tullaroop Reservoir for flood mitigation is likely to be prohibitively expensive. Preliminary modelling has also indicated that flood events through Carisbrook are largely dominated by local flows and flows in McCallums Creek. | 10.5 |
| **10** | McCallums Creek | Additional storages on McCallums Creek | 4 | 1 | 1 | 1 | The construction of a storage upstream on McCallums Creek large enough to reduce flood levels in major and extreme events in Carisbrook is likely to be cost prohibitive. No major storages have ever been built in Victoria for the purpose of flood mitigation. | 10 |
| **11** | Carisbrook Creek | Reinstate Carisbrook Reservoir | 3 | 2 | 2 | 4 | The repair and recommissioning of Carisbrook Reservoir may have a small impact on flood levels in the south of the township provided the reservoir is not at capacity. The catchment above Carisbrook Reservoir is significant but is only one of seven small catchments which contribute to local flows in Carisbrook.<br>The repair and ongoing maintenance of Carisbrook Reservoir is likely to be prohibitively expensive. | 11 |

| | | | | | | | | |
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| **12** | Private land to the west and south-west of Carisbrook township | Build ring road to west of town which would also act as a levee | 4 | 1 | 2 | 3 | Building a ring road to the west of the township to act as a levee is likely to reduce flood levels in the south and west of the township where inundation is a result of local overland flows. It would be a costly option, however, and would require acquisition of private land.<br>An assessment of this option would be required using the hydraulic model to determine the overall change in flood levels. | 11.5 |
| **13** | Drain/Levee along Belfast Road | Divert local flows from the south into McCallums Creek using upgraded levee/drain along Belfast Rd. | 4 | 4 | 5 | 4 | Upgrading of the levee along Belfast Road would divert additional flow towards McCallums Creek and is likely to reduce flood levels at properties south of Victoria Street. In addition blocking the flow from entering the main north-south drain to reduce flood levels in the west of the township which are located close to the drain. An upgrade of the culvert under Landrigan Road would also be required.<br>An assessment of the levee would be required using the hydraulic model to determine the overall change in flood levels. | 16.5 |
| **14** | Drain along Williams Road near Cemetery | Divert local flows from south into McCallums Creek using upgraded levee/drain along Williams Road near cemetery Upgrade of culvert under Landrigan Road. | 3 | 4 | 5 | 4 | Upgrading of the levee/drain along near the cemetery would divert flow from the local catchments into McCallums Creek and is likely to reduce flood levels at properties south of Victoria Street. An upgrade of the culvert under Landrigan Road would also be required.<br>An assessment of the levee would be required using the hydraulic model to determine the overall change in flood levels. | 14.5 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **15** | Private land to the west and south-west of Carisbrook township | Extend Carisbrook-Eddington Road southwards to act as a levee and divert local flows from the west | 3 | 2 | 3 | 3 | Extending the Carisbrook-Eddington Road southwards to act as a levee to the west of the township is unlikely to reduce flood levels significantly and may have the potential to increase flood levels in the township in large ARI events where flooding is from McCallums or Tullaroop Creek. It would be a costly option, and would require acquisition of private land.<br><br>An assessment of this option would be required using the hydraulic model to determine the overall change in flood levels. | 11 |
| **16** | Private land to the west and south-west of Carisbrook township | Diversion channel from McCallums Creek to west of town near racecourse and back into Tullaroop Creek | 4 | 1 | 2 | 2 | Constructing a diversion channel from McCallum Creek through the west of the township has the potential to reduce flood levels through the township in large ARI events however construction of a channel with enough capacity to reduce flows in large ARI events is likely to be very expensive. Much of the channel would also have to be constructed on private land further reducing its feasibility. | 11 |
| **17** | Carisbrook township | Additional street drainage in town | 3 | 3 | 3 | 4 | Additional street drainage may reduce flood levels in low ARI events where flooding is a result of local stormwater. It is unlikely to change flood levels which are a result of flows from the local catchments or flooding from McCallum or Tullaroop Creeks. | 12.5 |
| **18** | Along Pyrenees Highway | Additional strategic levees to protect township from large flows in McCallums/ Tullaroop Creeks | 4 | 2 | 3 | 3 | Additional strategic levees in the area where McCallums Creek breaks out through the township has the potential to reduce flood levels in large ARI events where flooding is a result of large flows in McCallums or Tullaroop Creek. It may be an expensive option and reduce the general amenity and aesthetics of the township. Levees may also need to be located on private land.<br><br>An assessment of this option would be required using the | 13 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | hydraulic model to determine the overall change in flood levels and the location and size of levees required. | |
| **19** | | Installation of "Flood Gates" on Tullaroop Reservoir | 2 | 2 | 2 | 4 | The use of Tullaroop Reservoir for flood mitigation is likely to be prohibitively expensive. Preliminary modelling has also indicated that flood events through Carisbrook are largely dominated by local flows and flows in McCallums Creek. Even when Tullaroop Reservoir is at capacity it quite effectively attenuates flows along Tullaroop Creek. | 9 |

Using the prefeasibility assessment above, the 19 mitigation options have been ranked by weighted score. Their ranking is shown below in Table 6-4

**Table 6-4 Weighted prefeasibility mitigation Scores**

| Rank | Option No. | Mitigation Option | Weighted Score |
|---|---|---|---|
| **1** | 13 | Divert local flows from the south into McCallums Creek using upgraded levee/drain along Belfast Rd. | 16.5 |
| **2** | 4 | Upgrading of the levee along Belfast Road | 14.5 |
| **3** | 5 | Increase capacity of main north/south bluestone drain | 14.5 |
| **4** | 14 | Divert local flows from south into McCallums Creek using upgraded levee/drain along Williams Road near cemetery Upgrade of culvert under Landrigan Road. | 14.5 |
| **5** | 7 | Diversion of flows around west of town using a combination of additional open drains and a levee | 14 |
| **6** | 18 | Additional strategic levees to protect township from large flows in McCallums/Tullaroop Creeks | 13 |
| **7** | 2 | Increase Tullaroop Creek channel capacity by deepening and/or widening the channel | 12.5 |
| **8** | 8 | Increase railway line culvert capacity | 12.5 |
| **9** | 12 | Build ring road to west of town which would also act as a levee | 11.5 |
| **10** | 1 | Clear Tullaroop Creek of woody debris and vegetation | 11 |
| **11** | 11 | Reinstate Carisbrook Reservoir | 11 |
| **12** | 15 | Extend Carisbrook-Eddington Road southwards to act as a levee and divert local flows from the west | 11 |
| **13** | 16 | Diversion channel from McCallums Creek to west of town near racecourse and back into Tullaroop Creek | 11 |
| **14** | 3 | Increase the capacity of Pyrenees of the Highway bridge by either widening the bridge or by construction of additional culverts | 10.5 |
| **15** | 6 | Clear drains of weeds/silt | 10.5 |
| **16** | 9 | Use of Tullaroop Reservoir for flood mitigation | 10.5 |
| **17** | 17 | Additional street drainage in town | 10.5 |
| **18** | 10 | Additional storages on McCallums Creek | 10 |
| **19** | 19 | Installation of "Flood Gates" on Tullaroop Reservoir | 9 |

The prefeasibility assessment identified a number of works as unfeasible on the basis of low associated damage reduction, high costs and other constructability or environmental issues.

Based on the above rankings two mitigation packages (Mitigation Option 1 & 2) were initially identified and discussed with the Steering Committee members on the 9th July 2011. Option 1 was aimed at protecting from the local catchment flows while Option 2 was aimed at protecting from riverine flooding. It was agreed in that meeting that these two packages would be modelled first and then the results used to guide a third and final package of modelling.

The results of the first two packages were presented to the steering committee and technical working group in a joint meeting held on the 5th October 2012. In that meeting it was decided to model a 3rd option which was aimed at protecting from riverine flooding through changes to the Pyrenees Highway road bridge.

The results from the third package were presented in another joint meeting on 10th December 2012. The steering committee expressed ongoing concerns regarding the local flows being diverted into McCallums Creek and wished to model an option where the local flows were diverted around the western side of the town. This option formed the 4th package of modelling.

**It must be noted that these four modelled packages of options are different to the final packages presented to the community at the final community meeting on 15th February 2013. The final packages presented will be further discussed later in this report.**

### 6.1.3 Structural Mitigation Options Modelling

The four packages of mitigation options that were modelled were:

***Mitigation Option 1***: An upgrade of local drainage to protect from the local catchment flows. The option involved an upgrade of existing drains and levees and the use of one way valves to prevent water surcharging up from the larger waterways.

***Mitigation Option 2***: This option was aimed at protecting from riverine flooding and includes a strategic levee, clearing of vegetation along McCallums and Tullaroop Creek and construction of a floodway under the railway bridge. A number of different combinations of those options were also trialled.

***Mitigation Option 3***: This option involved investigating the role the Pyrenees Highway road bridge has in flooding, modelling an increased capacity under the bridge including additional culverts and a complete bridge replacement.

***Mitigation Option 4:*** This option involved construction of a 3 km long strategic levee to divert overland flow around the western side of the township as an alternative to Mitigation Option 1.

It is recommended that any preferred options include a one-way flap valve or regulating gate structure on the culvert under Landrigan Road adjacent to the school to prevent water surcharging back up the drain in large flood events.

The impacts of all four mitigation options on flood behaviour were assessed for the full range of design events. The four mitigation options are described in more detail below.

***Mitigation Option 1***

Package 1 was aimed at protecting the township from local runoff flowing from catchments to the south-west of the township and largely involved an upgrade of the existing drainage and ad hoc levee arrangement.

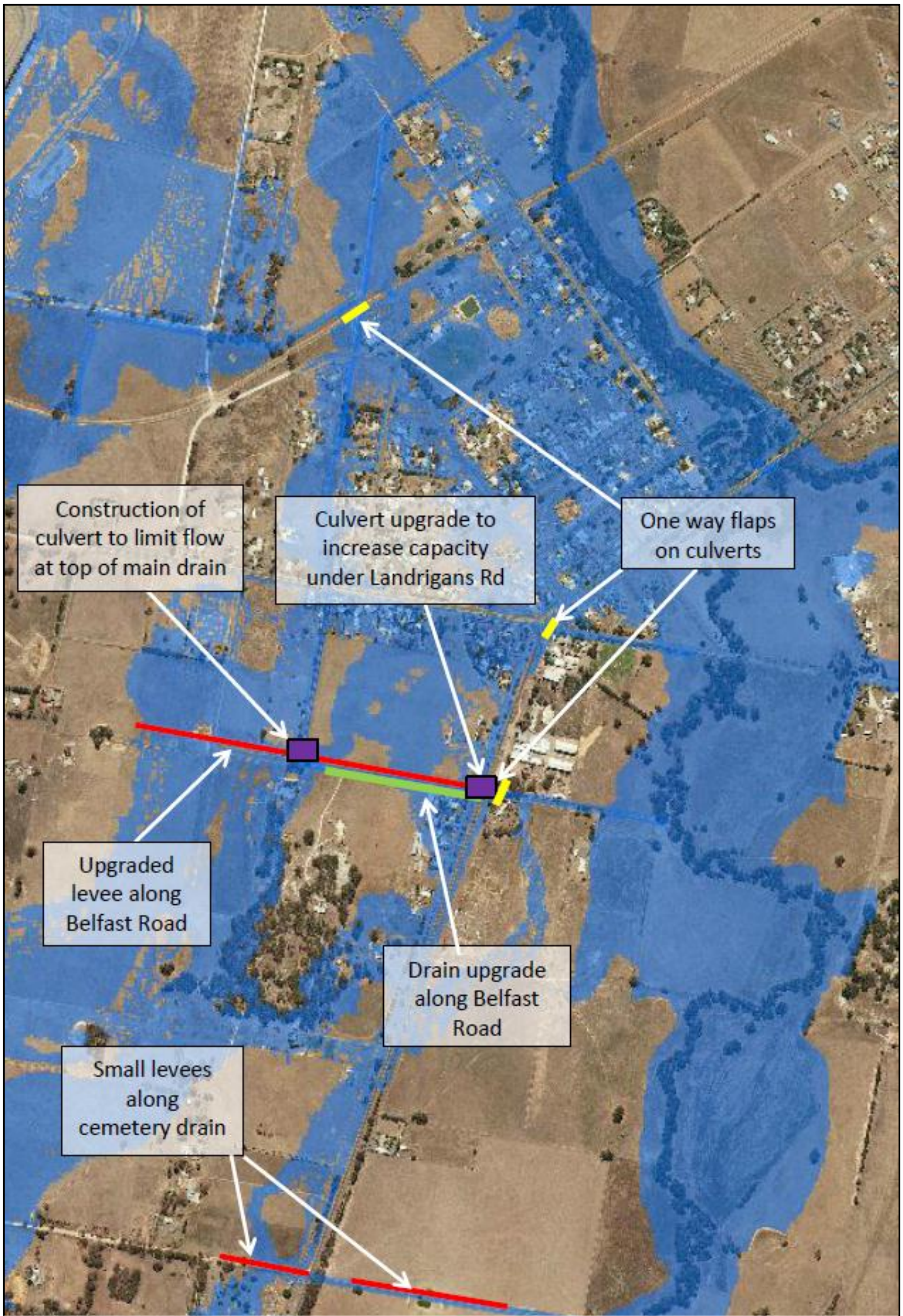
The Package 1 model consisted of the following:

- Two circular culverts and associated headwall placed at the upstream end of the main north-south drain to restrict flow to approximately 2 $m^3/s$. This was modelled with two 750 mm diameter culverts;
- Belfast Road levee extended and height increased. The maximum height of the levee occurs at the upstream end of the main north-south drain where the levee would need to be

approximately 1.8 m high which includes 300 mm freeboard above the 100 year ARI water level;

- Capacity of Belfast Road drain between Landrigan Road and the main drain increased by upgrading to a trapezoidal drain which has been deepened by approximately 300 mm;
- Culvert under Landrigan Road at corner of Belfast Road upgraded to increase capacity to approximately 6 $m^3/s$ from an existing capacity of approximately 2.3 $m^3/s$. The culverts have been modelled by upgrading the existing two 0.6 x 1.2 m box culverts to two 0.6 x 2.1 m box culverts;
- One way flap valves or regulating gate structures placed at the following culverts – main railway culverts, Belfast/Landrigan Road culverts, Camp St drain to prevent water surcharging up the drains in large riverine flood events; and
- Smaller levee placed along Williams Road to divert more flow into the cemetery drain and culvert and into McCallums Creek. The levee would need to be approximately 800 mm in height which includes 300 mm freeboard above the 100 year ARI water level.

The mitigation package 1 options described above are shown in Figure 6-2 below.




*Option marked up over the 100 year ARI flood extent for existing conditions to show the need for the works. The resulting mitigation flood extent is shown in next Figure.*

**Figure 6-2 Mitigation Package 1 Options**

***Results***

The results of the Package 1 modelling indicate the following:

- Package 1 prevents flooding of most buildings which were impacted by the local catchment flows in a 100 year ARI event (and below); Package 1 protects approximately 25 properties adjacent to the main north-south drain and to the south of Victoria St that are flooded under existing conditions in a 100 year event;
- The remaining inundation of properties through the township is from the large breakout from McCallums Creek;
- The package reduces flow along the north-south main drain resulting in no overtopping of the drain other than at the downstream end of the drain which is a result of additional flow into the drain in that area from the large breakout from McCallums Creek;
- The difference plot in Figure 6-4 demonstrates that there the Package 1 options do not cause any significant increase in flood levels in the central township or along McCallums Creek;
- An increase in flood levels of approximately 15cm occurs near the corner of Belfast and Landrigan Road due to water backing up behind the raised Belfast Road levee. This negatively impacts three properties in that area. Of those three properties only one floods above floor and does so under existing conditions as well. A minor ring levee would be required to protect those properties from the raised water levels.
- The diversion of flow into McCallums Creek has a minor impact on flood levels in Carisbrook with an increase of approximately 10-20 mm through the central township in the 100 year ARI event. Immediately upstream of the Pyrenees Highway bridge there was an increase of 13mm.

The 100 year ARI depth results for Option 1 are shown in Figure 6-3 and a different plot is shown in Figure 6-4.

***Discussion***

The results show that Mitigation Option 1 is very effective at protecting Carisbrook from local overland flows with around 25 properties protected compared with existing conditions. The only negative impact occurs at three properties at the corner of Landrigan and Belfast Road where an increase of up to 15 cm occurs. It is likely that these impacts could be mitigated with some additional works such as ring levees, additional diversions into the drain at Williams Rd or an increase in the Belfast Rd drain capacity.

A concern raised by the steering committee was that the diversion of additional flow into McCallums Creek will raise flood levels around the township in major flood events. The results show that the diversion has a minimal impact on flood levels in central Carisbrook, 10-20 mm. The short response time of the local catchment compared to the longer response time of McCallum Creek assists in this regard with the local runoff peaking much earlier and flowing out of Carisbrook before the larger creeks peak.

Option 1 is largely an upgrade of existing drainage infrastructure and so is likely to be a relatively affordable option compared with the other modelled mitigation options which all involve significant new works, many of which are on private land.

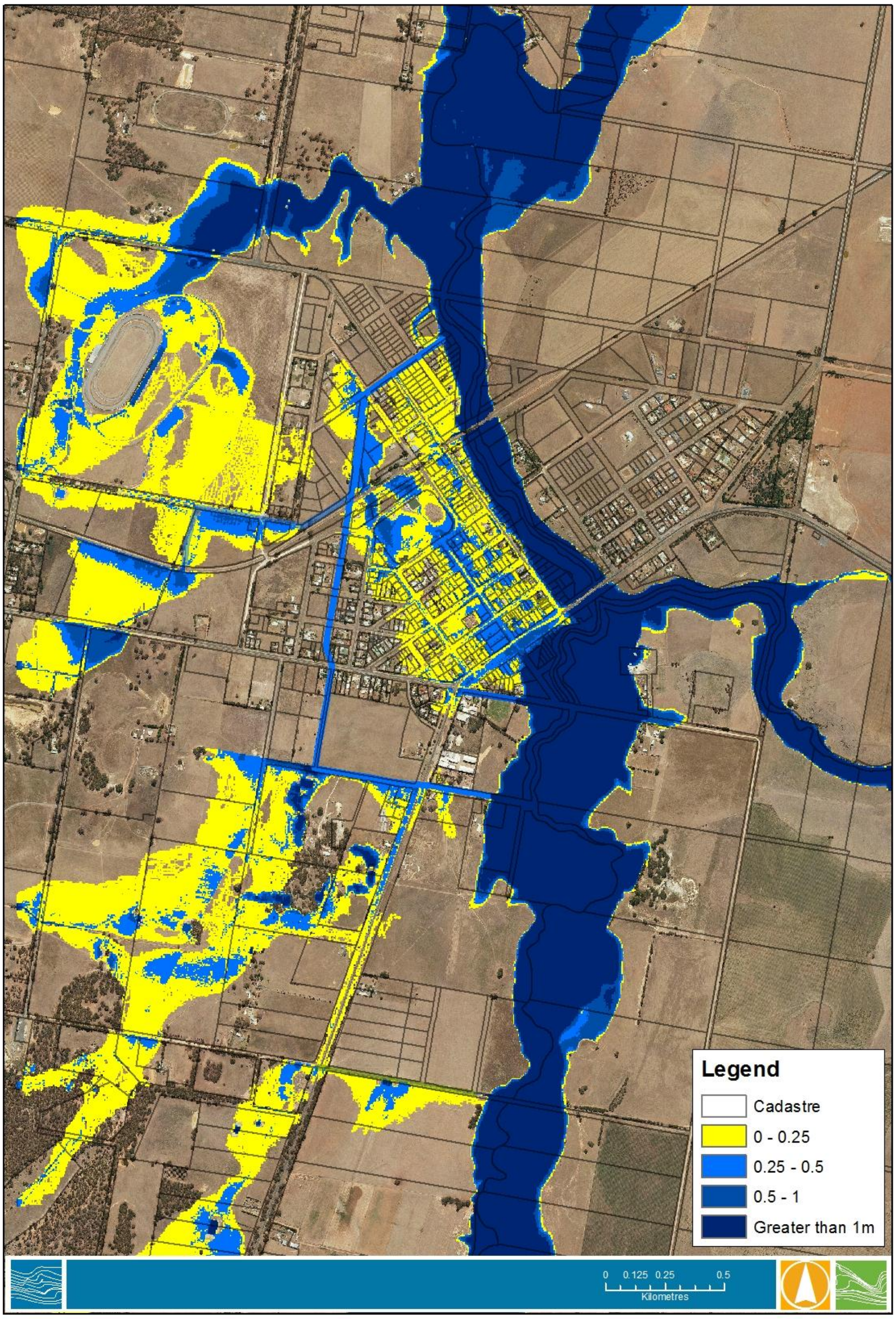



**Figure 6-3 Mitigation Option 1 – 100 year ARI depth results**

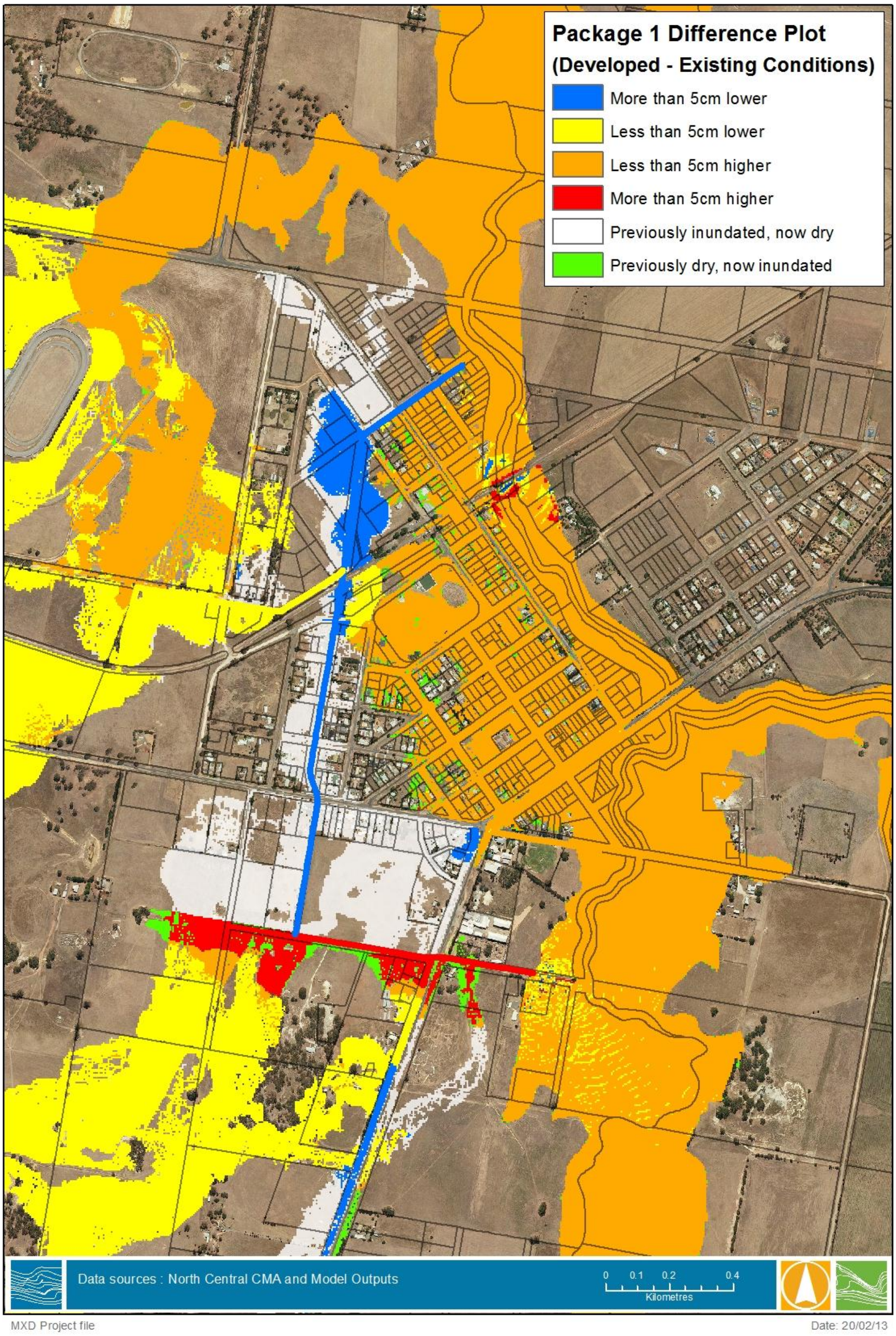



**Figure 6-4 Mitigation Option 1 – Difference Plot**

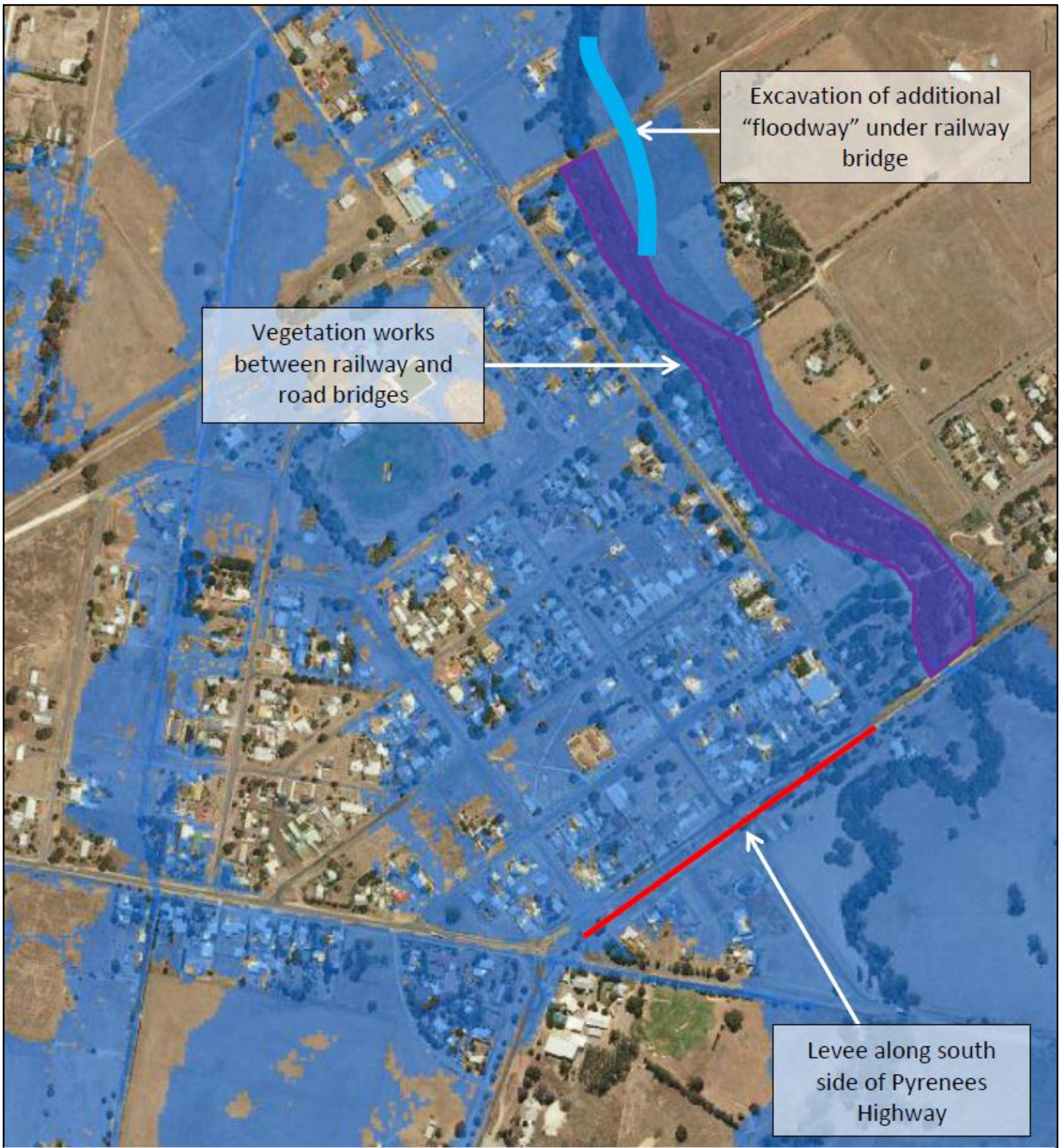
***Mitigation Option 2***

Package 2 was aimed at protecting the township from both the local runoff as in Package 1 and the large breakouts from McCallums and Tullaroop Creeks which occur in major rainfall events. Package 2 consisted of all of the options used in Package 1 as a number of additional options.

The Package 2 model consisted of the following:

- Package 1 options;
- Levee constructed on the southern side of the Pyrenees Highway to protect against significant breakouts from McCallums/Tullaroop Creeks. Maximum levee height of approximately 1.2 m (includes 300mm freeboard);
- Reduction in vegetation along Tullaroop Creek between the Railway and Road Bridge represented by a change in roughness from 0.045 to 0.04 in the channel and a reduction from 0.08 to 0.06 in the trees and dense vegetation adjacent to the channel; and
- Additional floodplain storage under the railway bridge over Tullaroop Creek through excavation of an additional “flood channel” through the right bank of the floodplain. The “flood channel” is approximately 25 m wide and 2 m deep (the feasibility of this needs further investigation in terms of the impact on bridge footings).

The mitigation package 2 options described above are shown in Figure 6-5 and a different plot is shown in Figure 6-8.




*Option marked up over the 100 year ARI flood extent for existing conditions to show the need for the works. The resulting mitigation flood extent is shown in next Figure.*

**Figure 6-5 Package 2 Mitigation Options**

***Results***

The results of the Package 2 modelling indicated the following:

- The option is very effective at protecting from local overland flows in a 100 year ARI event as expected from the Package 1 results;
- The large breakout through the township can be prevented in a 100 year ARI event resulting in approximately 135 properties being protected from below floor flooding and 42 properties from above floor flooding;
- The difference plot presented in Figure 6-8 demonstrates that the Package 2 option does not cause any significant increase in flood levels along McCallums Creek or through the township compared with existing conditions; and
- As with the Package 1 results there is an increase in flood levels of approximately 15 cm at the corner of Belfast and Landrigan Road. These are the only properties in Carisbrook where flood levels are made worse by Option 2. At all other properties, including those on the southern side of the strategic levee, flood levels are lower in a 100 year ARI event compared with existing conditions as a result of the vegetation clearance and the railway floodway.

The 100 year ARI depth results for Option 2 are shown in Figure 6-7 below and a different plot is shown in Figure 6-8.

***Discussion***

The results show that Mitigation Option 2 is very effective at protecting from both overland and riverine flooding. The large breakout through Carisbrook has been prevented with this option which alone protects approximately 175 homes. This option also protects a further 25 properties from overland flooding as with Package 1.

Concerns were raised by the steering committee regarding properties located on the southern side of the strategic levee and thus not being protected. The results show that, despite not being protected by the levee, flood levels in those properties are significantly lower than existing conditions due to the effects of the vegetation works and floodway. The only properties which are negatively impacted by this option are the same three on Belfast Road which are also impacted with Option 1.

The alignment of the strategic levee in Option 2 was chosen due to concerns that other potential alignments would be in close proximity to residential properties. An alternative alignment was later considered which follows the line of the escarpment between Camp and Chapel Streets and protects the residential properties in that area. The levee would, however, need to be located very close to several homes in order to follow the line of the escarpment and remain above the floodplain. The alternative alignment would probably also require either the closure of Chapel St or drop boards to be placed across the road when a large flood is approaching. The two possible alignments are shown in Figure 6-6.

It must be noted that Mitigation Option 2 would not offer complete protection to the central township from a flood event of the magnitude of January 2011. The highway levee would not overtop however testing has indicated that in such an event flood water would eventually break out over Bucknall St and enter the township from the east. Flood depths are likely to be significantly lower, however, than under existing conditions.

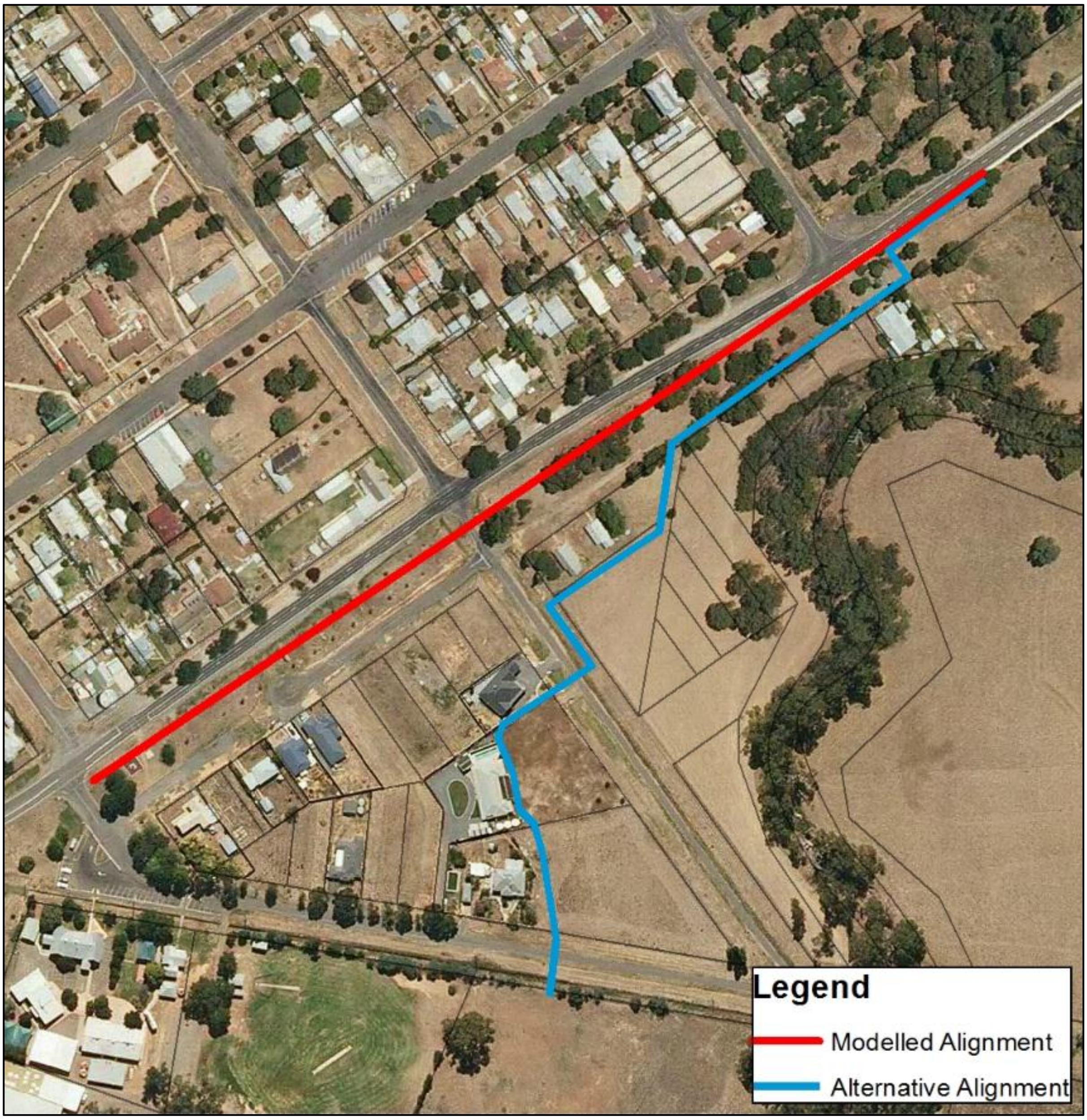



**Figure 6-6 Option 2 Modelled and Alternative Levee Alignments**

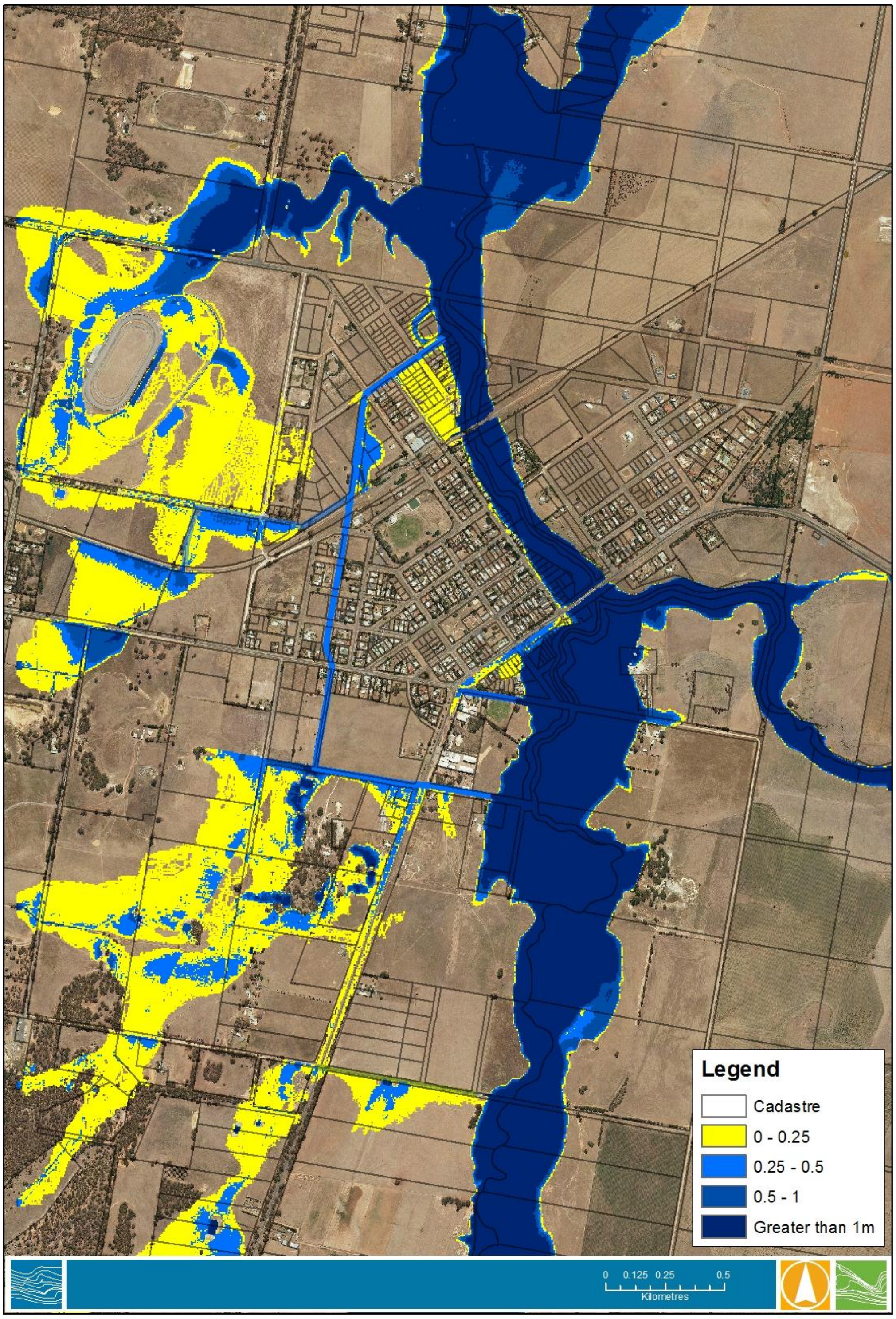



**Figure 6-7 Mitigation Option 2 (highway alignment) – 100 year ARI depth results**

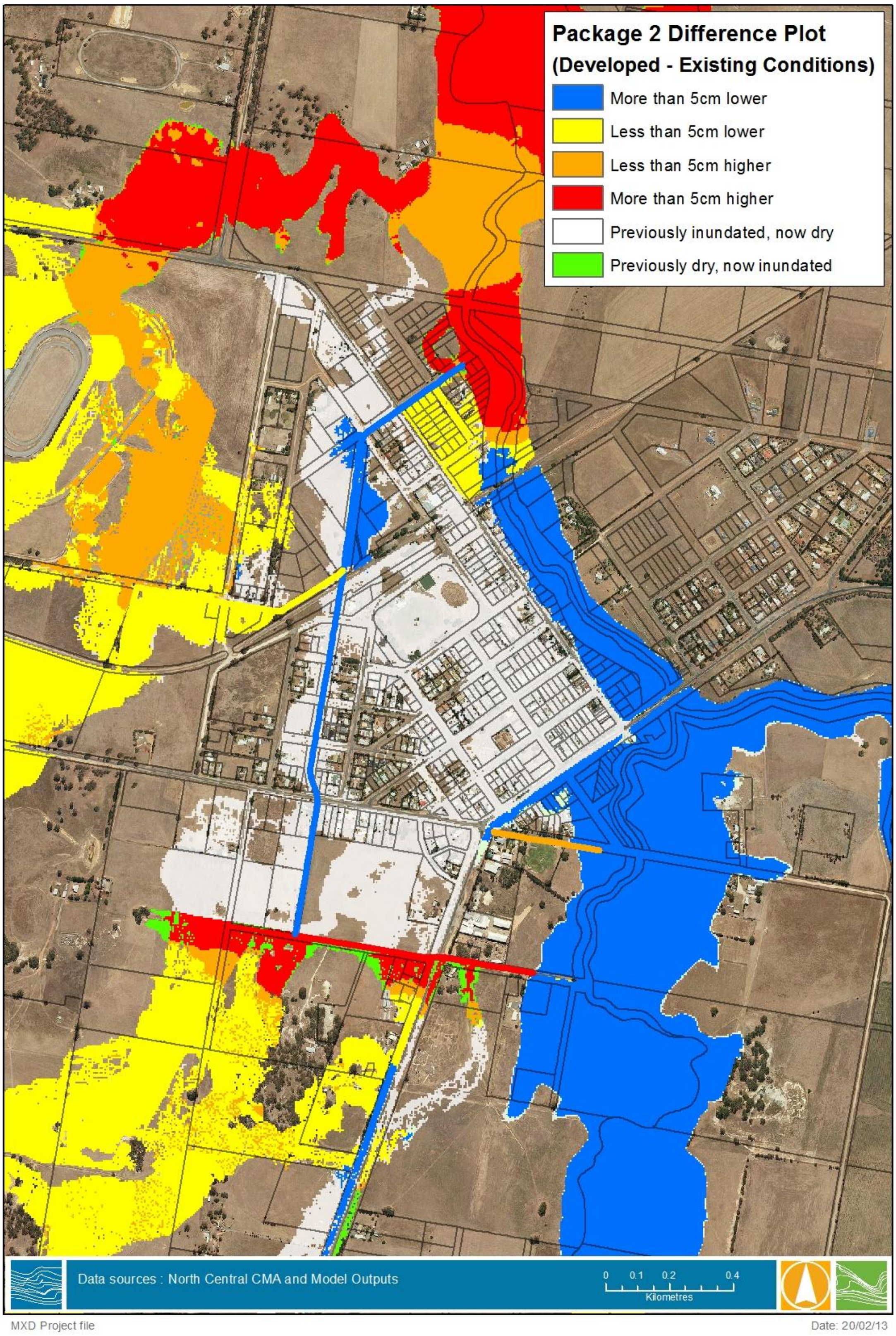



**Figure 6-8 Mitigation Option 2 – Difference Plot**

### *Mitigation Option 3*

Package 3 consisted of the following options:

- Package 1 options aimed at protecting from local catchment flows. As described above.
- Package 2 options aimed at protecting from the larger watercourses. As described above.
- Complete removal of the highway road bridge from the model. In reality this would involve the replacement of the road bridge with a clear span structure.
- Preliminary modelling was also completed which involved testing the impact of an increased capacity of the highway road bridge through the use of culverts in the eastern approach. The bridge was modelled with an additional 6 x (2.1 x 1.2 m) box culverts. The additional culverts provide an additional 15 $m^2$ of flow area in large flow events.

### *Results*

The results of the Package 3 modelling indicated the following:

- The bridge has a significant impact on flood levels upstream. When the bridge is completely removed upstream water levels reduce by approximately 20 cm in a 100 year ARI event compared with the Package 2 levels. A slight increase in flood levels of approximately 5 cm is evident downstream of the location of the road bridge once the bridge is removed.
- Preliminary testing of additional culverts in the approaches found that there was a negligible impact on upstream flood levels. The inclusion of 6 additional box culverts resulted in a difference of less than 1cm in upstream flood levels.
- A longitudinal plot of the Package 3 results can be seen in Figure 6-9. It can be clearly seen that the bridge replacement results in a significant drop in upstream flood levels and complete removal of the head drop that currently exists across the bridge.
- Compared with Option 2 this option only protects one additional property from above floor flooding and 4 additional properties from below floor flooding.

The 100 year ARI depth results for Option 3 are shown in Figure 6-10 below and a different plot is shown in Figure 6-11.

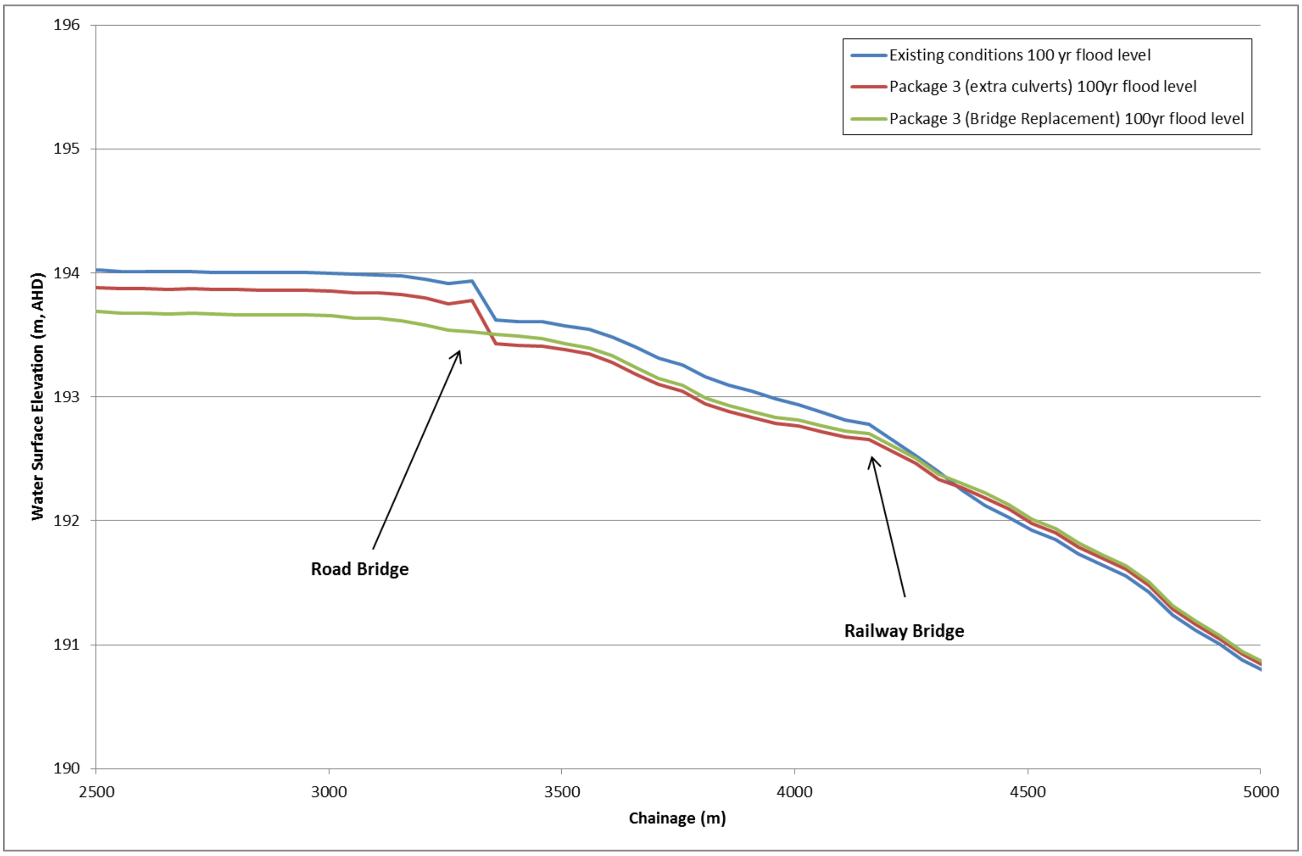



**Figure 6-9 Long-section plot of Package 3 results**

***Discussion***

The results demonstrate that the highway road bridge does have a significant impact on upstream flood levels with a reduction of approximately 20 cm when the bridge is removed completely. Preliminary testing has also shown that the construction of additional culverts does not create enough additional flow area and has a negligible impact on upstream flood levels.

The pre-feasibility assessment indicated that this would be a very costly option and would be unlikely to receive funding in the short-term. Indicative estimates from VicRoads have estimated a bridge replacement to a clear span structure would cost in the region of $7.1 million. Despite the very high cost this option provides very little additional benefit compared with Option 2 with only 5 additional properties protected.

The steering committee has acknowledged the prohibitively high cost of this option and requested that one outcome from this study be a long-term recommendation that the bridge be replaced with a clear span structure when the bridge is due for replacement (or sooner should funding become available).

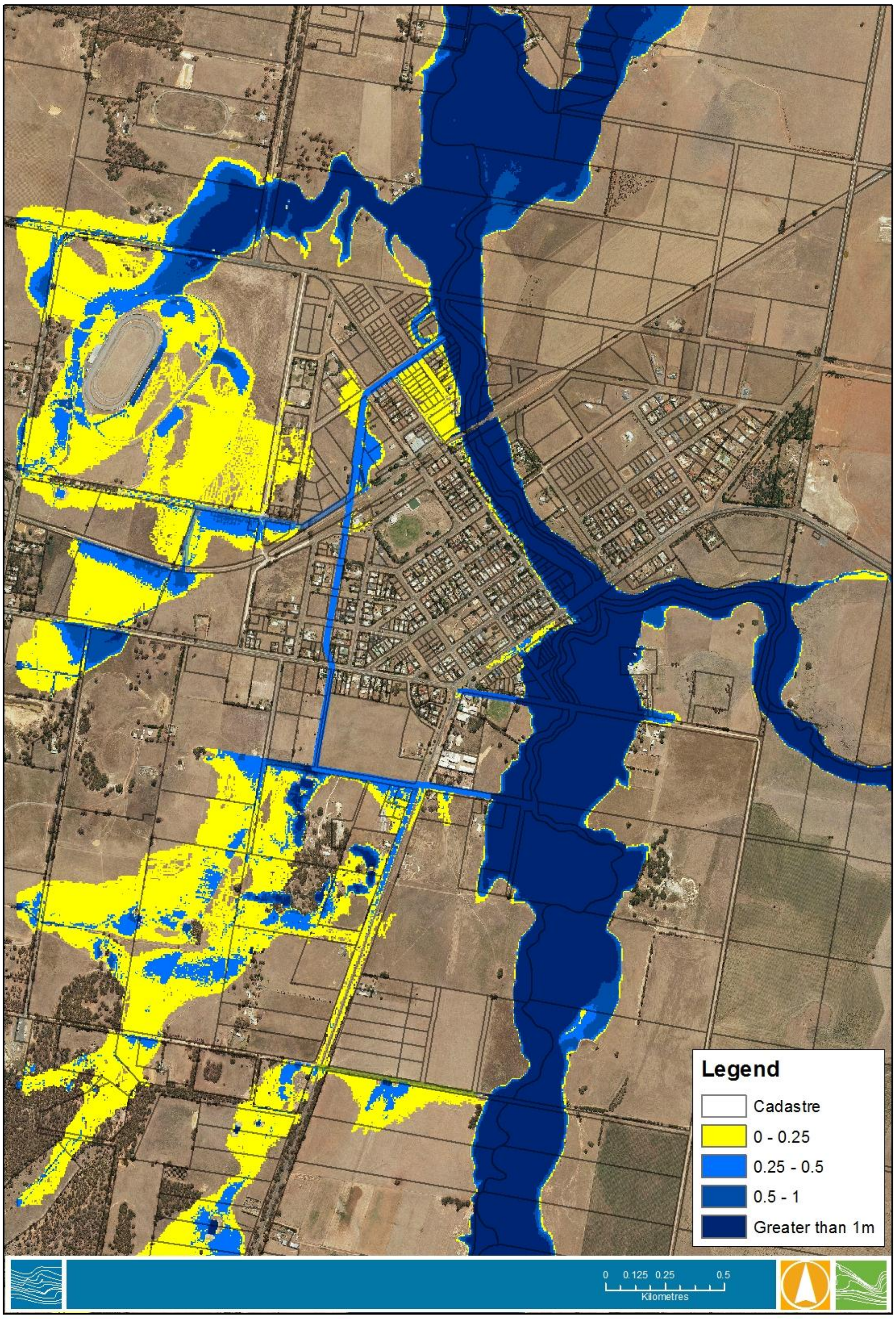



**Figure 6-10 Mitigation Option 3 – 100 year ARI depth results**

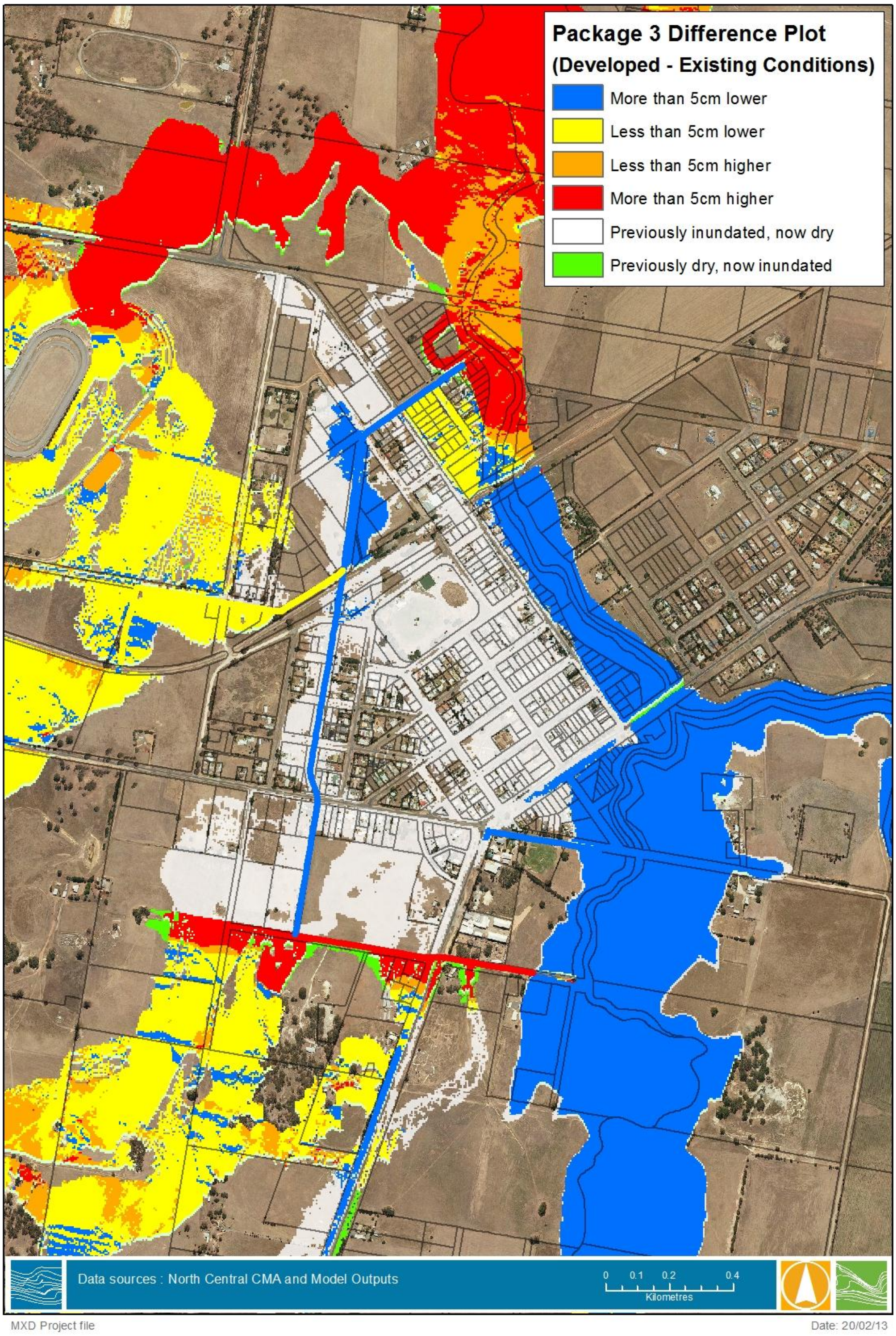



**Figure 6-11 Mitigation Option 3 – Difference Plot**

***Mitigation Option 4***

A western levee to divert local catchment flows was requested by the steering committee as part of a fourth package for detailed modelling. Following further investigation of how the Package 4 options could be implemented the following specific works were included in the mitigation modelling. The Package 4 model included the following works:

- A 3 km long levee extending from the southern end of the Curraghmoor Road Reserve extending northwards past the Pyrenees Highway, running parallel to Pleasant Street, past the Railway Line and then into the crown land on which the Maryborough Harness Racing Club lies.
- Construction of culverts under the Pyrenees Highway. Three 1.2 x 0.75 m culverts were used in modelling which allowed 600 mm of cover to the road deck level. Variations on this arrangement may occur with further design work as Vicroads has since advised that only 500 mm of cover would be required.
- Construction of culverts under the railway line. Four 1.2 x 0.45 m culverts were used in modelling which allowed 600 mm of cover to the railway deck level.
- Excavation of a trapezoidal channel adjacent to the levee primarily between Curraghmoor Road and the railway line as there is no natural fall in the topography along much of that section of the levee. The depth of the channel varies and is approximately 750 mm at its deepest point.
- Vegetation management works along McCallums and Tullaroop Creeks between Camp Street and the railway line bridge. Note that these works cover a larger extent than vegetation works considered in all previous modelled options.
- A one way valve constructed in the culvert under Landrigan Rd adjacent to the school to prevent water surcharging back under Landrigan Rd in large flood events.

The mitigation package 4 options described above are shown in Figure 6-12 below.

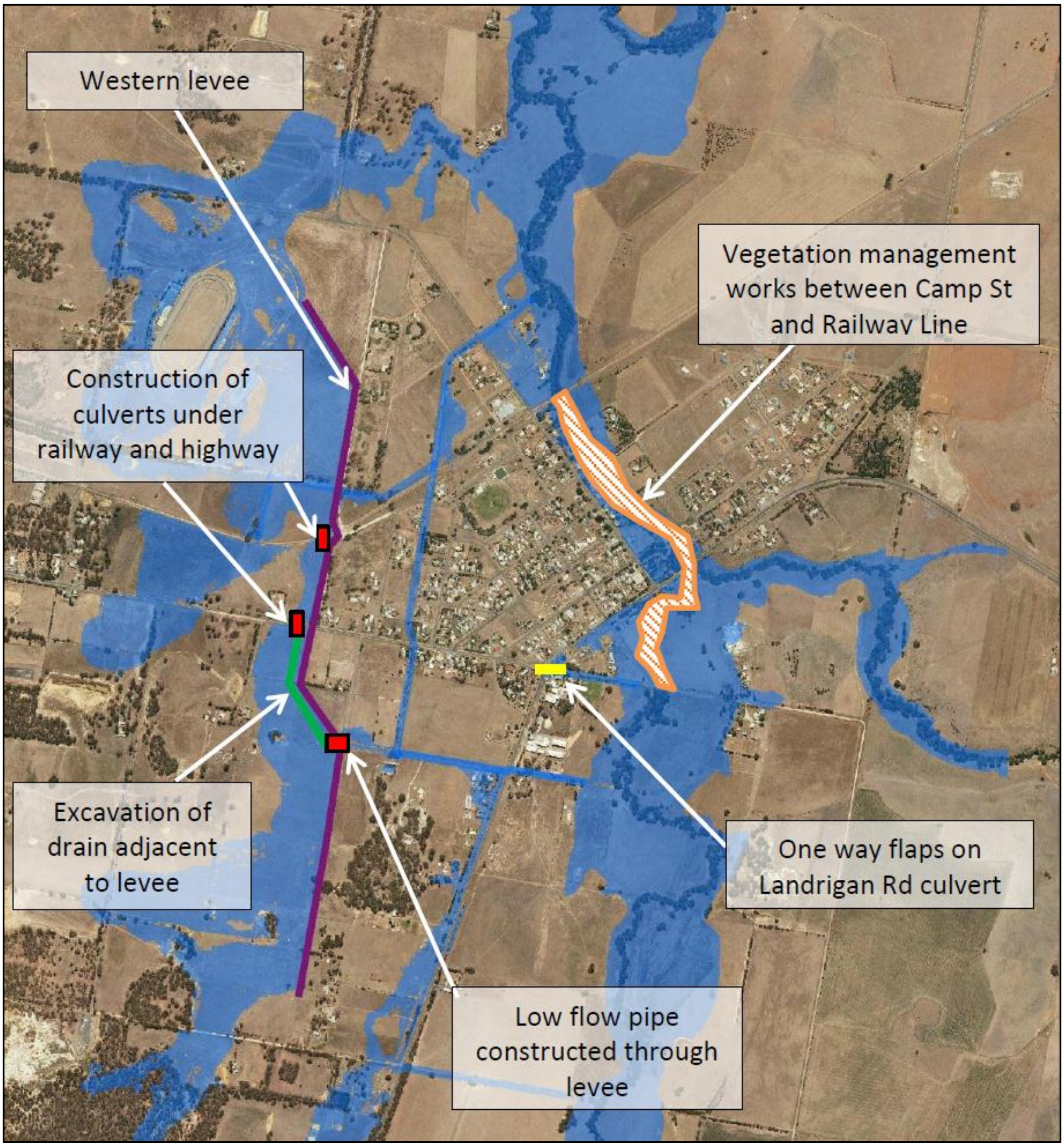



**Figure 6-12 Package 4 Mitigation Options**

***Results***

The preliminary results of the Package 4 modelling indicate the following:

- Package 4 protects the town from the local catchment flows. Most of the local flow is diverted around the western side of the town so there is no overtopping of the drains at Belfast Road or along the main bluestone drain through the township.
- The clearing of vegetation has resulted in a significant drop in water level upstream of the Highway Bridge of approximately 25 cm. This has prevented the breakout across the Pyrenees Highway from occurring in the 100 year ARI event and flowing through the township. Note that the town would still most likely be flooded from a January 2011 event as it is larger than the 100 year ARI event and would still overtop the Pyrenees Highway.
- The one way valve has prevented water surcharging back under Landrigan Road protecting flooding of a number of properties to the south of the highway.

- This option has protected 44 properties from above floor flooding and 161 from below floor flooding in a 100 year ARI flood event. The majority of those properties protected are protected as a result of the vegetation works lowering flood levels and preventing the large breakout across the Pyrenees Highway. Approximately 25 properties have been protected as a result of the levee diverting overland flows.

The 100 year ARI depth results for Option 4 are shown in Figure 6-13 below and a difference plot in Figure 6-14.

***Discussion***

The results of the Package 4 modelling indicate that this option achieves its purpose of effectively protecting the town from both overland and riverine flows. It demonstrates that significant improvements in flood levels in the main waterways can be achieved through vegetation works and this has prevented the main breakout through the township from occurring in a 100 year ARI event. The majority of properties protected are protected as a result of the vegetation works. It should also be noted that this option has included an extended vegetation clearance as compared to previously modelled options. The previous options if modelled with this extended vegetation clearance would see further reductions in water levels upstream of the Pyrenees Highway offering further protection.

It should be noted that this option would not protect from riverine flooding from events larger than a 100 year ARI event (such as a January 2011 event) where significant flow would still overtop the Pyrenees Highway and flow through the township. If protection to the January 2011 event is required then a levee would still be required and even then it is unlikely that full protection could be achieved, as floodwaters would breakout downstream of the Pyrenees highway and inundate the town albeit to a lower level.

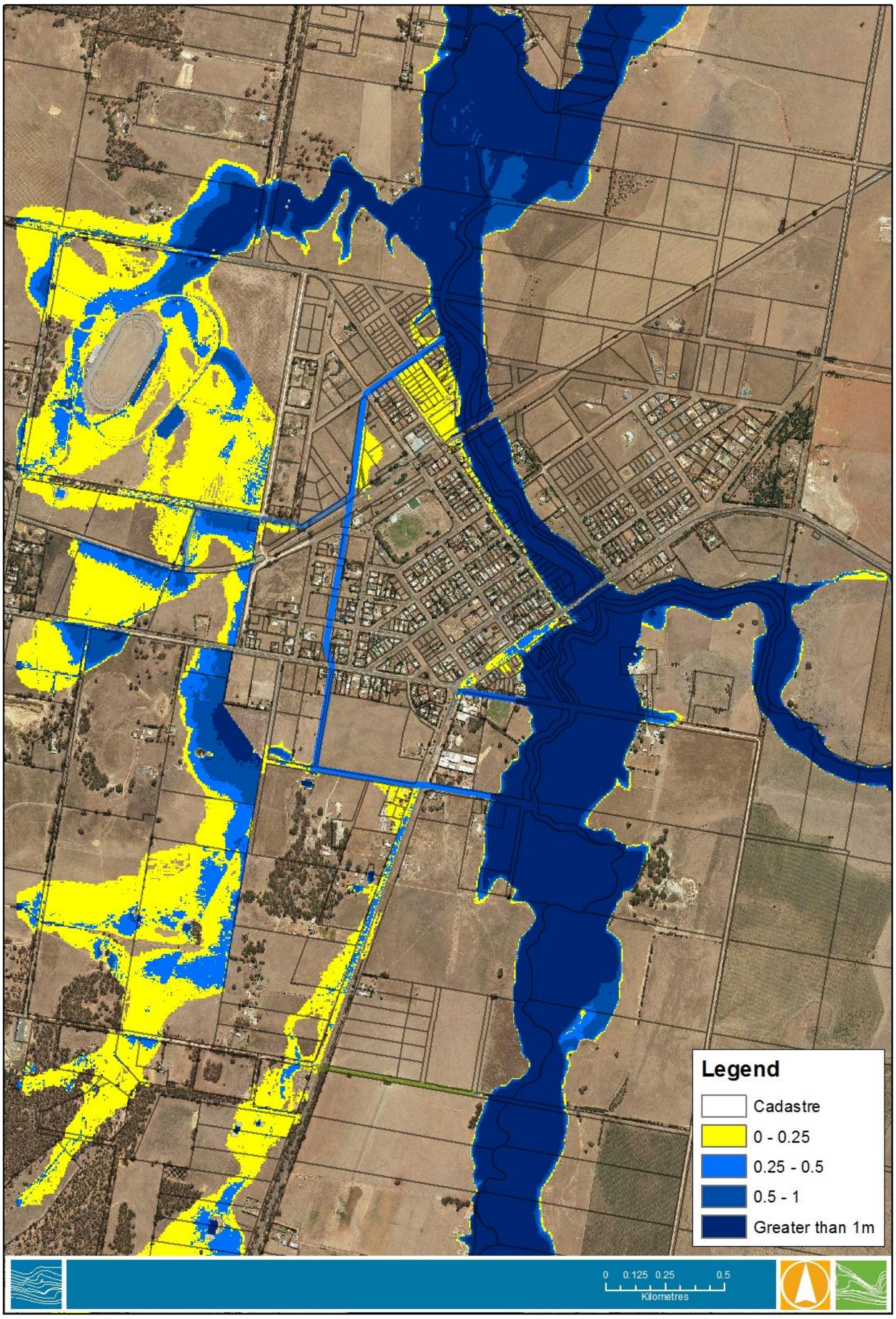



**Figure 6-13 Mitigation Option 4 – 100 year ARI depth results**

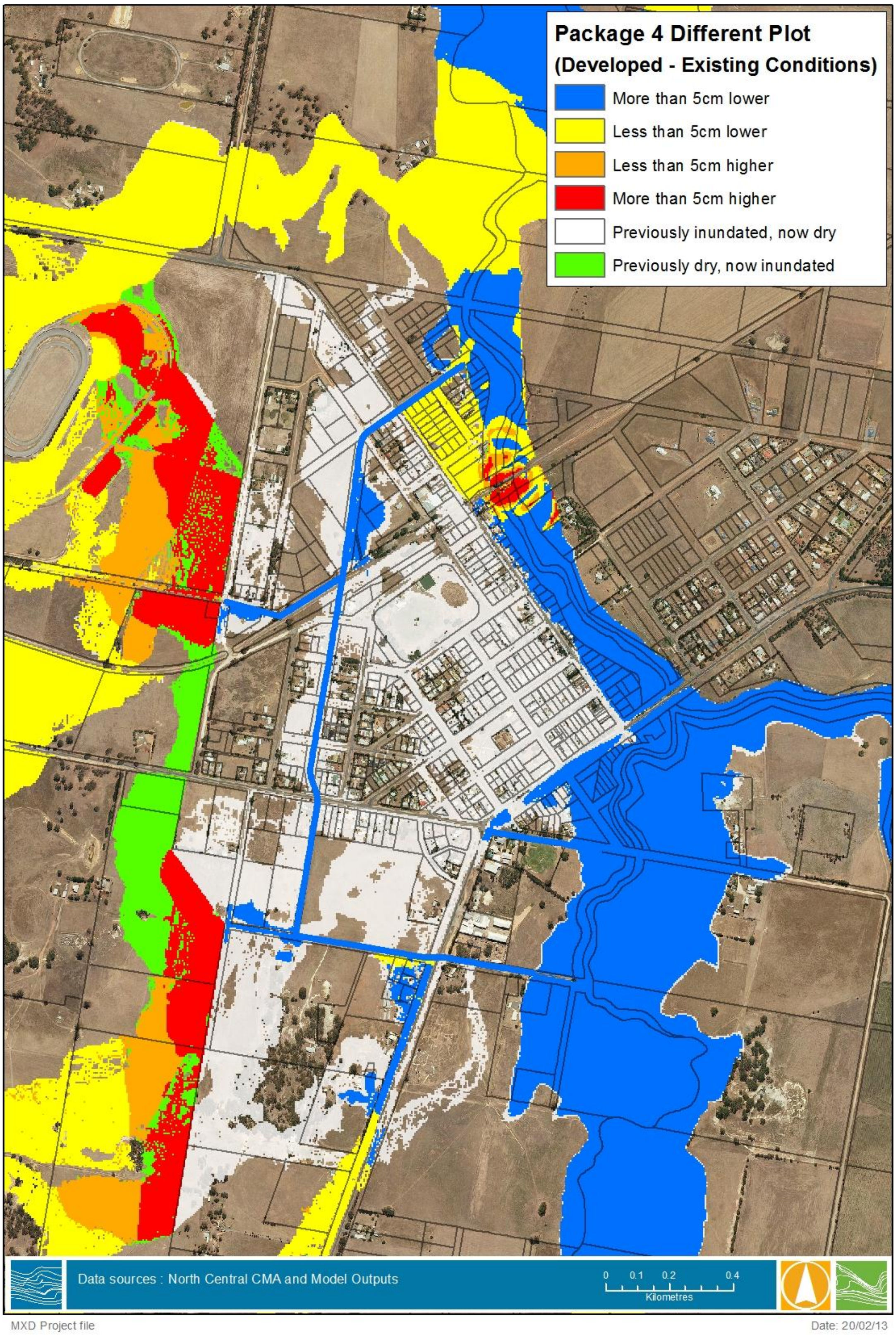



**Figure 6-14 Mitigation Option 4 – Difference Plot**

## 6.2 Non Structural Mitigation Options

There are a range of non-structural mitigation options that can be implemented including land use planning, flood warning, flood response and flood awareness. This section discusses Land Use Planning while the Flood Warning System for Carisbrook is discussed in Section 11.

### 6.2.1 Land Use Planning

The Victoria Planning Provisions (VPPs) contain a number of controls that can be employed to provide guidance for the use and development of land that is affected by inundation from floodwaters. These controls include the Floodway Overlay (FO), the Land Subject to Inundation Overlay (LSIO), the Special Building Overlay (SBO), the Urban Floodway Zone (UFZ) and the Environmental Significance Overlay (ESO).

Section 6(e) of the Planning and Environment Act 1987 enables planning schemes to 'regulate or prohibit any use or development in hazardous areas, or areas likely to become hazardous'. As a result, planning schemes contain State planning policy for floodplain management requiring, among other things, that flood risk be considered in the preparation of planning schemes and in land use decisions.

Guidance for applying flood controls to Planning Schemes is available from the Department of Planning and Community Development's (DPCD) Practice Note on Applying Flood Controls in Planning Schemes.

Planning Schemes can be viewed online at http://services.land.vic.gov.au/maps/pmo.jsp. It is recommended that the planning scheme for Carisbrook is amended to reflect the flood risk identified by this project. Figure 6-16 shows proposed FO and LSIO for consideration into such an amendment. The draft planning scheme map is based on the 'Advisory Notes for Delineating Floodways' (NRE, 1998), with three approaches considered.

**Flood frequency** - Appendix A1 of the advisory notes suggest areas which flood frequently and for which the consequences of flooding are moderate or high, should generally be regarded as floodway. The 10 year ARI flood extent was considered an appropriate floodway delineation option for Carisbrook.

**Flood hazard -** Combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 6-15 for delineating the floodway based on flood hazard. The flood hazard for the 100 year ARI event was considered for this study.

**Flood depth -** Regions with a flood depth in the 100 year ARI event greater than 0.5 m were considered as FO based on the flood depth delineation option.

All three of the above flood frequency, hazard and depth maps were enveloped to provide the final proposed FO maps as shown below.

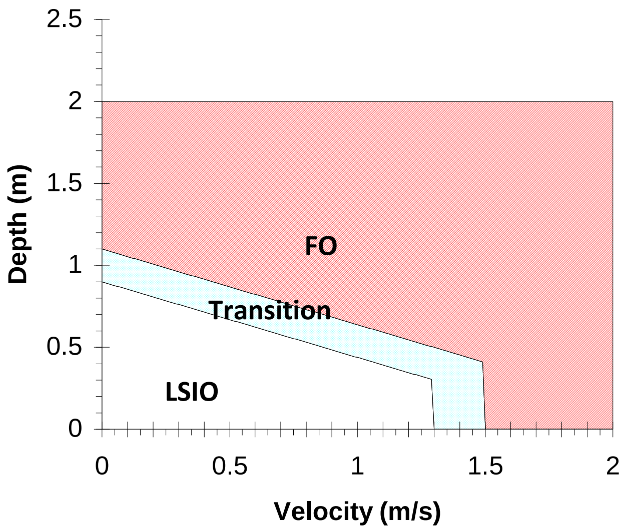



**Figure 6-15 Flood Hazard Delineation of FO**

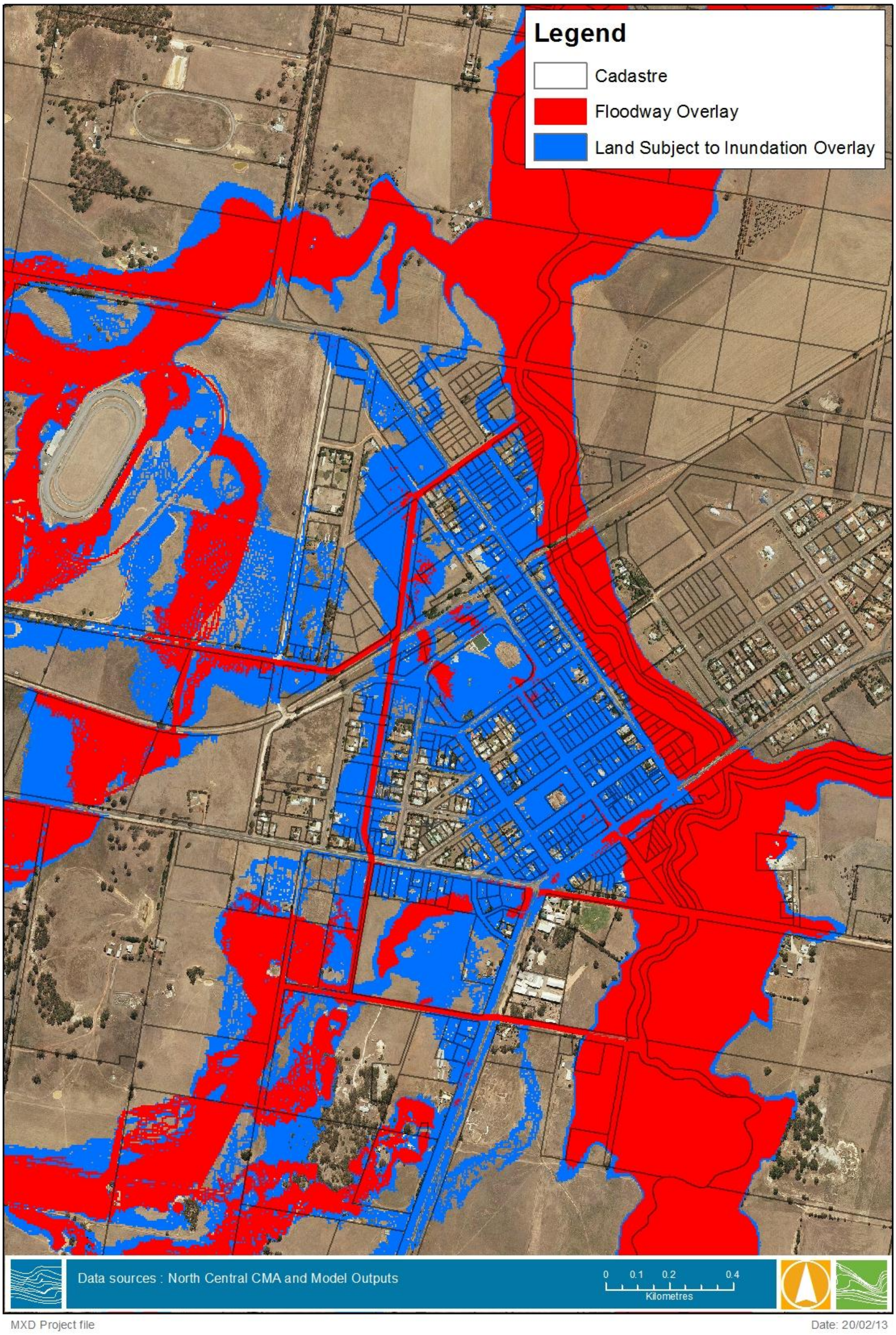



**Figure 6-16 Draft LSIO and FO Map for Existing Conditions**

# 7. BENEFIT COST ANALYSIS

## 7.1 Overview

A benefit cost analysis was undertaken to assess the economic viability of the five modelled mitigation options. Indicative benefit-cost ratios were based on the construction cost estimates and average annual damages. For the analysis, a net present value model was used, applying a 6% discount rate over a 30 year project life.

It should be noted that it was only possible to do a benefit cost analysis on the five modelled mitigation options detailed in earlier sections and not the revised packages that were later presented to the community and are described in Section 8. The revised packages have not undergone detailed modelling of all design events and so it is not possible to conduct a damages assessment or benefit cost analysis of those packages. Each of the options used in the revised packages has been modelled but in slightly different combinations than those proposed in the revised packages.

## 7.2 Mitigation Option Costs

The mitigation works were costed based on a number of key references:

- Melbourne Water's standard rates for earthworks and pipe/headwall construction costs.
- Rawlinson's Australian Construction Handbook Rates
- Advice from VicRoads and Vic Track regarding bridge and culvert works costs
- Comparison to cost estimates for similar mitigation works for other flood studies
- Council and CMA estimates of works costs

A summary of the cost estimates for the four mitigation options are shown in Table 7-1 below. A detailed breakdown of the costing for each mitigation option is included in Appendix B. Option 3 includes a full bridge replacement which represented a significant portion of the total cost outlay for that option. The principal cost elements for the remaining mitigation options include the construction of levee banks, culvert and channel works. The cost for the proposed levees, bunds and embankment walls have been calculated based on the estimated volume of material required to construct the structure. Similarly the cost for the channel works have been determined using a standard excavation rate based on the earthwork removed.

The cost estimates for the various mitigation options also include the costs for vegetation works and installing headwalls for the one way flap valves.

A 30% contingency cost has been added along with engineering and administration costs. An annual maintenance cost of 1.5% of the construction cost was also factored in for the channel and levee works.

**Table 7-1 Mitigation Option Cost Breakdown**

| Option | Total Construction Cost | Annual Maintenance |
|---|---|---|
| Mitigation Option 1 | $590,009 | $9,509 |
| Mitigation Option 2 | $3,032,393 | $12,828 |
| Mitigation Option 3 | $10,461,004 | $16,001 |
| Mitigation Option 4 | $1,651,373 | $23,275 |

## 7.3 Benefit Cost Analysis

The results of the benefit cost analysis are shown below in Table 7-2. Mitigation Options 2 and 4 have the highest benefit-cost ratio with a ratio of 0.1. They have a higher ratio because they are both effective at protecting a large number of properties from inundation by preventing the large damaging breakout through the central township in the 1% AEP event. Mitigation Option 3 has a lower benefit cost ratio due to the very high capital cost associated with the full bridge replacement. Mitigation Option 1 has the lowest benefit cost ratio as it is targeting the local flows and so only a limited number of properties are protected compared with the other options which are aiming to protect from the larger watercourses.

**Table 7-2 Benefit Cost Analysis**

| | Existing Conditions | Mitigation Option 1 | Mitigation Option 2 | Mitigation Option 3 | Mitigation Option 4 |
|---|---|---|---|---|---|
| **Average Annual Damage** | $108,674 | $102,792 | $79,648 | $72,017 | $75,575 |
| **Annual Maintenance Cost** | | $9,509 | $12,828 | $16,001 | $23,275 |
| **Annual Cost Saving** | | -$3,627 | $16,198 | $20,656 | $9,824 |
| **Net Present Value** | | -$51,004 | $227,783 | $290,473 | $138,149 |
| **Capital Cost of Mitigation** | | $590,009 | $3,032,393 | $10,461,004 | $1,651,373 |
| **Benefit – Cost Ratio** | | -0.1 | 0.1 | 0.0 | 0.1 |

## 7.4 Benefit Cost Analysis of Vegetation Works

Vegetation works was an option frequently brought up by both the steering committee and community members yet had not been modelled in isolation. It was clear by the latter stages of the project that any preferred package was likely to include vegetation works so an estimated benefit cost analysis was completed on the vegetation works alone. As the option had not been subject to detailed modelling the Average Annual Damages had to be estimated and this was determined based on the results of other packages and the known impact of the vegetation works on water levels in McCallums and Tullaroop Creeks. The results of the analysis are shown below. A benefit-cost ratio of 1.1 was determined which demonstrates its cost effectiveness. It is suggested that the vegetation works be considered as an essential item in any future mitigation works.

**Table 7-3 Estimated Benefit Cost Analysis of Vegetation Works**

| | Existing Conditions | Vegetation Works (estimated AAD) |
|---|---|---|
| **Average Annual Damage** | $108,674 | $80,000 |
| **Annual Maintenance Cost** | | $10,000 |
| **Annual Cost Saving** | | $18,674 |
| **Net Present Value** | | $262,601 |
| **Capital Cost of Mitigation** | | $250,009 |
| **Benefit – Cost Ratio** | | 1.1 |

# 8. REVISED MITIGATION PACKAGES

Following completion of the detailed mitigation modelling the results were presented to the steering committee and technical working group. Based on the results and subsequent discussions a revised set of packages were determined which were presented to the community. Some options included in the original mitigation modelling, such as the railway floodway, were not included in the revised packages due to concerns around cost, constructability and community support. The revised packages consisted of:

## 8.1 Option A - Western Levee and Vegetation Works

Option A consisted of a Western Levee and vegetation works as previously described by the modelled mitigation option package 4. Specifically this included:

- Western levee and floodway (as previously described)
- A smaller levee near Williams Road to divert additional overland flow into McCallums Creek through the existing bluestone drain
- A non-return valve on culverts under Landrigan Road near Camp Street
- Vegetation works along McCallums and Tullaroop Creek extending upstream from Camp Street to a point 500 m downstream of the railway bridge

This package was almost identical to the original Option 4 modelled package with the only difference being the vegetation works were extended both upstream and downstream. The estimated construction cost for this option is **$1,651,373** not including compensation and land easement costs or ongoing maintenance. Appendix D contains a detailed breakdown of the costs for this option.

Based on results from the detailed modelling this option would provide good protection up to and including a 100 year ARI event. The large breakout across the Pyrenees Highway would be prevented as a result of the vegetation works lowering flood levels in McCallums and Tullaroop Creeks. With this option the township would not be protected from events larger than the 100 year ARI event such as that which occurred in January 2011, with flood waters overtopping the Pyrenees Highway and flowing through the central township.

Vegetation works was mitigation option frequently brought up by community and steering committee members. Modelling has demonstrated that the thinning of vegetation along the major waterways in Carisbrook can have a significant impact on lowering flood levels in both small and large events. This option is effective in Carisbrook due to the dense understorey that exists along McCallums and Tullaroop Creek, and the fact that flows are largely confined to the creek even in large flood events. Vegetation works would require significant thinning of the understory and for this option to be effective the works would need to be maintained into the future.

The vegetation works were modelled by applying a reduction in roughness of 0.02 in the dense vegetation which exists adjacent to the channel. While appropriate resources where used to select roughness values there is, however, a level of uncertainty in translating “on ground” vegetation thinning to a reduction in roughness values.

## 8.2 Option B - Belfast Road Levee and Vegetation Works

Option B consisted of a levee along Belfast Road and drainage upgrades combined with vegetation works. Specifically this included:

- Belfast Road levee and drainage upgrades (as previously described)

- A smaller levee near Williams Road to divert additional overland flow into McCallums Creek through the existing bluestone drain
- A non-return valve on culverts under Landrigan Road near Camp Street
- Vegetation works along McCallums and Tullaroop Creek extending upstream from Camp Street to a point 500 m downstream of the railway bridge

This package is similar to the original Option 1 modelled package but with the inclusion of the vegetation works to lower levels along the main waterways. The estimated construction cost for this option is **$742,252.** It is assumed that compensation and land easement costs are zero for this option, as the existing drainage works are sited in easements, and it is understood from Council, that there is already an agreement with the local landholder to upgrade the Belfast drain along its current alignment. Appendix D contains a detailed breakdown of the costs for this option.

Based on the results of detailed modelling of Packages 1 and 4 this option would also provide good protection up to and including a 1oo year ARI event. The large breakout across the Pyrenees Highway would be prevented as a result of the vegetation works lowering flood levels in McCallums and Tullaroop Creeks. As with Option A the township would not be protected from events larger than the 1oo year ARI event such as that which occurred in January 2011, with flood waters overtopping the Pyrenees Highway and flowing through the central township.

This option was presented to the community but was not supported by the steering committee due to concerns around diverting additional overland flow into McCallums Creek. The modelling results demonstrated that the additional flow into McCallum Creek had a minor impact on flood levels in the main waterways particularly when combined with vegetation works but despite this the preferred option of the steering committee to address overland flows was Option A, the Western Levee.

## 8.3 Option C – Pyrenees Highway Bridge upgrade

Option C consisted of an upgrade to the Pyrenees Highway Bridge. Preliminary testing during the mitigation modelling indicated that constructing additional culverts would not make a meaningful difference and that a full bridge replacement would be required. This option is considered as an add-on to one of the other options, and is most likely a longer term prospect. It has been costed below as standalone. The option consists of:

- Replacement of the existing highway bridge with a clear span structure.

The estimated construction cost for this option is **$7,100,000** as per a VICROADS concept estimate. Maintenance has not been included as an annual cost to this project. As the bridge is a VICROADS asset it is assumed it would be maintained through standard VICROADS maintenance programs.

This option was modelled in the original Package 3 of detailed modelling but was combined with other measures such as vegetation works, a strategic levee and the railway floodway. It has not been modelled in isolation. The relative impact of Option C would be to reduce the water level upstream of the Pyrenees Highway by approximately 20 cm, with a minor increase downstream of approximately 5 cm. If combined with Package A or B it would help to lower levels in events larger than the 100 year ARI event but would not offer full protection. In the 100 year ARI event and smaller it would offer minimal additional benefit if combined with Package A or B as the vegetation works themselves are most effective.

This option was deemed to be cost-prohibitive and not a feasible short-term option. The steering committee has recommended that when the bridge is due for a replacement in the future (or when funding becomes available) that it be replaced with a clear span structure.

## 8.4 Option D – Strategic Levee

Option D consisted of a strategic levee to protect the township from the large breakouts from McCallums Creek. Specifically, this included:

- Construction of a strategic levee along either the Pyrenees Highway or along the floodplain escarpment near Camp and Chapel Streets (as previously discussed). These two alignments are shown in Figure 6-6.
- Construction of headwalls and drop boards over the Chapel Street and Camp Street road crossing.

The estimated construction cost for this option with the highway alignment is **$180,949** not including compensation and land easement costs. The compensation and land easement cost is thought to be minimal for this option as the levee alignment is contained within the road reserve. There is one property close to the bridge that may have access issues with the levee alignment.

The estimated construction cost for this option with the escarpment alignment is **$402,269** not including compensation and land easement costs. Compensation and land easement costs are likely to be considerable in this option as the levee alignment runs very close to buildings through three properties. Appendix D contains a detailed breakdown of the costs for these options.

Based on the results of the Package 2 detailed modelling this option would offer minimal additional benefit if combined with Option A or B in the 100 year ARI event and smaller. Preliminary modelling has indicated that in events larger than the 100 year ARI event (like the January 2011 event), the levees would result in lower flood depths through the township but would not offer full protection due to breakouts occurring downstream of the Pyrenees Highway, with flood waters overtopping Bucknall Street.

The steering committee did not reach agreement to support this option due to concerns around visual amenity, potential road closures and impacts to properties that lie on the creek side of the levees.

# 9. COMMUNITY CONSULTATION

A key objective of the Plan was to ensure strong community engagement and to demonstrate strong community support for the final Plan. A key aspect of all community engagement was to provide information to ensure community understanding and then to seek feedback verbally at meetings and through more formal feedback methods. Three public meetings held at various stages of the Plan development were all strongly attended. Feedback from these meetings guided the development of the Plan.

Key findings of the Draft Carisbrook Flood Mitigation and Drainage Management Plan were presented to the community in a public meeting held on 15th February 2013. A summary brochure outlining the mitigation packages and preferred option along with a feedback form was provided to all meeting attendees and a three week consultation period then ensued.

Following the period of public consultation a total of 113 submissions were received from the community, with 100 submissions supporting the preferred option and 13 not supporting the preferred option or unsure.

The results of the feedback are summarised below:

- 100 of the 113 respondents supported the 'preferred' package of works which was Option A the Western Levee and vegetation works.
- 13 of the 113 respondents did not support the preferred package of works or were unsure
- A very small number of respondents elected to remain anonymous.

As a result of the extensive community consultation, and public feedback, it is clear that the steering committee's proposed scheme for Carisbrook has strong community support.

# 10. FINAL PREFERRED OPTION

Based on the study results, steering committee discussions and the community consultation feedback the preferred option of the steering committee remained the same. The steering committee's final preferred option was:

- A Western Floodway and Levee to divert overland flows to the west of the township
- Vegetation works on Tullaroop and McCallums Creek extending from Camp Street to a point 500 m downstream of the railway bridge
- A smaller levee near Williams Road to divert additional overland flow into McCallums Creek through the existing bluestone drain
- A non-return valve on culverts under Landrigan Road near Camp Street
- A long-term recommendation that the highway bridge be replaced with a clear-span structure when the bridge is due for replacement (or when funding becomes available).

The final preferred options are shown in Figure 10-1

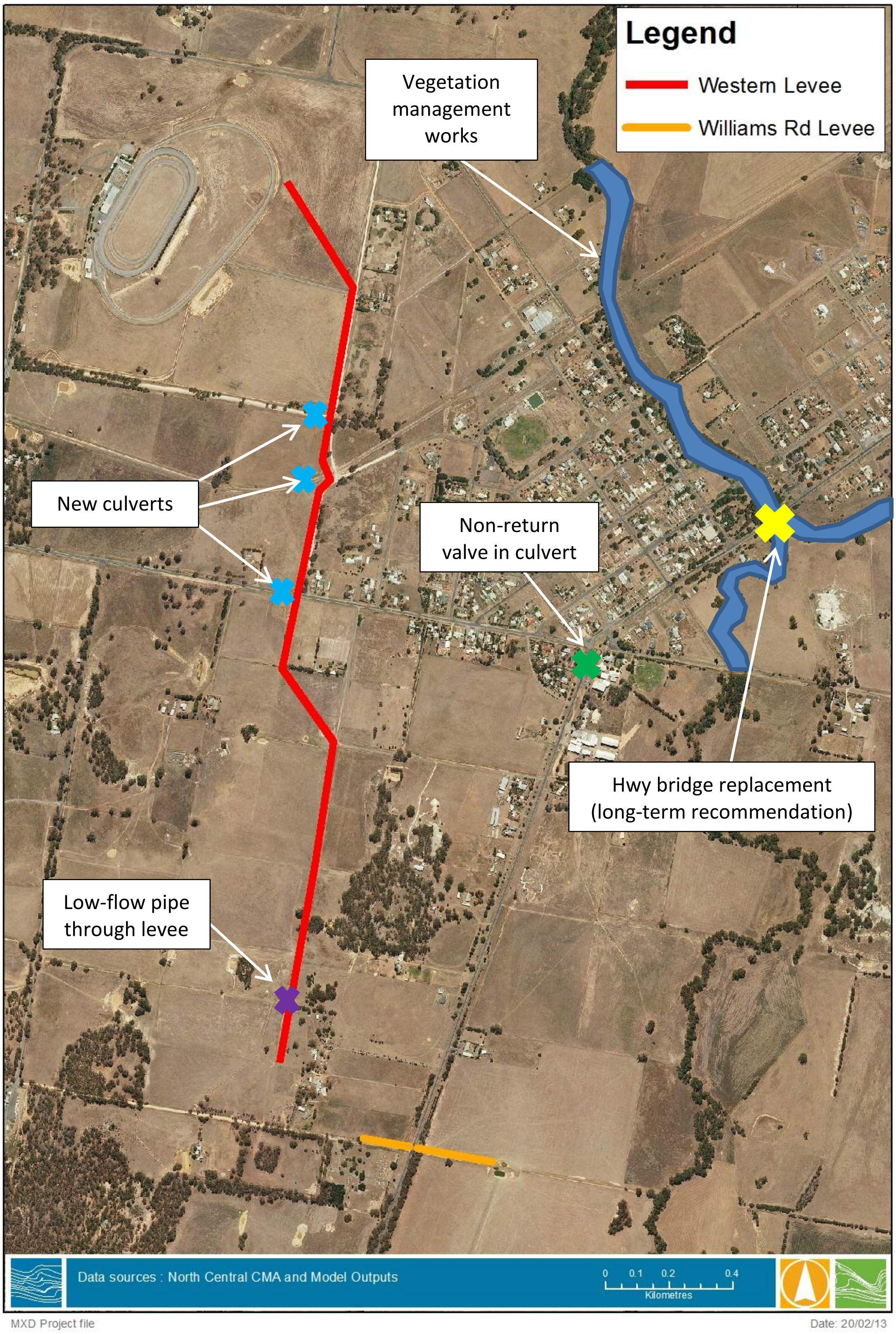



**Figure 10-1 Final Preferred Options for Carisbrook**

# 11. FLOOD WARNING SYSTEM

The full flood warning assessment and recommendations report is available in Appendix C. The key recommendations from that report are provided below.

## 11.1 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 flood warning systems aim to enable and persuade people and organisations to take action to increase personal safety and reduce the damage caused by flooding[6].

It is essential that flood warning systems consider not only the production of accurate and timely forecasts / alerts but also the efficient dissemination of those forecasts / alerts to response agencies and threatened communities in a manner and in words that elicit appropriate responses based on well-developed mechanisms that maintain flood awareness. Thus, equally important to the development of flood warning mechanisms is the need for quality, robust flood awareness (education) programs to ensure communities are capable of response.

## 11.2 Flood Warning Recommendations

A staged approach to the development of a flash flood warning system for Carisbrook is proposed. The stages have been ordered and the tasks within each stage grouped to facilitate growth of all elements of the Total Flood Warning System (TFWS) in a balanced manner. While it may be tempting to immediately move to install additional rain and river gauges and to develop / strengthen forecast capability, there are other more fundamental matters that experience tells us need to be addressed first. Thus early attention is directed at ensuring roles and responsibilities are agreed, understood and accepted and that there is a firm foundation for the development of an effective flash flood warning system: one that does not fail when it is needed most. Attention is then directed to establishing a robust framework for communicating and disseminating flood related information so that immediate and maximum use can be made of available information as the ability to detect and predict flooding at Carisbrook improves. Next, attention is focussed on securing the funding needed to buy, install and operate field equipment as well as other services needed to build elements of the TFWS. The installation of data collection equipment follows, with a two tiered approach in the event that funding is not available or is delayed. Development of other technical elements and the build and delivery of on-going flood awareness activities can then occur in the knowledge that required data is / will be available and that robust and sustainable arrangements are in place that will enable maximum benefit to be derived from any information or programs delivered to the community.

**Stage 1**

1. Council, NCCMA, VICSES and other entities to determine the responsible entity in relation to "ownership" of <u>each element of the flash flood warning system</u> for Carisbrook, where ownership is considered to denote overall responsibility for funding as well as the functioning of the system element and, in the event of failure, responsibility for either fault-fix or the organisation of appropriate fault-fix actions along with associated payments. VFWCC[7] provides guidance on this

[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).

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

matter although recommendations 1 and 5 from the Comrie Review Report[8] suggest that some clarifications may be required.

**Stage 2**

1. Council to champion and in conjunction with VICSES oversee the establishment of a flash flood action or flood warden group for Carisbrook. Clearly establish the role for this group along with its authority and structure with due regard for liability issues. Essentially the group would:
   - Collect and collate rain and water level / flow data and also monitor rain and river information via the BoM's website.
   - Make initial assessments of the likelihood and scale of flooding at Carisbrook based on available rainfall data, water levels and trends at upstream locations and at Carisbrook, and the indicative quick look 'flood / no-flood' tool developed for Carisbrook and included in the Central Goldfields MFEP.
   - In the event of likely flooding, call VICSES to advise of likely flooding and, subject to discussion with the RDO or IC, call the Central Goldfields MERO and initiate flood response actions within Carisbrook consistent with the MFEP. This may include door knocking and through the MFEP, identification of roads and properties likely to be impacted and the coordination of removal of items susceptible to damage from floodwater from buildings likely to be flooded over-floor when conditions indicated it is warranted or necessary and thereafter work closely with VICSES, CFA and Council.
   - Maintain a watching brief on flood response arrangements within Carisbrook, including the availability of sand and sand bags, and provide feedback to Council on the adequacy and efficacy of arrangements in place at the time.
2. Council to share the MFEP with the Carisbrook community.
3. Council to establish arrangements for the timely supply of sandbags and sand within Carisbrook.
4. Council and VICSES to encourage and assist residents and businesses to develop individual flood response plans.
5. Council to load and maintain flood related material (including the MFEP) to its website.
6. Council with the support of VICSES, NCCMA and the Carisbrook community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements of a TFWS for Carisbrook.

**Stage 3**

1. Install a series of staff gauges (may require 5) immediately upstream of the Pyrenees Highway Bridge at Carisbrook. Set to either AHD or local datum and survey to AHD. Consider marking the January 2011 and September 2010 flood levels on the gauges, as well as the design flood levels determined through the Carisbrook Flood and Drainage Study. Establish on-going maintenance arrangements, ideally through the Surface Water Monitoring Partnership.
2. Update the MFEP with staff gauge datums and other relevant details.
3. Council in conjunction with VICSES to establish and document in the MFEP for the timely:
   - Pick-up and removal of items susceptible to damage from floodwater from buildings likely to be flooded but not amenable to sandbagging (e.g. weatherboard buildings);
   - Supply of sandbags and sand within Carisbrook with sufficient lead time to enable buildings at risk of minimal over-floor flooding to be sandbagged / protected.
4. VICSES to initiate a community engagement program at Carisbrook in order to communicate how the flood warning system will work. This will need to be repeated as the system matures

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

5. VICSES to develop and distribute a FloodSafe brochure / Local Flood Guide for Carisbrook.
6. Council to oversee the development, printing and distribution of property-specific flood depth charts for properties within Carisbrook.

**Stage 4A – to be actioned only if funding to undertake Stage 4B is either not available or is delayed**

1. Determine the location of private rain gauges in the upper parts of the McCallum Creek catchment and on the hills facing Carisbrook to the west / south west (if the outcome from 1 above was negative) and establish arrangements for the provision of rainfall data to the flood action or flood warden group at frequent intervals during heavy rain events.

   Alternatively, source two rain gauges and distribute to local residents willing to provide rainfall data at frequent intervals during heavy rain events:

   - In the upper parts of the McCallum Creek catchment (priority 1).
   - On the hills facing Carisbrook to the west / south west (priority 2).

**Stage 4B**

1. Using equipment similar to (or the same as) that already installed and operational at the Tullaroop Creek at Clunes and McCallum Creek at Carisbrook gauging stations:
   - Establish a telemetered rain and stream gauge at Carisbrook immediately upstream of the Pyrenees Highway Bridge (i.e. at the newly established staff gauge site); and
   - Add a rain gauge and telemetry to the Smeaton and Creswick Creek at Clunes gauging stations.
2. Install 2 x ERTS rainfall only stations: in the upper parts of the McCallum Creek catchment and on the hills facing Carisbrook to the west / south west. Will need to explore possible opportunity to partner with DSE on the McCallum Creek installation before committing to funding and works.
3. Establish on-going maintenance (and data archival) arrangements for all installed equipment, ideally through the Surface Water Monitoring Partnership.
4. Approach BoM to add all telemetered sites to appropriate rainfall and river level bulletins accessible via the BoM website. Requires telemetry systems used to be fully compatible with BoM systems.
5. If appropriate and following achievement of full operational status of each telemetered site providing additional rain and river data, retire the manual readers in the general vicinity who have previously provided that data for the Carisbrook flash flood warning system.

**Stage 5**

1. In conjunction with VICSES, NCCMA and the Carisbrook-based flood action or flood warden group, Council to determine appropriate rain and river trigger levels for the initiation of SMS alerts and / or email alerts from telemetry sites.
2. Council to begin building a relationship between levels / flows at Tullaroop head gauge, McCallum Creek at Carisbrook and Deep Creek at Carisbrook in order to assist flood assessment and response at Carisbrook and in order to inform the development and / or firming up of flood class levels.

**Stage 6**

1. Install flood depth indicator boards at key locations in and around Carisbrook (e.g. in the low spot on Simpson Street to the west of the Pyrenees Highway Bridge or as indicated by the flood hazard maps delivered by the Carisbrook Flood and Drainage Study) and further afield.

**Stage 7**

1. Longer term and following the identification of an appropriate and responsible entity to develop, run and maintain the model (and as part of a "best possible" flash flood warning system), establish a rainfall-runoff based flood forecast model for the catchment to Carisbrook.

# 12. FLOOD WARNING BENEFIT COST ANALYSIS

To undertake a benefit cost analysis of flood warning for Carisbrook, firstly the costs were estimated. As part of the flood warning recommendations a number of items were costed. The recommendations included items that are considered essential through to items that are considered a luxury. For the purposes of the benefit cost analysis we have chosen from all items recommended and formed three packages, essential, standard and complete packages. Table 12-1 below summarises the packages. Note that for the costing, items that require agency in-kind support have not been included as a cost to the project.

**Table 12-1 Flood Warning Packages for Benefit Cost Analysis – Key Items**

| Package | Essential | Standard | Complete |
|---|---|---|---|
| **Items** | Installation of 5 staff gauges in Carisbrook<br>Install depth indicator board at key locations in Carisbrook<br>Establishment of a flash flood action or flood warden group<br>Several recommendations around developing relationships between stakeholders and determining roles in the flood warning system<br>See Appendix E for full package details | Add a rain gauge and telemetry to the Smeaton and Creswick gauges<br>VicSES to initiate a community engagement program and floodsafe brochures for Carisbrook<br>Installation of 5 staff gauges in Carisbrook<br>Install depth indicator board at key locations in Carisbrook<br>Establishment of a flash flood action or flood warden group<br>Several recommendations around developing relationships between stakeholders and determining roles in the flood warning system<br>See Appendix E for full package details | Install 2 telemetered rainfall gauges in upper McCallums catchment and local Carisbrook catchments<br>Establish a telemetered rain and stream gauge in Carisbrook<br>Council to develop property-specific flood depth charts<br>Add a rain gauge and telemetry to the Smeaton and Creswick gauges<br>VicSES to initiate a community engagement program and floodsafe brochures for Carisbrook<br>Installation of 5 staff gauges in Carisbrook<br>Install depth indicator board at key locations in Carisbrook<br>Establishment of a flash flood action or flood warden group<br>Several recommendations around developing relationships between stakeholders and determining roles in the flood warning system |

| | | | |
|---|---|---|---|
| | | | See Appendix E for full package details |
| **Capital Cost** | $17,300 | $50,300 | $118,300 |
| **Maintenance Cost** | $2,500 | $7,500 | $16,000 |

The benefits of flood warning through reduced flood damages have long been recognised, however the benefit delivered by providing flood warning is very difficult to quantify. A number of papers and previous studies were reviewed to determine an appropriate methodology to quantify the flood warning benefit for Carisbrook[9,10,11,12]. A number of different approaches to assessing the benefit of flood warning have been suggested in the literature, the most simple, common and accepted of which are versions on the Day curve[13]. The Day curve relates warning time to percentage reduction in tangible damages. The Day curve can be further complicated by combining the effect of flood depth, as there is some data that suggested that flood warning provides a larger benefit in cases where the eventual flood depth is high rather than low[14]. This analysis has not considered such an effect. Carsell et. al.[11] suggest that the effectiveness of the warning time must be factored in, providing a range of factors that could be applied to adjust the effectiveness of the damage reduction due to response rate from the community. This analysis has applied an 80% effectiveness factor to the reduced tangible damages from the Day curve. Figure 12-1 below shows the modified Day curve adopted in this analysis.

9 Department of Natural Resources and Environment (2000), Rapid Appraisal Method (RAM) for Floodplain Management, *Section 5.4*.

10 Foundation for Water Research (2006), Assessing the Benefits of Flood Warning: A Scoping Study.

11 Carsell, K. M. et. al. (2004), Quantifying the Benefit of a Flood Warning System, *Natural Hazards Review, American Society of Civil Engineers*.

12 Ball, T. et. al (2012), Assessing the Benefits of Flood Warning, *Journal of Flood risk Management*.

13 Day, H.J. (1970), Flood Waring Benefit Evaluation – Susquehanna River Basin, *ESSA Technical Memo WBTM Hydro-10*.

14 Chatterton, J.B. and Farrell, S.J. (1977), Nottingham Flood Warning Scheme: Benefit Assessment, *Severn-Trent Water Authority*.

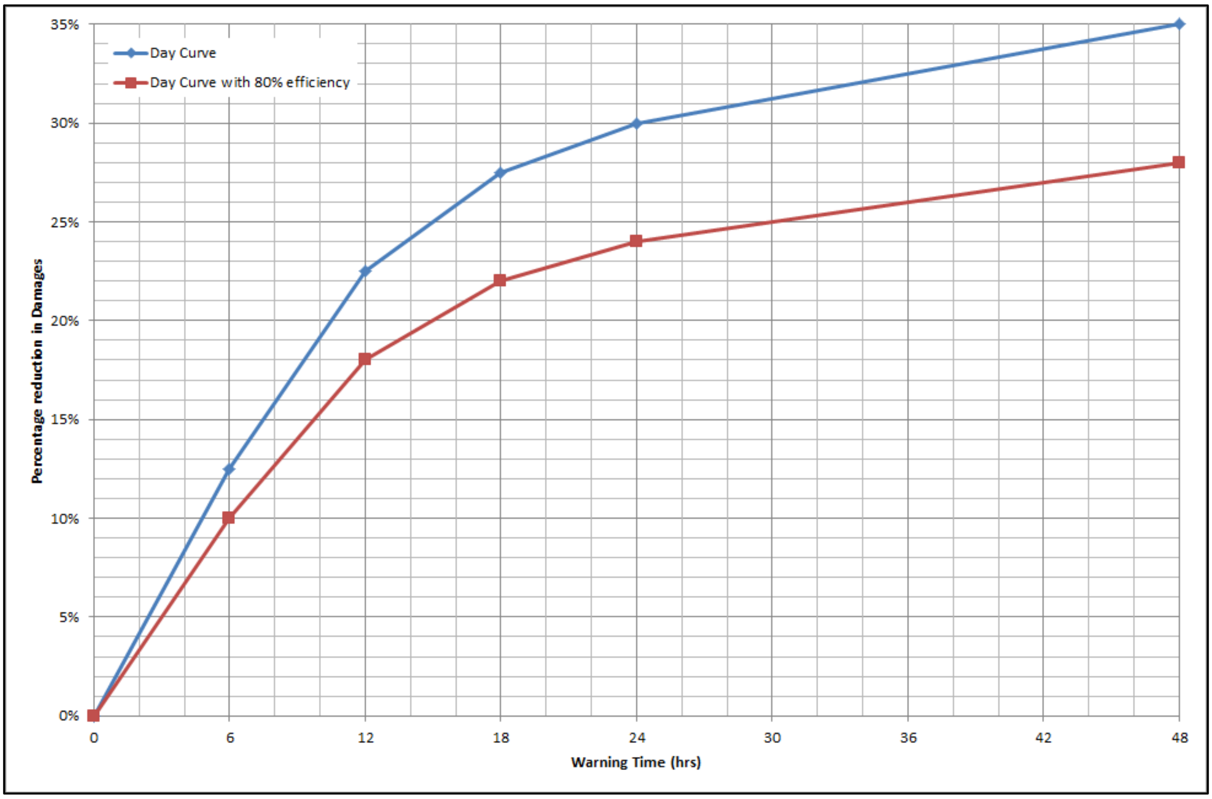



**Figure 12-1 Modified Day Curve for Evaluating Flood Warning Benefit**

Based on previous experience from the recent 2010/11 floods and a knowledge of the current flood response arrangements, it was estimated that Carisbrook would receive approximately 6 hours of warning time under the current arrangements. It is anticipated that provided with flood warning the warning time may be increased to 12 hours if the Complete system is implemented, an increase of 6 hours from the current arrangements. It is estimated that the Standard system could increase the warning time to 10 hours while the Essential system could increase the warning time to 8 hours.

Reading off the Day curve an increase in warning time from 6 to 12 hours at Carisbrook for the Complete system may result in a reduction in tangible flood damages of 8%. This percentage reduction in tangible damages translates to a monetary reduction of average annual damages of $3,515, well short of the estimated annual maintenance costs.

An increase in warning time from 6 to 10 hours at Carisbrook for the Standard system may result in a reduction in tangible flood damages of 5%. This percentage reduction in tangible damages translates to a monetary reduction of $2,197, still well short of the estimated annual maintenance costs.

An increase in warning time from 6 to 8 hours at Carisbrook for the Essential system may result in a reduction in tangible flood damages of 2.5%. This percentage reduction in tangible damages translates to a monetary reduction of $1,098, still short of the estimated annual maintenance costs.

The flood warning packages were subject to a benefit cost analysis following the same approach as that adopted for the structural mitigation options. The benefit-cost ratio was calculated as -1.1, -1.5 and -1.5 for the essential, standard and complete packages respectively. All the benefit cost ratios are negative because the likely reduction in the flood damages is less than the annual maintenance costs.

In this case flood warning does not appear to have a very strong benefit cost ratio, however it is recommended that at least the essential tasks be considered for implementation, with further flood warning options considered in the future should funding become available.

# 13. CONCLUSIONS AND RECOMMENDATIONS

The Carisbrook Flood and Drainage Management Plan has been successful in providing a much better understanding of flood behaviour around Carisbrook and identified a number of mitigation measures which can effectively protect the township from both overland and riverine flooding.

The Plan has verified the information gathered from the local community, that some areas of town were indeed inundated from local runoff prior to the creek flooding.

The September 2010 and January 2011 food events were successfully modelled, replicating the observed behaviour, with a detailed description of the flood behaviour from these recent historic events described in the Plan. The September 2010 event was estimated as a 75 year ARI event, with January 2011 estimated to be much larger at 135 year ARI event.

A series of design flood events were modelled, providing critical intelligence regarding potential future flood events, from small in-channel events to large events even bigger than the January 2011 event.

A number of climate change scenarios were also modelled and demonstrated that climate change will have a significant impact on flooding at Carisbrook. The results indicated that riverine peak flow rates could increase by up to 125% in a 5yr ARI event and 89% in a 100yr ARI event. With climate change, extreme events, such as the January 2011 event, would become considerably more frequent.

A detailed assessment of a range of mitigation options has been undertaken and each mitigation option was assessed against a number of criteria including potential reduction in flood damage, cost of construction, feasibility of construction, environmental impact and community support.

After significant consultation with the community and stakeholders the steering committee recommends a package of works that will provide protection for the vast majority of the township up to and including a 100 year ARI at a total estimated cost of $1.65 million (note: excludes any land easement and compensation costs that may be associated with the recommended works).

The works proposed include:

- A Western Floodway and Levee to divert overland flows to the west of the township
- Vegetation works on Tullaroop and McCallums Creek extending from Camp Street to a point 500 m downstream of the railway bridge
- A smaller levee near Williams Road to divert additional overland flow into McCallums Creek through the existing bluestone drain
- A non-return valve on culverts under Landrigan Road near Camp Street
- A long-term recommendation that the highway bridge be replaced with a clear-span structure when the bridge is due for replacement (or when funding becomes available).

This preferred option has received overwhelming support from the local community with 100 of the 113 written responses received by North Central CMA strongly supporting the preferred option.

The North Central CMA in conjunction with Central Goldfields Shire will now apply for funding for the vegetation works and for detailed design of the Western Floodway and Levee option.

The following actions are also recommended:

- The staged implementation of a flood warning system for Carisbrook which may include several new rainfall gauges in the upstream catchments (at the Carisbrook local catchment, Smeaton, Clunes and the upper McCallums Creek catchment) and a new stream flow gauge and boards to be installed at Carisbrook (upstream of the highway bridge).
- The flood warning system should be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system;

- It is recommended that a flood response plan be adopted into the Municipal Flood Emergency Plan and the community is engaged along with the responsible agencies (BoM, SES, CGS, North Central CMA etc.) in developing appropriate actions.

# 14. REFERENCES

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Institution of Engineers, Australia (1987) *Australian Rainfall and Runoff, Vol. 1&2*. (Ed: Pilgrim, D.H.) Institution of Engineers, Australia.

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

# APPENDIX A CARISBROOK SITE VISIT REPORT

# Carisbrook Site Visit Report

| | |
|---|---|
| **Date:** | Tuesday, 20th December 2011 |
| **Time:** | 3:00pm – 5.00pm |
| **Location:** | Carisbrook |

# Site Visit Record

| | | | |
|---|---|---|---|
| **Attendees:** | Ben Tate | Louisa Clarkson | Stan Hendy |
| | Julian Skipworth | Lyn Symons | Robert Rowe |
| | Camille White | Trish Couts | Ken Coates |
| | Shane O'Loughlin | | |
| **Via Phone:** | | | |
| **Apologies:** | | | |

A site visit was undertaken by Water Technology on 20th December 2011 initially with representatives from the steering committee. The purpose of the site visit was to gain a better understanding of the flood issues in Carisbrook, identify key structures for the hydraulic modelling and investigate locations/options for future mitigation works. Information gathered from the site visit is documented below.

### Notes of Conversations with Steering Committee Members

- Local residents advised that the Deep Creek channel downstream of the Pyrenees Highway bridge used to be much deeper and contained a swimming hole 20-30 years ago. They advised that since then the channel has filled up with both silt and woody debris. They feel that this is restricting flow and causing an increase in flood levels. The swimming hole at Bland Reserve used to have a beach and be situated on a water hole approximately 1.5m deep. It was felt by some residents that the Deep Creek channel needs to be cleared between Pyrenees Highway and the Railway Bridge downstream.
- It was reported that up until early this year much of the area under the Pyrenees Highway bridge contained vegetation and woody debris which also restricted flow and that this was cleared following the major flood events of last summer. Some residents feel that the road bridge continues to be the main obstruction to flow during large flood events.
- It was advised by local residents that local resident Brian Perry has a wealth of information and photos regarding the flood events and should be contacted.
- It was advised that an old bluestone drainage channel to the south of the town had only recently been discovered and cleaned out.
- It was felt by some residents that the main culverts under Victoria Street/Pyrenees Highway in in the west of Carisbrook are too small and should have an increased capacity. It was advised that houses in this area to the south of the road at this location were inundated in both of the flood events of 2010/2011.

Following an initial visit to Bland Reserve with members of the steering committee Water Technology visited a number of sites around town to gain a better understanding of the town's drainage system and key hydraulic structures. A number of culverts were measured and are detailed below:

## Survey of Structures

Below is a list of the structures that were roughly surveyed to the road crest levels. These can then be tied into AHD using the available LiDAR. Note this is a rough approximation, but will be sufficient.

| Structure Details | Measurements |
|---|---|
| **Deep Creek Pyrenees Highway bridge**<br> | Survey to be provided by VicRoads |
| **Deep Creek Pedestrian Bridge**<br> | Survey to be provided by CGS |
| **Deep Creek Railway Bridge** | Survey to be provided by VicTrack |

| | |
|---|---|
|  | |
| Railway Culverts – adjacent to Chaplins Rd  | Survey to be provided by VicTrack |
| **Bluestone channel north of township** | 3m wide at top<br>2.5m wide at base<br>1.2m high |

| | |
|---|---|
| Bluestone channel at north of town near Hood St and outlet to Tullaroop Creek (looking West)  | |
| **Bucknall St/Hood St culvert**  | 1.7m (obvert)<br>2.15m (deck height)<br>3m wide |
| **Annesly/Hood St culvert** | Clear span<br>1.3m high x 3m wide (top width) |

| | |
|---|---|
|  Culvert at corner of Hood and Annesley St | |
| **Victoria St/Pyrenees Hwy main culvert**  Pyrenees Hwy main culvert looking south | Clear span<br>1.1m high x 3.5m wide (top width) |
| **High St culvert**  Culvert on High St south of railway | Clear span<br>1m high x 3m wide (top width) |
| **Pyrenees Hwy near Potts Lane culvert** | Box culvert<br>1.2m high x 2.4m wide |

| | |
|---|---|
| <br> | |
| **Railway Culvert (primary) – angled**<br><br> | Clear span<br>1.2m high x 4m wide |
| **Railway Culvert (secondary)**<br><br> | Clear Span<br>1.2m high x 2.4m wide |
| **Landrigan Road Box Culverts (next to school)** | 2 Box Culverts<br>2 x 0.9m high x 1.2m wide |

| | |
|---|---|
|   | |
| **Landrigan Road Box Culvert (next to Belfast Rd)**   | 2 Box Culverts<br>2 x 0.6m high x 1.3m wide |
| **Landrigan Rd/Williams Rd Culvert**  | Box Culvert<br>0.8m high x 1.2m wide |
| **2 bridges at front of primary school** | Clear Span<br>Both 1.2m high x 3m wide (top width) |


Bluestone channel looking east past the school from Landrigan Rd

# APPENDIX B COSTINGS OF MODELLED MITIGATION OPTIONS

## Table 14-1 Mitigation Option 1 Costs

| Status | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Mitigation Option 1 | Belfast Road Levee | $127,251 | $1,909 |
| | Williams Road Levee | $42,535 | $638 |
| | Landrigans Road Culvert Upgrade | $44,890 | $673 |
| | Main Drain Culvert & Headwall Construction | $10,421 | $156 |
| | Belfast Road Drain Enlarging Works | $17,197 | $258 |
| | Drainage System - One Way Valves | $17,500 | $875 |
| | Vegetation Works | $120,000 | $5,000 |
| | Ring Levee Belfast/Landrigans Rd | $0 | $0 |
| | **Compensation/Land Easement Costs - TBC*** | | |
| | **Sub-total 'A'** | $379,794 | |
| | 'A' x Engineering Fee @ 15% | $56,969 | |
| | **Sub-total 'B'** | $436,763 | |
| | 'B' x Administration Fee @ 9% | $39,309 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | |
| | **Sub-total 'C'** | $476,071 | |
| | 'A' x Contingencies @ 30% | $113,938 | |
| | **FORECAST EXPENDITURE** | **$590,009** | **$9,509** |

## Table 14-2 Mitigation Option 2 Costs

| Status | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Mitigation Option 2 | Belfast Road Levee | $127,251 | $1,909 |
| | Cemetary Levee | $42,535 | $638 |
| | Landrigans Road Culvert Upgrade | $44,890 | $673 |
| | Main Drain Culvert & Headwall Construction | $10,421 | $156 |
| | Belfast Road Drain Enlarging Works | $17,197 | $258 |
| | Drainage System - One Way Valves | $17,500 | $263 |
| | Ring Levee Belfast/Landrigan Rd | $0 | $0 |
| | Vegetation Works (Hwy to Railway Bridge) | $120,000 | $10,000 |
| | Strategic Levee - Highway Alignment (inc. headwalls & dropbo | $116,478 | $1,747 |
| | Floodway | $1,455,703 | $2,184 |
| | **Sub-total 'A'** | $1,951,975 | |
| | 'A' x Engineering Fee @ 15% | $292,796 | |
| | **Sub-total 'B'** | $2,244,771 | |
| | 'B' x Administration Fee @ 9% | $202,029 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | - |
| | **Sub-total 'C'** | $2,446,800 | |
| | 'A' x Contingencies @ 30% | $585,592 | |
| | **FORECAST EXPENDITURE** | **$3,032,393** | **$17,828** |

## Table 14-3 Mitigation Option 3 Costs

| Status | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Mitigation Option 3 | Belfast Road Levee | $127,251 | $1,909 |
| | Cemetary Levee | $42,535 | $638 |
| | Landrigans Road Culvert Upgrade | $22,056 | $331 |
| | Main Drain Culvert & Headwall Construction | $244,784 | $3,672 |
| | Belfast Road Drain Enlarging Works | $17,197 | $258 |
| | Drainage System - One Way Valves | $17,500 | $263 |
| | Ring Levee Belfast/Landrigans Rd | $0 | $0 |
| | VegetationWorks | $120,000 | $5,000 |
| | Strategic Levee - Highway Alignment (inc. headwalls & dropb | $116,478 | $1,747 |
| | Floodway | $1,455,703 | $2,184 |
| | Bridge Replacement (approximate estimate by VicRoads) | $7,100,000 | - |
| | **Sub-total 'A'** | $9,263,504 | |
| | 'A' x Engineering Fee @ 15% | $324,526 | |
| | **Sub-total 'B'** | $9,588,030 | |
| | 'B' x Administration Fee @ 9% | $223,923 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | |
| | **Sub-total 'C'** | $9,811,952 | |
| | 'A' x Contingencies @ 30% | $649,051 | |
| | **FORECAST EXPENDITURE** | **$10,461,004** | **$16,001** |

## Table 14-4 Mitigation Option 4 Costs

| | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Option A - Western Floodway | Highway Culvert Upgrade* | $120,000 | $1,800 |
| | Railway Culvert Upgrade** | $240,000 | $3,600 |
| | Culverts under Wills St | $42,918 | $644 |
| | Williams Road Levee | $42,535 | $638 |
| | Drainage System - One Way Valve | $5,000 | $250 |
| | Western Levee | $391,104 | $5,867 |
| | Western Levee Drain | $40,945 | $614 |
| | Low flow pipe through Levee | $2,500 | $38 |
| | Vegetation Works*** | $178,000 | $10,000 |
| | **Compensation/Land Easement Costs - TBC******** | | |
| | **Sub-total 'A'** | $1,063,002 | |
| | 'A' x Engineering Fee @ 15% | $159,450 | |
| | **Sub-total 'B'** | $1,222,452 | |
| | 'B' x Administration Fee @ 9% | $110,021 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | |
| | **Sub-total 'C'** | $1,332,473 | |
| | 'A' x Contingencies @ 30% | $318,901 | |
| | **FORECAST EXPENDITURE** | **$1,651,373** | **$23,450** |

*** Indicative cost provided by Vicroads**
**** Indicative cost provided by VicTrack**
***** Estimate of maintenance cost to to be confirmed by Council/CMA**
****** Estimate to be provided by Council/CMA**

# APPENDIX C COSTINGS OF REVISED MITIGATION OPTIONS

## Table 14-5 Option A Costing – Western Floodway

| | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Option A - Western Floodway | Highway Culvert Upgrade* | $120,000 | $1,800 |
| | Railway Culvert Upgrade** | $240,000 | $3,600 |
| | Culverts under Wills St | $42,918 | $644 |
| | Williams Road Levee | $42,535 | $638 |
| | Drainage System - One Way Valve | $5,000 | $250 |
| | Western Levee | $391,104 | $5,867 |
| | Western Levee Drain | $40,945 | $614 |
| | Low flow pipe through Levee | $2,500 | $38 |
| | Vegetation Works*** | $178,000 | $10,000 |
| | **Compensation/Land Easement Costs - TBC******** | | |
| | **Sub-total 'A'** | $1,063,002 | |
| | 'A' x Engineering Fee @ 15% | $159,450 | |
| | **Sub-total 'B'** | $1,222,452 | |
| | 'B' x Administration Fee @ 9% | $110,021 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | |
| | **Sub-total 'C'** | $1,332,473 | |
| | 'A' x Contingencies @ 30% | $318,901 | |
| | **FORECAST EXPENDITURE** | **$1,651,373** | **$23,450** |

*** Indicative cost provided by Vicroads**
**** Indicative cost provided by VicTrack**
***** Estimate of maintenance cost to to be confirmed by Council/CMA**
****** Estimate to be provided by Council/CMA**

## Table 14-6 Option B Costing – Belfast Road Levee

| Status | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Option B - Belfast Rd Levee | Belfast Road Levee | $127,251 | $1,909 |
| | Williams Road Levee | $42,535 | $638 |
| | Landrigans Road Culvert Upgrade | $44,890 | $673 |
| | Main Drain Culvert & Headwall Construction | $10,421 | $156 |
| | Belfast Road Drain Enlarging Works | $17,197 | $258 |
| | Drainage System - One Way Valves | $17,500 | $875 |
| | Vegetation Works** | $178,000 | $5,000 |
| | Ring Levee Belfast/Landrigans Rd | $40,000 | $600 |
| | **Compensation/Land Easement Costs - TBC*** | | |
| | **Sub-total 'A'** | $477,794 | |
| | 'A' x Engineering Fee @ 15% | $71,669 | |
| | **Sub-total 'B'** | $549,463 | |
| | 'B' x Administration Fee @ 9% | $49,452 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | |
| | **Sub-total 'C'** | $598,914 | |
| | 'A' x Contingencies @ 30% | $143,338 | |
| | **FORECAST EXPENDITURE** | **$742,252** | **$10,109** |

*** Estimate to be provided by Council/CMA**
**** Estimate of maintenance cost to to be confirmed by Council/CMA**

## Table 14-7 Option C Costing – Pyrenees Highway Bridge Replacement

| Status | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Option C - Bridge Replacement | Bridge Replacement (approximate estimate by VicRoads)* | $7,100,000 | |
| | **Sub-total 'A'** | $7,100,000 | |
| | 'A' x Engineering Fee @ 15% | $0 | |
| | **Sub-total 'B'** | $7,100,000 | |
| | 'B' x Administration Fee @ 9% | $0 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | |
| | **Sub-total 'C'** | $7,100,000 | |
| | 'A' x Contingencies @ 30% | $0 | |
| | **FORECAST EXPENDITURE** | **$7,100,000** | **$0** |

*** Concept estimate provided by VicRoads**

### Table 14-8 Option D Costing – Highway Alignment

| Status | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Option D - Strategic Levee (Highway Alignment) | Strategic Levee - Highway Alignment | $102,298 | $1,534 |
| | Headwalls (x4) and drop boards across Chapel and Camp St | $14,180 | $213 |
| | **Compensation/Land Easement Costs - TBC*** | | |
| | **Sub-total 'A'** | $116,478 | |
| | 'A' x Engineering Fee @ 15% | $17,472 | |
| | **Sub-total 'B'** | $133,950 | |
| | 'B' x Administration Fee @ 9% | $12,056 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | - |
| | **Sub-total 'C'** | $146,006 | |
| | 'A' x Contingencies @ 30% | $34,943 | |
| | **FORECAST EXPENDITURE** | **$180,949** | **$1,747** |

*** Estimate to be provided by Council/CMA**

### Table 14-9 Option D Costing – Escarpment Alignment

| Status | Works Description | Estimated Construction Cost | Estimated Annual Maintenance Cost |
|---|---|---|---|
| Option D - Strategic Levee (Escarpment Alignment) | Strategic Levee - Escarpment Alignment | $234,364 | $3,515 |
| | Headwalls (x4) and drop boards across Chapel and Camp St | $24,580 | $369 |
| | **Compensation/Land Easement Costs - TBC*** | | |
| | **Sub-total 'A'** | $258,944 | |
| | 'A' x Engineering Fee @ 15% | $38,842 | |
| | **Sub-total 'B'** | $297,785 | |
| | 'B' x Administration Fee @ 9% | $26,801 | |
| | *(Land Acq only)* 'B' x Administration Fee @ 1% | - | - |
| | **Sub-total 'C'** | $324,586 | |
| | 'A' x Contingencies @ 30% | $77,683 | |
| | **FORECAST EXPENDITURE** | **$402,269** | **$3,884** |

*** Estimate to be provided by Council/CMA**

# APPENDIX D DAMAGE ASSESSMENT METHODOLOGY

Two primary sources for flood damage calculations were used, the original ANUFLOOD cost curves (CRES 1992) and the RAM methodology (Reed Sturgess and Associates (RSA) 2000). Further details on the ANUFLOOD methodology are provided in a guidance report produced by DNR (2002). ANUFLOOD cost curves cover residential and commercial direct costs applicable for townships. The RAM methodology incorporates the ANUFLOOD approach and extends it to include indirect and intangible costs resulting from flooding and provides guidance on costs for agricultural enterprises. A major study of the Economics of Natural Disasters in Australia by the Bureau of Transport Economics (BTE 2001) provides some further information on indirect costs and a recent study by Geoscience Australia (Middelmann-Fernandes 2010) provides information for accounting for the impact of velocity in flood damage assessments. These key references are described below.


- Bureau of Transport Economics (2001). Economic Costs of Natural Disasters in Australia. Report 103. Bureau of Transport Economics, Canberra.
- CRES (1992). ANUFLOOD : A field guide, prepared by D.I. Smith and M.A. Greenaway, Centre for Resource and Environmental Studies, ANU, Canberra.
- Department of Natural Resources and Mines (DNR) (2002). Guidance on assessment of Tangible Flood Damages. Queensland Department of Natural Resources and Mines, September 2002.
- Middelmann-Fernandes, M.H. (2010). Flood damage estimation beyond stage-damage functions: an Australian example. *Journal of Flood Risk Management* 3 (2010): 88-96.
- Reed Sturgess and Associates (2000). Rapid Appraisal Method (RAM) for floodplain management. May 2000. Report prepared for the Department of Natural Resources and Environment.


Before any stage damage curves from the literature were applied in the Creswick flood damage assessment they were adjusted to today's value by scaling using a ratio of today's CPI and the CPI at the time of development of the stage-damage curve. A number of stage damage curves are included below, representing the value at the time of development (i.e. no CPI adjustment).

This appendix does not include a detailed methodology of how the damage assessment was carried out but does include the majority of the source data sets that were used in the development of the methodology.

**Table C1 Above floor level stage damage relationships for residential properties (from ANUFLOOD 1992; reproduced from DNR 2002)**

| | | Small house (< 80 m2) | Medium house ( 80 – 140m2) | Large house (> 140m2) |
|---|---|---|---|---|
| Depth over flood level | 0 m | $905 | $2 557 | $5 873 |
| | 0.1 m | $1 881 | $5 115 | $11 743 |
| | 0.6 m | $7 370 | $13 979 | $25 351 |
| | 1.5 m | $17 379 | $18 585 | $32 276 |
| | 1.8 m | $17 643 | $18 868 | $32 768 |

**Table C2 Size categories for commercial properties (from ANUFLOOD 1992; reproduced from DNR 2002)**

| Size category | Guideline |
|---|---|
| **Small** | < 186 m2 |
| **Medium** | 186 – 650 m2 |
| **Large** | 650 m2 |

**Table C3 ANUFLOOD Commercial properties cost curve (reproduced from DNR 2002)**

| | Small commercial properties (<186m$^2$) | | | | | Medium commercial properties (186-650m$^2$) | | | | | Large commercial properties (>650m$^2$)* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value class | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| 0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| 0.25 | $2 202 | $4 405 | $8 809 | $17 618 | $35 237 | $6 975 | $13 948 | $27 896 | $55 791 | $111 583 | $7 | $15 | $32 | $61 | $122 |
| 0.75 | $5 506 | $11 011 | $22 023 | $44 046 | $88 092 | $16 884 | $33 768 | $67 537 | $135 074 | $270 147 | $39 | $78 | $154 | $308 | $619 |
| 1.25 | $8 258 | $16 518 | $33 034 | $66 069 | $132 137 | $25 693 | $51 387 | $102 773 | $205 574 | $411 094 | $81 | $162 | $326 | $649 | $1297Ł |
| 1.75 | $9 176 | $18 352 | $36 705 | $73 410 | $146 819 | $28 445 | $56 893 | $113 785 | $227 570 | $455 140 | $132 | $267 | $533 | $1065 | $2129 |
| 2 | $9 726 | $19 454 | $38 907 | $77 814 | $155 628 | $30 281 | $60 564 | $121 126 | $242 252 | $484 504 | $159 | $318 | $636 | $1 272 | $2 545 |

* units of $/m$^2$

**Table C4 External / below floor damage per building (from DPIE Floodplain Management in Australia (1992))**

| Depth above ground (m) | External Damage ($) |
|---|---|
| 0 | 0 |
| 0.065 | 0 |
| 0.26 | $1 833 |
| 0.5 | $4 000 |
| 0.75 | $6 166 |
| 1 | $8 333 |
| 2 | $8 333 |

**Table C5 Unit damages for roads and bridges (per kilometre of road inundated) (From DNR 2002)**

| | Initial road repair ($) | Subsequent accelerated deterioration of roads ($) | Initial bridge report and subsequent increased maintenance ($) | Total cost to be applied per km of road inundated ($) |
|---|---|---|---|---|
| Major sealed road | 34, 860 | 17 430 | 11 985 | 64 275 |
| Minor sealed road | 10 895 | 5 450 | 3 815 | 20 160 |
| Unsealed road | 4 900 | 2 450 | 1 740 | 9 090 |

**Table C6 Actual to Potential Damages Ratio from RAM (RSA 2002)**

| | Actual to Potential Damages Ratio | |
|---|---|---|
| Warning time (hrs) | Past Flood Experience | No Flood Experience |
| 0 | 0.8 | 0.9 |
| 2 | 0.8 | 0.8 |
| 7 | 0.6 | 0.8 |
| 12 | 0.4 | 0.8 |
| 12 | 0.4 | 0.7 |
| 96 | 0.4 | 0.7 |

**Table C7 Indirect costs following BTE (1999)**

| Indirect damages | Cost ($) | Note |
|---|---|---|
| Clean-up costs per Residential property | | |
| -cost of materials | $330 | |
| -cost of labour (40 hours) | $1,102 | This is the 2007 avg weekly wage from ABS |
| Clean-up costs per Commercial property | | |
| -total cost to clean up | $2,400 | |
| Alternative Housing per Residential property | | |
| -relocation of household items | $53 | |
| -alternative accommodation | $473 | Based on 2.6 ppl per household & 7 nights |
| Emergency Response Costs | | |
| -cost of labour | $4,000 - $20,000 | Different magnitude events require different responses |

# APPENDIX E FLOOD WARNING REPORT

# 1. FLOOD WARNING SYSTEMS

## 1.1 Aim and Function

Put simply, flood warning systems provide a means of gathering information about impending floods, communicating that information to those who need it (those at risk) and facilitating an effective and timely response. Thus flood warning systems aim to enable and persuade people and organisations to take action to increase personal safety and reduce the damage caused by flooding[15]. Effective flood warning systems maximise the opportunity for the implementation of public and private response strategies aimed at enhancing the safety of life and property and reducing avoidable flood damage.

It is essential that flood warning systems consider not only the production of accurate and timely forecasts / alerts but also the efficient dissemination of those forecasts / alerts to response agencies and threatened communities in a manner and in words that elicit appropriate responses based on well-developed mechanisms that maintain flood awareness. Thus, equally important to the development of flood warning mechanisms is the need for quality, robust flood awareness (education) programs to ensure communities are capable of response.

## 1.2 Limitations of Flood Warning Systems

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

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

It is not surprising, given the above, that flood warning systems often work imperfectly and have, on occasions, failed. Indeed, as Handmer[16] points out, "*flood warnings often don't work well and too frequently fail completely – and this despite great effort by the responsible authorities*." While in some cases the problem is the result of a physical mechanical or technical failure (for example of gauges or telemetry or of communications equipment during a flood event), or perhaps in defining what constitutes success (or failure), the more common reason is that the systems have not been properly conceptualised at the design stage and in terms of their operation, despite the considerable and conscientious efforts of those involved. All too often, too little attention has been paid to issues of risk communication. In particular:

- To building a local awareness of flood risk along with knowledge of what can be done to minimise that risk;
- Determining what information is required by the at-risk community and with what lead times;

[15] 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).

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

- How warnings and required information will be distributed to and within the target communities;
- Ensuring that recipients of warning messages understand what the message is telling them and what it means for their property and individual circumstances in terms of the damage reducing actions they need to take.

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

In numerous cases where flood warning systems have been developed, the bulk of the effort has been devoted to creating and strengthening data collection networks, devising and upgrading forecasting tools and facilities and utilising new dissemination technologies to distribute the forecast to at-risk communities. While all these things are important, they are never sufficient by themselves to ensure that flood warnings are heeded by those who receive them. Other equally vital elements of the system such as risk communication and the comprehension that people have of the flood problems they may face (and the value that warnings can offer) need at least as much attention at the design stage and in system operation. The lesson from many studies of flood warning systems (e.g. Smith and Handmer (1986)[17]; Phillips (1998)[18]; Handmer (1997)[19], (2000)[20], (2001)[21], (2002)[22]; Comrie, (2011)[23] is that the status of all elements of the system must be given appropriate resourcing if the system is to be made capable of functioning effectively.

Studies of flood warning system failures (e.g. Brisbane in 1974, Charleville and Nyngan in 1990, Benalla in 1993, Canada in 1997, England in 1998, Kempsey and Grafton in 2001, New Zealand in 2005) suggest that the most common reasons for poor system performance are that those in the path of floods, whether emergency responders, householders, the owners of businesses or the operators of infrastructural assets, have either not understood the significance of the warnings they have received or have not known that there were things (or the most appropriate things) they could do to mitigate the effects of flooding. The result has all too often been unnecessary loss of private belongings and commercial and industrial plant, stock and records (for example, through late or non-existent responses) and / or unnecessary risk to life (for example, due to evacuation after it became dangerous rather than when it was relatively safe). Most studies report that warnings were of an adequate technical standard (that is, they were accurate and delivered with good lead times), but the information was poorly communicated and not understood by the target communities. As reported by Anderson-Berry[24] and Soste & Glass[25] , there is often insufficient attention to ensuring that people in flood liable areas understand the flood gauge or forecast heights which are incorporated in warning messages. The result is that those who have been warned fail to appreciate that the

[17] Smith, D.I. and Handmer, J.W. (eds) (1986): *Flood Warning in Australia: Policies, Institutions and Technology*. Centre for Resources and Environmental Studies, Australian National University, Canberra.

[18] Phillips, T.P. (1998): *Review of Easter Floods 1998: Final Report of the Independent Review Team to the Board of the Environment Agency: Volume 1.*

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

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

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

[22] 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.

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

[24] Anderson-Berry, L. (2002): *Flood Loss and the Community*. In: Smith, D.I & Handmer, J. (Eds), *Residential Flood Insurance. The Implications for Floodplain Management Policy*. Water Research Foundation of Australia, Canberra

[25] Soste, L. and Glass, J. (1996): *Facilitating an Appropriate Response to Flood Warnings: A Community Based Flood Awareness Program*. In Proceedings of NDR96 Conference on Natural Disaster Reduction, Gold Coast

information contained in the message has meaning for their own circumstances. Consequently, they fail to take appropriate or adequate protective measures. Such people often claim afterwards that they received no flood warnings. In many cases warnings were issued but the gap between the information provided and what was understood by those at risk was too large. The problem is one of poor communication.

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

## 1.3 The Total Flood Warning System Concept

In 1995 the Australian Emergency Management Institute, following a national review of flood warning practices after disastrous flooding in the eastern states in 1990, published a best-practice manual entitled '*Flood Warning: an Australian Guide*'[26]. In describing practices for the design, implementation and operation of flood warning systems in Australia, the manual introduced the concept of the 'total flood warning system' (TFWS). It also re-focused attention on flood warning as an effective and credible flood mitigation measure but made it clear that successful system implementation required the development of some elements that hitherto had been given little attention as well as the striking of an appropriate balance between each of the elements. In particular, it was noted that more attention needed to be given to risk communication and the education of communities about the flood risk, the measures that people could take to alleviate the problems that flooding causes and the place of warnings in triggering appropriate actions and behaviours. It also clearly enunciated the need for several agencies to play a part, with clearly-defined roles and with the various elements carefully integrated, and for the members of flood liable communities to be involved. Put another way, "*effective warning systems rely on the close cooperation and coordination of a range of agencies, organisations and the community*"[27] .

While the original manual has been updated and republished as Manual 21 of the Australian Emergency Manuals Series[28], 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)[29].

## 1.4 Total Flood Warning System Building Blocks

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

[26] Australian Emergency Management Institute (AEMI) (1995): *Flood Warning: An Australian Guide*.

[27] 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.

[28] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

[29] 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.

An effective flood warning system is made up of several building blocks. Each building block represents an element of the Total Flood Warning System. The blocks (derived from EMA, 2009[30]) along with the basic tools to facilitate delivery against each of the TFWS elements are presented in Table 3-1.

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

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

# 2. THE TASK FOR CARISBROOK

## 2.1 Introduction

Carisbrook is situated in the Loddon catchment at the confluence of McCallum and Tullaroop creeks. The combined area of the upstream catchments is approximately 1,240km$^2$ with the McCallum Creek catchment a little over half the size of Tullaroop Creek catchment at around 435km$^2$. Both creeks and their many small tributaries rise in the general vicinity of Ballarat and flow to the north.

Tullaroop Reservoir is located on Tullaroop Creek approximately 7km south-east (upstream) of Carisbrook and downstream from Clunes. The catchment area to the reservoir is approximately 743 km$^2$ and comprises the upper Tullaroop Creek and its tributaries including the catchments of Newlyn Reservoir and Hepburns Lagoon. The reservoir has a capacity of just under 73GL. It has limited ability to mitigate flood flows, especially when at or near full supply level, but does attenuate peak flows. For example, in the January 2011 event with the reservoir spilling, the peak outflow was around 45% lower than the peak inflow.

Flooding in Carisbrook can be caused by overland flooding from the local catchment between Carisbrook and Maryborough, as well as by riverine flooding from Tullaroop Creek and / or McCallum Creek. The area upstream of Carisbrook is relatively slow to react to rain until it wets up. McCallum Creek is the dominant contributor to flooding at Carisbrook despite having the smaller catchment. Response times are short on a wet catchment: of the order of 9 hours for McCallum Creek, a few hours longer for Tullaroop Creek and several hours less for the local tributaries and overland flows. This places Carisbrook in the flash flood category. These and related matters are discussed in Section 4 of this report.

The Bureau of Meteorology (BoM) collects and records rainfall at a number of locations within or close to the McCallum and Tullaroop creek catchments. Data from a number of these sites are available from the BoM website at intervals ranging from around 30 minutes to daily. **Daily-read rainfall data** is available from the BoM website for five sites near to Carisbrook: Bet Bet, Cairn Curran, Clunes, Dunolly and Maryborough. Similar data is available from Avoca and Archdale to the west and north and from Daylesford, Vaughan and Yandoit to the east. The BoM also operates a number of **AWS'** in the general vicinity: at Ballarat on the southern side of the Divide in the upper Leigh River catchment and further to the west at Ben Nevis at the top end of the Wimmera

[30] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

catchment near Mt Cole. **Synoptic stations** are operated by the BoM at Castlemaine and Maryborough. An **event reporting radio telemetry (ERTS) rainfall station** is located at Mt Hope in the upper parts of the Werribee catchment. Central Highlands Water also operates a number of rain gauges in the general vicinity.

**Stream flow data** is available from the BoM website for the following sites upstream of Carisbrook:

- Tullaroop Creek at Clunes (407222);
- McCallum Creek at Carisbrook (407213);
- The head gauge at Tullaroop Reservoir on Tullaroop Creek (407244); and
- The Tullaroop Reservoir outlet (407248).

Data from the **rain gauge** at the Tullaroop Creek at Clunes site, the Bet Bet Creek at Bet Bet site and a number of other stream flow gauging sites further to the east are also available from the BoM website.

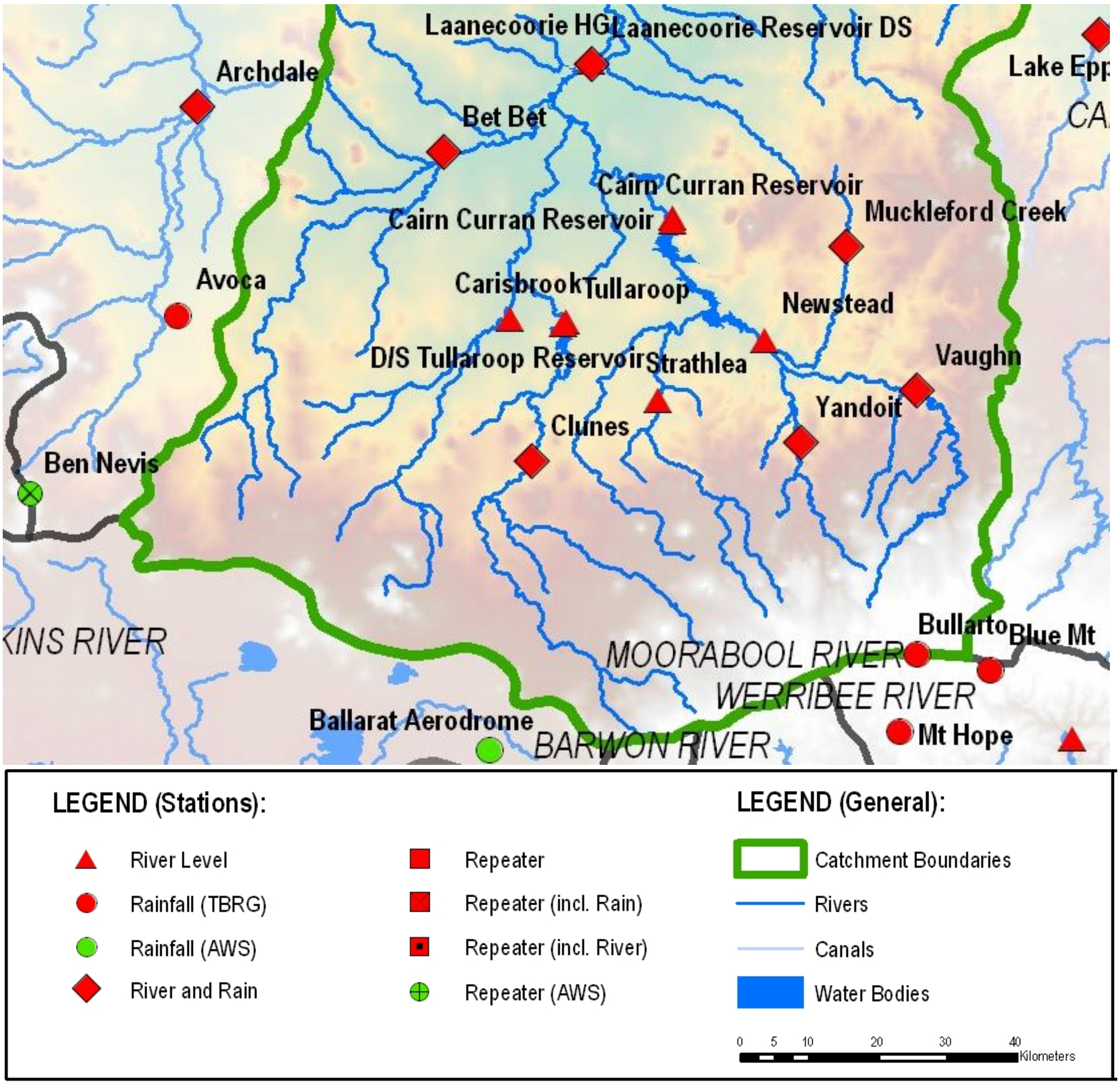


**Figure 2-1 Existing flood warning data collection network in the vicinity of Carisbrook**

It is understood that planning for the installation of telemetry equipment and a rain gauge at the Bet Bet Creek at Norwood site (407220) is well advanced and that the rain and river data will be available from the BoM's website soon after the equipment is fully operational. It is further understood that

DSE, as part of the Victorian Government's response to the 2010-2011 floods, is considering the installation of a telemetered rain gauge at the top end of the McCallum Creek catchment but that a location has not yet been determined.

It should be noted that Creswick and Clunes (Tullaroop Creek catchment) are also subject to flash flooding. Neither location is covered by formal flood warning systems and the rain and river data collection network in the area is sparse. A data collection network to support a flash flood warning system for Carisbrook may benefit from the development of possible future flood warning systems for Creswick and Clunes. It is therefore strongly suggested that opportunities to provide flood warning services for these locations along with the benefits that would accrue are considered when developing the case for capital and recurrent expenditures (the benefits and costs) associated with the development of a fully functional flash flood warning system for Carisbrook.

Attention will need to be given to each of the TFWS building block if an effective flash flood warning system is to be established for Carisbrook. Developing or augmenting the existing data collection network will not be sufficient. The following section outlines how each of the TFWS elements could be addressed in order to implement a fully functional, effective and sustainable flash flood warning system. An integrated and complete system is proposed in Section 4 of this Appendix. A staged approach to implementation of the proposed response to each TFWS element, aimed at achieving balanced TFWS growth along with early and best benefit as quickly as possible, is presented in Section 5 of this Appendix.

## 2.2 Data Collection, Collation and Flood Detection and Prediction

### 2.2.1 Introduction

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

### 2.2.2 Possible Additional Data Collection Sites

There is one telemetered rain gauge within the catchment upstream of Carisbrook providing data at a time scale suitable for flood warning purposes (Clunes) plus a further four in the general vicinity (Ben Nevi, Ballarat, Mt Hope and Bet Bet). The planned installation at Norwood and the proposed installation in the upper parts of the McCallum Creek catchment will add two additional rain gauges in the general vicinity.

Taken together, the six assured rain gauges provide reasonable spatial and temporal coverage of rainfall at what is probably an acceptable density given the topography and likely flood producing weather mechanisms and conditions. However, based on consideration of the range of prevailing rain producing weather conditions and flooding mechanisms there is an argument for improved coverage in the upper parts of the McCallum Creek catchment and in the general Maryborough – Carisbrook area. While the Ballarat AWS provides a reasonably good indication of rainfall depths across the top of the Tullaroop Creek catchment (even though it is on the southern side of the Divide) it does not provide a similar indication for the McCallum Creek catchment. Further, while the Ben Nevis AWS will provide some indication of rainfall across the upper parts of the McCallum Creek catchment there are likely to be circumstances under which it will not indicate rainfall depths sufficiently. A rain gauge in the upper part of the McCallum Creek catchment would address these deficiencies. Further, while there is a BoM synoptic station at Maryborough (reporting daily at 9am and 3pm), it does not provide rainfall data at a time scale suitable for the timely determination of likely flooding at Carisbrook caused by overland flows from the hills and local catchments to the south west of the town. A rain gauge near or between Maryborough and Carisbrook would assist.

The two stream gauges already in place within the catchment (McCallum Creek at Carisbrook and Tullaroop Creek at Clunes) together with the Tullaroop Reservoir head gauge, provide some indication of flows likely to be observed at Carisbrook. It is suggested that telemetering the existing stream gauge sites at Creswick Creek at Clunes (407214) and Birch Creek at Smeaton (406227) would assist earlier determination of likely spill from Tullaroop Reservoir and of possible flooding at Carisbrook. They would also have the added benefit of assisting recognition of likely flooding at Creswick and Clunes although it is acknowledged that flood warning requirements for these two towns have not yet been assessed.

The cost of adding a rain gauge to a stream gauging site is not prohibitive. It is therefore suggested that while exposure may not be ideal, upgrade of the existing Creswick Creek at Clunes (407214) and Birch Creek at Smeaton (406227) installations should include a rain gauge.

In addition to the above, it is suggested that Tullaroop Creek should be instrumented at Carisbrook, on the upstream side of the Pyrenees Highway Bridge. This will assist confirmation of the flood inundation maps and associated flood impacts during future riverine floods and assist in the development of a more robust flood prediction tool than the indicative quick look 'flood / no-flood' tool included as an Appendix in the Central Goldfields Municipal Flood Emergency Plan (MFEP). It will also enable local confirmation of creek rises and developing flood conditions.

If all the installations identified above were completed, there would be a minimum of ten (10) rain gauges and six (6) stream gauges available to inform flood forecasting and warning activities at Carisbrook.

Note that it is suggested that the existing rain gauges together with the proposed additional rain gauges will provide a sufficient indication of rainfall across the catchment to enable the indicative quick look 'flood / no-flood' tool developed for Carisbrook (refer to the Central Goldfields MFEP) to be used with good lead time to provide an initial heads-up of the likelihood and scale of possible flooding. Creek levels at the Tullaroop Creek at Carisbrook site and the Tullaroop Reservoir level together with flow and level conditions at the proposed site on the upstream side of the Pyrenees Highway in Carisbrook would provide confirmation of the likely scale and timing of flooding.

### 2.2.3 Turn-Key Data Collection & Alerting Systems

***Introduction***

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

***Greenspan***

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

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

- Sipan Sihaporas Hydro Electric Power Scheme in Indonesia;
- San Roque Dam and Hydro Power Scheme in the Philippines;
- SMART (Stormwater Management and Road Tunnel) in Kuala Lumpur in Malaysia;

- Public protection system for the Bruce Highway at Proserpine for Queensland Main Roads;
- Flash flood warning system for Warringah Mall in Brookevale in NSW.

Capital and operating costs are not available "off-the-shelf" but are generally more expensive than the loggers and other equipment already installed in the Loddon catchment. The technology being used however offers increased functionality.

### 2.2.4 Other Automated Data Collection and Alerting Systems

***Introduction***

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

***Campbell Data Logger***

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

***Other Data Loggers***

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

***Event-Reporting Radio Telemetry System***

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

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

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

The SMS alert provides a 'heads up' to a possible flash flood event. It is aimed at flagging the need for people to more closely monitor rainfall and other flood indicators (e.g. continuing heavy rain and other local indicators of a developing flood, radar imagery and rainfall data available from the BoM's website, etc.), and at enabling early activation of flood response and related plans in order to minimise the risk to life and property. For Carisbrook, the 'heads up' would also provide the trigger to use the indicative quick look 'flood / no-flood' tool developed for Carisbrook and included as an Appendix in the Central Goldfields MFEP.

A more detailed explanation of ERTS systems and their benefits when used in flash flood situations is provided by Wright[31].

### 2.2.5 Manual Data Collection and Alerting

Recognising that funding may not be available (either now or into the future) to purchase, install and maintain an automated data collection, collation and flood detection system, a simple and cheap alternative is outlined herein.

The simplest data collection network would comprise the existing telemetered data sites (i.e. the AWS' at Ballarat and Ben Nevis, the telemetered rain gauges at Clunes, Bet Bet, Norwood and Mt Hope) and the telemetered water level sites at Clunes, Tullaroop Reservoir and Carisbrook) plus additional manually read rain gauges and staff gauges. Data from all existing telemetered sites are available in near real-time from the BoM's website.

In order to fill the gaps in rainfall information in the upper part of McCallum Creek and between Carisbrook and Maryborough, a local person could be supplied with a rain gauge and recruited to provide readings to a nominated person at short time intervals during heavy or prolonged rain events. Specific locations for these readers have not been determined as it is suggested that the owners of existing private rain gauges within these general areas may be willing to take on this task.

A marginally more developed data collection network would include an additional water level site immediately upstream of the Pyrenees Highway Bridge in Carisbrook. The site would comprise a set of staff gauges set either to AHD (refer to discussion on page 56 of the Comrie Review Report[32]) or to a local datum with the correction to AHD determined as part of installation. This would enable the flood extent and depth maps delivered by the Carisbrook Flood and Drainage Study to be used to inform future flood response activities.

Local residents would need to be instructed on how to read the gauges so as to avoid possible confusion over water levels. In addition, a person (or group – see Sections 2.5.4 & 2.5.5 regarding the establishment of a community flash flood action group or similar and their role) would need to be nominated to read the gauges during heavy rain / high flow events.

It should be noted that even if an automated data collection system is established at the Pyrenees Highway Bridge, staff gauges will still need to be installed at the site.

[31] Wright, C.J. (1994): *Advances in Flash Flood Warning in South Australia.* Paper presented at Water Down Under '94, 25th Congress of the International Association of Hydrogeologists with the International Hydrology and Water Resources Symposium, Adelaide, 21- -25 November 1994.

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

## 2.3 Flood Detection & Prediction

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

It is necessary to know the levels at which floods begin to impact on the community in order to establish an effective flood warning system. In effect, to ensure that flood warnings are only provided when the consequences of flooding within an at-risk community are sufficient to warrant a warning and the coordinated mobilisation of resources to affect an appropriate response. Flood class levels, determined against standard definitions[33] are used to establish a degree of consistency in the categorisation of floods. Using the flood intelligence and inundation maps generated by the Carisbrook Flood and Drainage Study, preliminary flood class levels are proposed for Tullaroop Creek / Deep Creek immediately upstream of the Pyrenees Highway Bridge at Carisbrook as follows:

- Minor flood level 190,700 m AHD
- Moderate flood level 192.200 m AHD
- Major flood level 193.000 m AHD

There are currently no flood warning systems or arrangements in place for the McCallum Creek and Tullaroop Creek catchments or for Carisbrook. The tool provided in an Appendix to the Central Goldfields MFEP does however provide some guidance on the likelihood and severity of flooding at Carisbrook. Rainfall in the upper parts of the catchment and from the general vicinity of Carisbrook is used to indicate the likelihood and severity of flooding from McCallum and Tullaroop creeks and /or the local catchments to the south west of town.

It is suggested that a rainfall – runoff model that makes use of data telemetered from each of the existing and proposed data collection sites would provide a timely and best available flood prediction for Carisbrook. While the BoM is best positioned, as the agency responsible for the monitoring of situations likely to lead to flooding and for the prediction of floods throughout rural and provincial Victoria, to develop the model and to run it in the lead up to and during flood events, the flash flooding nature of the catchment to Carisbrook mitigates against this[34]. If a responsible entity could be found to develop, run and maintain a forecast model, the RORB model developed as part of the Carisbrook Flood and Drainage Study or the BoM's URBS model currently fitted to the Loddon catchment to Laanecoorie, may provide a good starting point for development and refinement. Alternatively, a peak height / flow correlation could be developed from Tullaroop Reservoir head gauge and the McCallum Creek at Carisbrook gauge to the proposed Deep Creek at Carisbrook river site.

As a first step and in the absence of identification of a responsible entity, the gauge reader or another person within the community flash flood action group would need to be nominated to receive, access and consider rainfall and river level readings and initiate local actions in the event of trigger levels being exceeded. These trigger levels should be set by the Carisbrook community. It is suggested however that cumulative rainfall depths that indicate a possible 5-year ARI flood or larger or a river level at the Pyrenees Highway Bridge of around the 5-year ARI flood level might be a useful initial alerting level[35]. The indicative quick look 'flood / no-flood' tool located in the MFEP would provide additional guidance on the need to initiate a local response.

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

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

[35] An initial alerting level of around the 5-year ARI level is suggested because at the 5-year level there are 12 residential properties with some over-ground flooding. Further, creek levels will rise quickly if the flood is going to be higher than a 5-year event and while it is appreciated that the first floor does not get flooded until a bit below the 20-year ARI level, the initial alert is aimed at providing the community with good lead time of possible flooding. As a minimum this will enable the mobilisation of local resources for sandbagging

## 2.4 Interpretation

The flood inundation maps and Central Goldfields MFEP Appendices developed as part of the Carisbrook Flood and Drainage 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 Appendices of the MFEP would need to be readily available to the Carisbrook community.

## 2.5 Message Construction and Dissemination

### 2.5.1 Available Alerting and Notification Tools and Technologies

According to Rogers and Sorensen[36], warning people of impending danger encompasses two conceptually distinct aspects—alerting and notification. Alerting deals with the ability of emergency officials to make people aware of an imminent hazard. Alerting frequently involves the technical ability to break routine acoustic environments to cue people to seek additional information. In contrast, notification focuses on how people interpret the warning message. It is the process by which people are provided with a warning message and information.

There are a number of alerting and notification tools and technologies available, some of which both alert and notify. Molino et al[37] provide a summary worth considering in the context of Carisbrook and flash flooding. Only those that can very quickly provide property owners and occupiers with an alert or notification have been considered herein due to the relatively quick response time associated with flooding at Carisbrook.

A summary of available tools / technologies and their applicability to the Carisbrook area is provided below.

- Those that alert only:
  - Sirens / alarms – do not alert those who live outside the immediate area and there may be some confusion with the Country Fire Authority siren currently in use.
  - Aircraft – impractical due to time, weather and noise limitations.
  - Modulating electrical supply voltage – frequent false alarms.
  - Modulating electrical supply frequency (e.g. NZ MeerKat system) – unlikely to be cost effective.
  - Coded visual signals (cf. fire danger signs) – not practical due to rapid onset of flooding and access issues during large floods.
  - Laser lights – health risks and high potential for theft of equipment.
- Those that alert and notify:
  - Personal notification – a fast response would be required due to the rapid onset of flooding and possible access issues.
  - Fixed and mobile public address systems – only serves immediate area.
  - Tone alert radios – not cost effective for a small area.
  - Dial-out systems and related technologies – worth considering.
  - Enhanced dial-out system – similar to above but more expensive and reliant on local power supply.

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and other activities. The suggested initial alert level is around the 5-year ARI level. The initial alert level to be used should be established in consultation with the Carisbrook community.

[36] Rogers G. & Sorensen J. (1988): *Diffusion of Emergency Warning—Comparing Empirical and Simulation Results.* Society for Risk Analysis Meeting 1988 Washington DC Paper, October 1988

[37] Molino, S., Begg, G., Stewart, L. Opper, S. (2002): *Bells and whistles, belts and braces – designing an integrated flood warning system for the Hawkesbury-Nepean Valley (Parts 1 & 2).* Australian Journal of Emergency Management, Emergency Management Australia, Vol 17.

 - Paging and mobile phones – potential if local community is flood aware.
- Those that provide notification only:
 - Mass media (radio, television) - already used, for example ABC radio (1026AM and 774AM).
 - Internet – BoM website displays warnings[38] and data from local rain and river sites[39].
 - FM-88 with community awareness program – per capita cost would be high for Carisbrook.

From the above it can be seen that while some information about flooding is available to the community through the internet there is need to, as a minimum, alert the Carisbrook community in a timely manner to the likely on-set of flooding and to then back this up with information about likely consequences.

The need to alert the community to flooding is not restricted to Carisbrook. Where time permits, the community alerting task is often achieved via local radio announcements. Active alerting is usually only undertaken occasionally and generally involves door knocking although in NSW the SES has employed loud-hailers to make street announcements. In rapidly responding areas (i.e. areas subject to flash flooding) in South Australia and Queensland, the BoM alerts and notifies selected stakeholder agency staff using an SMS message generated by Enviromon or through a system provided by StreetData. Within Victoria, many of the Councils involved in flood warning system upgrades in recent years and that utilise ERTS equipment have implemented Premier Global Services' Xpedite VoiceREACH system to alert and notify residents and property owners in flood-prone urban areas. Melbourne Water are piloting an in-house developed SMS alerting system for residents in an area subject to flash flooding alongside Brushy Creek in the City of Maroondah which is triggered by the exceedance of rain or water level alarm criteria[40].

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

The national Emergency Alert (EA) system provides VICSES with a means of delivering short messages to selected areas. While the EA has application for all emergency situations, it is unlikely for a number of reasons to be used during smaller flood events. Nevertheless, given the short lead times available it may not be suitable to warn Carisbrook residents of possible flash flooding.

### 2.5.2 Expedite VoiceREACH

A number of Councils within Victoria have had to address the issue of how best to alert their flood–prone urban communities to the on-set of flooding. In all cases (City of Greater Shepparton for Shepparton and Mooroopna, Latrobe City for Traralgon, Strathbogie Shire for Euroa, Moira Shire for Nathalia, City of Benalla for Benalla, City of Geelong for selected areas within the Municipality and City of Maribyrnong for Maribyrnong Township) Premier Global Services' Expedite VoiceREACH system was selected to perform the alert and notify task. A number of the Municipality also secured

[38] While the Bureau does not provide a flash flood warning service for Carisbrook or other locations within the McCallum Creek and Tullaroop Creek catchments, it does issue warnings of severe storms and thunderstorms for the district, phenomena that often lead to flash flooding.

[39] Rain and water level data from AWS' and other telemetered sites are available on the BoM's website in near real-time.

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

an FM-88 licence and associated equipment in order to provide a means of distributing flood and other emergency messages more widely including to visitors, road users, etc.

VoiceREACH is simple to set up, implement, use and maintain. When flooding is likely, a message is scripted by Council staff and, following log-in (from any computer with broadband internet access) to the VoiceREACH website, is read into a file by the user. The message is confirmed via playback and either edited or accepted for transmission. On acceptance for transmission, VoiceREACH delivers the voice message almost simultaneously to all telephone numbers in the user-managed telephone number file[41] located on the VoiceREACH website.

VoiceREACH provides a message despatch report and delivers (by email to the user) a delivery success or failure report for each number in the telephone number file. This provides a template for follow-up door knocking or other personal approaches, if and as appropriate.

While not confirmed, it is understood that VoiceREACH message delivery may be able to be initiated by Enviromon through delivery of a pre-formatted voice file on triggering of a field station sensor alarm level. Enviromon has the capability. The issue is whether VoiceREACH requires real-time interaction with the user or whether it can be automated. If it can, automatic activation driven by river and rainfall alarms should be possible. This would, however, require additional configuration of the existing Enviromon software and the establishment of a base station somewhere within the Central Goldfields Shire. At this stage, it is not clear how soon or to what extent BoM would be able to assist with this.

### 2.5.3 StreetData

StreetData offers an SMS delivery service[42]. The disadvantage of StreetData is that it can only deliver an SMS message. This means that unless a telephone handset recognises SMS protocols, only mobile phone owners can receive the message[43]. Further, there is no guarantee of delivery, delivery is not necessarily immediate and there is no confirmation that the message has been received: it is essentially a “fire and forget” system.

When coupled with Enviromon, StreetData can deliver a pre-scripted SMS message to a local user-maintained list of telephone numbers on the exceedance of alarm criteria on each sensor reporting into or interrogated by the base station. The alarm system operates on filtered rather than raw data which reduces but does not eliminate the opportunity for errors.

To set up the system, alarm criteria are set for each sensor, message scripts are develop and loaded to Enviromon and a StreetData account is opened. BoM has established a streamlined procedure with StreetData that makes this last step very easy. Essentially, all that is required is a credit card with which to purchase initial credits.

Enviromon can be set up to send the message to StreetData with a single, block of or all listed telephone numbers[44]. BoM recommends however that the message is sent to StreetData for each telephone number. This reduces the risk of message loss as, if there is a failure, only single, rather than many recipients fail to receive the message.

[41] The telephone number file is established and managed by the user. Numbers can be added and deleted online.

[42] There are a number of alternative SMS message service providers. Generally, these either have a higher minimum monthly spend or are domiciled outside Australia. StreetData has a flexible credits program that accommodates low usage without imposing a high cost and is fully based in Australia.

[43] This gap could be covered if flood wardens were appointed and given the responsibility of passing on information to groups of people without a mobile phone. Robyn Betts (OESC) suggested that flood wardens could also assist other community members in interpreting messages. Lack of time coupled with liability and other issues may mitigate against the appointment of and utility of wardens.

[44] There is a limit of 250 telephone numbers per message.

Enviromon can be configured to automatically drive the alerting process. It will monitor data from each sensor at each site[45] and can drop real time data into the pre-scripted messages.

StreetData credits expire at the end of each 12-month period unless further credits are purchased in which case they roll-over for a further 12-months. StreetData send a reminder email when credits are about to expire. Costs per call reduce with the number of credits purchased.

BoM is in the process of finalising documentation for the use of StreetData with Enviromon[46].

### 2.5.4 Community Involvement

It is generally recognised that a critical issue in developing and maintaining a (flash) flood warning system is the active and continued involvement of the flood-liable community in the design and development of the total system so that their warning needs are satisfied. It is therefore suggested that Central Goldfields Shire give strong consideration to championing the formation of a community flash flood action group (or similar) and the establishment of volunteer community based flood wardens.

Members of this group (the wardens) could play a key role in local flash flood warning operations.

### 2.5.5 A Solution for Carisbrook

In order to make maximum use of currently available rain and river data, other data if and as it becomes available and the indicative quick look 'flood / no-flood' tool for Carisbrook included in the Central Goldfields MFEP, it is suggested that a local flood warden system is established at Carisbrook. The primary role of the flood wardens would be to:

- Monitor rain and river information via the BoM's website and depending on the status of the proposed data collection network, obtain / receive other rain and / or river data from local observers;
- Assess the likelihood of flooding using the quick look 'flood / no-flood' tool;
- In the event of likely flooding, call VICSES to advise of likely flooding and, subject to discussion with the Regional Duty Officer or Incident Controller, call the Central Goldfields Shire MERO; and
- Initiate flood response actions within Carisbrook consistent with the MFEP.

The wardens must however recognise that VICSES is the Control Agency for flood and must follow directions or instructions issued by the Incident Controller.

## 2.6 Response

The Central Goldfield MFEP Appendices have been populated for Carisbrook as part of the Carisbrook Flood and Drainage Study. Information in the MFEP includes all available intelligence relating to flooding in Carisbrook along with an indicative quick look 'flood / no-flood' tool based on local and upper catchment rainfall depths. Flood inundation extent and depth maps are included together with a list of properties likely to be flooded and the expected depth of that flooding at each property. A flood intelligence card has also been prepared.

[45] This enables both data and system alerts to be generated. For example, if any pre-set alert criteria were exceeded an SMS message could be sent to a Duty Officer to prompt activation of Xpedite to alert the community to potential (or actual) flooding. An SMS message could also be sent to a Duty Officer if there was no activity on a sensor over a set period, thereby assisting local monitoring of system integrity.

[46] Enviromon can accommodate other programs that initiate other actions provided that an interface is available or developed. This means that if Central Goldfields Shire wished to initiate a siren (say) on exceedance of alarm criteria, provided there was a program available to activate the siren and provided that Central Goldfields had invested in a computer to host Enviromon and that an interface had been prepared, the Enviromon alarm function could be used to sound the siren.

A critical issue for flood response at Carisbrook is the determination of whether buildings should be sandbagged / protected or emptied of items susceptible to damage from floodwater and evacuated. A secondary issue is the timely availability of sandbags and sand within the town with sufficient lead time to enable buildings at risk of flooding over-floor (see Appendix C of the MFEP) to be sandbagged. Arrangements established in conjunction with Council and VICSES should be detailed in the MFEP.

## 2.7 Community Flood Awareness

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

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

Studies repeatedly show that communities that are not aware of flood hazard are less capable of responding appropriately to flood warnings or alerts and experience a more difficult recovery than a flood-aware community. Plain language flood awareness campaigns[47] should aim to erase these misconceptions

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

- Making the MFEP publicly available (Council offices, library, website) with a summary provided in Council welcome packages for new residents and business owners and with annual rate notices;
- Championing a community flash flood action group and the establishment of volunteer community based flood wardens (or similar);
- Periodically providing feature articles to local media on previous flood events and their effects on the community;
- Installing flood markers indicating the heights of previous floodwaters (e.g. on power poles, street signs, public buildings, sides of bridges, etc.);
- Preparing and distributing property specific flood depth charts for all properties likely to be affected by flooding within Carisbrook (the data to inform the charts can be extracted from the hydraulic model developed for the Carisbrook Flood and Drainage Study);
- Installing flood depth indicators where there is appreciable danger to human life due to flood depth and / or velocity (e.g. in the dip in Simpson Street to the west of the Pyrenees Highway Bridge and at other strategic locations as indicated by the flood hazard maps delivered by the Carisbrook Flood and Drainage Study);
- Photo displays of past flood events in local venues (these could be permanent); and

[47] Such as the VICSES FloodSafe program.

- Preparing and distributing (as an on-going program) a flash flood action guide or brochure (e.g. FloodSafe brochure and as described by Crapper et al[48], in relation to Shepparton and Mooroopna) aimed specifically at encouraging local residents and businesses to take a pro-active role in preparing their property and themselves for a flood as well as describing what people need to do during a flood event. These could be given out at local events and with council rate notices and / or other council communications.

# 3. SUGGESTED SYSTEM FOR CARISBROOK

Table 3-1 provides a brief description of the basic tools needed to deliver against each TFWS building block together with an outline of possible solutions that would be applicable to Carisbrook.

[48] Crapper G., Muncaster S. and Tierney G., 2005: *Spread the Word – Community Awareness and Alerting for Shepparton and Mooroopna.* Paper presented at the 4th Victorian Flood Management Conference, Shepparton, October, 2005.

**Table 3-1 Flash Flood Warning System Building Blocks and Possible Solution for Carisbrook with due regard for the EMMV, Commonwealth-State arrangements for flood warning service provision (BoM[49], VFWCC[50] and EMA[51])**

| Flood Warning System Building Blocks | Basic Tools | Possible Solution for Carisbrook |
|---|---|---|
| DATA COLLECTION & COLLATION | Data collection network (e.g. rain and stream gauges) | INITIALLY: Install a set of staff gauges at the Pyrenees Highway Bridge at Carisbrook and nominate a person or group to collect and collate data, and to make initial assessments of the likelihood of flooding.<br>NEXT: Recruit manual rainfall readers in the vicinity of the hills facing and to the west /south west of Carisbrook and in the upper parts of the McCallum Creek catchment.<br>LATER: Using equipment similar to (or the same as) that already installed and operational at Tullaroop Creek at Clunes, establish a telemetered stream (and rain?) gauge at the Pyrenees Highway Bridge in Carisbrook, add a rain gauge to the Smeaton and Creswick Creek at Clunes gauging stations, and install a telemetered (ERTS?) rain gauge in the upper parts of the McCallum Creek catchment and to the west / south west of Carisbrook. |
| | System to convey data from field to central location and / or forecast centre (e.g. radio or phone telemetry). | |
| | Data management system to check, store, display data. | Will require BoM to add sites to data tables accessible via the BoM website. |
| | Arrangements and facilities for system / equipment maintenance and calibration. For example, the Regional Surface Water Monitoring Partnership, data QA'ing and warehousing, etc. | Commercial arrangement between Council and a service provider for maintenance. Ideally this would be through the Surface Water Monitoring Partnership as this will also ensure that all data is QA'ed and archived. Include all capitalised system components on Council's asset management register. |
| DETECTION & PREDICTION (i.e. Forecasting) | Rainfall rates and depths likely to cause flooding together with information on critical levels / effects at key and other locations. | INITIALLY: Using data from the existing rainfall network together with water levels and trends at Clunes, Tullaroop Reservoir and McCallum Creek at Carisbrook, determine the likelihood and scale of possible flooding using the tool described below.<br>LATER: In order to initiate local alerting of potential flooding, use rainfall rates and depths from the MFEP tool to set rainfall gauge alarm criteria and use creek levels from the flood inundation maps to set creek level alarm criteria. This may lead to the refinement of flood class levels at Carisbrook. |
| | Appropriately representative flood class levels at key locations plus information on critical levels / effects. | |
| | Flood forecast techniques (e.g. hydrologic rainfall - runoff model, stream flow and / or height correlations, | INITIALLY: The indicative quick look 'flood / no-flood' tool developed for Carisbrook and included in the MFEP provides guidance on the likelihood and scale of possible flooding. |

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

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

[51] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

| Flood Warning System Building Blocks | Basic Tools | Possible Solution for Carisbrook |
|---|---|---|
| | simple nomograms based on rainfall). | Council responsible for maintaining the tool.<br>Decide how this tool is to be used and who by – Council, VICSES, NCCMA, community?<br>LATER: Peak height / flow correlations and / or rainfall-runoff forecasting model developed and used to provide quantitative flood forecasts for Tullaroop Creek (Deep Creek) at Carisbrook. |
| 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 Carisbrook Flood and Drainage Study have been captured to the MFEP. The quick look tool described above together with the MFEP enable those at risk to determine whether they are likely to be flooded with some lead time. |
| MESSAGE CONSTRUCTION | Warning messages / products and message dissemination system. | Short hydrologic response time hence simple automated messaging is likely to work best. There would be a role for the Emergency Alert during a severe flood event. |
| MESSAGE DISSEMINATION (i.e. Communication and Alerting) | **Formal media channels[52] – TV, radio and print.**<br>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.<br>Flood wardens<br>Door knocking<br>Informal local message / information dissemination systems or 'trees'.<br>Opportunity for at-risk communities to confirm warning details. | In the lead up to system implementation, establish a Council championed community flash flood action group.<br>On exceedance of alarm criteria, site loggers could be programmed to send an SMS message and / or email to key Municipal and / or VICSES personnel as well as perhaps to key community members who could then initiate a local phone-based information dissemination tree.<br>Alternative alerting mechanisms could include use of a siren or similar. |

[52] 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 Carisbrook |
|---|---|---|
| RESPONSE | Flood management tools (e.g. MFEP complete with inundation maps and 'intelligence', effective public dissemination of flood information, local flood awareness, individual and business flood action plans, etc.). | Establish arrangements for the timely pick-up and removal of items susceptible to damage from floodwater from buildings likely to be flooded. Arrangements established in conjunction with Council and VICSES should be detailed in the MFEP.<br>Establish arrangements for the supply of sandbags and sand within Carisbrook with sufficient lead time to enable non-weatherboard buildings and / or buildings at risk of minimal over-floor flooding (see list in MFEP) to be sandbagged / protected. Arrangements established in conjunction with Council should be detailed in the MFEP.<br>Initiate a community engagement program to communicate how the FWS will work.<br>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. |
| | Flood response guidelines and related information (e.g. Standing Operating Procedures). | |
| | Comprehensive use of available experience, knowledge and information. | |
| REVIEW | Post-event debriefs (agency, community), etc. | Review and update of alarm criteria, local flood intelligence (i.e. flood characteristics, impacts, etc.), local alerting arrangements, response plans, local flood awareness material, etc. (initially) after every flood that triggers an alarm. Best done by Council with input from VICSES, NCCMA and the Council championed community flash flood action group.<br>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 flash flood warning and response system, including the MFEP. |
| | Data from Rapid Impact Assessments. | |
| | Flood 'intelligence' and flood damage data from the event collected by residents, Council, NCCMA, etc. | |
| | Review and update of personal, business and other flood action plans. | |

<table>
<tr><th>Flood Warning System Building Blocks</th><th>Basic Tools</th><th>Possible Solution for Carisbrook</th></tr>
<tr><td rowspan="5">AWARENESS</td><td>Identification of vulnerable communities and properties (i.e. flood inundation maps, information on flood levels / depths and extents, etc.).</td><td rowspan="5">Develop, print and distribute flood awareness material (FloodSafe brochures, property specific flood depth charts, etc.), including information on how the flash flood warning system operates using information collated for the MFEP and available within the Carisbrook Flood and Drainage Study report and from the web.<br><br>Load and maintain material (including the MFEP) on Council's website with appropriate links to relevant useful sites (e.g. the Flood Victoria website http://www.floodvictoria.vic.gov.au/centric/home.jsp).<br><br>Routinely revisit and update awareness material to accommodate lessons learnt, additional or improved material and to reflect advances in good practice.<br><br>Routinely repeat distribution of awareness material and consider other measures.<br><br>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 key locations within Carisbrook (e.g. in the low spot on Simpson Street to the west of the Pyrenees Highway Bridge or as indicated by the flood hazard maps delivered by the Carisbrook Flood and Drainage Study) and further afield.</td></tr>
<tr><td>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).</td></tr>
<tr><td>Community education and flood awareness raising including VICSES FloodSafe and StormSafe programs.</td></tr>
<tr><td>Local flood education plans – developed, implemented and evaluated locally (e.g. Cities of Maroondah, Whitehorse, Wodonga, Benalla and Greater Geelong).</td></tr>
<tr><td>Flood response guidelines, residents' kits, flood markers, flood depth indicators, flood inundation maps and property listings, property specific flood depth charts, flood levels in meter boxes and on rate notices, etc. for properties identified as being subject to flooding through the Carisbrook Flood and Drainage Study.</td></tr>
</table>

# 4. ESTIMATED COSTS FOR TFWS FOR CARISBROOK

The following table provides indicative costs associated with the implementation and on-going operation of each of the TFWS elements proposed for Carisbrook as discussed above.

**Table 4-1 Estimated cost associated with the Flood Warning System Options**

| Item | Estimated cost as at January 2013 (excl GST) | Comments |
|---|---|---|
| In-kind estimates developed using at-cost (not commercial) rates for time, consumables, etc. | | |
| **1. Data Collection and Collation** | | |
| 5 x staff gauge plates on the upstream side of the Pyrenees Highway Bridge at Carisbrook. Set to AHD or local datum. Includes survey to AHD. | $3,200 total | Cost covers supply, installation and commissioning of equipment. It also includes estimated allowances for cultural heritage assessment and service checks and marking at site.<br>New station cost could be reduced by ~$2,000 if a less robust instrument housing was used.<br>Adding telemetry without a rain gauge would reduce capital upgrade costs at the two existing stream gauging stations. |
| New gauging station immediately upstream of the Pyrenees Highway Bridge at Carisbrook (as above). Includes concrete instrument housing on concrete pad, HS dry bubbler and pressure transducer, Campbell logger, modem, solar panel, antenna, cabling. | $25,000 total | |
| Add telemetry and rain gauge to Smeaton and Creswick Creek at Clunes gauging stations. Includes BoM spec TBRG, bird guard, enclosure, lightning protection, modem, antenna, cabling. | $8,000 per site<br>$16,000 for both | |
| Manually read rain gauges:<br>➢ Top end of McCallum Creek.<br>➢ Between Maryborough and Carisbrook preferably on the face of the hills to the west / south west of Carisbrook. | ~$150 per site<br>~$300 total | |
| Input from BoM, comprising assistance with site selection, radio path testing and advice on necessary and appropriate equipment for the 2 x ERTS rainfall only stations – see below. | In-kind estimates<br>~$4,000 total | Subject to operational and other workloads. |
| 2 x ERTS rain only installations at locations as indicated for the manually read gauges. Includes steel instrument housing, BoM spec TBRG, ERTS canister, logger, solar panel, antenna, cabling. | $14,000 per site<br>$28,000 total | Cost covers supply, installation and commissioning of equipment.<br>Possible opportunity to partner with DSE on installation of the McCallum Creek rain gauge. Cost reduction? |
| Recurrent costs:<br>➢ Staff gauge site.<br>➢ Manual rain gauge site.<br>➢ ERTS rain only site.<br>➢ Rain - river site (no gauging). | $1,000/year/site<br>nil<br>$2,000/year/site<br>$4,000/year/site | Indicative costs only and dependent on the work scope and whether the sites are brought into the Surface Water Monitoring Partnership. |
| Council to champion and oversee the establishment of a flood action or flood warden group for Carisbrook. This group would collect and collate rain and river data and undertake the initial assessment of the likelihood and scale of | In-kind estimates<br>~$5,000 to set up<br>~$500/y ongoing | Will need to clearly establish the role for this group along with its authority and structure. VICSES should be invited to be involved in setting up the group / wardens. |

| Item | Estimated cost as at January 2013 (excl GST) | Comments |
|---|---|---|
| In-kind estimates developed using at-cost (not commercial) rates for time, consumables, etc. | | |
| flooding at Carisbrook. | | Liability issues need to be resolved. |
| **2. Flood Detection and Prediction** | | |
| 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. | In-kind estimate ~$3,000/flood | MFEP intelligence will need to be updated following flooding at Carisbrook. |
| Use the indicative quick look 'flood / no-flood' tool developed for Carisbrook to determine the likelihood and scale of possible flooding. | In-kind estimate ~$500/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 the tool over time.<br>Calibration events from the Carisbrook Flood and Drainage Study could be utilised. |
| Establish and set rain and creek level triggers for each telemetered site. | Establishment: In-kind estimate ~$500 total<br>Setup at site: ~$500/site | |
| Build relationship between levels / flows at Tullaroop head gauge, McCallum Creek at Carisbrook and Deep Creek at Carisbrook. | In-kind estimate<br>~$2,000 to setup<br>~$500/flood | Council to establish and maintain. Will take some time to establish. |
| Longer term and as part of a "best possible" system, establish rainfall – runoff model for the catchment to Carisbrook. | In-kind by entity estimated at ~$7,000 to setup.<br>Operational and ongoing costs not included. | No indication of likely timetable for this as will depend on identification of responsible entity to develop, run and maintain the model.<br>The RORB rainfall-runoff model developed for the Carisbrook Flood and Drainage Study would be suitable for this. |
| **3. Interpretation** | | |
| Make relevant parts of the MFEP and flood inundation and related mapping available to the Carisbrook community. | In-kind estimate ~$1,000 | Council to work with community on how best to achieve access. |
| The indicative quick look 'flood / no-flood' tool | As costed above, | MFEP intelligence will need to be |

| Item | Estimated cost as at January 2013 (excl GST) | Comments |
|---|---|---|
| In-kind estimates developed using at-cost (not commercial) rates for time, consumables, etc. | | |
| together with the MFEP enable those at risk to determine whether they are likely to be flooded with some lead time. | in-kind estimate ~$500/flood | updated following flooding at Carisbrook. |
| **4. Message Construction and Dissemination** | | |
| Council to champion and oversee the establishment of a flood action or flood warden group for Carisbrook. The primary role of the group / wardens would be to:<br>➢ Collect and collate rain and water level / flow data and also monitor rain and river information via the BoM's website<br>➢ Assess the likelihood and scale of likely flooding using the quick look 'flood / no-flood' tool<br>➢ In the event of likely flooding, call VICSES to advise of likely flooding and, subject to discussion with the RDO or IC, call the Central Goldfields MERO and initiate flood response actions within Carisbrook consistent with the MFEP. | As costed above, in-kind estimate<br>~$5,000 to set up<br>~$500/y ongoing | Will need to clearly establish the role for this group along with its authority and structure. VICSES should be invited to be involved in setting up the group / wardens.<br>Liability issues need to be resolved.<br>Establish SOPs acceptable to all TFWS stakeholders.<br>Establish a local telephone-based information dissemination tree. |
| Program site loggers to send an SMS message and / or email to key Municipal and / or VICSES personnel as well as perhaps to key community members who could then initiate a local phone-based information dissemination tree. | Establishment: In-kind estimate ~$500 total<br>Setup at site: ~$500/site | Is an extension of action identified under 'flood detection and prediction'. |
| **5. Response** | | |
| Council to share relevant parts of the MFEP with the Carisbrook community. | In-kind estimate ~$500 to set up | Will assist the implementation of an informed local response when it next floods. |
| Establish arrangements for the timely pick-up and removal of items susceptible to damage from floodwater from buildings likely to be flooded and not amenable to protection by sandbagging (e.g. weatherboard buildings). | In-kind estimate ~$1,000 to set up | Arrangements established in conjunction with Council and VICSES should be detailed in the MFEP. |
| Establish arrangements for the timely supply of sandbags and sand within Carisbrook with sufficient lead time to enable buildings at risk of minimal over-floor flooding to be sandbagged / | In-kind estimate ~$1,000 to set up | Arrangements established in conjunction with Council and VICSES should be detailed in the MFEP. |

| Item | Estimated cost as at January 2013 (excl GST) | Comments |
|---|---|---|
| In-kind estimates developed using at-cost (not commercial) rates for time, consumables, etc. | | |
| protected. | | |
| Encourage and assist residents and businesses to develop individual flood response plans. | In-kind estimate $500 to promote | Council and VICSES. |
| Initiate a community engagement program to communicate how the FWS will work. | In-kind estimate ~$3,000 to start ~$1,000 to repeat | VICSES with assistance from Council. Will need to be repeated as the system matures. |
| **6. Review and Keeping the System Alive** | | |
| Post-event review and on-going maintenance of the system in order to keep it alive within the community (e.g. exercises to test procedures, website maintenance, asset replacement, operational costs, involvement with a community flash flood action group and so on).<br>Assuming that replacement spares were purchased as part of the initial capital investment, asset replacement expenses are considered to be included in site recurrent costs. | In-kind estimate ~$2,000/year for activities while operational costs are absorbed into incident management activities. | Costs will vary year to year and will depend on rainfall and seasonal conditions. |
| **7. Community Flood Awareness** | | |
| Develop and distribute a FloodSafe brochure / Local Flood Guide for Carisbrook. | Up to $12,000 but expected to be covered by other funding through VICSES | Cost will depend on how much of the work is out-sourced and how much is done by VICSES as an in-kind contribution. |
| Develop, print and distribute property-specific flood depth charts for properties within Carisbrook. | $5,000 | Cost will depend on how much of chart build is out-sourced. |
| Load and maintain flood related material (including the MFEP) to Council's website. | In-kind estimate<br>~$1,000 to cover initial load<br>~$500 ongoing | |
| Install flood depth indicator boards at key locations in and around Carisbrook. | ~$500/board | Locations to be determined from hazard maps. |

# 5. SUGGESTED ACTIONS

A staged approach to the development of a flash flood warning system for Carisbrook is proposed. The stages have been ordered and the tasks within each stage grouped to facilitate growth of all elements of the TFWS in a balanced manner and with full regard for matters discussed in Section 3 of this appendix. While it may be tempting to immediately move to install additional rain and river gauges and to develop / strengthen forecast capability, there are other more fundamental matters that experience tells us need to be addressed first. Thus early attention is directed at ensuring roles and responsibilities are agreed, understood and accepted and that there is a firm foundation for the development of an effective flash flood warning system: one that does not fail when it is needed most. Attention is then directed to establishing a robust framework for communicating and disseminating flood related information so that immediate and maximum use can be made of available information as the ability to detect and predict flooding at Carisbrook improves. Next, attention is focussed on securing the funding needed to buy, install and operate field equipment as well as other services needed to build elements of the TFWS. The installation of data collection equipment follows, with a two tiered approach in the event that funding is not available or is delayed. Development of other technical elements and the build and delivery of on-going flood awareness activities can then occur in the knowledge that required data is / will be available and that robust and sustainable arrangements are in place that will enable maximum benefit to be derived from any information or programs delivered to the community.

**Stage 1**

2. Council, NCCMA, VICSES and other entities to determine the responsible entity in relation to "ownership" of each element of the flash flood warning system for Carisbrook, where ownership is considered to denote overall responsibility for funding as well as the functioning of the system element and, in the event of failure, responsibility for either fault-fix or the organisation of appropriate fault-fix actions along with associated payments. VFWCC[53] provides guidance on this matter although recommendations 1 and 5 from the Comrie Review Report[54] suggest that some clarifications may be required.

**Stage 2**

7. Council to champion and in conjunction with VICSES oversee the establishment of a flash flood action or flood warden group for Carisbrook. Clearly establish the role for this group along with its authority and structure with due regard for liability issues. Essentially the group would:
    - Collect and collate rain and water level / flow data and also monitor rain and river information via the BoM's website.
    - Make initial assessments of the likelihood and scale of flooding at Carisbrook based on available rainfall data, water levels and trends at upstream locations and at Carisbrook, and the indicative quick look 'flood / no-flood' tool developed for Carisbrook and included in the Central Goldfields MFEP.

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

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

- In the event of likely flooding, call VICSES to advise of likely flooding and, subject to discussion with the RDO or IC, call the Central Goldfields MERO and initiate flood response actions within Carisbrook consistent with the MFEP. This may include door knocking and through the MFEP, identification of roads and properties likely to be impacted and the coordination of removal of items susceptible to damage from floodwater from buildings likely to be flooded over-floor when conditions indicated it is warranted or necessary and thereafter work closely with VICSES, CFA and Council.
- Maintain a watching brief on flood response arrangements within Carisbrook, including the availability of sand and sand bags, and provide feedback to Council on the adequacy and efficacy of arrangements in place at the time.

8. Council to share the MFEP with the Carisbrook community.
9. Council to establish arrangements for the timely supply of sandbags and sand within Carisbrook.
10. Council and VICSES to encourage and assist residents and businesses to develop individual flood response plans.
11. Council to load and maintain flood related material (including the MFEP) to its website.
12. Council with the support of VICSES, NCCMA and the Carisbrook community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements of a TFWS for Carisbrook.

**Stage 3**

7. Install 5 x staff gauges immediately upstream of the Pyrenees Highway Bridge at Carisbrook. Set to either AHD or local datum and survey to AHD. Consider marking the January 2011 and September 2010 flood levels on the gauges, as well as the design flood levels determined through the Carisbrook Flood and Drainage Study. Establish on-going maintenance arrangements, ideally through the Surface Water Monitoring Partnership.
8. Update the MFEP with staff gauge datums and other relevant details.
9. Council in conjunction with VICSES to establish and document in the MFEP arrangements for the timely:
   - Pick-up and removal of items susceptible to damage from floodwater from buildings likely to be flooded but not amenable to sandbagging (e.g. weatherboard buildings);
   - Supply of sandbags and sand within Carisbrook with sufficient lead time to enable buildings at risk of minimal over-floor flooding to be sandbagged / protected.
10. VICSES to initiate a community engagement program at Carisbrook in order to communicate how the flood warning system will work. This will need to be repeated as the system matures
11. VCISES to develop and distribute a FloodSafe brochure / Local Flood Guide for Carisbrook.
12. Council to oversee the development, printing and distribution of property-specific flood depth charts for properties within Carisbrook.

**Stage 4A – to be actioned only if funding to undertake Stage 4B is either not available or is delayed**

2. Determine the location of private rain gauges in the upper parts of the McCallum Creek

catchment and on the hills facing Carisbrook to the west / south west (if the outcome from 1 above was negative) and establish arrangements for the provision of rainfall data to the flood action or flood warden group at frequent intervals during heavy rain events.

Alternatively, source two rain gauges and distribute to local residents willing to provide rainfall data at frequent intervals during heavy rain events:

- In the upper parts of the McCallum Creek catchment (priority 1).
- On the hills facing Carisbrook to the west / south west (priority 2).

**Stage 4B**

6. Using equipment similar to (or the same as) that already installed and operational at the Tullaroop Creek at Clunes and McCallum Creek at Carisbrook gauging stations:
   - Establish a telemetered rain and stream gauge at Carisbrook immediately upstream of the Pyrenees Highway Bridge (i.e. at the newly established staff gauge site); and
   - Add a rain gauge and telemetry to the Smeaton and Creswick Creek at Clunes gauging stations.
7. Install 2 x ERTS rainfall only stations: in the upper parts of the McCallum Creek catchment and on the hills facing Carisbrook to the west / south west. Will need to explore possible opportunity to partner with DSE on the McCallum Creek installation before committing to funding and works.
8. Establish on-going maintenance (and data archival) arrangements for all installed equipment, ideally through the Surface Water Monitoring Partnership.
9. Approach BoM to add all telemetered sites to appropriate rainfall and river level bulletins accessible via the BoM website. Requires telemetry systems used to be fully compatible with BoM systems.
10. If appropriate and following achievement of full operational status of each telemetered site providing additional rain and river data, retire the manual readers in the general vicinity who have previously provided that data for the Carisbrook flash flood warning system.

**Stage 5**

3. In conjunction with VICSES, NCCMA and the Carisbrook-based flood action or flood warden group, Council to determine appropriate rain and river trigger levels for the initiation of SMS alerts and / or email alerts from telemetry sites.
4. Council to begin building a relationship between levels / flows at Tullaroop head gauge, McCallum Creek at Carisbrook and Deep Creek at Carisbrook in order to assist flood assessment and response at Carisbrook and in order to inform the development and / or firming up of flood class levels.

**Stage 6**

1. Install flood depth indicator boards at key locations in and around Carisbrook (e.g. in the low spot on Simpson Street to the west of the Pyrenees Highway Bridge or as indicated by the flood hazard maps delivered by the Carisbrook Flood and Drainage Study) and further afield.

**Stage 7**

1. Longer term and following the identification of an appropriate and responsible entity to develop, run and maintain the model (and as part of a "best possible" flash flood warning system), establish a rainfall-runoff based flood forecast model for the catchment to Carisbrook.

# 6. ACRONYMS

| | |
|---|---|
| AEMI | Australian Emergency Management Institute |
| AWS | Automatic Weather Station |
| BOM | Bureau of Meteorology |
| DoTARS | Department of Transport and Regional Services |
| EMA | Emergency Management Australia |
| EMMV | Emergency Management Manual Victoria |
| EA | Emergency Alert |
| ERTS | Event Report Radio Telemetry System |
| IC | Incident Controller |
| MERO | Municipal Emergency Resource Officer |
| MFEP | Municipal Flood Emergency Plan |
| NCCMA | North Central Catchment Management Authority |
| OESC | Office of the Emergency Services Commissioner |
| RDO | Regional Duty Officer |
| TFWS | Total Flood Warning System |
| VICSES | Victoria State Emergency Service |

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# APPENDIX F FLOOD WARNING PROVIDED BY BOM

# OVERVIEW OF FLOOD WARNING SERVICES PROVIDED BY BoM

## 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.

## 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.

## 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.

## 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.

Flood warnings are categorised as 'minor', 'moderate' or 'major' (see BoM website for an explanation of these terms and current flood class levels) and indicate the expected severity of the flood for agreed key locations along the river.

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) can also be obtained from the Bureau's website (www.bom.gov.au/hydro/flood/vic) or for the cost of a local call on ☎ 1300 659 217.

### 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.

# APPENDIX G FLOOD WARNING SYSTEM PACKAGES

| Recommendations | Estimated Cost | | Essential System Costs | | Standard System Costs | | Complete System Costs | | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **STAGE 1** | Initial Cost | Ongoing Cost (p.a.) | Initial Cost | Ongoing Cost (p.a.) | Initial Cost | Ongoing Cost (p.a.) | Initial Cost | Ongoing Cost (p.a.) | |
| 1) Council, NCCMA, VICSES and other entities to determine the responsible entity in relation to "ownership" of <u>each element of the flash flood warning system</u> for Carisbrook, where ownership is considered to denote overall responsibility for funding as well as the functioning of the system element and, in the event of failure, responsibility for either fault-fix or the organisation of appropriate fault-fix actions along with associated payments. VFWCC[1] provides guidance on this matter although recommendations 1 and 5 from the Comrie Review Report[2] suggest that some clarifications may be required. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |
| **STAGE 2** | | | | | | | | | |
| 1) Council to champion and in conjunction with VICSES oversee the establishment of a flash flood action or flood warden group for Carisbrook. Clearly establish the role for this group along with its authority and structure with due regard for liability issues. Essentially the group would: | $5,000.00 | $500.00 | $5,000.00 | $500.00 | $5,000.00 | $500.00 | $5,000.00 | $500.00 | Included in all systems |
| Collect and collate rain and water level / flow data and also monitor rain and river information via the BoM's website. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |
| Ø Make initial assessments of the likelihood and scale of flooding at Carisbrook based on available rainfall data, water levels and trends at upstream locations and at Carisbrook, and the indicative quick look 'flood / no-flood' tool developed for Carisbrook and included in the Central Goldfields MFEP. | $500.00 | | | | | | | | Not included as Tool provided as an output of the Plan, any other labour will be inkind |
| Ø In the event of likely flooding, call VICSES to advise of likely flooding and, subject to discussion with the RDO or IC, call the Central Goldfields MERO and initiate flood response actions within Carisbrook consistent with the MFEP. This may include door knocking and through the MFEP, identification of roads and properties likely to be impacted and the coordination of removal of items susceptible to damage from floodwater from buildings likely to be flooded over-floor when conditions indicated it is warranted or necessary and thereafter work closely with VICSES, CFA and Council. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |

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| Ø Maintain a watching brief on flood response arrangements within Carisbrook, including the availability of sand and sand bags, and provide feedback to Council on the adequacy and efficacy of arrangements in place at the time. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |
| 2) Council to share the MFEP with the Carisbrook community. | $1,000.00 | | | | | | $1,000.00 | | Only included in Complete package |
| 3) Council to establish arrangements for the timely supply of sandbags and sand within Carisbrook. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |
| 4) Council and VICSES to encourage and assist residents and businesses to develop individual flood response plans. | $500.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost), VICSES floodsafe program should also cover this item |
| 5) Council to load and maintain flood related material (including the MFEP) to its website. | $1,000.00 | $500.00 | | | $0.00 | $0.00 | $1,000.00 | $500.00 | Only in Complete package |
| 6) Council with the support of VICSES, NCCMA and the Carisbrook community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements of a TFWS for Carisbrook. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |
| **STAGE 3** | | | | | | | | | |
| 1) Install 5 x staff gauges immediately upstream of the Pyrenees Highway Bridge at Carisbrook. Set to either AHD or local datum and survey to AHD. Consider marking the January 2011 and September 2010 flood levels on the gauges, as well as the design flood levels determined through the Carisbrook Flood and Drainage Study. Establish on-going maintenance arrangements, ideally through the Surface Water Monitoring Partnership. | $3,200.00 | $5,000.00 | $7,000.00 | $1,000.00 | $7,000.00 | $1,000.00 | $7,000.00 | $1,000.00 | Included in all systems |

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| 2) Update the MFEP with staff gauge datums and other relevant details. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all but in-kind cost |
| 3) Council in conjunction with VICSES to establish and document in the MFEP arrangements for the timely: | | | | | | | | | |
| Ø Pick-up and removal of items susceptible to damage from floodwater from buildings likely to be flooded but not amenable to sandbagging (e.g. weatherboard buildings); | $1,000.00 | | | | | | $1,000.00 | | Flood response costs and so included in Complete System only |
| Ø Supply of sandbags and sand within Carisbrook with sufficient lead time to enable buildings at risk of minimal over-floor flooding to be sandbagged / protected. | $1,000.00 | | $1,000.00 | | $1,000.00 | | $1,000.00 | | Included in all systems |
| 4) VICSES to initiate a community engagement program at Carisbrook in order to communicate how the flood warning system will work. This will need to be repeated as the system matures | $3,000.00 | $1,000.00 | | | $3,000.00 | $1,000.00 | $3,000.00 | $1,000.00 | Included in Complete and Standard systems only |
| 5) VICSES to develop and distribute a FloodSafe brochure / Local Flood Guide for Carisbrook. | $12,000.00 | | | | $12,000.00 | | $12,000.00 | | Included in complete and standard systems only |
| 6) Council to oversee the development, printing and distribution of property-specific flood depth charts for properties within Carisbrook. | $5,000.00 | | | | | | $5,000.00 | | included in Complete system only |
| **STAGE 4A** | | | | | | | | | |
| 1) Determine the location of private rain gauges in the upper parts of the McCallum Creek catchment and on the hills facing Carisbrook to the west / south west (if the outcome from 1 above was negative) and establish arrangements for the provision of rainfall data to the flood action or flood warden group at frequent intervals during heavy rain events. | $300.00 | | $300.00 | | $300.00 | | $300.00 | | Included in all systems |

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| Alternatively, source two rain gauges and distribute to local residents willing to provide rainfall data at frequent intervals during heavy rain events: n the upper parts of the McCallum Creek catchment (priority 1). On the hills facing Carisbrook to the west / south west (priority 2). | | | | | | | | | |
| **STAGE 4B** | | | | | | | | | |
| 1) Using equipment similar to (or the same as) that already installed and operational at the Tullaroop Creek at Clunes and McCallum Creek at Carisbrook gauging stations: | | | | | | | | | |
| · Establish a telemetered rain and stream gauge at Carisbrook immediately upstream of the Pyrenees Highway Bridge (i.e. at the newly established staff gauge site); and | $25,000.00 | $4,000.00 | | | | | $25,000.00 | $4,000.00 | included in complete system only |
| · Add a rain gauge and telemetry to the Smeaton and Creswick Creek at Clunes gauging stations. | $16,000.00 | $2,000.00 | | | $16,000.00 | $2,000.00 | $16,000.00 | $2,000.00 | Included in complete and standard systems only |
| 2) Install 2 x ERTS rainfall only stations: in the upper parts of the McCallum Creek catchment and on the hills facing Carisbrook to the west / south west. Will need to explore possible opportunity to partner with DSE on the McCallum Creek installation before committing to funding and works | $28,000.00 | $4,000.00 | | | | | $28,000.00 | $4,000.00 | included in complete system only |
| | $4000. 00 | $0.00 | | | | | $4000. 00 | $0.00 | included in complete system only |
| 3) Establish on-going maintenance (and data archival) arrangements for all installed equipment, ideally through the Surface Water Monitoring Partnership. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |
| 4) Approach BoM to add all telemetered sites to appropriate rainfall and river level bulletins accessible via the BoM website. Requires telemetry systems used to be fully compatible with BoM systems. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |

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| 5) If appropriate and following achievement of full operational status of each telemetered site providing additional rain and river data, retire the manual readers in the general vicinity who have previously provided that data for the Carisbrook flash flood warning system. | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 | Included in all (inkind cost) |
| **STAGE 5** | | | | | | | | | |
| 1) In conjunction with VICSES, NCCMA and the Carisbrook-based flood action or flood warden group, Council to determine appropriate rain and river trigger levels for the initiation of SMS alerts and / or email alerts from telemetry sites. | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | $500.00 | Included in all systems |
| 2) Council to begin building a relationship between levels / flows at Tullaroop head gauge, McCallum Creek at Carisbrook and Deep Creek at Carisbrook in order to assist flood assessment and response at Carisbrook and in order to inform the development and / or firming up of flood class levels. | $2,000.00 | $500.00 | $2,000.00 | $500.00 | $2,000.00 | $500.00 | $2,000.00 | $500.00 | Partially completed as part of this study |
| **STAGE 6** | | | | | | | | | |
| 1) Install flood depth indicator boards at key locations in and around Carisbrook (e.g. in the low spot on Simpson Street to the west of the Pyrenees Highway Bridge or as indicated by the flood hazard maps delivered by the Carisbrook Flood and Drainage Study) and further afield. | $1,500.00 | | $1,500.00 | | $1,500.00 | | $1,500.00 | | Included in all systems |
| **STAGE 7** | | | | | | | | | |
| 1) Longer term and following the identification of an appropriate and responsible entity to develop, run and maintain the model (and as part of a "best possible" flash flood warning system), establish a rainfall-runoff based flood forecast model for the catchment to Carisbrook. | $7,000.00 | | | | | | $7,000.00 | | Included in Complete system only |

| **Other Costs** | | | | | | | | | |
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| Post-event review and on-going maintenance of the system in order to keep it alive within the community (e.g. exercises to test procedures, website maintenance, asset replacement, operational costs, involvement with a community flash flood action group and so on). Assuming that replacement spares were purchased as part of the initial capital investment, asset replacement expenses are considered to be included in site recurrent costs. | $2,000.00 | $2,000.00 | | | $2,000.00 | $2,000.00 | $2,000.00 | $2,000.00 | Post-event costs, Included in Complete and Standard systems only |
| 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. | | | | | | | | | Tool provided as part of study |
| **Total** | $115,500.00 | $20,000.00 | $17,300.00 | $2,500.00 | $50,300.00 | $7,500.00 | $118,300.00 | $16,000.00 | |