Creswick Flood Mitigation and Urban Drainage Plan

Draft Study Report

November 2011

DOCUMENT STATUS

Version	Doc type	Reviewed by	Approved by	Date issued
v01	Report	Warwick Bishop	Ben Tate	12/05/2011
v02	Report	Ben Tate	Ben Tate	24/05/2011
v03	Report	Ben Tate	Ben Tate	27/06/2011
v04	Report	Ben Tate	Ben Tate	11/07/2011
v05	Report	Ben Tate	Ben Tate	04/11/2011
v06	Report	Ben Tate	Ben Tate	23/11/2011

PROJECT DETAILS

Project Name	Creswick Flood Mitigation and Urban Drainage Plan
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Job Number	1852-01
Report Number	R02
Document Name	1852-01R02v06b_CreswickFS.docx

Cover Photo: Aerial image of September 2010 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 significant event to be considered in the design process; various works within the floodplain may have different design standards. A design flood will generally have a nominated AEP or ARI (see above).
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

The Minster for Water announced funding for the Creswick Flood Mitigation and Urban Drainage Plan on the 9th February 2011, with the plan to include the following:

- A review of the available data, including data from the Creswick Community.
- Calibrated computer models for the catchment and results for a series of design events.
- Development of a series of flood and urban drainage mitigation options to reduce flood risk and an assessment of their feasibility
- Recommendations of preferred flood and urban drainage mitigation options for consideration by the Steering Committee, Technical Working Group and the Creswick community

The Creswick Flood Mitigation and Urban Drainage Plan was undertaken by Water Technology on behalf of North Central CMA and Hepburn Shire Council. The study has been led by a community based Steering Committee with support from a Technical Working Group. A number of community meetings were held during the project to ensure that community issues were heard and that community ideas were considered in the assessment of potential flood mitigation options.

The study included the development and calibration of hydrological and hydraulic models, calibration to the September 2010 and January 2011 flood events, design flood modelling and mapping, flood damage assessment, and consideration of flood mitigation options. These are summarised below.

Hydrologic Modelling

The study developed a detailed hydrological RORB model of the Creswick catchment. The RORB model extended down to the 'Creswick Creek @ Clunes' gauge and included the entire catchment upstream of that point, an area of approximately 311.3 km², with 85 km² upstream of Creswick. The model was calibrated to within 0.1 m^3/s of the gauged peak flow at Clunes for both events. Design hydrology estimates were generated using IFD techniques and were validated using a number of approaches. The design hydrology adopted indicates that the September 2010 and January 2011 events were approximately 25 and 35 year ARI flood events at Creswick.

Hydraulic Modelling

The hydrologic modelling was used as flow boundaries for the hydraulic modelling. A complex hydraulic model was developed of the township using MIKE FLOOD, a state of the art 1D-2D linked hydrodynamic modelling system. The hydraulic model was calibrated to the September 2010 and January 2011 events to a reasonable level of accuracy, reproducing surveyed flood levels and observed flood extents. It was also verified by anecdotal evidence by members of the Steering Committee and the community. The models were then used to simulate design floods of 5, 10, 20, 50, 100 and 200 year ARI events. From the observed recent flood events and the flood modelling, key observations of flood behaviour through Creswick was made.

Key Observations of Design Flood Behaviour

Due to the steep nature of the terrain and the confined floodplain, once Creswick Creek overtops its banks the flood extents do not change significantly. The 20, 50, 100 and 200 year ARI flood maps all had a similar inundation extent with some incremental changes as the flood magnitude increases. The following comments describe the key flood characteristics in Creswick for each design event.

5 Year ARI Event

- Water levels reach top of bank in Creswick Creek and spill out in low lying areas at Calembeen Park and Hammon Park Oval. Shallow overland depths with no properties affected above floor level.
- Saw Pit Gully and Nuggetty Gully overflows cause minor inundation of low lying areas.

10 Year ARI Event

- Floodwaters overtop the banks of Creswick Creek, between Water Street and Castlemaine Road, and start to encroach on properties.
- 8 properties flooded above floor (3 in Cushing Avenue/Cambridge Street area, 2 on North Parade, club rooms at Hammon Park and a shed at Calambeen Park).
- Floodwaters overtop Creswick Creek banks between Water St and Castlemaine Rd.
- Floodwaters from Creswick Creek back up Nuggetty Gully, flooding Cushing Avenue and a few properties south of Cushing Avenue.

20 Year ARI Event

- Water levels overtop the banks of Creswick Creek, causing widespread floodplain inundation. Flood extents comparable to the September 2010 and January 2011 floods.
- Properties inundated above floor level include those along Albert St, Cushing Av, Cambridge St, Castlemaine Rd, North Parade.
- Creswick Motel inundated above floor.
- 6 units in the south west corner of Semmens Village inundated above floor.
- Floodwaters overtop Albert Street inundating properties on the west side of Albert Street, Cambridge Street and Cushing Avenue.
- Nuggetty Gully flow overtops bluestone wall at primary school and run down Victoria Street.

50 Year ARI Event

- Flood extent and flood depths slightly larger than September 2010 and January 2011 events.
- Properties along Albert Street, between Water Street and the Bowling Club not inundated. It should be noted that these properties were inundated during the September 2010 and January 2011 flood events, but are now flood free as a result of the clean up works undertaken in February 2011.
- Castlemaine Road Bridge overtops.
- Additional properties inundated above floor on same streets as inundated in 20 year ARI event.
- 18 units in Seemens Village inundated above floor.

100 Year ARI Event

- Flood extent not increased significantly but flood depths increased by average of 170 mm.
- Additional properties flooded included the primary school (south-west building) and a few properties south of the Bowling Club, along Albert Street.
- CFA inundated above floor.
- Petrol station inundated above floor.
- 26 units in Semmens Village inundated above floor.

200 Year ARI Event

- Flood extent not increased significantly compared to the 100 year ARI event.
- Additional properties inundated included more properties south of the Bowling Club.
- Hepburn Shire Council depot inundated above floor.

Mitigation Options

After gaining a thorough understanding of the flood behaviour in Creswick various mitigation options were assessed. A comprehensive list of options were explored in a prefeasibility assessment, which clearly documented which options were appropriate to consider further. Five mitigation options were modelled with the aim of reducing the flood damage within Creswick. The first two initial options demonstrate what may be required to protect to a 100 year ARI design standard by means of raised levees and a deepened and widened creek. The third option looked at a combination of creek widening and deepening with minor levees and some bridge upgrades. The fourth option considered a similar widening and deepening with concrete lining of the creek. The fifth option considered the results of the previous four options and after a few iterations settled on a compromise between bridge upgrades, deepening the creek and minor levee works.

Preferred Mitigation Option

Assessment of the five mitigation options considered a full benefit-cost analysis. Community input highlighted concerns over the impact potential levees may have on the town's amenity. Option 5 was identified as the preferred option with a a superior benefit-cost ratio of 0.8 as compared to all other options with ratios less than 0.6. Option 5 was also considered by the Steering Committee to be an option that would be acceptable to the community, providing a balance between a reduction in flood risk without detracting from the amenity and character of the town. Mitigation option 5 includes the following works:

- Installation of two additional culverts at the Clunes/Castlemaine Road Bridges.
- Levee along the left bank of Creswick Creek starting at the Bowling Club and running along the creek line, before extending along Nuggetty Gully up to Cushing Avenue.
- Minor channel deepening/widening in Creswick Creek between Water Street to Saw Pit Gully and between Clunes Road Bridge and Nuggetty Gully.
- Bunds along Semmens Village (average depth 0.5 m) and the properties to the north of Semmens Village (average depth 0.7 m).
- Raised embankment wall along Nuggetty Gully at the primary school.
- Installation of drainage system flap valves on culverts discharging to Creswick Creek.

Recommendations

Following on from this study it is recommended that mitigation option 5 be considered further. It is suggested that a levee along North Parade also be considered in conjunction with option 5 as discussed in the report.

Other recommendations arising from this study include the following:

- Hepburn Shire Council to use the information from this study to complete the Municipal Flood Emergency Management Plan.
- Investigate and document the feasibility of a flash flood warning system for Creswick.
- Raise flood awareness in the community with a public campaign.
- Hepburn Shire Council, as a matter of priority, adopts the draft LSIO and FO maps and incorporates them into the planning scheme. This will ensure that any inappropriate development in the floodplain is controlled.

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.

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1. INTRODUCTION

1.1 Background

The Minster for Water announced funding for the Creswick Flood Mitigation and Urban Drainage Plan on the 9th February 2011, with the plan to include the following:

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- Recommendations of preferred flood and urban drainage mitigation options for consideration by the Steering Committee, Technical Working Group and the Creswick community.

The 2010-2011 Spring-Summer period saw a series of extensive flood-producing rainfall events across Victoria. Over this period there was a sequence of severe floods within Creswick, including the large events of September 2010 and January 2011. Following these events, Water Technology was commissioned in March 2011 by the North Central Catchment Management Authority (CMA) to undertake the Creswick Flood Mitigation and Urban Drainage Plan study.

This study built on the investigations and results of a preliminary hydraulic analysis of Creswick Creek, undertaken by Water Technology in February 2011. This previous work focused on estimating capacities and flood levels in Creswick Creek using a one-dimensional hydraulic model.

This study involved more detailed hydrological and hydraulic modelling of Creswick Creek, flood mapping, assessment of flood damages, and an assessment of potential flood mitigation options.

1.2 Study Area

The township of Creswick is located in central Victoria, approximately 18 km north of Ballarat. Creswick is within the North Central CMA boundary and is a major township within Hepburn Shire Council.

Creswick Creek is the main watercourse flowing through town. Creswick Creek's headwaters begin near Dean and flow north through Creswick along the eastern side of Midland Highway and Albert Street. Creswick Creek is crossed by Water Street, then Castlemaine Road (Midland Highway), and then Clunes Road before heading north-west through Calembeen Park towards Clunes. Immediately downstream of Clunes, Creswick Creek merges with Birch Creek, forming Tullaroop Creek. Immediately upstream of Creswick, at the confluence of Creswick and Slaty Creeks, the catchment area is approximately 85 km^2.

Slaty Creek, Sawpit Gully (also called Spring Gully) and Nuggetty Gully are major tributaries of Creswick Creek. Other tributaries in the upper catchment include Adekate Creek, Slattery Creek, Glendonald Creek, Reedy Creek, Glendanuel Creek and Kilkenny Creek. In addition, there are numerous small streams and gullies which also feed into Creswick Creek. There are two storages located upstream of Creswick along Creswick Creek; Cosgrave Reservoir and St Georges Lake (Refer to Figure 1-1).

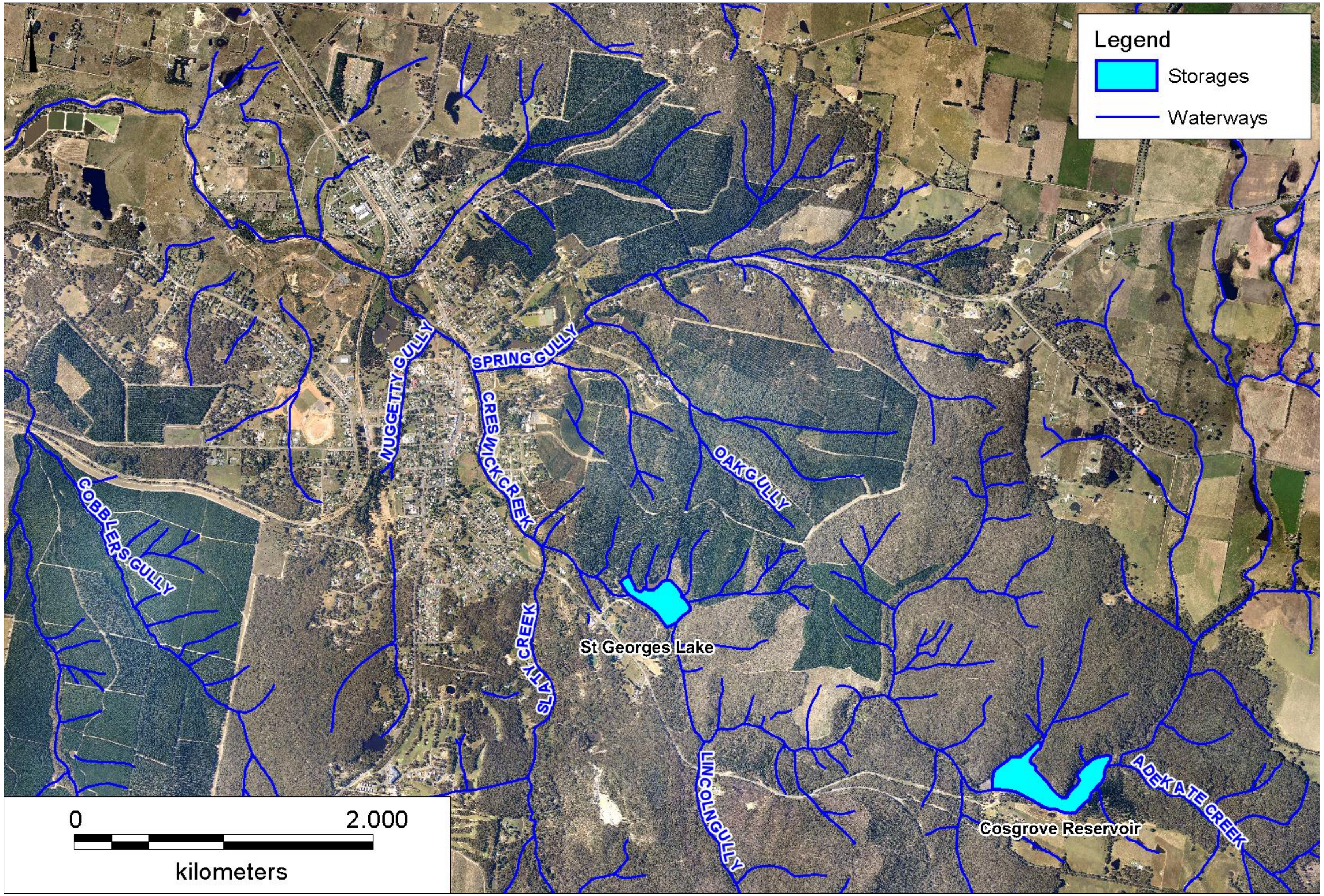


Figure 1-1 Major waterways in the vicinity of Creswick

1.3 Recent Flood Events

Creswick was subject to four separate flood events between late 2010 and early 2011, as follows:

- September 2010 (Large flood event)
- November 2010 (Minor flood event)
- January 2011 (Large flood event)
- February 2011 (Moderate flood event – highly localised)

The September and January flood events were significantly larger that the November and February events. Both major floods were a result of heavy rainfall in the upstream catchment, whilst the November and February flood events were due to heavy, localised rainfall across the upper reaches of the gullies near town. February in particular had a significant impact on Sawpit Gully.

Discussions with residents, North Central CMA and Hepburn Shire Council staff, site observations, and a review of hydrological data was undertaken to provide an understanding of the key flooding issues in Creswick. Understanding these flooding issues helped guide the model schematisation and calibration.

2. AVAILABLE INFORMATION

2.1 LiDAR Data

Light Detection and Ranging (LiDAR) data for the region was made available from two sources, the North Central CMA and Department of Sustainability (DSE). LiDAR is a form of aerial survey providing high detailed topographic survey over a large area. The type of hydraulic modelling undertaken during the course of this study is not possible without this detailed survey, so it is critical to the outcomes of the project.

A comparison of both datasets was undertaken in ARCGIS. Both datasets have the same horizontal resolution (1 m), however the LiDAR provided by DSE covered a slightly larger extent. No elevation difference was observed where the two datasets overlapped. DSE's LiDAR data was adopted for this study and is shown in Figure 2-1 below.

Ground survey was used to check the vertical accuracy of the LiDAR. Spot heights were taken at 10 locations in Creswick as shown in Appendix B. Overall the LiDAR was found to compare well (within +/- 100 mm) with the survey data of the floodplain outside the channel banks. Differences (up to +/- 300 mm) were found at two of the locations, at the channel banks near Water Street and Raglan Street.

The field survey also included 14 cross-sections taken along Creswick Creek, Saw Pit Gully and Nuggetty Gully (Appendix B). Cross-sections were extracted from the LiDAR and compared to the surveyed sections. The comparison shows that the LiDAR does not accurately capture the low flow channel profile. This is most likely due to the dense vegetation along the gullies and water in the creek when the LiDAR was flown. Another source of difference is the clearing of Creswick Creek following the recent flood events. In particular, cross-sections at the downstream end of Nuggetty Gully and sections along Creswick Creek near Water Street and the bowling club showed large differences, up to 1 meter. The field survey was not used in the cross-sections for hydraulic modelling of the September 2010 and January 2011 events, rather sections from the LiDAR (with minor edits) were used to represent Creswick Creek and Nuggetty Gully in the reaches where the post-flood waterway works were carried out. The field survey cross-sections were used in the hydraulic modelling for design events representing the existing conditions within the township.

In general, the LiDAR provided an accurate terrain model of the floodplain, suitable for the purposes of flood modelling. Within Creswick Creek, Nuggetty Gully and Sawpit Gully, minor editing of the LiDAR cross-sections was required to accurately model the channel capacities.

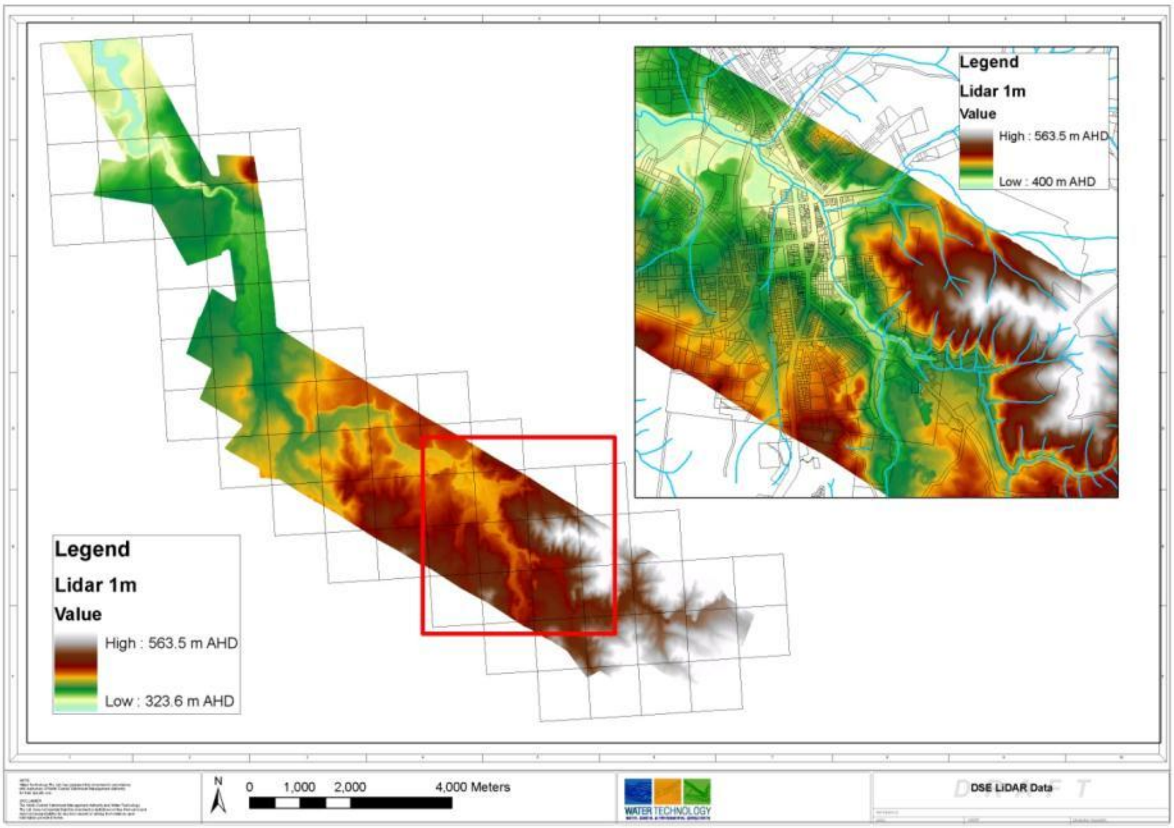


Figure 2-1 **1m LiDAR extent for Creswick (LiDAR supplied by DSE, 2011)**

2.2 Crossings and Drainage Infrastructure Survey

Survey information of the key hydraulic structures along Creswick Creek, Sawpit Gully and Nuggetty Gully was captured for input into the hydraulic model. Structures included bridge crossings and culverts under roads. Two of the structures (Castlemaine Road and Clunes Road bridges) were previously surveyed by Tomkinson Group in January 2011. Additional survey of the remaining structures was commissioned by the North Central CMA after completion of the *Data Review, Model Scoping and Mitigation Prefeasibility Report* (Water Technology, April 2011).

Details of the underground drainage network are also important for the establishment of the hydraulic model and identification of drainage related flood issues. The main pipe network which runs under Victoria Street and discharges into Creswick Creek was surveyed and was included in the model to simulate/check pipe backflow.

The survey commissioned by the North Central CMA also picked up channel cross-sections upstream of all key structures and additional cross-sections along Nuggetty Gully. Details of the modelled structures and drainage network are provided in Appendix A.

2.3 Streamflow Data

Streamflow data was required for the calibration of the hydrological model. The closest active streamflow gauge was at 'Creswick Creek in Clunes', approximately 23 km downstream of Creswick. Instantaneous streamflow data for the September 2010 and January 2011 flood events were sourced from the Department of Sustainability and Environment (DSE).

A gauge was found on Creswick Creek upstream of Cosgrave Reservoir with an upstream catchment of just 22 km². The gauge measures instantaneous level, and has a rating curve to convert level to flow. The September 2010 event was measured but the gauge was '*inactive*' from the 10th of December 2010. The September peak level of 1.53 m on the gauge was recorded on Saturday the 4th of September 2010 at 9:30 am. The level exceeds the rating curve, but with extrapolation of the rating curve it is estimated that the September peak flow at the gauge was just over 6 m^3/s.

Table 2-1 Streamflow gauge details

Station Name	Station No.	Status	Data Type	**Period of record**
Creswick Creek @ Clunes	407214	Active	Instantaneous Flows, Instantaneous Levels	August 1943 - Present
Creswick Creek @ Creswick (upstream of Cosgrave Reservoir)	407237	Inactive	Instantaneous Levels	21/4/2010 to 10/12/2010

2.4 Rainfall Data

Two main types of rainfall gauges were utilised during this study, pluviographs and daily rainfall gauges. Pluviographs record continuous rainfall indicating the temporal variation over a storm event. There are relatively few pluviograph gauges in the Creswick area. Daily rainfall gauges record rainfall on a daily basis, generally lumping all rainfall over a 24 hour period as recorded at to 9 am. There are many daily gauges in the catchment providing a spatial distribution of storm events. Figure 2-2 shows the locations of daily rainfall and pluviograph stations in the region.

Pluviograph records (half hourly rainfall data) for the region were only available at the Ballarat station. Daily rainfall records were obtained from 12 rainfall stations spread across and around the catchment. Notably, only the Creswick rainfall gauge lies within the Creswick Creek catchment, with all other gauges just outside the catchment boundary.

Table 2-2 Daily rainfall station details

Station Name	**Station Number**	**Period of Record**
Ballarat	89002	1908 - Present
Clunes	88015	1878 - Present
Creswick	88019	1949 - Present
Moorabool Reservoir	87045	1912 - Present
Smeaton	88113	1968 - Present
White Swan Reservoir	89048	1953 - Present
Addington	89106	1991 - Present
Beaufort	89005	1922 - Present
Campbelltown	88011	1889 - Present
Lillicur	88137	2002 - Present
Majorca	88160	1987 - Present
Talbot	88056	1898 - Present

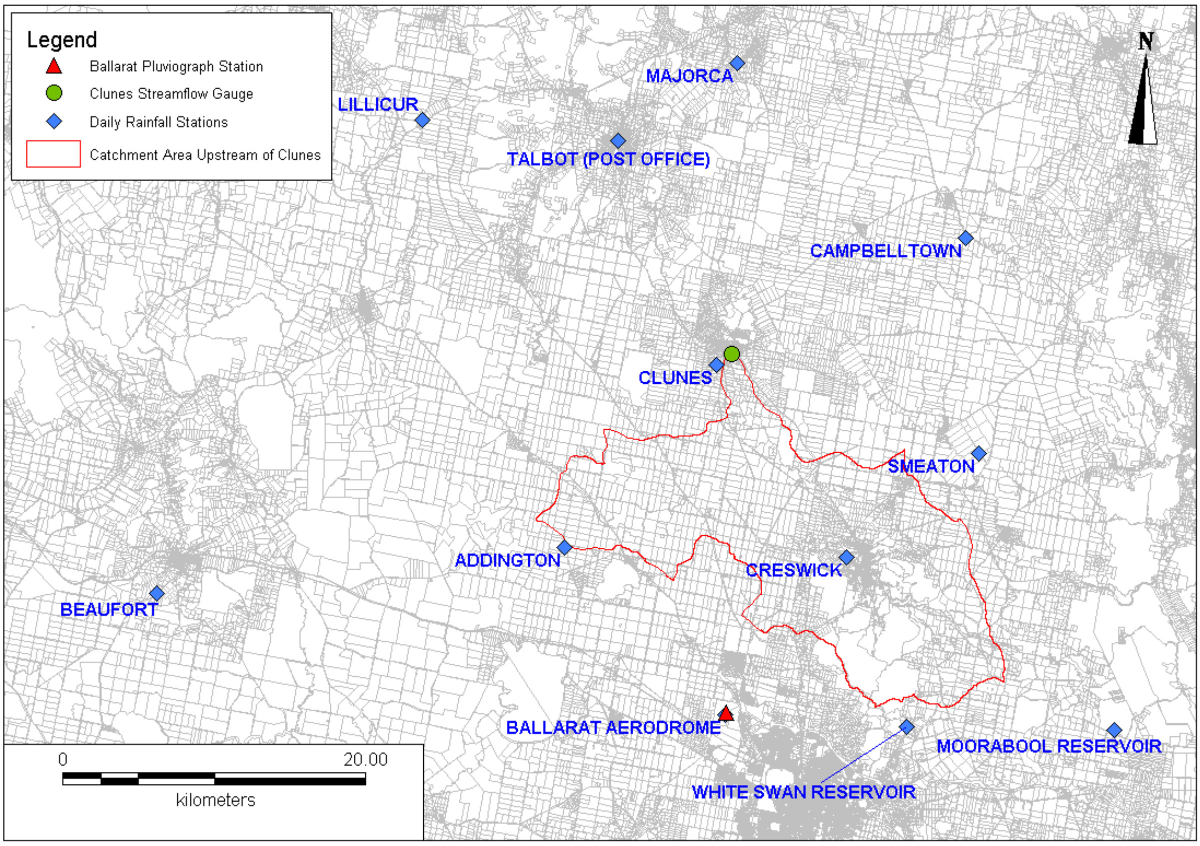


Figure 2-2 Location of rainfall stations and streamflow gauges for this study

2.5 Storage Data

There are two main water storages located along Creswick Creek, just upstream of Creswick:

- Cosgrave Reservoir - A 680 ML capacity reservoir managed by the Central Highlands Water Authority. Cosgrove Reservoir receives water pumped from Newlyn Reservoir, which is then transferred into White Swan Reservoir at a maximum rate of 2.5 ML/day.
- St Georges lake - A recreational waterbody managed by Parks Victoria, located downstream of Cosgrave Reservoir. This is a much smaller storage with an estimated capacity of 200 ML.

It is important to incorporate the main storages within the hydrological model as they can have an impact on downstream hydrographs. Central Highlands Water and Parks Victoria were contacted to provide information on the respective storages. The data available for the two storages is shown below. There is a lack of recorded data for the storages, particularly for St Georges Lake.

- Cosgrave Reservoir
  - Storage capacity
  - Stage-storage relationship
  - Gauged water levels
- St Georges Lake
  - Approximate depth
  - Storage capacity
  - Primary and secondary spillway details

2.6 Other Background Data

High resolution (1 m) aerial images of Creswick were sourced from NearMap. For flood mapping, the most recent aerial imagery (20th January 2011) was used in this study.

Other background data was made available for the study, including:

- Numerous photos of the flood events including aerial imagery of the September floods;
- Video of the September and January flood event;
- Flood mark levels, for the January event, at various locations in the township (survey undertaken by the North Central CMA);
- Floor level survey of a number of properties in town;
- 10 m contour dataset; and
- Cadastral information sourced from DSE.

This data was used during model set-up, calibration and result presentation.

3. PROJECT CONSULTATION

3.1 Overview

A key element in the development of a flood mitigation plan for Creswick was the active engagement of residents in the study. This engagement was developed over the course of the study through several different means including community information sessions, a public questionnaire, media releases and meetings with the Technical Working Group and community based Steering Committee. The community consultation sessions were largely managed by the North Central CMA and Hepburn Shire Council. The aims of the community consultation were as follows:

- To raise awareness of the study and to identify key resident and community concerns.
- To provide information to the community and seek their feedback/input regarding the study outcomes including the existing flood behaviour and proposed mitigation plan for the township.

3.2 Technical Working Group and Steering Committee Meetings

A Technical Working Group (TWG) was developed and tasked with reviewing and providing input over the technical aspects of the study. Eight meetings were conducted with the TWG at key hold points throughout the study. The technical working group comprised of representatives from North Central CMA, Hepburn Shire Council, DSE, SES, VICROADS and Parks Victoria.

The TWG was also developed to support and provide information to the Steering Committee, which comprised of community representatives from the local area. The Steering Committee was responsible for reviewing and providing feedback at each stage of the project,

3.3 First Community Information Session

An initial community information session was held on 11th March 2011 discussing results from a preliminary hydraulic analysis undertaken, commenting on the creek clearing works undertaken in February 2011 and outlined future plans/outcomes for the Creswick Flood Mitigation Plan and Urban Drainage Study. Community feedback regarding the recent floods and resident's concerns regarding flooding was also collated at this meeting.

3.4 Second Community Information Session

A second community consultation session was held on 11th August 2011 with over 50 residents in attendance. The information session provided updates on the progress of the Creswick Flood Mitigation Plan, focusing on the proposed flood mitigation options. This consultation session was also used to present the initial Emergency Response Plan to residents.

The first part of the session involved a presentation of the study findings to the residents. The hydrology results, design flood maps and two proposed mitigation options were all presented to the community. This was followed by a more informal open discussion session. Discussions and contributions from the residents over the choice of mitigation works revealed that deepening/widening Creswick Creek was preferred over a levee solution for the town.

3.5 Community Questionnaire

The first community questionnaire was distributed to local residents during the first consultation session to seek information regarding knowledge of the recent September 2010 and January 2011 floods and an understanding of community concerns regarding the key flooding issues in Creswick.

A second questionnaire was distributed during the second consultation session. The questionnaire covered the following key issues:

- Acceptable level of protection for the township; The majority of respondents agreed that protection up to the recent January flood event was acceptable.
- Preferred mitigation option between channel works or raised levee banks; The feedback was largely supportive of channel works. Most respondents were not in favour of levees but some did acknowledge that some levee works may be necessary to protect specific areas.

4. HYDROLOGIC ANALYSIS

4.1 Overview

A hydrologic model of the catchment was developed for the purpose of extracting flows to be used as boundary conditions to the hydraulic model. The rainfall-runoff program, RORB was utilised 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. Observed or design storm rainfall is input to the centroid of each subarea. Specific losses are then deducted, and the excess routed through the reach network.

The following methodology was applied for the RORB modelling:

- Creswick Creek catchment area upstream of Clunes delineated;
- Catchment divided into subareas based on the site's topography and required hydrograph print (result) locations;
- RORB model constructed using appropriately selected parameters including reach types, slopes and subarea fraction impervious values;
- Storm files for the September 2010 and January 2011 events were constructed;
- RORB model parameters were calibrated to the observed 'Creswick Creek @ Clunes' stream flow hydrograph for the September 2010 and January 2011 events;
- Design loss parameters were adopted;
- Design flood events for the 5, 10, 20, 50, 100 and 200 year ARI events were run for multiple durations; and
- Hydrographs were extracted from RORB for use as inflow boundaries to the hydraulic model;

Design hydrographs were extracted at the following locations:

- Creswick Creek upstream of Creswick (Downstream of the Creswick Creek and Slaty Creek confluence);
- Nuggetty Gully;
- Sawpit Gully; and
- Unnamed tributary, upstream of the railway crossing in Creswick.

4.2 RORB Model Construction

4.2.1 Subarea and Reach Delineation

The RORB model included the entire catchment of Creswick Creek upstream of Clunes. The RORB model covers a catchment area of approximately 311.3 km^2, with approximately 85 km^2 upstream of Creswick.

The RORB model was constructed using MiRORB (MapInfo RORB tools), RORB GUI and RORBWIN V6.0. Initially a catchment boundary was delineated from the available 10 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. The RORB model included 114 sub-areas. Figure 4-1 below shows the RORB sub catchment delineation for the study area.

Nodes were placed at areas of interest, the downstream end of every sub-catchment and the junction of any two reaches. Nodes were then connected by RORB reaches, each representing the length, slope and reach type. Reach slopes were calculated using a digital elevation model (DEM) created from the 10 m contours.

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 the storages. All other reaches were set to natural, representative of the open grassed areas and natural waterways in the catchment. A relatively small reach section through Creswick is lined, but changing this has a negligible impact on the broader catchment's hydrology. Figure 4-2 shows a graphical representation of the completed RORB model highlighting the reach types used.

4.2.2 Fraction Impervious Data

Fraction impervious values were calculated using MiRORB for each subarea. Default sub-area fraction impervious values were calculated based on the current Planning Scheme zones and then reviewed and amended as necessary based on recent aerial photos (from NearMap). The total imperviousness of the catchment was calculated to be 0.11, reflecting the predominantly rural nature of the catchment. The spatial distribution of the fraction impervious data is shown in Figure 4-3, showing the Creswick township having a higher fraction impervious than the broader catchment.

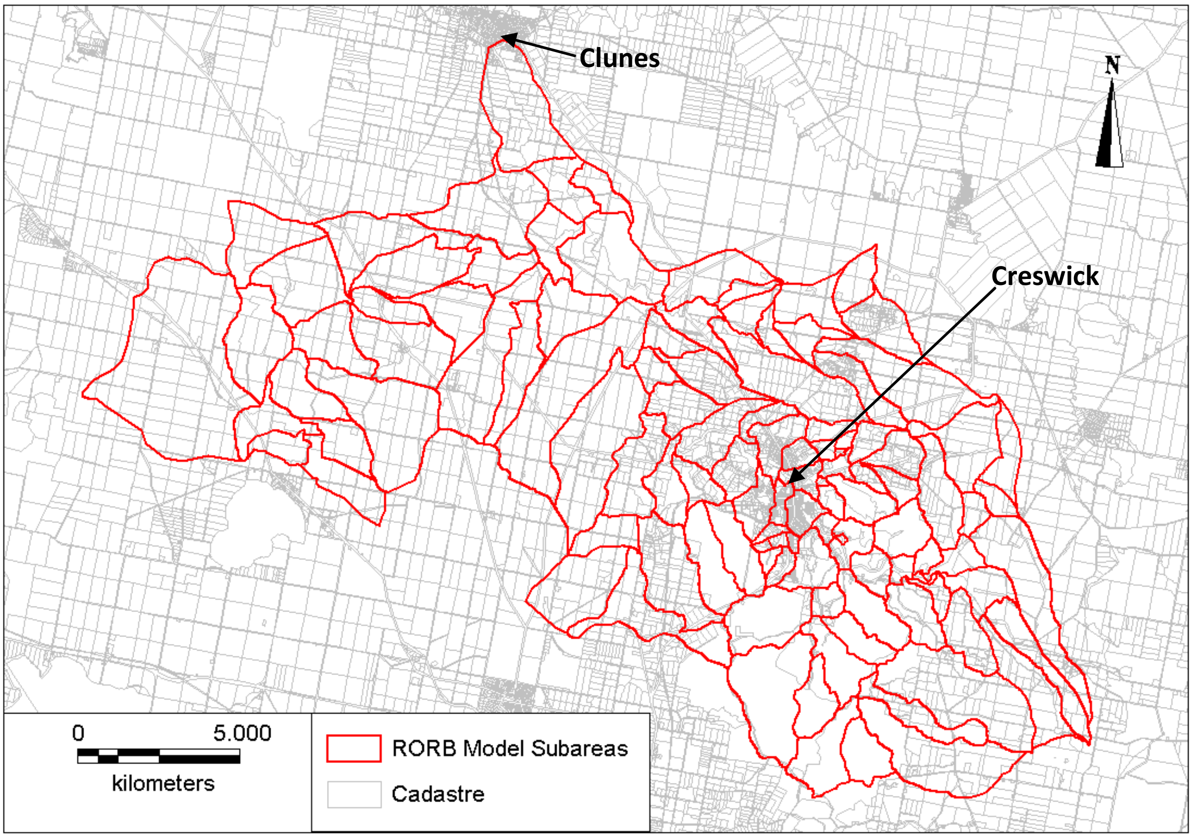


Figure 4-1 RORB model sub-area delineation

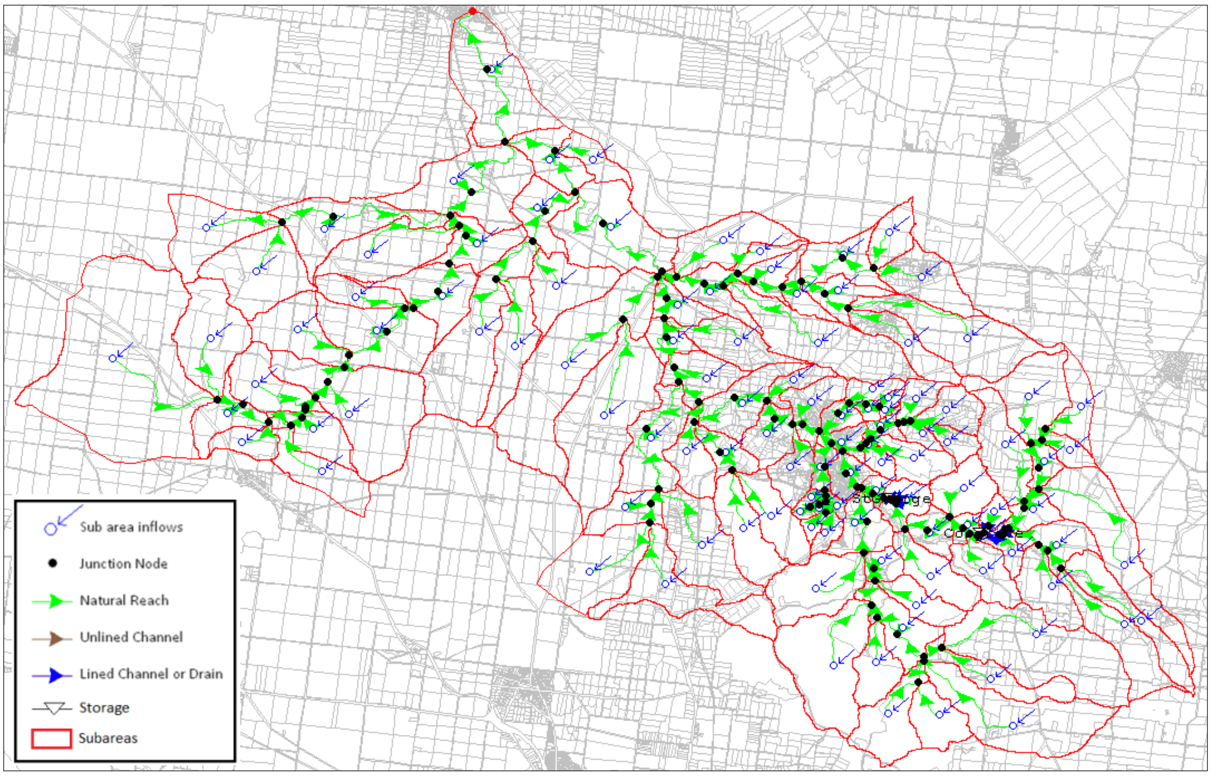


Figure 4-2 Graphical representation of the RORB model

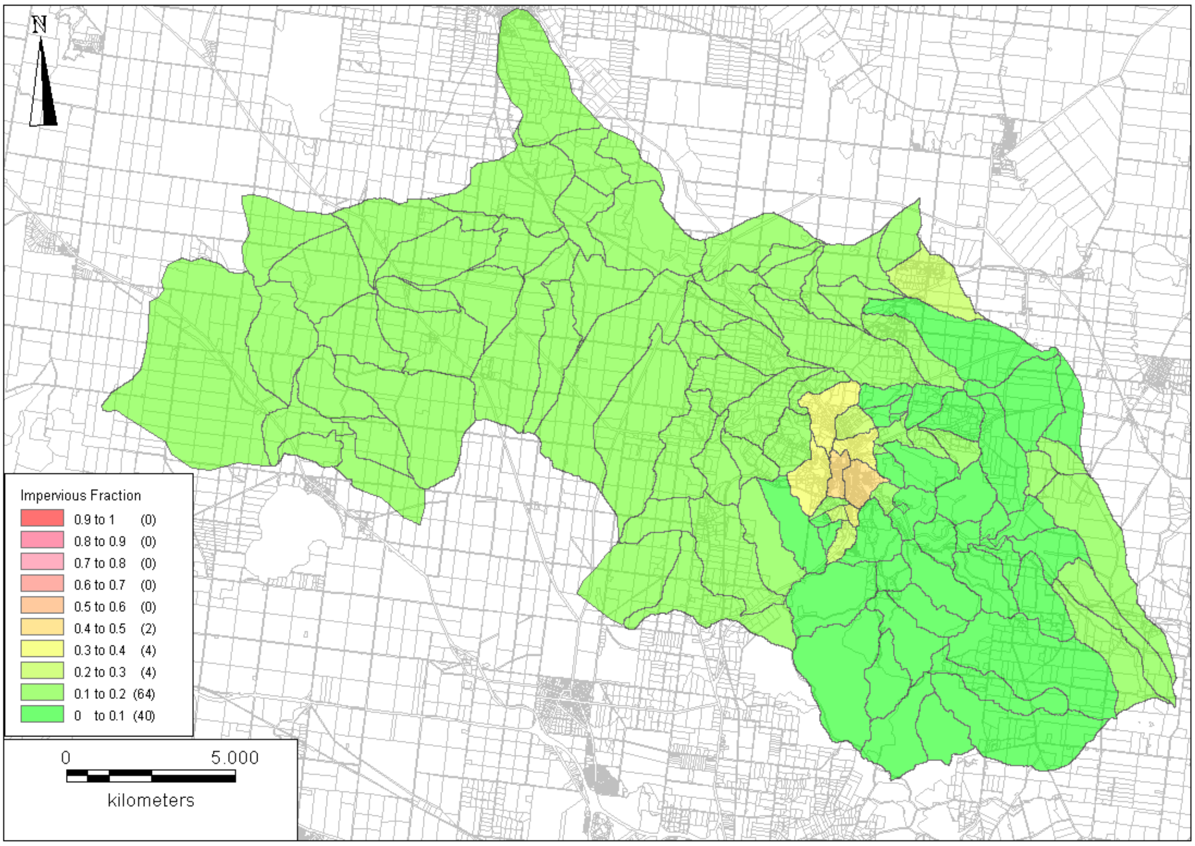


Figure 4-3 RORB model fraction impervious values

4.2.3 Storage Basins

The storages were defined in RORB using a stage-storage (H-S) relationship and a storage-discharge (S-Q) relationship. Cosgrave Reservoir has 680 ML of storage, while St Georges Lake has a smaller capacity at 200 ML. The available data from Central Highlands Water and Parks Victoria was useful in defining the storage capacity but not the outflow rate. A lack of stage discharge rating curves meant that discharge relationships were based on theoretical computations given the outlet arrangement. The spillway length (45 m) for Cosgrave Reservoir was estimated from the site visit. Analysis of the water levels in Cosgrave Reservoir (Figure 4-4) shows that the reservoir was full prior to the September flood event and remained full throughout January. As such the 680 ML reservoir would have had little impact on attenuating peak flows in Creswick during this period. No levels have been provided for St Georges Lake but given that the lake is immediately downstream (approx. 3.3 km) of Cosgrave Reservoir which filled by mid-August 2010, it is likely that St Georges Lake was also full prior to the floods. The RORB model calibration and design events were run with the storages set to full at the beginning of the simulation.

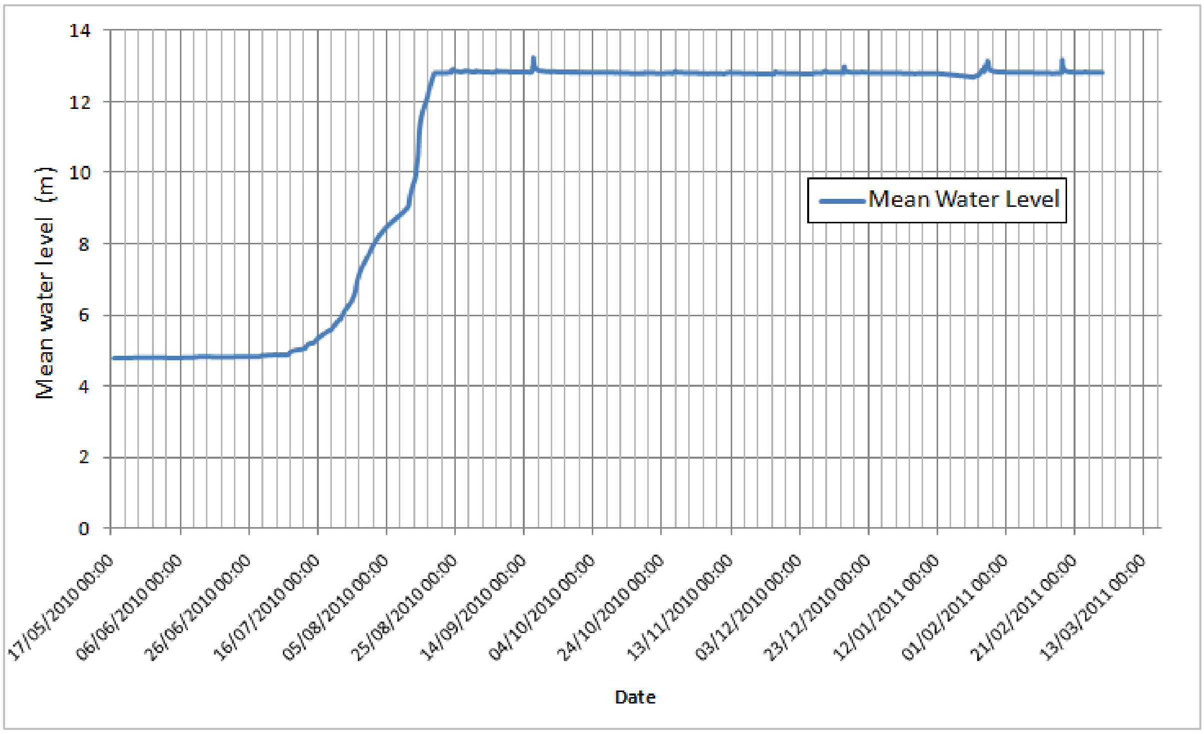


Figure 4-4 Cosgrave Reservoir water levels

4.3 RORB Model Calibration

4.3.1 Overview

The RORB model was calibrated to the September 2010 and January 2011 flood events. Calibration was based on the 'Creswick Creek @ Clunes' streamflow gauge.

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

4.3.2 RORB Model calibration event data

Observed Stream Flow Data

The only active streamflow gauge in the region was the "Creswick Creek @ Clunes" gauge. Instantaneous flow data from the Clunes gauge was assessed to determine its suitability for use in the RORB model calibration.

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 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.

To fill in the flow gaps, Thiess were contacted to provide an extrapolated rating curve. Given the request, Thiess derived a new rating curve for the station using standard industry practices. The new rating table was developed to obtain flows at the higher water levels seen during the September and January events. As seen in Figure 4-5 the new rating curve differs from the previous curve for levels above 1.9 m. This may be due to changes in level/flow characteristics of the measurement site over time or changes in Thiess methodology for calculating a rating curve at this site (previous rating dated from September 1996).

The missing flows during the event peaks were calculated using the new rating curve. Additionally all recorded flows corresponding to water levels above 1.9 m were updated using the new rating curve relationship. The recorded hydrographs at Clunes for September and January events are shown in Figure 4-6 and Figure 4-7 respectively.

In September, the observed hydrograph at Clunes had three distinct peaks which occurred on Saturday, 4th September 2010. The first peak was recorded at 6:30 am Saturday morning and later on the same day two higher peaks were observed at 12:00 pm and 4:00 pm. The peaks correspond with a recorded 0.64 m drop in water level between 12:00 pm and 4:00 pm on Saturday, however no anecdotal evidence was found to confirm this.

During the January 2011 event, the observed hydrograph at Clunes recorded two distinct peaks; a small rise on Wednesday evening, 12th January 2011, and a second much higher peak on the morning of Friday the 14th of January 2011, following successive days of heavy rainfall.

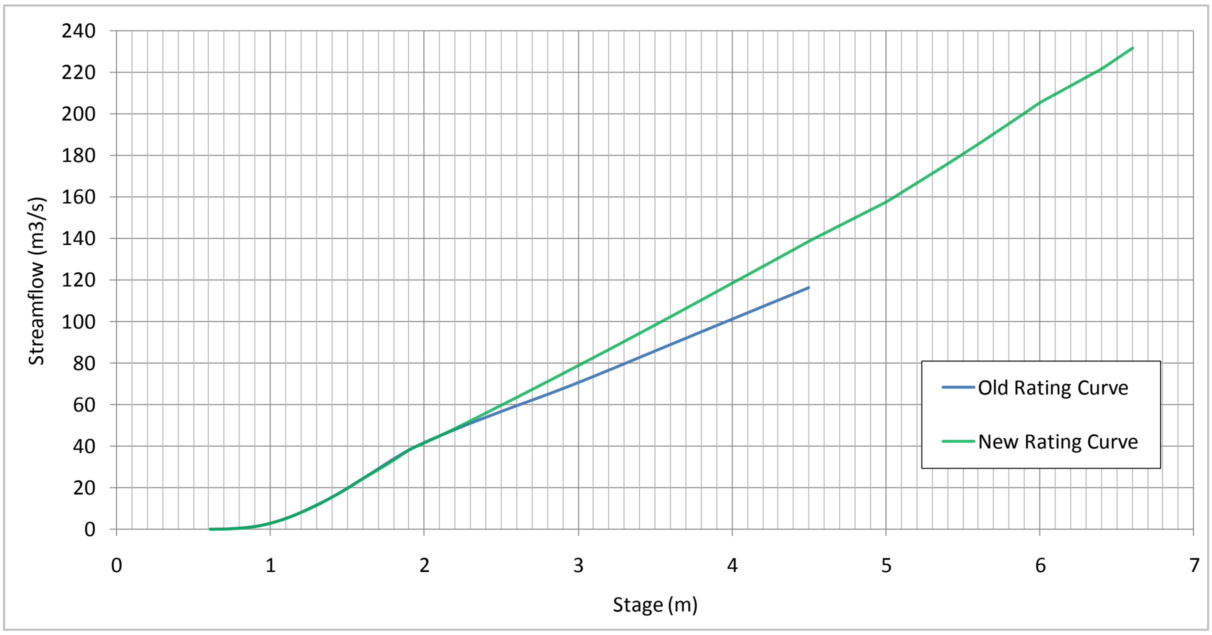


Figure 4-5 Creswick Creek @ Clunes gauge rating curve

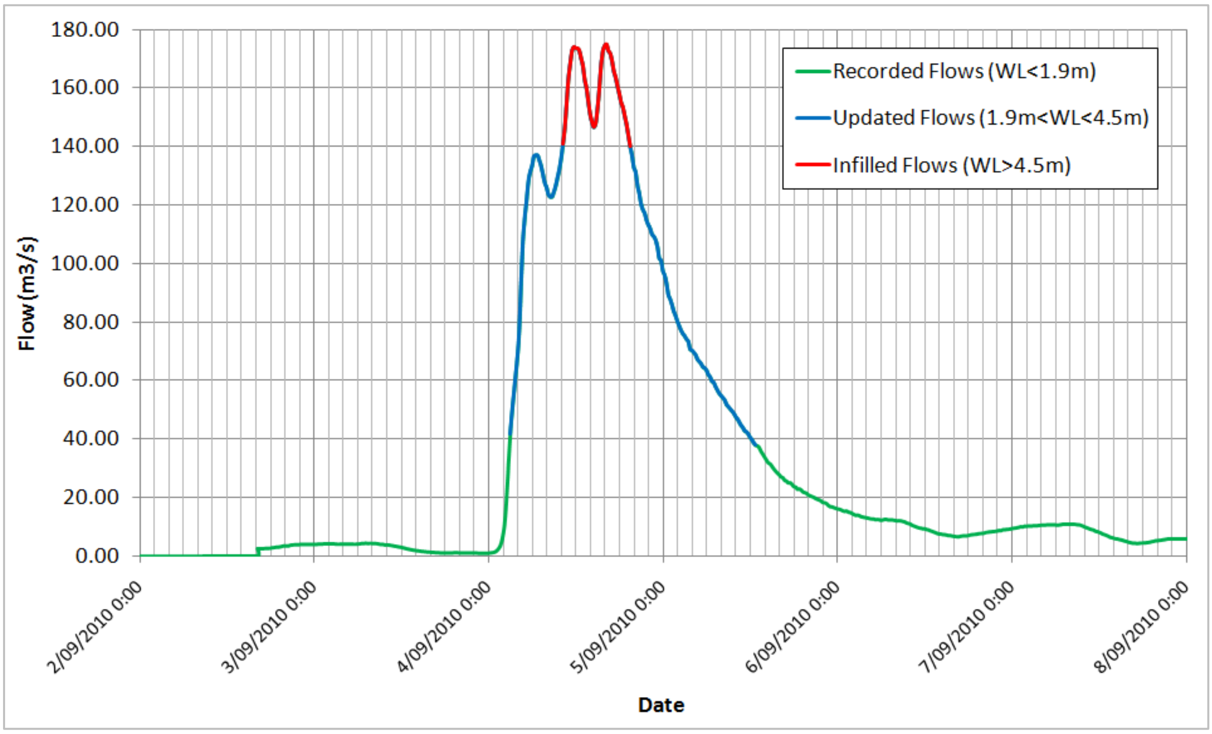


Figure 4-6 Creswick Creek @ Clunes flow hydrograph – September 2010

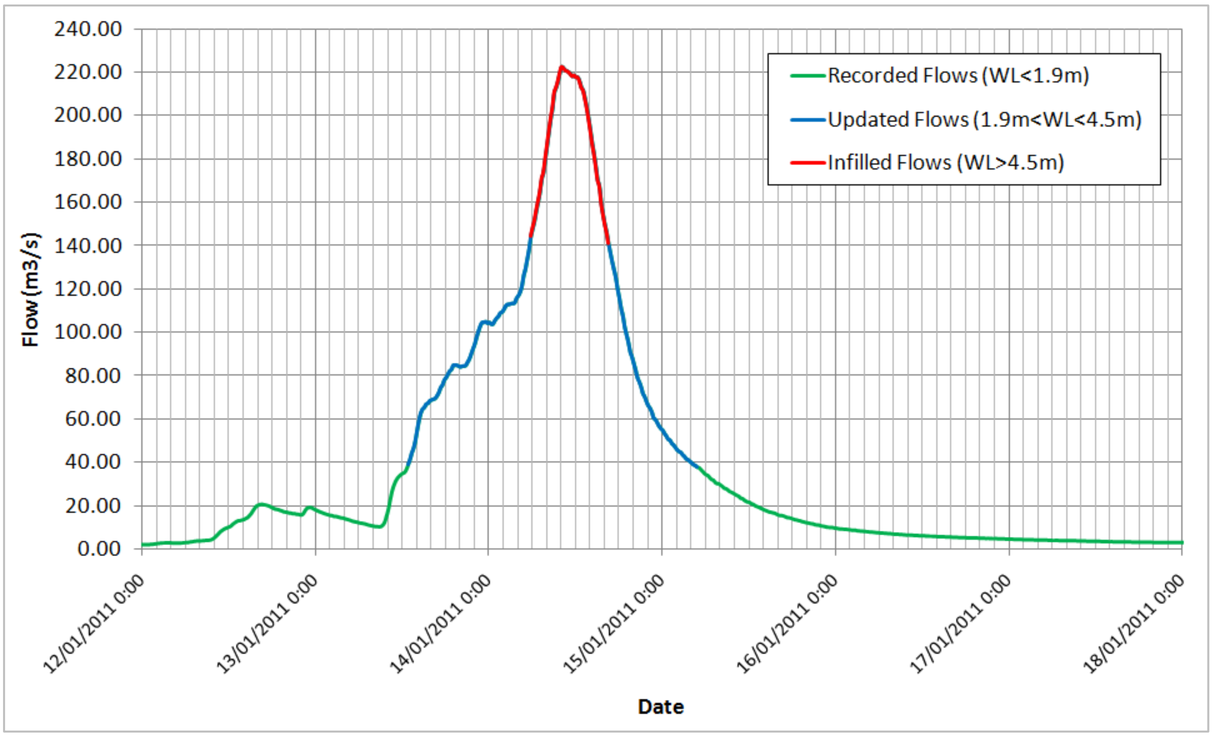


Figure 4-7 Creswick Creek @ Clunes flow hydrograph – January 2011

Observed Rainfall Data

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 the January 2011 event, a multi burst approach was adopted. The following points summarise the rationale behind adopting a multi burst approach:

- The rainfall event ran over four days, with daily rainfall totals across the catchment varying over the event;
- The Ballarat pluviograph (Figure 4-9) shows two separate rainfall events during the January flood event. The events were separated by a 16 hour period of no rainfall; and,
- The hydrographs recorded at Clunes show a multi-peaked hydrograph. Multi-peaked hydrographs are often easier to replicate using a multi burst approach.

Whilst the September rainfall event ran overnight across two days, it was a continuous rainfall record and was modelled as a single burst in RORB.

The rainfall depth for each subarea was estimated using storm event rainfall isohyets. Three rainfall isohyets were created, one for the single burst in September and two for the double bursts in January.

The temporal rainfall distribution was determined using the rainfall pattern from the Ballarat pluviograph. Figure 4-8 and Figure 4-9 display the pluviographs for the September 2010 and January 2011 events. As the Ballarat gauge is on the other side of the divide, there is some uncertainty in the appropriateness of this temporal pattern for the Creswick Creek catchment, however this is the nearest and considered to be the best available data for the study area.

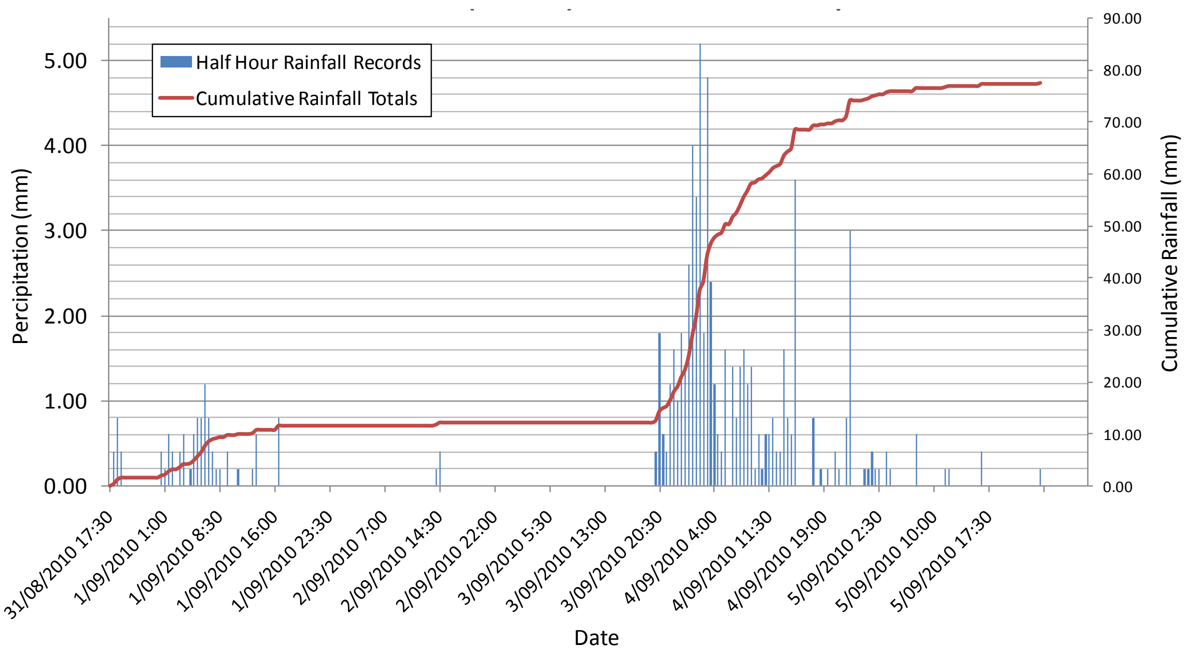


Figure 4-8 **Ballarat Aerodrome (089002) pluviograph – September 2010**

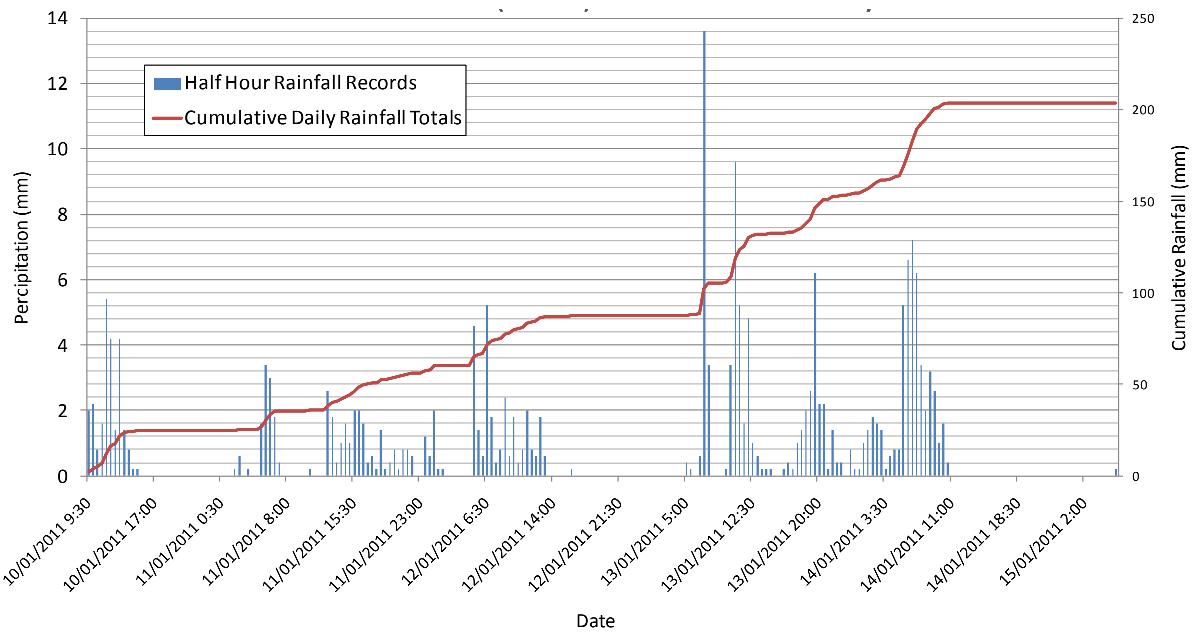


Figure 4-9 **Ballarat Aerodrome (089002) pluviograph – January 2011**

4.3.3 RORB Model Calibration Parameters

RORB requires the calibration of three model parameters (Kc, initial loss and continuing loss). 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 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 January vary with time, decreasing from the first to the second burst.
- A continuing loss (CL) was selected to achieve a reasonable fit between the modelled and observed hydrograph volumes. The CL remains constant across the separate January bursts.
- 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. Because both events had similar antecedent conditions and were of a similar magnitude at Creswick, it was decided to use a constant kc value for both events.

Details of the selected calibration events are provided in Table 4-1 below.

Table 4-1 RORB model calibration event summary

Event	Event Start & Finish Date	Average Catchment Rainfall (mm)	Recorded Peak Flow at Clunes Gauge (m^3/s)
September 2010	03/09/2010 8:00pm - 06/09/2010 12:00am	83.5 mm (over a 36 hour period)	174.6
January 2011	11/01/2011 10:30am - 15/01/2011 23:30pm	166 mm (over a 3 day period)	222.4

4.3.4 RORB Model Flood Event Calibration

The calibration results are summarised in Table 4-2 and Table 4-3. Figure 4-10 and Figure 4-11 display the modelled and observed flood hydrographs for the calibration events at the 'Creswick Creek @ Clunes' gauge.

Table 4-2 RORB model calibration parameters – September 2010

September 2010	kc	IL	CL	Peak flow (m^3/s)	
				Observed	Calculated
	29.2	24	1.8	174.6	174.5

Table 4-3 RORB model calibration parameters – January 2011

January 2010		Burst 1		Burst 2		Peak flow (m^3/s)	
	kc	IL	CL	IL	CL	Observed	Calculated
	29.2	40	1.8	24	1.8	222.4	222.3

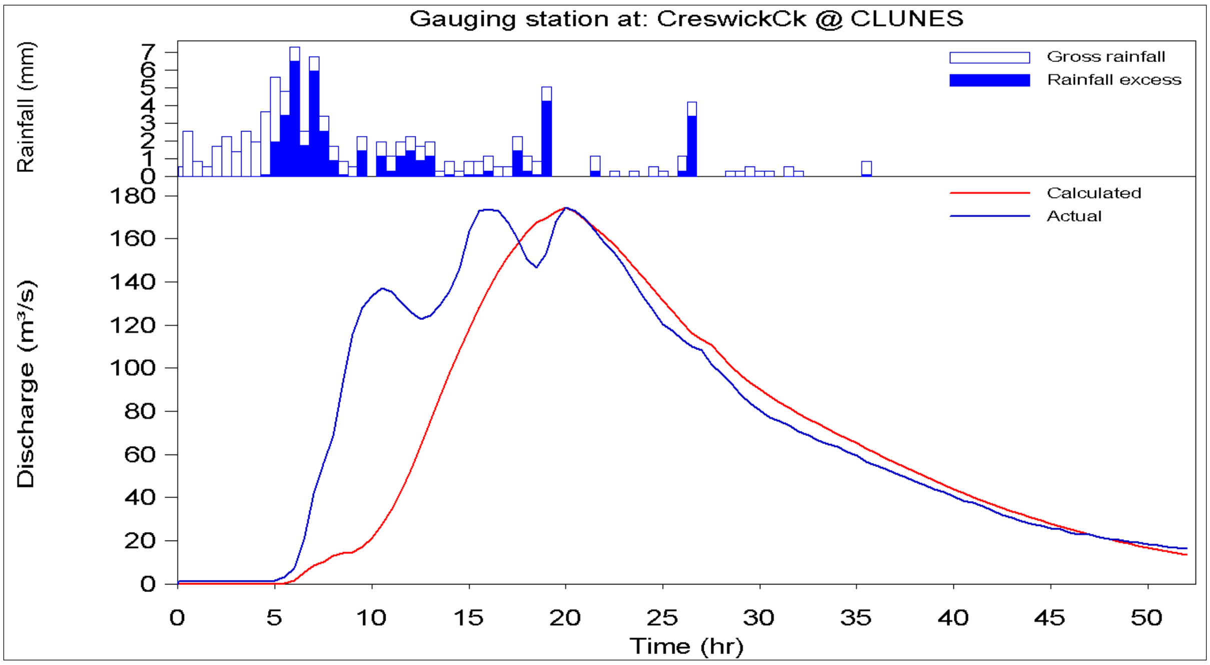


Figure 4-10 RORB model calibration hydrograph – September 2010

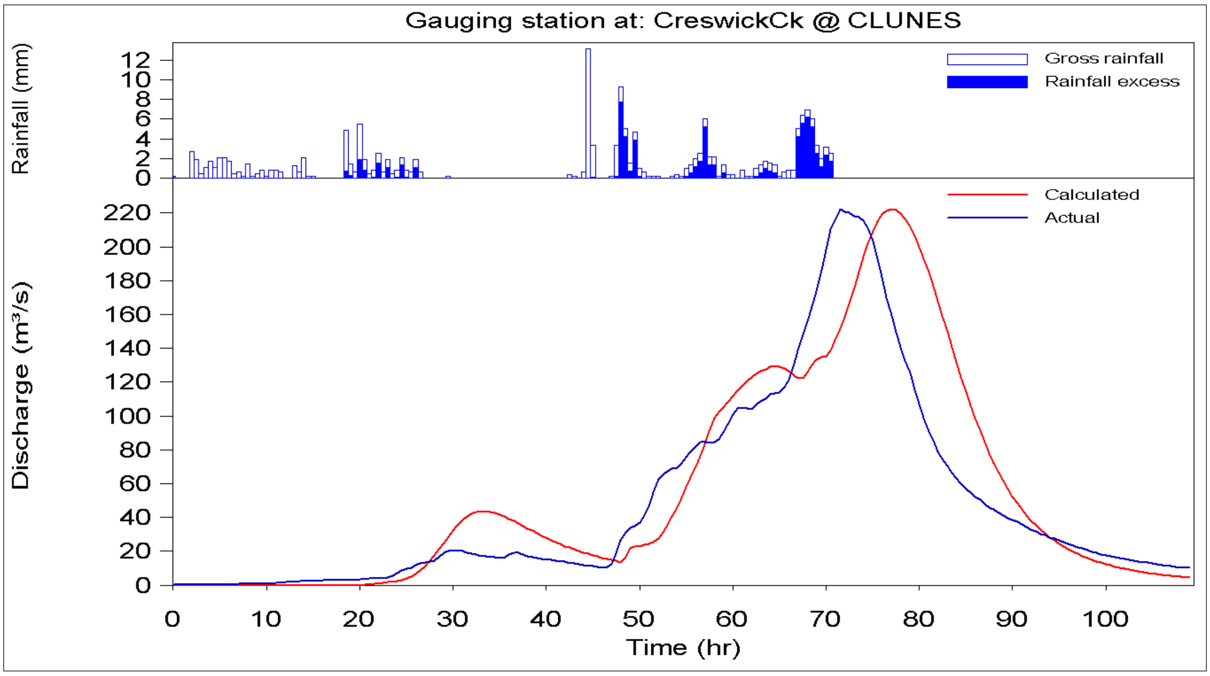


Figure 4-11 RORB model calibration hydrograph – January 2011

4.4 Discussion

4.4.1 September 2010 Flood Event Calibration

For the September 2010 event, the calibration of the modelled hydrograph to the observed hydrograph provided a match to peak flow but failed to reproduce the multiple peaks observed at Clunes. The multiple peaks at Clunes were most likely associated with isolated thunderstorms across the catchment, which is not reflected in the available pluviograph at Ballarat. It is extremely difficult to reproduce these multiple peaks without spatial and temporal rainfall data inside the catchment. Also there is some doubt as to whether the two higher peaks actually occurred. There is no record of this in any discussions with residents or media articles suggesting that the creek dropped 0.6 m then rose again. This was investigated with North Central CMA and Hepburn Shire Council staff, and no one could verify if this multiple peak actually occurred.

Comparisons between the observed and modelled hydrographs showed that:

- The modelled hydrograph had a flatter rising limb, resulting in lower volumes than the observed hydrograph;
- The peak of the modelled hydrograph matched the observed peak; and,
- The recession of the modelled hydrograph fitted the recession of the observed hydrograph well.

The area of interest for this study was at Creswick. The calculated RORB hydrograph at Creswick peaked at approximately 7:00 am, earlier than the anecdotal evidence suggesting the creek overtopped its banks around 9:00 am with inundation of the township through till about 4 pm. This is most likely due to differences in the timing of the rainfall between the Ballarat Aerodrome pluviograph and the rainfall falling in the catchment upstream of Creswick.

4.4.2 January 2011 Flood Event Calibration

For the January event, the modelled hydrograph at Clunes reproduced the peak flow and general hydrograph shape reasonably well but there was a time lag in the modelled and observed peaks. The initial burst of the calculated hydrograph was higher than that observed at Clunes however overall volumes matched reasonably well.

4.4.3 Inflow Hydrographs at Creswick

Hydrographs were extracted from the calibrated models at various points of interest in Creswick. The extracted hydrographs from September 2010 and January 2011 are shown in Figure 4-12 and Figure 4-13 below.

At Creswick, similar magnitude flows were recorded during the September 2010 and January 2011 events. The peak flow in January 2011 was approximately 10% higher than in September 2010, consistent with the heavier rainfall recorded in January.

During both flood events, the tributaries in Creswick peaked approximately three hours before Creswick Creek started to peak.

Table 4-4 Modelled peak flows in Creswick during the recent flood events

Location	4th of September 2010		14th of January 2011	
	Modelled Peak Flow (m^3/s)	Modelled Peak Time	Modelled Peak Flow (m^3/s)	Modelled Peak Time
Creswick Creek @ Creswick	**93.8**	7:00 am	**100.2**	10:30 am
Saw Pit Gully	**15.8**	4:30 am	**15.4**	8:30 am
Nuggetty Gully	**6.4**	4:00 am	**5.5**	8:00 am
Unnamed Tributary	**5.4**	4:00 am	**5.2**	8:00 am

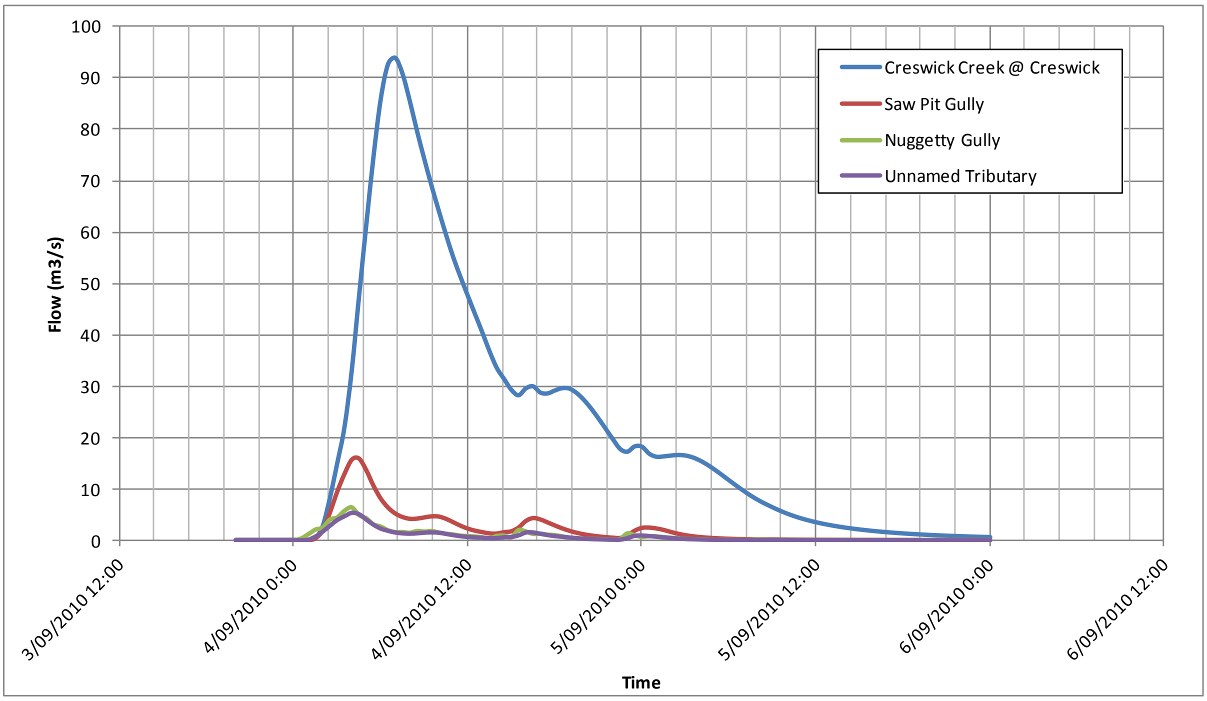


Figure 4-12 Flood hydrographs in Creswick – September 2010

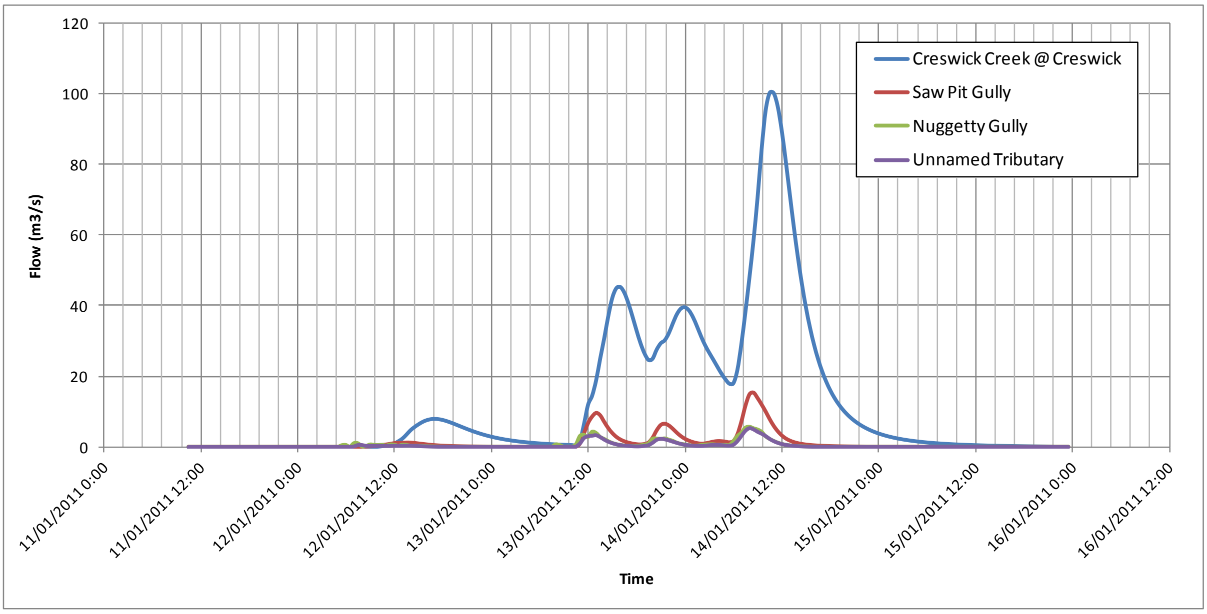


Figure 4-13 Flood hydrographs in Creswick – January 2011

4.4.4 Using Existing Storages as Retarding Basins

As discussed previously in Section 4.2.3, Cosgrave Reservoir and St Georges Lake were full prior to the September 2010 and January 2011 flood events. To check the feasibility of utilising these storages for flood protection, the initial storage water levels in the RORB model were drawn down and the model re-run for the September 2010 and the January 2011 events.

In order for Cosgrave Reservoir and St George Lake to function as effective retarding basins, a control structure (usually an outflow pipe) is required at the outlet. The control structure allows outflows to vary gradually with any change in water level. Given the size of Cosgrave Reservoir, it is likely that there are a number of outlet pipes. Central Highlands Water was contacted to obtain information on the outlet configuration for Cosgrave Reservoir. The response was that the exact capacity of the outlet structure is unknown, but is quite limited. The outlet structure for Cosgrave Reservoir does not allow for rapid drawdown of the reservoir storage levels. Similarly, information collected for St Georges Lake indicated that the lake had an outlet conduit however its exact location and configuration was also unknown.

To enable testing of the reservoirs as retarding basins, a nominal outlet pipe size (225 mm) was selected with overflows discharging from the spillways. Four separate scenarios were considered for the September 2010 and January 2011 events. The four scenarios investigated included:

- Scenario 1: Both storages drawn down completely
- Scenario 2: Both storages drawn down to 50%
- Scenario 3: Cosgrave Reservoir drawn down completely and St Georges Lake full
- Scenario 4: St Georges Lake drawn down completely and Cosgrave Reservoir full

The impact of storage drawdown on peak flow in Creswick Creek is shown below in Table 4-5.

Table 4-5 Effects of storage reservoirs on peak flows in Creswick Creek upstream of Creswick

Scenario	Description	September 2010 Peak Flow (m^3/s)	January 2011 Peak Flow (m^3/s)
Historic	As was the case during the recent events	93.8	100.2
Scenario 1	Cosgrave and St George 100% drawdown	53.2	94.0
Scenario 2	Cosgrave and St George 50% drawdown	58.7	94.1
Scenario 3	Cosgrave 100% drawdown, St Georges full	58.5	94.4
Scenario 4	Cosgrave full, St George 100% drawdown	93.8	94.4

The combined use of both storages for flood protection (100% drawdown) provides a significant (43%) peak flow reduction in Creswick Creek during the September 2010 event, but only a 6% reduction for the January 2011 event. The results show a greater reduction in peak flows during the September 2010 flood presumably due to the shorter more intense storm event. Using the storages as flood mitigation during the January 2011 event had little impact on peak flows as the reservoirs were effectively full from the few days of heavy rainfall preceding the peak of the flood event.

In summary Cosgrave Reservoir does provide some benefit as a retarding basin provided that the reservoir is drawn down prior to the peak of the flood event. This may have an impact for events of similar intensity and duration as the September 2010 event, but for events such as the January 2011 event will have very limited impact. St Georges Lake does not provide sufficient peak flow attenuation and is not seen as a feasible option for flood storage.

4.5 Design Event Modelling

The goal of the RORB model design runs 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 the storages set to full, consistent with conditions during the September 2010 and January 2011 events. The inputs for the design flood estimation are described below.

4.5.1 Design Rainfall

Design rainfall depths

Design rainfall depths were determined using the IFD methodology outlined in AR&R Volume 2, 1987. The IFD parameters were generated for a location in Creswick (143.8947E, -37.42404S) and are shown in Table 4-6 below.

Table 4-6 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
19.96	4.03	1.16	40.23	7.97	2.15	0.33	4.33	14.87	2

Design temporal pattern

The temporal patterns used in the design events were 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.

Creswick sits close to the boundary of Zone 1, 2 and 6. Zone 6 temporal patterns were not appropriate for Creswick and were excluded from the analysis. As a sensitivity test, the design temporal patterns for Zone 1 and Zone 2 were compared to the observed temporal patterns of the September 2010 and January 2011 events. The 30 hour duration was selected for comparison as it represented the duration of the observed flood events. A comparison of the temporal patterns is shown in Figure 4-14 below.

Both observed events had varying temporal patterns. The results showed that the Zone 2 temporal pattern matched the September 2010 temporal pattern reasonably well, but neither design temporal patterns matched the January 2011 flood event.

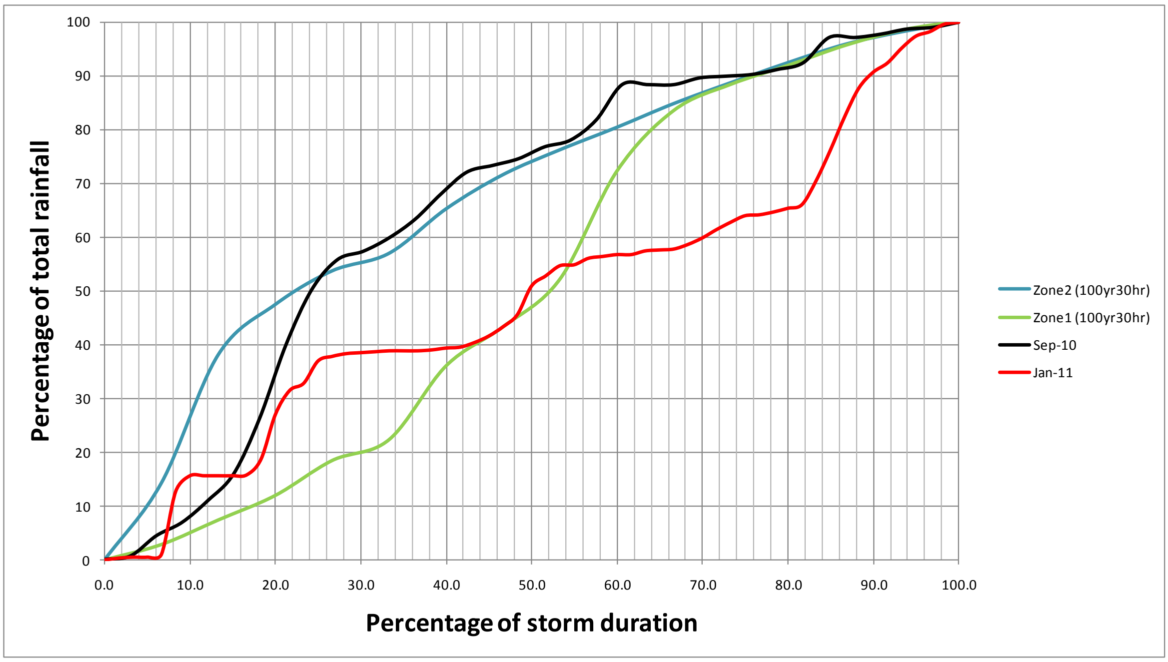


Figure 4-14 Design and observed temporal pattern comparison

As a further test, the RORB model was rerun using Zone 1 temporal patterns. A comparison of flood peaks resulting from the two temporal patterns is shown in Table 4-7. Zone 1 temporal patterns resulted in a 34% increase in peak 100 year flows at Creswick compared to Zone 2 peak flows. In addition the hydrograph shapes and critical durations were different for both temporal patterns. Zone 1 temporal patterns produced a hydrograph that peaked later compared to the Zone 2 hydrograph (Figure 4-15).

Given that the Zone 2 temporal pattern matched the September 2010 temporal pattern and produced lower peak flows, this temporal pattern was adopted. Using the Zone 1 temporal pattern resulted in higher design flows and in turn lowered the ARI of the September 2010 and January 2011 events.

The Technical Steering Committee discussed this issue and decided that the Zone 2 temporal patterns were to be adopted for this study.

Table 4-7 Peak flow comparison for Zone 1 & 2 temporal patterns

	Creswick Creek at Creswick				
	Zone 2		Zone 1		Peak flow difference
ARI	Peak flow (m3/s)	Duration (hrs)	Peak flow (m3/s)	Duration (hrs)	
5	34.0	6h	75.0	12h	120%
10	56.1	6h	100.5	12h	79%
20	84.2	6h	134.1	12h	59%
50	129.4	6h	180.9	9h	40%
100	167.2	6h	224.3	9h	34%
200	209.5	6h	271.7	9h	30%

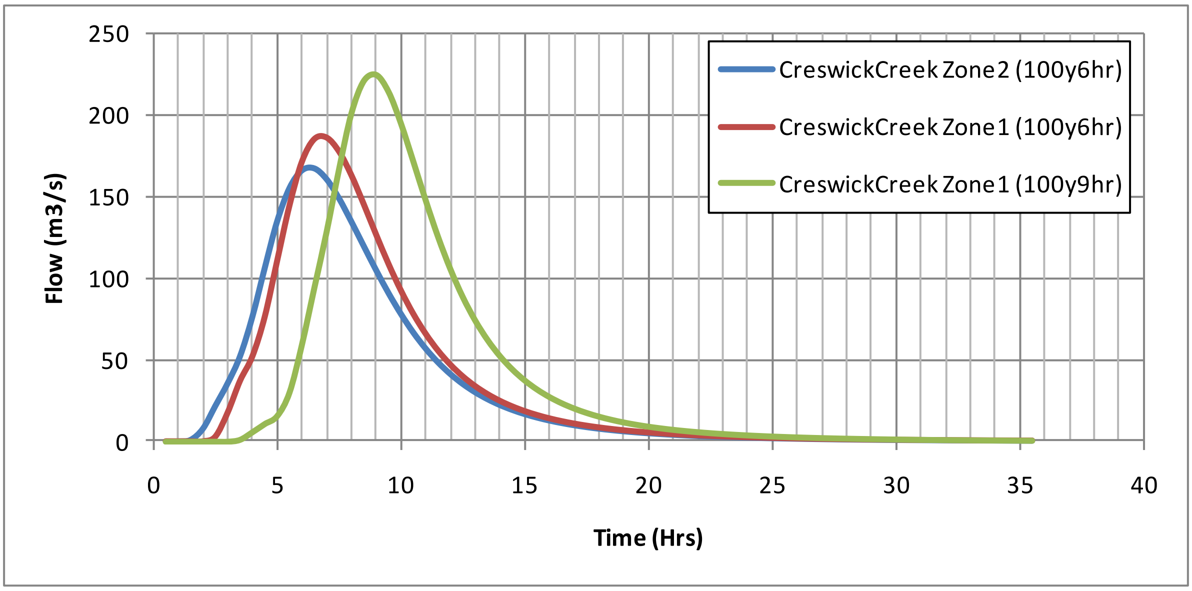


Figure 4-15 Temporal pattern hydrograph comparison

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.

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 upstream of Creswick, 85 km^2.

4.5.2 Design Model Parameters

Routing Parameters

Various regional kc estimation equations were trialled for the calibration process and a value of 29.2 was found to provide a good fit of the observed and modelled hydrographs. Table 4-8 shows a comparison between this study's adopted kc value and regional kc estimates. A final kc value of 29.2 and m value of 0.8 was adopted as routing parameters for the design flood estimation.

Table 4-8 Comparison of adopted kc and regional kc estimates

Source	kc value
Adopted kc	29.2
Regional Equation For Areas where Annual Rainfall <800mm (kc = $0.49*A^{0.65}$ Catchment area = 311.3 km^2)	20.5
MMBW (kc = $1.19*A^{0.56}$ Catchment area = 311.3 km^2)	29.6
DVA (kc = $1.53*A^{0.55}$ Catchment area = 311.3 km^2)	36.0

Design Losses

This study adopted an initial loss of 20 mm and a continuing loss of 2.5 mm as the design loss parameters. The loss parameters were applied across all ARI events and durations. The loss parameters adopted are consistent with design loss parameters as set out within AR&R 1987.

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.

4.5.3 Design Flood Hydrographs

Design flood hydrographs were determined at input locations into the hydraulic model. A range of storm durations were run (10min – 48hrs) to ensure the critical storm durations of the large branches and smaller tributaries were determined. Table 4-9 displays the calculated design peak flows and critical storm durations for various ARI events.

Table 4-9 RORB model design peak flows and critical storm durations at selected locations

	Creswick Creek at Creswick		Sawpit Gully		Nuggetty Gully		Unnamed Tributary U/S of Railway Line	
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	34.0	6h	5.6	4.5h	4.0	20m	1.9	4.5h
10	56.1	6h	8.4	6h	4.8	20m	2.7	4.5h
20	84.2	6h	12.1	4.5h	6.2	1h	4.0	48h
50	129.4	6h	18.1	3h	9.9	1h	6.0	48h
100	167.2	6h	23.6	3h	12.1	1h	7.6	3h
200	209.5	6h	29.3	3h	14.3	1h	9.4	3h

The design flows indicate that the September 2010 and January 2011 flood events were approximately 25 and 35 year ARI events respectively in Creswick Creek at Creswick.

4.5.4 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) allows the estimation of peak selected ARI flows based on a statistical analysis. An FFA was undertaken for the 'Creswick Creek @ Clunes' gauge to provide an estimate of the 100 year ARI flow at Clunes. An annual flood series was extracted from the available 68 years of instantaneous streamflow data, from 1943 to 2011. The first two years of data (1943 and 1944) is incomplete and was excluded from the analysis.

FLIKE was used to perform the FFA. FLIKE uses a different fitting procedure to that outlined in AR&R. 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. AR&R recommends the 'Log Pearson III' distribution for general use. A Flood Frequency Analysis using the 'Log Pearson III' distribution produced a poor fit to the Clunes annual flood series (Figure 4-16). As such, a second probability distribution, the 'Generalised Extreme Value (GEV)' distribution was trialled to obtain a better fit. The results of the GEV distribution FFA is shown in Figure 4-17. A peak flow comparison of the two distribution methods is summarised in Table 4-10.

The use of the GEV distribution method did not improve the fit of the results. The 'Log Pearson III' distribution was therefore adopted as the best fit 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 (325.8 m^3/s) as estimated from the RORB modelling. The large difference was 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. The estimated 100 year ARI flow from the RORB modelling still fell well inside the large confidence limits of the FFA.

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.

Table 4-10 FFA Peak ARI Flow Comparison

ARI (Years)	Peak Design flow (m3/s)	
	Log Pearson III	GEV
5	64.8	60.3
10	101.0	106.8
20	136.4	178.9
50	179.5	339.6
100	208.5	543.3
200	234.0	863.0

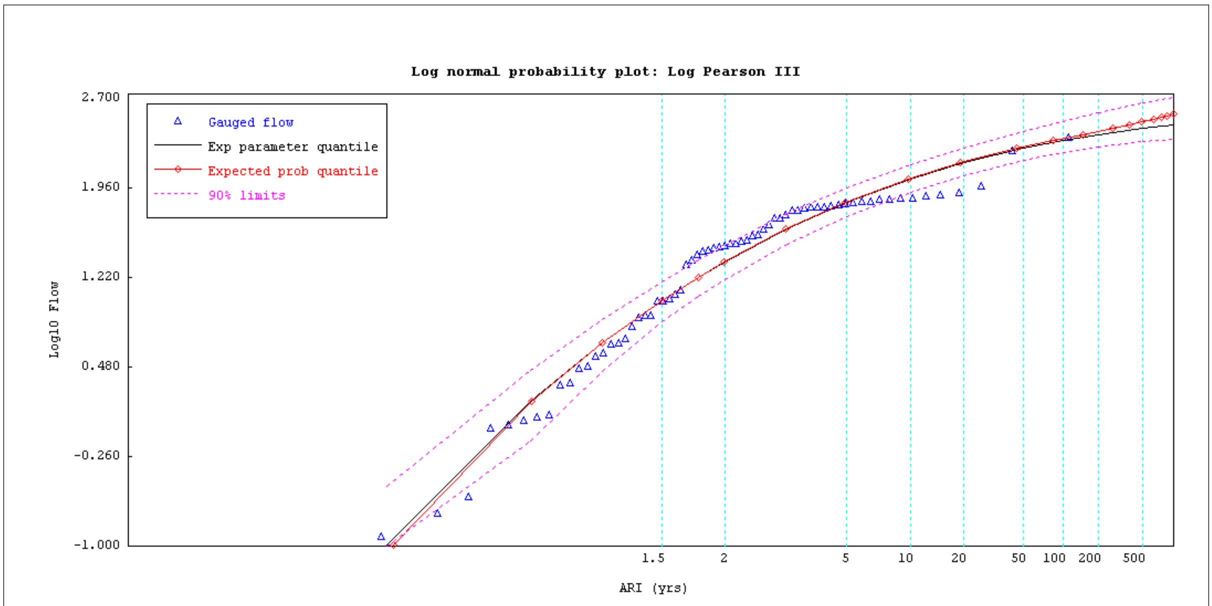


Figure 4-16 Log Pearson III flood frequency analysis – Creswick Creek @ Clunes

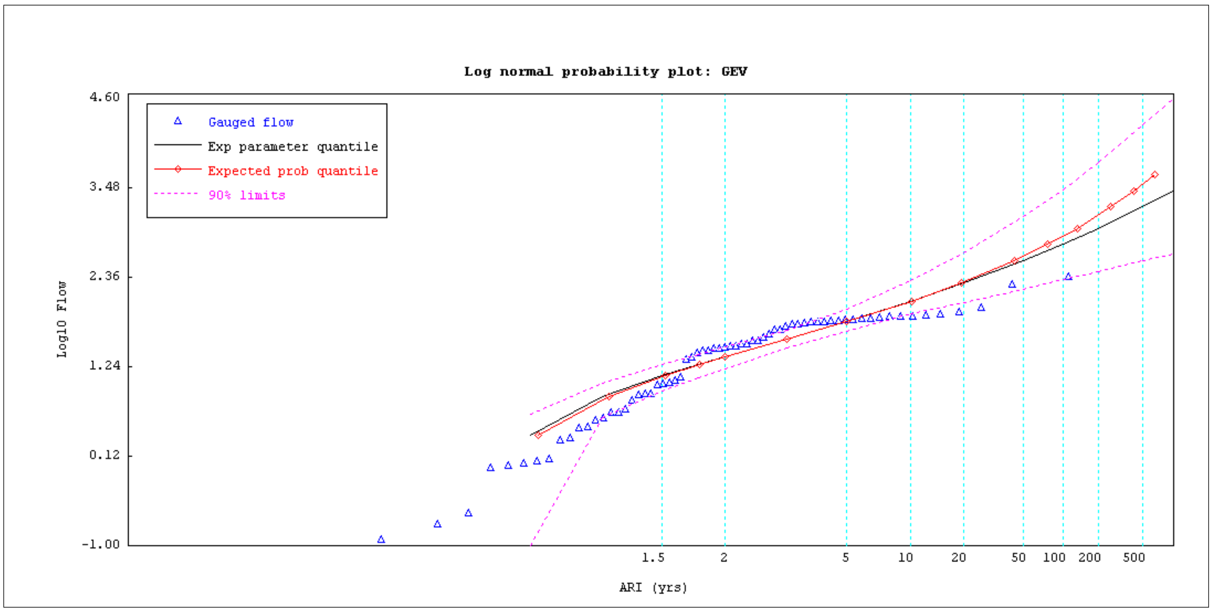


Figure 4-17 Generalised Extreme Value flood frequency analysis – Creswick Creek @ Clunes

Rational Method

A rational method calculation was performed as part of the preliminary hydraulic analysis carried out previously by Water Technology (Creswick Flood Information Draft Memo, 1st March 2011). The rational method estimated a considerably lower 100 year flow at Creswick of 74 m^3/s, compared to the design 100 year flow of 167.2 m^3/s.

Regional Method

The hydrological recipes – Estimation Techniques in Australian Hydrology (Grayson et al, 1996), provides a regional equation for the 100 year ARI event in rural catchments. The peak 100 year ARI design flow at Creswick 167.2 m^3/s) compared reasonably well to the regional method flow analysis of 156 m^3/s that was conducted as a part of the preliminary hydraulic analysis carried out previously by Water Technology (Creswick Flood Information Draft Memo, 1st March 2011).

Flow Comparison to Similar Catchments

Design flows generated at Creswick were compared to design flows from the neighbouring Yarrowee catchment. Yarrowee River's catchment is located to the south of Creswick Creek's catchment, separated by the Great Dividing Range. Yarrowee River flows to the south-west, crossing the Western Freeway before entering Ballarat. Land use in the Yarrowee River catchment, upstream of the Western Freeway, is a mix of cleared and forested land, reasonably similar to the rural conditions upstream of Creswick.

Design flows for the Yarrowee River catchment were sourced from the *Ballarat Urban Waterways Floodplain Mapping Report* (Water Technology November 2007). The design 100 year ARI flow for the Yarrowee River catchment is 70.4 m^3/s over a 45.4 km^2 catchment area. The Yarrowee River design flows were scaled, using an area weighted ratio to the power of 0.8, to Creswick Creek's catchment area, allowing flows to be compared between the two catchments. The scaled flows for Yarrowee River (115.9 m^3/s), were lower than the 100 year ARI design flows at Creswick (167.2 m^3/s).

Table 4-11 Scaled Design Flow for the Yarrowee River Catchment

Location	Yarrowee River 100 year ARI Flow		Creswick Creek 100 year ARI Flow (m^3/s)
	Design flow (m^3/s)	Scaled Design Flow (m^3/s) *	
Yarrowee River Catchment U/S of Western Freeway	70.4	**115.9**	**167.2**

*scaled to the catchment area upstream of Creswick, 84.7 km^2

4.6 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 Clunes. The model was then used to generate design flows for the 5, 10, 20, 50, 100 and 200 year ARI event. The choice of hydrological model parameters used to generate design flows was comprehensively checked using sensitivity testing. The design flows indicate that the September 2010 and January 2011 flood events were approximately 25 and 35 year ARI events respectively in Creswick Creek at Creswick.

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 waterways, 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 initial hydraulic analysis was carried out for the September 2010 and January 2011 flood events, with the model calibrated to reproduce the observed flood heights and extents.

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 1D Model Component

1D Network

The MIKE11 model explicitly modelled the channels, gullies and pipe networks in Creswick. The 1D model network consisted of four key branches:

- **Main branch, Creswick Creek** – Between Semmens Avenue (D/S Slaty Creek-Creswick Creek confluence) and Ring Road.
- **Tributary branch; Sawpit Gully** - Between Sawpit Road and Creswick Creek. The extents for Sawpit Gully are limited by the LiDAR extents.
- **Tributary branch; Nuggetty Gully –** Between Raglan Street and Creswick Creek. The section of Nuggetty Gully between Hyde Park Road and Raglan Street has been modelled in 2D.
- **Pipe branch; Victoria St Drain –** From Creswick Primary School, down Victoria St towards Creswick Creek.

For the calibration model, the 1D waterway branch was developed using regularly spaced cross-sections (approximately at 50m intervals) generated from the LiDAR. The cross sections were extended out up to the top of bank on either side.

Additional surveyed channel bed cross sections were taken in March 2011, representing the post flood conditions after the significant waterway works undertaken by Hepburn Shire Council in February 2011. For the design flood simulations, cross-sections from the LiDAR were replaced with the surveyed cross sections to account for the post flood waterway works.

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. Further details of the key hydraulic structures are provided in Appendix A.

Pipe/Pit Configuration

The pipe which runs along Victoria Street and discharges into Creswick Creek is included in the 1D model to simulate both the drainage capacity along Victoria St and backflow up the pipe from a raised Creswick Creek water level. The dimensions of the underground drain (pipe size, alignment and inverts) were obtained from survey data. The pipes were modelled as culverts while the pits were represented as small lateral links with closely spaced cross-sections in MIKE11.

Channel Roughness

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

- Within waterways (Creswick Creek, Nuggetty Gully and Saw Pit Gully) - 0.04
- Concrete Pipes and Culverts - 0.013

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

5.2.2 2D Model Component

2D Grid Size and Topography

The 2D model was linked to the 1D model distributing the out of bank 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.

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

The section of Nuggetty Gully downstream of Hyde Park Road is undefined and splits into two meandering channels before merging into a more defined channel upstream of Raglan Street. This broad section of Nuggetty Gully between Hyde Park Road and Raglan Street was difficult to represent in 1D and has been modelled in the 2D grid.

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 and open space with dense vegetation. The hydraulic roughness grid (Figure 5-1) is based primarily on recent aerial photos from NearMap. 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.

Table 5-1 2D hydraulic model roughness parameters

Floodplain Element	Mannings 'n' value
Roads/Car Parks/Railway	0.02
Buildings	0.1
Open Grassed Areas	0.035
Dense Vegetation	0.08
Waterway	0.04

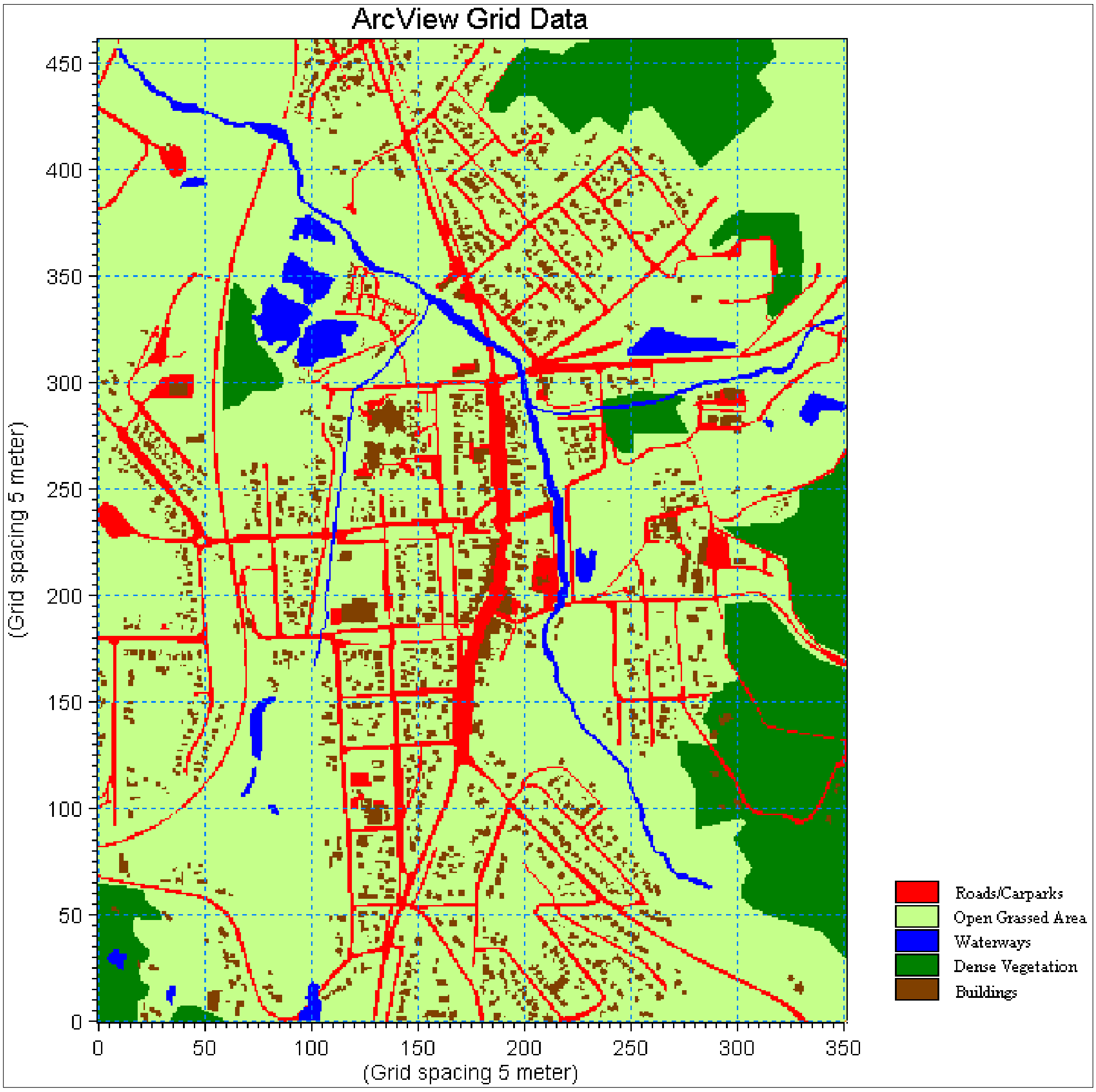


Figure 5-1 2D hydraulic model roughness grid

5.2.3 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

Creswick Creek, Sawpit Gully and Nuggetty Gully were 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 to link the 1D sections of Nuggetty Gully with the 2D section of Nuggetty Gully between Hyde Park Road and Raglan Street. This approach allowed for an exchange of flows from the 1D section of Nuggetty Gully as it discharged onto the 2D grid downstream of Hyde Park Road and re-entered the 1D network, immediately upstream of Raglan Street.

The connection between the pipes under Victoria Street (modelled in MIKE 11) and the 2D grid was set up using lateral links. The pipe pits were laterally linked to a single cell in 2D with the cell height set to the obvert level of the pit. This allowed surface flows to laterally flow into the pit and enter the pipe where pipe capacity was available. It also allowed the pipes to surcharge onto the surface when the capacity is exceeded.

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

5.2.4 Boundary Conditions

Hydrographs from the RORB model were used as inflow boundaries into the 1D MIKE11 model. There were a total of four inflow boundaries and one downstream boundary in the 1D model. No boundaries were applied to the 2D model.

Inflow Boundary

Inflow hydrographs were applied at the upstream end of Creswick Creek, Nuggetty Gully and Saw Pit Gully. A fourth inflow boundary, representing the unnamed tributary upstream of the railway line was applied directly into the Creswick Creek branch as a source point.

Outflow Boundary

A Q-H relationship was developed at Ring Road and applied as the models downstream boundary in MIKE11. The 2D model was linked at the downstream end across the entire floodplain using a standard link, transitioning into a 1D branch with the Q-H relationship at Ring Road 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.

Figure 5-2 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 formed the basis of which to calibrate the modelled results to.

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

- Extended the bluestone wall adjacent to Creswick Primary School (the LIDAR only picked up part of this wall)
- Increased the 1D Creswick Creek bed roughness from 0.04 to 0.05 (reasonable given the dense vegetation in the creek prior to the clean up works)
- Increased the open grassed area roughness from 0.035 to 0.04 to better simulate flood depths through town

The increased roughness resulted in an average water level increase of approximately 50-100 mm across the floodplain, giving a better calibration for both September 2010 and January 2011. The modelled results are discussed below.

5.3.2 September 2010 Calibration

A limited number of flood marks from the September 2010 flood event were collected by the NCCMA. In total four flood marks were surveyed, however the precise location of the flood marks are unknown as only property addresses detailing their locations were supplied, so minor uncertainty is associated with these surveyed flood levels. A rough flood extent provided by the North Central CMA was also used to check the modelled flood extent. The calibration plot for the September 2010 flood event is shown in Figure 5-3 below.

The calibration showed a good fit between the survey flood marks and modelled data. The four flood marks taken at North Parade, Cambridge Street, Semmens Village and the "Farmers Arms Hotel drive through bottle shop" were within +/-100 mm of the modelled flood depths.

The modelled flood extent also matched well with observations, aerial photographs and the rough flood extent provided.

5.3.3 January 2011 Calibration

A larger set of survey flood marks were collected for the January 2011 flood event. The calibration plot of the January 2011 flood event is shown in Figure 5-4. Of the 10 survey flood marks located within the study area:

- 4 points are within +/- 100 mm
- 5 points are within +/- 200 mm
- 1 point at the southern end of Calembeen Park fell slightly outside the modelled flood extent

The overall trend showed that the modelled flood levels were slightly lower than the surveyed flood levels. The modelling results generally match up well with the surveyed flood marks and observations.

5.4 September 2010 and January 2011 Flood Behaviour

The modelled flood extents and depths were very similar for both events, with the January levels approximately 3 cm greater than the September levels through town. The model results for the January 2011 and September 2010 floods replicated the observed flood behaviour through the town accurately; this was confirmed by DSE, SES and CMA staff as well as community members during public consultation. Information obtained from the preliminary impact assessment undertaken in September 2010 and January 2011 also matched well with modelled flood extents. The flood behaviour for these two events as shown in the modelling is described below.

The smaller tributaries, Nuggetty Gully and Saw Pit Gully peaked approximately 2-3 hours before Creswick Creek. Breakout flow from Saw Pit Gully overtopped Moore Street and inundated units in Semmens Village and a few properties along Castlemaine Road. At the same time flows from Nuggetty Gully overtopped the bluestone wall along the primary school and pooled in the low lying north-east corner of the school field before running down Victoria Street. Some of this breakout flowed across Albert Street and flowed east towards Creswick Creek while the remaining flow travelled north-west towards the low lying area near the motel (through the Farmers Arms). This breakout flow from Nuggetty Gully was a low flow with low flood depths, and did not last as long as the peak of Creswick Creek. It is possible that this was not of particular note during the flood due to its low depth, and the possibility of local drainage reducing the impact of that shown in the modelling. This flow path has been observed in previous historic floods and is documented in historic newspaper articles of Creswick flooding.

Shortly after flows began to breakout at the downstream end of Nuggetty Gully. Nuggetty Gully overtopped its left and right banks downstream of Cushing Avenue, inundating Calembeen Park, the Cushing Avenue-Cambridge Street intersection and the low lying area near the motel. The low lying area around the motel and the Cushing Avenue-Cambridge Street intersection was inundated primarily from Creswick Creek backing up Nuggetty Gully and spilling out, the Nuggetty Gully peak flow had passed prior to this area becoming inundated. In January 2011 with Creswick Creek having multiple peaks over the 4 day storm event, this area flooded and receded a number of times prior to the large peak flood.

Creswick Creek reached capacity and started to break its banks at North Parade and Calembeen Park. As Creswick Creek continued to rise floodwaters broke out of bank in Hammon Park and the section between Water Street and Castlemaine Road Bridge. Creswick Creek overtopped its banks, flooding properties on the east side of Albert Street, North Parade, units in Semmens Village and properties along Castlemaine road upstream of the Castlemaine Road Bridge. As Creswick Creek continued to rise further, floodwaters overtopped Albert Street and flowed towards the north-west inundating more properties along Albert Street, Cambridge Street and Cushing Avenue.

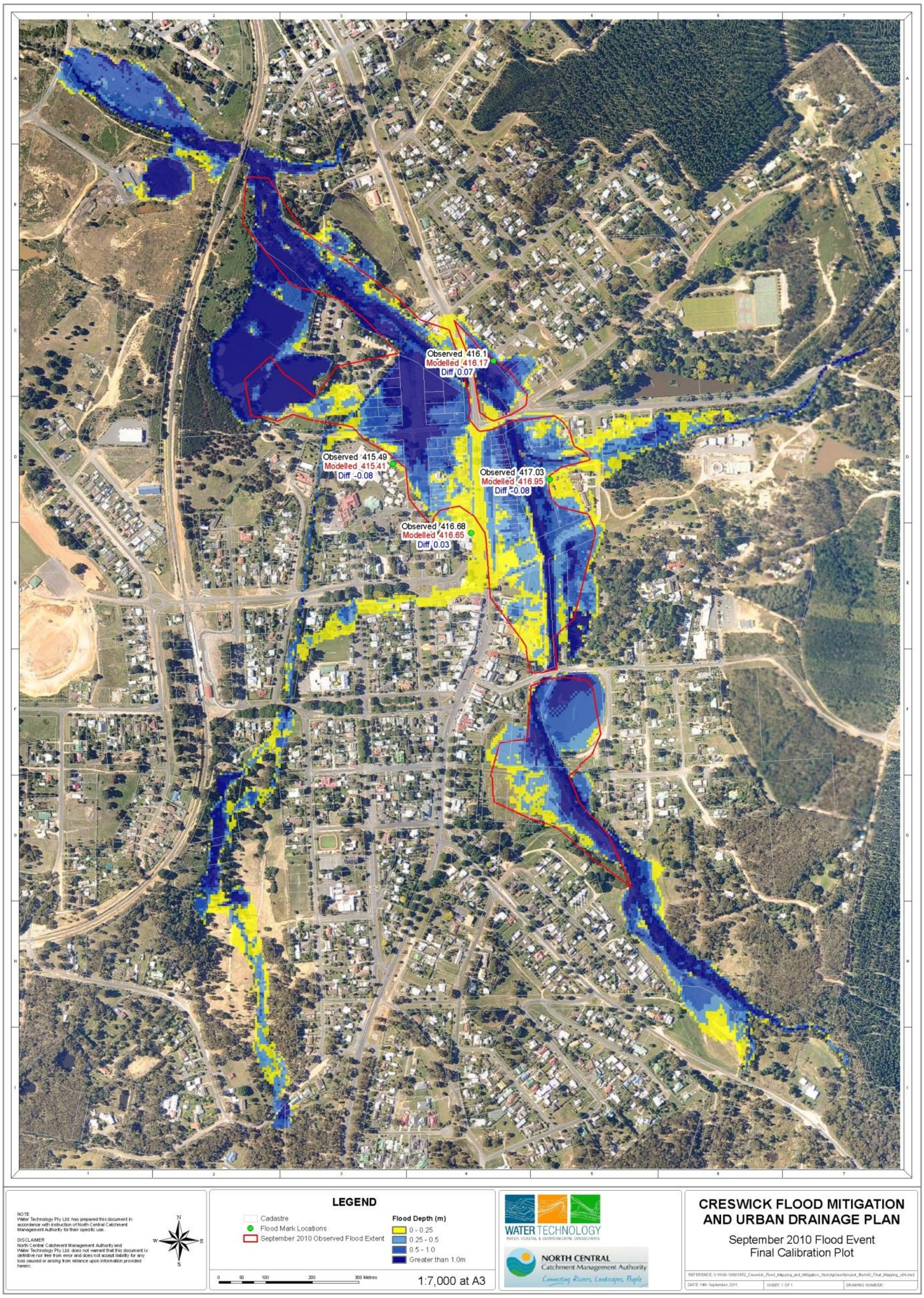


Figure 5-3 Hydraulic model calibration plot – September 2010

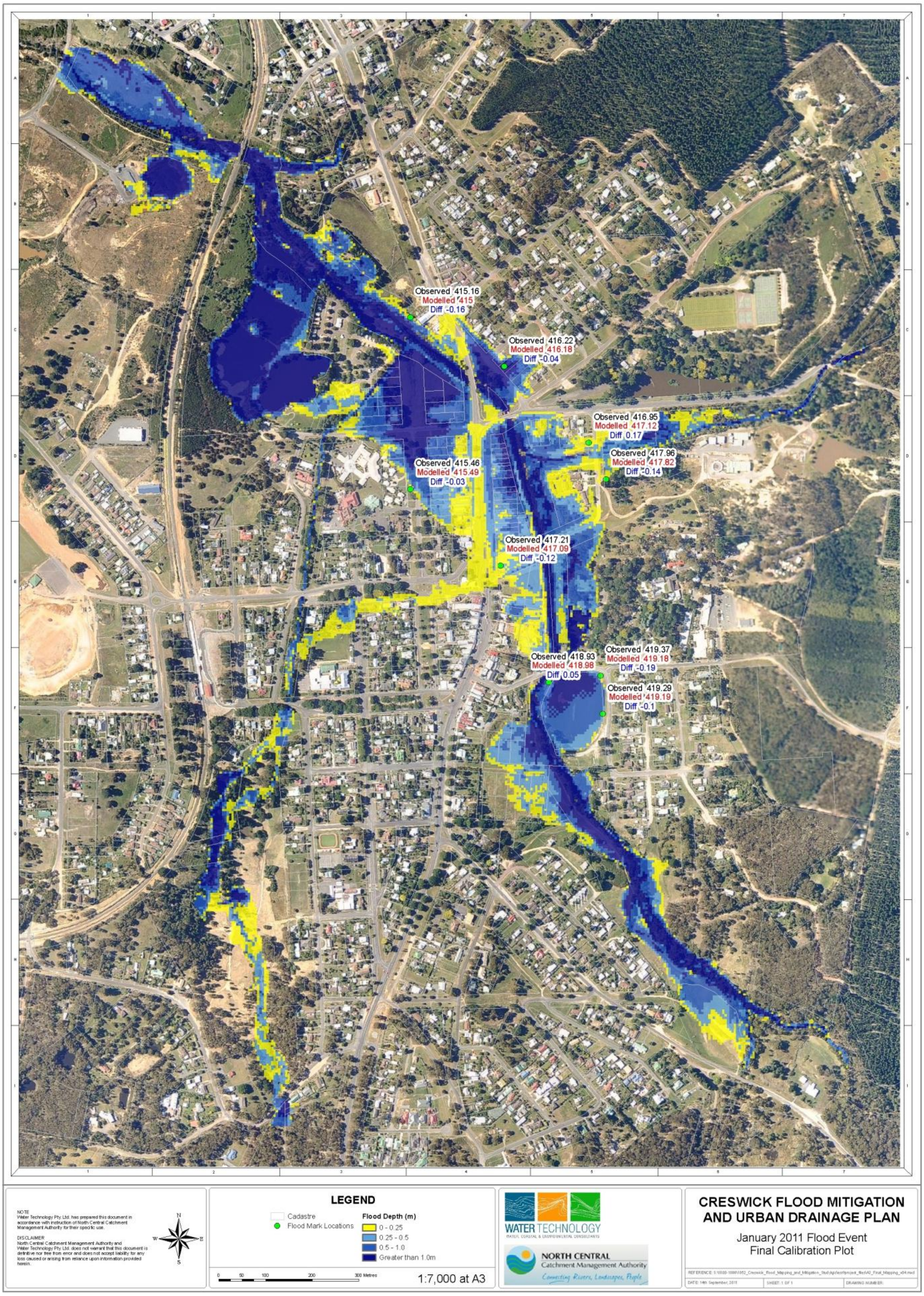


Figure 5-4 **Hydraulic model calibration plot – January 2011**

5.5 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 Creswick. After the January 2011 flood event, the Hepburn Shire Council undertook channel clearing works and some other minor works aimed at improving the hydraulic efficiency of the waterways. The following modifications were made to the model to represent post flood conditions:

- Mannings 'n' value in Creswick Creek reduced from 0.05 to 0.035 for the section between Water Street and Nuggetty Gully, representing the vegetation clearing.
- Creswick Creek widened and deepened between Water Street and Nuggetty Gully, representing the minor geometry change from the removal of vegetation and sedimentation.
- The section of Nuggetty Gully downstream of Cushing Avenue widened to reflect post flood earthworks.
- Two new 950x750mm box culverts installed under the Nuggetty Gully crossing at the caravan park entrance.

Field survey cross sections taken in May 2011 were used to model the modified channel sections in Creswick Creek and Nuggetty Gully. There was a significant gap between the surveyed cross sections from the Bowling Club footbridge down to the Ring Road. As the survey through this section was insufficient, the closest surveyed cross section at the footbridge, along with photographs and observations of the post flood channel profile were used to estimate the profile of the widened channel section.

Utilizing the updated hydraulic model, the design flood events were run for all six ARI events. Each design event was run for the 20min, 1hr, 3hr and 6hr 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.

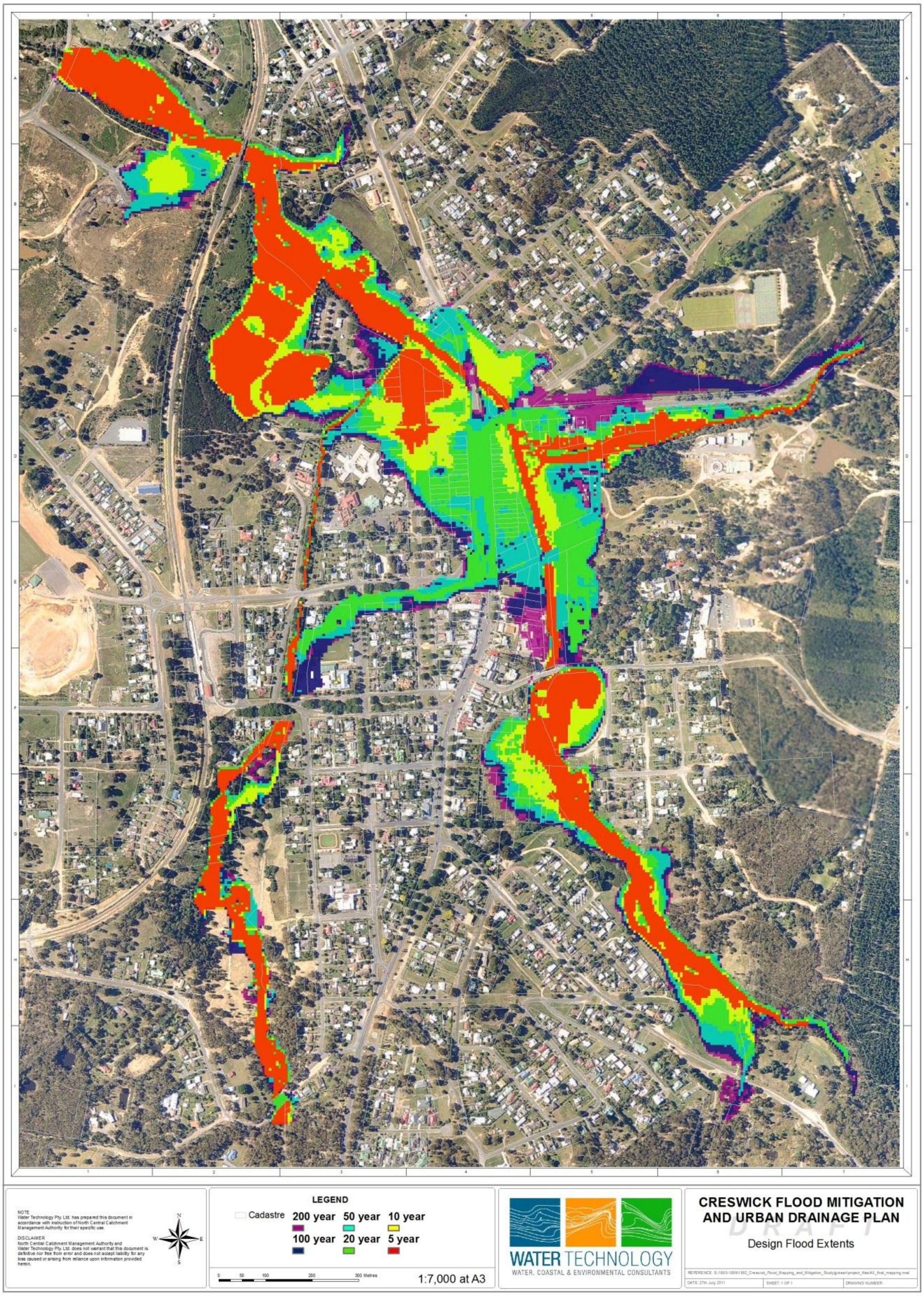


Figure 5-5 Hydraulic modelling design flood extents

5.6 Design Flood Behaviour

Due to the steep nature of the terrain and the confined floodplain, once Creswick Creek overtops its banks the flood extents do not change significantly. The 20, 50, 100 and 200 year ARI flood maps all had a similar inundation extent with some incremental changes as the flood magnitude increases. The following comments describe the key flood characteristics in Creswick for each design event.

5 Year ARI Event

- Water levels reach the top of bank in Creswick Creek and spill out in low lying areas at Calembeen Park and Hammon Park Oval. Shallow overland depths with no properties affected above floor level.
- Saw Pit Gully and Nuggetty Gully overflows cause minor inundation of low lying areas.

10 Year ARI Event

- Floodwaters overtop the banks of Creswick Creek, between Water Street and Castlemaine Road, and start to encroach on properties.
- 8 properties flooded above floor (3 in Cushing Avenue/Cambridge Street area, 2 on North Parade, club rooms at Hammon Park and a shed at Calambeen Park).
- Floodwaters overtop Creswick Creek banks between Water St and Castlemaine Rd.
- Floodwaters from Creswick Creek back up Nuggetty Gully, flooding Cushing Avenue and a few properties south of Cushing Avenue.

20 Year ARI Event

- Water levels overtop the banks of Creswick Creek, causing widespread floodplain inundation. Flood extents comparable to the recent September 2010 and January 2011 floods.
- Properties inundated above floor level include those along Albert St, Cushing Av, Cambridge St, Castlemaine Rd, North Parade.
- Creswick Motel inundated above floor.
- 6 units in the south west corner of Semmens Village inundated above floor.
- Floodwaters overtop Albert Street inundating properties on the west side of Albert Street, Cambridge Street and Cushing Avenue.
- Flows from Nuggetty Gully overtop the bluestone wall along the primary school and run down Victoria Street.

50 Year ARI Event

- Flood extent and flood depths slightly larger than the September 2010 and January 2011 events.
- Properties along Albert Street, between Water Street and the Bowling Club not inundated. It should be noted that these properties were inundated during the September 2010 and January 2011 flood events, but are now flood free as a result of the clean up works undertaken in February 2011.
- Castlemaine Road Bridge overtops.
- Additional properties inundated above floor on same streets as inundated in 20 year ARI event.
- 18 units in Seemens Village inundated above floor.

100 Year ARI Event

- Flood extent not increased significantly but flood depths increased by an average of 170 mm.

- Additional properties flooded included the primary school (south-west building) and a few properties south of the Bowling Club, along Albert Street.
- CFA inundated above floor.
- Petrol station inundated above floor.
- 26 units in Semmens Village inundated above floor.

200 Year ARI Event

- Flood extent not increased significantly compared to the 100 year ARI event.
- Additional properties inundated included more properties south of the Bowling Club.
- Hepburn Shire Council depot inundated above floor.

6. FLOOD MITIGATION OPTIONS

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

6.1 Structural Mitigation Option Prefeasibility Assessment

This section provides a preliminary assessment of potential structural flood mitigation measures. Possible mitigation measures are listed below, with some preliminary comments as to the feasibility of these options. The mitigation options assessed are from discussions with the Technical Steering Committee and correspondence North Central CMA has passed on from community members.

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 6-1 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 6-2 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 Creswick. While these options were reviewed and scored individually it is important to consider a combination of options when developing a flood mitigation scheme.

Table 6-1 Ranking score for structural mitigation 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

Table 6-2 Structural Option Prefeasibility List

No.	Works Location	Mitigation Option	Criteria					Score
			Damage Reduction	Cost	Feasibility/ Constructability	Environmental Impact	Comments	
1	Creswick Creek	Left bank levee between Water Street and Castlemaine Road *Purpose: Protect properties along Albert Street from flooding*	5	2	4	4	• Raise dirt road behind houses • Will increase water levels on the right bank and further downstream • Sufficient room for construction between back of properties and creek • A 2.1m high levee bank, 290m long will provide protection up a 100 year event • Should be done in conjunction with a Nuggetty Gully levee at school to prevent Victoria St flows	14
2	Creswick Creek	Increase channel capacity between Water St and Castlemaine Road bridge *Purpose: Protect properties along Albert Street and Moore Street from flooding*	4	2	3	3	• Re-establishment of bluestone drain • Will increase the speed of flow and increase water levels downstream • Poses a higher risk of public liability (banks would be steep)	13
3	Creswick Creek	Increased channel capacity between Clunes Road and the railway crossing *Purpose: Protect caravan park and Cushing Avenue from flooding*	3	2	3	2	• Regrade the creek to lower the water surface profile • Would require ongoing maintenance	10.5
4	Creswick Creek	Increase capacity of Castlemaine Road and Clunes Road bridge crossings *Purpose: Reduce flood levels adjacent to the bridges*	4	1	2	4	• Either increase number of culverts of deepen channel • Very expensive on major roads • Existing culvert capacity is approximately $80m^3/s$ • Stage works to complete one bridge first and maintain access	12

5	Creswick Creek	Northcote and/or Hammon Park retarding basins *Purpose: To temporarily store flood flows in Northcote and Hammon Parks, reducing peak flows through Creswick*	4	1	2	4	• Parks have a limited storage capacity and were already partly inundated in the recent flood events, would need a high sill to delay filling until critical flow height • Northcote Park zoned for development, existing property with planning permission	12
6	Creswick Creek	Install small baffles to simulate meandering creek line upstream of town *Purpose: Reduce velocities and prevent bank erosion*	2	3	3	3	• Unlikely to have any impact in larger flood events (greater than 10 year ARI)	10
7	Nuggetty Gully	Raise/extend right bank adjacent to Creswick Primary School *Purpose: Prevent breakout flow from Nuggetty Gully travelling across the school ground down Victoria St towards Albert Street*	3	3	3	3	• A 0.5m levee bank, 150 m long will prevent breakout flow up a 100 year event • May back up flows upstream of Victoria St (where Nuggetty gully is restricted) • Bluestone wall, potential heritage structure	12
8	Nuggetty Gully	Retarding basin on the upstream reach of Nuggetty Gully *Purpose: To retard peak flows in Nuggetty Gully*	4	2	4	3	• Sufficient area for a retarding basin in the open space upstream of Raglan Street	13.5
9	Nuggetty Gully	Increase capacity of Cushing Avenue culvert *Purpose: Protect properties close to Cushing Avenue crossing, it was thought flood waters may overtop road and flow down Cushing Avenue*	2	5	4	4	• Cushing Avenue crossing currently has no impact on flooding • May be used as an offset if raising school levee increases flows	13
10	Nuggetty Gully	Increase capacity of Victoria St crossing *Purpose: Reduce water level upstream of Victoria St, preventing flood water spilling into school*	3	1	2	4	• Victoria Street crossing currently has no impact on flooding • May be a viable option together with raising the right bank adjacent to the Primary School	10
11	Nuggetty Gully	Route Nuggetty Gully overflows to Calembeen Park *Purpose: Reduce flooding in Cushing Avenue vicinity*	2	5	4	4	• Likely to have limited impact on flood damages • Inflow channel from Nuggetty Gully • Outflow channel/lower spillway to Creswick Creek	13
12	Nuggetty Gully	Formalise caravan park levee *Purpose: Protect caravan park from flooding*	2	4	4	4	• Likely to have limited impact on flood damages	12
13	Saw Pit	Increase capacity of culvert at DSE seedbank					• Outside LiDAR area. Not considered as part of this study	n/a

	Gully	*Purpose: Protect Seedbank Victoria from flooding*					• Should be subject of separate investigation • Increasing capacity upstream may have impact downstream in Creswick	
14	Saw Pit Gully	Realignment of Saw Pit Gully entry point into Creswick Creek *Purpose: Reduce water levels at the Saw Pit Gully - Creswick Creek junction*	2	3	3	3	• Limited benefit, inundation would be same upstream of Moore St, downstream of Moore St controlled by Creswick Ck level, breakout further upstream.	10
15	Saw Pit Gully	Protect Semmens Village (either levee or relocate) *Purpose: To protect Semmens Village (vulnerable community)*	4	3	4	4	• Likely to increase flood levels elsewhere • Other option may be to relocate	15
16	Upstream Reservoir	Operate upstream dams as flood mitigation *Purpose: Reduce peak flows and water levels in Creswick Creek by providing flood storage upstream of Creswick*	3	1	2	4	• Storage capacity likely to be too small to have any great impact (Section 4.4.4) • Used for water supply, so are not likely to be drawn down prior to flood • Little control on existing outlets, very expensive to construct gates etc.	10

Using the prefeasibility assessment above, the 15 identified mitigation options have been listed in order of total weighted score.

Table 6-3 Ranked mitigation options

Rank	Mitigation Option	Weighted Score
1	Protect Semmens Village	15
2	Creswick Creek left bank levee between Water Street and Castlemaine Road	14
3	Retarding basin on the upstream reach of Nuggetty Gully	13.5
4	Increase Creswick Creek capacity between Water St and Castlemaine Road	13
5	Route Nuggetty Gully overflows to Calembeen Park	13
6	Increase capacity of Cushing Avenue culvert	13
7	Raise/extend Nuggetty Gully right bank adjacent to Creswick Primary School	12
8	Increase capacity of Castlemaine Road and Clunes Road bridge crossings	12
9	Northcote and/or Hammon Park retarding basins	12
10	Formalise caravan park levee	12
11	Increased channel capacity between Clunes Road and the railway crossing	10.5
12	Install small baffles to simulate meandering creek line upstream of town	10
13	Increase capacity of Nuggetty Gully Victoria St crossing	10
14	Realignment of Saw Pit Gully entry point into Creswick Creek	10
15	Operate upstream dams as flood mitigation	10
16	Increase capacity of culvert at DSE seedbank	n/a

The prefeasibility assessment identified a number of works as unfeasible on the basis of low associated damage reduction, high costs, other constructability or environmental issues. The following works were deemed unfeasible at the prefeasibility stage and were not considered for hydraulic modelling:

- ***Operate upstream dams as flood mitigation***; high implementation/construction cost, difficult to regulate and low hydraulic benefit for large floods.
- ***Realignment of Saw Pit Gully entry point into Creswick Creek****;* will achieve limited reduction in flood damages.
- ***Increase capacity of Nuggetty Gully Victoria Street Crossing****;* will result in a minor reduction in flood damage.
- **Install baffles upstream of town**; will achieve no reduction in flood damages.

Based on the above ranking of mitigation options and considering the preliminary flood modelling results, two mitigation packages (Mitigation Option 1 & 2) were initially identified and discussed with the Steering Committee members on the 1st July 2011. The first two options were designed to provide upper bounds for what is required to protect Creswick against large floods. These options were presented to the community in a meeting held on the 11th August 2011, and was presented to show the mitigation works required for such large events. It was hoped that this would help to manage expectations and establish that it is very difficult to protect against all floods and that a compromise will be required between managing flood risk and amenity to the town. The consensus from the community meeting was that widening and deepening the creek (Option 2) was preferred to levees (Option 1).

Following this meeting further discussions were held with the Steering Committee to finalize the mitigation works for Creswick. It was decided that the previous option to widen the creek by 10 m (Option 2) was unfeasible at the bridges due to the high bridge work cost to clear span the creek. As a result, two additional options (Mitigation Option 3 and 4) were identified and modelled. These two options included some widening and deepening of Creswick Creek with minor levees, and also concrete lining of Creswick Creek.

After presenting the results of the first four options, the final fifth option was designed based on initial discussions with the Steering Committee, then further discussions with CMA and VICROADS.

Input from the community was used to shape the final three mitigation options. Based on the negative feedback received on the extreme levee heights required to protect Creswick up to a 100 year event, the design standards for flood protecting the town were revised. The standard level of flood protection in Victoria is the 100 year ARI event, however where this is unfeasible a lower level of protection may be acceptable. Following discussions with the community, it was decided that a 50 year level of protection would be adopted, which would provide protection for events such as the September 2010 and January 2011 events.

6.2 Structural Mitigation Options Modelled

The five mitigation options that have been run to date include:

1. ***Mitigation Option 1***: Levees constructed to protect against Creswick Creek and Saw Pit Gully overflows and a retarding basin constructed upstream of Nuggetty Gully. Works designed to protect up to the 100 year event.
2. ***Mitigation Option 2***: Creswick Creek widened and deepened and the Clunes/Castlemaine Road culvert bridges widened by 10m and converted into clear span structures. Works designed to protect up to the 100 year event.
3. ***Mitigation Option 3***: Combination of Creswick Creek widening and deepening with some minor levee alignments. Widening at the bridge is minimized by having steeper bank slopes. Levee works designed to protect up to a 50 year event (i.e. protect against floods of a magnitude slightly larger than January 2011).
4. ***Mitigation Option 4***: Formalizing Creswick Creek into a uniform channel and concrete lining the creek. Levee works designed to protect up to a 50 year event (i.e. protect against floods of a magnitude slightly larger than January 2011).
5. ***Mitigation Option 5***: Install an additional two culverts under each bridge along with levee works designed to protect up to a 50 year event (with 300 mm freeboard) and minor deepening of the creek.

All five options require pipes with one-way flap valves to ensure local runoff can enter Creswick Creek when the creek is low, but prevent back flooding from the creek. One way flap valves will be required at the main drain outfalls (Victoria Street Main Drain, Castlemaine Road Drain and the Cushing Avenue Stormwater Drain) as well as any smaller stormwater drains discharging into Creswick Creek.

The impacts of all five mitigation options on flood behaviour were assessed for the 10, 20, 50 and 100 year ARI events. The five mitigation options are described in more detail below.

6.2.1 Mitigation Option 1

Mitigation Option 1 was modelled to test the effectiveness and feasibility of developing a levee system for flood protection. Through discussions with the technical steering committee and a review of the existing topography, a number of potential levee alignments were identified. The location and key features of Mitigation Option 1 are shown in Figure 6-1 below.

Mitigation Option 1 included a levee starting at Water Street running along the left bank of Creswick Creek, extending across the Clunes and Castlemaine Roads before running across the back of the Motel and down Cushing Avenue. There is limited space to construct a levee on either side of Pearson Street which currently forms an informal levee bank, and any work would involve removing a significant number of trees along the creek. It was proposed that Pearson Street be raised to act as the levee itself. This levee would be approximately 1 km long with an average height of 1.8 m. The crest of the levee was designed with a 600 mm freeboard above the 100 year ARI water level. The maximum height along the levee wall is 3.1 m upstream of Castlemaine Road Bridge.

A number of secondary works were also proposed to reduce flooding from the tributary creeks, including:

- Ring levees around Semmens Village (average height 1.8 m) and properties to the north of Semmens Village (average height 1.7 m).
- An embankment wall constructed along the upper reaches of Nuggetty Gully. The embankment wall was designed with two 600 mm pipe outlets to retard the 100 year flow without any overflow over the top of the wall. It has been designed to create a temporary flood storage area and retard flows in Nuggetty Gully.

Discussion

The 100 year ARI results for Option 1 are shown in Figure 6-2 below. The inclusion of the main levee along Creswick Creek removed flooding along Albert Street, Cambridge Street and Cushing Avenue for events up to the 100 year ARI event. As the levees are required to extend across Castlemaine and Clunes Road Bridges, adjustable floodgates would be required at both bridge crossings to stop water flowing down the roads during a flood event.

Flood depths for the properties along North Parade were increased by up to 300 mm as a result of the left bank levee raising water levels in Creswick Creek.

The area upstream of the Nuggetty Gully embankment wall had an increased depth of flooding by up to 3.8 m. Even though there are no properties located upstream of the embankment wall that would be impacted by a raised water level, failure of this structure in a 100 year ARI event could pose a high risk to properties immediately downstream.

While Semmens Village remains flood free in a 100 year ARI event, access to the units would be cut off as the ring levees constrict Saw Pit Gully's flow path and increase water levels at the Moore Street crossing and around the village by up to 600 mm.

The location and significant heights of the levee banks required to protect up to a 100 year ARI event make this option unfavourable with the community (Section 3.4). As such no further investigation was undertaken for this option.

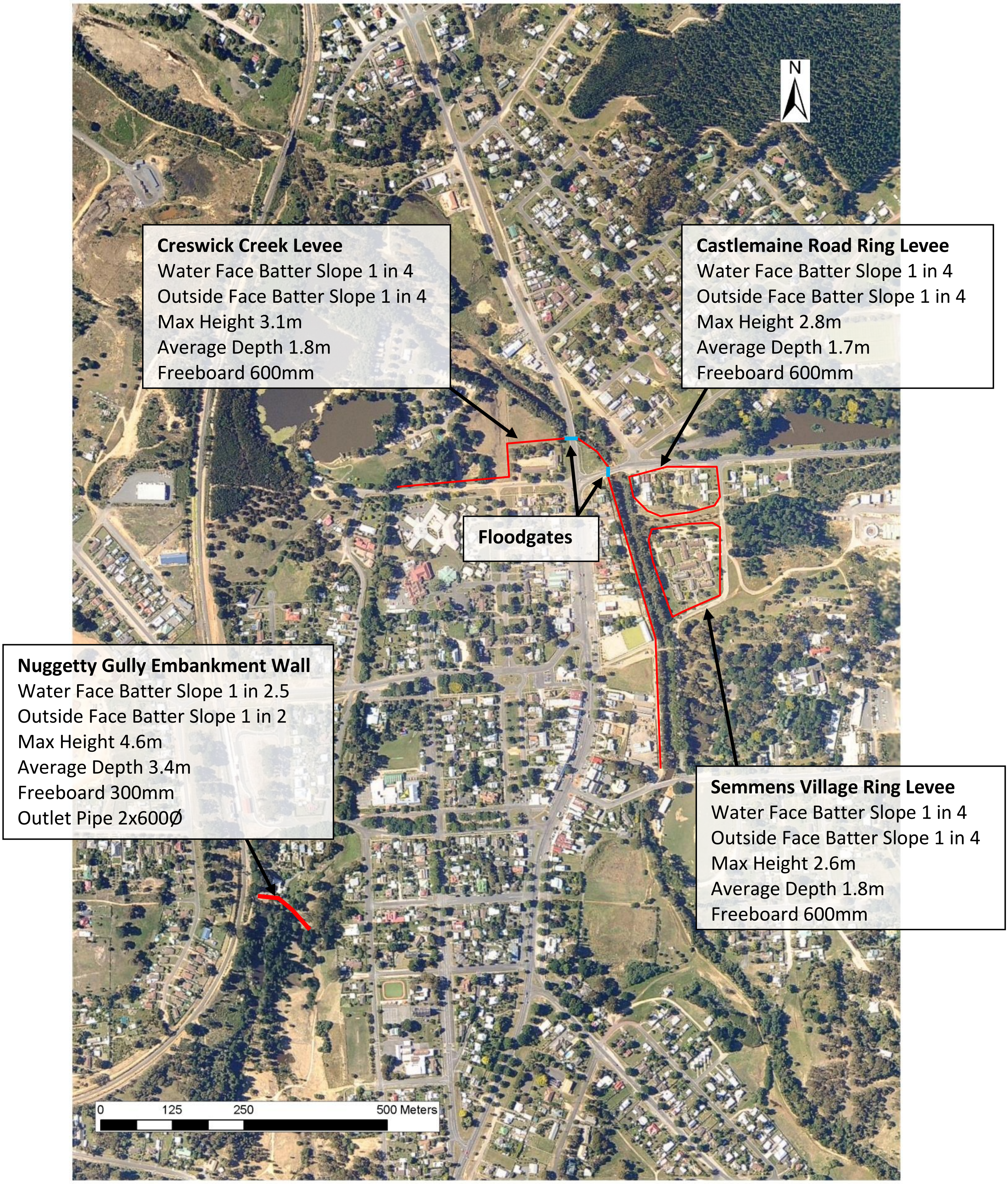


Figure 6-1 Proposed structural mitigation option 1

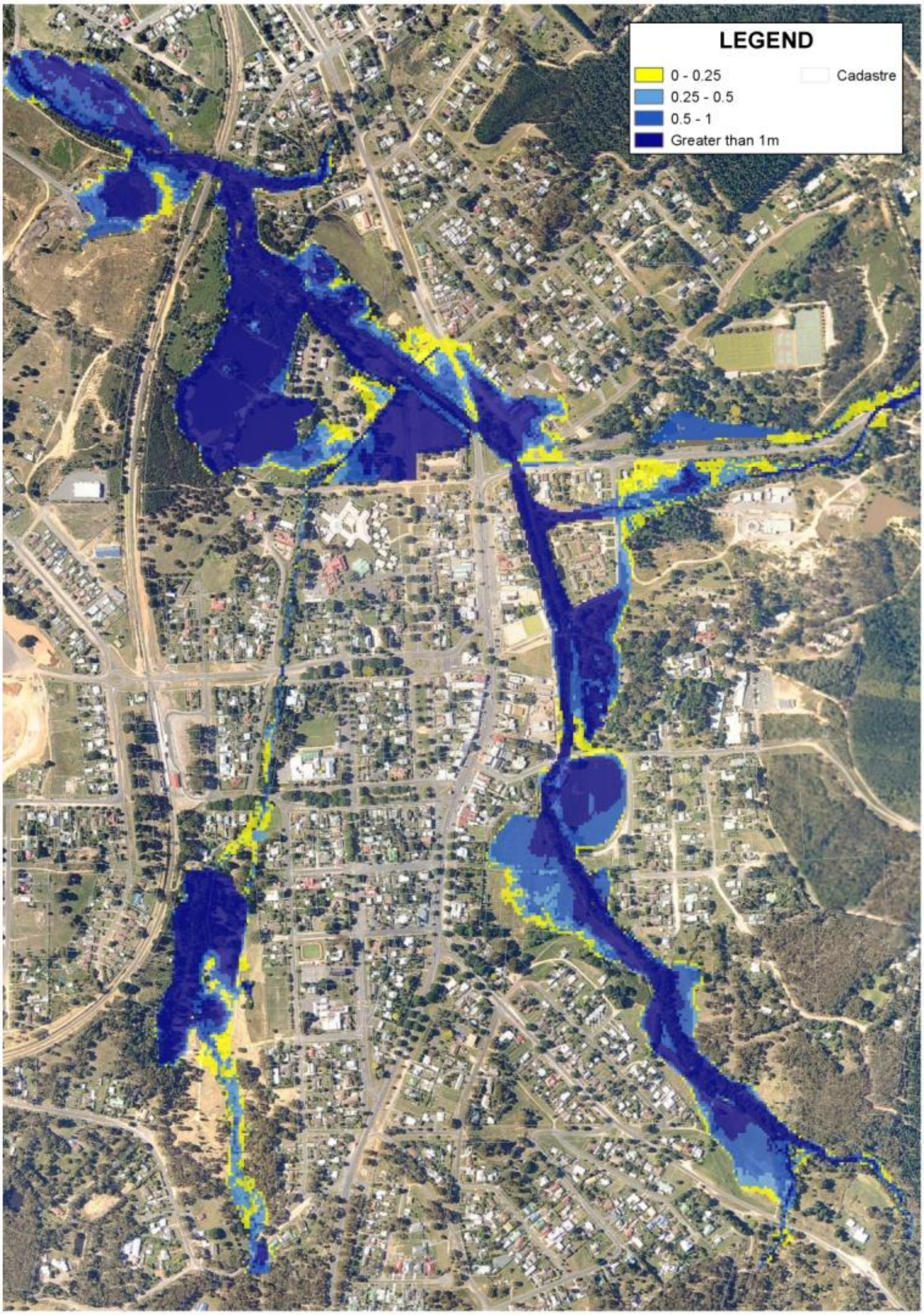


Figure 6-2 Proposed structural mitigation option 1 – 100 year ARI extent

6.2.2 Mitigation Option 2

Mitigation Option 2 was modelled to identify the scale of channel and bridge works necessary to prevent Creswick Creek from overtopping its banks during a 100 year ARI event. This option consisted of widening/deepening Creswick Creek and upgrading the Castlemaine and Clunes Road Bridges into clear span bridges. Under this option no secondary works were considered for the tributary creeks. The location and key features of Mitigation Option 2 were shown in Figure 6-3 below.

Preliminary conveyance calculations indicated that the creek's cross sectional area needed to be approximately doubled to achieve the 100 year ARI flow capacity within the creek. The proposed channel widening and deepening gradually transitioned from the existing creek bed invert at Water Street to 0.5 m below the existing bed level at the bowls club. Further downstream, between the Bowls Club and the Railway Bridge, the top width of the existing channel was widened by 10 m, batter slopes steepened to 1 in 5 and the creek bed lowered by 0.5 m below existing level. It was suggested that if this was to be pursued some realignment of the Creek would be required as the bridges would most likely be widened on the left bank but there is more open space between Water Street and Castlemaine road on the right bank.

The Castlemaine Road and Clunes Road Bridges would be converted into clear span bridges, matching the width of the widened creek way. As with Option 1, widening the creek by 10 m would involve clearing a significant number of trees along Creswick Creek.

Discussions

The 100 year ARI results for Option 2 is shown in Figure 6-4 below. The hydraulic results showed that a significant widening and deepening of Creswick Creek is required to contain the 100 year ARI flows within the channel banks between Water Street and the Clunes Road Bridge. The channel works resulted in an average reduction in flood depths of 220 mm across the floodplain. Flood levels near the bridges decreased by over 1 m.

The low spot to the north of Cushing Avenue (near the motel) remained flooded in a 10 year ARI event and above. Downstream of Clunes Road, Creswick Creek also overtopped North Parade, inundating a few properties.

Most of the overland flooding seen in the 100 year ARI result plot was from Nuggetty Gully and Sawpit Gully overflows. Since no works were considered for the tributary creeks in this option, it continued to overflow in both minor and major flood events.

The results also indicated that for channel works to be effective it would need to include a levee along the back of the motel and consider secondary works for the two tributary creeks.

Figure 6-3 Proposed structural mitigation option 2

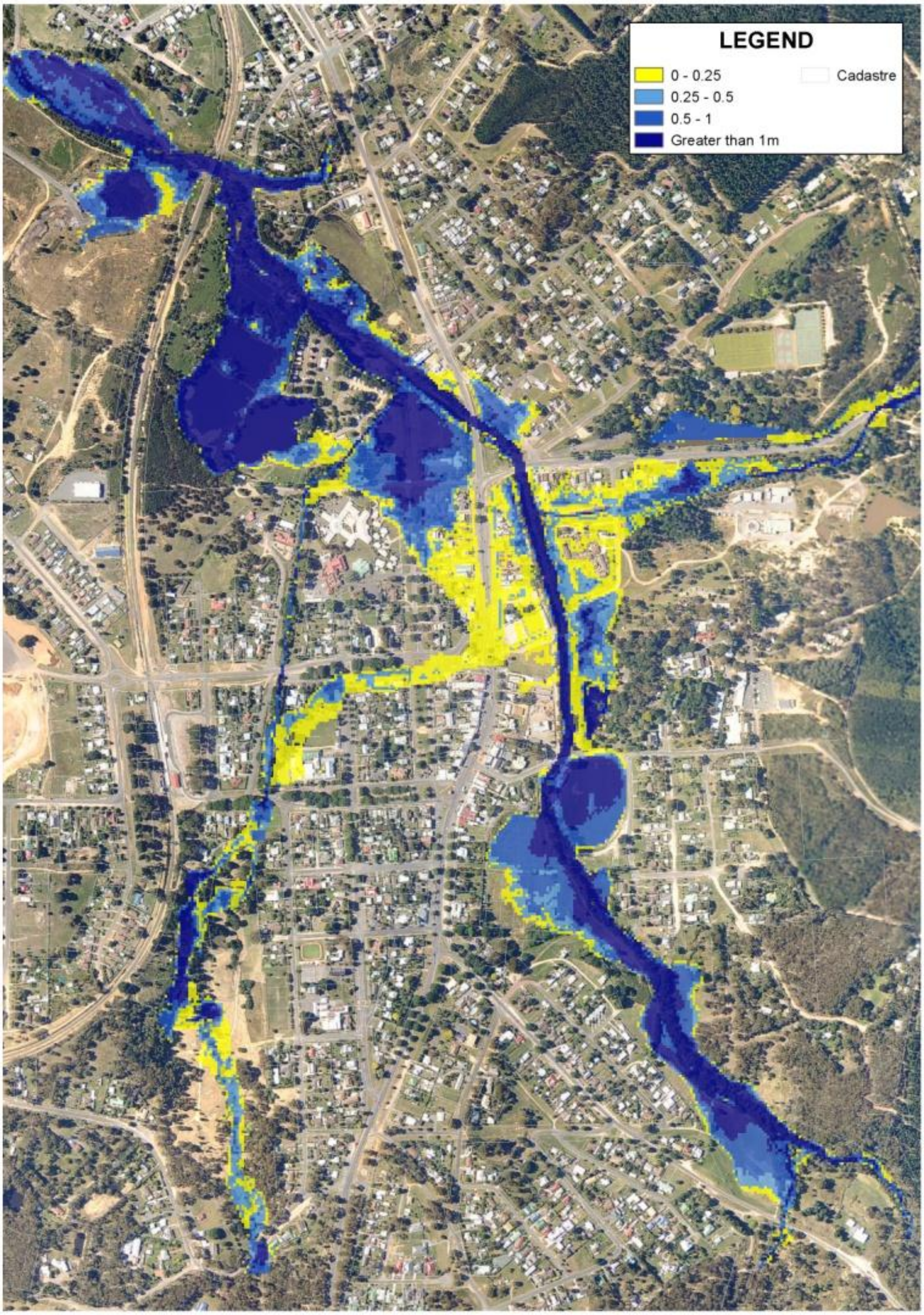


Figure 6-4 Proposed structural mitigation option 2 – 100 year ARI extent

6.2.3 Mitigation Option 3

Following discussions with the community and the Steering Committee it was agreed that the 50 year ARI was an acceptable protection level and was consistent with community expectations. Structural mitigation option 3 was a variation of option 2, consisting of widening and deepening of Creswick Creek similar to option 2, except for the section between Castlemaine and Clunes Road Bridges. The location and key features of mitigation option 3 are shown in Figure 6-5 below. The aim of option 3 was to provide flood protection to a 50 year ARI flood event whilst reducing the creek widening at the bridges to reduce the cost of clear spanning.

Between the two bridges, the channel was formalised into a trapezoidal channel with a bed width of 15 m and a top width of 20 m to minimise top width. This gave a batter slopes of about 1 in 1 and would require fencing for safety. As with option 2 the bridges were converted to clear span structures but with a shorter top span.

Away from the bridges the channel was shaped into a trapezoidal channel with a bed width of 12 m and a top width of approximately 28 m. The channel works began at Water Street with the channel gradually widening and deepening to 0.5 m below the current invert of the Castlemaine Road Bridge. Downstream of Clunes Road Bridge, the channel bed graded from 0.5 m below the bridge invert to the existing bed level just downstream of the railway bridge. This gave batter slopes of about 1 in 4 away from the bridges which would not require fencing.

A number of secondary works have also been proposed to alleviate flooding from the tributary creeks and the low lying area near the motel. This included the following:

- Levee around the back of the motel. The levee alignment was proposed along the high ground adjacent to the left bank of Creswick Creek, between Clunes Road and Nuggetty Gully. The levee alignment was extended along Nuggetty Gully up to Cushing Avenue, in order to prevent Creswick Creek floodwaters from back flooding Nuggetty Gully and inundating the low lying area. The option would require the removal of a number of trees along the left bank of Creswick Creek, behind the motel.
- Raising the bluestone wall along the primary school by up to 0.6 m over a distance of 150 m.
- Construction of low level bunds and low profile speed humps to form a floodway over Moore Street down to Creswick Creek.
- Flap valves on all drainage infrastructure draining into Creswick Creek beneath the levees.

Discussions

The 50 year ARI results for option 3 are shown in Figure 6-6 below. The structural works for option 3 were designed to protect up to the 50 year ARI event. The combined levee and channel works resulted in an average decrease in flood depths of 0.5 m through town. The only area with increases in flood depths was the forested area upstream of Moore Street, as floodwaters built up behind the bund wall, resulting in minor increases (up to 250 mm).

Flooding was still present along North Parade; however the flood depths through this area were decreased significantly (up to 1 m).

The works have been designed with little freeboard (100 mm) over the 50 year event, therefore the levees/bunds overtop during the 100 year ARI event.

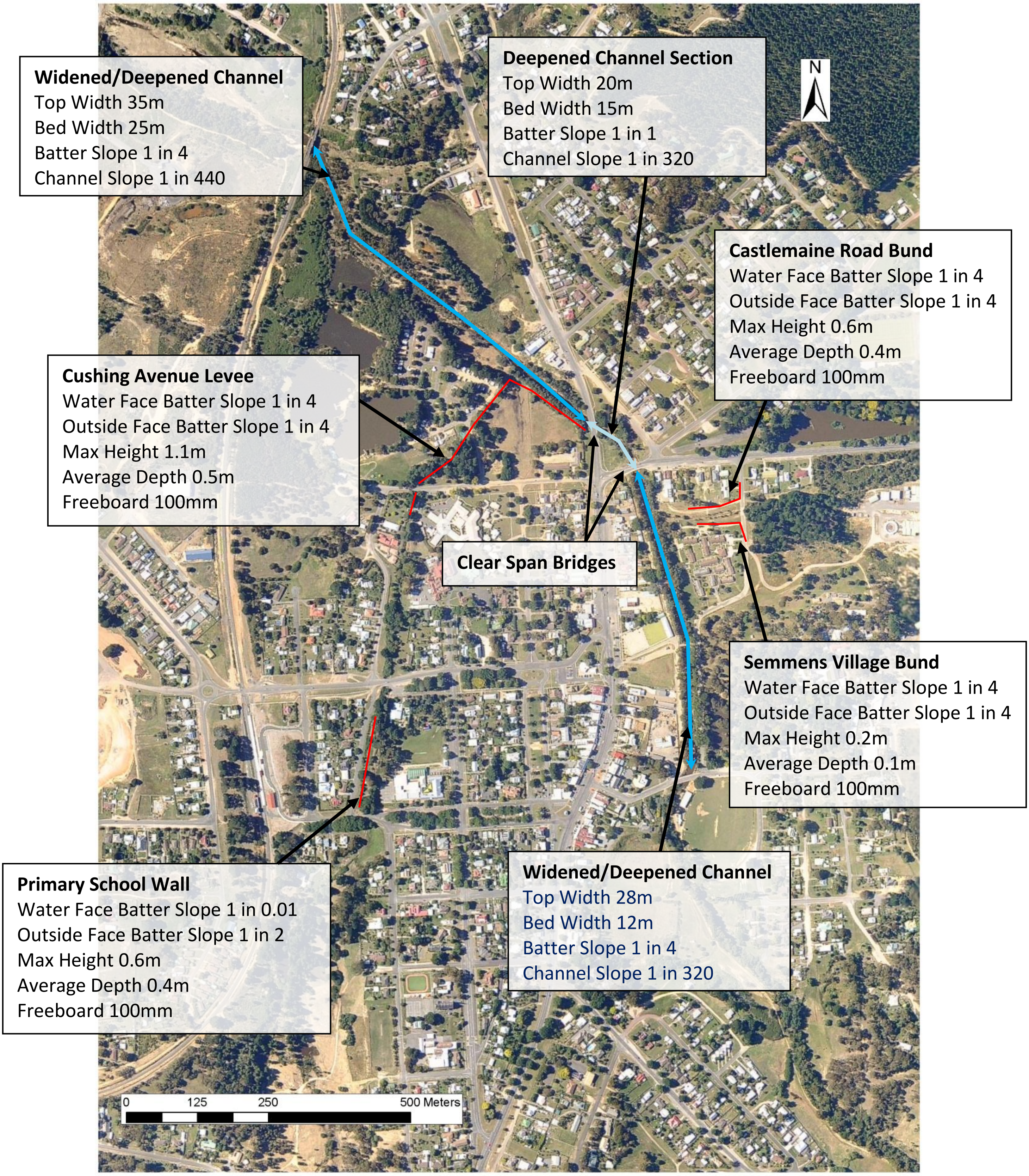


Figure 6-5 Proposed structural mitigation option 3

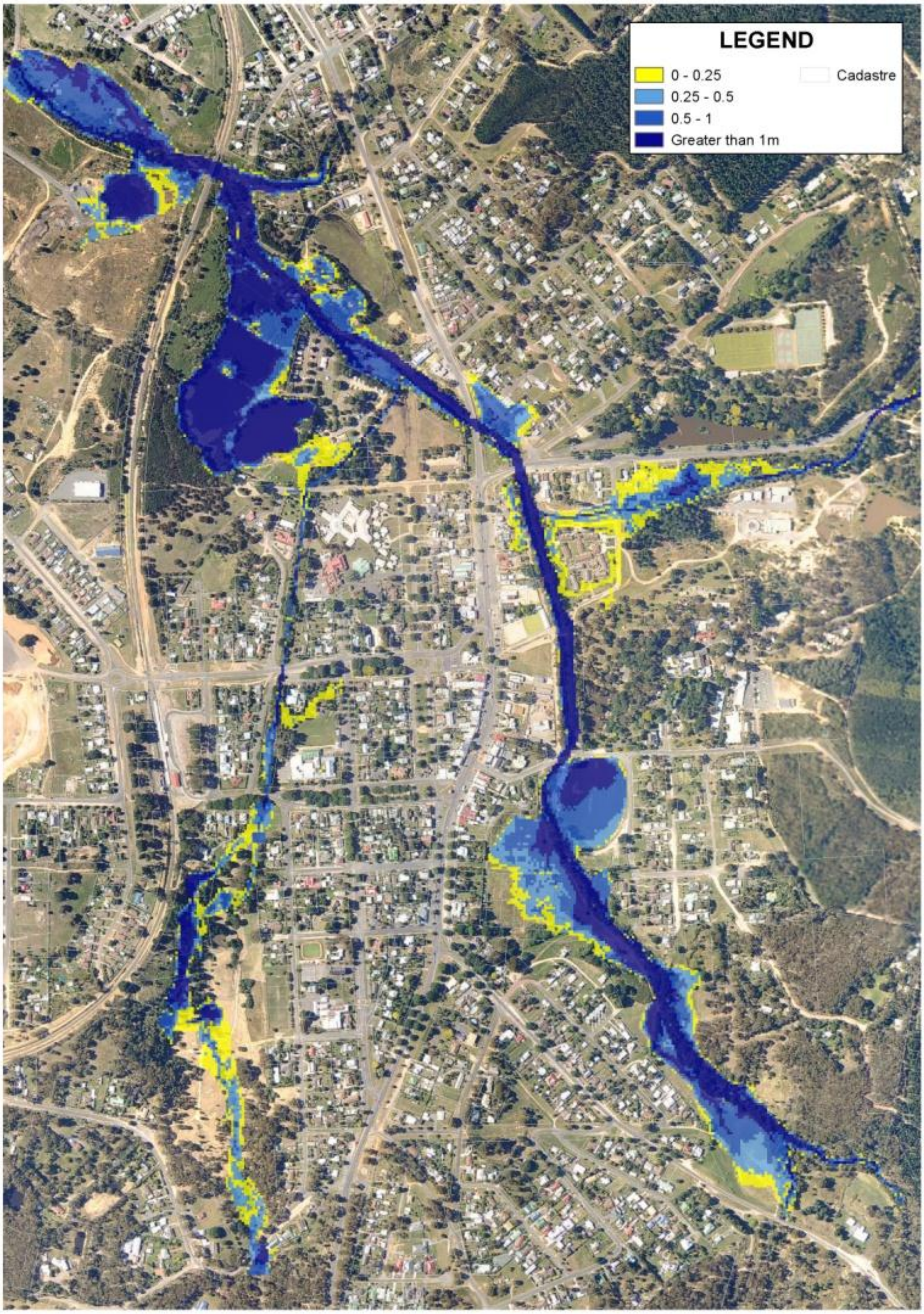


Figure 6-6 Proposed structural mitigation option 3 – 50 year ARI extent

6.2.4 Mitigation Option 4

Mitigation Option 4 involved formalising the creek into a uniform channel geometry and concrete lining Creswick Creek between Water Street and Clunes Road Bridge. This option was proposed by VICROADS with the aim to avoid any works at the bridges itself. The location and key features of mitigation option 4 are shown in Figure 6-7 below.

The creek cross-section was not changed dramatically, but merely reshaped to form a uniform trapezoidal channel. Minor excavation was proposed along Creswick Creek, between Water Street and Castlemaine Road, to form a uniform channel slope of 1 in 450 and uniform batter slopes of 1 in 2. The existing channel top width was largely maintained.

Between the two bridges, the channel was formalised into a trapezoidal channel while maintaining the existing bed width of 15 m and top width of 20 m. This gave batter slopes of about 1 in 1 and would require fencing for safety. No works were proposed for the Castlemaine and Clunes Road Bridges.

The secondary works were kept exactly the same as per option 3, in order to directly compare the effects of widening the creek against concrete lining.

Discussions

Concreting the creek increases the hydraulic efficiency and consequently the capacity of Creswick Creek. The results show a decrease in flood depths of up to 330 mm at the Bowling Green and 490 mm upstream of Castlemaine Road Bridge for the 50 year event as compared to existing conditions. The 50 year ARI results for Option 4 is shown in Figure 6-8 below.

No significant works were undertaken to increase the capacity of the existing Castlemaine/Clunes culvert bridges, hence there is still a relatively high afflux upstream of the structures.

A comparison of the 50 year results for mitigation options 3 and 4 indicated that concrete lining the creek, whilst reducing water levels from existing conditions, was not as effective as widening and deepening the creek. Option 4 resulted in water levels 0.35 and 0.8 m higher than option 3 at the bowling green and upstream of Castlemaine Road Bridge respectively. Given the significant environmental impacts associated with concreting Creswick Creek and minor benefits to the creek's flow capacity, option 4 was not considered further.

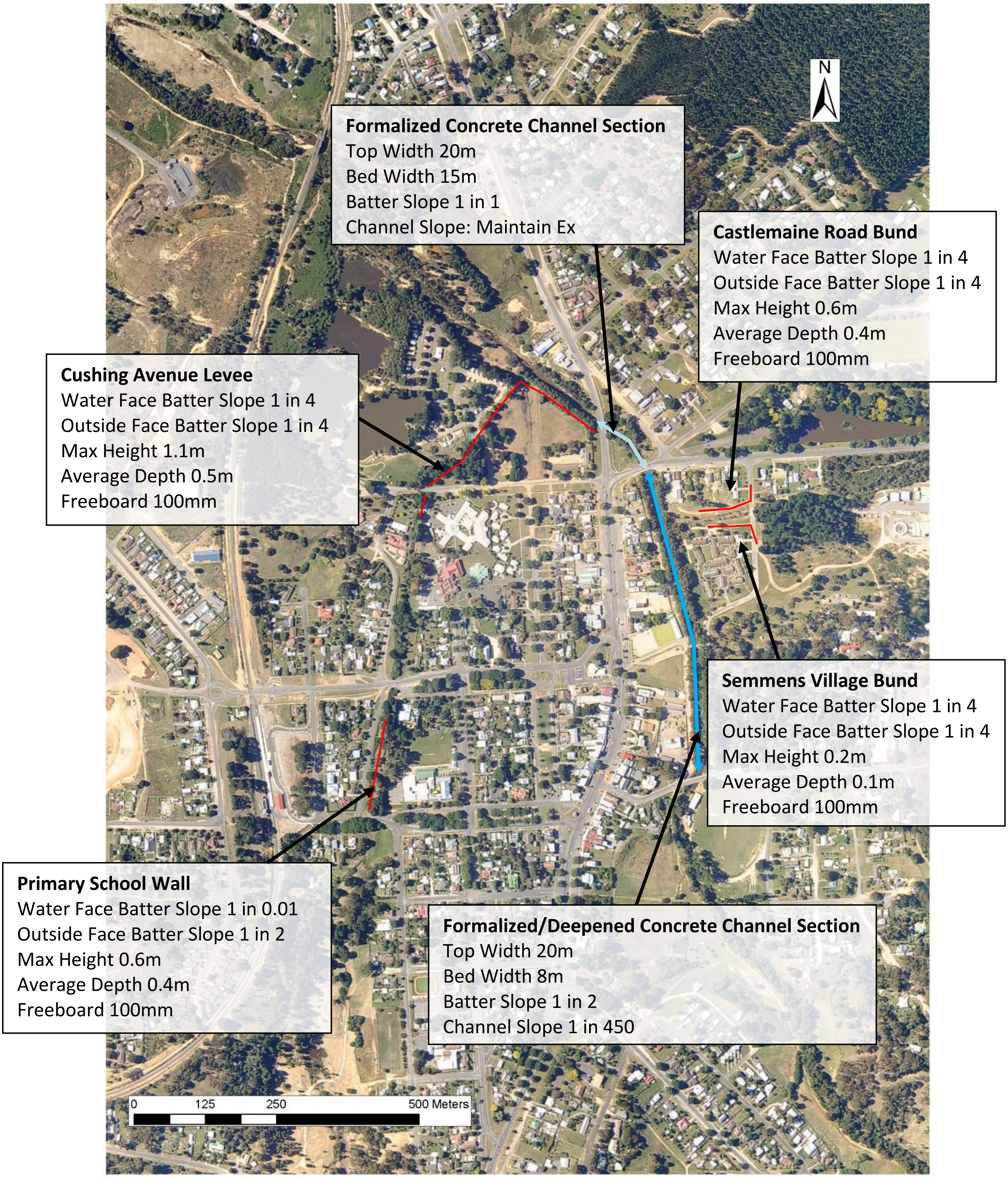


Figure 6-7 Proposed structural mitigation option 4

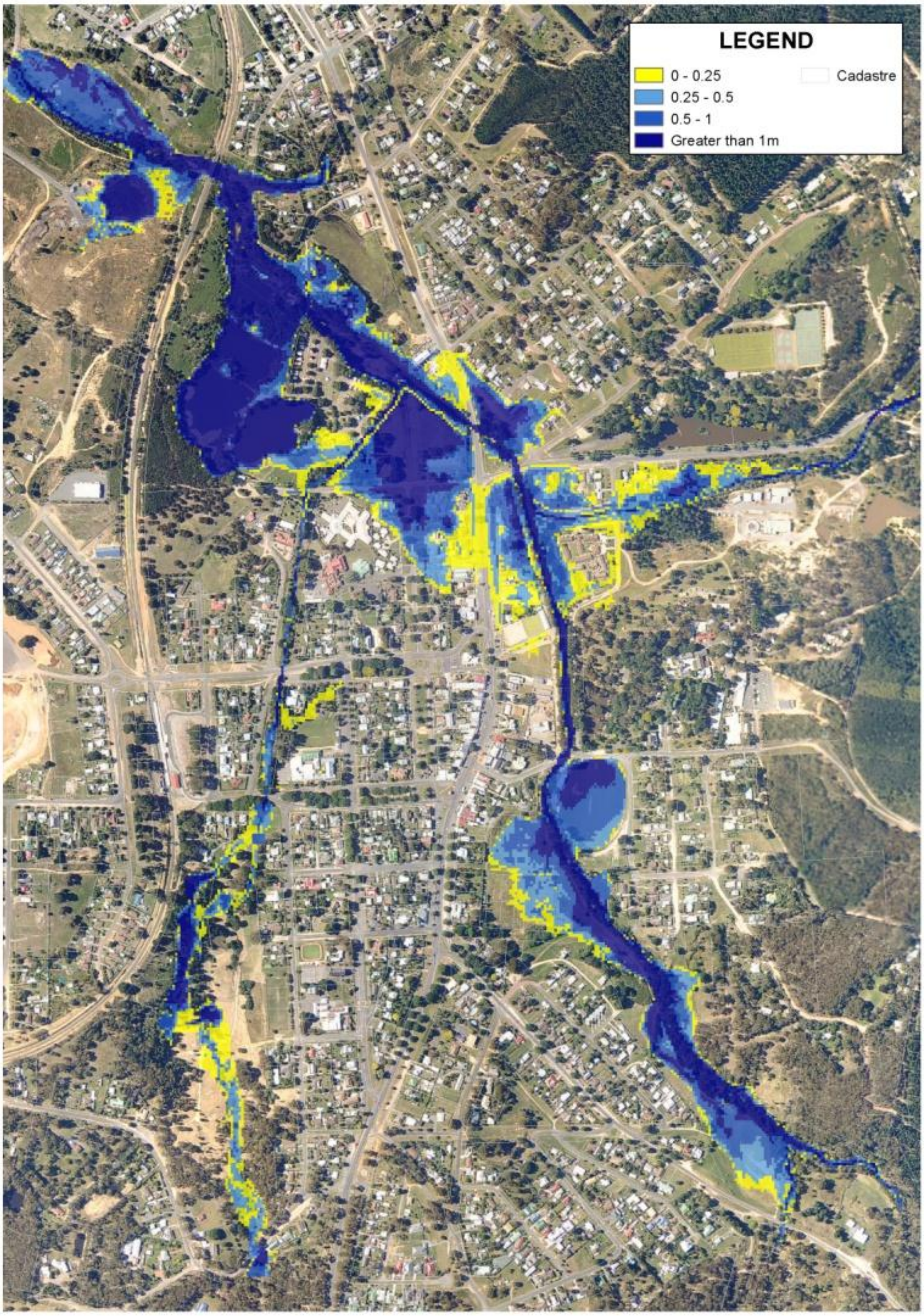


Figure 6-8 Proposed structural mitigation option 4 – 50 year ARI extent

6.2.5 Mitigation Option 5

Mitigation Option 5 investigated alternative bridge improvement works to reduce the cost associated with clear spanning both bridges. Discussions with VICROADS indicated that there is sufficient room to install an additional 2 box culverts under the Clunes and Castlemaine Road Bridges on the left bank of the creek. A preliminary hydraulic analysis of this option was undertaken, incorporating the additional culverts, to determine the height of levees required to flood protect the town with no additional channel works. The results indicated that the addition of two new culverts increased the capacity of the creek and reduced the heights of the levees required to flood protect the town to a 50 year ARI event.

This option was then refined with the inclusion of minor channel works away from the bridges to further reduce the levee heights. A finalised mitigation package was then developed for Option 5 which included the following works:

- Installation of two additional culverts of same geometry as the existing culverts at the Clunes/Castlemaine Road Bridges (requiring a concrete or rock lined apron)
- Levee along the left bank of Creswick Creek (average depth 0.8 m) starting at the Bowling Club and running along the creek line, before extending along Nuggetty Gully up to Cushing Avenue. The levee may be integrated with a walking track or cycle path adjacent to the creek. This option will require the removal of a number of trees along the left bank of Creswick Creek.
- Minor channel deepening in Creswick Creek (0.3 m at Water Street grading down to zero at the invert of the existing channel bed near Saw Pit Gully, and 0.3 m between Clunes Road Bridge and Nuggetty Gully). The channel excavation works include minor widening of the creek bed and steepening of the batter slopes to 1 in 4.
- Bunds along Semmens Village (average depth 0.5 m) and the properties to the north of Semmens Village (average depth 0.7 m). The bunds are designed with a slope of 1 in 4 which is reasonable for emergency vehicular access over the levee.
- Raised embankment wall along Nuggetty Gully at the primary school

The location and key features of Mitigation Option 5 are shown in Figure 6-9 below.

Discussions

The 50 year ARI results for option 5 is shown in Figure 6-10 below. This option successfully removed flooding along Albert Street, Cambridge Street and Cushing Avenue for the 50 year ARI event.

The levees/bunds have been designed with a freeboard of 300 mm on top of the 50 year ARI water level and will overtop during the 100 year event.

Five properties along Castlemaine Road, upstream of North Parade are inundated in the 50 year event. Of the five properties, two are flooded above floor by 0.45m and 0.05m. Since the downstream Saw Pit Gully bunds have not exacerbated the flooding at these five properties no further works are proposed. It is possible that further mitigation at this site be considered at a future date.

There were 6 buildings identified that remained flooded above floor for the 50 year ARI event. Three of the buildings included the two clubrooms at Hammon Park and a shed on the southern side of Calambeen Park, the other three buildings were on North Parade at numbers 5, 7 and 9. A preliminary analysis was undertaken to cost a levee to protect these properties on North Parade.

Two options exist. The first is to construct a 160 m long levee adjacent to North Parade on the creek side of the road, maximum height of 1.6 m. The second option would involve a 90 m long levee with a maximum height of 1.2 m immediately adjacent to the creek. This second option would require extending an existing culvert approximately 30 m so as to discharge into the creek under the levee. From the calculated volume of the levee options and the culvert works it is estimated that these works may cost somewhere in the order of $50,000. Making some basic assumptions for the reduction in the average annual flood damage the benefit cost ratio was recalculated and does not change significantly. This option is worth considering further as a part of mitigation option 5.

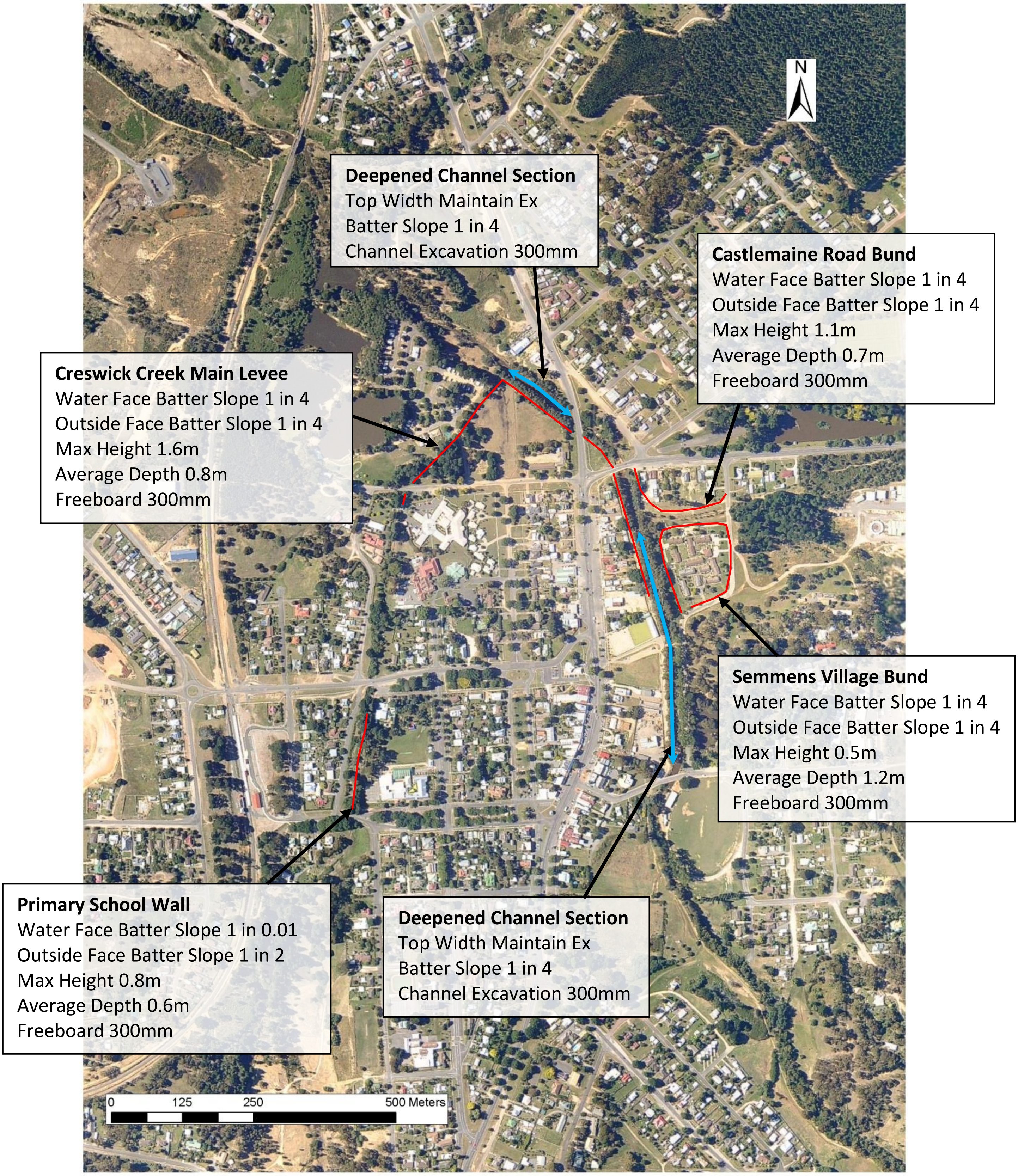


Figure 6-9 Proposed structural mitigation option 5

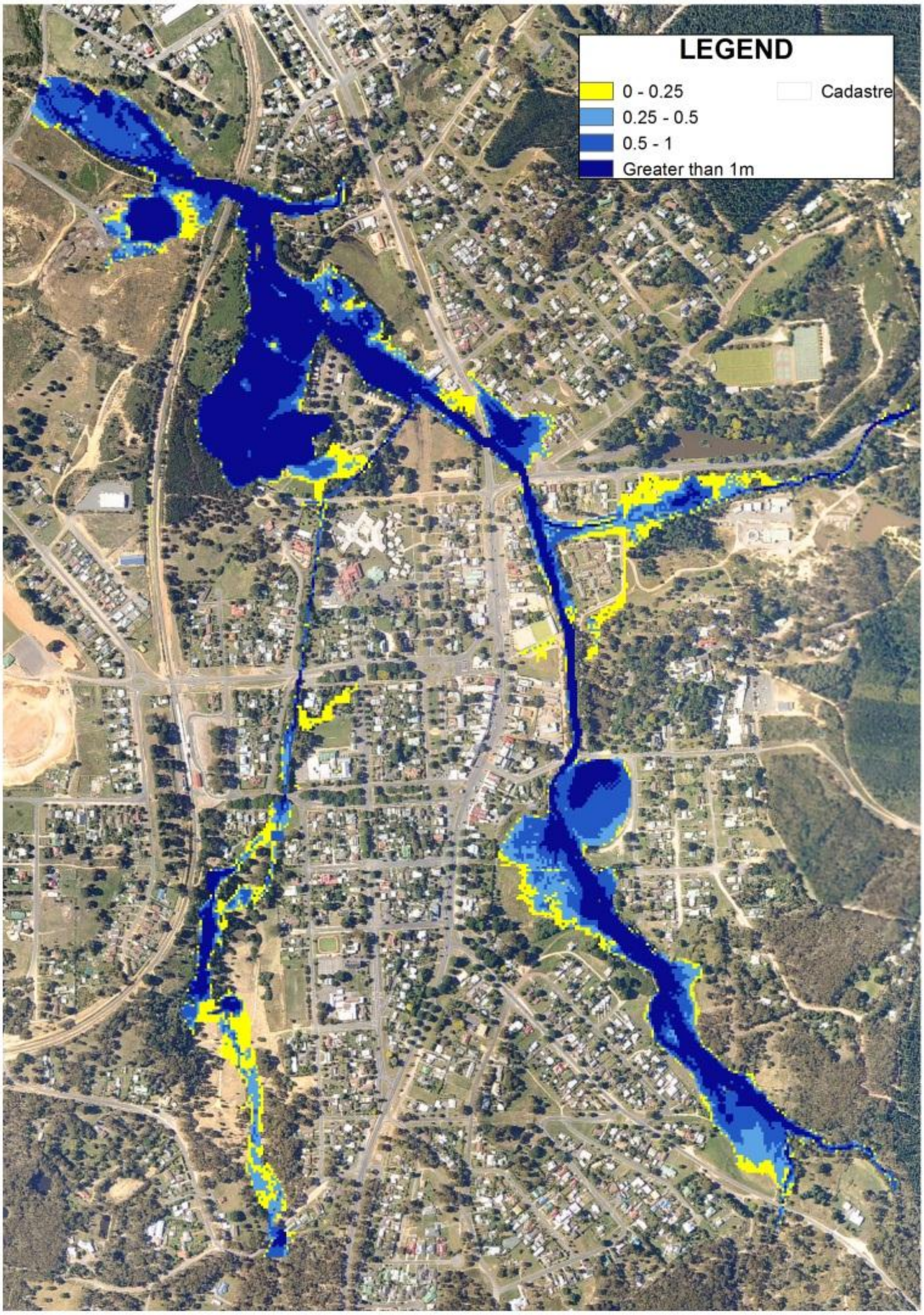


Figure 6-10 Proposed structural mitigation option 5 – 50 year ARI extent

6.3 Non Structural Mitigation Options

This section discusses a number of non-structural mitigation options, including land use planning, flood warning, flood response and flood awareness.

6.3.1 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), and the Urban Floodway Zone (UFZ).

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.

The current existing planning scheme is shown below in Figure 6-12. Planning Schemes can be viewed online at http://services.land.vic.gov.au/maps/pmo.jsp. Figure 6-12 below does not show the legend of the various zones and overlays, but is included to highlight one important fact, that currently there is no use of any of the four flood related planning controls listed above in the planning scheme. It is recommended that the flood related overlays shown in Figure 6-13 be adopted by Hepburn shire into the planning scheme.

The draft planning scheme maps are 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 Violet Town.

Flood hazard - combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 6-11 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.

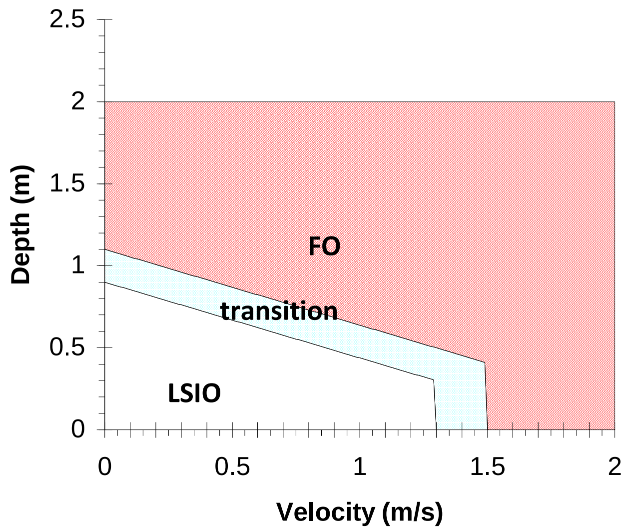


Figure 6-11 Flood hazard delineation of FO

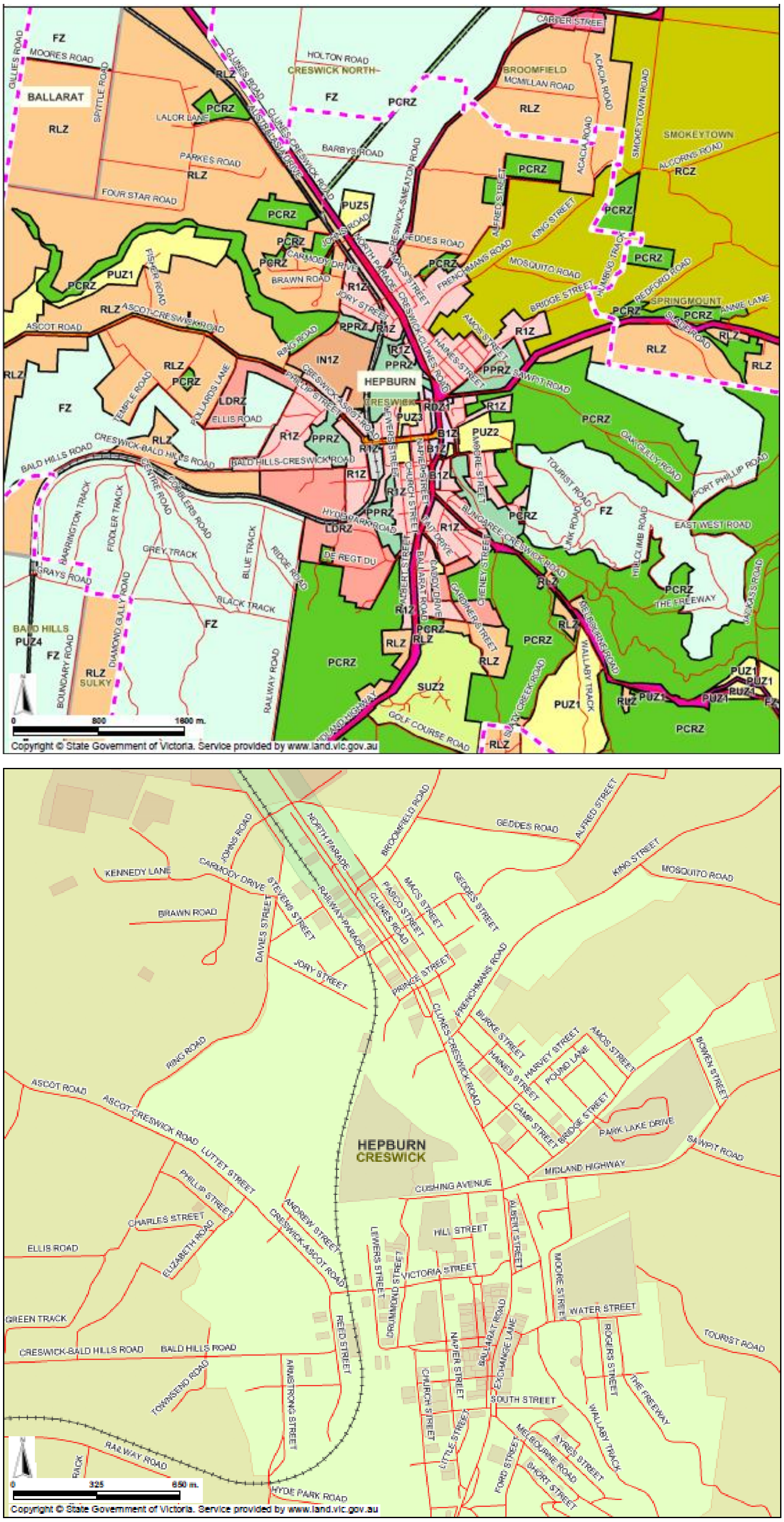


Figure 6-12 Current planning scheme zones and overlays for Creswick

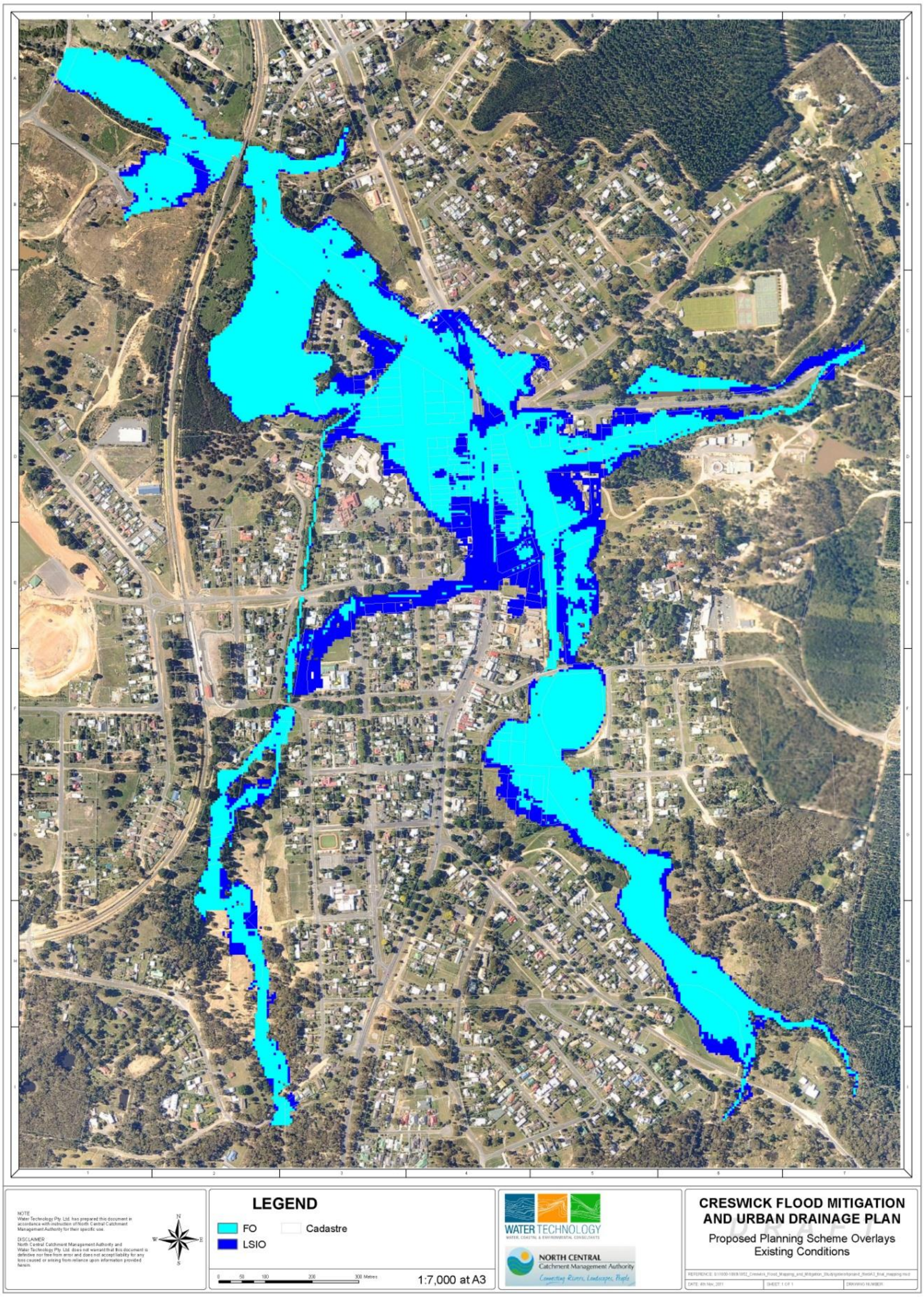


Figure 6-13 Draft LSIO and FO maps for existing conditions

6.3.2 Flood Warning, Response and Awareness

Flood Warning

Due to Creswick's location in the upper catchment the onset of flooding can potentially happen quite soon after heavy rainfall. The hydrological modelling showed that a six hour storm duration is generally the critical duration for a range of design storms. The onset of flooding can occur before the peak of the flood, so this means that the available flood warning time is potentially less than 6 hours after the start of the storm event. It is recommended that Hepburn Shire Council investigate and document the feasibility of a flash flood warning service. Hepburn Shire can seek assistance in this investigation from the Bureau of Meteorology and the North Central CMA.

There is currently no flood warning service provided by the Bureau of Meteorology at Creswick, and given the short available warning time the Bureau would most likely classify this as flash flooding so would not be covered under the traditional flood warning service. The Flood Warning Arrangements for Victoria (VFWCC, 2001) report outlines the following principles for flash flood warning services:

The Bureau of Meteorology has a responsibility to provide predictions of weather conditions likely to lead to flash flooding (e.g. thunderstorms);

Local Government has prime responsibility for flash flood warning extending from system establishment and operation through to the provision of predictions of stream levels if required; and

The Bureau of Meteorology will provide specialist technical assistance and advice to Local Government to assist in system establishment and in relation to flood prediction techniques.

This means that any flood warning system considered for Creswick would be the responsibility of Hepburn Shire Council, with the Bureau of Meteorology providing assistance in the development of the system and the supply of software, as well as the supply of severe weather warnings and flood watches. Hepburn Shire Council was identified in the Whelan Report (2010) as one of eighteen small rural councils that do not have the capacity to adequately service their communities. The Council will therefore require significant assistance in the development and maintenance of a flood warning system.

Any flash flood warning system should consider the eight building blocks of a flash flood warning system, these include:

- Data collection and collation
- Detection and prediction
- Interpretation
- Message construction
- Message dissemination
- Response
- Review
- Awareness

Failure to consider any one of these building blocks will considerably reduce the effectiveness of any flash flood warning system.

Flood Response

The information and understanding gathered during this project regarding the flood behaviour at Creswick for a range of events is critical to capture in order to improving the flood response at Creswick. This includes areas that are likely to be impacted by floods of various magnitudes, the timing and behaviour of flooding through town, areas most at risk, identifying vulnerable communities, access and egress issues, buildings inundated above and below floor, areas that need to be evacuated as a priority, etc. This information should be summarised in the Municipal Flood Emergency Management Plan. Hepburn Shire council in conjunction with VICSES is currently completing an interim flood emergency management plan. It is suggested that a gauge board be installed at an appropriate location in town so that the outputs from this study can be tied back to a common gauge level. An appropriate location for a gauge board may be at Water Street Bridge.

Flood Awareness

A flood aware and flood ready community stands a much better chance of reducing their flood damage than a community that is not aware of the flood risk before an event. This was clear in recent events, with the Creswick community able to respond to the January 2011 event much more effectively than the earlier September 2010 event. There are many misconceptions commonly held regarding flooding that may prevent a person from preparing to and then evacuating prior to the arrival of a flood. A strong community awareness campaign will reduce these misconceptions, it will never eliminate them entirely, but it will ensure that a greater percentage of the community is aware and ready to act when a flood is imminent.

Flood awareness can be improved by making this study available to the public, as well as more condensed brochure style documents that clearly explain the risk and what is being done about it by the relevant agencies, but more importantly what individuals can do to best prepare themselves. Establishing an active community group that promotes flood related issues in the community, this can be run in conjunction with a more formal program such as VICSES' FloodSafe program. Installing flood markers of historic or potentially design floods in suitable locations. This may include a town gauge board that may be part of a flash flood warning system, or at least linked to the outputs from this study in the flood response plans. Individual property flood intelligence cards have been prepared for some communities in Victoria. These generally link a flood level at a gauge to the commencement of flooding on the specific property, and the level at which above floor flooding is likely to occur, they also provide basic flood information including contact details and at what level on the gauge they should consider evacuating.

7. FLOOD DAMAGE ASSESSMENT

7.1 Overview

A flood damages assessment was undertaken for the study area under existing conditions. The flood assessment determined the monetary flood damages for design floods (5, 10, 20, 50, 100 and 200 year ARI events).

The flood damage assessment was also undertaken for all five mitigation options. The 5 and 200 year ARI events were not been modelled for the mitigation options.

Water Technology has developed an industry best practice damage assessment methodology that has been utilised for a number of studies in Victoria, combining aspects of the Rapid Appraisal Method, ANUFLOOD and other relevant flood damage literature. The model results for all mapped flood events were processed to calculate the numbers and locations of properties affected. This included properties with buildings inundated above floor, properties with buildings inundated below floor and properties where the building was not impacted but the grounds of the property were. In addition to the flood affected properties, lengths of flood affected roads for each event were also calculated. Details of the flood damage assessment methodology are provided in Appendix G.

7.2 Existing conditions

The 100 year ARI flood damage estimate for existing conditions was calculated to be over $2.5 million. A total of 138 properties are flooded in a 100 year ARI event, with 80 of those properties flooded above floor level. The January 2011 event is estimated as a 35 year ARI event. The total number of properties flooded is consistent with that reported in VICSES rapid impact assessments. The Average Annual Damages (AAD) was determined as part of the flood damage assessment. The AAD is a measure of the flood damage per year averaged over an extended period. The AAD for existing conditions for the study is estimated at approximately **$131,000**. This is effectively a measure of the amount of money that must be put aside each year in readiness for the event that a flood may happen in the future.

Table 7-1 Flood damage assessment for existing conditions

ARI (years)	200yr	100yr	50yr	20yr	10yr	5yr
AEP	0.005	0.01	0.02	0.05	0.1	0.2
Buildings Flooded Above Floor	93	80	59	26	8	0
Properties Flooded Below Floor	54	58	53	67	43	17
Total Properties Flooded	**147**	**138**	**112**	**93**	**51**	**17**
Direct Potential External Damage Cost	$316,279	$337,934	$335,259	$325,670	$101,309	$37,537
Direct Potential Residential Damage Cost	$1,440,727	$1,144,904	$808,071	$386,933	$69,150	$0
Direct Potential Commercial Damage Cost	$1,163,381	$875,478	$677,321	$299,256	$52,124	$0
Total Direct Potential Damage Cost	**$2,920,386**	**$2,358,316**	**$1,820,651**	**$1,011,860**	**$222,583**	**$37,537**
Total Actual Damage Cost *(0.8*Potential)*	**$2,336,309**	**$1,886,653**	**$1,456,521**	**$809,488**	**$178,067**	**$30,030**
Infrastructure Damage Cost	**$189,500**	**$161,007**	**$148,356**	**$96,991**	**$38,801**	**$25,381**
Indirect Clean Up Cost	$459,115	$396,202	$293,670	$129,746	$37,659	$0
Indirect Residential Relocation Cost	$52,674	$45,804	$34,353	$15,268	$3,817	$0
Indirect Emergency Response Cost	$23,269	$23,269	$18,615	$13,961	$9,308	$4,654
Total Indirect Cost	**$535,058**	**$465,275**	**$346,638**	**$158,975**	**$50,784**	**$4,654**
Total Cost	**$3,060,867**	**$2,512,934**	**$1,951,515**	**$1,065,454**	**$267,651**	**$60,065**
Average Annual Damage (AAD)	**$117,290**					

7.3 Mitigation Option 1

The AAD for mitigation option 1 was calculated to be approximately **$37,600**. During a 100 year ARI event, mitigation option 1 reduces the total number of properties inundated above floor level from 80 properties to 15 properties. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$66,200** per year by implementing mitigation option 1.

Table 7-2 Flood damage assessment for mitigation option 1

ARI (years) AEP	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	15	9	6	5	0
Properties Flooded Below Floor	25	30	30	17	0
Total Properties Flooded	**40**	**39**	**36**	**22**	**0**
Direct Potential External Damage Cost	$121,527	$132,083	$88,088	$30,733	$0
Direct Potential Residential Damage Cost	$213,523	$151,972	$89,615	$35,817	$0
Direct Potential Commercial Damage Cost	$260,010	$168,059	$103,436	$47,999	$0
Total Direct Potential Damage Cost	**$595,059**	**$452,114**	**$281,139**	**$114,550**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$476,047**	**$361,691**	**$224,911**	**$91,640**	**$0**
Infrastructure Damage Cost	**$88,301**	**$75,012**	**$49,138**	**$30,481**	**$0**
Indirect Clean Up Cost	$67,915	$41,141	$26,774	$21,331	$0
Indirect Residential Relocation Cost	$6,107	$3,817	$2,290	$1,527	$0
Indirect Emergency Response Cost	$23,269	$18,615	$13,961	$9,308	$0
Total Indirect Cost	**$97,291**	**$63,573**	**$43,025**	**$32,165**	**$0**
Total Cost	**$661,640**	**$500,277**	**$317,074**	**$154,286**	**$0**
Average Annual Damage (AAD)	$37,568				

7.4 Mitigation Option 2

The AAD for mitigation option 2 was calculated to be approximately **$32,300**. During a 100 year ARI event, mitigation option 2 reduces the total number of properties inundated above floor level from 80 properties to 25 properties. Although mitigation option 2 does not reduce as many properties flooded for the larger floods, it is more effective than option 1 for the lower events. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$64,200** per year by implementing Mitigation Option 2.

Table 7-3 Flood Damage Assessment for Mitigation Option 2

ARI (years) AEP	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	25	7	3	2	0
Properties Flooded Below Floor	81	74	47	17	0
Total Properties Flooded	**106**	**81**	**50**	**19**	**0**
Direct Potential External Damage Cost	$430,356	$332,130	$97,720	$33,743	$0
Direct Potential Residential Damage Cost	$233,627	$87,693	$0	$0	$0
Direct Potential Commercial Damage Cost	$249,188	$155,795	$91,718	$24,710	$0
Total Direct Potential Damage Cost	**$913,171**	**$575,618**	**$189,438**	**$58,453**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$730,537**	**$460,494**	**$151,551**	**$46,762**	**$0**
Infrastructure Damage Cost	**$98,210**	**$80,627**	**$44,524**	**$26,237**	**$0**
Indirect Clean Up Cost	$122,343	$32,217	$10,446	$6,964	$0
Indirect Residential Relocation Cost	$13,741	$3,054	$0	$0	$0
Indirect Emergency Response Cost	$23,269	$18,615	$13,961	$9,308	$0
Total Indirect Cost	**$159,352**	**$53,885**	**$24,407**	**$16,271**	**$0**
Total Cost	**$988,099**	**$595,006**	**$220,482**	**$89,270**	**$0**
Average Annual Damage (AAD)	$32,355				

7.5 Mitigation Option 3

The AAD for mitigation option 3 was calculated to be approximately **$22,300**. During a 50 year ARI event, mitigation option 3 reduces the total number of properties inundated above floor level from 59 properties to 5 properties. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$71,300** per year by implementing Mitigation Option 3.

Table 7-4 Flood Damage Assessment for Mitigation Option 3

ARI (years) / AEP	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	13	5	3	2	0
Properties Flooded Below Floor	73	32	17	12	0
Total Properties Flooded	**86**	**37**	**20**	**14**	**0**
Direct Potential External Damage Cost	$298,770	$106,433	$38,570	$26,233	$0
Direct Potential Residential Damage Cost	$154,674	$44,219	$0	$0	$0
Direct Potential Commercial Damage Cost	$209,915	$157,379	$82,085	$20,035	$0
Total Direct Potential Damage Cost	**$663,359**	**$308,031**	**$120,654**	**$46,268**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$530,687**	**$246,424**	**$96,523**	**$37,014**	**$0**
Infrastructure Damage Cost	**$82,223**	**$40,462**	**$32,679**	**$27,848**	**$0**
Indirect Clean Up Cost	$62,912	$21,331	$10,446	$6,964	$0
Indirect Residential Relocation Cost	$6,871	$1,527	$0	$0	$0
Indirect Emergency Response Cost	$23,269	$18,615	$13,961	$9,308	$0
Total Indirect Cost	**$93,052**	**$41,473**	**$24,407**	**$16,271**	**$0**
Total Cost	**$705,961**	**$328,359**	**$153,609**	**$81,133**	**$0**
Average Annual Damage (AAD)	$22,326				

7.6 Mitigation Option 4

The AAD for mitigation option 4 was calculated to be approximately **$46,800**. During a 50 year ARI event, mitigation option 4 reduces the total number of properties inundated above floor level from 59 properties to 31 properties. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$64,900** per year by implementing mitigation option 4.

Table 7-5 Flood Damage Assessment for Mitigation Option 4

ARI (years) / AEP	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	48	31	5	2	0
Properties Flooded Below Floor	63	61	25	16	0
Total Properties Flooded	**111**	**92**	**30**	**18**	**0**
Direct Potential External Damage Cost	$364,501	$339,582	$52,803	$28,194	$0
Direct Potential Residential Damage Cost	$778,772	$528,393	$52,122	$0	$0
Direct Potential Commercial Damage Cost	$348,169	$231,690	$100,141	$20,035	$0
Total Direct Potential Damage Cost	**$1,491,443**	**$1,099,666**	**$205,066**	**$48,228**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$1,193,154**	**$879,732**	**$164,053**	**$38,583**	**$0**
Infrastructure Damage Cost	**$133,573**	**$90,463**	**$35,261**	**$25,867**	**$0**
Indirect Clean Up Cost	$237,721	$154,999	$21,331	$6,964	$0
Indirect Residential Relocation Cost	$27,482	$18,322	$1,527	$0	$0
Indirect Emergency Response Cost	$23,269	$18,615	$13,961	$9,308	$0
Total Indirect Cost	**$288,472**	**$191,936**	**$36,819**	**$16,271**	**$0**
Total Cost	**$1,615,199**	**$1,162,131**	**$236,133**	**$80,721**	**$0**
Average Annual Damage (AAD)	$46,818				

7.7 Mitigation Option 5

The AAD for mitigation option 5 was calculated to be approximately **$30,000**. During a 50 year ARI event, mitigation option 5 reduces the total number of properties inundated above floor level from 59 properties to 6 properties. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$81,300** per year by implementing Mitigation Option 5.

Table 7-6 Flood Damage Assessment for Mitigation Option 5

ARI (years)	100yr	50yr	20yr	10yr	5yr
AEP	0.01	0.02	0.05	0.1	0.2
Buildings Flooded Above Floor	48	6	4	3	0
Properties Flooded Below Floor	65	28	20	13	0
Total Properties Flooded	**113**	**34**	**24**	**16**	**0**
Direct Potential External Damage Cost	$375,568	$95,363	$48,446	$26,501	$0
Direct Potential Residential Damage Cost	$691,269	$83,350	$20,297	$0	$0
Direct Potential Commercial Damage Cost	$285,885	$163,524	$98,941	$40,450	$0
Total Direct Potential Damage Cost	**$1,352,722**	**$342,237**	**$167,684**	**$66,951**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$1,082,178**	**$273,790**	**$134,147**	**$53,560**	**$0**
Infrastructure Damage Cost	**$120,417**	**$42,677**	**$33,454**	**$25,747**	**$0**
Indirect Clean Up Cost	$243,604	$26,774	$15,888	$10,446	$0
Indirect Residential Relocation Cost	$29,772	$2,290	$763	$0	$0
Indirect Emergency Response Cost	$23,269	$18,615	$13,961	$9,308	$0
Total Indirect Cost	**$296,645**	**$47,679**	**$30,613**	**$19,753**	**$0**
Total Cost	**$1,499,240**	**$364,146**	**$198,213**	**$99,061**	**$0**
Average Annual Damage (AAD)	$30,137				

7.8 Average Annual Damage Summary

The damage assessment shows that all five mitigation options have a significant impact on reducing the AAD in Creswick. The extensive bridge and channel widening works under mitigation option 3 has the highest impact on the AAD in Creswick while concrete lining the creek (mitigation option 4) has the least impact.

Table 7-7 Average Annual Damage Summary for Creswick

Options	Average Annual Damage
Existing Conditions	$117,300
Mitigation Option 1	$37,600
Mitigation Option 2	$32,400
Mitigation Option 3	$22,300
Mitigation Option 4	$46,800
Mitigation Option 5	$30,100

7.9 Non-Economic Flood Damages

The previous discussion relating to flood damages has concentrated on monetary damages, that is damages that are easily quantified. In addition to those damages, it is widely recognised that individuals and communities also suffer significant non-monetary damage, i.e. emotional distress, health issues, etc. There has been extensive research undertaken and documented in the scientific literature relating to the individuals and communities response to natural disasters. A recent publication entitled *"Understanding floods: Questions and Answers"* by the Queensland Floods Science Engineering and Technology Panel, when discussing the large social consequences floods have on individuals and communities states:

Floods can also traumatise victims and their families for long periods of time. The loss of loved ones has deep impacts, especially on children. Displacement from one's home, loss of property and disruption to business and social affairs can cause continuing stress. For some people the psychological impacts can be long lasting.

The *"Disaster Loss Assessment Guidelines"* (EMA, 2002) make the following key points:

- *Intangibles are often found to be more important than tangible losses.*
- *Most research shows that people value the intangible losses from a flooded home—principally loss of memorabilia, stress and resultant ill-health—as at least as great as their tangible dollar losses.*
- *There are no agreed methods for valuing these losses.*

There is no doubt that the Creswick community has suffered greatly as a result of the recent floods and will continue to do so with potential future floods. The Department of Human Services (DHS) has recognised the loss faced by the Creswick community and has recently managed 104 emergency grants within the shire along with 25 hardship grants in Creswick itself. The Hepburn Shire Council Flood Recovery Office also supplied statistics regarding 29 primary producer flood grants and 3 not for profit flood grants. DHS and Hepburn Shire Council have facilitated a number of sessions for the Creswick community with Doctor Rob Gordon, a clinical psychologist who specialises in providing psychological support to people involved in significant distressing events such as floods & bushfires. He has assisted the community to understand what they are going through and has provided some counselling in potential ways to deal with the recovery.

There is no doubt that the intangible non-monetary flood related damage in Creswick is high. The benefit-cost analysis presented later in this report (section 8.3) has not considered this cost. Any decisions made that are based on the benefit-cost ratios need to understand that the true cost of floods in Creswick is far higher than the economic damages alone. This would have the effect of increasing the benefit cost ratio, improving the argument for approving a mitigation scheme at Creswick.

8. BENEFIT COST ANALYSIS

8.1 Overview

A benefit cost analysis was undertaken to assess the economic viability of the five 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.

8.2 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.
- Rawlinsons Australian Construction Handbook Rates
- Advice from VIC ROADS regarding bridge work costs
- Comparison to cost estimates for similar mitigation works for other flood studies

A summary of the cost estimates for the five mitigation options are shown in Table 8-1 below. A detailed breakdown of the costing for each mitigation option is included in Appendix F. The cost of the bridge works represented a significant portion of the total cost outlay for Options 2, 3 and 5. Apart from the bridge works, the principal cost elements for the five mitigation options include the construction of levee banks 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 removing trees, constructing floodgates, concreting the creek 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 8-1 Mitigation Option Cost Breakdown

Option	Total Construction Cost	Annual Maintenance
Mitigation Option 1	$1,482,000	$13,600
Mitigation Option 2	$6,190,000	$20,600
Mitigation Option 3	$4,639,000	$23,700
Mitigation Option 4	$1,607,000	$5,580
Mitigation Option 5	$1,372,000	$5,840

8.3 Benefit Cost Ratio

The results of the benefit cost analysis are shown below in Table 8-2. Mitigation options 2 and 3 have a low benefit cost ratio, as the significant cost of demolishing and rebuilding the bridges far outweighs the benefits. Mitigation option 5 is the most economical solution with a benefit cost ratio of 0.8. The actual benefit cost ratio will be higher once non-monetary flood damages are considered. This further justifies the recommendation of this option as the preferred option.

Table 8-2 Benefit Cost Analysis

	Existing Conditions	Mitigation Option 1	Mitigation Option 2	Mitigation Option 3	Mitigation Option 4	Mitigation Option 5
Average Annual Damage	$117,300	$37,600	$32,400	$22,300	$46,800	$30,100
Annual Maintenance Cost		$13,600	$20,600	$23,700	$5,580	$5,840
Annual Cost Saving		$66,200	$64,300	$71,300	$64,900	$81,300
Net Present Value		$930,500	$904,700	$1,002,600	$912,500	$1,143,400
Capital Cost of Mitigation		$1,482,000	$6,190,000	$4,639,000	$1,607,000	$1,372,000
Benefit – Cost Ratio		0.6	0.1	0.2	0.6	0.8

9. CONCLUSIONS AND RECOMMENDATIONS

The Creswick Flood Mitigation and Urban Drainage Plan was undertaken by Water Technology on behalf of North Central CMA and Hepburn Shire Council. The study has been led by a community based Steering Committee with support from a Technical Working Group. A range of consultation activities, including community meetings, media releases and questionnaires, were held during the project to ensure that community issues were heard and community ideas were considered in the assessment of potential flood mitigation options.

The study developed a detailed hydrological model of the Creswick catchment along with a complex hydraulic model of the township. These models were calibrated to the September 2010 and January 2011 events. The models were then used to simulate design floods of 5, 10, 20, 50, 100 and 200 year ARI events. From the observed recent flood events and the flood modelling, key observations of flood behaviour through Creswick was made. This was documented in this report along with the many flood maps and flood animations.

After gaining a thorough understanding of the flood behaviour in Creswick various mitigation options were assessed. An initial prefeasibility assessment comprehensively reviewed options to determine those worthy of more detailed consideration. Five mitigation options were modelled with the aim of reducing the flood damage within Creswick. The first two initial options demonstrated the works required to protect to a 100 year ARI design standard by means of raised levees and a deepened and widened creek. The third option looked at a combination of creek widening and deepening with minor levees and some bridge upgrades. The fourth option considered a similar widening and deepening with concrete lining of the creek. The fifth option considered the results of the previous four options and after a few iterations settled on a balance between bridge upgrades, deepening the creek and minor levee works.

This study shows that mitigation option 5 is the preferred option. Option 5 has the superior benefit cost ratio of 0.8 as compared to all other options with ratios less than 0.6. This ratio was calculated based on monetary flood damages alone. The actual benefit cost ratio will be higher, taking into account intangible non-monetary flood related damages. Option 5 was also considered by the Steering Committee to be an option that would be acceptable to the community, providing a balance between a reduction in flood risk without detracting from the amenity and character of the town.

Following on from this study it is recommended that mitigation option 5 be considered further with applications for funding to carry out detailed design and construction of the preferred option. It is suggested that a levee along North Parade also be considered in conjunction with option 5 as discussed in the report.

Other recommendations arising from this study include the following:

- Hepburn Shire Council to use the information from this study to complete the Municipal Flood Emergency Management Plan.
- Investigate and document the feasibility of a flash flood warning system for Creswick along with installation of a town gauge board at Water Street Bridge (or other appropriate location), that can be linked to the outputs from this study.
- A campaign to raise flood awareness within the community
- Hepburn Shire Council, as a matter of priority, adopts the draft LSIO and FO maps and incorporates them into the planning scheme. This will ensure that any inappropriate development in the floodplain is controlled.

APPENDIX A DETAILS OF STRUCTURE SURVEY

Table A 1 key hydraulic structures in Creswick included in the hydraulic model

Creswick Creek - Water St Bridge 	Bridge on 2 rows of five 350x350 box piers U/S Invert (Bottom of bank) – 414.89 m AHD Road Crest – 419.35 m AHD
Creswick Creek - Footbridge near Bowling Green (Jane Way) 	Clearspan Bridge 25.2m long U/S Invert (Bottom of bank) – 414.66 m AHD

Creswick Creek - Castlemaine Rd Bridge 	5 box culverts 3m wide x 2m high U/S Invert (Bottom of bank) – 413.6 m AHD Top of Bridge Deck – 416.5 m AHD 1 culvert on left bank Invert – 1.6m to road crest Diameter – 1.2m Also a 0.8m diameter culvert flowing into Creswick Creek on right bank downstream of bridge
Creswick Creek - Clunes Rd Bridge 	5 box culverts 3m wide x 2m high U/S Invert (Bottom of bank) – 413.5 m AHD Top of Bridge Deck – 416.5 m AHD

Creswick Creek – Ring Road 	3x450mm culverts U/S Invert – 408.7 m AHD Road Crest – 409.66 m AHD
Sawpit Gully - Sawpit Road 	Arch culvert Bridge Half culvert is 2.4m wide at base and 1.9m high U/S Invert – 423.24 m AHD Road crest at centre – 426.86 m AHD Significant gravel in bottom of culvert
Sawpit Gully - Moore Street 	3x300mm culverts U/S Invert – 416.11 m AHD Road Crest – 416.71 m AHD

<table>
<tr><td>Nuggetty Gully – Hyde Park Road
</td><td>2x900mm culverts
U/S Invert – 441.41 m AHD
Road Crest – 442.85 m AHD</td></tr>
<tr><td>Nuggetty Gully - Raglan Street
</td><td>Bluestone Culvert 3.6m wide x 2.4m high
U/S Invert – 426.22 m AHD</td></tr>
<tr><td>Nuggetty Gully - Victoria Street
</td><td>Bluestone, headwalls, small capacity
<u>Arch culvert</u>
1.2m wide at base
1.2m high (including about 0.2m lined v-shaped channel)
U/S Invert – 421.49 m AHD
<u>Circular culverts</u>
2x450mm
U/S Invert – 422.99
A number of stormwater pipes connected</td></tr>
</table>

Nuggetty Gully – Cushing Avenue 	Bridge Crossing - 1m high x 2.5m wide U/S Invert – 415.45 m AHD Road Crest 416.78 m AHD
Nuggetty Gully - Caravan Park Entrance 	During the floods the structure had a single culvert (as seen on the left hand side) New culverts, channel works and levee bank constructed in February. Original Culvert One 1.2m wide x 0.75m high U/S Invert – 413.95 m AHD New Culverts Two 0.9m wide x 0.75m high Invert – 413.95 m AHD

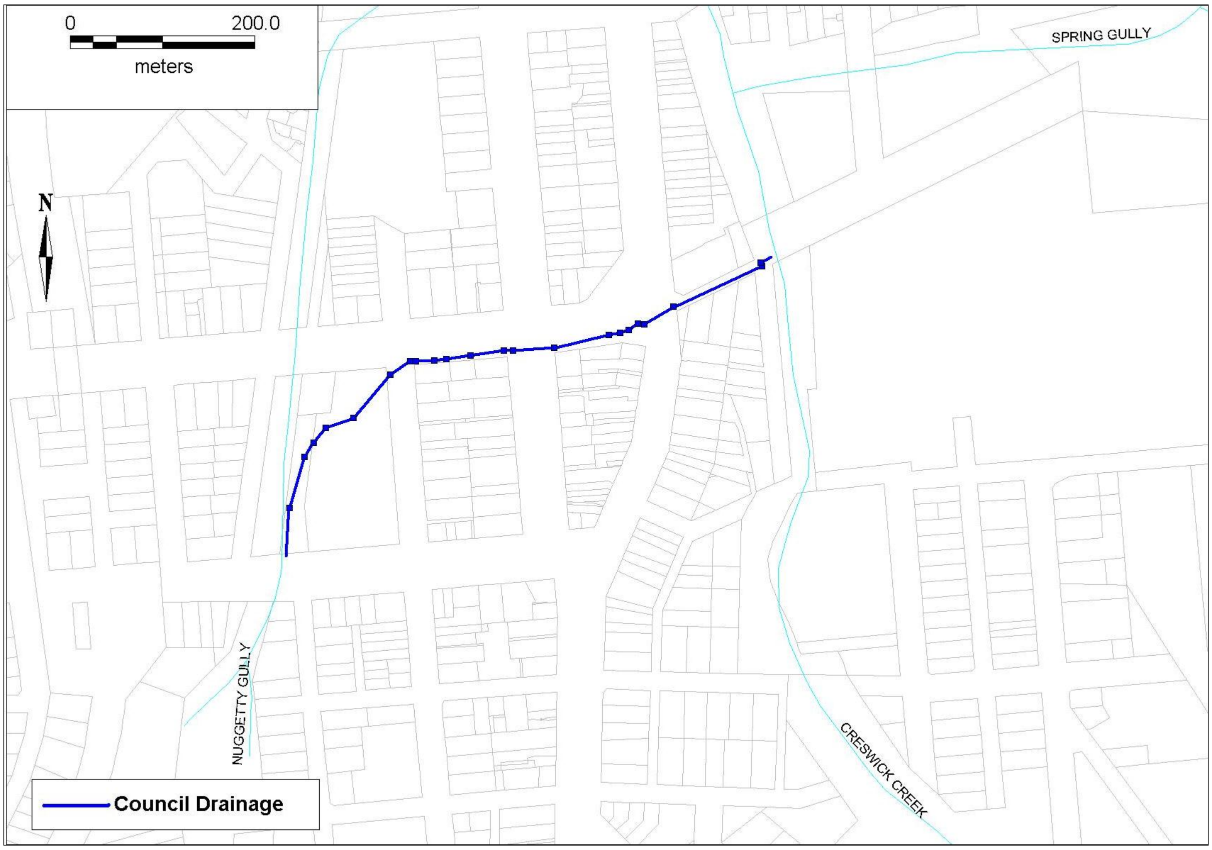


Figure A 1 Location of key pipe network in Creswick included in the hydraulic model

Table A 2 Information on key storages

St Georges Dam – View of Secondary Spillway 	Primary spillway is 6.5m wide Secondary spillway is 37m wide Capacity – 200ML Depth at peak close to top of BBQs, so maybe 1m. Managed by Parks Victoria
Cosgrave Dam – View of Spillway 	Capacity - 680ML Spilling during field inspection, large spillway, gauged Managed by Central Highlands Water.

APPENDIX B SURVEY DATA

Figure B 1 Location of Surveyed Points

Table B 1 Comparison Between LiDAR and Survey Points

ID	Location	Survey	LiDAR	Diff (m)	Diff (mm)
7/8	Banks near Water St bridge	418.57	418.71	0.14	137.99
7/8	Banks near Water St bridge	417.86	418.12	0.26	262.99
7/8	Banks near Water St bridge	418.58	418.71	0.13	128.99
7/8	Banks near Water St bridge	418.58	418.71	0.13	128.99
7/8	Banks near Water St bridge	417.87	418.17	0.30	304.01
7/8	Banks near Water St bridge	417.86	418.17	0.31	311.01
7/8	Banks near Water St bridge	418.58	418.71	0.13	126.99
7/8	Banks near Water St bridge	418.63	418.71	0.08	81.99
7/8	Banks near Water St bridge	417.86	418.12	0.26	259.00
7/8	Banks near Water St bridge	418.55	418.71	0.16	162.99
7/8	Banks near Water St bridge	417.87	418.17	0.30	302.01
5	Near Cushing Ave Bridge	415.86	415.94	0.08	79.00
5	Near Cushing Ave Bridge	415.85	415.94	0.09	86.00
5	Near Cushing Ave Bridge	415.86	415.94	0.08	83.00
5	Near Cushing Ave Bridge	415.86	415.94	0.08	81.00
5	Near Cushing Ave Bridge	415.85	415.94	0.09	86.00
5	Near Cushing Ave Bridge	415.85	415.94	0.09	86.00
5	Near Cushing Ave Bridge	415.87	415.94	0.07	66.00
5	Near Cushing Ave Bridge	415.84	415.94	0.11	105.00
1	Near Raglan St bridge	428.54	428.74	0.20	196.99
1	Near Raglan St bridge	428.54	428.74	0.20	196.99
1	Near Raglan St bridge	428.54	428.74	0.20	199.99
1	Near Raglan St bridge	428.56	428.74	0.18	180.99
3	Near Victoria St Bridge	426.83	426.84	0.01	9.00
3	Near Victoria St Bridge	426.83	426.90	0.07	66.99
3	Near Victoria St Bridge	426.83	426.90	0.07	66.99
3	Near Victoria St Bridge	426.83	426.90	0.07	74.99
3	Near Victoria St Bridge	426.85	426.90	0.05	45.99
6	Point along Cushing Ave	414.34	414.39	0.05	53.01
6	Point along Cushing Ave	414.21	414.39	0.18	184.01
6	Point along Cushing Ave	414.34	414.39	0.05	49.01
6	Point along Cushing Ave	414.33	414.39	0.06	61.01
6	Point along Cushing Ave	414.35	414.39	0.04	42.01
4	Point along Victoria St	423.97	424.05	0.08	75.99
4	Point along Victoria St	424.00	424.05	0.05	51.99
4	Point along Victoria St	424.00	424.05	0.05	51.99
4	Point along Victoria St	423.97	424.05	0.08	75.99
4	Point along Victoria St	423.97	424.05	0.08	75.99
4	Point along Victoria St	423.96	424.02	0.06	60.99
9/10	Near Saw Pit Rd Crosssing	426.40	426.39	-0.01	-8.99
9/10	Near Saw Pit Rd Crosssing	426.91	426.90	-0.01	-14.01
9/10	Near Saw Pit Rd Crosssing	426.91	426.90	-0.01	-14.01
9/10	Near Saw Pit Rd Crosssing	426.40	426.39	-0.01	-13.99
9/10	Near Saw Pit Rd Crosssing	426.34	426.39	0.05	51.01
9/10	Near Saw Pit Rd Crosssing	426.91	426.90	-0.01	-14.01
9/10	Near Saw Pit Rd Crosssing	426.33	426.39	0.06	59.01
9/10	Near Saw Pit Rd Crosssing	426.77	426.90	0.13	128.99
9/10	Near Saw Pit Rd Crosssing	426.34	426.39	0.05	46.01
9/10	Near Saw Pit Rd Crosssing	426.98	426.90	-0.08	-79.01
9/10	Near Saw Pit Rd Crosssing	426.91	426.90	-0.01	-14.01
2	West of school	424.06	424.11	0.05	52.98
2	West of school	424.06	424.11	0.05	52.98
2	West of school	424.11	424.11	0.00	3.99
2	West of school	424.11	424.11	0.00	-3.02

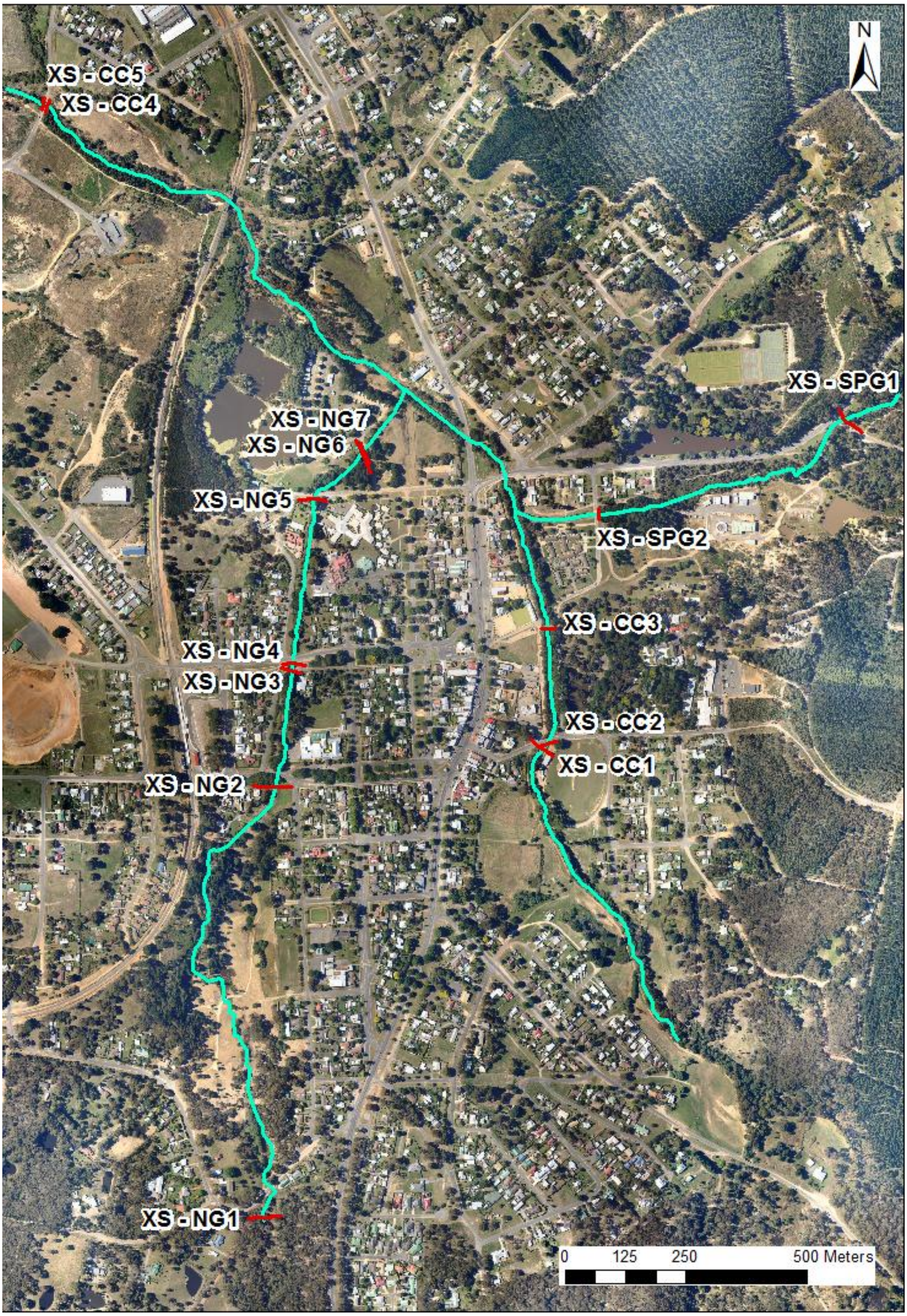
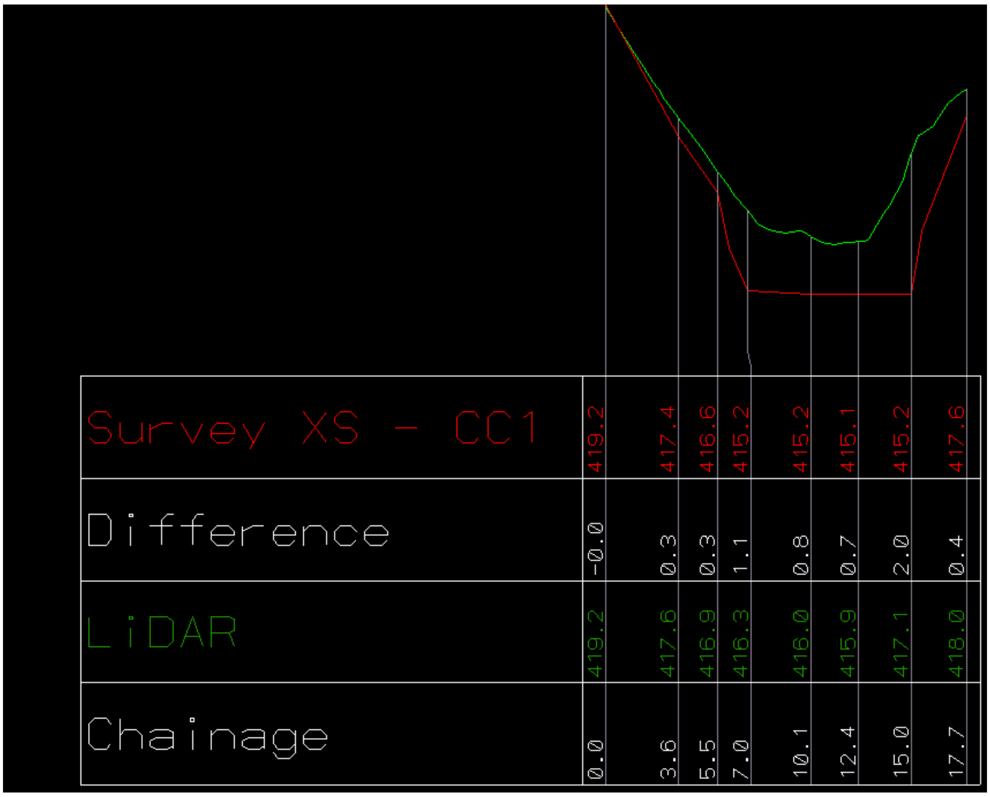
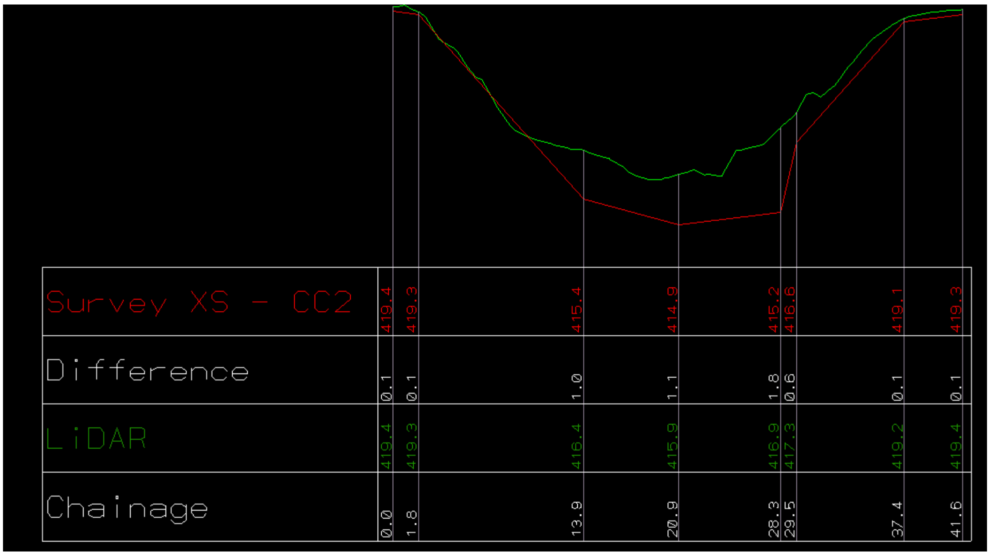
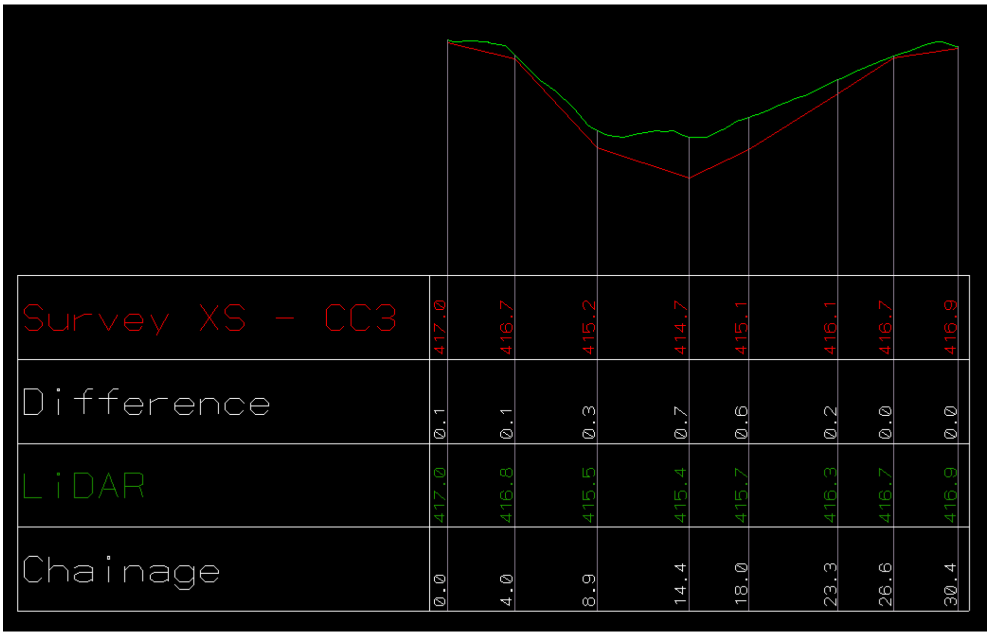
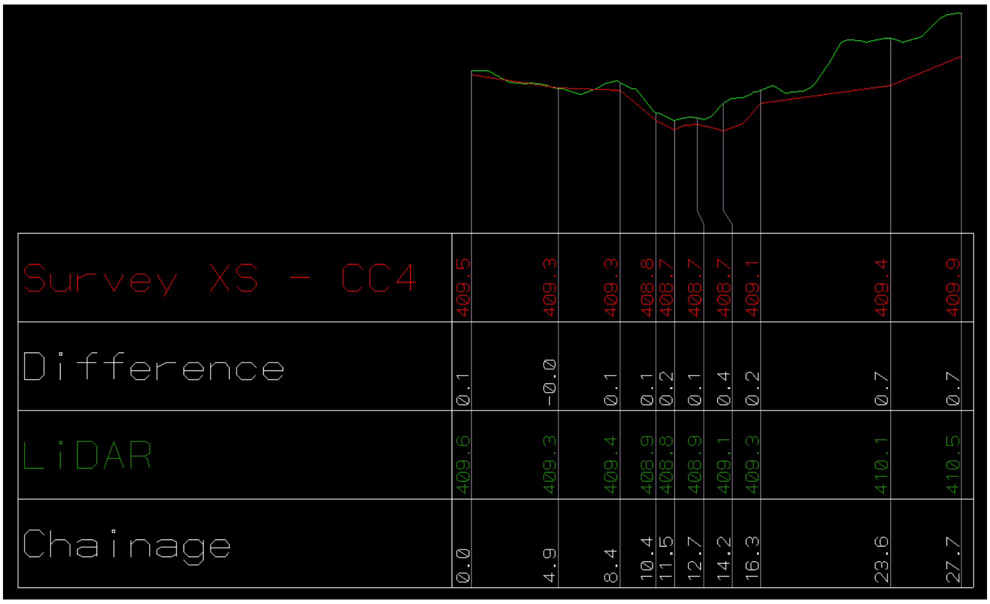


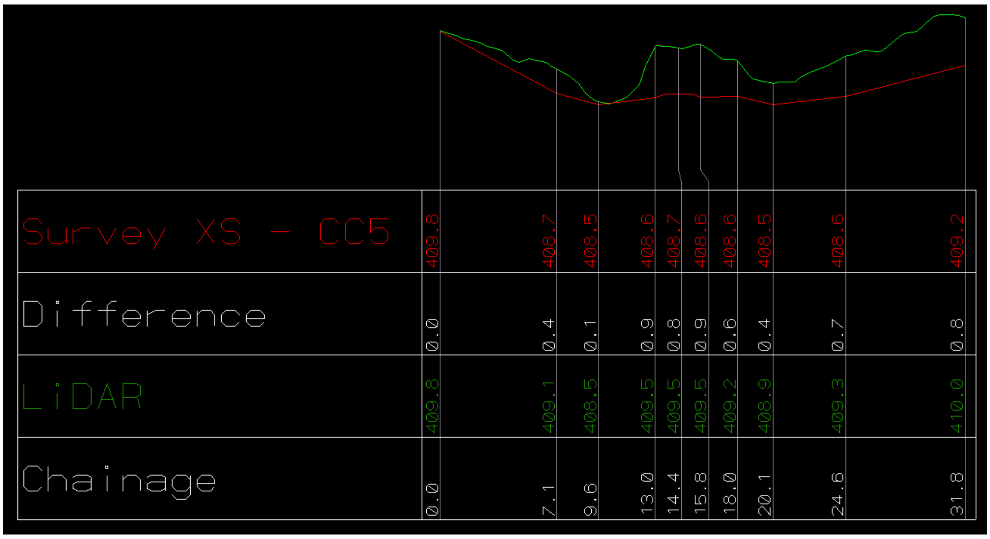
Figure B 2 Location of Surveyed Cross Sections

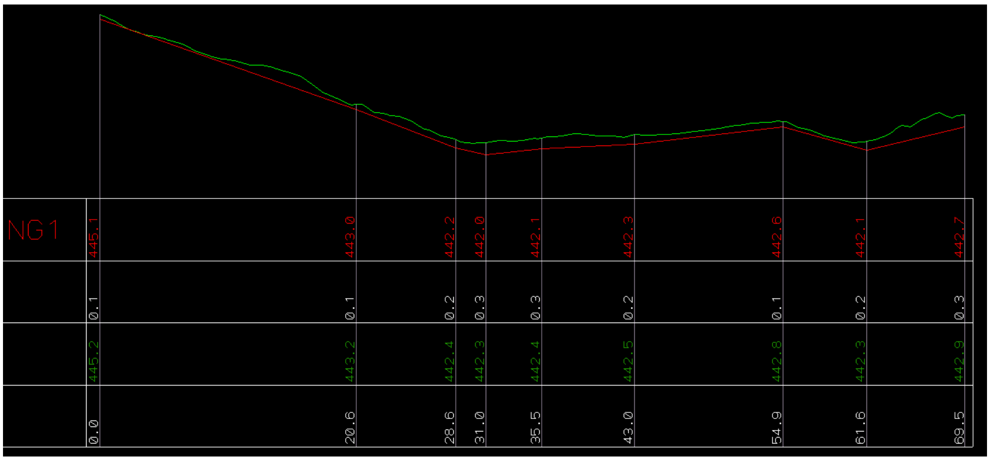

Survey XS - CC1
419.2 417.4 416.6 415.2 415.2 415.1 415.2 417.6
Difference
-0.0 0.3 0.3 1.1 0.8 0.7 2.0 0.4
LiDAR
419.2 417.6 416.9 416.3 416.0 415.9 417.1 418.0
Chainage
0.0 3.6 5.5 7.0 10.1 12.4 15.0 17.7

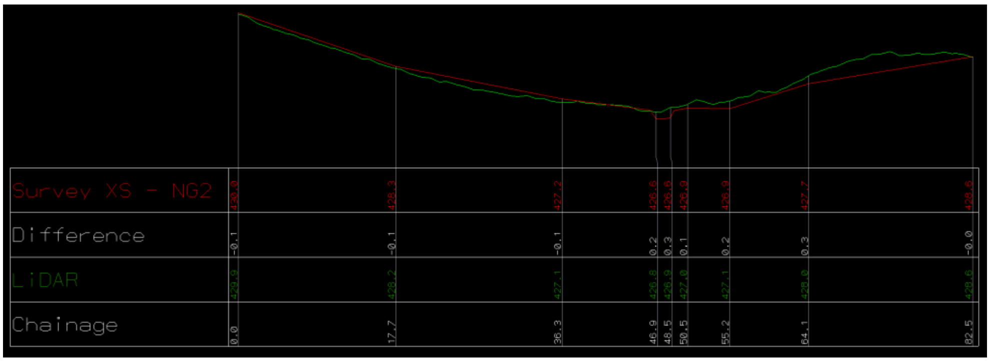

Survey XS - CC2
419.4 419.3 415.4 414.9 415.2 416.6 419.1 419.3
Difference
0.1 0.1 1.0 1.1 1.8 0.6 0.1 0.1
LiDAR
419.4 419.3 416.4 415.9 416.9 417.3 419.2 419.4
Chainage
0.0 1.8 13.9 20.9 28.3 29.5 37.4 41.6

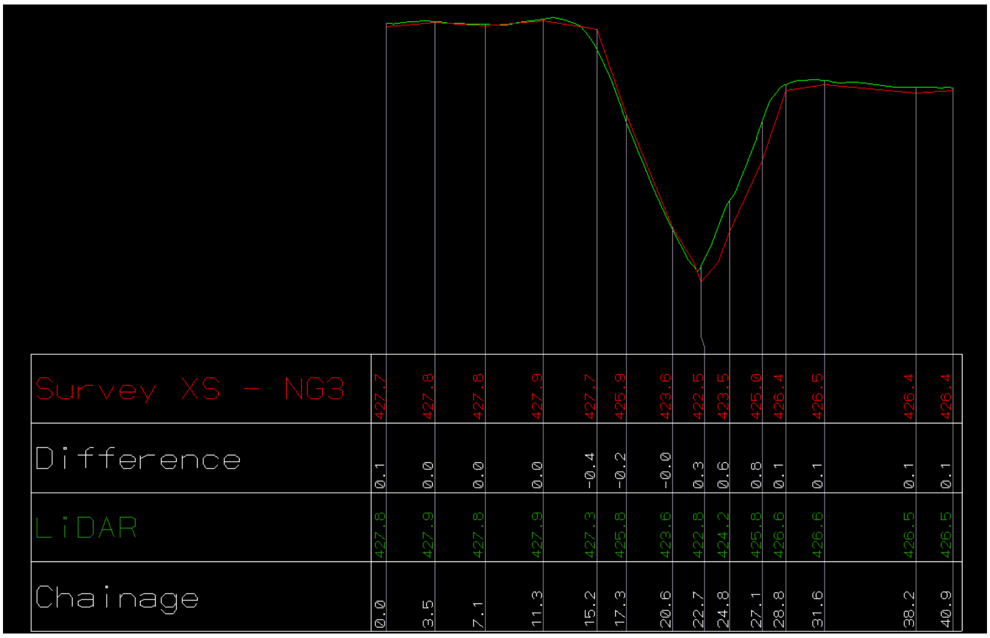

Survey XS - CC3
417.0 416.7 415.2 414.7 415.1 416.1 416.7 416.9
Difference
0.1 0.1 0.3 0.7 0.6 0.2 0.0 0.0
LiDAR
417.0 416.8 415.5 415.4 415.7 416.3 416.7 416.9
Chainage
0.0 4.0 8.9 14.4 18.0 23.3 26.6 30.4

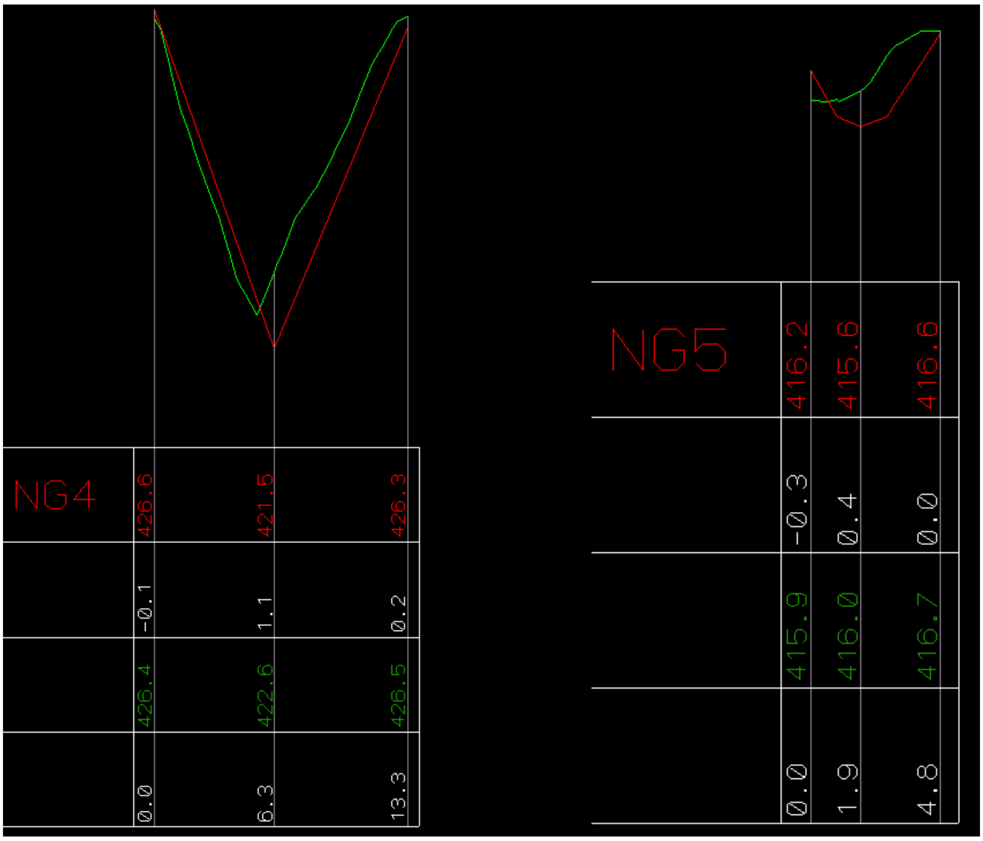

Survey XS - CC4
409.5 409.3 409.3 408.8 408.7 408.7 408.7 409.1 409.4 409.9
Difference
0.1 -0.0 0.1 0.1 0.2 0.1 0.4 0.2 0.7 0.7
LiDAR
409.6 409.3 409.4 408.9 408.8 408.9 409.1 409.3 410.1 410.5
Chainage
0.0 4.9 8.4 10.4 11.5 12.7 14.2 16.3 23.6 27.7

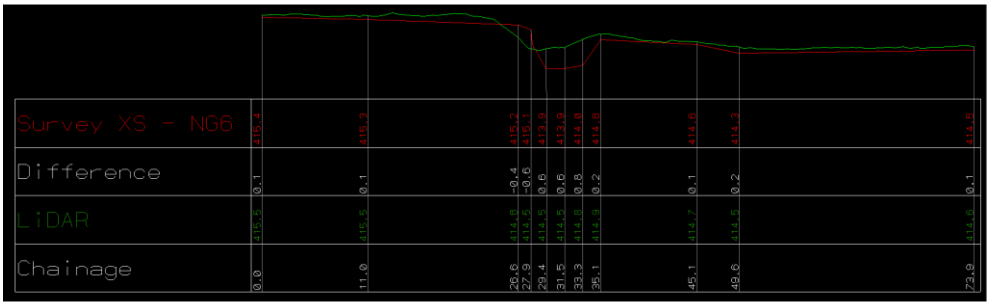

Survey XS - CC5
409.8 408.7 408.5 408.6 408.7 408.6 408.6 408.5 408.6 409.2
Difference
0.0 0.4 0.1 0.9 0.8 0.9 0.6 0.4 0.7 0.8
LiDAR
409.8 409.1 408.5 409.5 409.5 409.5 409.2 408.9 409.3 410.0
Chainage
0.0 7.1 9.6 13.0 14.4 15.8 18.0 20.1 24.6 31.8

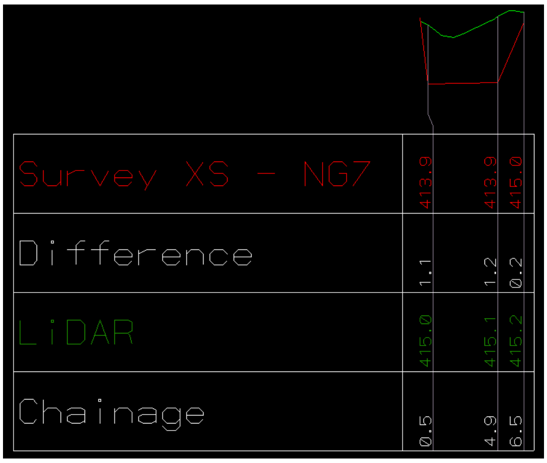

NG1
445.1 443.0 442.2 442.0 442.1 442.3 442.6 442.1 442.7
0.1 0.1 0.2 0.3 0.3 0.2 0.1 0.2 0.3
445.2 443.2 442.4 442.3 442.4 442.5 442.8 442.3 442.9
0.0 20.6 28.6 31.0 35.5 43.0 54.9 61.6 69.5

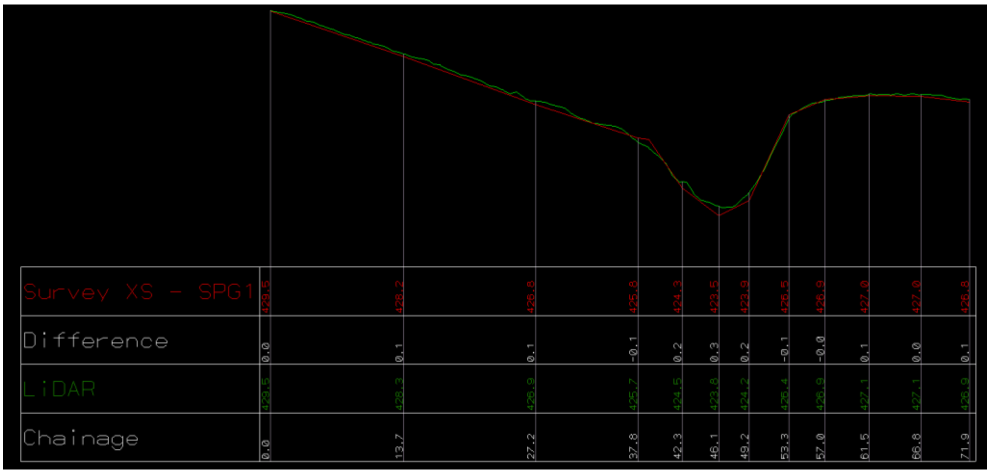

Survey XS - NG2
430.0 428.3 427.2 426.6 426.6 426.9 426.9 427.7 428.6
Difference
-0.1 -0.1 -0.1 0.2 0.3 0.1 0.2 0.3 -0.0
LiDAR
429.9 428.2 427.1 426.8 426.9 427.0 427.1 428.0 428.6
Chainage
0.0 17.7 36.3 46.9 48.5 50.5 55.2 64.1 82.5

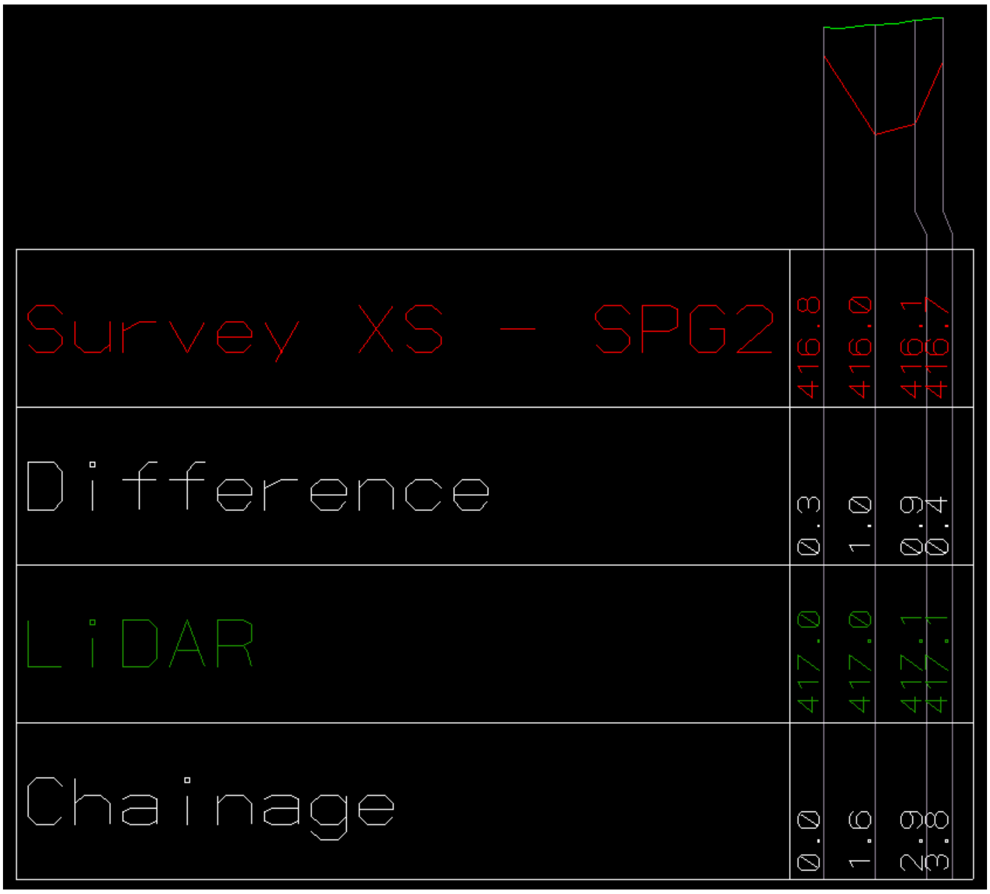

Survey XS - NG3
427.7 427.8 427.8 427.9 427.7 425.9 423.6 422.5 423.5 425.0 426.4 426.5 426.4 426.4
Difference
0.1 0.0 0.0 0.0 -0.4 -0.2 -0.0 0.3 0.6 0.8 0.1 0.1 0.1 0.1
LiDAR
427.8 427.9 427.8 427.9 427.3 425.8 423.6 422.8 424.2 425.8 426.6 426.6 426.5 426.5
Chainage
0.0 3.5 7.1 11.3 15.2 17.3 20.6 22.7 24.8 27.1 28.8 31.6 38.2 40.9


NG4
426.6
421.5
426.3
-0.1
1.1
0.2
426.4
422.6
426.5
0.0
6.3
13.3
NG5
416.2
415.6
416.6
-0.3
0.4
0.0
415.9
416.0
416.7
0.0
1.9
4.8


Survey XS - NG6
415.4
415.3
415.2
415.1
413.9
413.9
414.0
414.8
414.6
414.3
414.5
Difference
0.1
0.1
-0.4
-0.6
0.6
0.6
0.8
0.2
0.1
0.2
0.1
LiDAR
415.5
415.5
414.8
414.5
414.5
414.5
414.8
414.9
414.7
414.5
414.6
Chainage
0.0
11.0
26.6
27.9
29.4
31.5
33.3
35.1
45.1
49.6
73.9


Survey XS - NG7
413.9
413.9
415.0
Difference
1.1
1.2
0.2
LiDAR
415.0
415.1
415.2
Chainage
0.5
4.9
6.5


Survey XS - SPG1
429.5
428.2
426.8
425.8
424.3
423.5
423.9
425.5
426.9
427.0
427.0
426.8
Difference
0.0
0.1
0.1
-0.1
0.2
0.3
0.2
-0.1
-0.0
0.1
0.0
0.1
LiDAR
429.5
428.3
426.9
425.7
424.5
423.8
424.2
425.4
426.9
427.1
427.1
426.9
Chainage
0.0
13.7
27.2
37.8
42.3
46.1
49.2
53.3
57.0
61.5
66.8
71.9


Survey XS - SPG2
416.8
416.0
416.1
416.7
Difference
0.3
1.0
0.9
0.4
LiDAR
417.0
417.0
417.1
417.1
Chainage
0.0
1.6
2.9
3.8

APPENDIX C DESIGN FLOOD MAPS

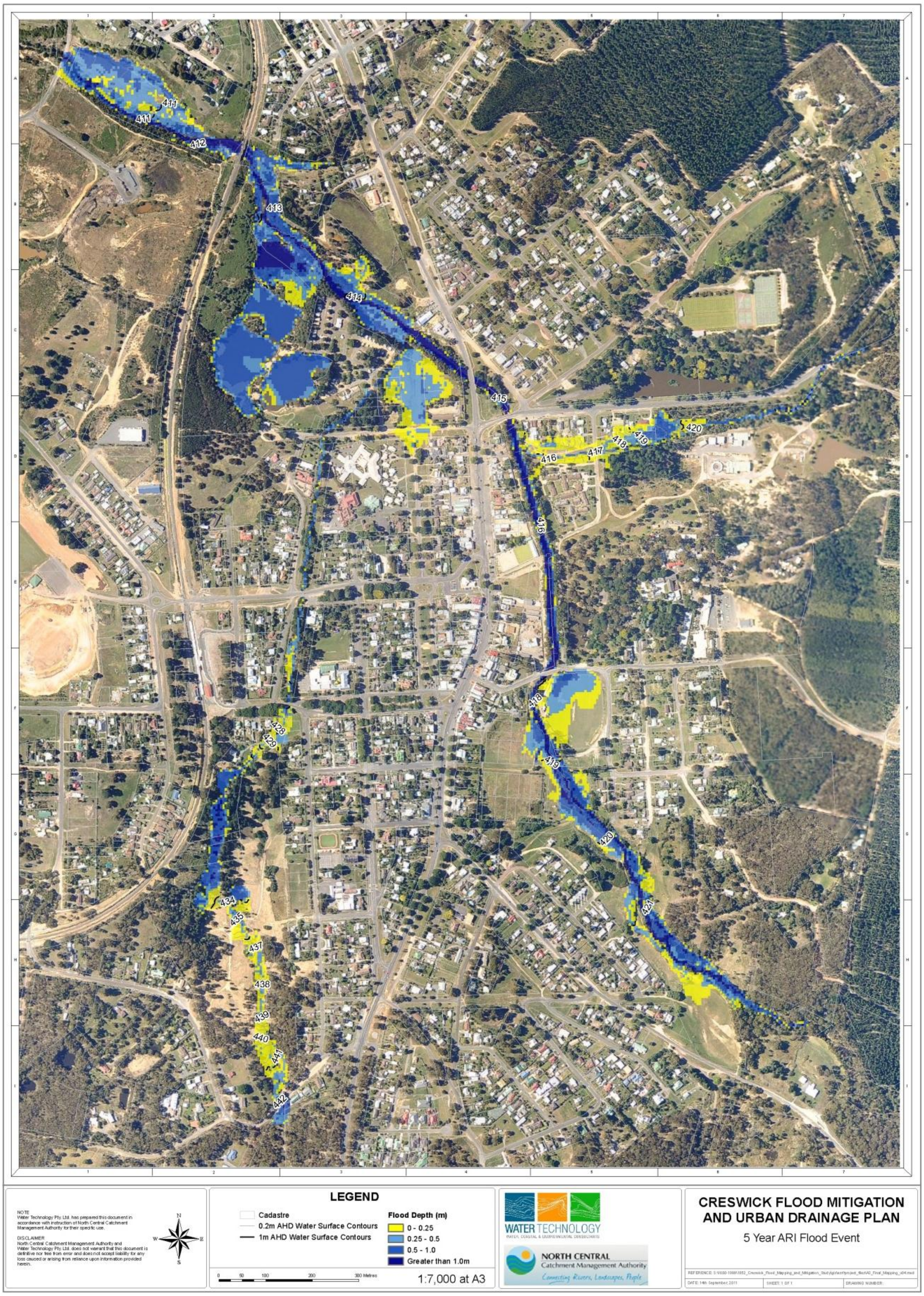


Figure C-1 5 Year ARI Flood Event

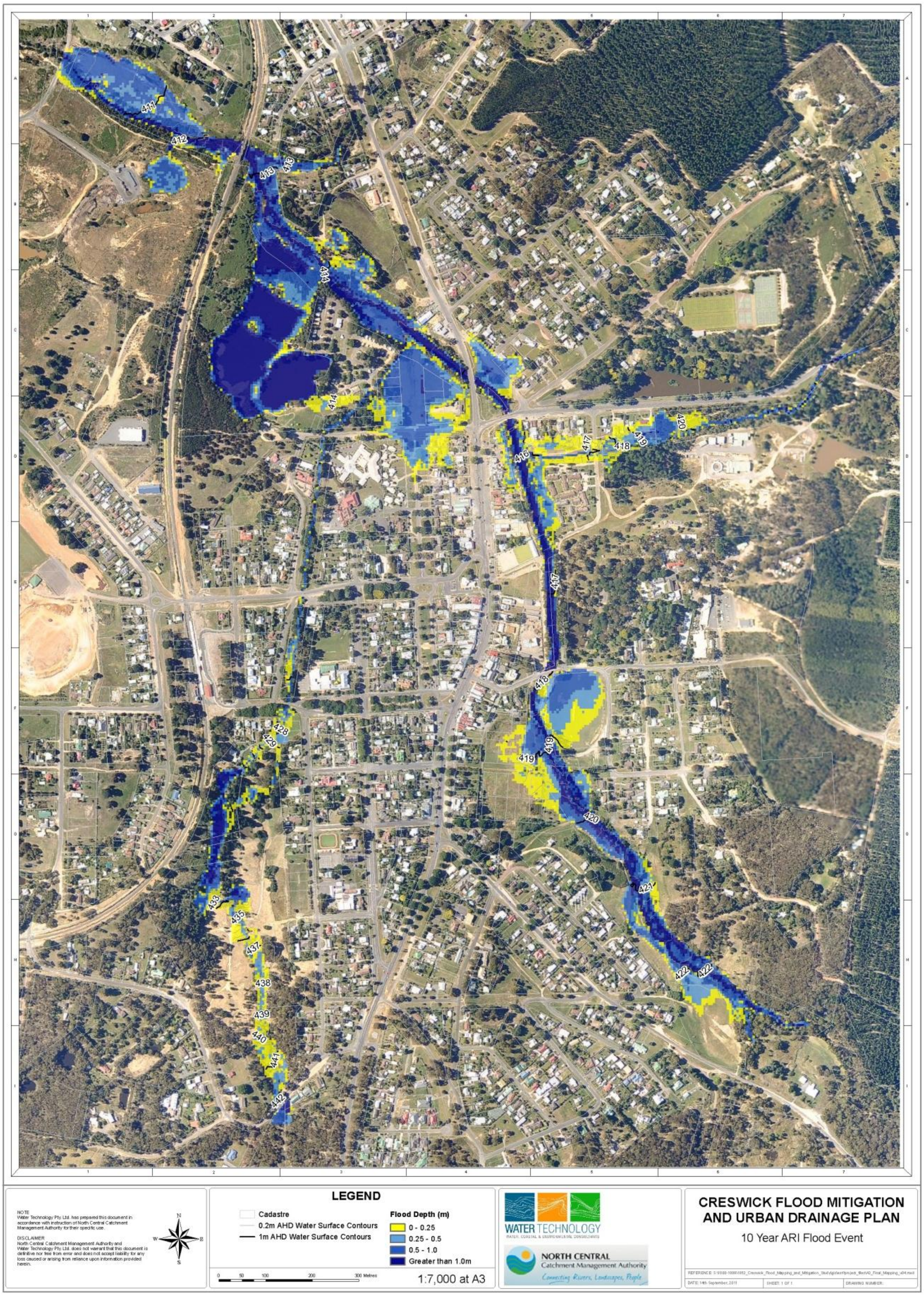


Figure C-2 10 Year ARI Flood Event

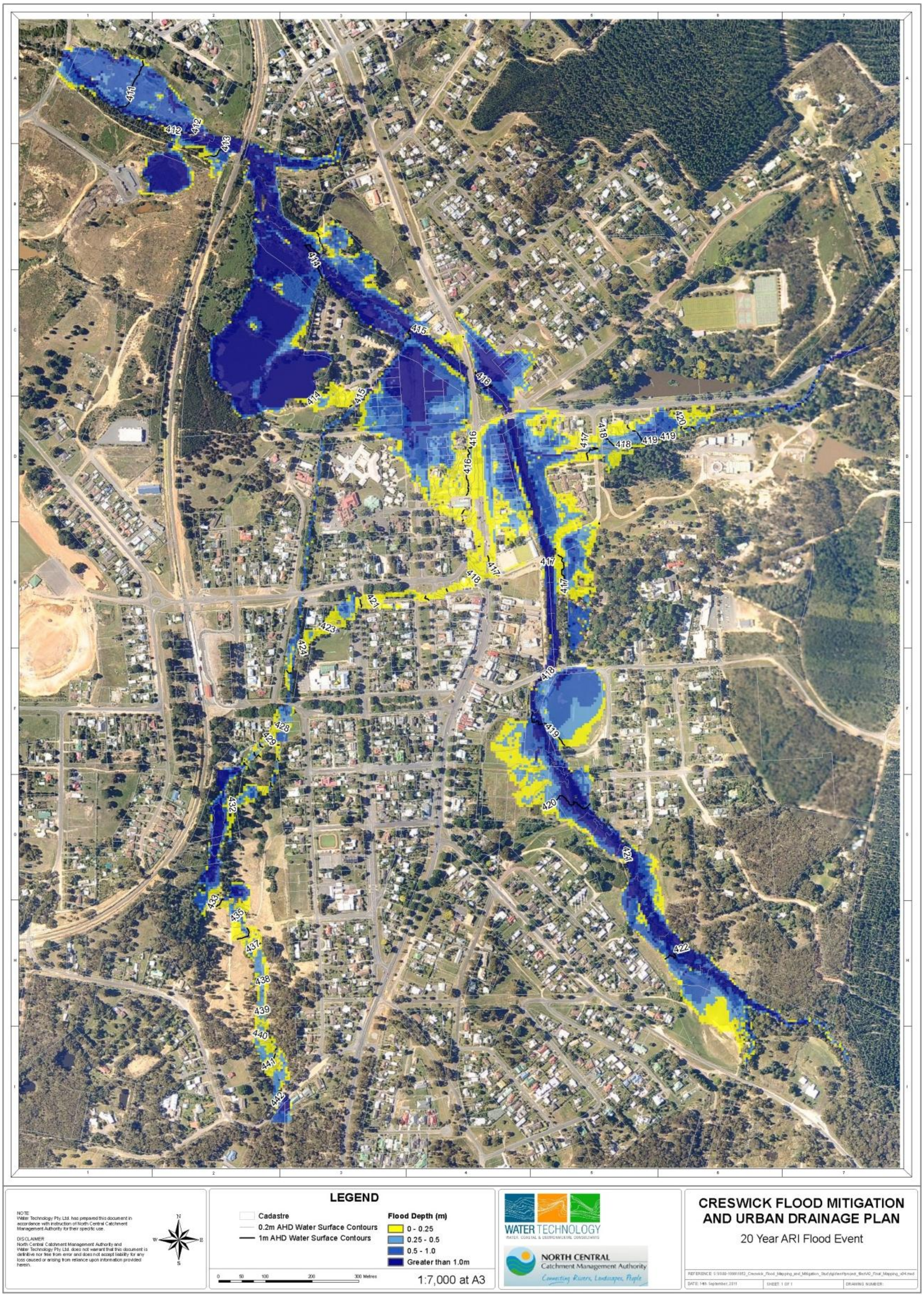


Figure C-3 20 Year ARI Flood Event

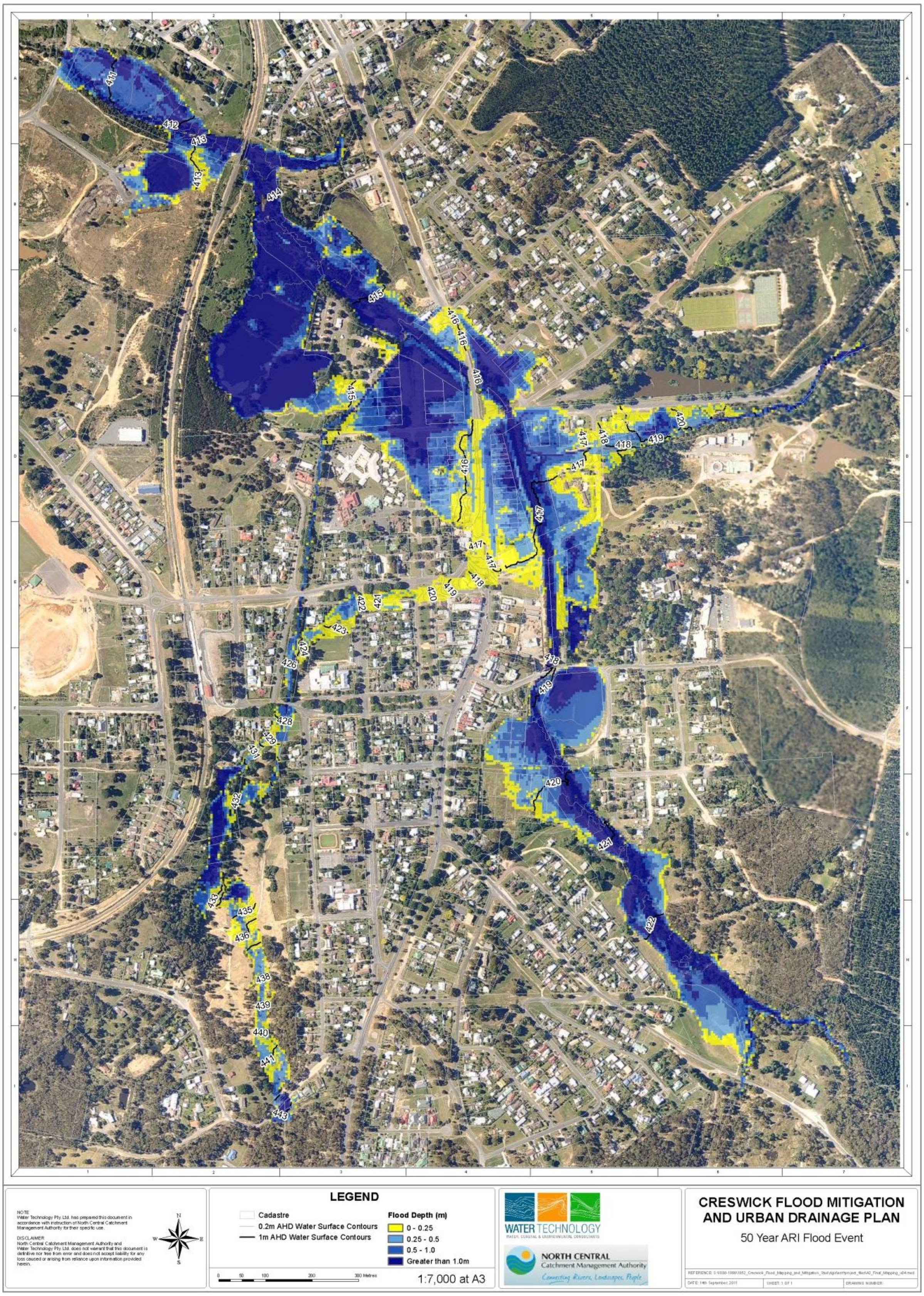


Figure C-4 50 Year ARI Flood Event

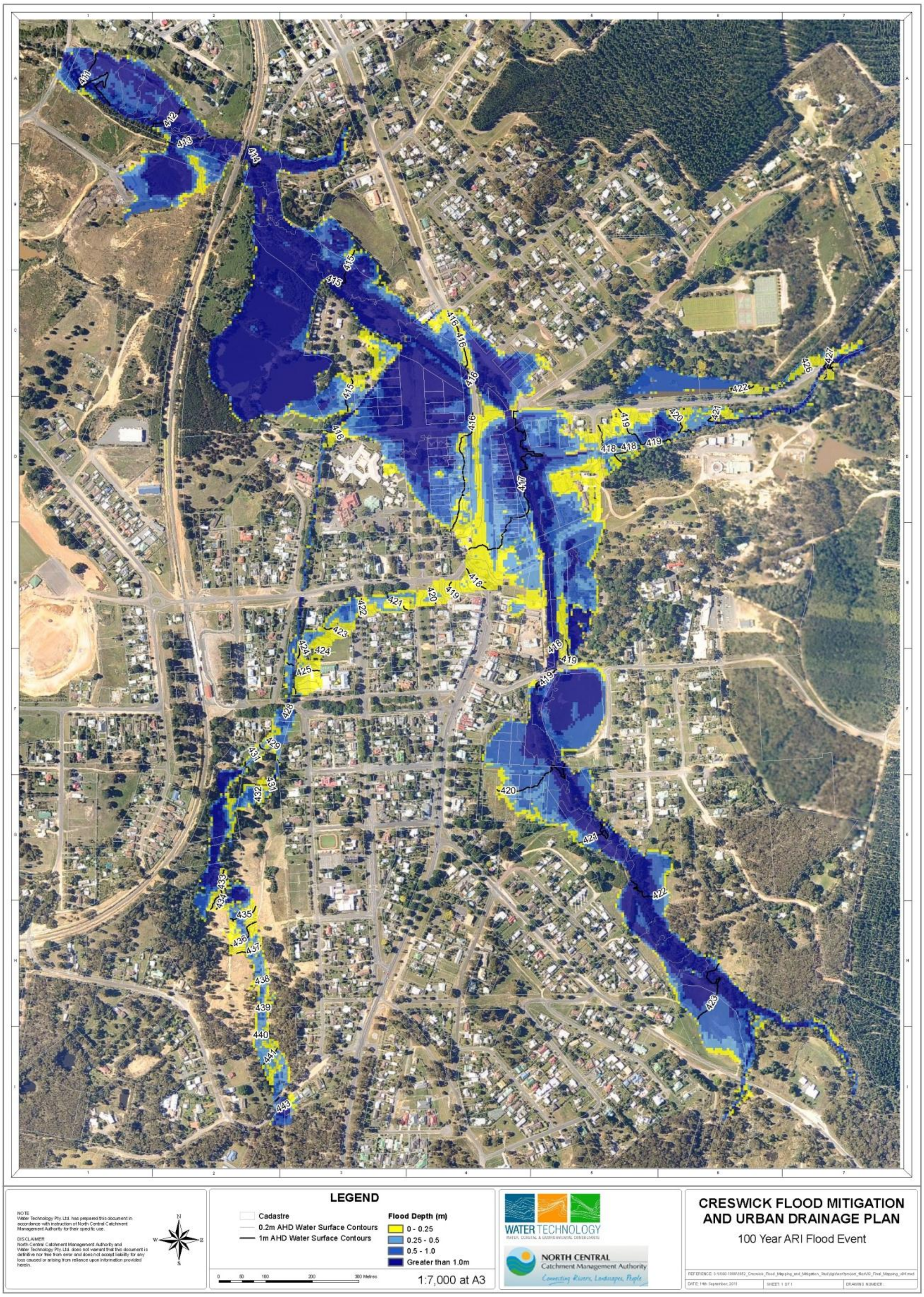


Figure C-5 100 Year ARI Flood Event

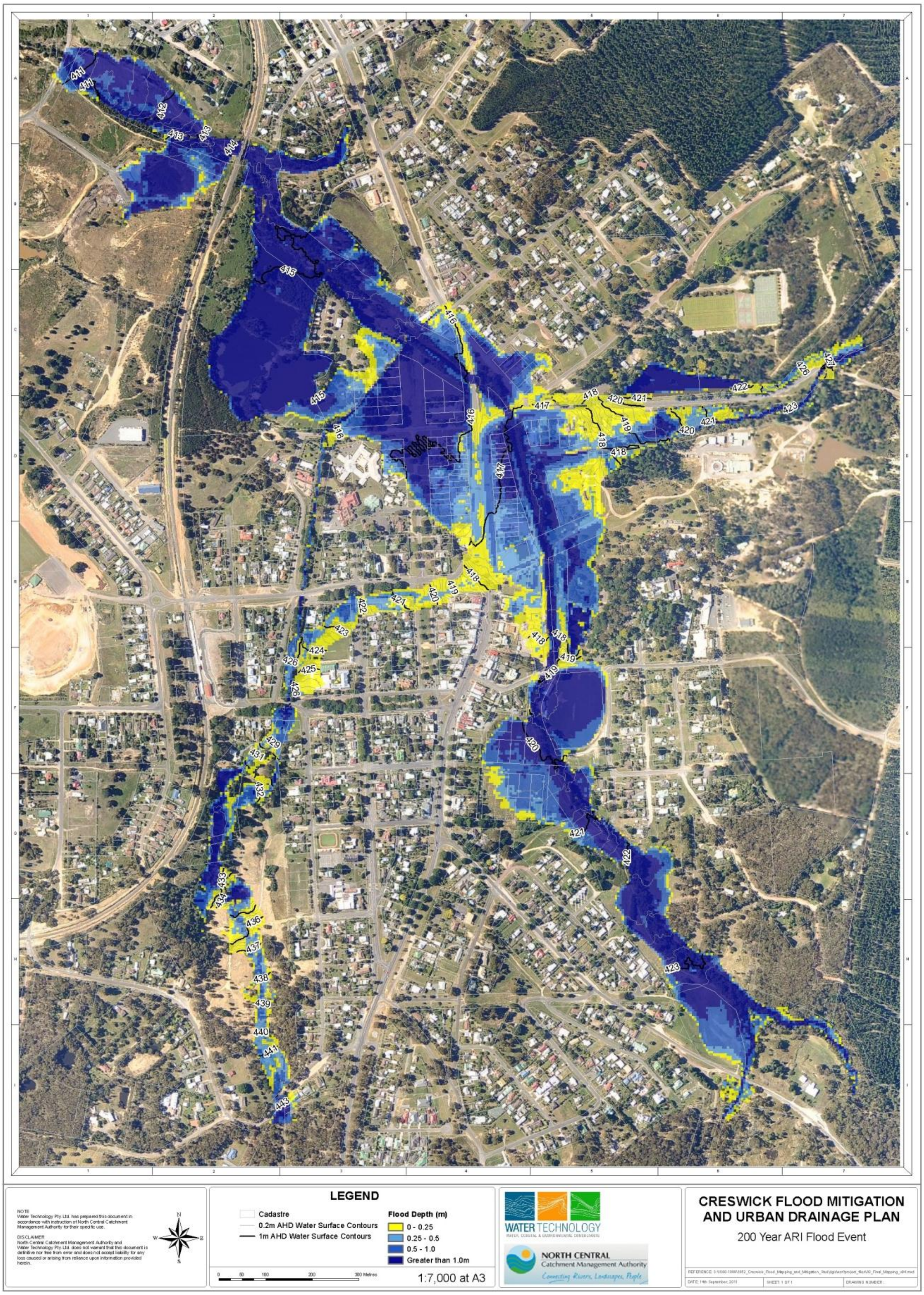


Figure C-6 200 Year ARI Flood Event

APPENDIX D MITIGATION OPTION 5 PLANS

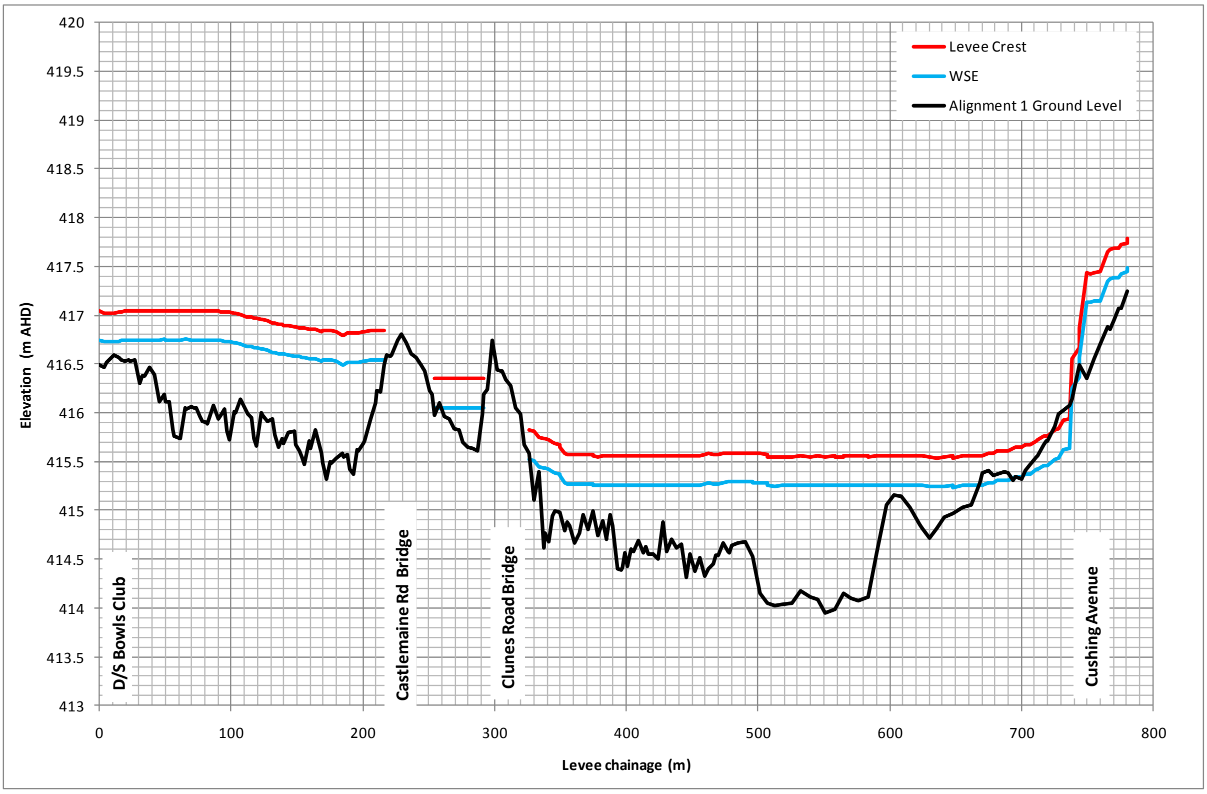


Figure D-1 Creswick Creek Levee - Long Section Plot

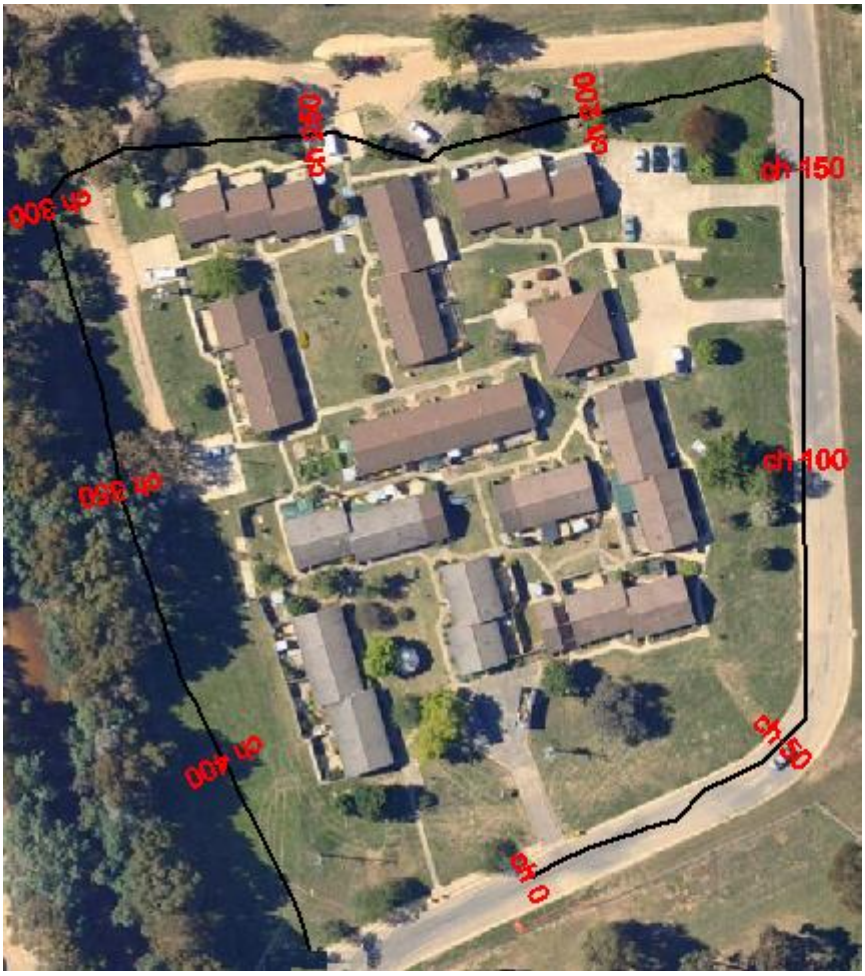


Figure D-2 Semmens Village Levee Alignment

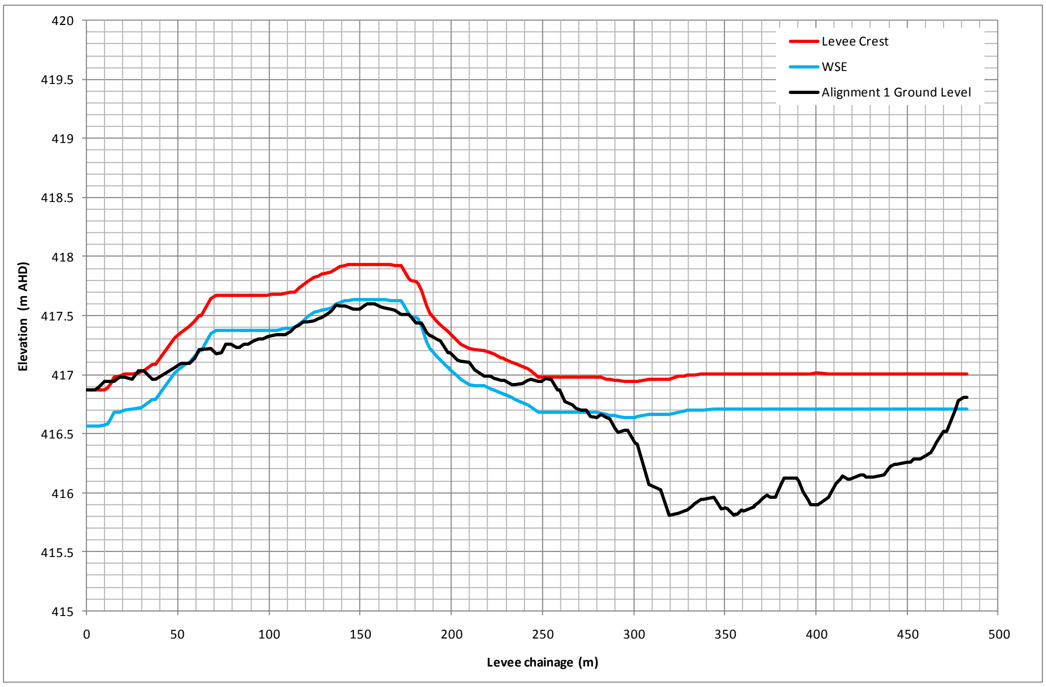


Figure D-3 Semmens Village Levee - Long Section Plot

Figure D-4 Saw Pit Gully Levee Alignment

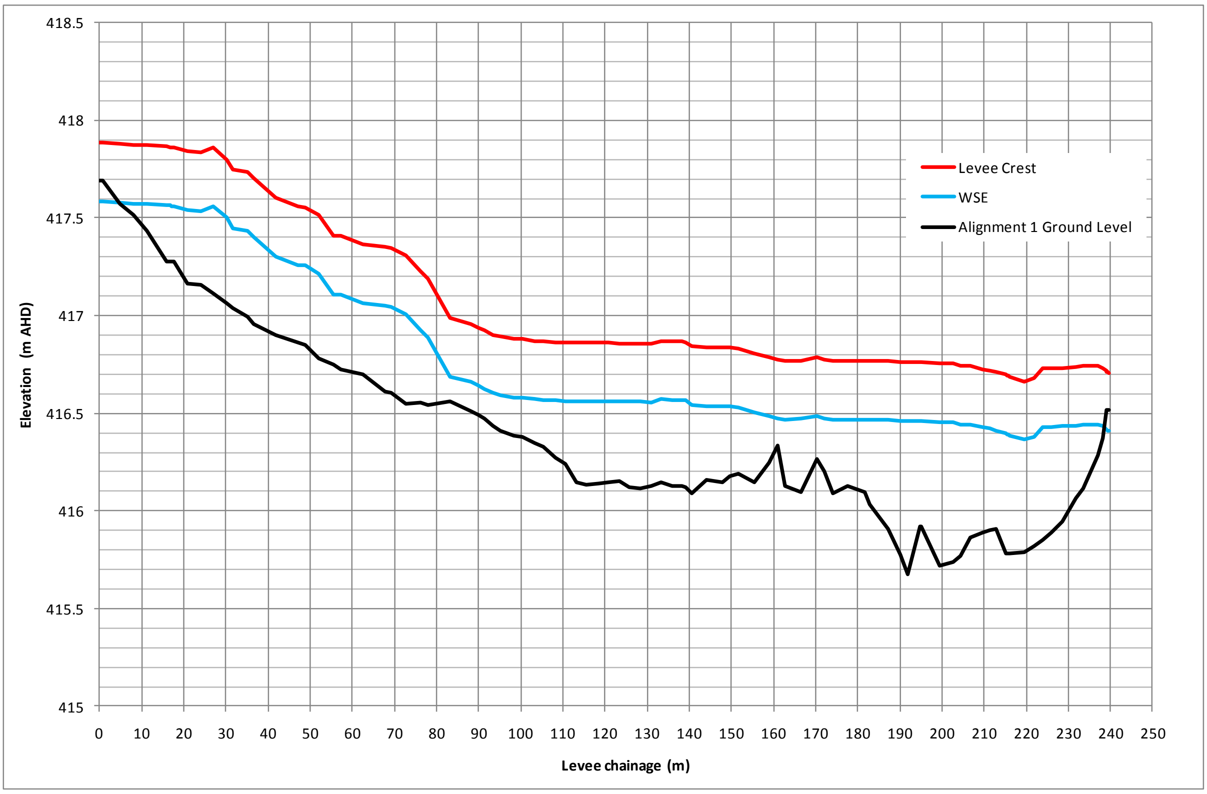


Figure D-5 Saw Pit Gully Levee - Long Section Plot

Figure D-6 Primary School Raised Wall Alignment

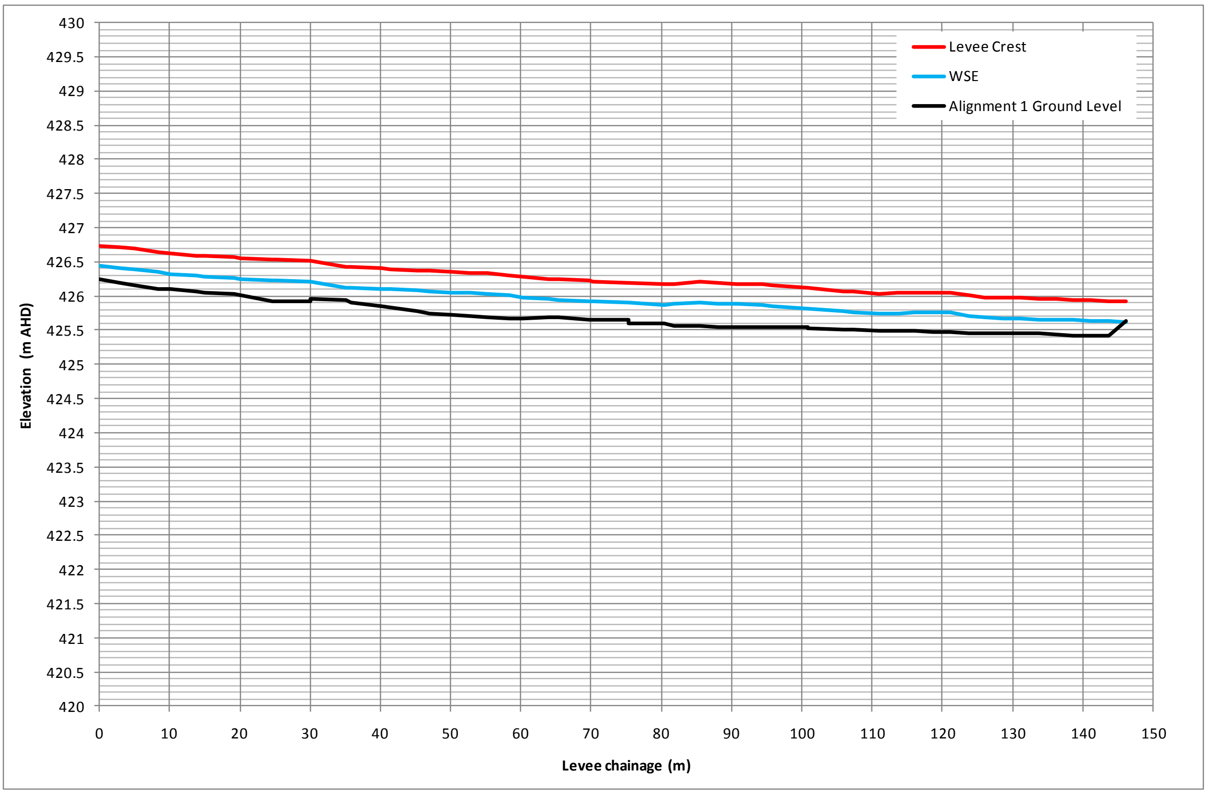


Figure D-7 Primary School Raised Wall - Long Section Plot

APPENDIX E MITIGATION OPTION 5 FLOOD MAPS

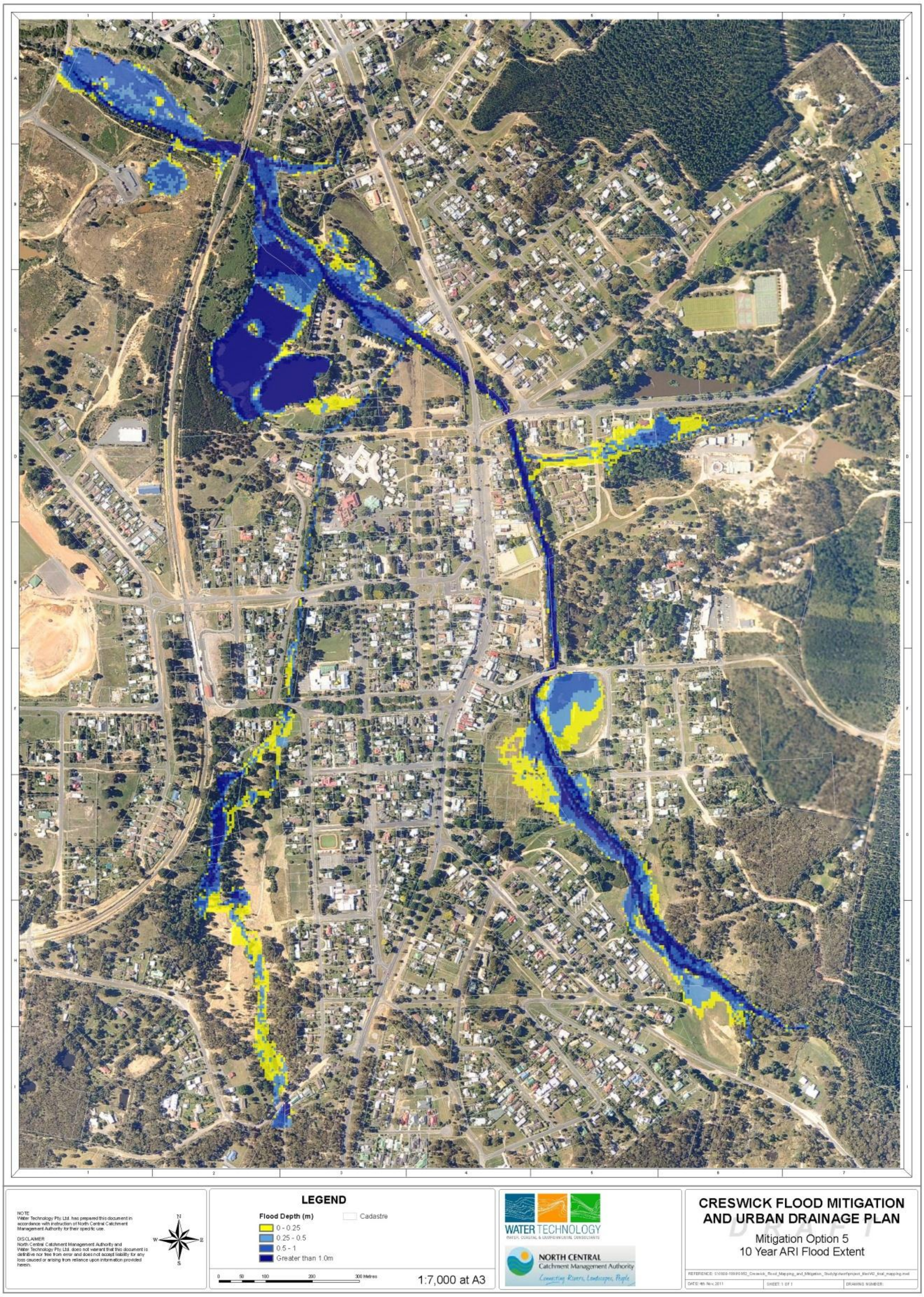


Figure E-1 10 Year ARI Flood Event

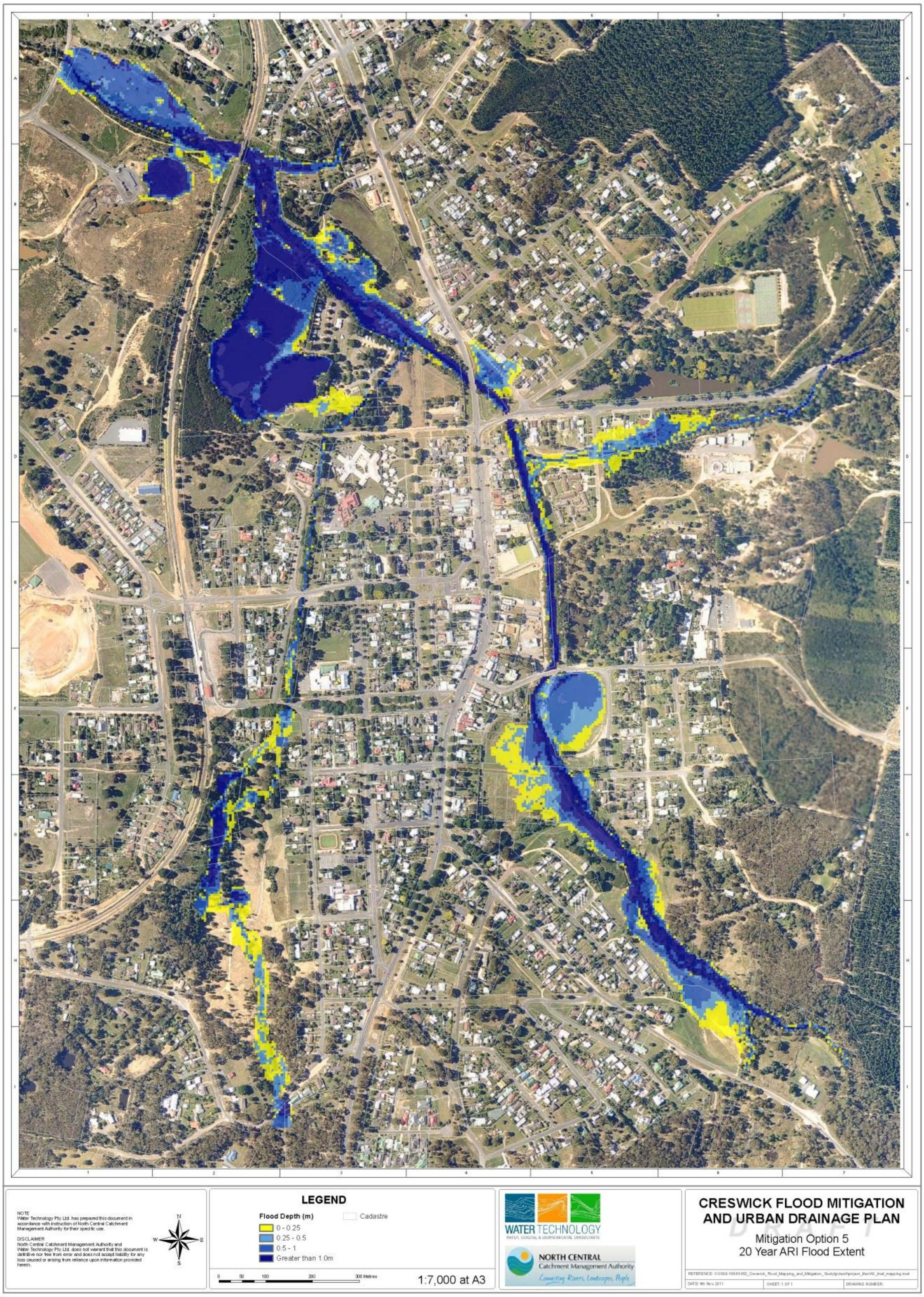


Figure E-2 20 Year ARI Flood Event

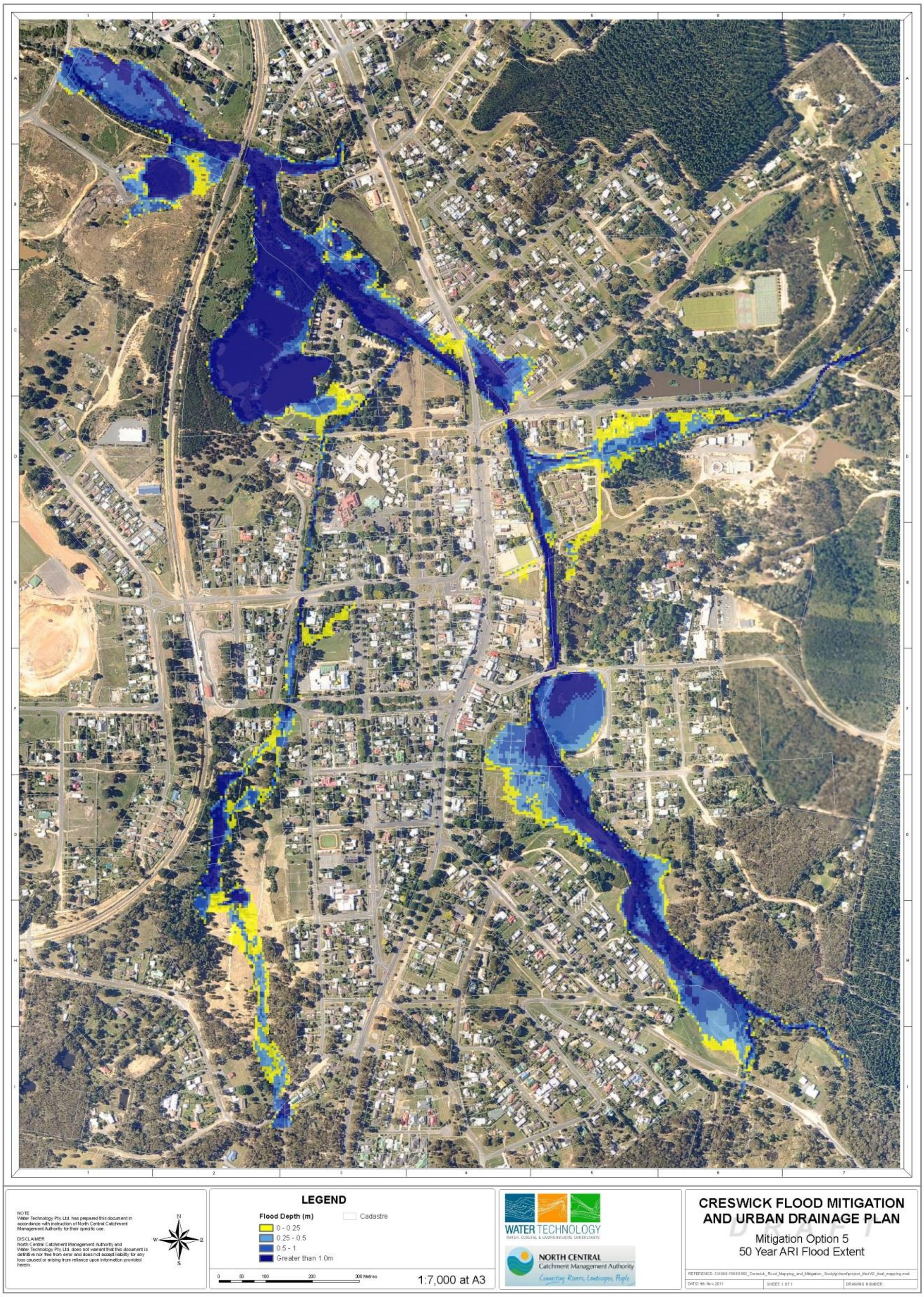


Figure E-3 50 Year ARI Flood Event

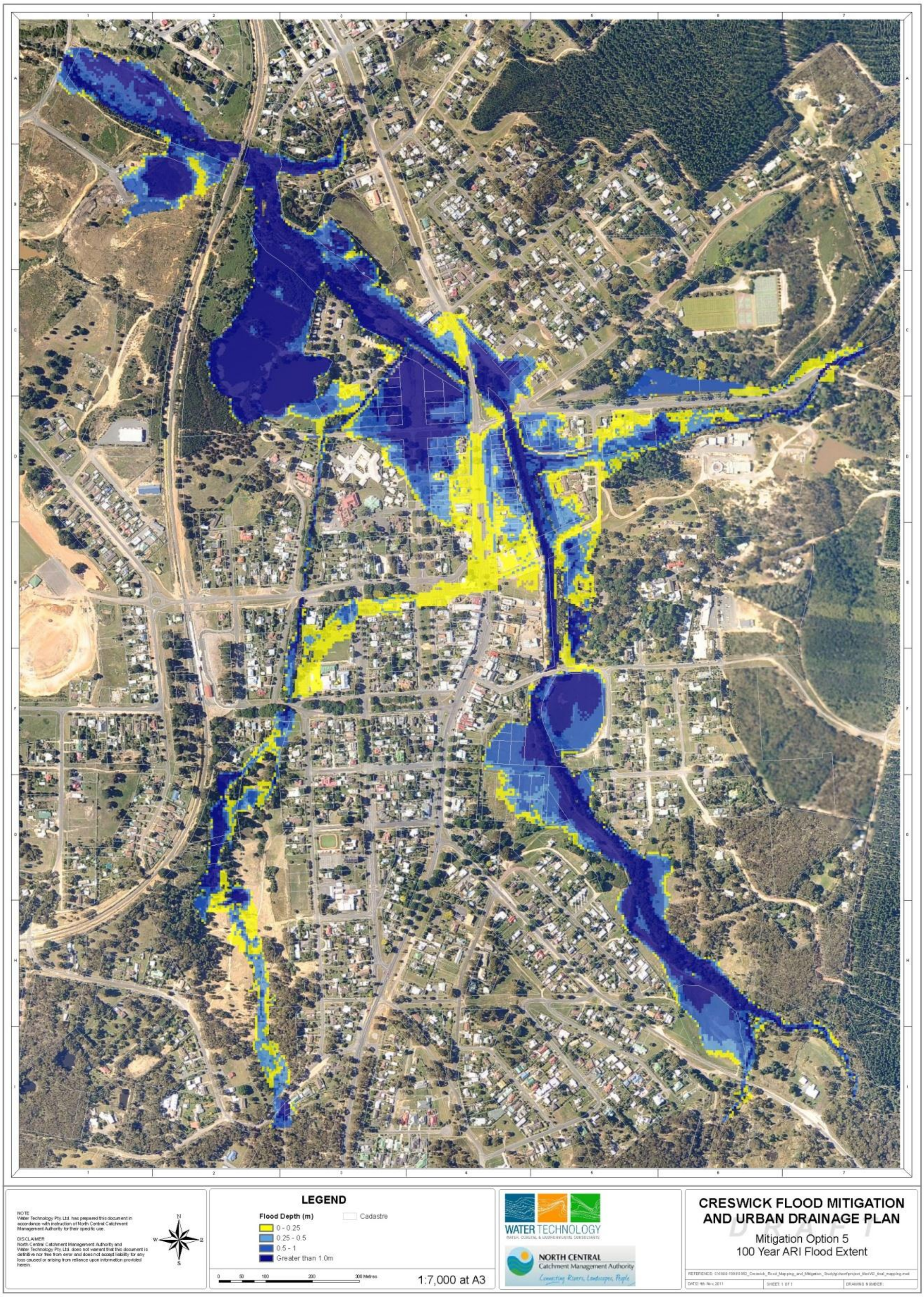


Figure E-4 100 Year ARI Flood Event

APPENDIX F MITIGATION OPTION COSTING

Table F1 Mitigation option 1 costs

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Creswick Creek Levee	$442,451	$6,637
Semmens Village Levee	$234,503	$3,518
Castlemaine Road Levee	$134,561	$2,018
Nuggetty Gully Retarding Basin Embankment Wall	$92,034	$1,381
Tree Removal	$38,655	N/A
Floodgates - Clunes Rd & Castlemaine Rd	$8,904	N/A
Drainage System - One Way Valves (Only Headwall Cost Cons	$3,014	N/A
SUB TOTAL	**$954,121**	**$13,553**
Engineering, Administration & Contingencies	$528,106	N/A
GRAND TOTAL	**$1,482,227**	**$13,553**

Table F2 Mitigation option 2 costs

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Creswick Creek Channel Works	$1,373,468	$20,602
Tree Removal	$33,540	N/A
Drainage System - One Way Valves (Only Headwall Cost Cons	$3,014	N/A
2 New Bridges	$4,000,000	
SUB TOTAL	**$5,410,022**	**$20,602**
Engineering, Administration & Contingencies	$780,447	N/A
GRAND TOTAL	**$6,190,469**	**$20,602**

Table F3 Mitigation option 3 costs

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Creswick Creek Channel Works	$1,521,042	$22,816
Cushing Avenue Levee	$33,214	$498
Primary School Embankment Wall	$15,378	$231
Saw Pit Gully - North Bund	$6,592	$99
Saw Pit Gully - South Bund	$1,454	$22
Tree Removal	$18,576	N/A
Drainage System - One Way Valves (Only Headwall Cost Cons	$12,320	N/A
2 New Bridges	$2,140,000	
SUB TOTAL	**$3,748,576**	**$23,665**
Engineering, Administration & Contingencies	$890,347	N/A
GRAND TOTAL	**$4,638,922**	**$23,665**

Table F1 Mitigation option 4 costs

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Concrete Lining Creswick Creek	$946,877	$4,734
Cushing Avenue Levee	$33,214	$498
Primary School Embankment Wall	$15,378	$231
Saw Pit Gully - North Bund	$6,592	$99
Saw Pit Gully - South Bund	$1,454	$22
Tree Removal	$18,576	N/A
Drainage System - One Way Valves (Only Headwall Cost Cons	$12,320	N/A
SUB TOTAL	**$1,034,411**	**$5,584**
Engineering, Administration & Contingencies	$572,546	N/A
GRAND TOTAL	**$1,606,957**	**$5,584**

Table F5 Mitigation option 5 costs

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Creswick Creek Channel Works	$162,875	$3,099
Creswick Creek Levee	$108,013	$1,620
Primary School Embankment Wall	$22,466	$337
Saw Pit Gully - North Bund	$20,588	$309
Saw Pit Gully - South Bund	$31,940	$479
Tree Removal	$42,312	N/A
Drainage System - One Way Valves (Only Headwall Cost Cons	$12,320	N/A
Two additional culverts for both bridges	$750,000	
SUB TOTAL	**$1,150,515**	**$5,844**
Engineering, Administration & Contingencies	$221,685	N/A
GRAND TOTAL	**$1,372,200**	**$5,844**

APPENDIX G 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 Enviornmental 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 ou but does include the majority of the source data sets that were used in the development of the methodology.

Table G1 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 G2 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 G3 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 G4 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 G5 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 G6 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 G7 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 ave 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