Clunes Flood Mitigation and Urban Drainage Plan

Final Study Report

June 2013

Quality System
Quality Endorsed Company
ISO 9001 QEC22878
SAI Global

DOCUMENT STATUS

Version	Doc type	Reviewed by	Approved by	Date issued
v01	Final Report	Stephen Duggan	Stephen Duggan	24/08/2012
v02	Draft Report	Ben Tate	Ben Tate	12/10/2012
FINAL	Final Report	Ben Tate	Ben Tate	24/06/2013

PROJECT DETAILS

Project Name	Clunes Flood Mitigation and Urban Drainage Plan
Client	North Central CMA
Client Project Manager	Camille White
Water Technology Project Manager	Aaron Vendargon
Report Authors	Aaron Vendargon
Job Number	2048-01
Report Number	R05
Document Name	2048-01R05v03_Clunes_Final_FS_Report.docx

Cover Photo: Clunes on 14th January 2011 (photo courtesy of www.thecourier.com.au)

15 Business Park Drive
Notting Hill VIC 3168

Telephone (03) 9558 9366
Fax (03) 9558 9365

ACN No. 093 377 283
ABN No. 60 093 377 283

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 datum's.
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.
1D (one dimensional)	Refers to the hydraulic modelling where creeks and hydraulic structures are modelled using 1 dimensional methods. Using surveyed cross-sections to represent the path of water flow, the model calculates how high and how fast the water will flow for the specified flow path.
2D (two dimensional)	Refers to the hydraulic modelling where the floodplain is modelled using 2 dimensional methods. Using a grid of topography data the model will estimate not only how high and how fast water will flow but will also calculate the direction of flow across the 2D grid.

EXECUTIVE SUMMARY

Overview

Following the recent flood events in September 2010 and January 2011, Clunes was identified as a high flood risk community and funding was approved for a flood study of the township. The flood study was run by North Central CMA in conjunction with Hepburn Shire Council.

In addition to the development of this flood study, a number of separate measures/works have been implemented to improve local drainage, improve waterway conditions and repair the damage caused by the recent floods.

Community Consultation and Feedback

A key element in the development of the flood mitigation plan was the active engagement of residents in the study. This engagement was developed over the course of the study through community consultation sessions, public questionnaires and information brochures. Three community meetings were held at various stages of the flood plan development.

Public feedback from the consultation sessions indicated that the community is strongly against the plans proposed option of flood levees to protect the town. This was evident from discussions with residents and feedback from the second community questionnaire. Concerns were expressed that the proposed levees would affect the aesthetics/liveability in the town and not provide a consistent level of protection for all properties. The community, whilst acknowledging the current flooding issues, wish to see any mitigation measures concentrate on further waterway management works.

Plan Mitigation Options

A detailed assessment of a range of mitigation options was undertaken. Each mitigation option was assessed against a number of criteria including potential reduction in flood damage, construction cost, feasibility of construction, environmental impact and community support. The following structural and non-structural mitigation options were put forward.

Structural Flood Mitigation Works

The final two structural mitigation options put forward to the community included:

- **Option 1 – Protection for Minor Floods**:
  This option was designed to protect Clunes to a small event, the 20 year ARI event with 300 mm freeboard. The proposed works involved reinstating the old levee on the left bank and constructing a relatively low level levee on the opposite bank.

  This option would remove above floor flooding at one residential property in a 20 year ARI event. External flooding would be reduced at the swimming pool, basketball court building and a number of residential properties along Purcell Street, Fraser Street and next to the oval. The only property not protected in a 20 year event would be the ‘old butter factory’. In larger events, the levee would not have any significant impact on the flood distribution and flood depths.

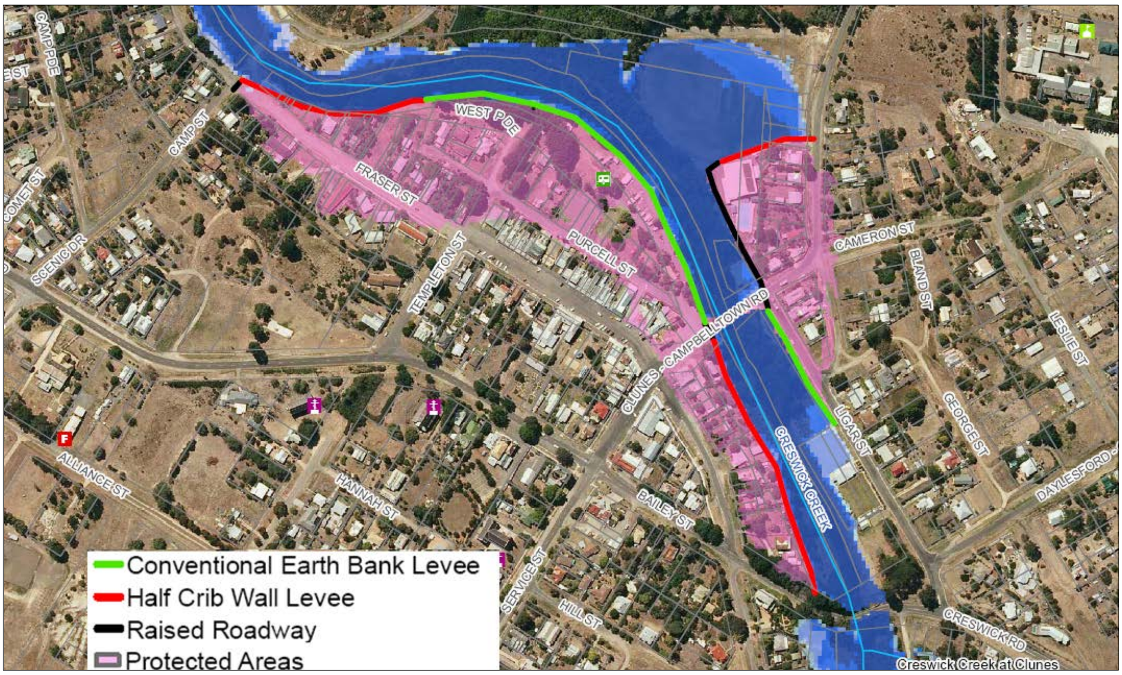
Mitigation Option 1 Works

- **Option 2 – Protection for Moderate Floods**

  Mitigation Option 2 was designed to provide flood protection up to the 50 year ARI event (comparable to the January 2011 flood event) with 300 mm freeboard. This option consisted of the following works:

  - Levee system downstream of Service Street on either side of the creek;
  - Levees system upstream of Service Street on either side of the creek; and
  - Service Street Bridge deck raised by 0.5 m to tie into the proposed levees.

  Mitigation Option 2 was subject to numerous design constraints, primarily due to the close proximity of properties to the creek. Construction of levees over private property would be unavoidable in some sections. This option would remove flooding across the entire township for a 50 year ARI event. As with Option 1, the only property not protected would be the 'old butter factory'.



Mitigation Option 2 Works

Option 1 has a total capital cost of roughly $109,000 and a benefit cost ratio of 0.3, while Option 2 has a total capital cost of roughly $2.16 million and a benefit cost ration of 0.1.

Non Structural Flood Mitigation Works

- VICSES with the assistance of Hepburn Shire Council to use the information from this study to complete the Municipal Flood Emergency Plan;
- Investigate the feasibility of a flood warning system for Clunes (requiring a number of new stream flow and rainfall gauges to be installed and a hydrological model developed);
- Amendment of the planning scheme for Clunes to reflect the flood risk identified by this project; and
- Raise awareness in the community with a public campaign through the implementation of the VICSES Flood Safe program.

Next Steps

The Clunes Flood Mitigation and Urban Drainage Plan will seek endorsement from both the North Central Catchment Management Authority Board and Hepburn Shire Council. As the structural mitigation options put forward in this plan have not been supported by the community, the following recommendations are made:

- Regular waterway management works to maintain the current creek condition, including vegetation (suckers) and debris removal. The responsibility for ongoing management of the creek will need to be determined, with funding and approval sought out;
- The feasibility of a flood warning system for Clunes to be investigated;
- Update of the planning scheme overlays;
- Completion of the Municipal Flood Emergency Plan for Clunes; and
- Further investigations undertaken into the local drainage issues and potential stormwater mitigation works.

Acknowledgements

The Clunes Flood Mitigation and Urban Drainage Plan was guided by the Clunes Flood Mitigation and Urban Drainage Plan Steering Committee and supported by the Technical Working Group.

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

Following the recent flood events in September 2010 and January 2011, Clunes was identified as a high flood risk community and funding was approved for a flood study of the township. The flood study has been run by North Central CMA in conjunction with Hepburn Shire Council.

In November 2011, Water Technology was commissioned by North Central CMA to undertake the flood mitigation and urban drainage study for the township.

This study involved a detailed hydrological and hydraulic analysis of the township, which was used to derive information on the flood levels and flood risk for Clunes. The study also looked into potential flood mitigation options for the town.

1.2 Study Area

The township of Clunes lies to the north of the Great Dividing Range, approximately 30 km north of Ballarat. Creswick Creek runs through the centre of town. The catchment area for Creswick Creek upstream of the township is approximately 311 km^2. Through the township, the creek consists of a 20-25m wide section located within a steep, confined valley. The creek section between Service Street and Camp Street is heavily vegetated along the banks and the creek bed is heavily silted. No main tributaries flow into Creswick Creek at Clunes but there are a few small, unnamed streams and gullies that feed into the creek (Figure 1-1).

Immediately downstream of Clunes, Kilkenny Creek flows into Creswick Creek and further downstream near Mount Cameron Road, Creswick Creek merges with Birch Creek, forming Tullaroop Creek.

Figure 1-1 Creswick Creek and Its Tributaries in Clunes

1.3 Flood Records

1.3.1 Historical Flooding

While flooding prior to September 2010 was a rare occurrence, there have been anecdotal records of similar, large flood events in the past. The last significant flood event on Creswick Creek was in 1933. Prior to the 1933 flood a series of large floods occurred in 1869, 1870, 1871 and 1893. A number of historic newspaper articles were sourced from trove.nla.gov.au using the search 'Clunes flood'. Other significant floods have most likely occurred and may be documented in archived local media and may be contained on the above website given a more thorough search.

Historical newspaper articles of the large flood in 1869 reported floodwaters extending from Fraser Street on the left bank to Angus Street on the right bank, and about four feet in depth near the corner of Templeton and Fraser Streets increasing to 8 feet at the bottom of Fraser Street. These historical newspaper articles are included in Appendix H , and make a very interesting read.

A 'Land Subject to Inundation Overlay' (LSIO) is available for Clunes; but the extent of the LSIO stops between Bailey Street and Fraser Street (Figure 1-2). This incomplete LSIO most likely represents a recent historical flood extent or a best estimate. It is unknown why the LSIO is incomplete between Bailey Street and Fraser Street, but most likely is a result of planning decision. The entire creek is zoned Public Park and Recreation and has an Environmental Significance Overlay, both of which work to restrict development in these areas.

Figure 1-2 Existing Incomplete LSIO Extent

1.3.2 Recent Flood Events

The September 2010 and January 2011 flood events were a result of heavy rainfall in the upper catchment causing Creswick Creek to overtop its banks. Prior to the creek overtopping, there was some runoff from the local catchment as well as issues of local drainage backing up and surcharging.

Site observations, hydrological data and aerial photos were used to provide an understanding of the flooding mechanisms in September 2010 and January 2011. Both flood events were similar given the confined nature of the floodplain; however water levels in January 2011 were much higher. An aerial photo of the January 2011 flood event (just past its peak) is shown in Figure 1-3 below.

Figure 1-3 Photo of the January 2011 Flood Event

1.4 Concurrent Work

In addition to the development of this flood study, a number of separate measures/works have been implemented to improve local drainage, improve waterway conditions and repair the damage caused by the recent floods. The following works have been undertaken:

- February 2011 waterway works, which involved the removal of debris and thinning out of vegetation over a section of Creswick Creek, from Service Street to the Camp Street ford. A hydraulic analysis was used to test the impact of the creek clearing works. The modelling showed that even with the creek cleared out prior to the January 2011 event, floodwaters would have overtopped the creek banks and flooded the town. The creek clearing would however have reduced the January 2011 flood levels by up to 250 mm. In events larger than the January 2011 event, the creek clearing works will have a lesser influence on flood levels. To date, the Clunes Waterway Management group have been working with North Central CMA to ensure that a maintenance regime is developed to maintain the current creek conditions. For this study, all flood mitigation options have been assessed on the basis that the current creek conditions will be maintained;

- Installation of a stormwater pipe to prevent flooding of the netball court from local runoff flowing down the steep gully to the north;
- Creek bank stabilisation works near the football oval;
- Re-grading of the access track around the football oval to allow local runoff to drain into the creek more efficiently;
- Repair works for the Victoria Park sport precinct facilities; and
- Rebuilding the Camp Street ford crossing with additional culverts.

2. AVAILABLE INFORMATION

The following information has been collated for the flood study:

- Hydrological Data – Streamflow and rainfall data for the catchment;
- Topographic Data – LiDAR, structure survey, council drainage plans, flood marks and floor level survey; and
- Other Background Data - Aerials, VICMAP spatial data, photos and videos of the recent flood events.

A detailed description of the information collated for the study is outlined in a separate report (Clunes Flood Study Technical Report, Water Technology, 2011).

3. PROJECT CONSULTATION

3.1 Overview

A key element in the development of this flood mitigation plan was the active engagement of residents in the study. This engagement was developed over the course of the study through community consultation sessions, public questionnaires, information brochures and meetings with a Technical Working Group and community based Steering Committee formed for the study. 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 community concerns; and
- 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 Steering Committee and Technical Working Group

The plan was led by a community based Steering Committee consisting of representatives from North Central CMA, Hepburn Shire Council and the Clunes community. A Technical Working Group (TWG) was also established to review the plan and provide technical support to the Steering Committee. The TWG consisted of representatives from North Central CMA, Hepburn Shire Council, Department of Sustainability and Environment, Victoria State Emergency Service (VICSES), Bureau of Meteorology, VicRoads and Water Technology.

The Steering Committee and TWG met on 5 occasions, at key points throughout the study, to manage the development of the plan.

3.3 Community Consultation

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

The public consultation process was led by the North Central CMA. The following community meetings were held as part of the consultation process:

- Initial community meeting, 25th August 2011 – The first public meeting was held to outline the objectives of the study to the community;
- Second community meeting, 18th April 2012 – Attended by 15 members of the community. This meeting presented initial results of the flood modelling and also outlined a list of potential flood mitigation options identified to date. Community feedback was sought on the flood modelling results and their preference/suggestions for flood mitigation options; and
- Third community meeting, 6th August 2012 – Attended by approximately 50 people. The results and flood mitigation recommendations from the study were presented to the community. Feedback was then sought on the community's preferred option. Discussions with the residents indicated that many of the residents present were open to the option of flood levees, although there were significant concerns voiced regarding access to properties, the cost of levees, issues of stormwater pooling behind levees and land acquisition.

3.4 Community Questionnaire

The first questionnaire was distributed to local residents during the second community meeting. This questionnaire was used to seek feedback regarding the community's preferred mitigation option. Ten feedback forms were filled in and returned to North Central CMA. Feedback from the questionnaires indicated that the favoured mitigation option was for waterway management works (vegetation clearing), followed by increasing the channel capacity. Seven respondents highlighted waterway management as their preferred option while six respondents were in favour of increasing the channel capacity between Service Street and Camp Street. Four respondents were in support of a levee option and one respondent strongly objected to the construction of levees.

A second community questionnaire was distributed during the third community meeting. To date, 27 feedback forms have been returned to the North Central CMA. The second questionnaire sought feedback on the following key issues:

- Acceptable level of protection for the township to which the majority of respondents (12) indicated their preference for protection to a January 2011 type event; and
- Comments on the proposed mitigation options presented in the meeting; the majority of respondents (17) have strongly indicated that they do not support the proposed mitigation option to construct flood levees. Most of the respondents (17) were in favour of further waterway management works including maintaining the current creek condition and in particular the removal of silt/debris from the creek bed.

A copy of the second questionnaire and a summary of the feedback received are provided in Appendix G.

3.5 Community Feedback on Flood Plan

The community in general have expressed that they are not in favour of flood levees to protect the town. This was evident from discussions with residents and feedback from the second community questionnaire. Concerns were expressed that the proposed levees would affect the aesthetics/liveability in the town and not provide a consistent level of protection for all properties. The community, whilst acknowledging the current flooding issues, wish to see any mitigation measures concentrate on further waterway management works.

4. HYDROLOGIC ANALYSIS

4.1 Overview

A summary of the hydrology modelling results are presented in this report. A detailed description of the results and the methodology used is available in the Clunes Flood Study Technical Report (Water Technology, 2012).

For the hydrological component, the catchment area for Clunes was divided into two separate areas; the upper catchment (Creswick Creek catchment) and local stormwater catchment.

4.2 Upper Catchment Hydrology

4.2.1 September 2010 and January 2011 Events

Records from the 'Creswick Creek @ Clunes' streamflow gauge were used to obtain flows for the recent flood events (September 2010 and January 2011 events). The hydrographs for both events are shown in Figure 4-1 and Figure 4-2 below. For the September 2010 event, minor edits were applied to the gauge records to smooth out a multi peak burst which did not match up with anecdotal evidence or the local rainfall peaks in Clunes.

The gauged hydrographs were used as the inflow boundary for the hydraulic model.

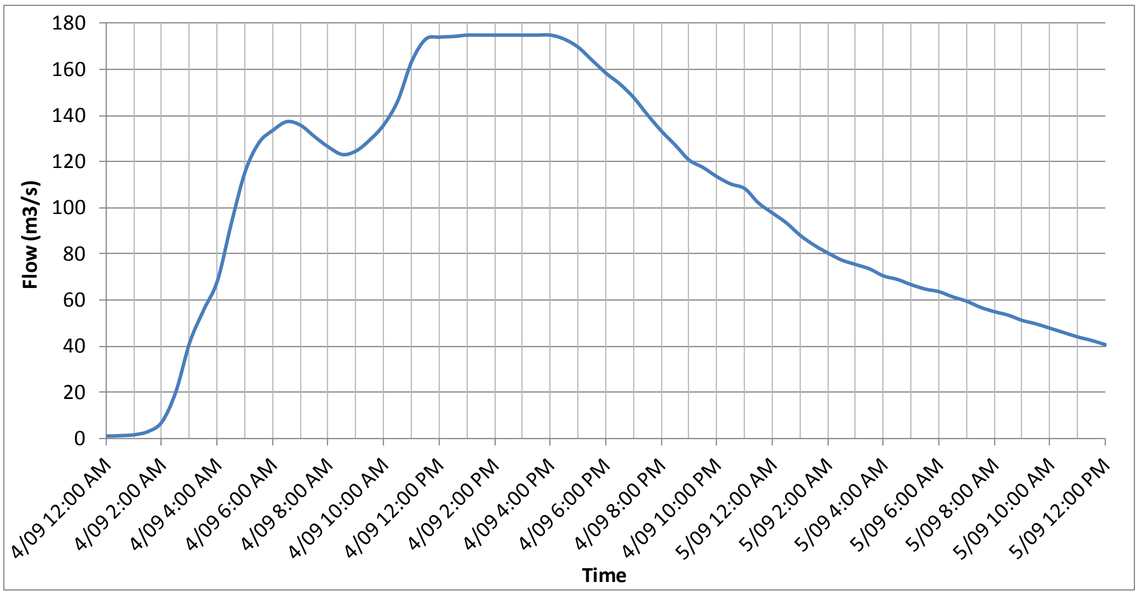


Figure 4-1 Creek Flows – September 2010

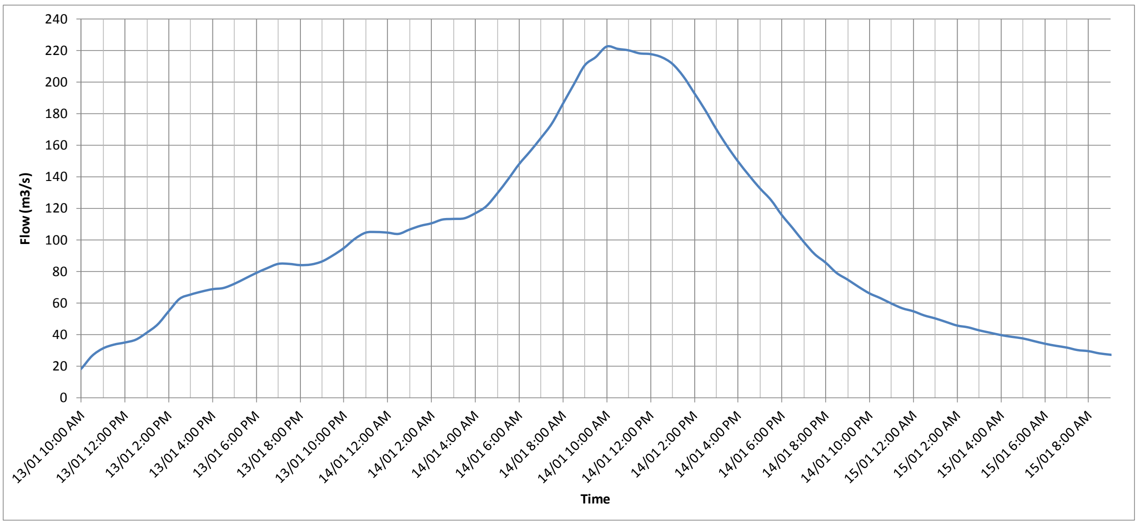


Figure 4-2 Creek Flows – January 2011

4.2.2 Design Events

A RORB model of the greater catchment area, developed for the Creswick Flood Mitigation and Urban Drainage Plan (Water Technology, 2012), was used to generate design flow hydrographs over a range of ARI's for input into the hydraulic model. Minor changes to the RORB model were made. For this study the 5, 10, 20, 50, 100 and 200 year ARI events were run.

Table 4-1 RORB Design Peak Flows and Critical Storm Durations at Creswick Creek @ Clunes

ARI	Peak flow (m3/s)	Duration (hrs)
5	53.1	24h
10	88.3	18h
20	147.3	18h
50	237.1	12h
100	315.4	18h
200	393.7	12h

The design flows indicate that the September 2010 (174.6 m^3/s) and January 2011 (222.4 m^3/s) flood events were approximately 25 year and 40 year ARI events.

4.3 Local Catchment Hydrology

The local catchment for Clunes was modelled using a 'rain on grid' approach. This approach removes the need for a detailed hydrological model of the local catchment. Only a basic hydrologic model is required which produces hyetographs for the desired events. The hyetographs were then input directly into the hydraulic model, once rainfall losses were subtracted.

4.3.1 September 2010 and January 2011 Hyetographs

Temporal patterns from the Tullaroop Creek pluviograph station were applied to the daily rainfall totals at Clunes to generate hyetographs for two recent flood events.

During the September 2010 event, the most intense rainfall period was between midnight and 3:00 am on Saturday morning (4th September), followed by a second intense burst from 7:00 am to 9:00 am Saturday morning (Figure 4-3).

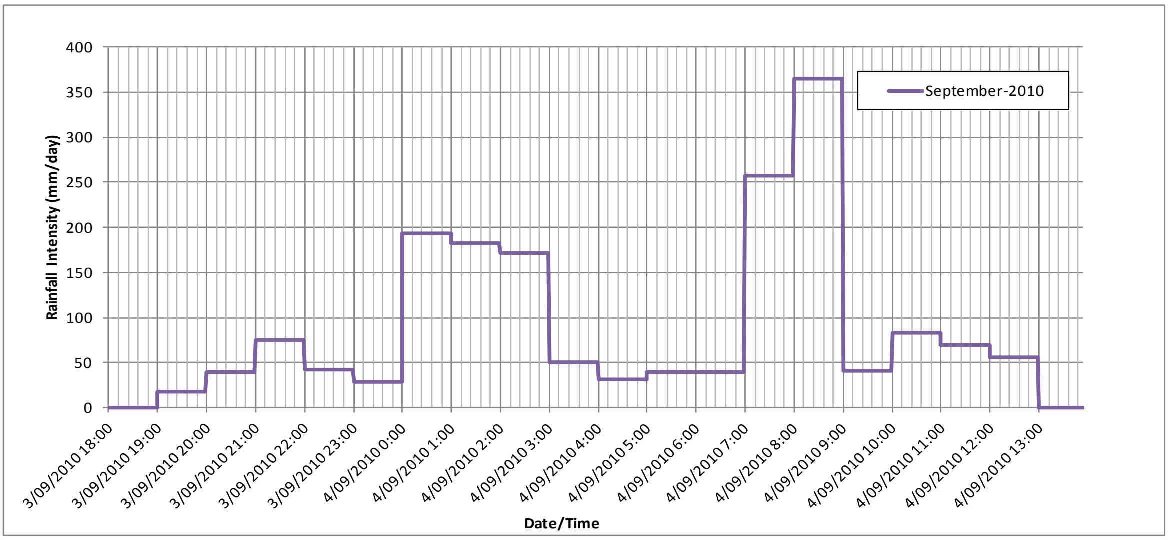


Figure 4-3 September 2010 Hyetograph

The January 2011 hyetograph at Clunes is shown in Figure 4-4 below. Between 7:00 am Thursday morning and 9:00 am Friday morning, there were four separate bursts of heavy rainfall, with the most intense rainfall period between 3:00 am and 9:00 am on Friday morning.

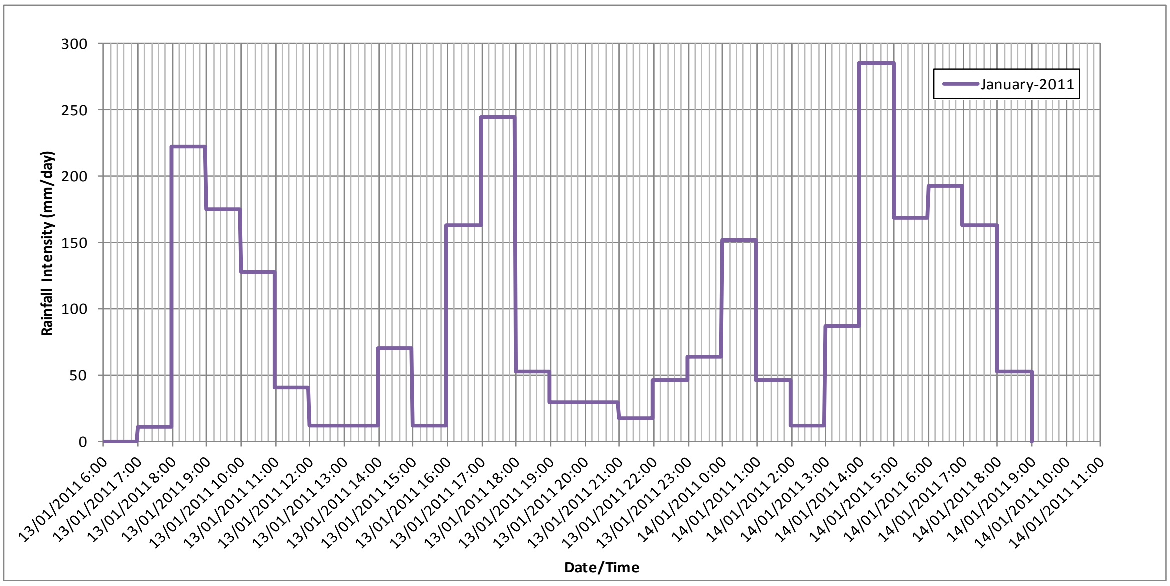


Figure 4-4 January 2011 Hyetograph

4.3.2 Design Event Hyetographs

Using the IFD parameters for Clunes, hyetographs were produced for the 10 and 100 year ARI events for the critical duration (approximately 45 minutes) of the local catchment. The design event hyetographs are shown in Figure 4-5 below.

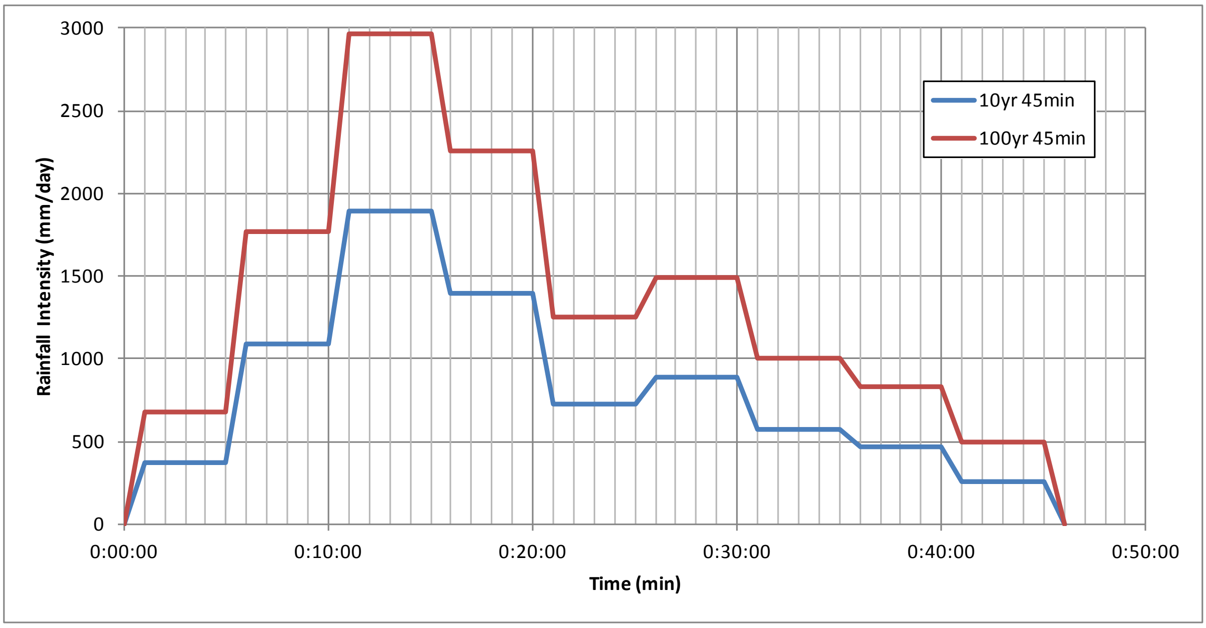


Figure 4-5 Design Rainfall Hyetographs

5. HYDRAULIC ANALYSIS

5.1 Overview

A detailed hydraulic model of the township was developed to determine flood levels and extents over a range of flood events and mitigation options. The hydraulic modelling software MIKE FLOOD developed by the Danish Hydraulic Institute (DHI) was used for the study. The calibrated hydraulic model is able to simulate flow behaviour from Creswick Creek as well as runoff from the local catchment.

The setup of the hydraulic model is detailed in a separate report, the Clunes Flood Study Technical Report (Water Technology, 2012).

5.2 Hydraulic Model Calibration

5.2.1 January 2011 Calibration

The January 2011 flood event was calibrated first as there was a larger data set available for calibration purposes. Four survey flood marks were collected from the January 2011 flood event as well as aerial photographs of the event.

Figure 5-1 shows the flood depths for the January 2011 event along with the calibration results for the surveyed flood marks.

The calibration showed a good fit between the surveyed flood marks and modelled data (Table 5-1). The modelled flood depths were within +/-30 mm of the surveyed flood marks. The modelled flood extent also matched up well with general observations and the aerial photographs (see Figure 5-2).

Table 5-1 January 2011 Calibration Points

Location	Surveyed Level (m AHD)	Modelled Level (m AHD)	Difference (m)
200 m upstream of Government Bridge, left bank	301.9	301.89	-0.01
100 m upstream of Government Bridge, right bank	301.7	301.71	0.01
Downstream of Camp Street crossing, right bank	297.87	297.9	0.03
Intersection of Camp Street and Blackmore's Street (next to white picket fence)	298.42	298.45	0.03

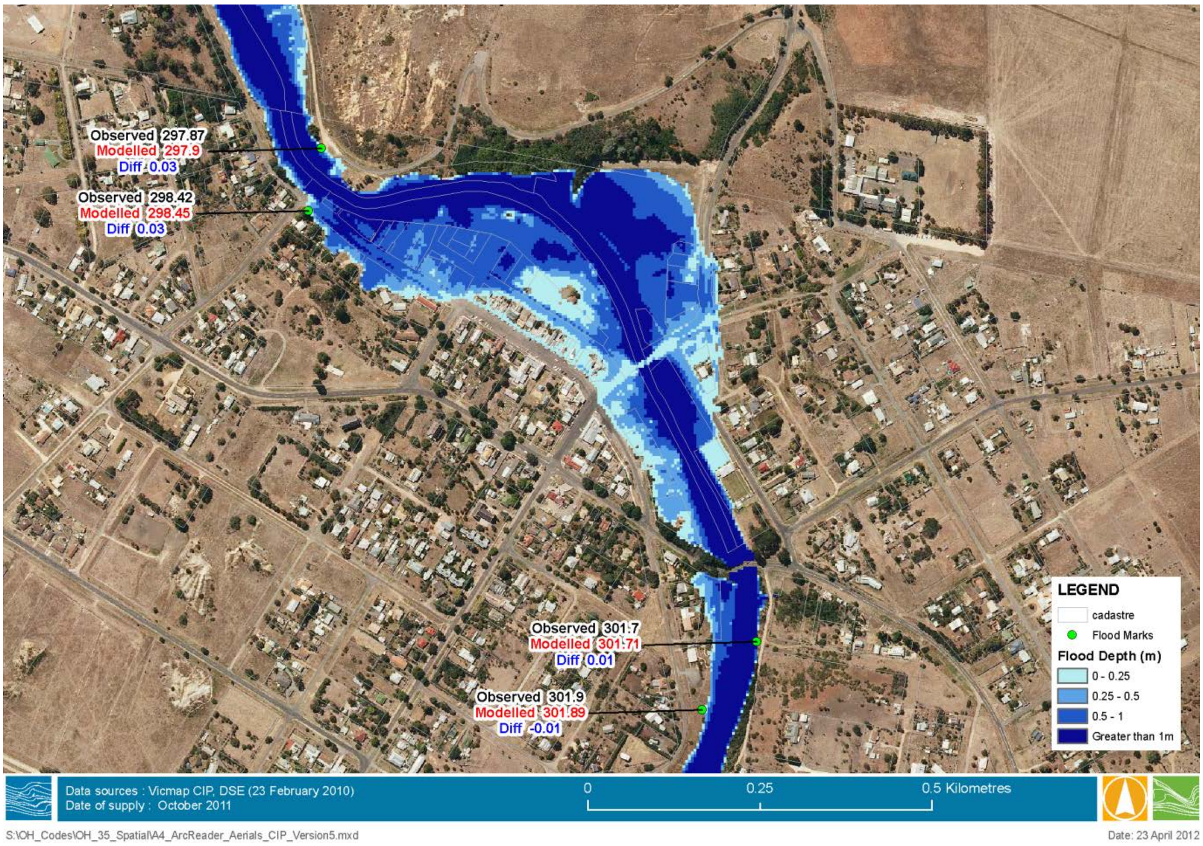


Figure 5-1 January 2011 Calibration Plot

Figure 5-2 Observed and Modelled Extents of the January 2011 Event

5.2.2 September 2010 Calibration

Figure 5-3 shows the flood depths for the September 2010 event along with the calibration results for the surveyed flood marks. The September 2010 calibration showed a good fit to the three surveyed flood marks (Table 5-2). Of the three flood marks, two were underestimated by up to 60 mm and one was overestimated by 90 mm. The lack of available calibration data and flood information for the September event made it difficult to further fine tune the September 2010 results.

Table 5-2 September 2010 Calibration Points

Location	Surveyed Level (m AHD)	Modelled Level (m AHD)	Difference (m)
9 Fraser Street (stain inside rear of house)	298.32	298.41	0.09
19 Fraser Street (mark on bricks, side of building)	299.08	299.02	-0.06
19 Fraser Street (mark on bricks at door)	298.98	298.93	-0.05

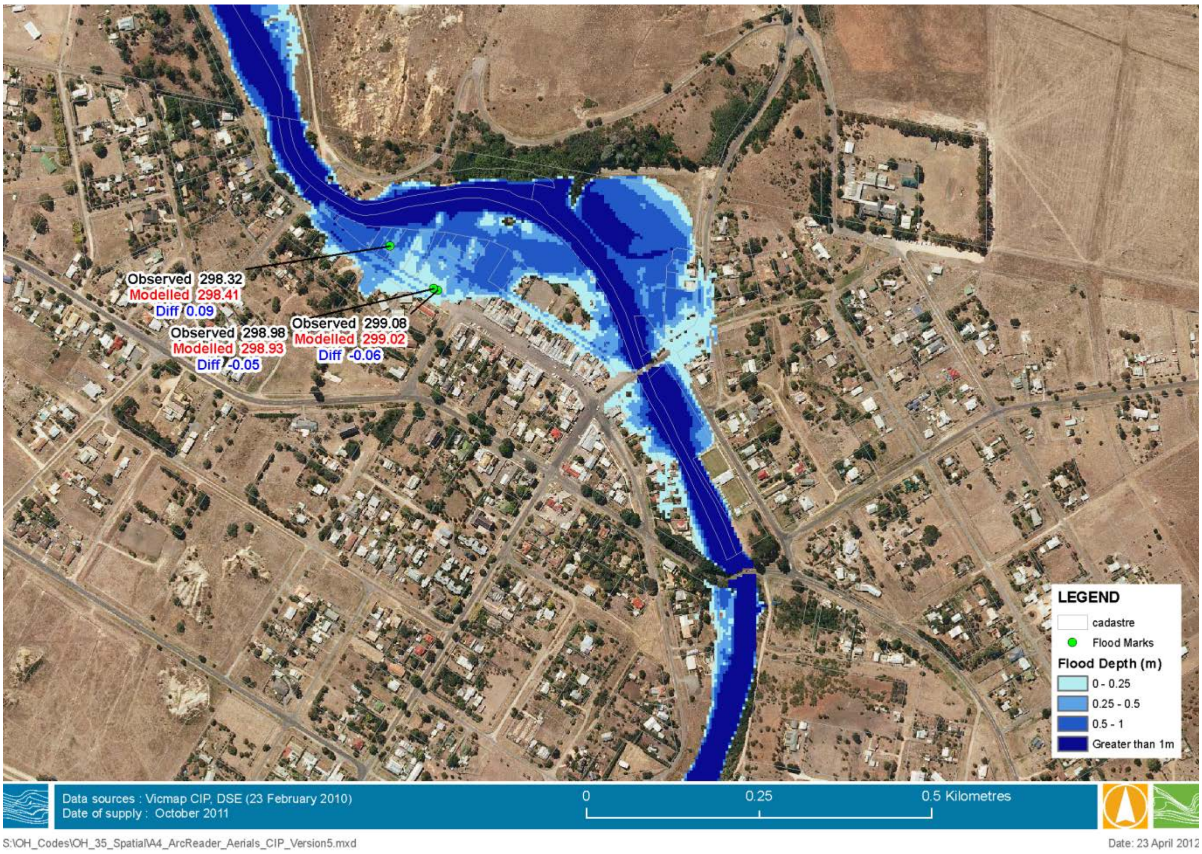


Figure 5-3 September 2010 Calibration Plot

The calibration achieved for the two historic flood events is considered excellent, with all calibration points well within 0.1 m, which is the nominal accuracy of the underlying LiDAR data.

5.2.3 Local Runoff Calibration

For the local runoff component, the model was run with two source boundaries (local rainfall and Creswick Creek inflows) to determine the interaction between stormwater flooding and creek flooding. As there were no formal records of localised flooding, the local runoff component was calibrated to observations made during the recent events and previously identified locations with drainage issues within the township. Enveloped results of the stormwater flood peak and Creswick Creek flood peak are shown in Figure 5-4 and Figure 5-5 for the January 2011 and September 2010 events respectively.

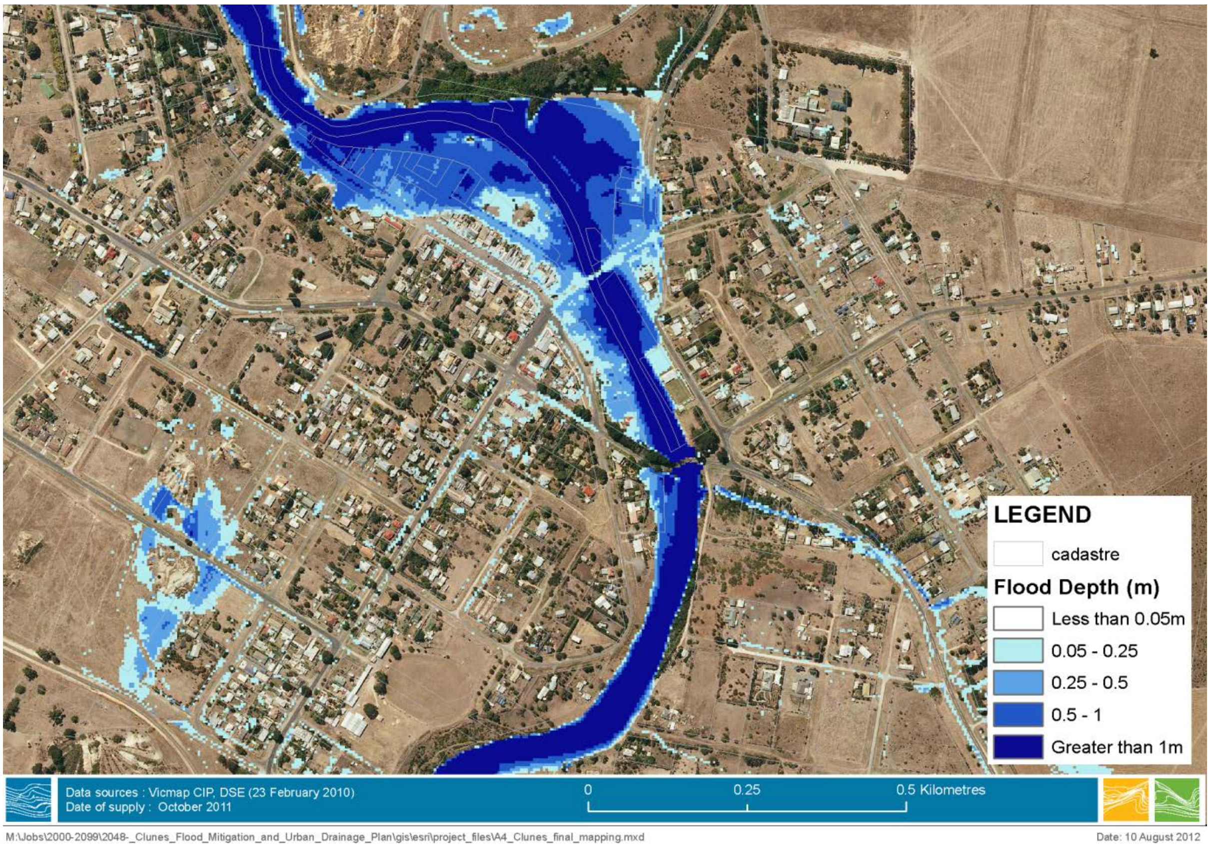


Figure 5-4 January 2011 – Enveloped Results of Stormwater and Creek Flooding

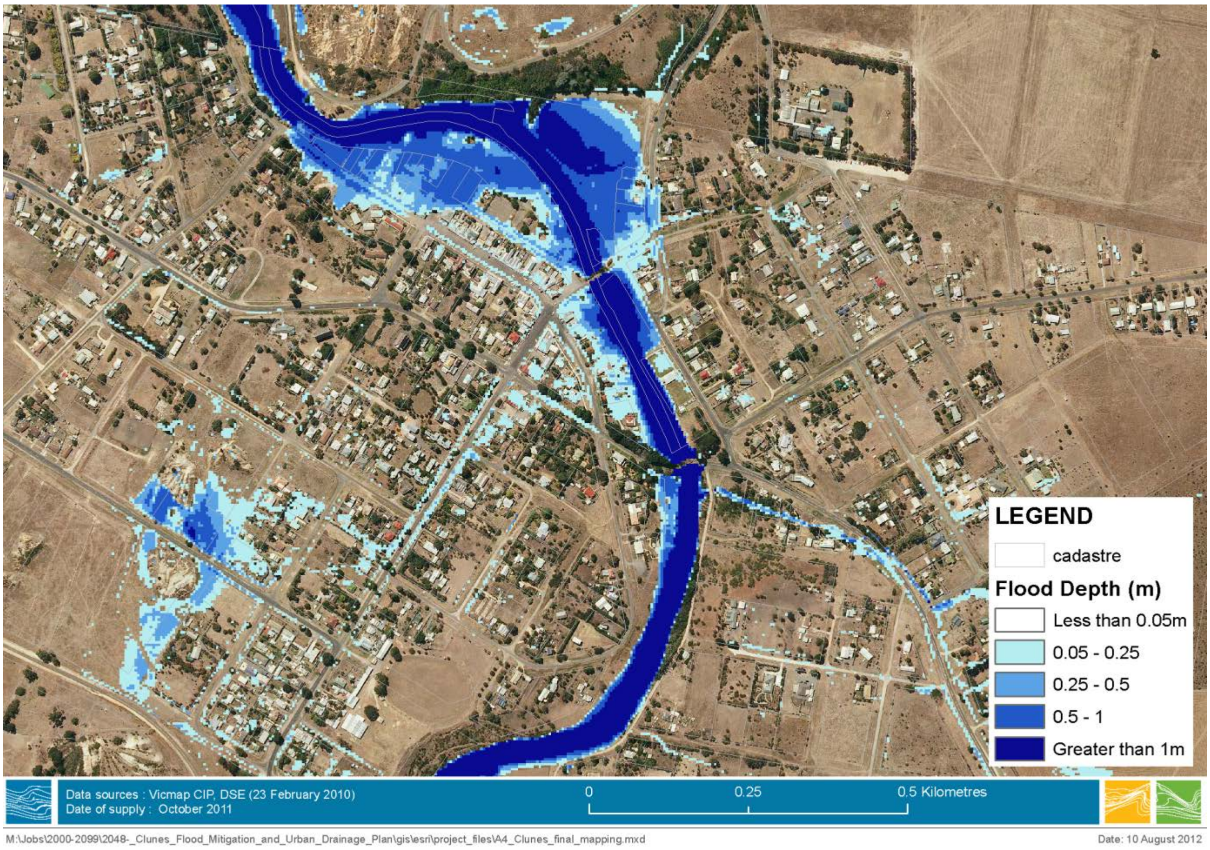


Figure 5-5 September 2010 – Enveloped Results of Stormwater and Creek Flooding

5.3 September 2010 and January 2011 Modelled Flood Behaviour

The flood extent from Creswick Creek is similar for both events given the confined nature of the floodplain; however water levels in the January 2011 event were higher. Service Street Bridge only overtopped in the January 2011 event while Government Bridge was not overtopped in either event. The flooding mechanism from Creswick Creek is described below:

- The first signs of creek breakout are on the right bank just downstream of the football oval and also upstream of Service Street;
- As floodwaters continues to rise, the football oval starts to flood;
- The first few properties inundated are the low lying properties near Camp Street and the single property at 1A Cameron Street (location of the old butter factory);
- As the creek rises further, floodwaters break out on the left bank at the end of the caravan park forming an overland flow path that moves to the west;
- Floodwaters then overtop Ligar Street on the right bank and inundate the swimming pool, sports building and nearby properties. At the same time Fraser Street is inundated at the lower end, near Camp Street;
- As creek flows continue to rise, Purcell Street is completely inundated. At the same time flood depths rise rapidly upstream of Service Street, impacting properties along the creek. At this point the September 2010 event reached its peak;
- In the January 2011 event, floodwaters continued to rise and Service Street Bridge overtopped, sending floodwaters down Service Street on the left bank. At the same time the northernmost bowling club was inundated; and
- Floodwaters then ran down the main part of Fraser Street encroaching on the commercial buildings along Fraser Street. At this point the January 2011 event had peaked.

Stormwater flooding was experienced in both the September 2010 and January 2011 floods. The stormwater behaviour for both events was similar:

- Stormwater runoff started before Creswick Creek overtopped. As the creek started to overtop, stormwater continued to runoff from the steep local catchment. At the peak of the flood event (from Creswick Creek), it had stopped raining and the stormwater had receded;
- Flood depths from the stormwater runoff (prior to the creek overtopping) are generally below 250 mm;
- Table drains along Service Street, Templeton Street, Fraser Street and Purcell Street were at capacity and started to overtop;
- The sports oval and nearby properties started to flood before Creswick Creek overtopped its banks; and
- Stormwater pools in low lying areas on the left and right banks of Creswick Creek.

The local runoff would have resulted in:

- Increased depths at low lying spots during the rainfall event i.e. prior to the flood peak from Creswick Creek;
- Flooding of areas not impacted by the creek overflows (e.g. the netball court); and
- Multiple flow paths observed prior to the flood peak from Creswick Creek.

The local runoff would not have resulted in increased flood depths at the peak of the flood event, as the peaks of the stormwater runoff and creek flooding did not coincide and the volume of local runoff is very small compared to the volume of flow that breaks out of bank during a large flood.

5.4 Hydraulic Model Application

5.4.1 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. The changes in flood conditions after the January 2011 event are a result of the post flood works undertaken. The following modifications were made to the model to represent post flood conditions:

- To represent the creek clearing work between Service Street and Camp Street, the roughness parameter along the bank of the creek was reduced through this section;
- Two new 900 mm culverts included at the Camp Street crossing. This was part of the repair works at the ford crossing; and
- Inclusion of a new drain to the north of the netball court. This drain was installed to prevent flooding of the netball courts from local runoff.

Using the updated hydraulic model, all six ARI design events were run for the Creswick Creek flood component. Figure 5-6 shows all six design flood extents overlayed on the one figure for comparison. The suite of flood maps across the six ARI design events is shown in Appendix A.

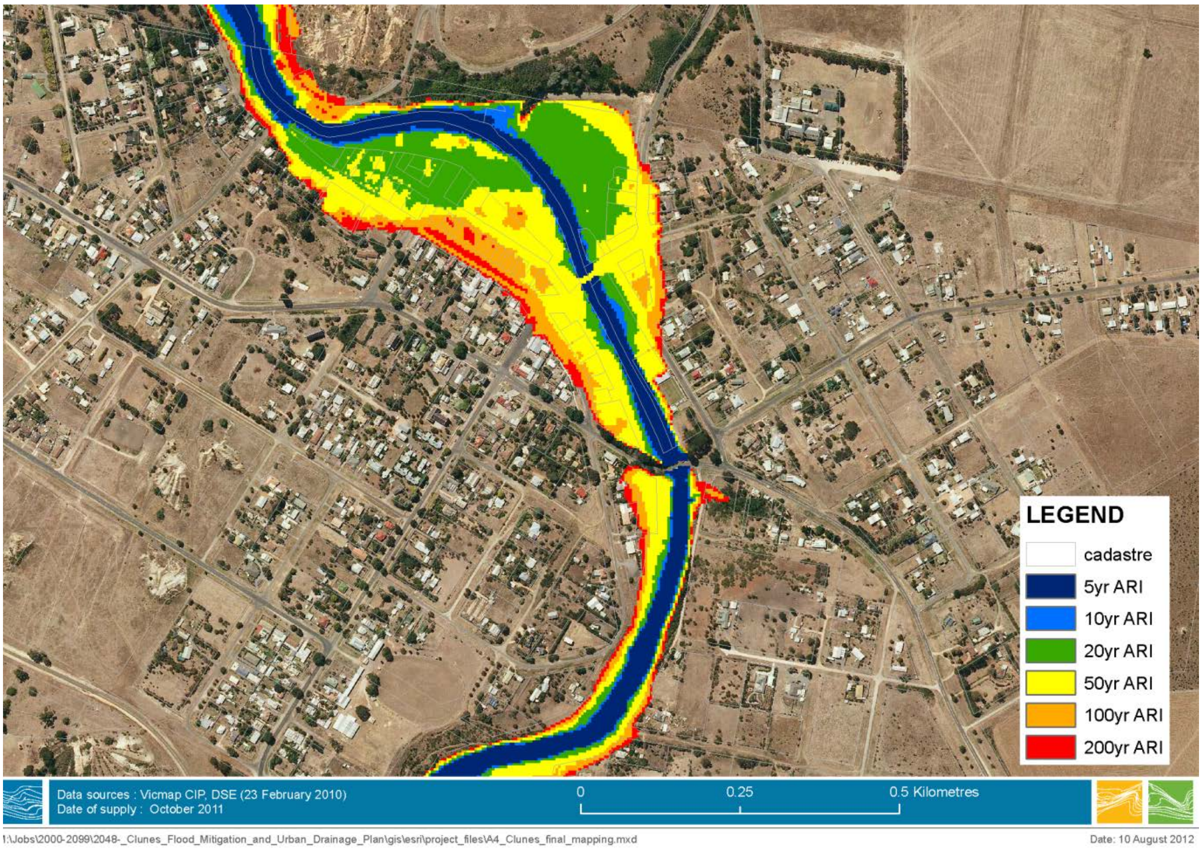


Figure 5-6 Design Flood Event Extents

In addition to the six design events for creek flooding alone, two additional runs were carried out adopting a joint probability approach for the local runoff and creek flood events, as follows:

- Model run with the 10 year ARI flow in the creek and 100 year ARI storm applied across the local catchment, with the peaks coinciding to produce the worst-case scenario; and
- Model run with the 100 year ARI flow in the creek and the 10 year ARI storm applied across the local catchment, with the peaks coinciding to produce the worst-case scenario.

The flood extents for the two combined creek flooding and stormwater runoff 'design event' scenarios are shown in Appendix B.

5.4.2 Design Flood Behaviour

The flood behaviour for the six ARI design events (creek component) is described below. Up to the 10 year ARI event, flows are largely contained within Creswick Creek. Once flows exceed the 10 year ARI (approx. 90m^3/s) Creswick Creek starts to overtop. No properties are impacted in the 5 and 10 year ARI events.

In a 20 year ARI event, widespread flooding is experienced downstream of Service Street. On the left bank, floodwaters inundate the low lying areas downstream of the caravan park while on the right bank, the football oval, swimming pool and nearby properties are flooded. The total number of properties inundated is 23 in a 20 year ARI event. Two properties are flooded above floor in a 20 year ARI event; the 'butter factory' (1A Cameron Street) and a residential dwelling along the left bank of the creek (1 Purcell Street).

Going from a 20 to 50 year ARI event, there is a significant increase in flood extent and number of properties affected. The total number of properties impacted increases from 23 in a 20 year event to 52 in a 50 year event. Out of the 52 properties flooded in a 50 year event, 26 are flooded above floor.

In the 100 year ARI event, floodwaters start to overtop the section of Fraser Street between Templeton Street and Service Street, inundating the commercial buildings/shops. In total 70 properties are flooded in a 100 year ARI event, with 48 properties flooded above floor.

Above the 100 year ARI event (up to the 200 year ARI event) there is an increase in flood depths but no major change in the flood extents. An additional 6 properties are impacted compared to the 100 year event; however the number of properties flooded above floor has increased significantly, from 48 to 64 properties.

6. FLOOD MITIGATION OPTIONS

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

6.1 Structural Mitigation Option Prefeasibility Assessment

A number of structural mitigation options have been proposed to reduce the flood risk in Clunes. The list of potential structural mitigation options was developed based on formal discussions with the community (feedback from the meetings and community questionnaire), informal community correspondence passed on from North Central CMA and suggestions from the Steering Committee and Technical Working Group. A prefeasibility assessment of the options was undertaken to determine which options were worth pursuing further. Each mitigation option was assessed against four main criteria:

- Reduction in flood damage
- Cost
- Feasibility
- Environmental impact

The score for each criteria was based on a ranking system of 1 to 5 (Table 6-1), 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. 'Reduction in flood damage' was the most heavily weighted criteria as this is really the main objective of any flood mitigation option. Preliminary mitigation option modelling was used to guide the score for the 'reduction in flood damages' criteria.

Table 6-2 below shows the total score for each mitigation option assessed against the four main criteria. Options with the higher scores indicate the most appropriate mitigation solutions for Clunes.

While these options were reviewed and scored individually it is important to consider a combination of options when developing a flood mitigation scheme. Other issues such as social factors were also considered in the final recommendation of the preferred mitigation option.

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 Options Prefeasibility Assessment

No	Works Location	Mitigation Option	Comments	Criteria: Damage Reduction	Criteria: Cost	Criteria: Feasibility/ Constructability	Criteria: Environmental Impact	Score
1	Creswick Creek	Left bank levee - downstream of Service St	•Proposed to protect a large number of properties downstream of Service St on the left bank •Involves reconstructing/extending the old levee between Service St and Camp St •This option will increase water levels on the opposite bank and further downstream •Preliminary modeling indicated that levee heights up to 2 m are required to provide protection up to the 100 yr flood event •Minimal room to construct a levee along the caravan park and at the downstream end near Camp St. •Where space is restrictive, a crib wall or retaining wall levee can be considered	5	2	5	3	16
2	Creswick Creek	Right bank levee - downstream of Service St	•Proposed to protect the properties south of the football oval •Minimal room to construct a levee particularly due to single property ('old butter factory') located directly along the creek •Alternatively protection may be achieved by raising Ligar St (Refer No. 4) •The levee will have to extend along the south corner of the oval, where space is a constraint	4	2	3	4	13.5
3	Creswick Creek	Left bank levee - upstream of Service St	•Proposed to protect the properties upstream of Service St, along Fraser St •The levee will run between Government Bridge and Service St •Major constraint is a lack of space between the creek and the property boundaries	4	1	2	3	11.5
4	Creswick Creek	Raising Ligar St - between Bland St and Service St	•Proposed to protect the properties upstream of Service St, along the right bank •Raising the road will cause access issues for the properties located along Ligar St	4	2	4	2	13
5	Creswick Creek	Raise Service St - between Fraser St and Angus St	•Proposed to prevent creek overflows from overtopping Service St and running down Fraser St •Will increase flood levels upstream of Service St	4	2	3	2	12.5
6	Creswick Creek	Increasing channel capacity between Service St and Camp St	•The creek capacity will have to be doubled (approx.) to prevent flooding of properties in a 100 year event •The capacity of the creek section along the caravan park can be increased by steepening the right bank slope to match the 1 in 1.5 left bank profile •Downstream of the caravan park there is room to widen the creek, mainly on the right bank, but will involve heavy earthworks and vegetation removal •This may involve realignment of the existing walking track and may also impact on the construction of the replacement pedestrian bridge damaged in the floods	4	2	2	2	12
7	Creswick Creek	Increasing channel capacity between Government Bridge and Service St	•The creek capacity will have to be doubled (approx.) to prevent flooding of properties in a 100 year event •There is no room to widen the creek along the entire section given the close proximity of properties on the left bank and the location of the bowls clubs on the right bank. Potential to widen in certain sections as outlined below: •There is room to widen the creek on the right bank upstream of Service St, extending out into the open space/playground north of the bowls club •There is a 50 m section downstream of Government Bridge where the creek has a left bank slope of 1 in 4. There is some room to increase the creek capacity here by cutting into/steepening this bank. •Further deepening the channel is unsafe because the creek banks already have a steep profile of approx. 1 in 2 (flattening out to 1 in 3 at the bottom)	3	2	1	2	9.5
8	Creswick Creek	Increased channel capacity near the ford crossing at Camp St	•Proposed to improve channel capacity by allowing floodwaters to be released quicker through the downstream section •There is room on the right bank to increase the channel capacity however it will involve heavy earthworks and vegetation removal •To test the impact of this option, the flood model was run with a large section of the creek's right bank near Camp Street excavated out (8,000 m^3). The modeling results showed minor reductions in flood levels (up to 150 mm) immediately upstream of Camp Street but no significant reduction further upstream near Service Street.	4	2	3	2	12.5
9	Creswick Creek	Increased channel capacity further D/S, where Kilkenny Creek joins Creswick Creek	•Proposed to improving the capacity of the Creswick Creek by reducing downstream water levels, allowing flows to be released more quickly	3	2	3	2	10.5

			•Has no significant impact as demonstrated in the model testing of increasing the capacity at Camp Street.					
10	Creswick Creek	Waterway management works (Improvements/Maintenance)	•Model sensitivity testing showed that the creek clearing works undertaken in February 2011 has lowered the 50 year flood level by up to 250 mm and 100 year flood levels by up to 150 mm •The waterway management works will have a larger impact on the lower magnitude events •Will require ongoing maintenance	4	3	5	3	15
11	Creswick Creek	Increasing the capacity of Service St Bridge	•Proposed to decrease water levels upstream of the bridge and to prevent Service St from overtopping •May be achieved by cutting into the sloped banks/abutments or raising the bridge deck •The bridge is only just overtopped in the January 2011 event, which is comparable to the 50 year ARI design event. In the 50 year ARI event, there is very little head drop (100 to 150 mm) across the bridge and modeling of the bridge with an increased cross section area confirms that the bridge has little impact on flood levels. The capacity of the creek is the main limiting factor through town.	3	3	4	3	12.5
12	Creswick Creek	Combined flood storage/wetland	•Significantly large storage volumes are required to retard the 50 and 100 year flows. Approximately 5,670 ML (100yr event) and 2,550 ML (50yr event) of storage is required to prevent flooding of properties. •Given the large flows and long flood event durations from Creswick Creek, flood storages are not seen as a feasible option	5	1	1	1	12
13	Local Drainage	Upgrading the capacity of the existing stormwater network	•Involves increasing the pipe/drain network capacity to reduce overland flooding from local runoff •Designed to protect properties subject to stormwater runoff i.e. mainly the properties along Purcell Street and properties next to the oval •Will have very little impact on flooding from Creswick Creek •Should be considered to deal with local drainage issues	2	3	3	5	11
14	Local Drainage	Realignment of the stormwater drainage outfall locations	•Outside the scope of this study •Will have very little impact on flooding from Creswick Creek but may improve local drainage issues during localized rainfall events	2	2	1	3	8
15	Local Drainage	Flap valves on the drainage network outfalls	•Designed to prevent high water levels in the creek from backflooding the stormwater drains •To be used in conjunction with any levee works	2	4	5	5	13

Using the prefeasibility assessment results, the 15 identified structural mitigation options have been listed in order of total weighted score. Note that when designing a total flood mitigation scheme no single option in isolation will provide the solution, instead a number of options will be combined as a package to offer the best means of reducing flood risk.

Table 6-3 Ranked Mitigation Options

Mitigation Options	Score
Western bank levee - downstream of Service St	16
Waterway management works (Improvements/Maintenance)	15
Eastern bank levee - downstream of Service St	13.5
Raise Ligar St - between Bland St and Service St	13
Flap valves on the drainage network outfalls	13
Raise Service St - between Fraser St and Angus St	12.5
Increased channel capacity near the ford crossing at Camp St	12.5
Increasing the capacity of Service St Bridge	12.5
Increasing channel capacity between Service St and Camp St	12
Combined flood storage/wetland	12
Western bank levee - upstream of Service St	11.5
Upgrading the capacity of the existing stormwater network	11
Increased channel capacity d/s of the township, where Kilkenny Ck joins Creswick Ck	10.5
Increasing channel capacity between Government Bridge and Service St	9.5
Realignment of the stormwater drainage outfall locations	8

6.2 Structural Mitigation Options Modelled

6.2.1 Selection of Options to Model

Based on the above ranking of mitigation options, two options stood out as the most feasible measures to reduce the flood risk:

- Flood levees; and
- Waterway management works.

The waterway management works (undertaken in February 2011) have provided a moderate reduction in flood levels of up to 250 mm. This option ranked highly as it's a relatively cost effective and feasible option. To this effect, all other flood mitigation works have been assessed on the basis that the current creek conditions will be maintained. This has been agreed by the Steering Committee with Hepburn Shire Council and North Central CMA providing an ongoing commitment to maintain the creek in its current condition.

In order to protect the town against large flood events, similar to the September 2010 and January 2011 flood events, flood levees have been considered along with the waterway management works.

A number of different levee alignments and protection levels were investigated. Following discussions with the Steering Committee, an initial levee option was developed and modelled (refer Figure 6-1). This option was designed to protect the properties downstream of Service Street and consists of the following works:

- Left bank levee extending from Service Street to Camp Street; and
- Right bank levee downstream of Service Street, protecting the properties south of the oval

Figure 6-1 Preliminary Mitigation Option - Iteration 1

During the initial 50 year ARI model run it became evident that the proposed levees were constricting the flow path and significantly increasing water levels upstream of Service Street by up to 0.9 m. This is not acceptable as there are numerous properties located upstream of Service Street which would be adversely impacted.

To offset the afflux (upstream increase in water level), a number of modifications to the base levee option were considered. The following design changes were modelled, in the order listed below.

Table 6-4 Description and Comments on the Preliminary Mitigation Option Iterations

Model Iterations	Additional Works/Changes to base alignment	Impact on 50 year flood levels
Iteration 2 (Figure 6-2)	Along with levee works, the capacity of the creek section along the caravan park was increased by steepening the creek's right bank slope	Minor impact on upstream water levels, not significant enough to reduce the 0.9 m afflux.
Iteration 3 (Figure 6-3)	A shorter levee alignment used on the right bank to reduce afflux. This new alignment excludes the basketball court, swimming pool and the single dwelling adjacent to the creek	Afflux reduced from 0.9 m to 0.7 m. Afflux still high so further options were considered.
Iteration 4 (Figure 6-4)	As per Iteration 3 (i.e. shorter right bank levee) with the capacity of Service Street Bridge significantly increased (from 180 m^3/s to 280 m^3/s) by cutting into the sloped abutments	Increasing the bridge capacity has a minimal impact on water levels. Afflux further reduced from 0.7 m to 0.6 m.

Iteration 5 (Figure 6-5)	Right bank levee removed and Ligar Street lowered by 0.4 m to direct more flow into the oval, away from the nearby properties. This option was designed to protect properties on the left bank while not increasing water levels on the opposite bank	Not an effective option. Water levels for properties on the right bank still increased by up to 0.3 m.
Iteration 6 (Figure 6-6)	Right bank levee removed. Left bank levee alignment shortened (now runs from the northern end of the Caravan Park to Camp Street). Designed to protect the downstream properties on the left bank while not increasing flood levels at the properties next to the oval.	Does not work. This levee alignment does not protect the properties behind it. Floodwaters travel along Fraser Street and fill in behind the levee
Iteration 7 (Figure 6-7)	As per Iteration 3, with the right bank levee extended to protect properties upstream of Service Street.	All properties on the right bank now protected. Afflux still present, but reduced to 0.3 m along the left bank only
Iteration 8 (Figure 6-8)	As per iteration 7, with a left bank levee upstream of Service Street. Effectively leveeing the whole town.	All properties protected, except for the 'butter factory'.
Iteration 9 (Figure 6-9)	As per iteration 6 with the left bank levee extended to cross Fraser Street. This option also includes major channel widening to offset the increased water levels caused by the levee.	Properties downstream of Templeton Street protected from flooding. The channel widening ensures that flood levels are not increased outside the levee.

Figure 6-2 Preliminary Mitigation Option - Iteration 2

Figure 6-3 Preliminary Mitigation Option - Iteration 3

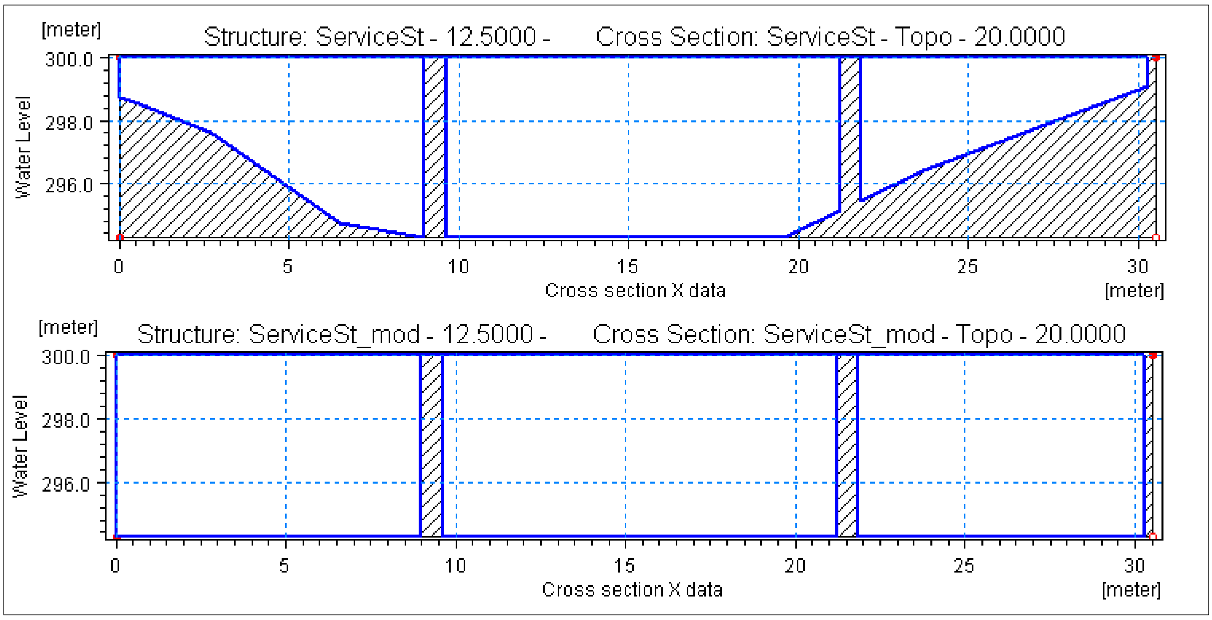


Figure 6-4 Preliminary Mitigation Option - Iteration 4

Figure 6-5 Preliminary Mitigation Option - Iteration 5

Figure 6-6 Preliminary Mitigation Option - Iteration 6

Figure 6-7 Preliminary Mitigation Option - Iteration 7

Figure 6-8 Preliminary Mitigation Option - Iteration 8

Figure 6-9 Preliminary Mitigation Option - Iteration 9

The preliminary assessment indicates that it would be difficult to install levees without further increasing water levels elsewhere in the town. This is mainly due to the close proximity of buildings to Creswick Creek, both on the upstream and downstream side of Service Street.

From the preliminary assessment, Iteration 8 and 9 were identified as the two options with the least impact on 'properties not protected by levee works'. These two options were used as a starting point for further discussions with the Steering Committee.

Preferred Mitigation Options for Detailed Modelling (Discussions on Iteration 8 and 9)

As described above, Iteration 9 consists of a levee designed to protect the properties downstream of Templeton Street, i.e. the most vulnerable properties located in the lowest part of the floodplain. To offset the increased flood levels outside the levee, Creswick Creek was widened by cutting into the right bank, downstream of the oval. This option was designed and modelled in detail and presented to the community at the third community meeting. Following discussions with members of the community and the Steering Committee, this option was not pursued further, as a preferred option, as it did not provide a consistent level of protection across the entire town.

Iteration 8 was viewed as a potential option to pursue further, with further discussions held with the Steering Committee to determine the preferred level of protection for the levees. Initially, the typical 100 year ARI level of protection (with freeboard) was considered.

Based on constructability issues and the significant levee heights required to protect up to a 100 year ARI event, a 50 year ARI level of protection was adopted instead. This would provide protection for events such as the September 2010 and January 2011 events. Through the community consultation process, the community strongly indicated that a level of protection from a January 2011 type event (similar to a 50 year ARI event) was acceptable.

The works proposed under Iteration 8 are subject to numerous design constraints, including the construction of works on private land and increased water levels at a single property 'the old butter factory' located outside the levee alignment. After discussions with the steering committee it was decided that Iteration 8 while providing the required level of protection, would have a low probability of receiving government funding due to the high cost and unlikelihood of it receiving strong support from the community.

In light of this an alternative option for protection against minor floods was developed. The level of protection was revised down to the 20 year ARI event, removing the need for major levee works and the positioning of works on private land.

While the likelihood of receiving funding for Iteration 8 (moderate level of protection) is low, it was still put forward to the community to seek their feedback.

The two mitigation options put forward to the community include:

- **Option 1 – Protection for Minor Floods**: A variation of Iteration 8 with levees constructed to protect up to the 20 year ARI event; and
- **Option 2 – Protection for Moderate Floods**: Iteration 8, with levees designed to protect up to the 50 year ARI event.

The Steering Committee discussed the idea of staging the works to provide minor protection immediately and if the community showed strong support for the moderate protection option, that could form Stage 2 of works, subject to future funding.

The two mitigations options are described in more detail below.

6.2.2 Mitigation Option 1 – Protection for Minor Floods

Mitigation Option 1 is designed to protect Clunes to a lower event, i.e. the 20 year ARI event with 300 mm freeboard. The proposed works for Option 1 involve reinstating the old levee on the left bank and constructing a relatively low level levee on the opposite bank (Figure 6-10).

Aerial imagery and LiDAR was used to design the levee alignment. Conceptual design of the proposed levees is shown in Appendix C.

Figure 6-10 Mitigation Option 1

This option is aimed at protecting the community assets on the right bank (swimming pool and basketball court) as well as reducing minor flooding on the left and right banks. Flood modelling results for the 20 year ARI event with the mitigation works in place is shown in Figure 6-11 below.

This option will remove above floor flooding at one residential property (1 Purcell Street) in a 20 year ARI event. External flooding will be reduced at the swimming pool, basketball court building and a number of residential properties along Purcell Street, Fraser Street and next to the oval. The only property still affected by above floor flooding in a 20 year event is the ‘old butter factory’.

Option 1 will not worsen flooding at any property up to the 20 year ARI event, including the ‘old butter factory’. In larger events, the levee will not have any significant impact on the flood distribution and flood depths. The levee does not worsen flooding at any properties in a 50 year ARI event. In the 100 year ARI event two additional properties are flooded above floor as a result of minor water level increases by up 100 mm.

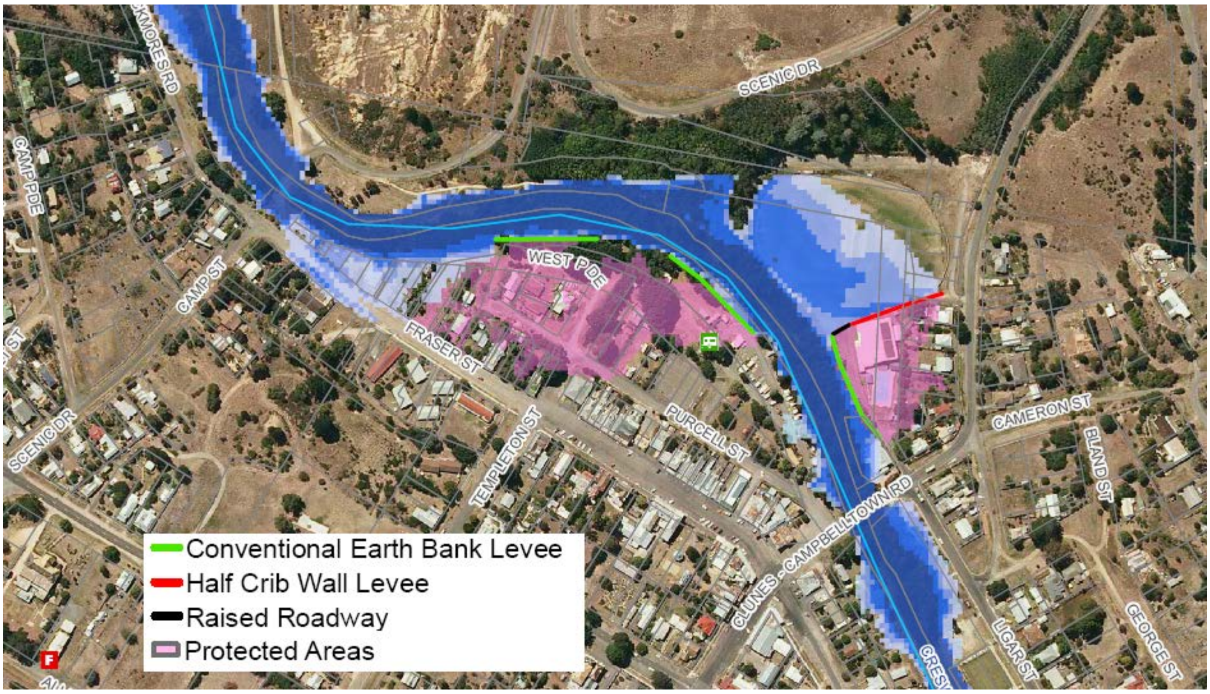


Figure 6-11 Mitigation Option 1 Modelling Results - 20 Year Event

The Option 1 levee alignment is relatively straightforward along the left bank; however the levee alignment on the right bank will have a number of constructability issues.

On the left bank an earthen bank levee is proposed along the edge of the creek. Detail design of the levee should aim to minimise the impact on nearby vegetation and the caravan park.

On the right bank, different levee types were used to deal with the lack of space and road crossing issues. A short section of right bank levee crosses Ligar Street and can be constructed by raising the road. It is proposed that the raised road section is built up to the flood level, with additional freeboard provided by sandbags during a flood event. Construction of the levee along the south corner of the oval is restricted by a lack of space. To avoid having the levee encroach onto the oval, concrete retaining walls or crib walls can be used. Examples are shown in Figure 6-12 and Figure 6-13 below. Detail design will have to consider access issues for the oval. Along Creswick Creek an earthen levees is proposed next to Ligar Street. The right bank levee alignment stops just before the old butter factory next to the creek.

Figure 6-12 Crib Wall Levee

Figure 6-13 Concrete Wall Levee

6.2.3 Mitigation Option 2 – Protection for Moderate Floods

Mitigation Option 2 was designed to provide flood protection for Clunes up to the 50 year ARI event with 300 mm freeboard. This option consists of the following works:

- Levee system downstream of Service Street on either side of the creek;
- Levees system upstream of Service Street on either side of the creek; and
- Service Street Bridge deck raised by 0.5 m to tie into the proposed levees.

Aerial imagery and LiDAR was used to design the levee alignment. Conceptual design of the proposed levees is shown in Appendix D. The maximum height for various sections of the levee is shown in Figure 6-14 below.

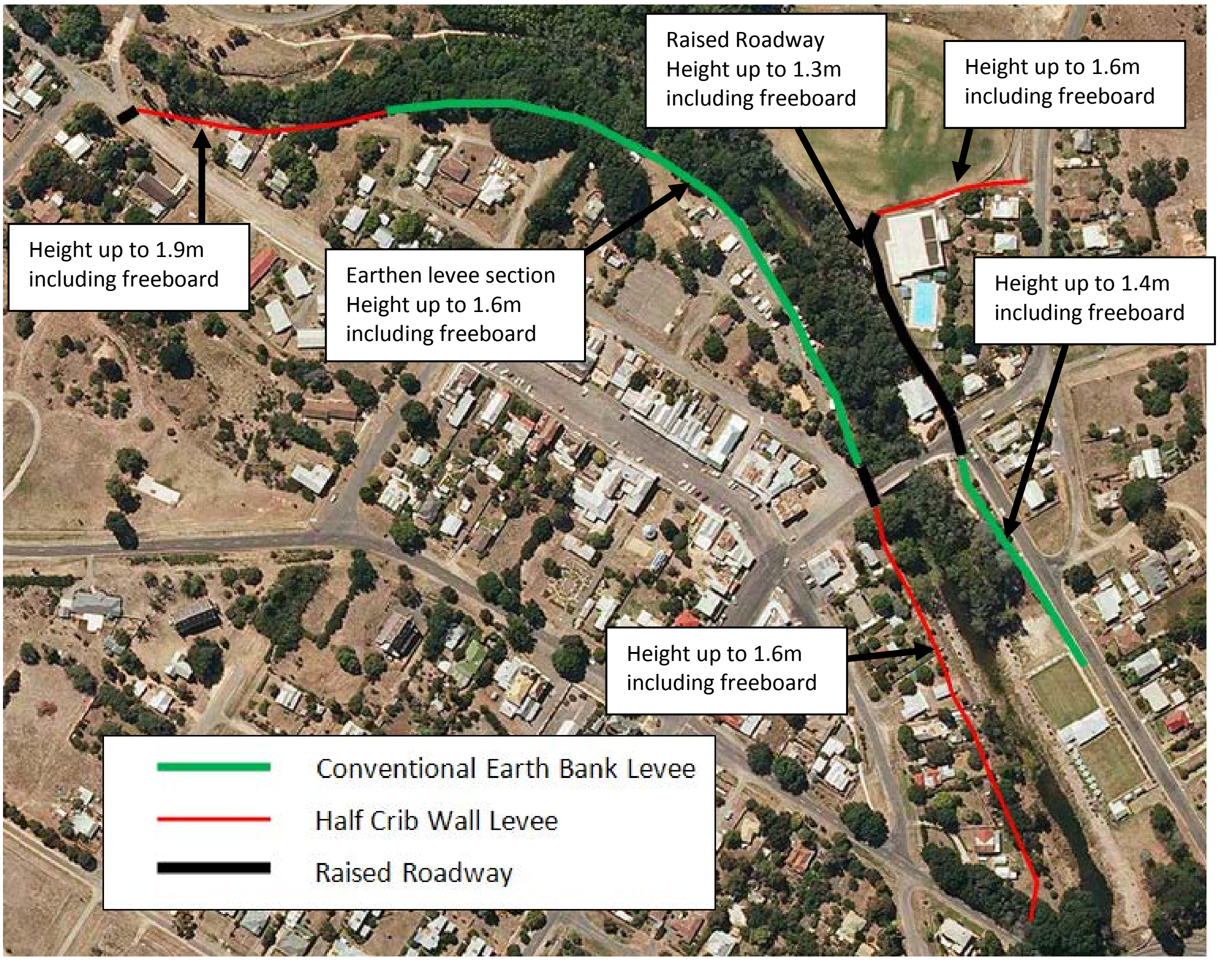


Figure 6-14 Mitigation Option 2

Mitigation Option 2 is subject to numerous design constraints, primarily due to the close proximity of properties to the creek. The design constraints are listed below:

- Protecting properties on the left bank, upstream of Service Street, requires the construction of a levee over private land. There is also the issue of a sewer line along the backyard of these properties which would complicate the construction of a levee;
- The downstream end of the left bank levee (near Camp Street) encroaches on a number of private lots;
- Some of the cabins/caravans in the caravan park would have to be relocated to construct the left bank levee;
- The right and left bank levee alignments cross Service Street on either side of the bridge. This will involve raising the road to tie into the levee alignments on either side. Raising the

road would require considerable work to ensure that the required grades are met to provide access over the bridge and access from the approach roads. To minimise the impact, the raised road section can be built up to the flood level, with the additional 300 mm freeboard provided by sandbags. This would limit the road raising to 0.5 m;

- The right bank levee excludes the 'old butter factory'. The proximity of this property to the creek means that there is insufficient room to include the property in the levee alignment. Option 2 will increase water levels at this property by up to 0.4 m in the 50 year ARI event;
- Part of the right bank levee involves raising Ligar Street which presents access issues to the local sports facilities and the 'old butter factory'; and
- As with mitigation option 1, construction of the right bank levee along the south corner of the oval is restricted by a lack of space.

To overcome some of the construction issues, different levee types have been considered. Construction over private property is still unavoidable in some sections, but the use of concrete walls or crib walls will reduce the levee footprints.

This option will remove flooding across the entire township for a 50 year ARI event (comparable to the January 2011 flood event). As discussed above, the only property not protected is the 'old butter factory'. Flood modelling results for the 50 year ARI event with the mitigation works in place is shown in Figure 6-15 below.

During a 50 year ARI event, mitigation Option 2 reduces the number of properties flooded above floor from 26 properties to a single property. The one property still inundated is the 'old butter factory'.

The effects of the Option 2 levees on larger flood events (100 year ARI event) is minimal, with flood depth increases of up to 150 mm (impacting some properties along Fraser Street and properties south of the oval) as a result of the levees overtopping and floodwaters building up behind the levees. The minimal increase in flood levels does however increase the number of properties flooded above floor in a 100 year event; from 48 properties under existing conditions to 53 properties with the levees in place.

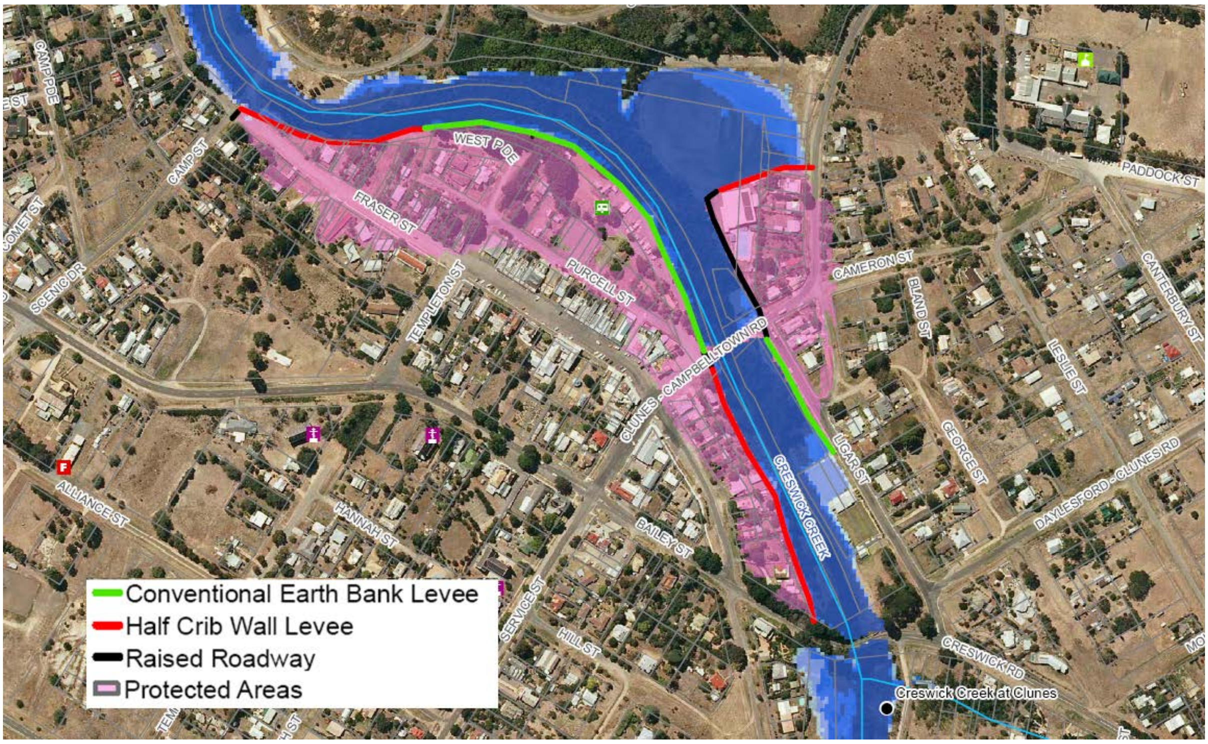


Figure 6-15 Mitigation Option 2 Modelling Results - 50 Year Event

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.

Planning Schemes can be viewed online at http://services.land.vic.gov.au/maps/pmo.jsp. It is recommended that the planning scheme for Clunes is amended to reflect the flood risk identified by this project. Figure 6-17 shows proposed FO and LSIO for consideration into such an amendment. The draft planning scheme map is based on the 'Advisory Notes for Delineating Floodways' (NRE, 1998), with three approaches considered.

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

Flood hazard - Combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 6-16 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.

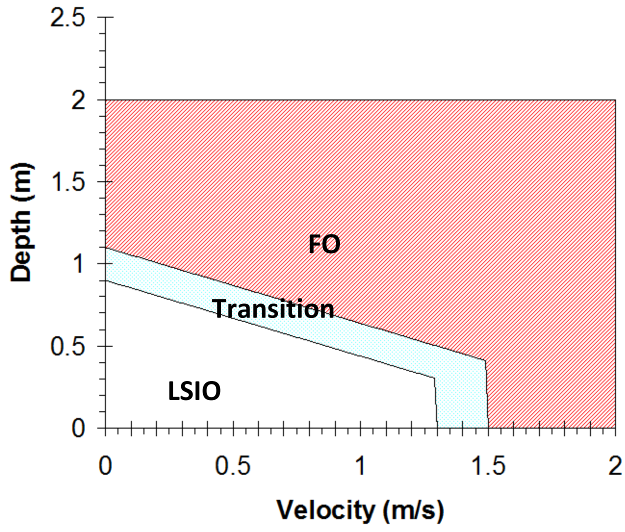


Figure 6-16 Flood Hazard Delineation of FO

Figure 6-17 Draft LSIO and FO Map for Existing Conditions

6.3.2 Flood Warning System

Any flood warning system developed should be constructed within the Total Flood Warning System framework as described in the report "Flood Warning" (Manual 21 of the Australian Emergency Manuals Series, Commonwealth Attorney-General's Department). A basic outline of a recommended service is provided below. The scope of this project was to provide broad recommendations regarding flood warning.

The basic building blocks of the Total Flood Warning System as described by the Australian Emergency Manual referred to above, is presented in Figure 6-18. All components of the Total Flood Warning System must be present for a flood warning system to be effective. If one component is neglected then the entire system is at risk of failure.

The broad recommendations for flood warning provided in this report comments briefly on the 'Monitoring and Prediction' and 'Interpretation' components of the Total Flood Warning System. It is strongly recommended that if a specialised flood warning service is to be developed for Clunes that all components be thoroughly investigated.

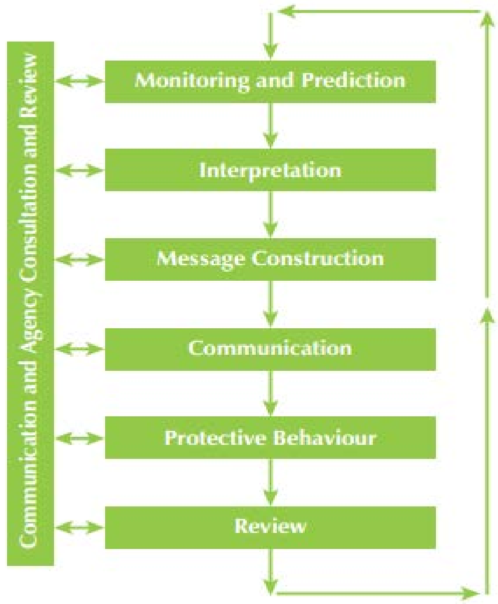


Figure 6-18 Flood Warning System Components

The Australian Emergency Manual also recognises the fact that an effective flood warning system requires the involvement of a number of agencies including federal, state and local government agencies as well as regional authorities. A detailed description of the responsibilities of the various agencies is provided in the 'Arrangements for Flood Warning Services in Victoria' report.

The Bureau of Meteorology is responsible for the 'monitoring and prediction' component for floods in rural Victoria, except in the case of flash flooding. Flash flooding is generally classified where flooding occurs within about 6 hours of heavy rainfall. In the event of flash flooding, the local government has the main responsibility, with the Bureau of Meteorology providing advisory support.

Flood lead times for the township of Clunes were based on the available historical data and hydrological modelling of the catchment. The historical data used to assess lead times for the Clunes township refers to the two recent large events in September 2010 and January 2011. No information on flood timing was found for events prior to the September 2010 flood.

A comparison of flows at Creswick and Clunes, during the recent flood events indicated that the peak flow at Clunes correlated to roughly twice the recorded peak flow at Creswick. This rough correlation between flows at Creswick and Clunes should not be relied upon for flood warning as there is a large contributing catchment flowing into Creswick Creek between the two towns.

Table 6-5 Peak Flow Comparison at Creswick and Clunes

Flood Event	Modelled Flows at Creswick (m^3/s)	Gauged/Recorded Flows at Clunes (m^3/s)
September 2010	93.8	174.6
January 2011	100.2	222.4

The hydrological modelling undertaken as part of this study suggests that there is a short response time (in the order of 12 to 18 hours) between rainfall in the upper catchment and the flood peaks in Clunes. This response time is based on the design floods and can vary depending on the rainfall patterns and antecedent catchment conditions. The onset of flooding can occur well before the peak of the flood, so this means that the available warning time can be significantly less. During the September 2010 flood event the time from when the rainfall began and when properties began to become inundated was roughly 6 to 8 hours, with the peak of the flood occurring some 6 to 10 hours later. The January 2011 flood event had a similar lead time to the onset of flooding but a longer time to the peak of the flood due to the longer duration of the event.

Given that the catchment response time to the onset of flooding is approximately 6 hours or greater with the peak of the flood another 6 hours later, it is recommended that flooding in Clunes from rainfall in the upper catchment not be classified as flash flooding and that an assessment into the feasibility of developing a flood warning system for Clunes be undertaken. This would likely require a number of new stream flow and rainfall gauges to be installed and a hydrological model developed, as discussed below.

It is also recommended that any flood warning system developed for Clunes considers the requirements of other flood prone townships in the catchment such as Creswick upstream (which is likely classified as flash flooding) and Carisbrook downstream. This may provide the opportunity to streamline the installation of rainfall and stream flow gauges to support the multiple towns.

Monitoring and Prediction

A map of all active streamflow and rainfall gauges in the area is shown in Figure 6-19 below.

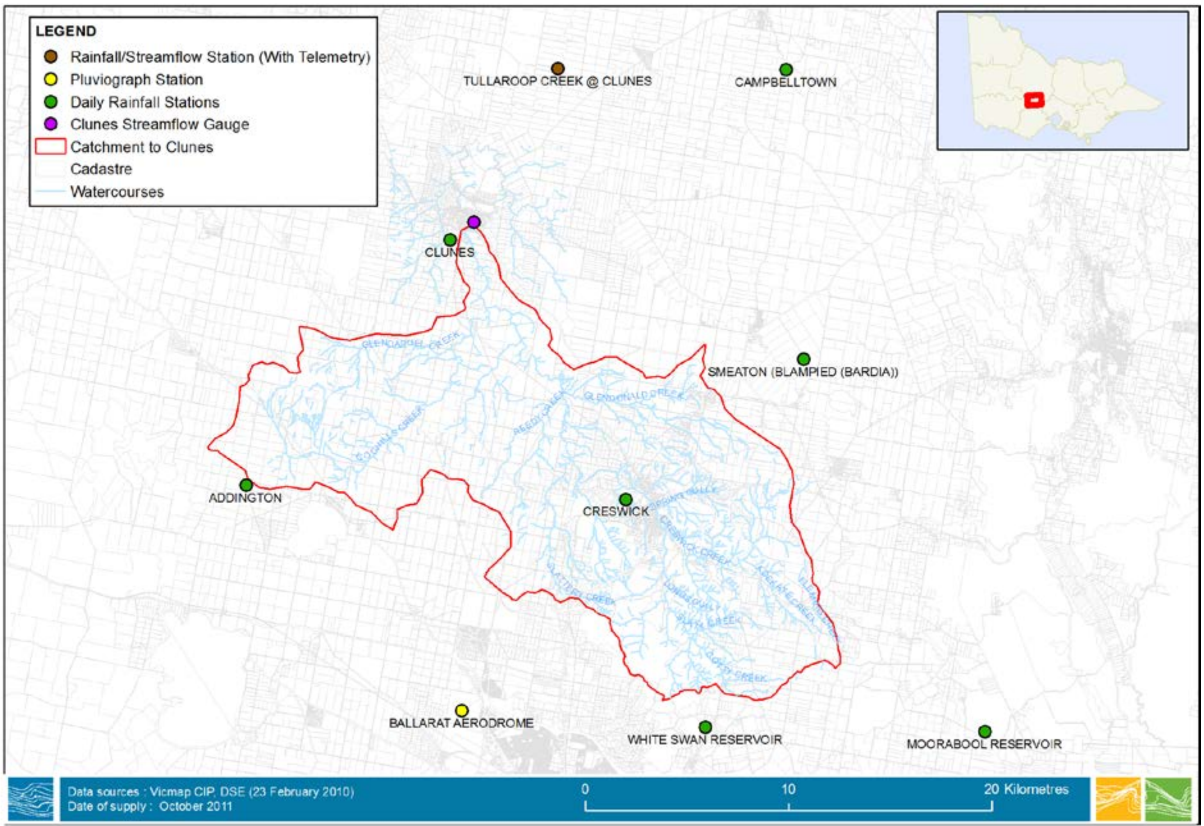


Figure 6-19 Locations of Streamflow Gauges and Rainfall Stations Surrounding Clunes

It is suggested that a new flood warning stream flow gauge be installed at Creswick. This gauge would be located approximately 20 km upstream from Clunes and would provide approximately 3 to 6 hours warning time to Clunes. It is also recommended that the 'Creswick Creek at Clunes' stream flow gauge located upstream of Government Bridge be updated to a flood warning gauge and that the flood warning service for Clunes be developed for this gauge. These two gauges alone however are not sufficient to develop an effective warning system, given the:

- Short timing of peaks between Creswick and Clunes (from the two recent flood events the timing of the flood peaks between Creswick and Clunes was in the order of 3 to 6 hours); and the
- Large catchment flowing into Creswick Creek between Creswick and Clunes.

In addition to a stream flow gauge at Creswick, it is also suggested that rainfall stations in the upper catchment are used to provide predictions. At present, Clunes is covered by flood watch for the North Central catchments; this area includes the Campaspe, Loddon, Avoca and Wimmera catchments. The rainfall data recorded at 'Tullaroop Creek at Clunes' is included in rainfall bulletins provided by the Bureau of Meteorology on its website.

There are no rainfall gauges with telemetry within the catchment upstream of Clunes. The upper catchment is however surrounded by two daily rainfall gauges located just outside the catchment (White Swan Reservoir and Moorabool Reservoir stations) and a pluviograph station at Ballarat.

An assessment as to the benefit of adding new rainfall gauges within the Clunes upper catchment should be undertaken as opposed to converting the existing rainfall gauges surrounding the upper catchment for flood warning purposes. It should be noted that while rain gauges outside the catchment are useful, it cannot replace rain gauges within the catchment. If new rainfall gauges were to be installed it is recommended that at least one is sited upstream of Creswick near Dean, and another placed to the west of the catchment perhaps at Coghills Creek. The rainfall gauges along with the current Clunes gauge could then be monitored and used to predict rainfall inputs to the hydrological model, producing estimates of flow at Clunes.

Interpretation

Using the revised rating curve for the 'Creswick Creek at Clunes' gauge, the predicted flow from the flood warning system could then be converted to a water level for messaging to the community. This prediction could then be used to interpret the 5, 10, 20, 50 and 100 year flood maps produced during this study so that an estimated flood extent and flood impact could be determined. For flows greater than the January 2011 event flows, the rating curve level is exceeded, however the modelled flows and corresponding water level at the gauge location is marked up in the flood study maps. As well as the maps this report includes descriptive flood intelligence information regarding flood impacts for a range of events, that when combined with the list of properties impacted above and below floor, provides the full set of information required to formulate a flood response plan.

6.3.3 Flood Response

The information and understanding gathered during this project regarding the flood behaviour at Clunes for a range of events is critical to improving the flood response in Clunes. 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 which is being prepared by Hepburn Shire council in conjunction with VICSES. To assist the authorities with responses during a flood event, the design event mapping outputs from this study have been tied back to the 'Creswick Creek at Clunes' gauge, located upstream of Government Bridge. As discussed above, this study has also produced extensive flood intelligence of flood impacts that can be used directly and efficiently to populate the flood response plan for Clunes.

6.3.4 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 Clunes community able to respond to the January 2011 event much more effectively than the earlier September 2010 event.

The following activities can be used to improve flood awareness:

- 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 the VICSES Flood Safe program;
- Installing flood markers of historic or potential design floods in suitable locations. This may include a town gauge board that may be part of a flood warning system, or at least linked to the outputs from this study in the flood response plans; and
- 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.
- Community events aimed at communicating clearly any new flood warning system that may be installed and ensuring people know how to use it.

7. FLOOD DAMAGE ASSESSMENT

7.1 Overview

A flood damage assessment of Clunes was undertaken. The damage assessment was used to determine the monetary flood damage for the design floods (5, 10, 20, 50, 100 and 200 year ARI events).

The flood damage assessment was also undertaken for the two flood mitigation options put forward to the community. The 5 year ARI event was not 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 F.

7.2 Existing Conditions

The flood damage assessment for existing conditions is shown in Table 7-1. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$43,900**. The AAD is a measure of the flood damage per year averaged over an extended period. This is effectively a measure of the amount of money that must be put aside each year in readiness that a flood event may happen in the future.

It should be noted that no properties are inundated in the lower magnitude events (5 and 10 year ARI events) and only two properties are flooded above floor in a 20 year ARI event.

Table 7-1 Flood Damage Assessment for Existing Conditions

ARI (years) AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	64	48	26	2	0	0
Properties Flooded Below Floor	12	22	26	21	0	0
Total Properties Flooded	**76**	**70**	**52**	**23**	**0**	**0**
Direct Potential External Damage Cost	$196,604	$233,592	$232,585	$150,719	$0	$0
Direct Potential Residential Damage Cost	$1,024,369	$735,197	$533,439	$29,754	$0	$0
Direct Potential Commercial Damage Cost	$564,585	$316,129	$255,311	$0	$0	$0
Total Direct Potential Damage Cost	**$1,785,558**	**$1,284,918**	**$1,021,334**	**$180,473**	**$0**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$1,428,446**	**$1,027,934**	**$817,067**	**$144,378**	**$0**	**$0**
Infrastructure Damage Cost	**$99,806**	**$83,031**	**$63,090**	**$23,931**	**$2,809**	**$2,433**
Indirect Clean Up Cost	$285,588	$220,073	$123,864	$10,886	$0	$0
Indirect Residential Relocation Cost	$24,429	$20,612	$12,978	$1,527	$0	$0
Indirect Emergency Response Cost	$23,269	$23,269	$23,269	$13,961	$0	$0
Total Indirect Cost	**$333,285**	**$263,954**	**$160,110**	**$26,374**	**$0**	**$0**
Total Cost	**$1,861,537**	**$1,374,920**	**$1,040,267**	**$194,683**	**$2,809**	**$2,433**
Average Annual Damage (AAD)	$43,891					

7.3 Option 1 – Protection for Minor Floods

The AAD for mitigation option 1 was calculated to be approximately **$38,800**. Mitigation option 1 is only effective in reducing largely below floor flooding damages for a large number of properties in the 20 year ARI event. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$5,100** per year by implementing mitigation option 1.

Table 7-2 Flood Damage Assessment for Mitigation Option 1

ARI (years) AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	64	50	26	1	0	0
Properties Flooded Below Floor	12	20	26	4	0	0
Total Properties Flooded	**76**	**70**	**52**	**5**	**0**	**0**
Direct Potential External Damage Cost	$196,793	$224,229	$234,194	$17,096	$0	$0
Direct Potential Residential Damage Cost	$1,026,045	$746,883	$533,607	$19,363	$0	$0
Direct Potential Commercial Damage Cost	$569,127	$322,069	$257,844	$0	$0	$0
Total Direct Potential Damage Cost	**$1,791,965**	**$1,293,182**	**$1,025,645**	**$36,459**	**$0**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$1,433,572**	**$1,034,545**	**$820,516**	**$29,167**	**$0**	**$0**
Infrastructure Damage Cost	**$99,806**	**$83,085**	**$63,358**	**$13,303**	**$2,809**	**$2,433**
Indirect Clean Up Cost	$285,588	$228,998	$123,864	$5,443	$0	$0
Indirect Residential Relocation Cost	$24,429	$21,375	$12,978	$763	$0	$0
Indirect Emergency Response Cost	$23,269	$23,269	$23,269	$13,961	$0	$0
Total Indirect Cost	**$333,285**	**$273,642**	**$160,110**	**$20,167**	**$0**	**$0**
Total Cost	**$1,866,663**	**$1,391,272**	**$1,043,984**	**$62,637**	**$2,809**	**$2,433**
Average Annual Damage (AAD)	$38,819					

7.4 Option 2 – Protection for Moderate Floods

The AAD for mitigation option 2 was calculated to be approximately **$20,200**. Mitigation option 2 is effective in reducing damages up to the 50 year ARI event but will result in a minor increase in damages for the 100 year ARI event. Over a long period of time with a range of flood events, the AAD may be reduced by approximately **$23,700** per year by implementing mitigation option 2.

Table 7-3 Flood Damage Assessment for Mitigation Option 2

ARI (years) AEP	200yr 0.005	100yr 0.01	50yr 0.02	20yr 0.05	10yr 0.1	5yr 0.2
Buildings Flooded Above Floor	67	53	1	1	0	0
Properties Flooded Below Floor	10	19	1	0	0	0
Total Properties Flooded	**77**	**72**	**2**	**1**	**0**	**0**
Direct Potential External Damage Cost	$171,160	$219,920	$4,741	$0	$0	$0
Direct Potential Residential Damage Cost	$1,070,897	$769,198	$44,934	$19,239	$0	$0
Direct Potential Commercial Damage Cost	$676,473	$428,980	$0	$0	$0	$0
Total Direct Potential Damage Cost	**$1,918,530**	**$1,418,098**	**$49,675**	**$19,239**	**$0**	**$0**
Total Actual Damage Cost *(0.8*Potential)*	**$1,534,824**	**$1,134,478**	**$39,740**	**$15,391**	**$0**	**$0**
Infrastructure Damage Cost	**$101,309**	**$84,991**	**$20,120**	**$10,512**	**$2,809**	**$2,433**
Indirect Clean Up Cost	$297,994	$237,483	$5,443	$5,443	$0	$0
Indirect Residential Relocation Cost	$25,192	$20,612	$763	$763	$0	$0
Indirect Emergency Response Cost	$23,269	$23,269	$23,269	$13,961	$0	$0
Total Indirect Cost	**$346,455**	**$281,363**	**$29,475**	**$20,167**	**$0**	**$0**
Total Cost	**$1,982,588**	**$1,500,832**	**$89,335**	**$46,070**	**$2,809**	**$2,433**
Average Annual Damage (AAD)	$20,175					

7.5 Average Annual Damage Summary

The damage assessment shows that mitigation option 1 will have a minor impact on reducing the AAD in Clunes. This is primarily because there are very few properties impacted from the frequent, lower magnitude flood events. Mitigation option 2 will have a moderate impact on reducing the AAD in Clunes.

Table 7-4 Average Annual Damage Summary for Clunes

Scenario	Average Annual Damage
Existing Conditions	$43,900
Mitigation Option 1	$38,800
Mitigation Option 2	$20,200

7.6 Non – Economic Flood Damages

The previous discussion relating to flood damages has concentrated on monetary damages, i.e. 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. As a result of the two flood events, many residents in Clunes have experienced emotional trauma from the floods and also from the subsequent lack of action from insurance companies.

There is no doubt that the intangible non-monetary flood related damage in Clunes is high. The benefit-cost analysis presented later in this report 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 Clunes 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 Clunes.

8. BENEFIT COST ANALYSIS

8.1 Overview

A benefit cost analysis was undertaken to assess the economic viability of the two mitigation options. Indicative benefit-cost ratios were based on the construction cost estimates and average annual damages calculated.

Figure 8-1 Option 1-Minor Flood Protection

Figure 8-2 Option 2-Moderate Flood Protection

8.2 Mitigation Options Costs

The cost estimates for the two mitigation options are shown in Table 8-1. A 30% contingency cost has been included along with engineering and administration costs. A detailed breakdown of the costing for each mitigation option is shown in Appendix E. It should be noted that these costs are based on estimated rates and should be checked during the detailed design phase.

The costing rates were based on a number of references:

- Melbourne Water rates for earthworks and pipe construction costs;
- Melbourne Water rates for land acquisition;
- Estimates from VIC ROADS regarding the bridge work costs; and
- Comparison to cost estimates for similar works for other flood studies.

An annual maintenance cost (1.5% of the total construction cost) was factored in for the channel and levee works. Given the importance of maintaining current waterway conditions, an annual maintenance cost for waterway management works (maintaining elm suckers) has also been included.

Table 8-1 Mitigation Option Cost Breakdown

Scenario	Total Cost of Works	Annual Maintenance
Mitigation Option 1	$109,200	$2,900
Mitigation Option 2	$2,157,400	$9,900

8.3 Benefit Cost Ratio

The results of the benefit-cost analysis are shown below in Table 8-2. For this analysis, a net present value model was used, applying a 6% discount rate over a 30 year project life. The benefit-cost ratio should ideally be equal to or greater than 1. In this case both mitigation options have a benefit-cost ratio considerably lower than 1.

Table 8-2 Benefit Cost Analysis

	Existing Conditions	Mitigation Option 1	Mitigation Option2
Average Annual Damage	$43,900	$38,800	$20,200
Annual Maintenance Cost		$2,900	$9,900
Annual Cost Savings		$2,200	$13,800
Net Present Value		$30,200	$194,100
Capital Cost of Mitigation		$109,200	$2,157,400
Benefit - Cost Ratio		0.3	0.1

9. CONCLUSIONS AND RECOMMENDATIONS

Following the recent flood events in September 2010 and January 2011, Clunes was identified as a high flood risk community and funding was approved for a flood study of the township. The Clunes Flood Mitigation and Urban Drainage Plan was run by North Central CMA in conjunction with Hepburn Shire Council.

The study involved the development of a detailed hydraulic model of the township, successful calibration to the recent September 2010 and January 2011 flood events, simulation of a number of design flood events, design of potential flood mitigation options and a cost-benefit analysis.

Throughout the study, a range of community consultation activities were undertaken, including community meetings, media releases and questionnaires to ensure that community issues were heard and the community ideas were considered in the development of potential flood mitigation options. The preferred level of protection as indicated by the community was the 50 year ARI event (similar to January 2011 flood event). This was found to be difficult to achieve through waterway works (vegetation/silt removal and creek widening) alone.

An initial prefeasibility assessment of 15 structural mitigation options was undertaken. From the prefeasibility assessment, waterway management works and flood levees stood out as the two best options for reducing the flood risk in Clunes.

Following on from the prefeasibility assessment, two mitigation options were developed and investigated in detail. Option 1 was developed to provide flood protection from a minor (20 year ARI) flood event while Option 2 was developed to protect protection to a moderate (50 year ARI) flood event. Both options involve the construction of flood levees and regular maintenance of Creswick Creek. A full assessment of the two options was undertaken which included hydraulic modelling of the proposed works and a full benefit-cost analysis.

The benefit-cost ratio for both options is very low, less than 0.3, indicating that the two proposed mitigation options are not economically viable. The true benefit-cost ratio is actually higher because the calculated benefit-cost ratio does not consider any of the intangible, non-economic flood related damages. Regardless of the benefit-cost ratio, either option will not be considered unless it has the strong support of the community.

Formal feedback received from the community has indicated that a large number of residents are strongly against Option 2. Option 1 did receive slightly more support from the community; however it should be noted that the majority of residents who responded were totally against any levee works. The general consensus is that the Clunes community is in favour of further waterway management work, in particular the removal of gravel and silt from Government Bridge to Service Street, to reduce the flood risk in Clunes.

Plan Recommendations

Following significant consultation with the community the plan recommends the following flood mitigation measures:

- Regular waterway management works to maintain the current creek condition, including vegetation (suckers) and debris removal;
- The feasibility of a flood warning system for Clunes (requiring a number of new stream flow and rainfall gauges to be installed and a hydrological model developed) to be investigated. The flood warning system could be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system;
- It is recommended that a flood response plan be completed using the flood intelligence developed in this study. The inputs required for the flood response plan could be taken directly from this study with little effort and at low cost;

- It is also recommended that the planning scheme for Clunes is amended to reflect the flood risk identified by this project; and
- A number of local drainage issues have been identified in Clunes. Whilst not part of this study, it is recommended that detailed investigations into the local drainage issues are undertaken.

APPENDIX A DESIGN FLOOD MAPS

Figure A - 1 Design Map – 5 Year ARI Flood Event

Figure A - 2 Design Map – 10 Year ARI Flood Event

Figure A - 3 Design Map – 20 Year ARI Flood Event

Figure A - 4 Design Map – 50 Year ARI Flood Event

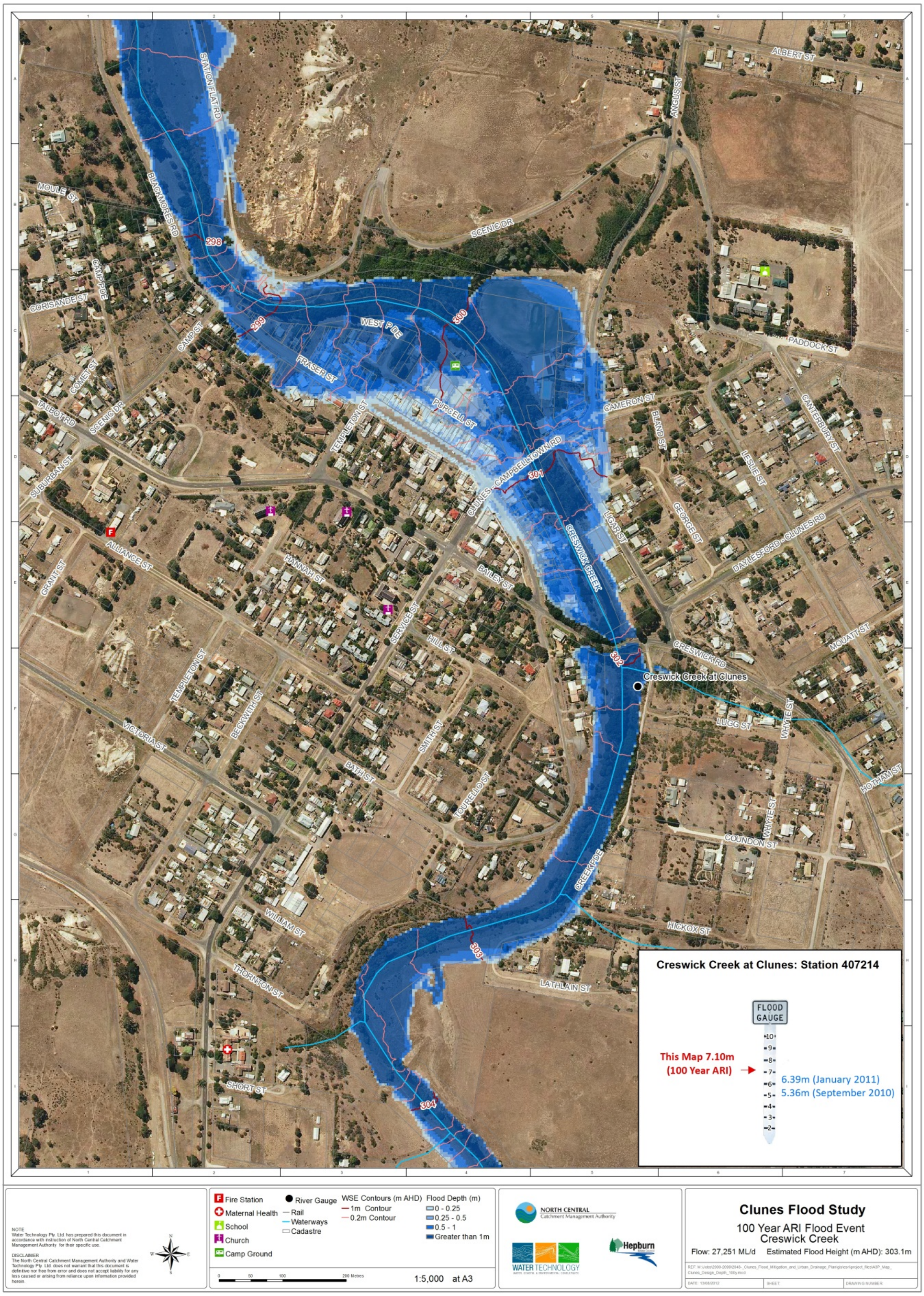


Figure A - 5 Design Map – 100 Year ARI Flood Event

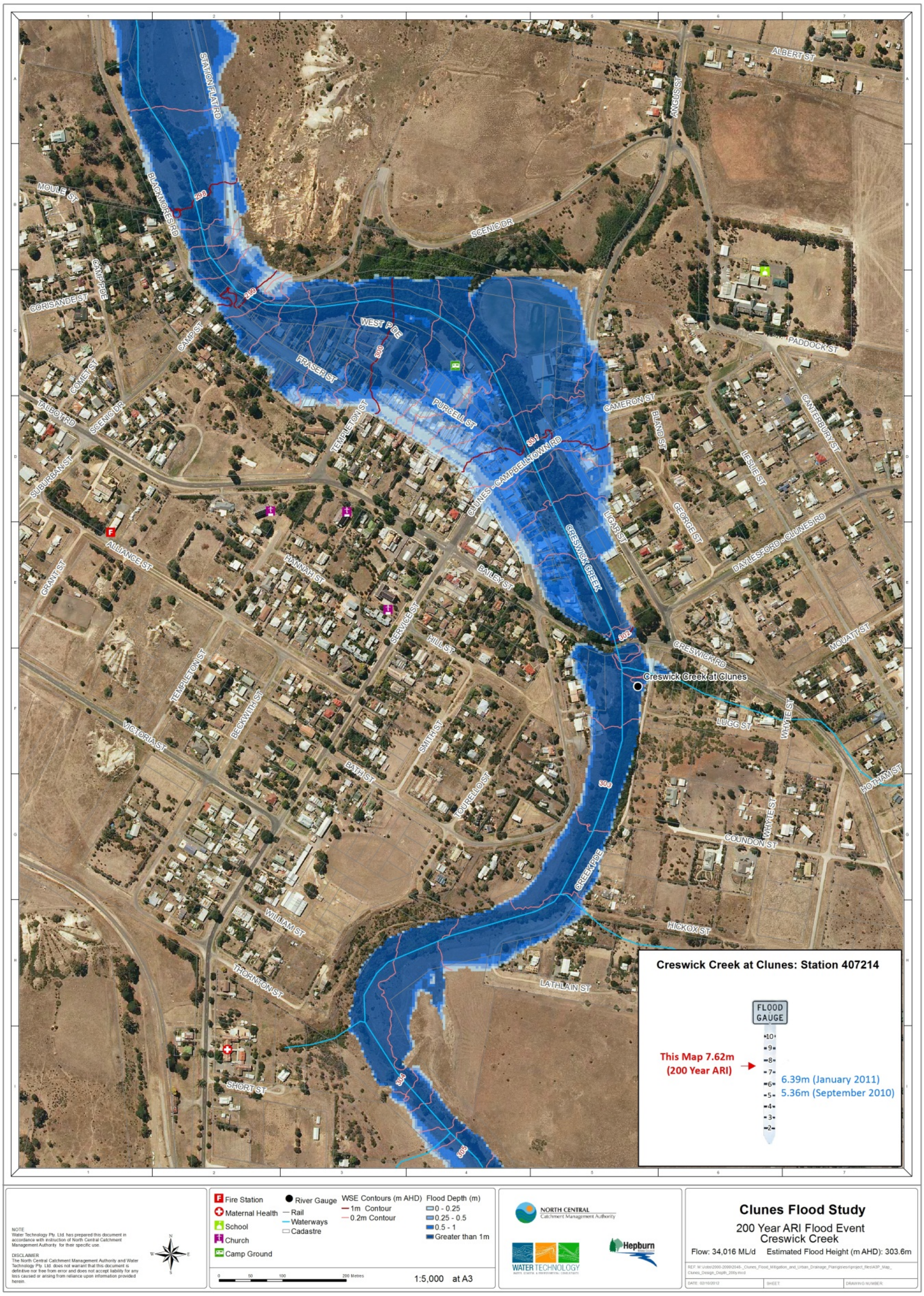


Figure A - 6 Design Map – 200 Year ARI Flood Event

APPENDIX B ADDITIONAL DESIGN MAPS – COMBINED LOCAL RUNOFF & CREEK FLOODING

Figure B - 1 Design Map – Combined 10 Yr Event in Creswick Creek & 100 Yr Local Runoff in Clunes

Figure B - 2 Design Map – Combined 100 Yr Event in Creswick Creek & 10 Yr Local Runoff in Clunes

APPENDIX C MITIGATION OPTION 1 PLANS

Figure C - 1 Mitigation Option 1 – Right Bank Levee Alignment

Figure C - 2 Mitigation Option 1 – Left Bank Levee Alignment

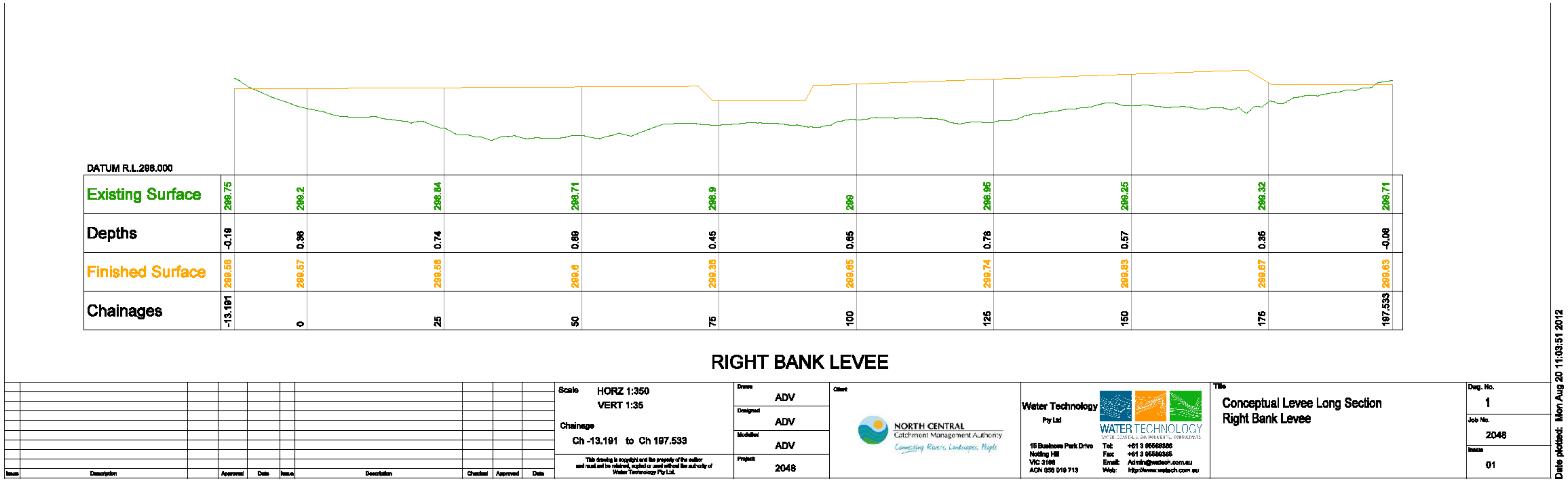


Figure C - 3 Mitigation Option 1 – Right Bank Levee Long Section Plot

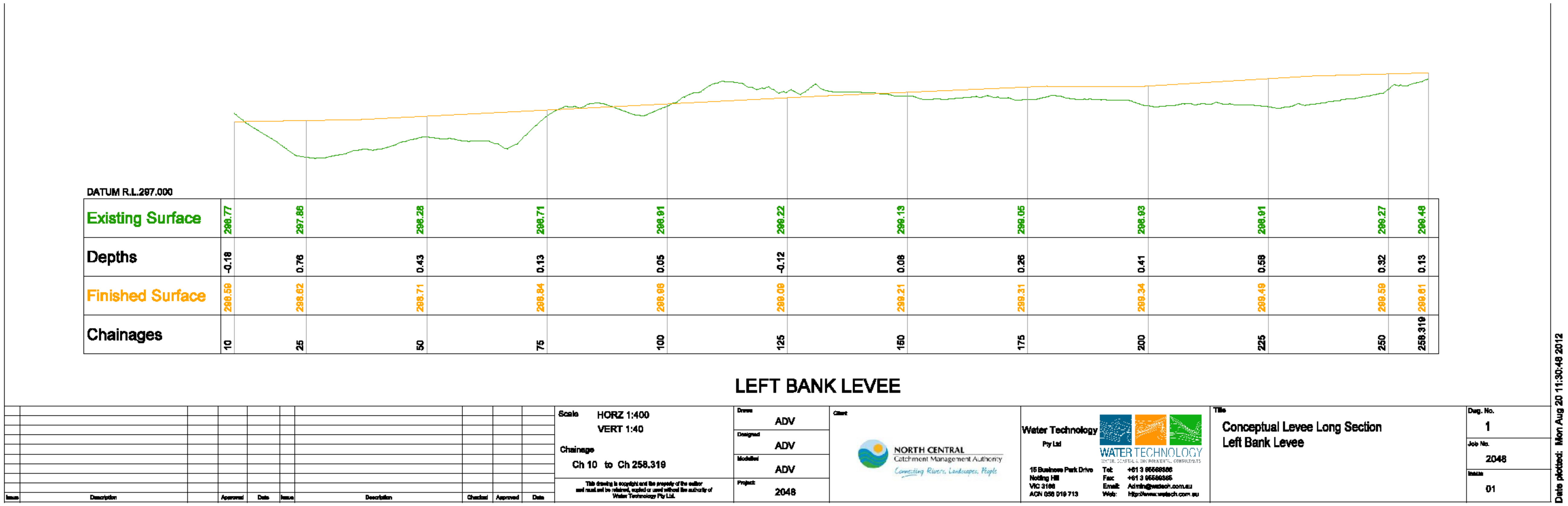
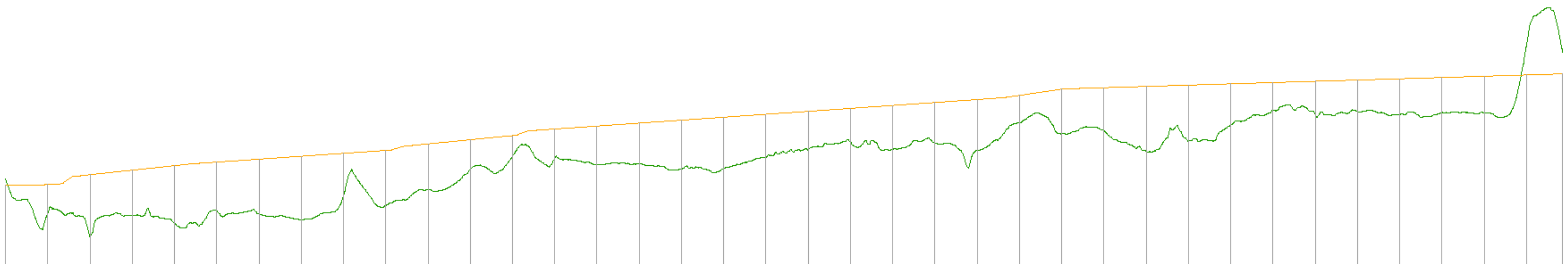


Figure C - 4 Mitigation Option 1 – Left Bank Levee Long Section Plot

APPENDIX D MITIGATION OPTION 2 PLANS



DATUM R.L.296.000

Existing Surface	298.63	297.59	296.91	297.55	297.32	297.69	297.59	297.43	298.14	297.85	298.32	298.91	299.29	299.23	299.06	299.1	298.94	298.95	299.28	299.5
Depths	-0.18	0.88	1.85	1.35	1.71	1.45	1.63	1.88	1.26	1.64	1.35	0.89	0.63	0.89	1.15	1.2	1.44	1.52	1.27	1.14
Finished Surface	298.45	298.47	298.76	298.9	299.03	299.14	299.22	299.31	299.4	299.49	299.67	299.8	299.92	300.12	300.21	300.3	300.38	300.47	300.55	300.65
Chainages	0	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475

Existing Surface	299.73	299.52	299.7	299.49	300.32	299.98	300.08	299.45	299.76	300.24	300.68	300.56	300.63	300.55	300.61	300.6	302.6	302.4
Depths	1	1.3	1.21	1.5	0.8	1.32	1.27	1.94	1.66	1.22	0.82	0.98	0.94	1.06	1.04	1.08	-0.88	-0.64
Finished Surface	300.73	300.82	300.91	301	301.12	301.3	301.35	301.39	301.42	301.46	301.5	301.54	301.57	301.61	301.65	301.69	301.72	301.76
Chainages	500	525	550	575	600	625	650	675	700	725	750	775	800	825	850	875	900	921.361

LEFT BANK LEVEE

Scale HORZ 1:1500 VERT 1:75
Chainage Ch 0 to Ch 921.361

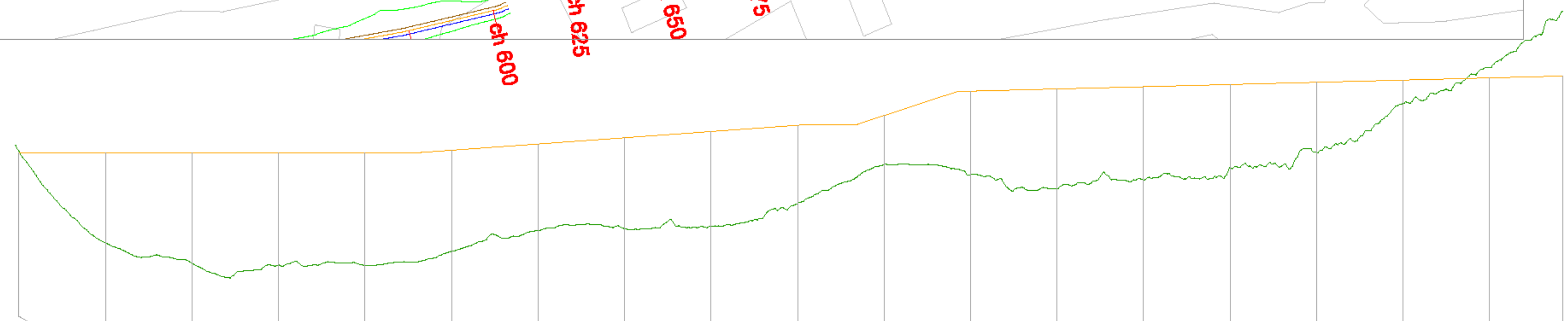
Drawn ADV
Designed ADV
Modelled ADV
Project 2048

Client: NORTH CENTRAL Catchment Management Authority — Connecting Rivers, Landscapes, People

Water Technology Pty Ltd

Title: Conceptual Levee Long Section
Left Bank Levee

Dwg. No. 1
Job No. 2048
Issue 01



DATUM R.L.298.000

Existing Surface	300.66	300.58	299.24	298.94	298.92	298.91	299.12	299.41	299.45	299.48	299.8	300.37	300.23	300.02	300.15	300.33	300.55	301.25	301.78	302.59
Depths		-0.02	1.31	1.6	1.63	1.63	1.46	1.25	1.31	1.37	1.14	0.71	1.21	1.44	1.35	1.2	1.01	0.34	-0.15	-0.94
Finished Surface		300.55	300.55	300.55	300.55	300.55	300.58	300.67	300.76	300.85	300.94	301.08	301.43	301.47	301.5	301.53	301.56	301.59	301.63	301.65
Chainages	-1.073	0	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	446.002

RIGHT BANK LEVEE

Issue	Description	Approved	Date	Issue	Description	Checked	Approved	Date

Scale HORZ 1:700
VERT 1:35

Chainage
Ch -1.073 to Ch 446.002

Drawn ADV
Designed ADV
Modelled ADV
Project 2048

Client
NORTH CENTRAL Catchment Management Authority
Connecting Rivers, Landscapes, People

Water Technology Pty Ltd
WATER TECHNOLOGY
15 Business Park Drive
Notting Hill
VIC 3168
ACN 093 377 283
Tel: +61 3 95589366
Fax: +61 3 95589365
Email: Admin@watech.com.au
Web: http://www.watech.com.au

Title
Conceptual Levee Long Section
Right Bank Levee

Dwg. No. 1
Job No. 2048
Issue 01

APPENDIX E MITIGATION OPTION COSTING

Table E - 1 Mitigation Option 1 Costing

Estimate Sheet

Clunes Flood Mitigation Works - Mitigation Option 1

22/08/12 | Prepared by: ADV

Item No.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	AMOUNT
	LEVEE				
	CONVENTIONAL EARTH BANK LEVEE (180m section along the left bank)				
	Construction and compaction	**238**	m^3	**$20.00**	$ 4,760.00
	Topsoil (100mm)	**72**	m^3	**$17.00**	$ 1,224.00
	HALF CRIB WALL LEVEE (100m section along the southern boundary of the bowls club)				
	Construction and compaction	**133**	m^3	**$20.00**	$ 2,660.00
	Topsoil (100mm)	**32.7**	m^3	**$17.00**	$ 556.00
	Reinforced concrete retaining wall (150mm thick) - average height 0.8m	**80**	m^2	**$477.00**	$ 38,160.00
	CONVENTIONAL EARTH BANK LEVEE (180m section along the left bank)				
	Construction and compaction	**210**	m^3	**$20.00**	$ 4,200.00
	Topsoil (100mm)	**50.2**	m^3	**$17.00**	$ 853.00
	ROADWORKS				
	RAISED SECTION OF LIGAR ST				
	Road crest raised by 400mm (excluding freeboard)				
	Crushed rock base course including grading, rolling and consolidating to receive paving	**65**	m^3	**$105.00**	$ 6,825.00
	Bituminious concrete paving (50mm thick)	**80**	m^2	**$26.00**	$ 2,080.00
	BRIDGEWORKS				
	-				
	DRAINAGE				
	FLAP VALVES				
	Complete installation of flap valves on all drainage network outfalls. Install endwall and flap gate	**3**	No.	**$3,000.00**	$ 9,000.00
	CREEK WORKS				
	-				
	LAND ACQUISITION				
	-				
	MISCELLANEOUS				
	CREEK MAINTENANCE WORK				

Table E - 2 Mitigation Option 2 Costing

Estimate Sheet

Clunes Flood Mitigation Works - Mitigation Option 2

22/08/12 Prepared by: ADV

Item No.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	AMOUNT
	LEVEE				
	HALF CRIB WALL LEVEE (180m section U/S of Camp St along the left bank)				
	Construction and compaction	**956**	m^3	**$20.00**	$ 19,120.00
	Topsoil (100mm)	**103.2**	m^3	**$17.00**	$ 1,754.00
	Reinforced concrete retaining wall (150mm thick) - average height 1.5m	**270**	m^2	**$477.00**	$ 128,790.00
	CONVENTIONAL EARTH BANK LEVEE (390m section D/S of Service St along the left bank)				
	Construction and compaction	**2360**	m^3	**$20.00**	$ 47,200.00
	Topsoil (100mm)	**308.6**	m^3	**$17.00**	$ 5,246.00
	HALF CRIB WALL LEVEE (270m section U/S of Service St along the left bank)				
	Construction and compaction	**1074**	m^3	**$20.00**	$ 21,480.00
	Topsoil (100mm)	**137.4**	m^3	**$17.00**	$ 2,336.00
	Reinforced concrete retaining wall (150mm thick) - average height 1.3m	**351**	m^2	**$477.00**	$ 167,427.00
	HALF CRIB WALL LEVEE (100m section along the southern boundary of the bowls club)				
	Construction and compaction	**506**	m^3	**$20.00**	$ 10,120.00
	Topsoil (100mm)	**51.9**	m^3	**$17.00**	$ 882.00
	Reinforced concrete retaining wall (150mm thick) - average height 1.6m	**160**	m^2	**$477.00**	$ 76,320.00
	CONVENTIONAL EARTH BANK LEVEE (155m section U/S of Service St along the right bank)				
	Construction and compaction	**760**	m^3	**$20.00**	$ 15,200.00
	Topsoil (100mm)	**104.1**	m^3	**$17.00**	$ 1,770.00
	ROADWORKS				
	RAISED SECTION OF FRASER ST (near Camp St)				
	Road crest raised by 450mm (including freeboard)				
	Crushed rock base course including grading, rolling and consolidating to receive paving	**85.5**	m^3	**$105.00**	$ 8,978.00
	Bituminious concrete paving (50mm thick)	**190**	m^2	**$26.00**	$ 4,940.00
	RAISED ROAD SECTION WEST OF SERVICE ST BRIDGE				
	Intersection raised by 500mm (excluding freeboard)				
	Crushed rock base course including grading, rolling and consolidating to receive paving	**135**	m^3	**$105.00**	$ 14,175.00
	Bituminious concrete paving (50mm thick)	**270**	m^2	**$26.00**	$ 7,020.00
	RAISED INTERSECTION EAST OF SERVICE ST BRIDGE				
	Intersection raised by 500mm (excluding freeboard)				
	Crushed rock base course including grading, rolling and consolidating to receive paving	**320**	m^3	**$105.00**	$ 33,600.00
	Bituminious concrete paving (50mm thick)	**640**	m^2	**$26.00**	$ 16,640.00
	RAISED SECTION OF LIGAR ST TO ACT AS LEVEE				
	Average height 1.2m - including freeboard				
	Crushed rock base course including grading, rolling and consolidating to receive paving	**1308**	m^3	**$105.00**	$ 137,340.00
	Bituminious concrete paving (50mm thick)	**1090**	m^2	**$26.00**	$ 28,340.00
	BRIDGEWORKS				
	SERVICE STREET BRIDGE RAISED BY 500mm				
	Raise bridge deck and install larger bearings. Bridge road deck to tie into raised intersection level.	**1**	ITEM		$ 400,000.00
	DRAINAGE				
	FLAP VALVES				
	Complete installation of flap valves on all drainage network outfalls. Install endwall and flap gate	**10**	No.	**$3,000.00**	$ 30,000.00
	CREEK WORKS				
	-				
	LAND ACQUISITION				
	5 LOTS UPSTREAM OF CAMP ST (2 occupied & 3 vacant lots)				
	Obtain 6.5m easement over private lots	**812.5**	m^2	**$50.00**	$ 40,625.00
	RELOCATE SECTION OF CARAVAN PARK	**2100**	m^2	**$50.00**	$ 105,000.00
	8 LOTS UPSTREAM OF SERVICE ST (7 occupied & 1 vacant lot)				
	Obtain 5.5m easement over private lots	**1375**	m^2	**$50.00**	$ 68,750.00
	SINGLE VACANT LOT NEXT TO BOWLS CLUB				
	Obtain 6.5m easement over vacant lot	**195**	m^2	**$50.00**	$ 9,750.00
	RELOCATE/RAISE FLOOR LEVEL AT 1A CAMERON ST				
	Raise floor level (1.25m) to the 50 year flood level without freeboard		ITEM		$ 25,000.00
	MISCELLANEOUS				
	CREEK MAINTENANCE WORK				

Table E - 3 Mitigation Option 1 Cost Summary

Works Description	Estimated Cost	Estimated Annual Maintenance Cost
Levees	$52,413	$786
Roadworks	$8,905	-
Bridgeworks	$0	-
Drainage	$9,000	$135
Creek Works	$0	$0
Miscellaneous - Creek Maintenance	-	$2,000
Sub-total 'A'	$70,318	-
'A' x Engineering Fee @ 15%	$10,548	-
Sub-total 'B'	$80,866	-
'B' x Administration Fee @ 9%	$7,278	-
Land Acquisition Cost 'C'	$0	-
C' x Administration Fee @ 1%	$0	-
Sub-total 'D'	$88,144	-
'A' x Contingencies @ 30%	$21,095	-
'C' x Contingencies @ 30%	$0	-
FORECAST EXPENDITURE	**$109,239**	**$2,921**

Table E - 4 Mitigation Option 2 Cost Summary

Works Description	Estimated Cost	Estimated Annual Maintenance Cost
Levees	$497,645	$7,465
Roadworks	$251,033	-
Bridgeworks	$400,000	-
Drainage	$30,000	$450
Miscellaneous - Creek Maintenance	-	$2,000
Sub-total 'A'	$1,178,678	-
'A' x Engineering Fee @ 15%	$176,802	-
Sub-total 'B'	$1,355,480	-
'B' x Administration Fee @ 9%	$121,993	-
Land Acquisition Cost 'C'	$249,125	-
C' x Administration Fee @ 1%	$2,491	-
Sub-total 'D'	$1,729,089	-
'A' x Contingencies @ 30%	$353,603	-
'C' x Contingencies @ 30%	$74,738	-
FORECAST EXPENDITURE	**$2,157,430**	**$9,915**

APPENDIX F DAMAGE ASSESSMENT METHODOLOGY

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

Bureau of Transport Economics (2001). Economic Costs of Natural Disasters in Australia. Report 103. Bureau of Transport Economics, Canberra.

CRES (1992). ANUFLOOD: A field guide, prepared by D.I. Smith and M.A. Greenaway, Centre for Resource and Environmental Studies, ANU, Canberra.

Department of Natural Resources and Mines (DNR) (2002). Guidance on assessment of Tangible Flood Damages. Queensland Department of Natural Resources and Mines, September 2002.

Middelmann-Fernandes, M.H. (2010). Flood damage estimation beyond stage-damage functions: an Australian example. *Journal of Flood Risk Management* 3 (2010): 88-96.

Reed Sturgess and Associates (2000). Rapid Appraisal Method (RAM) for floodplain management. May 2000. Report prepared for the Department of Natural Resources and Environment.

Before any stage damage curves from the literature were applied in the Clunes flood damage assessment they were adjusted to today's value by scaling using a ratio of today's CPI (June, 2011 CPI used because the June 2012 data was not yet available) and the CPI at the time of development of the stage-damage curve. A number of stage damage curves are included below, representing the value at the time of development (i.e. no CPI adjustment).

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

Table F - 1 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 F - 2 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 F - 3 ANUFLOOD Commercial Properties Cost Curve (Reproduced from DNR 2002)

	Small commercial properties (<186m²)					Medium commercial properties (186-650m²)					Large commercial properties (>650m²)*				
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	$1297L
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 $/m²

Table F - 4 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 F - 5 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 F - 6 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 F - 7 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

APPENDIX G SECOND COMMUNITY QUESTIONNAIRE

COMMUNITY QUESTIONNAIRE

For use in the finalization of the Clunes Flood Mitigation and Urban Drainage Plan.

North Central CMA and Hepburn Shire Council seek feedback from the Clunes community on mitigation options to reduce the risk of future flooding.

Please answer the following questions to the best of your knowledge.

1. Name, address and contact details

   ____

   ____

2. What are key assets/things to protect in Clunes?
   - ☐ Community buildings such as the pool, basketball courts and football oval/clubhouse.
   - ☐ Residential Houses.
   - ☐ Caravan park.
   - ☐ Commercial Businesses.

3. What level of protection would you like to see for Clunes?
   - ☐ Protection from a September 2010 event (1 in 25 year flood event).
   - ☐ Protection from a January 2011 event (1 in 50 year flood event).
   - ☐ Protection from a 1 in 100 year flood event.

4. What is your preferred flood mitigation option? Please number in order of preference.
   - ☐ MAJOR: Combination of eastern and western levee banks upstream and downstream of Service Street and an increase in Council bridge capacity. Protects majority of town from a 1 in 50 year flood event.
   - ☐ ITERATIONS: Combination of minor levee upstream of Service Street, with creek widening and raising of Service Street Bridge. Protects majority of town from a 1 in 50 year flood event.
   - ☐ MINOR: Combination of reinstatement of existing levee on eastern banks and minor levee on western banks to protect to a 1 in 20 year event.

5. Do you have any comment on the proposed mitigation options?

   ____

   ____

   ____

   ____

   ____

   ____

   ____

Twenty-seven questionnaires were returned to North Central CMA and the feedback was collated and summarised. In summary, more than half the respondents were not in support of any of the proposed mitigation options. Five responses strongly objected to the levees, though it is noted that three of which came from the same person who owns three properties in Clunes. A more detailed breakdown of the feedback is provided below.

What are key assets/things to protect in Clunes?

- Out of the 27 replies, 21 of the respondents considered protection to community buildings and residential houses as important for Clunes.
- Out of the 27 replies, 18 of the respondents selected protection for the Caravan Park and commercial businesses as important.
- It is noted that five respondents did not fill in this option

What level of protection would you like to see for Clunes?

The majority of respondents (9) wanted protection up to the 100 year ARI flood event, while six respondents selected protection up to the January 2011 event and five selected the September 2011 flood event. It is noted that seven respondents did not fill in this option.

What is your preferred flood mitigation option?

Seventeen responses received did not have any of the mitigation option boxes ticked. For the purpose of this exercise, it is assumed that these 17 respondents were not in favour of any of the mitigation options, as indicated by their comments.

Out of the remaining 10 respondents which selected an option(s), all 10 were in support of the minor levee option, 9 of the 10 supported the major levee option and 7 of the 10 supported the 'Iteration 9' option (levee/creek works). A summary of the support level for each option, based on the questionnaire feedback, is shown in Figure G - 1 below:

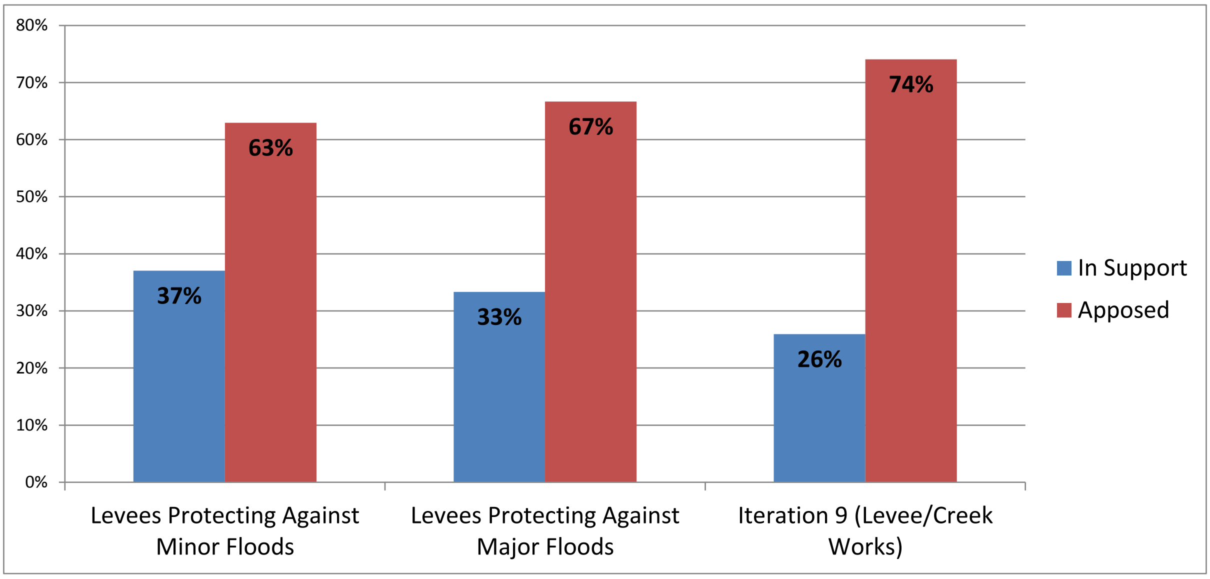


Figure G - 1 Preferred Mitigation Option Summary from the Third Community Questionnaire

Further comments on the proposed flood mitigation options

Levees

There were five strong objections to levees, three of which came from the same person who owns three properties in Clunes. These objections stemmed from:

- Concerns over the aesthetics of the levee devaluing property, being an eyesore to locals and deterring potential real estate buyers/investors;
- Impacts on tourism in Clunes by detracting visitors and associated loss of financial income;
- The levees causing more damage, chaos and distraction to the community and their family; and
- Loss of income to the operators of the caravan park.

Of those in support of the levees, three indicated that a levee bank should be located from the Purcell Street-Templeton Street intersection down to the Camp Street ford crossing. One respondent suggested extending the levee as far as Kilkenny Creek.

Singular comments regarding the levee include:

- Levees to protect as many houses and businesses as possible;
- Levees would not resolve the issue of water coming down the hill;
- The owner of 1A Cameron Street (Old Butter Factory) commented that each mitigation option reduces flooding on other properties but increases the impacts at her property;
- Revegetate earthen levees;
- Council to be responsible for levees; and
- Concerns with levee maintenance and redirection of water.

Creek Dredging

Four respondents suggested that the creek needs to be cleared of silt and gravel. One respondent recommended dredging from Purcell Street to beyond the ford, while another put forward clearing 200 meters below the ford up to the bowling club.

Improved Waterway Management (Vegetation Management)

In total, seventeen respondents indicated the need for improved waterway management. Of those seventeen, nine respondents indicated that the creek needs to be kept clear of suckers and weeds, while a further eight indicated that general maintenance, including removal of debris and clearing of the creek, is required. Four respondents proposed regular maintenance of the creek to clear out debris.

Improved Stormwater Drainage

Eight respondents suggested improvements to the stormwater drainage network including:

- General cleaning out and improvement of stormwater drains;
- Increasing the capacity of stormwater drains at end of Fraser Street, near the Camp Street ford;
- Improving stormwater drainage to reduce runoff on western side of creek (2 respondents);
- Improvements to the Templeton Street local drainage outlets to the creek. Flap valves would be useful to prevent backflows up the drain;
- Inadequate or no drainage along Fraser Street, Templeton Street or Purcell Streets. Needs addressing to divert stormwater runoff into the creek; and
- Two responders replied that the drains/gutters require ongoing maintenance or a maintenance/inspection program to ensure efficient operation.

Water Diversion/Storage Dams

Two responses recommended using water storage/diversion dams to remove the large quantities of water from the creek.

Increase the capacity of creek

Three responders suggested widening the creek at the lower end near the Camp Street ford and near the caravan park/football oval down to the ford.

Raised Floor Levels/Structures

One respondent indicated that permanent caravans and cabins should be raised and another recommend that property floor levels should be raised above flood levels. Another response suggested rebuilding the footbridge 1.5m higher than the previous bridge.

APPENDIX H HISTORICAL FLOOD ARTICLES