Natimuk Flood Investigation Study Report

January 2013

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PROJECT DETAILS

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MCA

Cover Photo: Flooding through Natimuk taken on Wednesday the 12th of January at 11.05am (Source: WCMA)

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GLOSSARY OF TERMS

Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare but it would be relatively large.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier 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	The 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

Following the December 2010 and January 2011 flood events, Water Technology was commissioned by the Wimmera CMA to undertake the Natimuk Flood Investigation. This included detailed hydrological and hydraulic modelling of Natimuk Creek and Little Natimuk Creek, flood mapping of the Natimuk township area, flood mapping of the entire upstream catchment, and also provided recommendations for flood mitigation works.

As part of the investigation the following reports were produced:

- Data Collation, Review and Model Scoping Report (19/01/2012)
- Survey and LiDAR analysis Memo (30/03/2012)
- Hydrology Report (18/05/2012)
- Preliminary Flood Mitigation Assessment Memo (23/05/2012)
- Hydraulics Report (19/06/2012)
- Flood Intelligence Report (01/10/2012)
- Flood Warning Recommendations Report (3/10/2012)
- Study Report (09/01/2013)

Natimuk is situated on the Wimmera Highway approximately 25 km to the west of Horsham. The township of Natimuk sits at the confluence of Natimuk Creek and Little Natimuk Creek, with Natimuk Creek continuing north and terminating in Natimuk Lake. Both Natimuk Creek and Little Natimuk Creek are ephemeral. Both have no available streamflow information upstream of the township, with minimal information available for Natimuk Creek at Natimuk Lake.

The township of Natimuk has a history of past flooding. Anecdotal evidence and discussions with local residents indicate that prior to the December 2010 and January 2011 floods, the last major flood event occurred in August 1981 for which no significant data is available.

The Flood Investigation was led by a Steering Committee consisting of representatives from Wimmera CMA, Horsham Rural City Council (HRCC), Department of Sustainability and Environment (DSE), Bureau of Meteorology (BoM), State Emergency Service (SES), Water Technology and the Natimuk community.

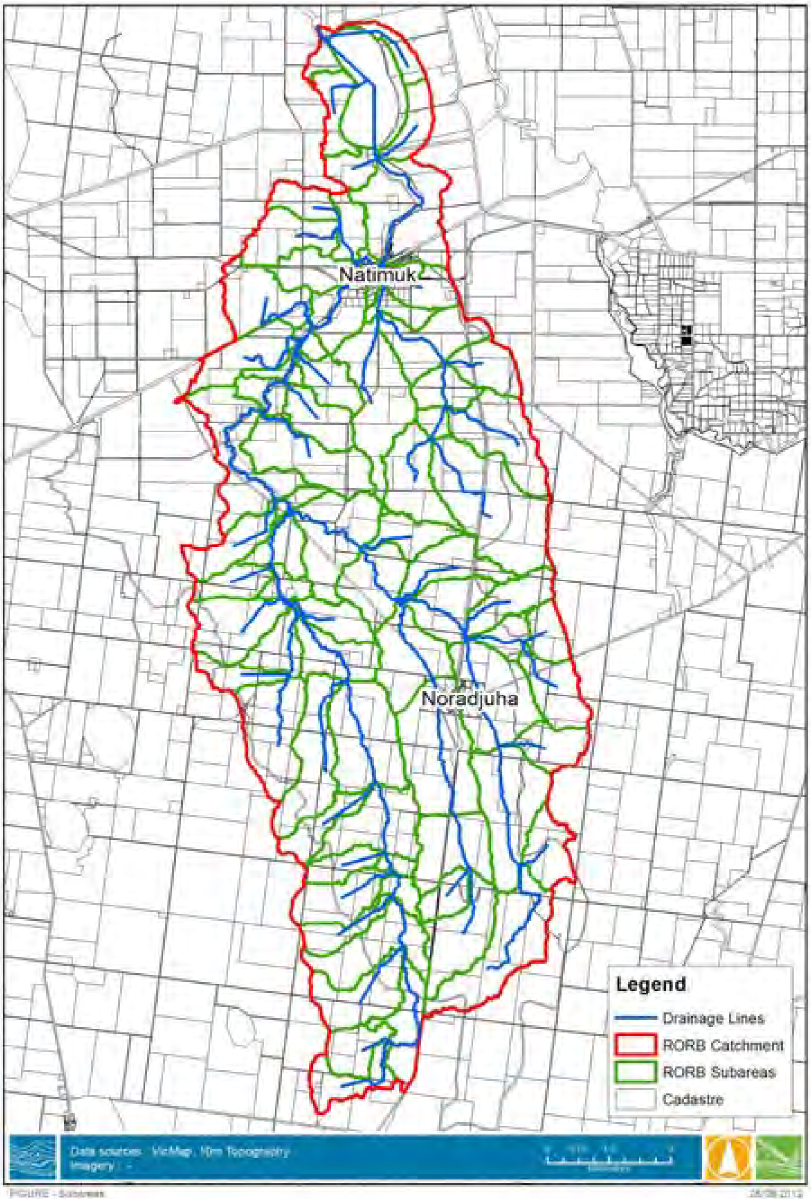
A key element in the development of the Natimuk Flood Investigation was the active engagement of residents in the study area. This engagement was developed over the course of the study through community consultation sessions, public questionnaires and meetings with the Steering Committee. The community consultation sessions were largely managed by the Wimmera CMA and Horsham Rural City 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 options for the township.

All community meetings were supported by media releases to local papers and meeting notices advertising meetings well in advance. The following community meetings were held as part of the consultation process:

- Initial community meeting, 12 December 2011 – The first public meeting was held to outline the objectives of the study to the community and to distribute the community questionnaire;
- Second community meeting, 11 July 2012 – 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, 7 November 2012 – The final community meeting presented the mitigation options that had been selected by the Steering Committee and sought comments from the community. Two major options were presented. Detail included in the Natimuk Flood Intelligence Study Report was also presented.

A hydrologic model of the catchment was developed for the purpose of extracting flows to be used as boundary conditions in the hydraulic model. The rainfall-runoff program, RORB, was utilised. A basic outline of the RORB model is shown below highlighting the Natimuk Creek catchment, RORB subareas and RORB drainage lines (reaches).



The RORB generated flows were input into a hydraulic model developed in DHI's (Danish Hydraulics Institute) MikeFlood. MikeFlood is linked 2D/1D hydraulic model used to replicate historic and design flood events using the physical attributes of the creeks, floodplain and hydraulic structures in the vicinity of Natimuk. The model was separated into 1D and 2D components, linked using standard links. The combined 1D/2D model was comprised of the following components:

- Little Natimuk Creek (1D) – from Browns Road to downstream of J Sudholz Road. This reach was schematised to represent the flow constriction caused by Browns and J Sudholz Roads.
- Natimuk Creek (1D) – Downstream of the Natimuk township to the outlet of Natimuk Lake. This reach was schematised to represent the storage and influence of Natimuk Lake. This allowed testing of various options regarding improving capacity in the downstream reach and understanding how the operation of Natimuk Lake impacts flood levels through town, a key question from the community.
- Hydraulic structures (1D) - The MIKE11 model was used to model flow through all major floodplain and drainage structures on Natimuk Creek and Little Natimuk Creek. The structures were dynamically coupled with the 2D model.
- Natimuk Creek (2D) – Downstream of J Sudholz Road to downstream of the Natimuk township. This reach was schematised to show the hydraulic impact of floodplain features and generate a representation of flood levels and extents for historic and design events.
- Little Natimuk Creek (2D) – Downstream of J Sudholz Road to the confluence of Natimuk Creek. This reach was schematised to show the hydraulic impact of floodplain features and generate a representation of flood levels and extents for historic and design events.

The basic hydraulic model schematisation is shown below.

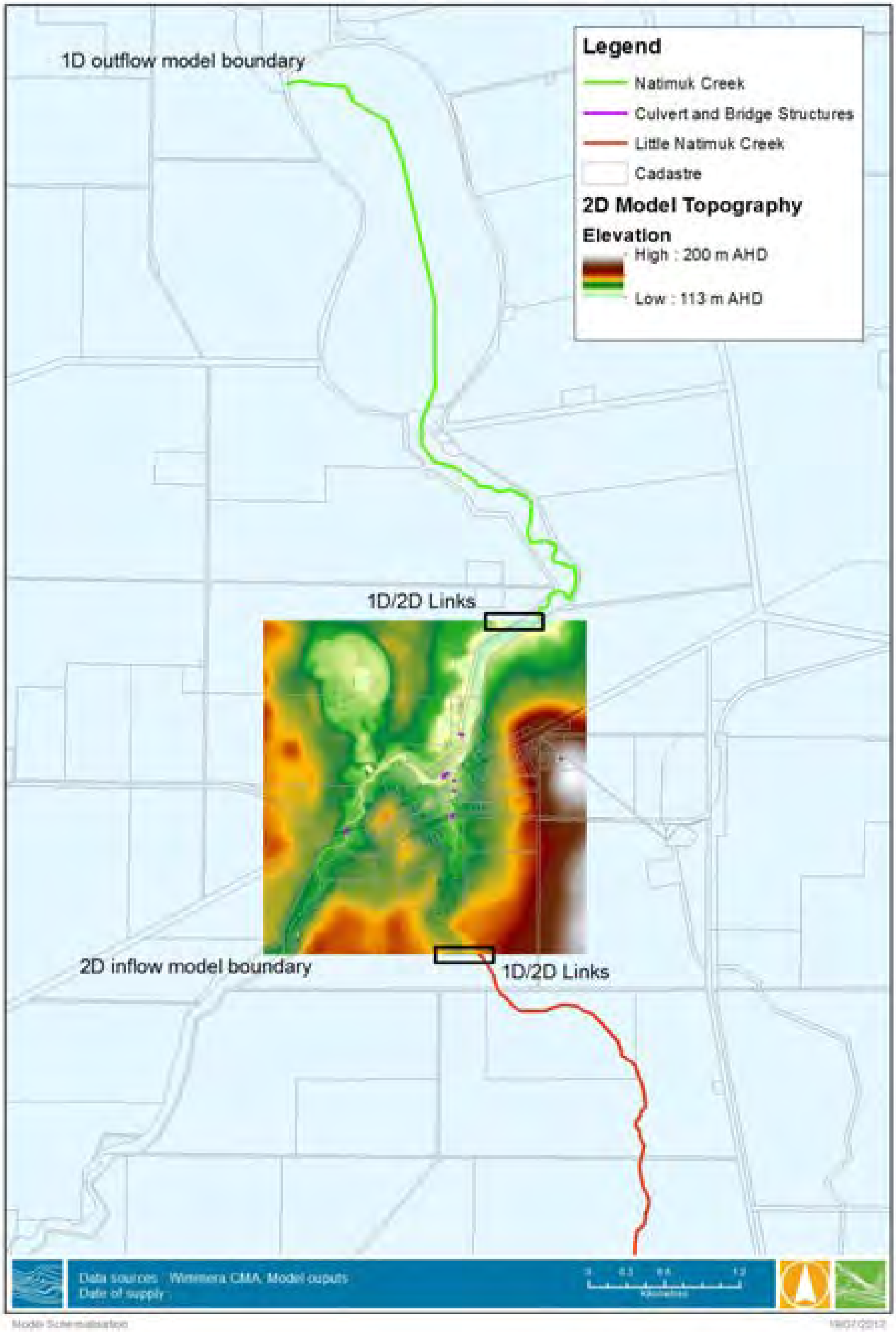
The hydraulic model was verified to observed events in January 2011 and December 2010. There was varying information available for each of these events. The information available included:

  - Aerial photography
  - Surveyed flood heights
  - Ground photography
  - Significant anecdotal evidence

Verification of the RORB model and hydraulic model was completed using a twostep approach. RORB predicted flows were trialled in the hydraulic model and assessed against the overall fit to calibration data. Once RORB flows resulted in the hydraulic model predicting water levels which broadly matched the calibration data, the hydraulic model was refined in localised areas to finalise the verification of the hydraulic model.

Once the RORB model and hydraulic model were verified as producing accurate predictions, a series of design events were modelled. The modelled events included 5, 10, 20, 50, 100 and 200 year ARI events and the PMF event.

As well as the detailed hydraulic model of Natimuk a whole catchment 'rainfall-on-grid' model was created. This model was run for the 100 year ARI event only and the purpose of the model was to generate a coarse 100 year ARI extent which the Wimmera CMA could use to assist in the planning referral process where they currently have a limited amount of data.


Legend
Natimuk Creek
Culvert and Bridge Structures
Little Natimuk Creek
Cadastre
2D Model Topography
Elevation
High : 200 m AHD
Low : 113 m AHD
1D outflow model boundary
1D/2D Links
2D inflow model boundary
1D/2D Links
Data sources : Wimmera CMA, Model ouputs
Date of supply

A series of structural flood mitigation options were assessed using the combination of a prefeasibility assessment and the verified hydraulic model. These mitigation measures were comprised of suggestions from the general public, members of the Steering Committee and Water Technology. The original list of structural flood mitigation options consisted of twelve options. The prefeasibility assessment narrowed this down to six which were assessed using the hydraulic model.

Post hydraulic modelling two final mitigation options were proposed, these were a levee on Elmes Street and a combined option, utilising a levee on Elmes Street, a levee on Lake Avenue and an increase to the existing bywash channel to the north (back) of properties on Lake Avenue.

A figure summarising these two options is shown below.

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. The benefit cost analysis for each option is shown below with comparison to the existing conditions.

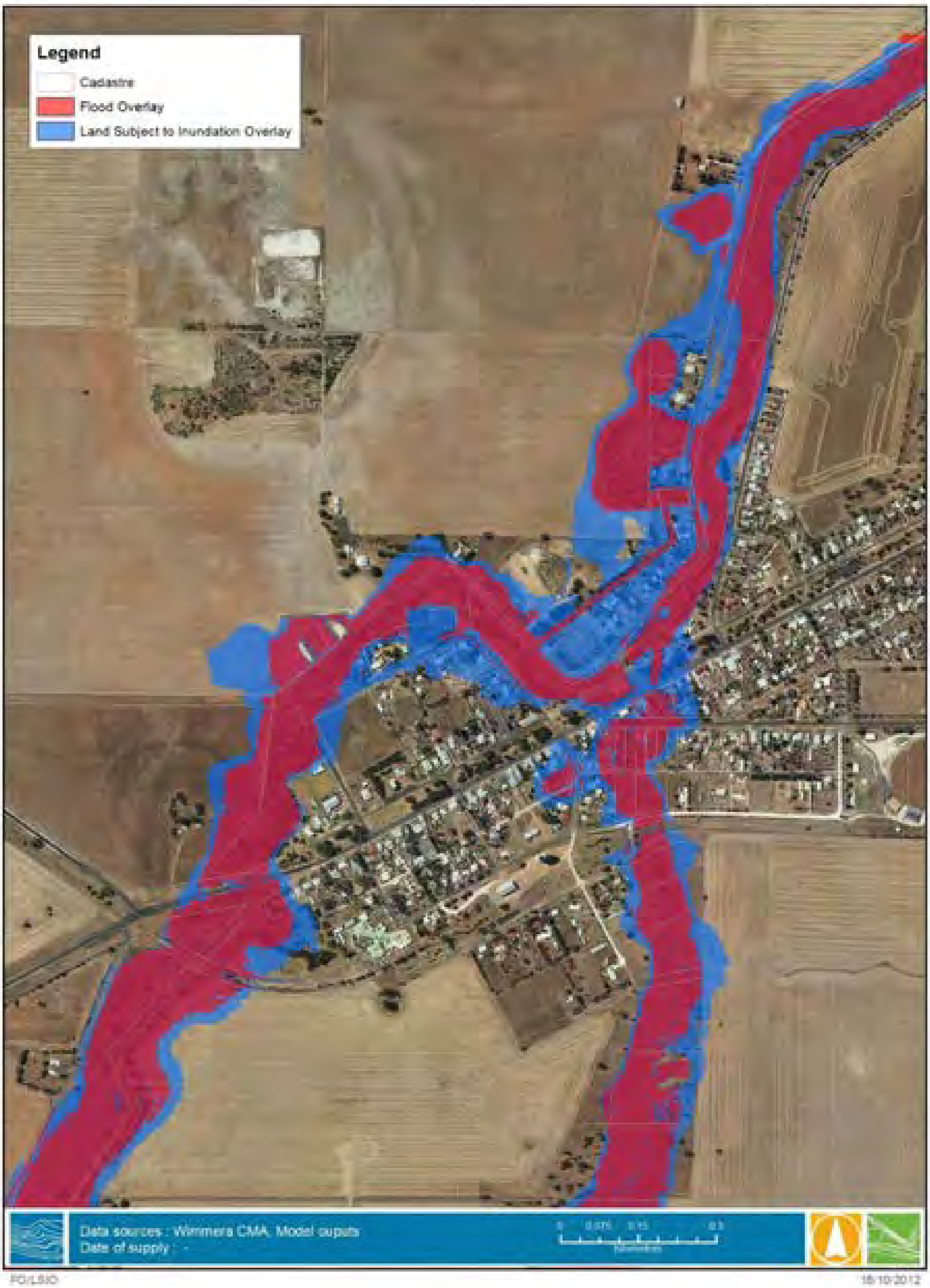
	Existing Conditions	Elmes Street Levee	Combined Mitigation Option 03b
Average Annual Damage	$37,252	$35,499	$27,861
Annual Maintenance Cost	-	$495	$4,932
Annual Cost Savings	-	$2,258	$4,459
Net Present Value	-	$31,753	$78,717
Capital Cost of Mitigation	-	$33,000	$449,192
Benefit-Cost Ratio	**-**	**0.96**	**0.14**

The Elmes Street Levee is a far more feasible than the Combined Mitigation Option 03b. The combined option does protect a much larger number of houses but the cost of its construction and maintenance far exceeds the potential annual damage savings

The two options have varying levels of community support with the Elmes Street levee seen as a less intrusive option. The majority of Natimuk residents are more concerned with the impact the options may have on their neighbours than protection of their own properties. The general community are most concerned with how the mitigation options may impact on the aesthetics of the township.

A number of non-structural mitigation options were also discussed, including land use planning, flood warning, flood response and flood awareness. The Victoria Planning Provisions (VPPs) contain a number of controls that can be employed to provide guidance for the use and development of land that is affected by inundation from floodwaters. These controls include the Floodway Overlay (FO), the Land Subject to Inundation Overlay (LSIO), the Special Building Overlay (SBO), the Urban Floodway Zone (UFZ) and the Environmental Significance Overlay (ESO).

The Natimuk Flood Investigation generated an LSIO and FO for the township of Natimuk, as shown below.



A range of recommendations were made for the community of Natimuk these include:

- The staged implementation of a flood warning system for Natimuk requiring two new rainfall gauges (one in the Little Natimuk Creek catchment and one in the Natimuk Creek catchment) and two new stream flow gauge boards to be installed (at the Wimmera Highway at both Natimuk Creek and Little Natimuk Creek).
- The flood warning system should be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system;

- It is recommended that a flood response plan be adopted into the Municipal Flood Emergency Plan and the community is engaged along with the responsible agencies (BoM, SES, HRCC, Wimmera CMA etc.) in developing appropriate actions.
- It is recommended that the planning scheme for Natimuk is amended to reflect the flood risk identified by this project; and
- It is recommended the Elmes Street levee option be submitted for funding for detailed design with further consultation with Elmes Street residents.

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1. INTRODUCTION

1.1 Background

Following the December 2010 and January 2011 flood events, Water Technology was commissioned by the Wimmera CMA to undertake the Natimuk Flood Investigation. This included detailed hydrological and hydraulic modelling of Natimuk Creek and Little Natimuk Creek, flood mapping of the Natimuk township area, flood mapping of the entire upstream catchment, and also provided recommendations for flood mitigation works.

As part of the investigation process there were several reporting stages to ensure the study was reviewed and approved by the study team and the Steering Committee. This report is the Study Report encapsulating all reporting stages of the Natimuk Flood Investigation, including the following staged reports:

- Data Collation, Review and Model Scoping Report (19/01/2012)
- Survey and LiDAR analysis Memo (30/03/2012)
- Hydrology Report (18/05/2012)
- Preliminary Flood Mitigation Assessment Memo (23/05/2012)
- Hydraulics Report (19/06/2012)
- Flood Intelligence Report (01/10/2012)
- Flood Warning Recommendations Report (3/10/2012)

All report stages are included within the body of this Study Report, except the Flood Intelligence Report which is included in Appendix F.

The Study Report is structured in a slightly different way to the traditional flood investigation, with the hydrologic and hydraulic models discussed together in three stages; model development, model verification, and design event modelling. This is due to the fact that no gauged streamflow exists for the Natimuk Creek catchment, so hydrologic modelling could only be verified by observed flooding (i.e. hydraulic model results) within Natimuk.

1.2 Study Area

Natimuk is situated on the Wimmera Highway approximately 25 km to the west of Horsham. The township of Natimuk sits at the confluence of Natimuk Creek and Little Natimuk Creek, with Natimuk Creek continuing north and terminating in Natimuk Lake. Natimuk Lake is managed by Parks Victoria and is used for recreation only.

Natimuk Creek flows through largely agricultural areas (dry land cereal and cropping) around Noradjuha and Nurrabiel before flowing through the township of Natimuk. Natimuk Creek and Little Natimuk Creek have catchment areas of approximately 114 km^2 and 25 km^2 respectively. The catchment of these waterways extending to downstream of Natimuk Lake is shown in Figure 1-1. Much of the infrastructure in this rural township is located on a floodplain. Natimuk was highlighted as an area of concern in the Wimmera Floodplain Management Strategy[1] and again in the Wimmera Region Flood Report[2] following flooding in early December 2010 and January 2011. Both reports recommended that a flood investigation should be carried out for Natimuk given the limited information currently available and the pressure on the town for development. The Wimmera Region Flood Report also described Natimuk as an area potentially subject to flash flooding and not covered by a formal flood warning system.

[1] Wimmera CMA (2001), Wimmera CMA Floodplain Management Strategy
[2] Water Technology (2011), Wimmera Region Flood Report – January 2011, Wimmera CMA

Both Natimuk Creek and Little Natimuk Creek are ephemeral. Both have no available streamflow information upstream of the township, with minimal information available for Natimuk Creek at Natimuk Lake, consisting only of a water quality gauge with nine spot level readings across April 2006 to October 2007.

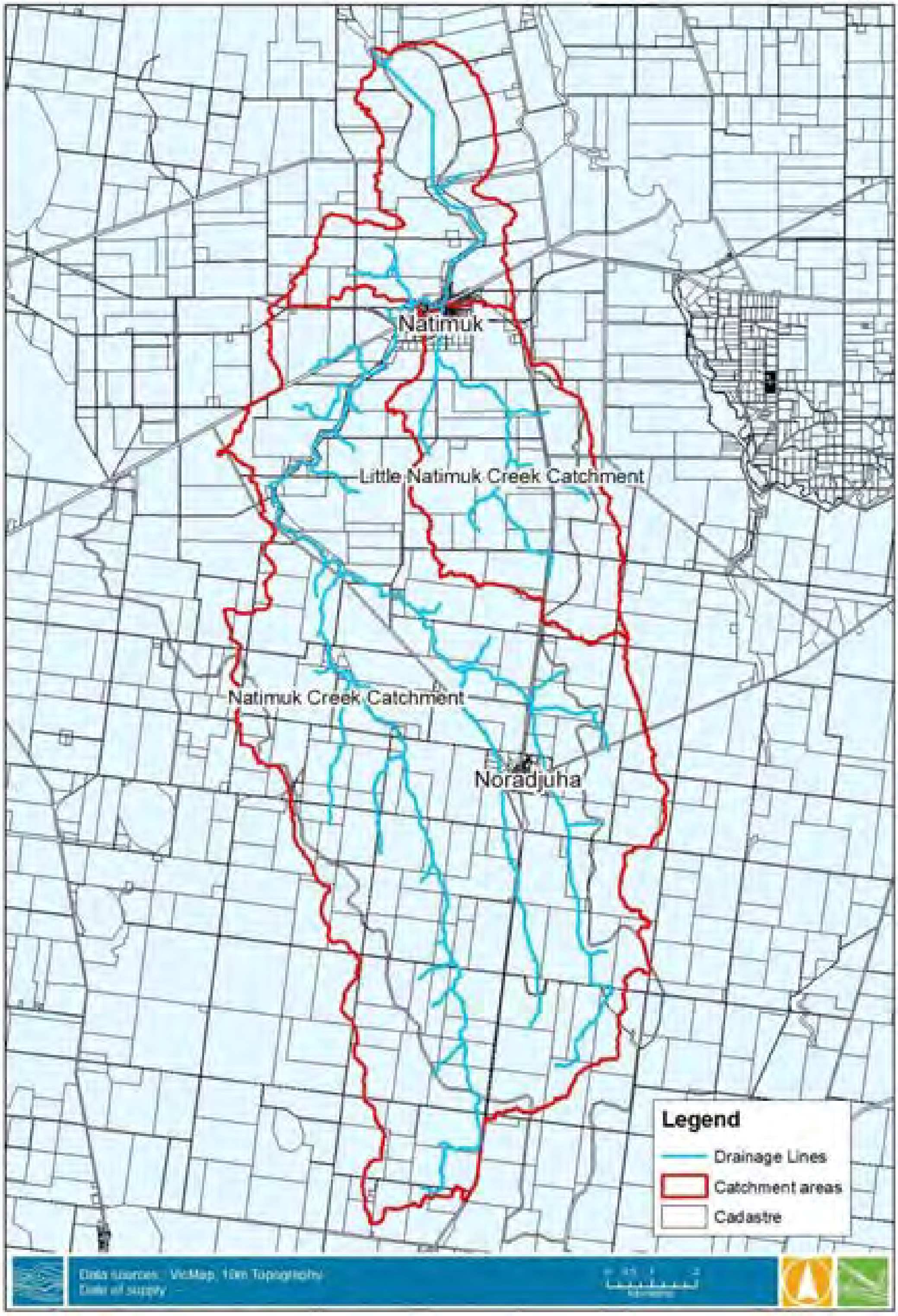

Figure 1-1 Natimuk Creek and Little Natimuk Creek catchment

2. DATA COLLATION AND REVIEW

2.1 Site Visit

Two site visits were undertaken by Water Technology on 21st November 2011 with a representative from the Wimmera CMA (Abdul Aziz); and on the 12th December 2011, prior to the initial steering and community meetings.

During both site visits, Natimuk Creek and Little Natimuk Creek were not flowing, with some water ponding in deeper pools of Natimuk Creek. Due to the relatively small township, both waterways were able to be investigated on foot for the expected hydraulic model extent. The upper catchment areas were explored during the second site visit by car, prior to the initial steering committee and community meetings. During both site visits a number of photos were taken of the Natimuk Creek, Little Natimuk Creek, drainage structures, floodplain features and the general floodplain. These photos are shown in Appendix G. The dimensions of all structures located along both creeks were roughly surveyed using a tape measure measuring back to the road deck. These field measurements were used in combination with feature survey as part of the hydraulic model development.

2.2 Current Planning Scheme

Natimuk Creek and Little Natimuk Creek through Natimuk are currently covered by a Land Subject to Inundation Overlay (LSIO) within the Horsham Rural City Council planning scheme. This overlay was developed based on geological mapping and orthophotos, as shown below in Figure 2-1. The January 2011 flooding resulted in a significantly greater extent of inundation than that of the LSIO.

Figure 2-1 Current Land Subject to Inundation Overlay for Natimuk

2.3 Historical Flooding

The township of Natimuk is situated on a floodplain and has a history of past flooding. Anecdotal evidence and discussions with local residents indicate that prior to the December 2010 and January 2011 floods, the last major flood event occurred in August 1981 for which no significant data is available.

The recent January 2011 flood event is thought to be the largest flood event in Natimuk in living memory. Records indicate that flooding historically occurs over the spring/summer period, corresponding to periods of heavy rainfall as indicated by the Bureau of Meteorology (BoM) records shown in Table 5-1 later in this report.

Figure 2-2 below shows the mean and median monthly rainfall totals for the entire length of record at the Natimuk rainfall gauge. The wettest months are largely in winter with June, July and August recording the highest mean values. The large difference between the mean and median monthly rainfall totals is an indication of the occurrence of extreme events, as they will statistically have a greater impact on the mean than the median. Larger differences between the mean and median monthly rainfalls are observed in the months of December, January and February, indicating those months have witnessed a greater proportion of extreme events.

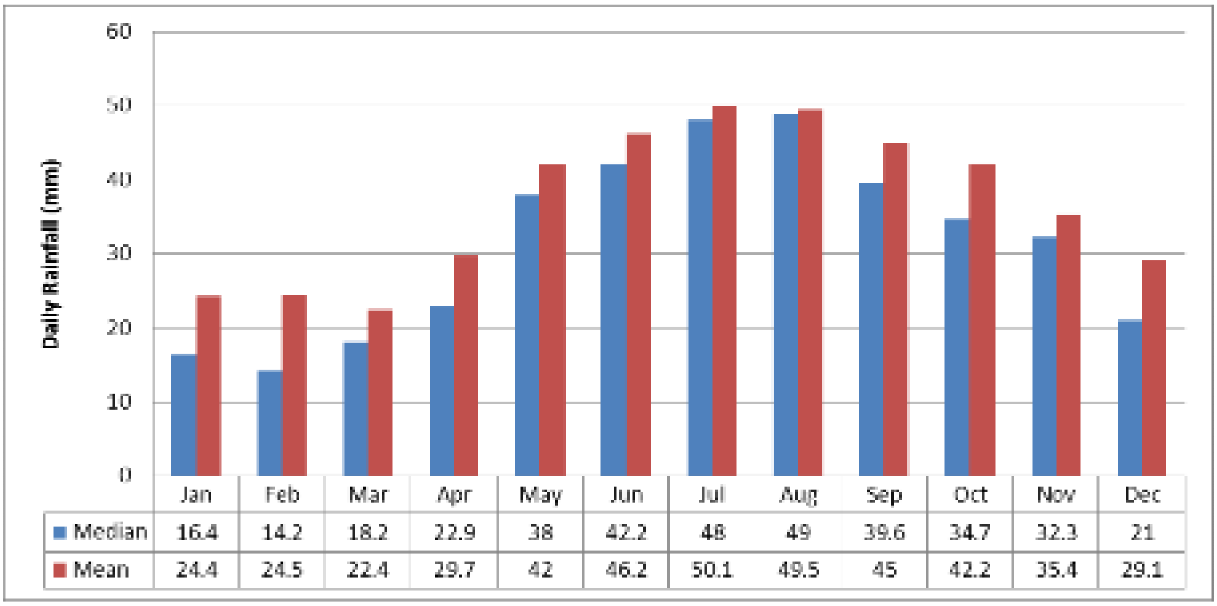

Figure 2-2 BOM historical rainfall records for the Natimuk Rainfall gauge (BOM, 2011)

2.3.1 December 2010

Rainfall

The December 2010 event was relatively isolated with no other townships within the Wimmera region experiencing flooding of the nature witnessed in Natimuk. The Longerenong pluviograph indicated the highest intensity rainfall occurred at approximately 1.00pm on Monday 6th December. The event was very short with the gauge record indicating more than 40% of the total rainfall depth fell in 2 hours.

Over a three day period up to 9am on the 8th of December 2010, between 56 and 125 mm of rainfall was recorded at surrounding gauges. A distribution of rainfall depths over the 3 day period is shown in Figure 2-3.

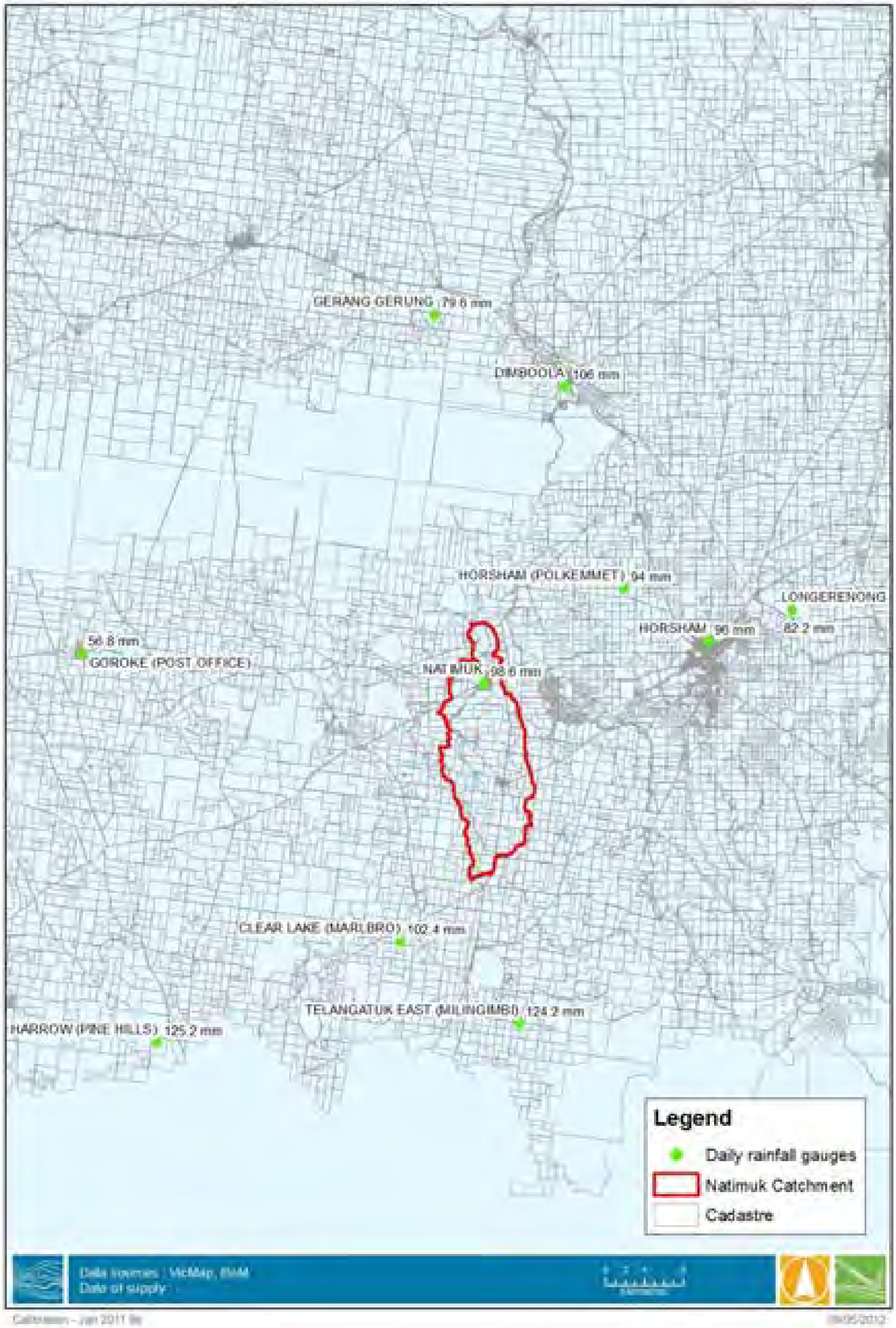

Figure 2-3 December 2010 rainfall totals (cumulative 3 day total to 9am 8th December 2010)

Flooding

Natimuk Creek began flooding soon after the rainfall with very little warning. Although there were no buildings flooded above floor level, many homes were inundated below floor level and one home was evacuated. Water did not overtop the Main Street in Natimuk but several smaller roads within Natimuk were inundated.

During the initial community meeting a survey was distributed to attendees, the survey was also available at the Natimuk Post Office. As there were no surveyed heights of the December flood event anecdotal evidence was collated from the community. The responses confirmed that the December 2010 flood event was 20-60 cm lower than the January flood event.

2.3.2 January 2011

Rainfall

The January 2011 rainfall event was widespread with record rainfall totals falling across Victoria. Heavy rainfall began on Tuesday 11th January 2011 at around 10 pm. The Horsham pluviograph indicated the highest intensity rainfall occurred at 6.26am Wednesday morning. Record daily rainfall totals were recorded at the Horsham (Polkemmet Rd), Clear Lake, Telangatuk East (Milingimbi), Kanagulka and Horsham (Aerodrome) gauges. Natimuk experienced high rainfalls in the 24 hours prior to 9am on the 12th and 14th of January. Figure 2-4 shows the daily totals recorded at 9am on the 12th of January 2011.

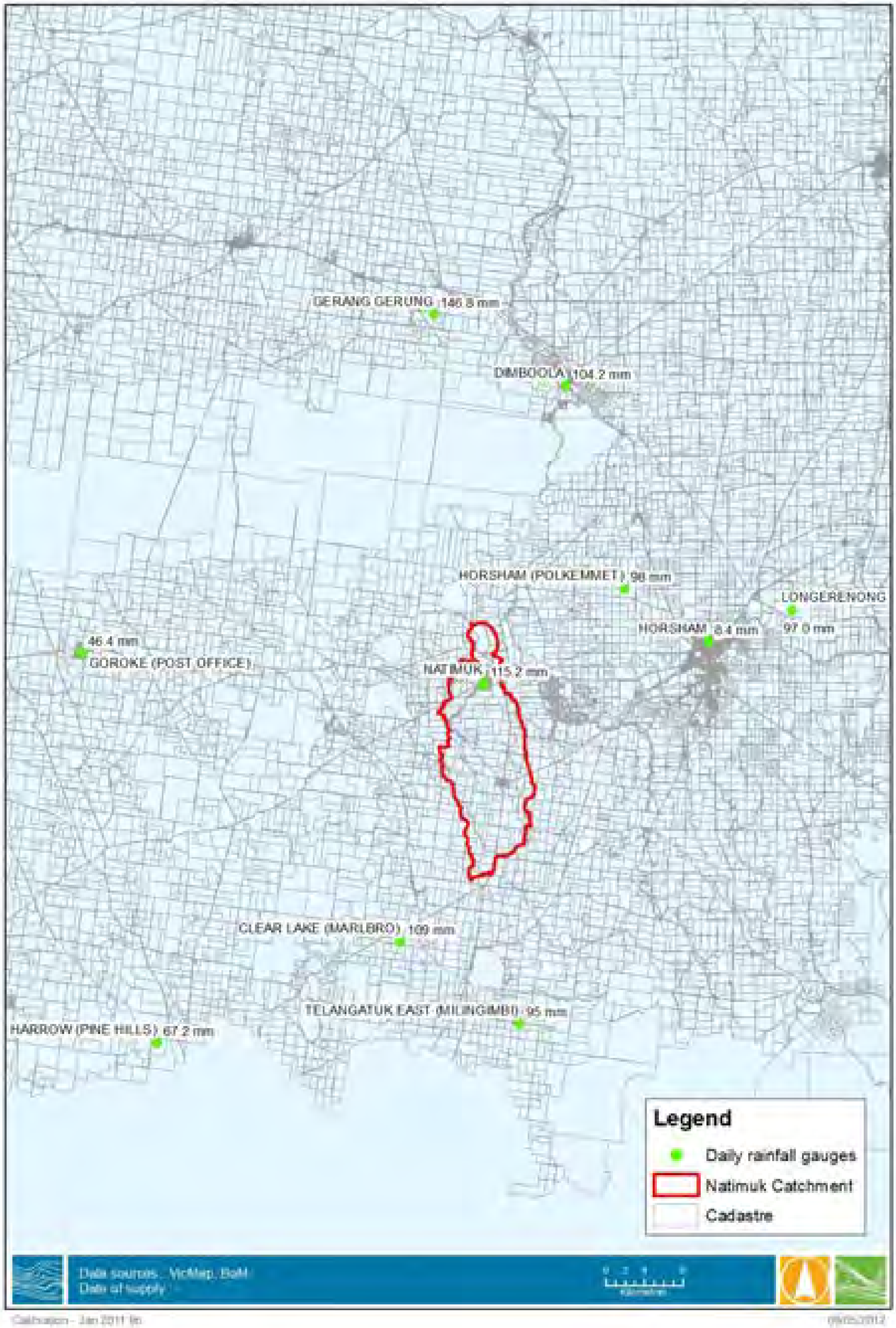

Figure 2-4 January 2011 rainfall totals (cumulative 3 day total to 9am 8th December 2010)

Flooding

Natimuk Creek began to flood around 7am on Wednesday 12th January; around 9 hours after rainfall began. Water levels continued to rise and peaked at approximately 2pm, after which they began to recede. Twelve homes were evacuated during the event with a total of 21 buildings were reported to be inundated above floor level within the township[3], since this initial assessment residents have highlighted some buildings were inundated below floor with sheds on the property inundated above floor. The flood-affected properties were located in Lake Avenue, Elmes St, Wimmera Highway, Depot Lane and Jory Street. Figure 2-5 below shows an aerial view of Natimuk with the flood affected properties originally identified. Figure 2-6 shows an aerial photo of the flooding at Natimuk taken on Wednesday 12th January at 11.05am.

Figure 2-5 Natimuk township, showing properties flooded above floor (Wimmera CMA)[3]

Figure 2-6 Flooding though Natimuk taken on Wednesday the 12th of January at 11.05am (Wimmera CMA)

[3] Wimmera Region Flood Report – January 2011, Water Technology 2011

2.4 Survey Data

Components of this study are based on topographic Light Detection And Ranging (LiDAR) data. As part of the investigation the LiDAR data was verified against feature survey data. Analysis was undertaken to verify the levels predicted by the LiDAR against feature survey to ensure its accuracy for input to the hydraulic model.

Three sources of topographic/survey data were obtained to prepare the hydrological and hydraulic models used in the Natimuk Flood Investigation:

- Vicmap Elevation DTM (a raster representation of Victoria's elevation at a 10 m grid resolution as provided by the Department of Sustainability and Environment)
- Field survey (undertaken by Ferguson and Perry Surveying)
- LiDAR data sets, flown in 2004 and 2011 (provided by the Wimmera CMA)

2.4.1 Field Survey

Key hydraulic structure information along Natimuk Creek and Little Natimuk Creek was required for input into the hydraulic model. Some information on these structures was provided by VicRoads and the Horsham Rural City Council. Others were unavailable and were surveyed. Figure 2-7 shows the location of the key waterway structures in the Natimuk township. Table 2-1 shows the details of the structures, and source of the data. Field survey was also required to confirm the reliability of LiDAR data.

Figure 2-7 Key hydraulic structures through Natimuk

Table 2-1 Details of key hydraulic structures in Natimuk

Waterway	Crossings	Structure Details	Data Source	Structure
Natimuk Creek	Wimmera Highway	Wide span two culvert	FP Survey	01
	Lake Avenue	Single pier road bridge	HRCC	02
Little Natimuk Creek	Railway Line	Six pipes	FP Survey	03
	Jory Street	Three pipes (Two sizes)	FP Survey	04
	Wimmera Highway - Road	Three culvert road	VicRoads	05
	Wimmera Highway - Pedestrian	Three culvert pedestrian	HRCC	06
	Foot Bridge	Wooden foot bridge	HRCC	07
Drainage Line 01	Lake Avenue	Single culvert pedestrian	FP Survey	08

2.4.2 LiDAR Data

LiDAR Coverage

Two LiDAR data sets were available for the Natimuk Flood Investigation. These were flown in 2004 and 2011. The 2004 LiDAR covers the entire Natimuk Creek catchment, while the 2011 LiDAR does not cover parts of the upper catchment. Figure 2-8 shows the coverage of both LiDAR data sets. The 2011 LiDAR data covers Natimuk and the immediate surrounds, and was used in the construction of the Natimuk hydraulic model.

A larger hydraulic model covering the entire Natimuk Creek catchment was created by combining both LiDAR data sets.

The stated accuracy of each of the data sets is shown below in

Table 2-2. The stated accuracy of the data puts it within the requirements of the Natimuk Flood Investigation.

Table 2-2 LiDAR data stated accuracy and coverage

	2011 LiDAR	2004 LiDAR
Vertical Accuracy	±0.10m (68% Conf.) on bare earth	±0.15m to 1 sigma
Average horizontal point spacing	1.8 pts/m	2.5m
Coverage	Parts of the Wimmera River, Natimuk Creek, Mackenzie River, Norton Creek, Dunmunkle Creek, Wattle Creek, Howard Creek, Concongella Creek, floodplain near Natimuk Horsham, Navarre, Landsborough and Rupanyup	WCMA extent, excluding the Wimmera River floodplain (Jeparit to Glenorchy), Yarriambiack Creek Floodplain surrounding Warracknabeal

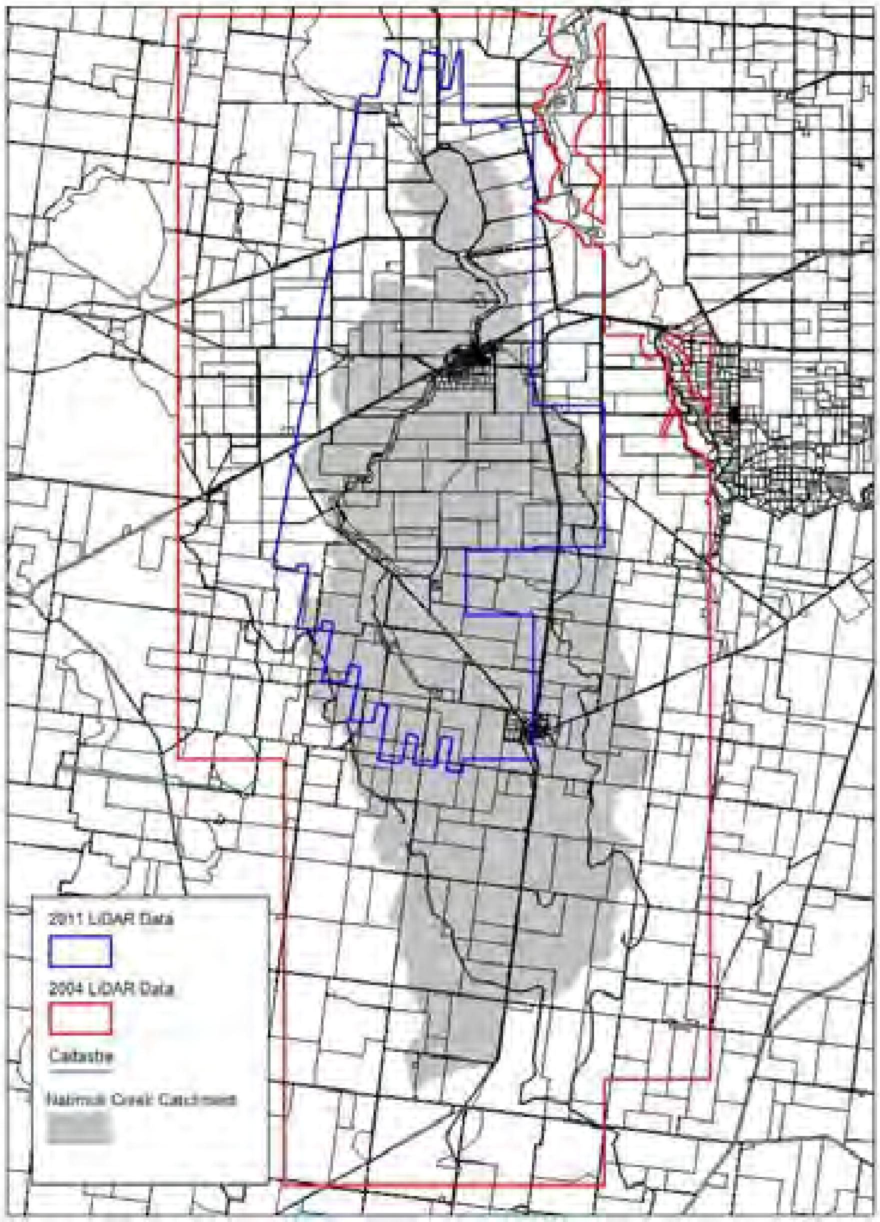

Figure 2-8 2004 and 2011 LiDAR data coverage

Survey Comparison

A comparison of the two LiDAR data sets and field survey was undertaken to ensure the different survey datasets were consistent. Two transects were surveyed along Station Street and Lake Avenue. These roads were chosen as they are relatively flat and have no camber. The LiDAR was then compared to the two surveyed transects. Figure 2-9 shows the locations of comparison. The extracted transects are shown below in Figure 2-10 and Figure 2-11.

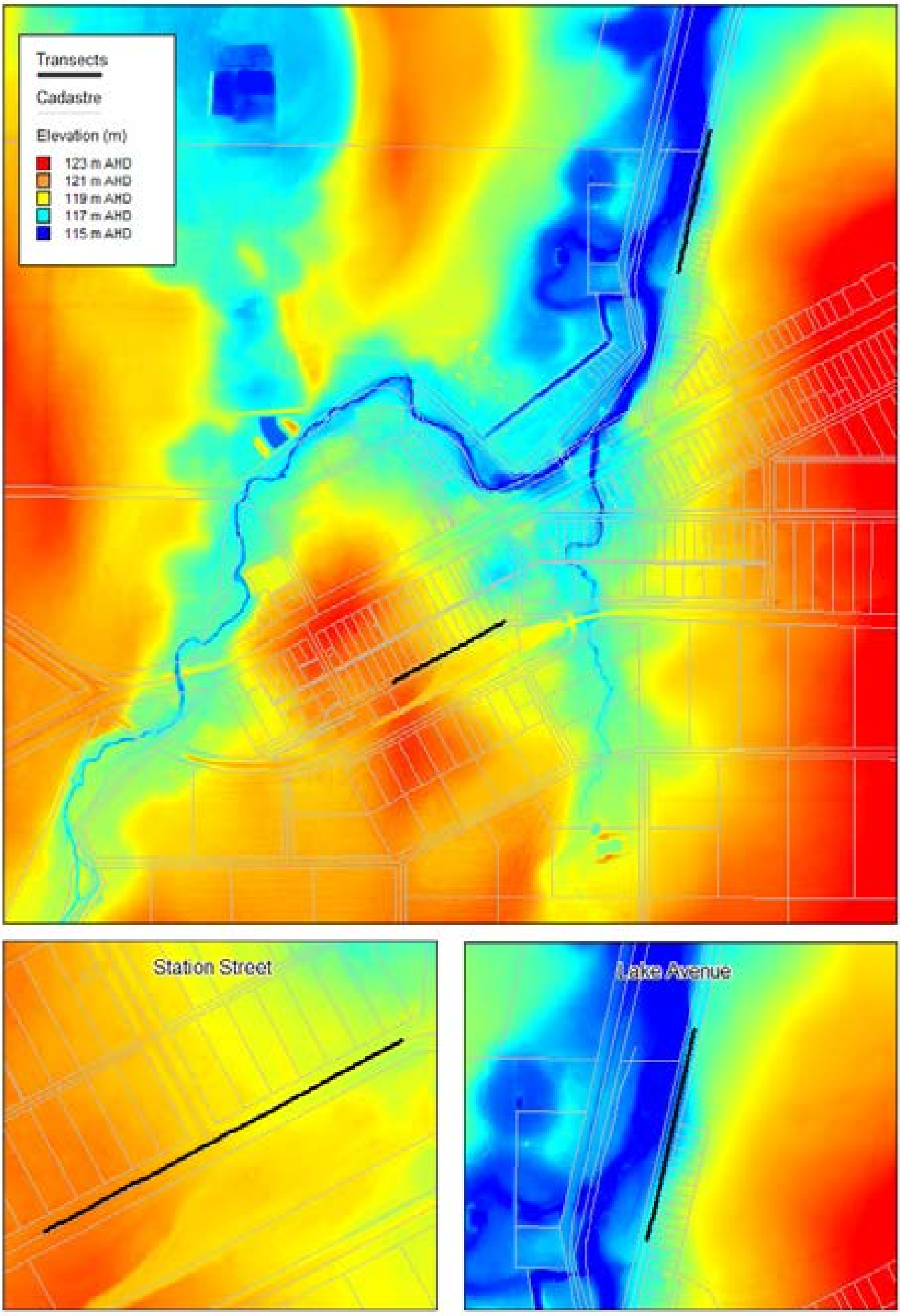

Figure 2-9 Locations of surveyed transects

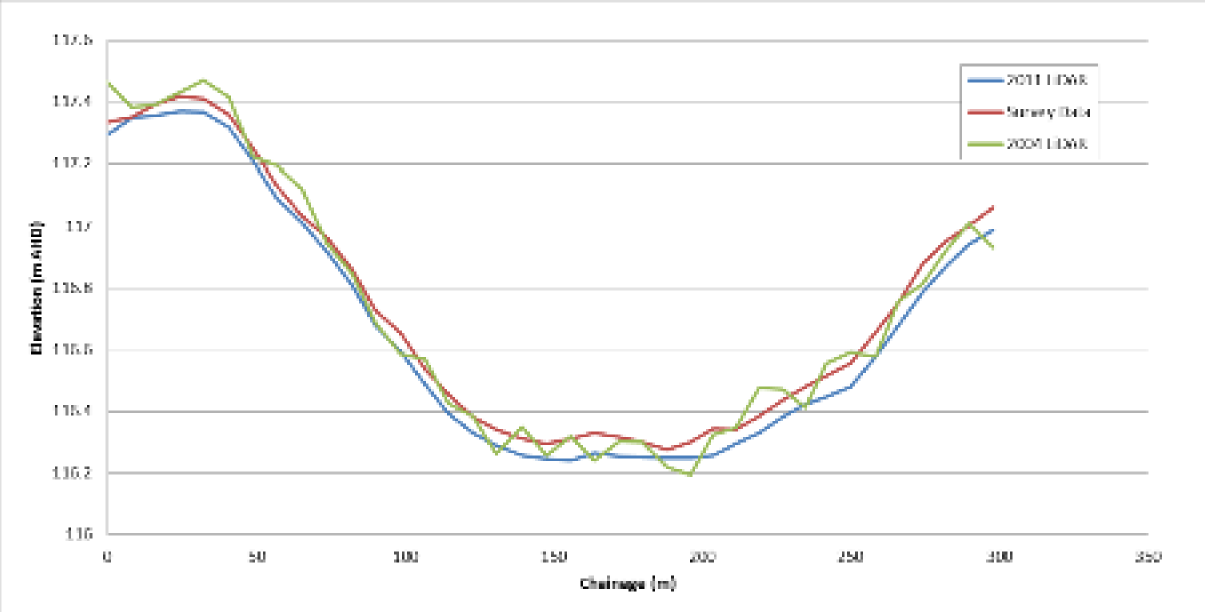

Figure 2-10 Lake Avenue survey comparison transect

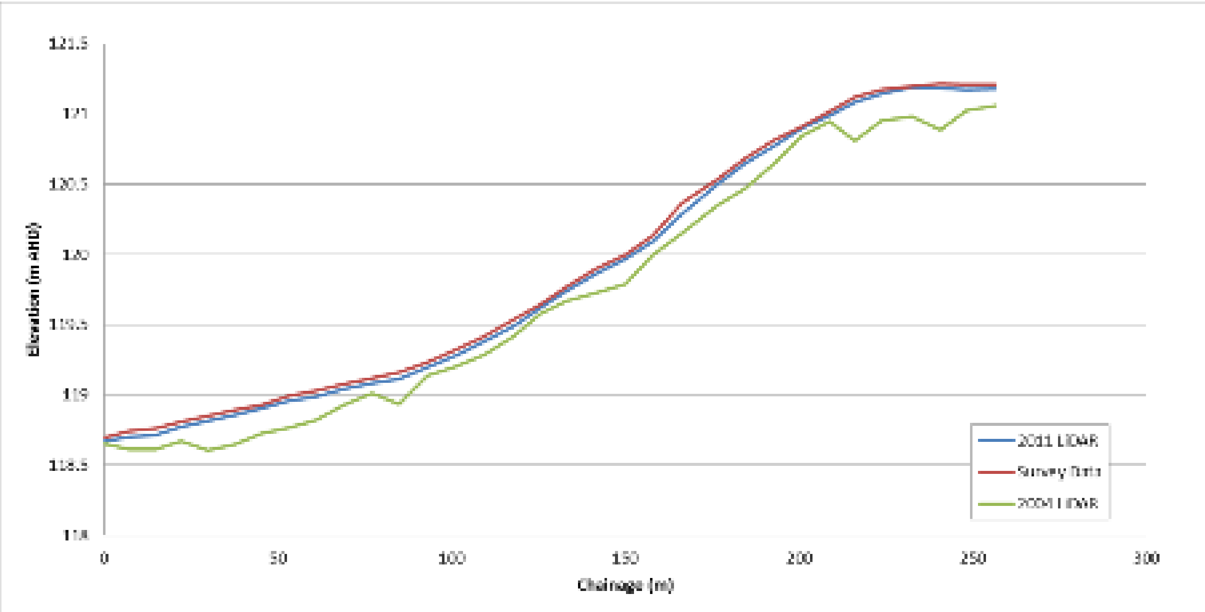

Figure 2-11 Station Street survey comparison transect

In both comparison transects the 2011 and 2004 LiDAR data was slightly lower than the surveyed data. The 2011 LiDAR was also much smoother than the 2004 LiDAR. These differences have been observed in other LiDAR comparisons, and are a result of improved LiDAR capture and processing between the two LiDAR capture projects. Statistics extracted from survey points taken at each transect are shown below in

Table 2-3.

Table 2-3 LiDAR and field survey comparison statistics

Difference Statistics	LiDAR minus field survey	
	2011 LiDAR	2004 LiDAR
Mean (m)	-0.045	-0.081
Standard Dev. (m)	0.018	0.102
Median (m)	-0.043	-0.068
Min. (m)	-0.092	-0.327
Max. (m)	-0.003	0.128

The comparison of both LiDAR data sets and the survey data showed a small negative mean difference as compared to the field survey. Both data sets are within their error bounds at ±0.1 m and ±0.15 m for the 2011 and 2004 data respectively.

The small range between the maximum and minimum difference and the small standard deviation in difference for the 2011 LiDAR highlights the smoothness or consistency of the 2011 LiDAR data as opposed to the 2004 LiDAR.

To assist in understanding the spatial variance between the two LiDAR data sets, a comparison of the two surfaces was made by subtracting the 2004 topography from the 2011. In areas where the 2011 LiDAR is higher than the 2004 LiDAR a positive value was the result. Figure 2-12 below shows a comparison of the two LiDAR grids approximately covering the Natimuk area. There were several areas of obvious difference due to the time of year the data was collected. Private water storages were fuller in the 2011 LiDAR, with the lower end of Natimuk Creek also returning higher values in the 2011 LiDAR. Crops also appear to be at a later stage in the growing cycle and appear higher in the 2011 LiDAR. The LiDAR data is processed to remove vegetation and other non-ground heights using ground survey points but in the case of low, dense vegetation this can be difficult. Water is unable to be censored from the data.

Another obvious non-environmental difference in the two LiDAR datasets is clearly shown in Figure 2-12 with the presence of banding. This banding is a known issue in earlier LiDAR products and has been observed by the authors across numerous other LiDAR datasets. The banding occurs during the processing of the various flight swaths. The new LiDAR does not appear to have the same banding issue.

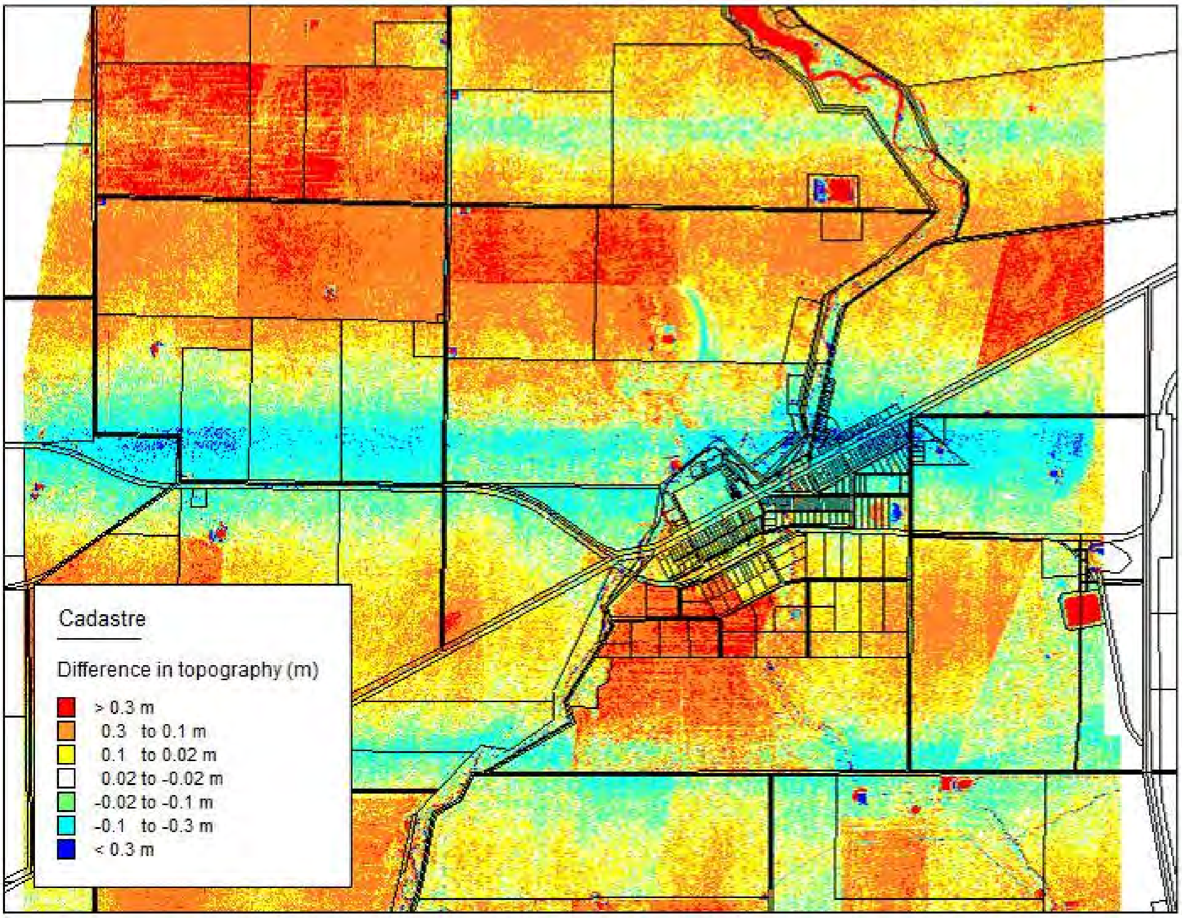

Figure 2-12 Difference plot of 2011 LiDAR minus 2004 LiDAR

Statistics extracted from the comparison of the two LiDAR datasets is shown below in Table 2-4. The minimum and maximum differences between the grids are likely to be a result of the presence or absence of water in private storages or localised earthworks. On average the 2011 LiDAR is slightly higher than the 2004 LiDAR.

Table 2-4 LiDAR comparison statistics

Difference Statistics	2011 minus 2004 LiDAR
Mean	0.072
Standard Dev.	0.149
Median	0.073
Min	-3.200
Max	3.450

The LiDAR data flown in 2011 was shown to meet the stated accuracy requirements of the study and was determined as adequate for use in the Natimuk Flood Investigation. Similarly the 2004 LiDAR was also considered to be adequate for use in the study. The 2011 LiDAR was used in preference and covers the entire hydraulic model study area. The 2004 LiDAR was used only for modelling the upper catchment for mapping of the 100 year ARI flood extent along the major waterways.

2.5 GWMWater Channel Infrastructure

There are two major channels present in the Natimuk catchment, the Natimuk Channel and the Natimuk Offtake Channel.

Natimuk Channel was used prior to the construction of the Wimmera Mallee Pipeline and historically passed water into the Natimuk Creek catchment. At the time of the study this channel was due to be filled in during GWMWater's Channel Decommissioning Project.

Discussion with GWMWater confirmed the channel can contribute flow to Little Natimuk Creek during a flood, however this flow is fairly minor and is directed to the previously used storages, and is unlikely to impact on Little Natimuk Creek flood flows[4].

The Natimuk Offtake Channel transfers water across from the Little Natimuk Creek catchment to the Natimuk Creek catchment; it also intersects with Little Natimuk Creek, as shown in Figure 2-13.

[4] GWMWater - Pers. Comm. Peter Cooper (2010)

Figure 2-13 The Little Natimuk Creek and Natimuk Offtake Channel intersection

The intersection between Little Natimuk Creek and Natimuk Offtake Channel was modelled in 2D to determine its influence on Little Natimuk Creek flows. Using the preliminary estimates of the January 2011 event the model showed that the channel may convey approximately 0.1 m^3/s of an estimated peak flow of 36.8 m^3/s in Little Natimuk Creek. The Natimuk Offtake Channel was considered insignificant in terms of impact on flood flows.

2.6 Storages

2.6.1 Natimuk Lake

Natimuk Lake is the only recognised water body located in the Natimuk Creek Catchment as shown in Figure 2-14. Natimuk Lake is currently managed by Parks Victoria but was previously managed by the Shire of Arapiles and the Horsham Rural City Council. The lake is also managed by the Natimuk Lake Foreshore Committee. Management of the Natimuk Lake weir is the responsibility of Parks Victoria. Currently this occurs informally and at a local level with staff at the Natimuk Parks Victoria office removing weir boards when it is deemed appropriate. This study has shown there is no necessity for board removal for protection of the Natimuk township.

Natimuk Lake is located approximately 3.5 km downstream of the township and therefore is unlikely to have any impact on flooding within the town. This was tested using the hydraulic model and is discussed later in the report.

There are a number of smaller water bodies located along tributary reaches within the study area. These storages are too small to have a significant impact on the flows in Natimuk Creek and Little Natimuk Creek and were therefore not considered in the hydrological modelling.

Figure 2-14 Location of Natimuk Lake downstream of Natimuk (DSE, 2012)

A privately owned low depression exists to the north west of town and is currently leveed off from Natimuk Creek. The low depression currently receives inflow from the local catchment only. The depression would fill during floods with overflows from Natimuk Creek if the levee was not in place, and would remain full after the flood receded, unable to drain. The depression is currently used for agricultural purposes.

2.7 Other Background Data

A large number of geo-referenced aerial photographs flown during the January 2011 event were provided by the DSE, these were used to assist in calibrating the hydraulic model to the January 2011 flood event.

Surveyed flood levels were also provided by the Wimmera CMA at 25 locations though the township; these were used during the calibration process.

Other background data available for the study included:

- Numerous photos of the flood events including aerial imagery of the January 2011 flood;
- Video of the September and January flood event;
- Floor level survey of a number of properties in town; and
- Cadastral information sourced from DSE.

This data was used in model set-up, calibration and result presentation. Data without a confirmed data and time was difficult to use as whether or not the peak level was captured is unknown.

The floor level survey was commissioned during the investigation; this survey was used for assessing damages and determining the viability of mitigation measures via a cost benefit analysis.

3. PROJECT CONSULTATION

3.1 Overview

A key element in the development of the Natimuk Flood Investigation was the active engagement of residents in the study area. This engagement was developed over the course of the study through community consultation sessions, public questionnaires and meetings with a Steering Committee containing several members of the community. The community consultation sessions were largely managed by the Wimmera CMA and Horsham Rural City 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 options for the township.

3.2 Steering Committee and Technical Working Group

The Flood Investigation was led by a Steering Committee consisting of representatives from Wimmera CMA, Horsham Rural City Council (HRCC), Department of Sustainability and Environment (DSE), Bureau of Meteorology (BoM), State Emergency Service (SES), Water Technology and the Natimuk community. Members of the Steering Committee and their respective organisations were as follows:

- Paul Fennel, Abdul Aziz (Wimmera CMA);
- John Martin, Martin Bride and Edwin Ervine (HRCC);
- Simone Wilkinson (DSE);
- Gavin Kelly and Stacy Noonan (SES);
- Bill Lovell (Chair) and Keith Lockwood (Natimuk Community);
- Ben Hughes (Water Technology); and
- Ben Tate (Water Technology).

The Steering Committee met on 6 occasions at key points throughout the study, to manage the development of the plan.

3.3 Community Consultation

All community meetings were supported by media releases to local papers and meeting notices advertising meetings well in advance. The following community meetings were held as part of the consultation process:

- Initial community meeting, 12 December 2011 – The first public meeting was held to outline the objectives of the study to the community and to distribute the community questionnaire;
- Second community meeting, 11 July 2012 – 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, 7 November 2012 – The final community meeting presented the mitigation options that had been selected by the Steering Committee and sought comments

from the community. Two major options were presented. Detail to be included in the Natimuk Flood Intelligence Report was also presented.

3.4 Community Questionnaire

A community questionnaire was distributed to local residents during the first community meeting. This questionnaire was used to seek feedback on flooding in Natimuk. The following eight questions were listed on the questionnaire:

- How long have you lived in Natimuk and when have you been affected by floods in the past (month and year)?
- Were there any significant differences in flooding during the December 2010 and January 2011 floods?
- What damage did you personally sustain from the recent floods in Natimuk?
- If your property was flooded in December 2010 or January 2011 can you estimate the height of the water level above or below floor?
- What do you think are the major flooding issues in Natimuk?
- What do you think would improve the flood situation in Natimuk?
- How did you find out that a flood was imminent, did you receive warning, and how long did you have before flood waters arrived?
- Do you have any other comments to make regarding flooding in Natimuk?

Thirteen feedback forms were filled in and returned to the Wimmera CMA. Feedback from the questionnaires indicated what the community saw as potential flood mitigation and provided data for model calibration.

A summary of the feedback received is provided in Appendix D.

3.5 Community Feedback on Flood Investigation

During the final community meeting the major outcomes from the Natimuk Flood Investigation were presented. Post this meeting the Wimmera CMA made all presented information available on their website[5] for public comments.

These comments were received via written submissions, telephone conversations and comments on the Natimuk Community Facebook page[6].

A number of mitigation measures alternate to those presented at the meeting were suggested. These included widening, deepening and the removal of debris and vegetation in both Natimuk Creek and Little Natimuk Creek and removing a sediment sill at the Natimuk Creek entry into Natimuk Lake. Most of these alternative mitigation measures had already been tested during the project and discussed at previous community meetings.

Vegetation removal was tested using the calibrated hydraulic model developed during the study. Modelling showed a reduction in roughness in Natimuk Creek achieved a reduction of 0.1-0.15 cm in the central areas of Natimuk, this reduction in roughness is equivalent to creating a trapezoidal channel with a gravel bottom and concrete sides with no vegetation present. This is discussed further in Section 8.

A number of concerns surrounding the proposed mitigation options were also raised. Concerns focused on how the levees would impact the aesthetics of Natimuk and the view of Natimuk Creek. Questions such as:

[5] Wimmera CMA Website - http://www.wcma.vic.gov.au/
[6] Nati Noticeboard - http://www.facebook.com/groups/320408231309988/?fref=ts

- How high are the levees required to be?
- Will vegetation removal be necessary?
- Will the levees look natural?

The general community consensus was that they didn't want other residents in the town to be negatively impacted by any flood mitigation. There was a greater support for the Elmes Street levee than Combined Option 3 due to the works required for each option. Some community members were against the construction of any levee options as they felt they would be adversely impacted. However, these views were a minority.

The final designs of the each levee would be determined if it was decided they were to proceed to a further stage. Based on the preliminary conceptual designs the levees would be required to have the attributes shown below:

Elmes Street Levee

- Average Height - 0.6 m
- Max Height – 0.8 m
- Batter slopes 1:4
- Length – 400 m

Lake Avenue Levee 01

- Average Height - 0.7m
- Max Height 1.3 m
- Batter slopes 1:4
- Length – 940 m

Lake Avenue Levee 02 and 03

- Average Height – 1.2 m
- Max Height - 2.2 m
- Batter slopes - 1:4
- Length – 270m and 530m

The levees would be grassed and landscaped into the surrounding topography to ensure they are as unobtrusive as possible. In addition driveways would be regraded to maintain access over the levee.

Further details on the proposed levee options are discussed in Sections 8 and 10.

All community feedback submitted to the Wimmera CMA post the final community meeting is shown in Appendix I.

4. MODEL DEVELOPMENT

4.1 Overview

A hydrologic model of the catchment was developed for the purpose of extracting flows to be used as boundary conditions in the hydraulic model. The rainfall-runoff program, RORB, was utilised for this study. RORB is an abbreviation of 'runoff routing'. The 'B' previously stood for the computer the program was developed and maintained on, a Borroughs B6700. It no longer has any significance[7].

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

The following methodology was applied for the RORB modelling:

- The catchment area of Natimuk Creek and Little Natimuk Creek upstream of Natimuk Lake was delineated;
- The catchment was divided into subareas based on the site's topography and required hydrograph print (result) locations;
- The RORB model was constructed using appropriately selected parameters including reach types, slopes and subarea fraction impervious values;
- Storm files for the December 2010 and January 2011 events were constructed;
- RORB model parameters were calculated based on the available but limited calibration data and regional prediction equations;
- Hydrographs were extracted from RORB for use as inflow boundaries to the hydraulic model.
- The RORB calibration was run in series with the hydraulic modelling. As there was no gauged flow data the flood extents, levels and time to peak was used to calibrate both the hydrologic and hydraulic models. Flows were generated in the RORB model, the flows were run through the hydraulic model, the results were assessed, and the RORB model parameters were adjusted accordingly. The process was repeated until a reasonable calibration was achieved.
- Design loss parameters were investigated using a number of techniques, with final parameters adopted;
- Design flood events for the 5, 10, 20, 50, 100 and 200 year ARI and PMF were run for multiple durations; and

Hydrographs were extracted at the following locations:

- Natimuk Creek at the Wimmera Highway; and
- Little Natimuk Creek at Browns Road.

A number of minor inflows from small drainage lines were also extracted from RORB sub-areas around the township and entered directly into the hydraulic model as source points directly into the waterway.

These hydrographs from RORB were extracted and used as input into the hydraulic model.

[7] Monash University - http://eng.monash.edu.au/civil/research/centres/water/rorb/faqs.html Accessed 10/12/2012

A combined 1D-2D hydraulic modelling approach was adopted. The hydraulic model consisted of the following components:

- Two dimensional (2D) hydraulic model of the broader floodplain and all waterways;
- One dimensional (1D) hydraulic model of hydraulic structures within the study area and a 1D representation of the floodplain from the study area through to the Natimuk Lake outlet;
- Links between the 1D hydraulic structures and the 2D waterways to accurately model flow through these structures.

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

The hydraulic model was developed using LiDAR data for the topography and field survey of the waterways and hydraulic structures were incorporated. Roughness maps were digitised from aerial photography. The results of the hydraulic model verification of the December 2010 and January 2011 events were compared to observations made by the community, emergency services and surveyed flood marks. A number of hydrologic and hydraulic model verification iterations were run until the models best fitted observed information. At this stage community feedback on the model performance was obtained. The results were presented at the second community meeting with members present approving the models replication of the December 2010 and January 2011 events. The models were then used to run a series of design events.

For design event modelling a number of adjustments to the model geometry were undertaken to reflect current waterway conditions and works carried out since the recent floods. A number of design events were then modelled, including the 5, 10, 20, 50, 100, 200 year ARI and PMF.

Using the design events a series of mitigation options were tested and two final options assessed for the township. The design events were also used to inform planning and flood response activities.

Additional to the 1D/2D model for the Natimuk township a hydraulic model of the Natimuk Creek Catchment was constructed using a rainfall-on-grid model. This model shows inundation throughout the catchment and is discussed in Section 7.

The hydrologic and hydraulic model development is discussed in further detail below, with model verification and design modelling discussed in subsequent sections.

4.2 RORB Model

4.2.1 Subarea and Reach Delineation

The downstream outlet of the RORB model is at the end of Natimuk Lake, and covers the entire upstream catchment. The RORB model covers an area of approximately 157 km^2. Upstream of Natimuk township, Natimuk Creek and Little Natimuk Creek have catchment areas of approximately 114 km^2 and 25 km^2 respectively as shown in Figure 4-1.

The RORB model was constructed using MiRORB (MapInfo RORB tools), RORB GUI and RORBWIN V6.15. A catchment boundary was delineated from the 10 m Vicmap Digital Elevation Model (DEM) of the area. Sub-area boundaries were delineated using ARCHydro and revised as necessary to allow flows to be extracted at the points of interest. The RORB model was delineated into 76 sub-areas. Figure 4-2 shows the RORB sub area delineation for the study area. The sub-area delineation represents the current Natimuk Creek catchment, and reflects the way roads, drains and other man made features interact with the natural surface to control the path of surface water flow.

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

Reach types in the model were set to be consistent with the land use across the catchment. Five different reach types are available in RORB (1 = natural, 2= excavated & unlined, 3= lined channel or pipe, 4= drowned reach, 5= dummy reach). Drowned reaches were used within Natimuk Lake. All other reaches were set to natural, representative of the open grassed areas and natural waterways in the catchment.

Figure 4-3 shows a graphical representation of the RORB model in RORB GUI highlighting the location of sub-area nodes and reaches.

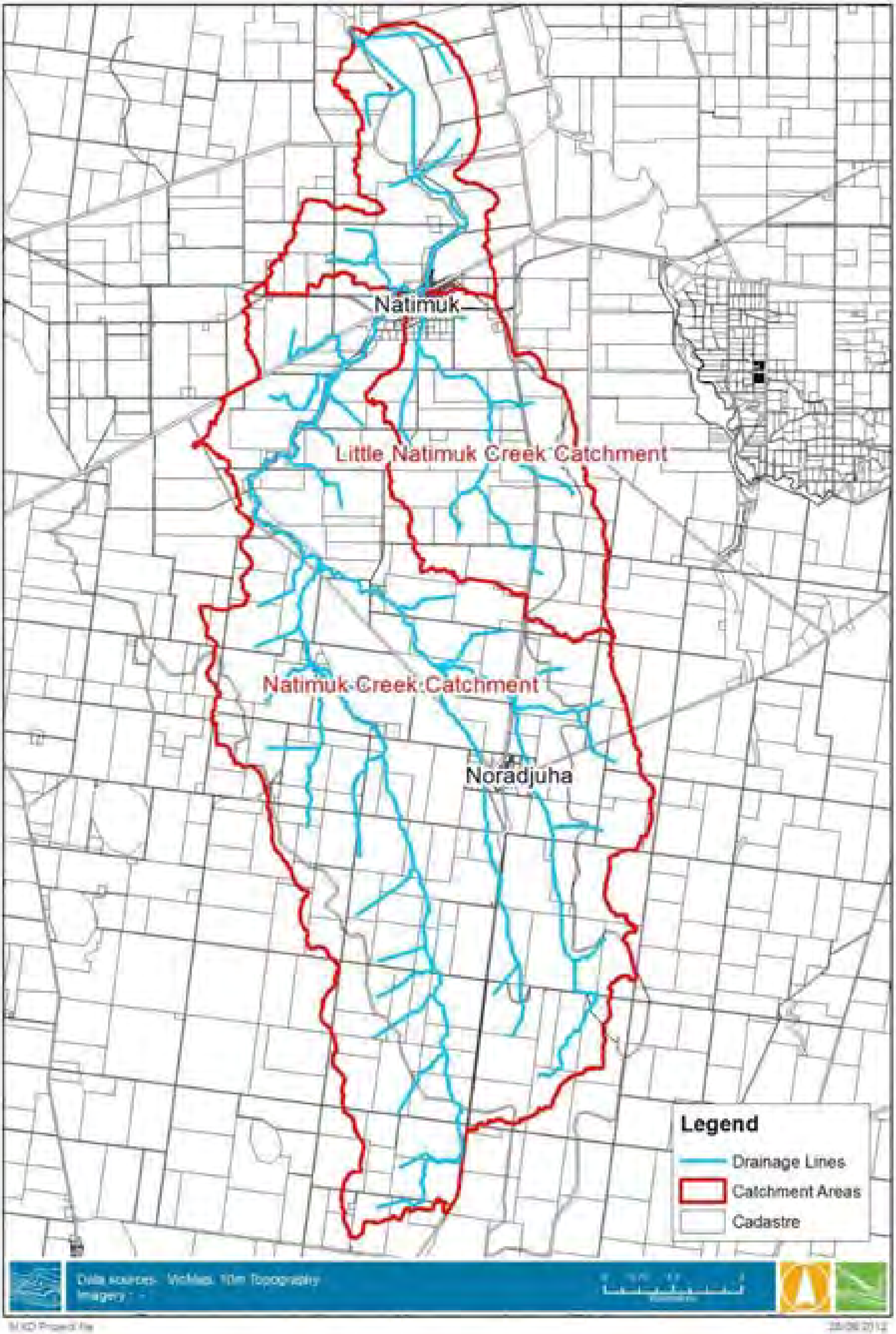

Figure 4-1 **Catchment areas of Natimuk Creek and Little Natimuk Creek**

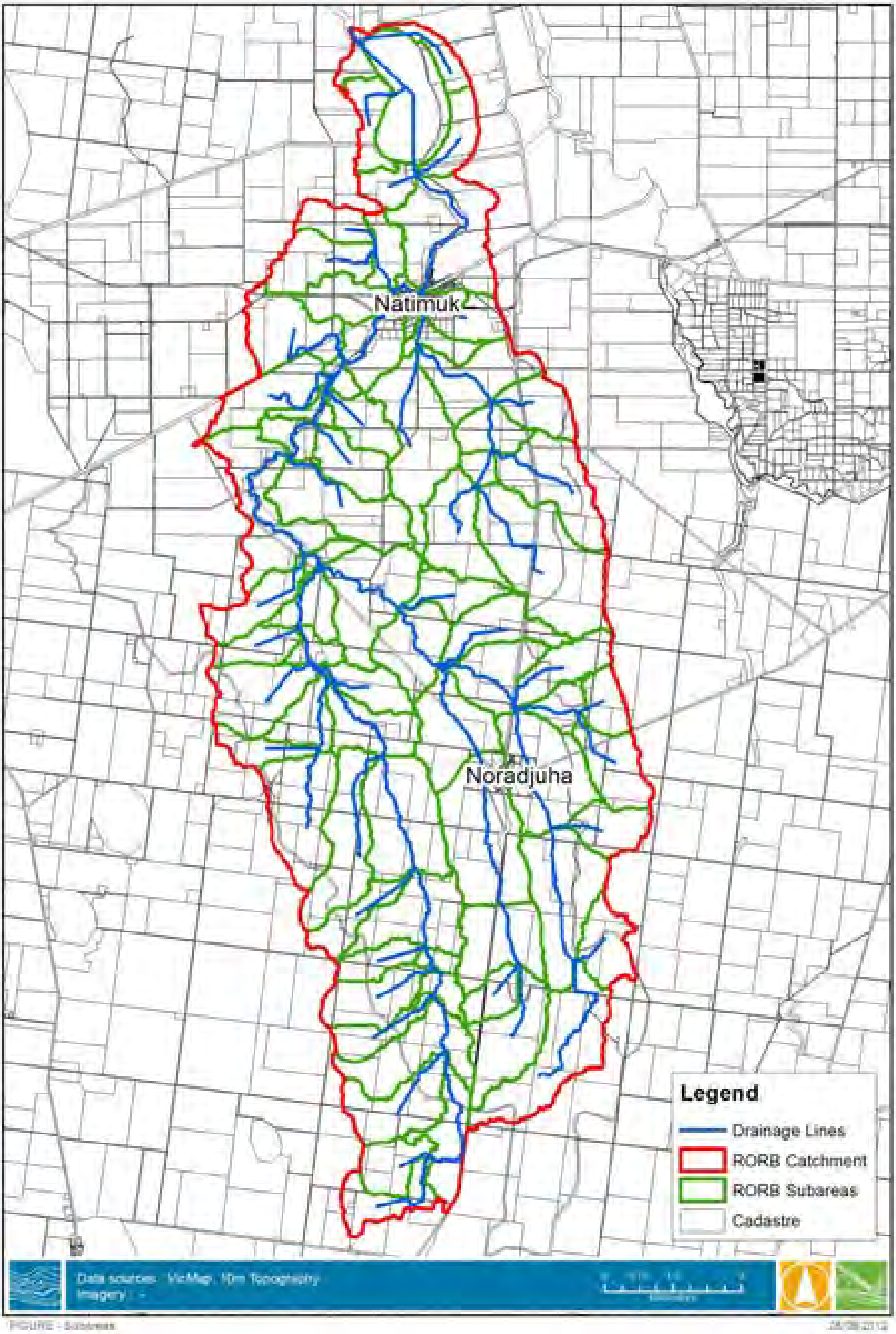

Figure 4-2 RORB Model sub-area breakup

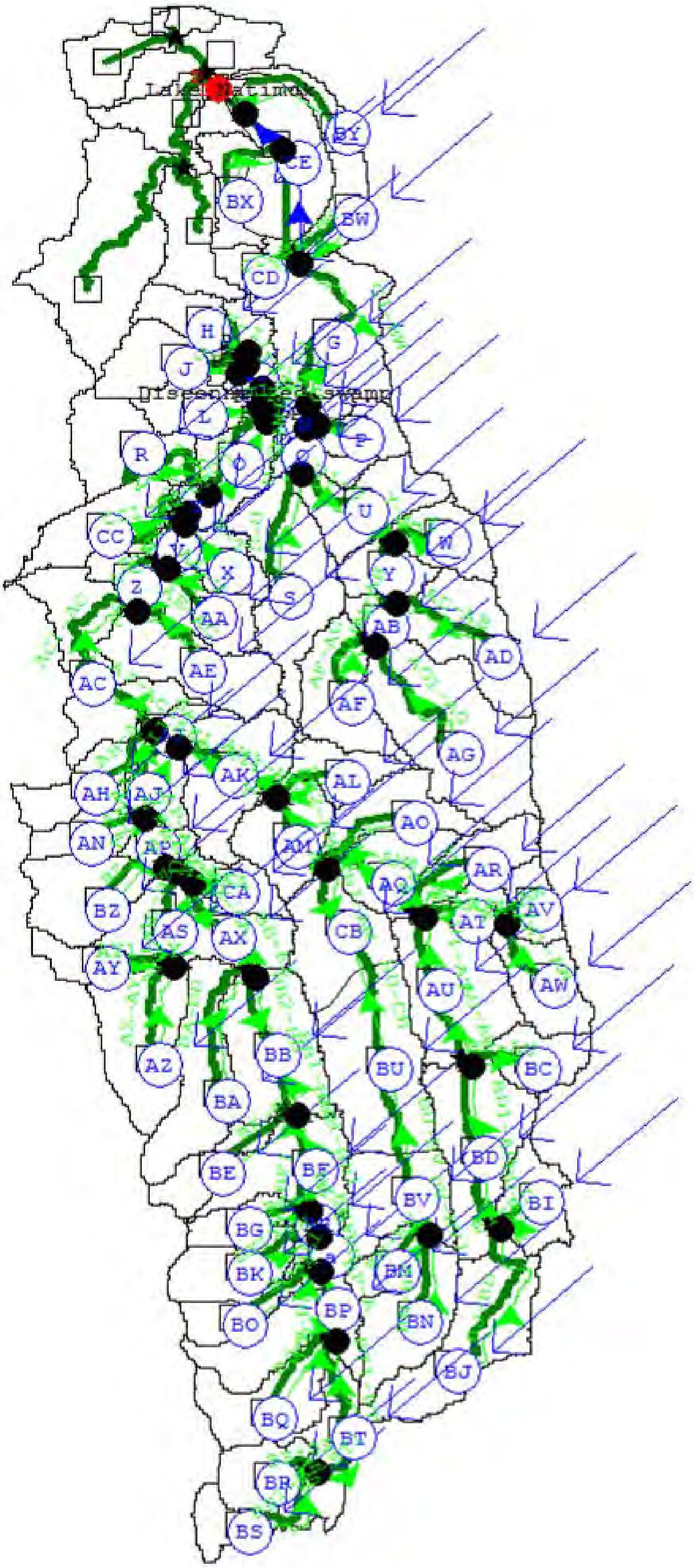

Figure 4-3 Graphical Representation of the RORB Model (MiRORB)

4.2.2 Fraction Impervious Data

The RORB model requires Fraction Impervious (FI) values for each subarea. The FI value for each catchment determines the area which is able to generate runoff. A higher FI means greater runoff and therefore higher peak flows. FI values were calculated using MiRORB. Default sub-area FI values were calculated based on the Planning Scheme Zones (current May 2012) and then reviewed and amended as necessary based on recent aerial photos (8th December 2011). The area weighted average FI of the Natimuk Creek and Little Natimuk Creek catchments' respectively were calculated to be 0.11 and 0.12, reflecting the predominantly rural nature of the catchment. The spatial distribution of the Land Use Zones is shown in Figure 4-4 showing the catchment is dominated by Rural Land Use (low Fraction Impervious) and the two townships of Natimuk and Noradjuha (high Fraction Impervious). The different zones and their corresponding fraction impervious values used in the construction of the RORB model are shown below in Table 4-1.

The weighted average for each sub-area was calculated and used in the RORB model. A graphical representation of the sub-area delineation and the applied FI is shown in Figure 4-5. These figures show that the residential areas of Natimuk and Noradjuha to have a higher fraction impervious than the broader catchment and therefore increase the fraction impervious of the sub-areas that cover them.

Table 4-1 RORB Model fraction impervious values and zones[8]

Zone	Description	Typical Fraction Impervious
FZ	Farming Zone	0.1
PCRZ	Protection of natural environment or resources.	0
PPRZ	Main zone for public open space, incl golf courses.	0.1
PUZ1	Power lines, Pipe tracks and retarding basins	0.05
PUZ2	Schools and Universities	0.7
PUZ3	Hospitals	0.7
PUZ7	Museums	0.6
RDZ1	Major roads and freeways.	0.7
RLZ	Predominantly residential use in rural environment.	0.2
TZ	Small township with little zoning structure	0.55

[8] Melbourne Water, 2010 – Music Guidelines, Recommended input parameters and modelling approaches for MUSIC users (Model for Urban Stormwater Improvement Conceptualisation)

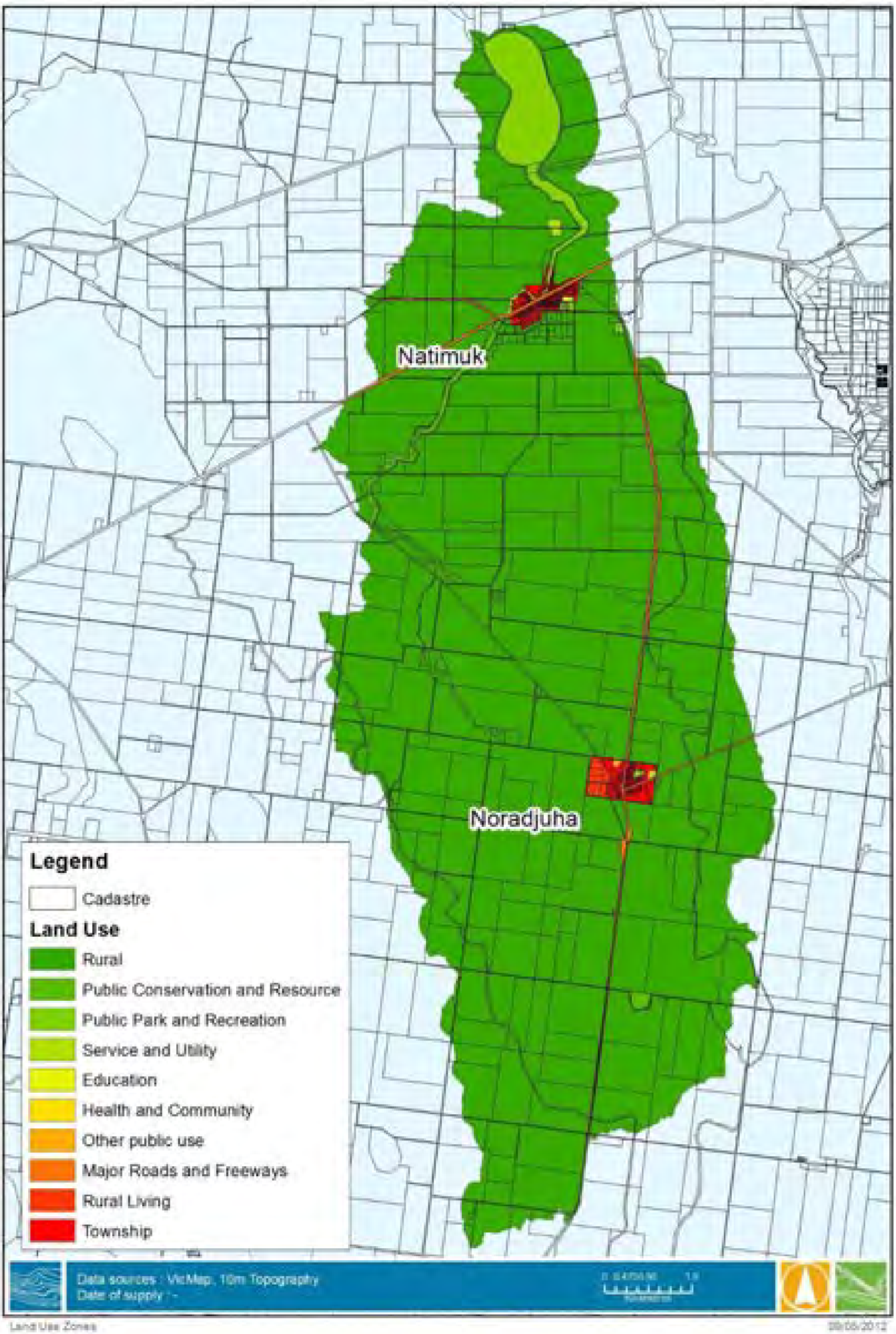

Figure 4-4 Natimuk catchment planning zones

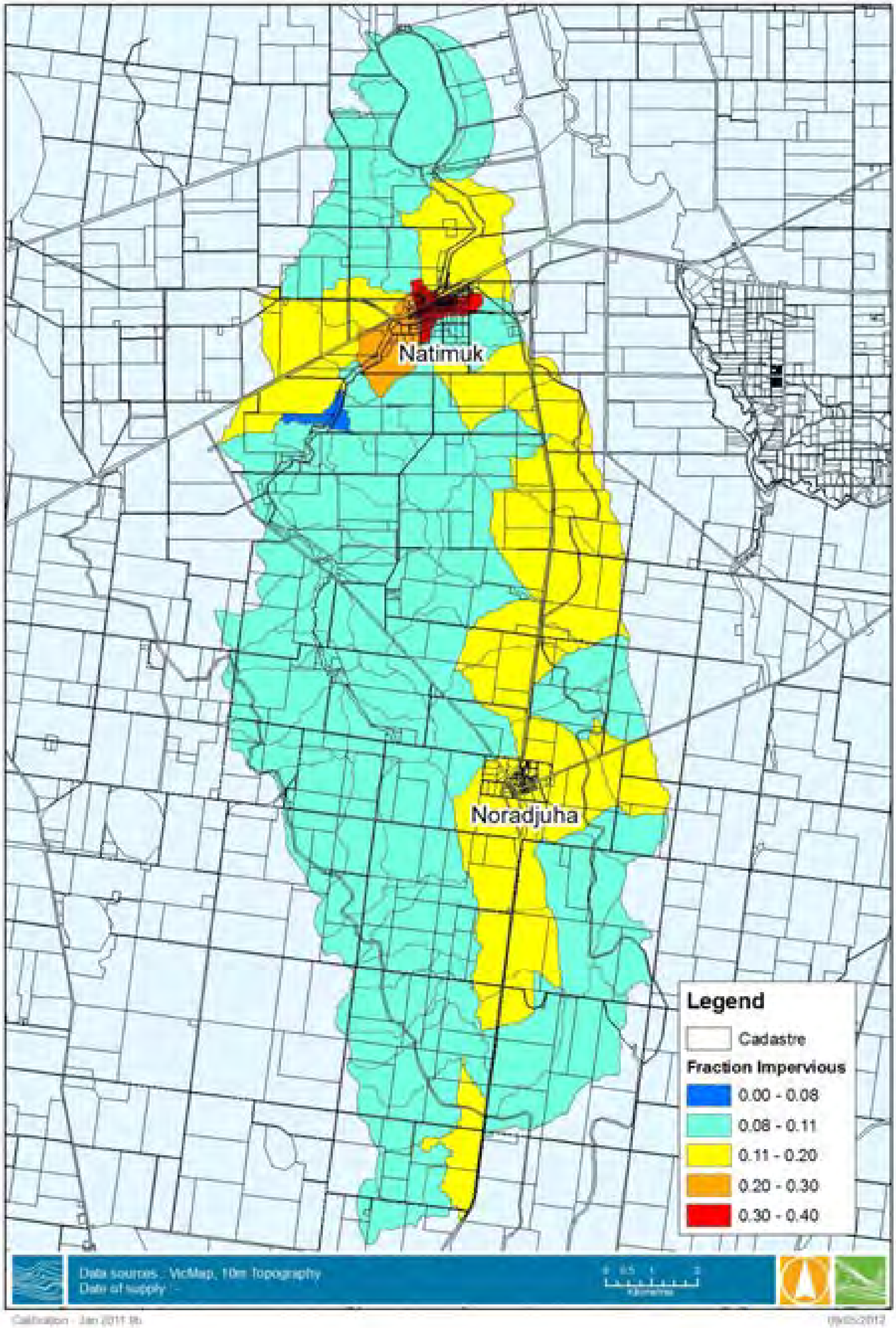

Figure 4-5 RORB sub-area fraction impervious values

4.2.3 Storage modelling

Natimuk Lake is the only named storage in the Natimuk Creek catchment, located at the downstream end of the model extent. There is however, a privately owned depression to the north east of the township which will also act as a storage retaining flow from its upstream catchment. Historically it is likely this area would have received water during a large flood event. The storage is separated from Natimuk Creek by a constructed embankment associated with the excavation of a dam.

There were no stage-storage (H-S) or storage discharge (S-Q) relationships available for either of these storages. The RORB model contains artificial stage-storage relationships that are not representative of on-ground conditions.

The storages were not modelled accurately in RORB as hydrographs were extracted upstream of the storages and they were included in the hydraulic model. The privately owned swamp was included in the 2D model domain while Natimuk Lake was included as a 1D extension, downstream of the 2D domain. Their inclusion into the hydraulic model provided an understanding of the potential attenuation they may cause, as well as the impact their initial storage levels may have on flows and flood levels at Natimuk. This allowed a range of Natimuk Lake water levels in to be modelled and assisted with the assessment of mitigation options.

Figure 4-6 below shows Natimuk Lake and the privately owned depression.

Figure 4-6 Natimuk Lake and the privately owned depression

4.3 Hydraulic Model

4.3.1 Model schematisation

The hydraulic model was schematised to optimise the model representation of the physical attributes of the creeks, floodplain and hydraulic structures in the vicinity of Natimuk. The model was separated into 1D and 2D components, linked using standard links. The combined 1D/2D model was comprised of the following components:

- Little Natimuk Creek (1D) – from Browns Road to downstream of J Sudholz Road. This reach was schematised to represent the flow constriction caused by Browns and J Sudholz Roads.
- Natimuk Creek (1D) – Downstream of the Natimuk township to the outlet of Natimuk Lake. This reach was schematised to represent the storage and influence of Natimuk Lake. This allowed testing of various options regarding improving capacity in the downstream reach and understanding how the operation of Natimuk Lake impacts flood levels through town, a key question from the community.
- Hydraulic structures (1D) - The MIKE11 model was used to model flow through all major floodplain and drainage structures on Natimuk Creek and Little Natimuk Creek. The structures were dynamically coupled with the 2D model.
- Natimuk Creek (2D) – Downstream of J Sudholz Road to downstream of the Natimuk township. This reach was schematised to show the hydraulic impact of floodplain features and generate a representation of flood levels and extents for historic and design events.
- Little Natimuk Creek (2D) – Downstream of J Sudholz Road to the confluence of Natimuk Creek. This reach was schematised to show the hydraulic impact of floodplain features and generate a representation of flood levels and extents for historic and design events.

The above described model schematisation is shown below in Figure 4-7.

4.3.2 1D Model

Boundaries

The 1D model included an upstream boundary on Little Natimuk Creek at Browns Road. A hydrograph was extracted at this location from RORB and used as input to the hydraulic model.

A 1D representation of Natimuk Creek from the 2D model boundary down to Natimuk Lake was developed. This ensured that results through the Natimuk township were not impacted by the models tail water condition and also allowed a Q-H relationship to be used as a boundary condition at the lakes outlet rather than setting a constant water level boundary. The QH relationship was derived by extracting a cross-section of Natimuk Lake's outlet point and a Manning's Equation calculation, which is completed by the 1D Mike11 model. The main reason for this approach was to allow the Q-H relationship to determine an accurate representation of the flood levels at the downstream boundary rather than setting a constant water level representative of the water level expected at the peak of the flood. A constant water level is not representative of all flows or all points in time across a single event. With a Q-H relationship, the model outflow is determined by a hydraulic relationship and requires no estimation of an appropriate water level for each event. It allows the downstream area to fill and drain as it should during a flood rather than being constantly inundated by the backwater of the downstream boundary.

Structures

Information (dimensions, inverts, etc.) of the key hydraulic structures along Natimuk Creek and Little Natimuk Creek was required for input into the hydraulic model. Some information on these structures was provided by VicRoads and the Horsham Rural City Council. Others were unavailable and were surveyed by Ferguson and Perry Surveying. Figure 4-8 shows the location of key waterway structures within Natimuk, with discussion on each structure shown in Section 2.4.1.

All hydraulic structures were modelled as MIKE11 culvert structures. Culvert structures simulated flow under the road with flow over the road simulated in the 2D model.

Channel Roughness

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

- Within waterways (Little Natimuk Creek and Natimuk Creek) - 0.035
- Concrete pipes and culverts - 0.013

These roughness parameters remained constant throughout the calibration and design event modelling process.

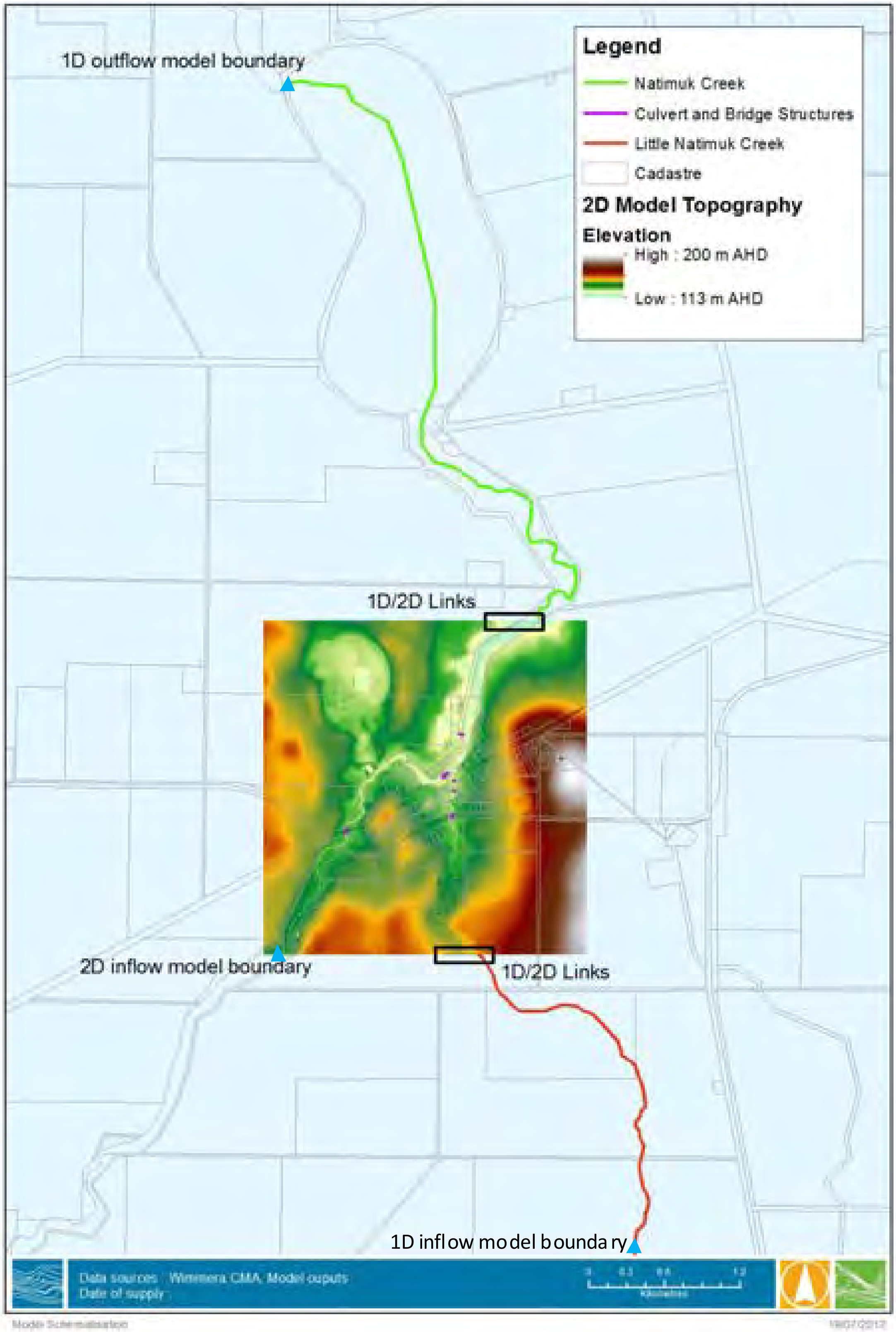

Figure 4-7 Hydraulic model schematisation

Figure 4-8 Key hydraulic structures through Natimuk

4.3.3 2D Model

Model Extent

The 2D hydraulic model component consists of a single model domain of the Natimuk and Little Natimuk Creek floodplain. The key items considered in schematising the 2D model were model extent, grid size, hydraulic roughness and boundary conditions imposed on the model.

The model extent covered the Natimuk township and any dwellings on the outskirts of town that could easily be included. The model also covered a privately owned depression to the north west of Natimuk, as shown in Figure 4-9. The 2D model extent is centred on the township and is approximately 2.6 km north-south and east-west.

The 2D boundary locations were chosen because of their confined nature. Figure 4-6 shows a lack of out of bank inundation during January 2011 at these locations, and Figure 4-9 shows that the waterway cross-sections are relatively confined; ensuring overland flow paths in the model are well represented.

Grid Size

A 3 m grid size was adopted for the 2D hydraulic model topography. The selection of grid size is critically important, and dictates the model's ability to represent particular floodplain features such as levees, waterways and roads. The selected grid size will also dictate the model simulation times. A 3 m grid was selected as it was considered to represent the key topographic features while allowing for reasonable model simulation time.

The 3 m grid size yielded a model with 852 x 879 grid cells. The model topography is shown below in Figure 4-9.

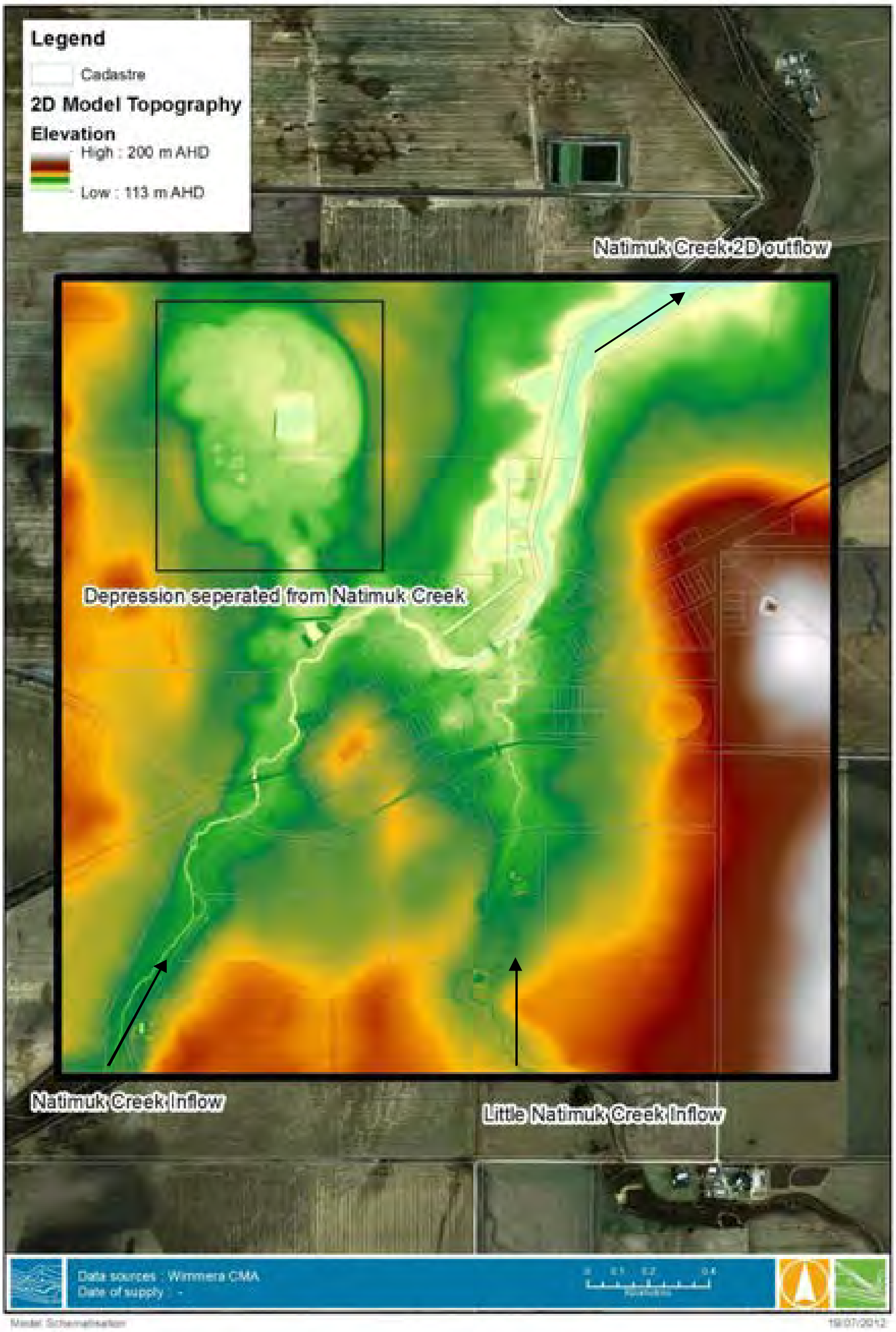

Figure 4-9 Hydraulic model topography grid

Hydraulic Roughness

Variations in hydraulic roughness across the floodplain were represented spatially as a 2D map, Figure 4-10. The hydraulic roughness (Manning's 'n') values for the floodplain were based primarily on aerial photography of Natimuk and observations from the site inspection undertaken. Roughness categories are shown below in Table 4-2. These values are consistent with values recommended in Chow (1959)[9].

Table 4-2 2D hydraulic model roughness values

Floodplain Element	Manning's 'n' value
Roads/Car Parks/Railway	0.02
Buildings	0.08
Open Grassed Areas	0.03
Mature row crops	0.03
Dense Vegetation	0.08
Waterway (low vegetation)	0.035
Waterway (medium vegetation)	0.04

Other 2D Parameters

There are numerous other parameters used in MIKEFLOOD, the chosen hydraulic modelling software package. These are summarised below in Table 4-3.

Table 4-3 Other 2D hydraulic model parameters

Model Parameter	Value	Explanation
Timestep	0.4 sec	Chosen to optimise run time and model stability.
Eddy Viscosity	0.2	Eddy viscosity is used to represent sub grid scale effects in 2D modelling. Practically speaking, eddy viscosity is used to stabilise models in areas of high velocity and depth.
Flood and Dry	0.03 and 0.02 m	Standard values for wetting and drying calculations

[9] Chow, 1959 - Open Channel Hydraulics, Ven-Te Chow

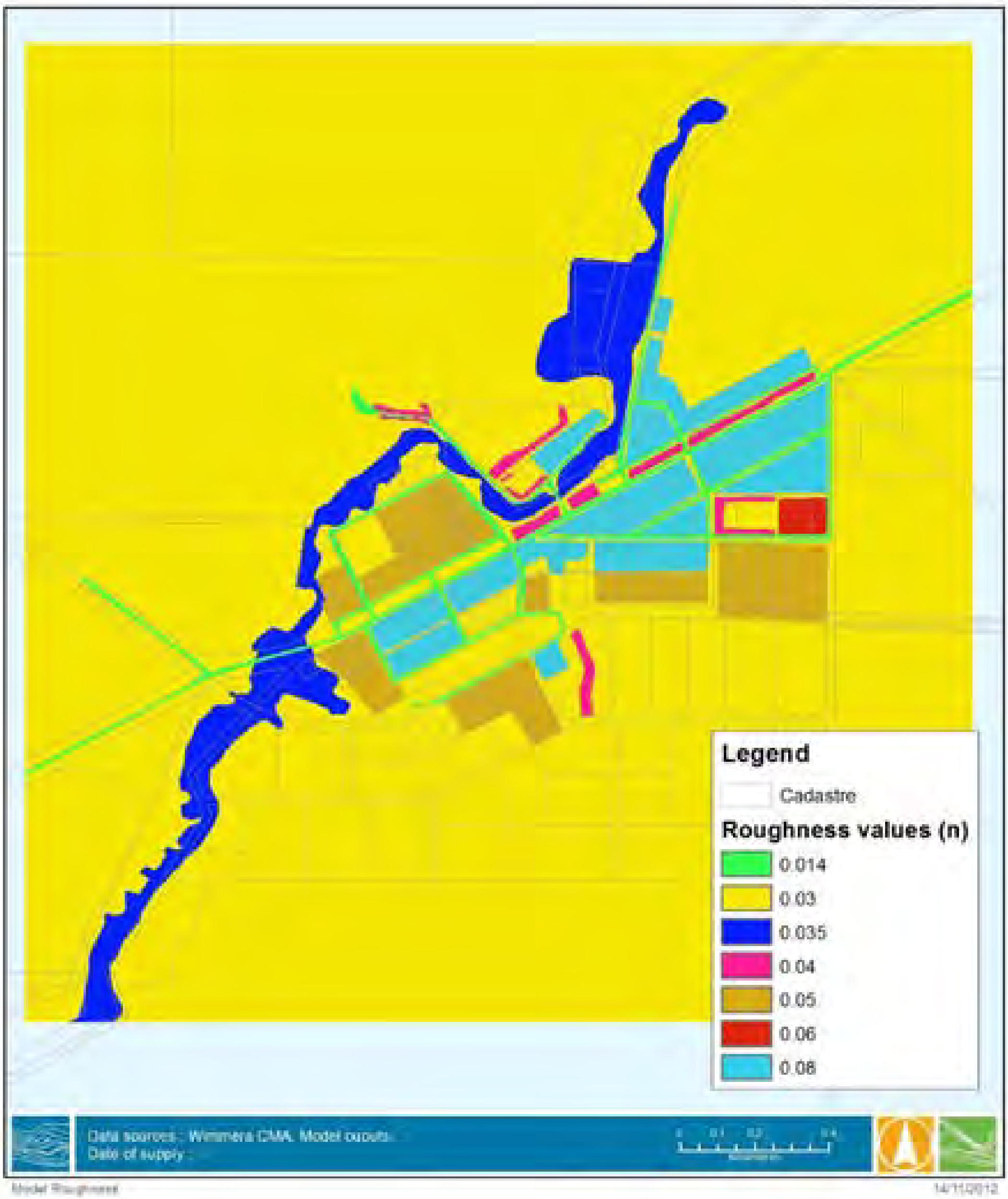

Figure 4-10 Hydraulic model roughness values

4.3.4 1D-2D Model Linking

Within MIKE FLOOD there are a number of options to link 1D and 2D models. The hydraulic model used standard links only, as both Little Natimuk Creek and Natimuk Creek were modelled in 2D throughout the township. The small grid size and relatively low bank profiles for both waterways meant that this method was the best approach.

The standard links were used upstream and downstream of all structures modelled within the 2D model domain, and also to connect the upstream 1D Little Natimuk Creek branch and the downstream 1D Natimuk Creek branch to the 2D model grid.

4.3.5 Boundary Conditions

The inflow boundary on Little Natimuk Creek and the outflow boundary on Natimuk Creek were modelled in 1D and were described earlier. The remaining model boundaries were applied to the 2D model.

The upstream boundary on Natimuk Creek was applied to the 2D model, as were a number of discrete source points representing local inflow along drainage lines entering the 2D domain. These source points were applied directly to the 2D model in the waterways. They represent local catchment inflows in and around Natimuk; their peak discharge is observed in Natimuk immediately after rainfall.

5. MODEL VERIFICATION

The lack of available streamflow information for Natimuk Creek made traditional RORB model calibration impossible. Instead the RORB model was run in series with the MIKE FLOOD hydraulic model, effectively using the hydraulic flood extents and water levels as verification of the RORB modelled flows. The verification process and results are described below.

5.1 RORB Model

5.1.1 Event selection

The events chosen for verification were December 2010 and January 2011. These events were chosen due to the quality of information available on flood level and extent, but also because they were the most recent and largest in living memory. Due to the devastation caused by these events, particularly January 2011, they were a focus of the community's understanding of flooding. The local community was able to participate in the development and verification of the models by providing valuable observations and sharing personal experiences of these recent flood events. These events also reflected the most up to date approximation of the current catchment conditions and flood behaviour. There was also significant difference in the magnitude of flooding between the two events, which enables testing of the model over a range of flood magnitudes.

The only other potential verification event highlighted at the initial community meeting was August 1981. Rainfall records of this event at the Natimuk rainfall gauge indicate the maximum daily rainfall was 28.0 mm with a total of 42.4 mm over two days. Due to the time since the event and the lack of any surveyed flood height information it was not selected for use in the verification.

The use of two events allowed the verification to be more robust, testing different rainfall patterns, total depths and intensities.

Available verification data

The available datasets for each calibration event were as follows:

December 2010

- Ground photography
- Significant anecdotal evidence

January 2011

- Aerial photography
- Surveyed flood heights
- Ground photography
- Significant anecdotal evidence

5.1.2 Rainfall

Overview

Both pluviograph and daily rainfall records were required for the hydrological analysis. The daily rainfall gauges record the 24 hour rainfall total prior to 9 am on any given day, whereas pluviograph rainfall gauges record rainfall on a continuous basis, measuring the rainfall intensity.

The pluviograph rainfall data is used to define the temporal distribution of rainfall during an event while daily rainfall data provides an understanding of the spatial variation. Figure 5-1 shows the locations of daily rainfall and pluviograph stations in the region.

Pluviograph records were available at the Horsham AWS (079100), Horsham Polkemmet Road (079023) and Longerenong (079028) gauges. Daily rainfall records are available from a number of stations spread out across the catchment; these are listed in Table 5-1.

Rainfall gauges that were of relevance to the Natimuk Flood Investigation are shown in Figure 5-1 and Table 5-1. Data is available at other rainfall gauges to the north and east of the Natimuk catchment, as shown in Figure 5-1 (green markers), however these were not used in the analysis as there is sufficient daily rainfall data for that part of the catchment (blue markers). On the western side of the catchment there are also other gauges but these are all at a greater distance than those selected. The Karnak (Rosedale) gauge was excluded as it had no recordings post August 2008. Charam was also excluded due to limited data. There is limited gauge information to the north west, with the closest rainfall gauge located at Kaniva, 75 km away.

Table 5-1 Rainfall gauges relevant to Natimuk Creek and Little Natimuk Creek

Name	Number	Length of Record	Highest Daily Recording (and date of occurrence) (mm)	January 2011 rainfall depth (and date) (mm)	December 2010 rainfall depth (and date) (mm)
Natimuk	79036	1889-Current	105.4 (Jan 1941)	115.2 (over 12th and 13th)	54.2 (8th)
Horsham (Polkemmet Rd)*	79023	1873-Current	98 (Jan 2011)	98.0 (12th)	60.2 (8th)
Clear Lake	79008	1903-Current	109 (Jan 2011)	109.0 (12th)	71.6 (8th)
Harrow (Pine Hills)	79022	1883-Current	88.9 (Jan 1952)	75.0 (14th)	82.0 (8th)
Telangatuk East (Milingimbi)	79078	1968-Current	95 (Jan 2011)	95.0 (12th)	80.0 (8th)
Harrow	79021	1908-Current	108 (Mar 1946)	45.0 (12th)	72.0 (7th)
Horsham AWS*	79100	1990-Current	101.4 (Jan 2011)	101.4 (12th)	9.4 (3rd)
Dimboola	78010	1878-Current	131.6 (Feb 1957)	104.2 (12th)	65.2 (8th)
Gerang Gerung	78013	1897-2011	146.8 (Jan 2011)	146.8 (12th)	54.0 (8th)
Goroke (Post Office)	79017	1886-Current	110.5 (Mar 1910)	46.4 (12th)	35.0 (8th)
Longerenong*	79028	1860-Current	106.7 (Feb 1957)	97.0 (12th)	47.0 (8th)

* Pluviograph rainfall gauges

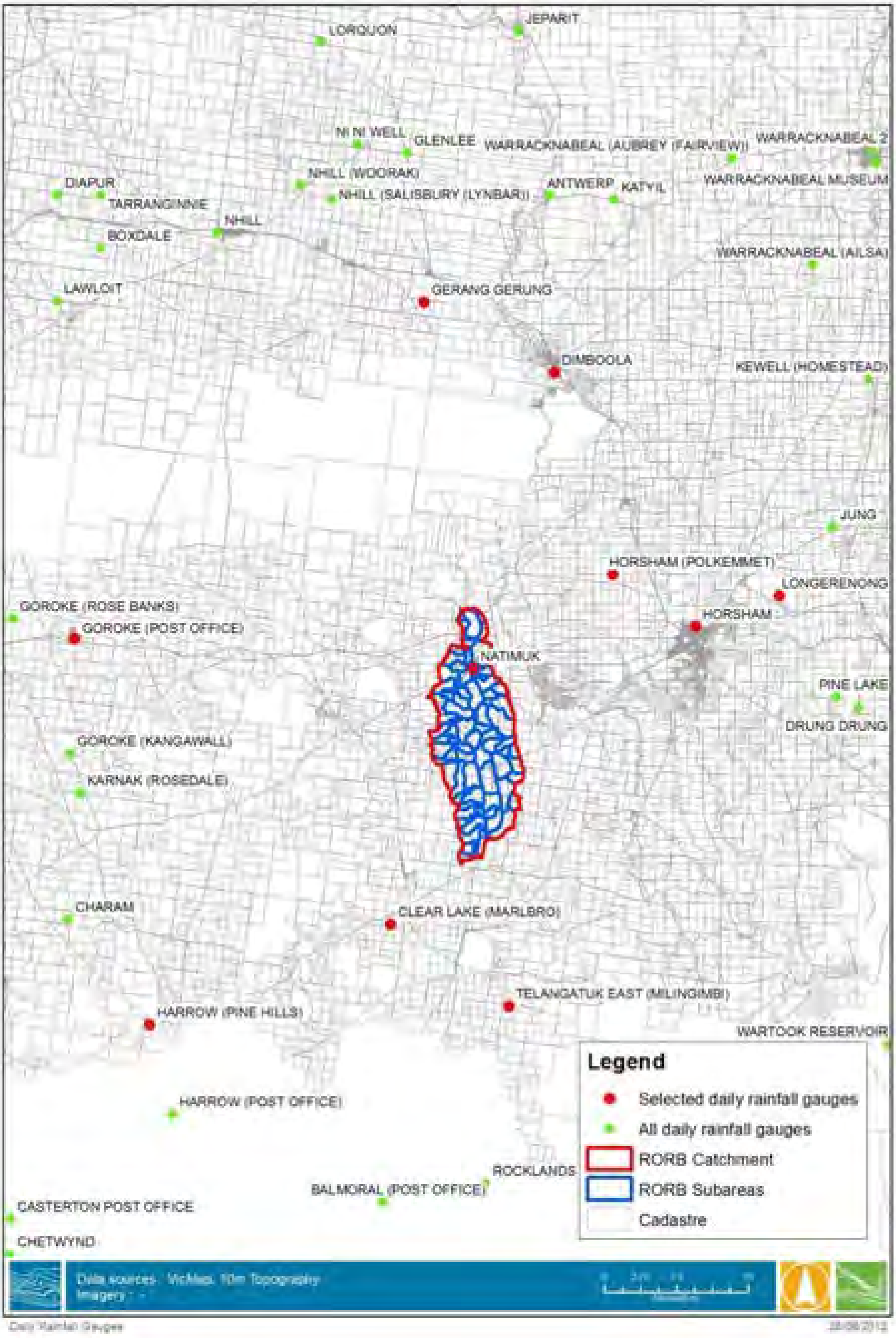

Figure 5-1 **Rainfall gauges surrounding the Natimuk Flood Investigation study area (pluviographs are located at Horsham AWS, Horsham Polkemmet Road and Longerenong).**

The December 2010 event was relatively isolated within the region with no other townships in the Wimmera suffering flooding to the same degree as Natimuk. A distribution of rainfall depths over the 3 day period 6-8th December 2010 is shown in Figure 5-1.

The January 2011 event was widespread with record daily totals recorded across the State. Flooding was experienced in a large number of Victorian towns across the majority of the north central and north west of the State. Natimuk experienced high rainfalls in the 24 hours prior to 9am on the 12th and 14th January 2011. Figure 5-2 shows the daily totals on 12th – 14th January 2011 as this rainfall preceded the maximum inundation in the Natimuk and Little Natimuk Creek catchments.

At the initial community meeting there was an anecdotal report of higher rainfall totals in the upper Natimuk Creek catchment. As this contradicted the gauged depths a request for additional rainfall data was distributed to the community via advertisement in local papers and a letter drop. However, no response was received. Given the statewide spatial and temporal distribution of the rainfall it is expected gauge recordings around the Natimuk catchment are correct and the best information available. The sensitivity of the temporal pattern was tested during modelling of the January 2011 event and is discussed further in Section 5.2.

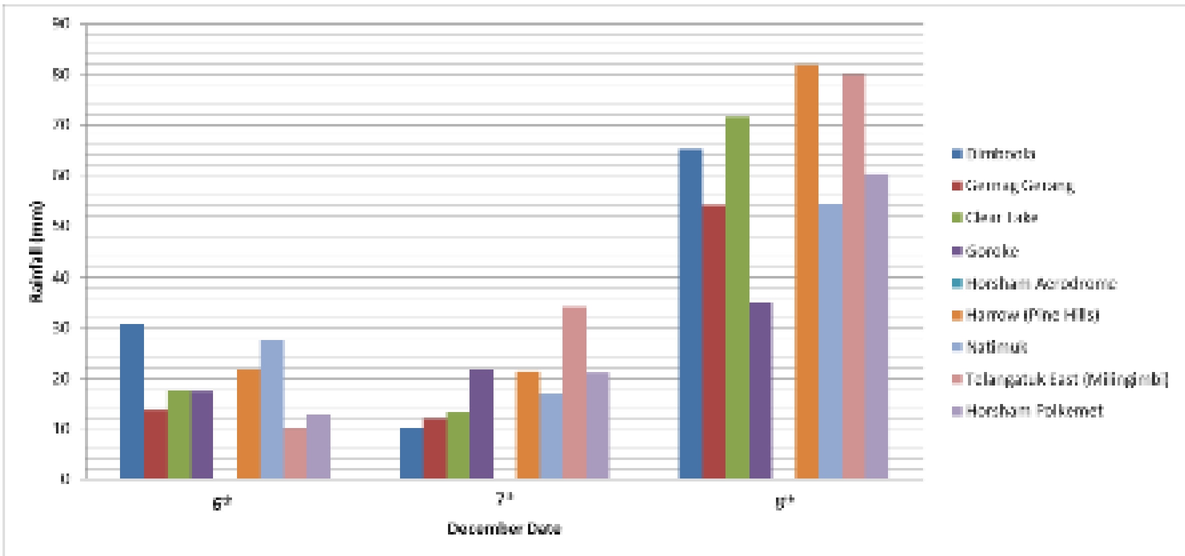

Figure 5-2 Daily Rainfall totals over the December 2010 event (6th- 8th), measurements taken at 9am on the specified day.

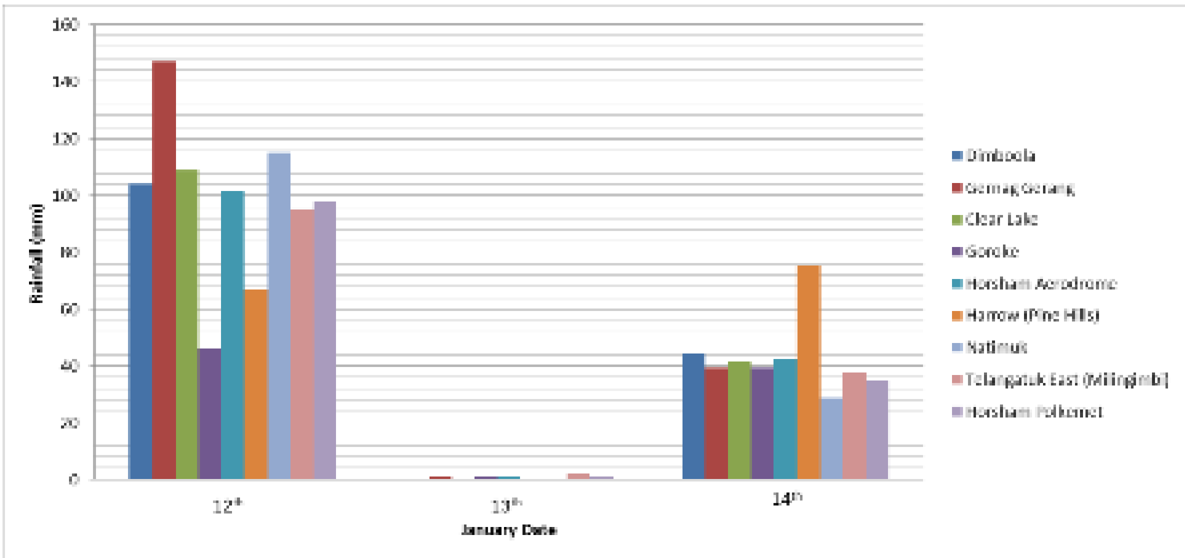

Figure 5-3 **Daily Rainfall totals over the January 2011 event (12th-14th), measurements taken at 9am on the specified day.**

Radar

Radar rainfall data recorded by the Bureau of Meteorology was considered to be too unreliable for use in this study. The closest radar stations to Natimuk are located in Melbourne and Mt Gambier, approximately 280 and 160 km from Natimuk respectively. The Bureau of Meteorology website explains the decreasing accuracy of Radars ability to show rainfall with increasing distance of the location from the base station as follows:

The "*radar beam becomes further from the ground with distance (partly because of the Earth's curvature, and partly because the beam is angled upwards by a fraction of a degree), thereby missing the lower parts of the rain. A horizontal radar beam detects raindrops at a height of 1 kilometre above the Earth's surface from rain that is 100 kilometres away from the radar. It detects raindrops at a height of 3 kilometres from rain that is 200 kilometres away, and at a height of around 7 kilometres at a distance of 500 kilometres from the radar. In winter especially, the rain clouds can be below the radar beam at a distance of more than 200 kilometres from the radar, and hence the radar beam will overshoot the rain. As a result, the radar image will not show any rain even though at the ground level it may be raining at the time.*"[10]

Figure 5-4 and Figure 5-5 below shows approximate Radar coverage for Australia and Victoria respectively.

[10] http://www.bom.gov.au/australia/radar/about/radarfaq.shtml. Accessed: 27/09/2012

Figure 5-4 Australian Radar coverage[11]

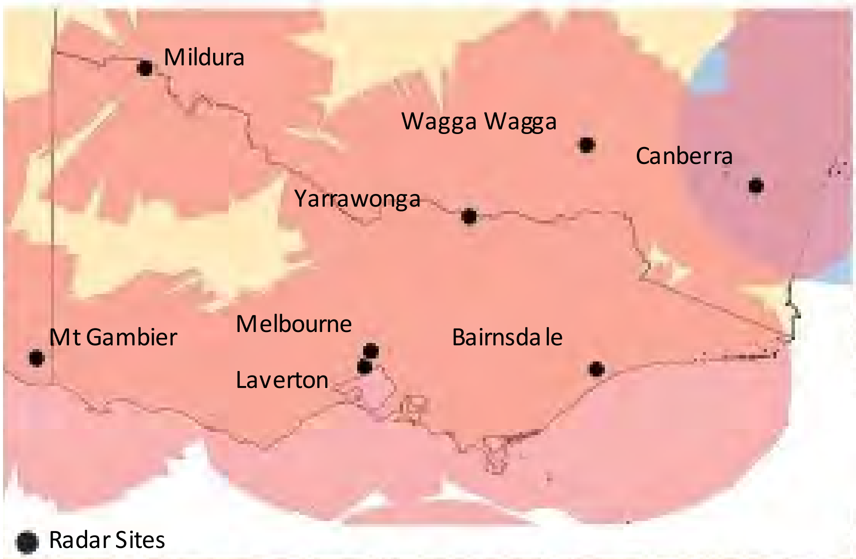

Figure 5-5 Victorian Radar coverage[12]

Rainfall IFD

The recorded rainfalls at stations in close proximity to the Natimuk Creek catchment were compared for the 24 and 48 hour durations. For comparison they were converted to Unrestricted 24 and 48

[11] BoM - http://210.8.186.60/weather/radar/about/radar_coverage_national.shtml Accessed: 14/12/2012
[12] Weekly Times - http://www.weeklytimesnow.com.au/article/2012/11/22/550096_national-news.html Accessed: 14/12/20212

hour duration rainfalls by multiplication with adjustment factors. These factors are 1.16 and 1.11 respectively for the 24 and 48hr durations respectively[13].

Table 5-4 shows the results of this comparison for the rainfall stations closest to the Natimuk Creek catchment and indicates that the 24 and 48 hour rainfall totals for the January 2011 event represent an ARI of 100 years or greater, while the December 2010 rainfall event is estimated to be a 20 to 50 year ARI event. This analysis was supplied by the DSE Review Panel.

[13] Boughton and Jakob, 2008 - Adjustment factors for restricted rainfall. Australian Journal of Water Resources, Vol. 10. No. 1, pp 37-47

Table 5-2 Summary of losses from prediction equations[14]

Name	Number	Highest Daily Recording in mm (date of occurrence)	Recorded Rainfall Totals Adjusted to Unrestricted Durations			
			Jan-11		Dec-10	
			Depth	ARI	Depth	ARI
Natimuk	79036	105.4 (Jan 1941)	127.9	100 yr	127.9	100 yr
Horsham (Polkemmet Rd)	79023	98 (Jan 2011)	113.7	>100 yr	113.7	>100 yr
Clear Lake	79008	109 (Jan 2011)	126.4	>100 yr	126.4	>100 yr
Telangatuk East (Milingimbi)	79078	95 (Jan 2011)	110.2	100 yr	110.2	100 yr
Horsham	79100	101.4 (Jan 2011)	117.6	>100 yr	117.6	>100 yr
Dimboola	78010	131.6 (Feb 1957)	120.6	>100 yr	120.6	>100 yr

Temporal distribution of rainfall

As discussed previously the three pluviograph rainfall stations in close proximity to the Natimuk Creek catchment are Horsham (Polkemmet Road), Horsham (AWS) and Longerenong.

December 2010

During the December 2010 event, pluviograph data was missing for both the Horsham (Polkemmet Road) and the Horsham (AWS) gauges. The Horsham (Polkemmet Road) gauge had a recording issue and the Horsham (AWS) gauge was damaged on 7th December 2010 and not repaired until 22nd December 2010. The Longerenong gauge provides the best record of temporal variation of the December 2010 event. The gauge recorded an intense burst of rainfall on the 6th December at approximately 1pm; this was followed by less intense rainfall through till the 8th December 2010. Figure 5-6 below shows the temporal rainfall distribution during the December 2010 event.

There is some uncertainty in the appropriateness of this temporal pattern for the Natimuk Creek catchment as reports of the event suggest that the event was relatively isolated. However, it is considered to be the best available data for the study area, and was used to model the temporal distribution of the December 2010 event within RORB.

[14] DSE Review Panel – Natimuk Hydrology Report – Review Panel Comments

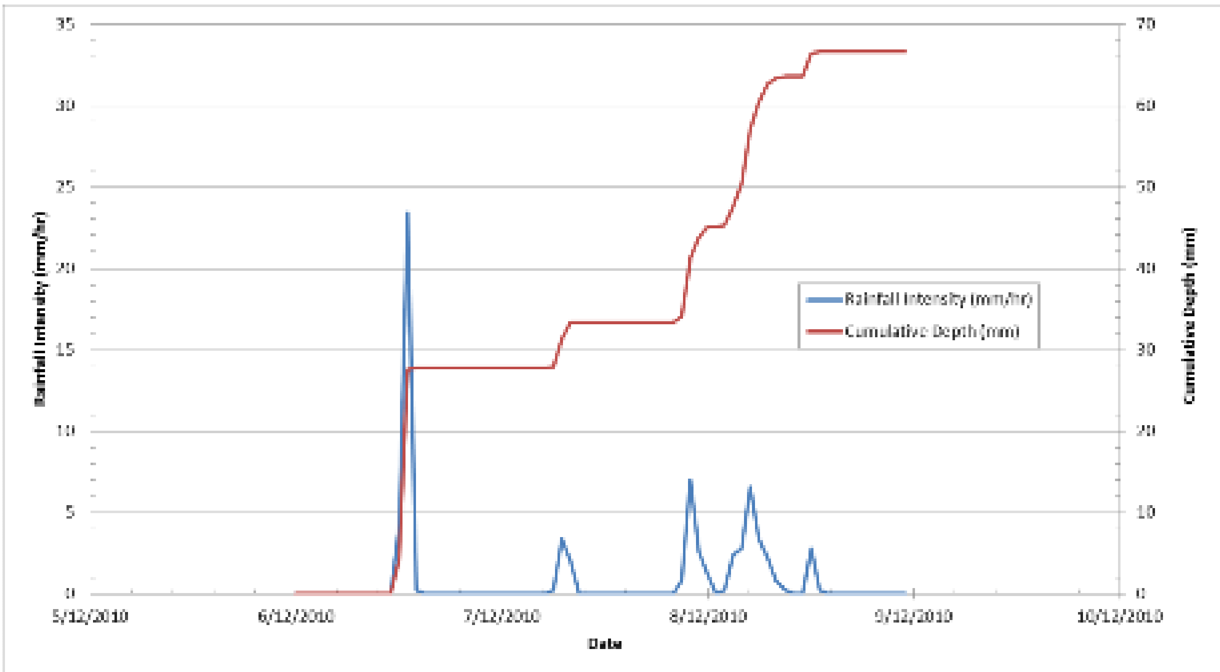

Figure 5-6 Longerenong Pluviograph records – December 2010 Event

January 2011

The Horsham (AWS) and Horsham (Polkemmet Road) pluviograph gauges recorded the January 2011 event without any missing data. The Longerenong gauge was not operational during the January 2011 event. The January 2011 event was defined in two separate bursts, the first on 12th January, recording maximum rainfall intensities between 6-6.30 am, and the second on 14th January, recording the highest intensity at 11 pm on the 13th.

Residents in Natimuk began observing elevated creek levels by 7 am on the 12th with the maximum water level observed at approximately 2 pm, approximately 8 hours after the most intense rainfall. Natimuk and Little Natimuk Creeks also rose following rainfall on 14th January; however the observed flood depths and extent were lower than the event on the 12th January. There were no recorded flood heights and minimal anecdotal evidence of the second peak.

The two rainfall events in January were considered as separate events with the focus on the first event up till 9 am on the 12th January.

The temporal distribution of rainfall at the Horsham AWS and Horsham Polkemmet Road gauges' is shown in Figure 5-7 and Figure 5-8.

The two pluviograph stations are located a short distance apart (Approx. 12 km) on the same side of the catchment. The temporal distribution of rainfall was tested using both gauging stations within RORB as there was significant variance between the two patterns.

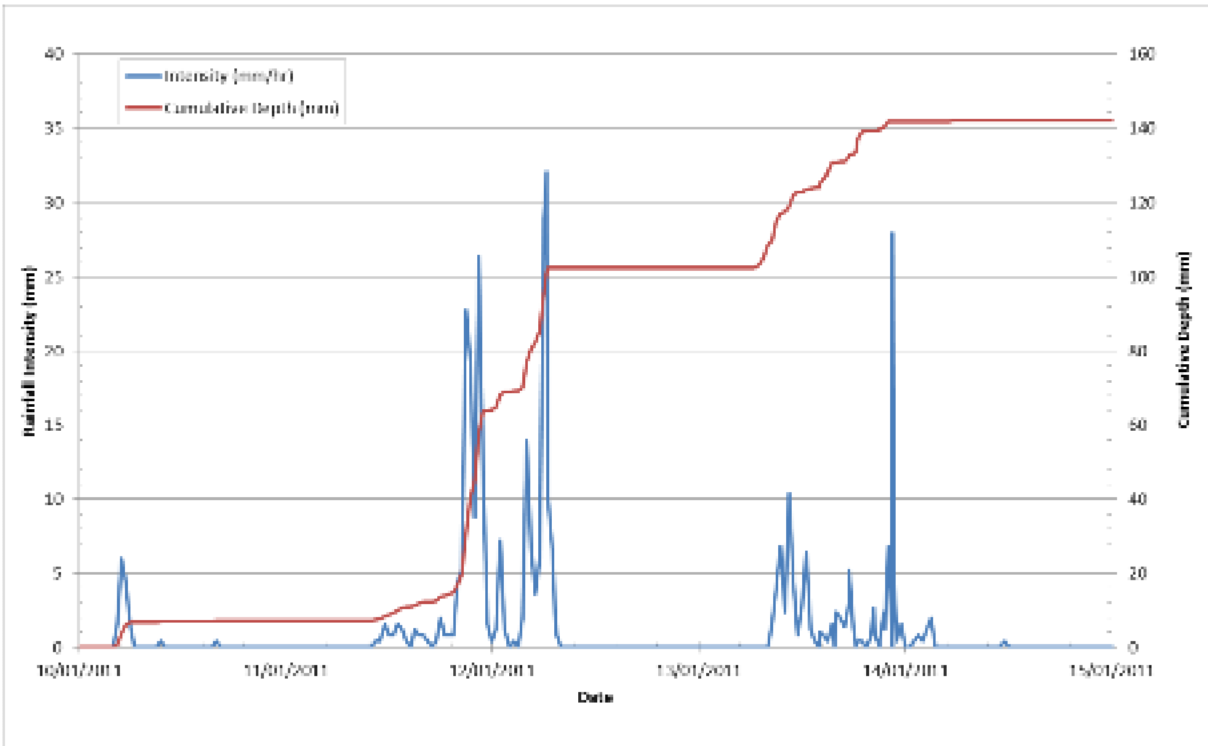

Figure 5-7 **Horsham Automatic Weather Station (AWS) Pluviograph records – January 2011 Event**

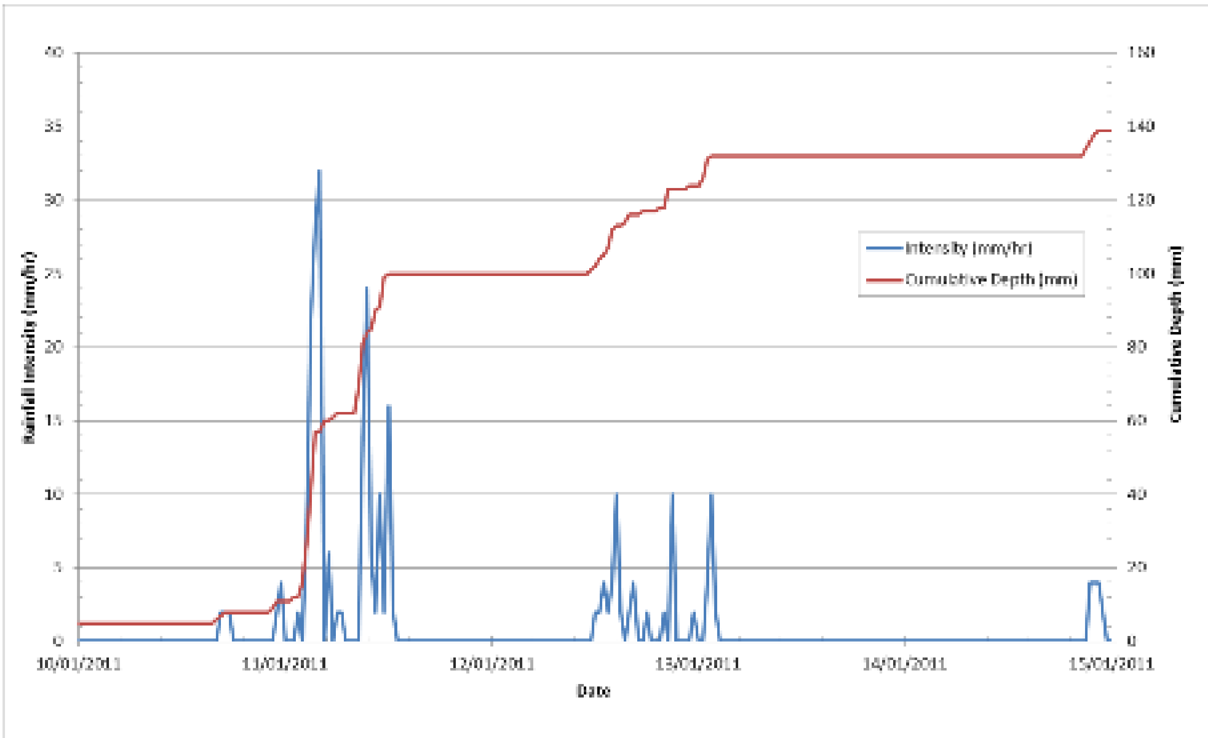

Figure 5-8 **Horsham Polkemmet Road Pluviograph records – January 2011 Event**

Spatial distribution of rainfall

To determine the spatial distribution of rainfall for the verification events, the rainfall totals from each daily rainfall gauge (both the December 2010 and January 2011 events used 24 hour totals), as shown in Figure 5-9 and Figure 5-10, was used to create a Triangulated Irregular Network (TIN)[15]. The TIN of rainfall values was converted to contours (isohyets) and are show in Figure 5-9 and Figure 5-10 for the December 2010 and January 2011 events respectively.

The spatial distribution of the December 2010 and January 2011 events varies considerably, emphasising the fact that no two floods are the same. January 2011 shows greater depths to the north of the catchment and December 2010 shows a greater depth to the south east. The January 2011 event approached the Natimuk Catchment from the north moving directly south, while the December 2010 event was much more isolated moving from north west to south east.

From the December 2010 and January 2011 TINs of total rainfall depth, a total depth for each RORB subarea was determined.

[15] AR&R, 1987 – Australian Rainfall and Runoff

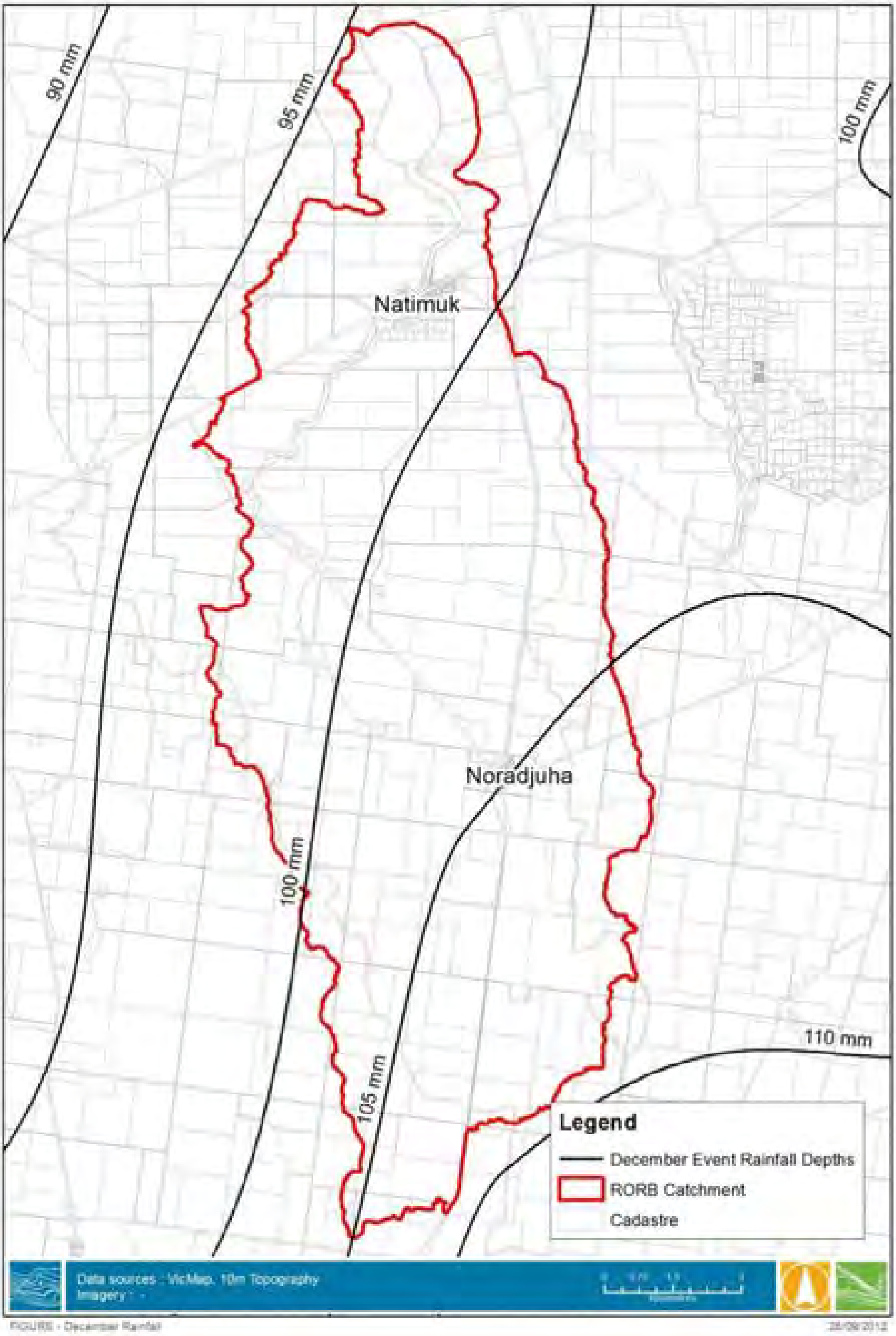

Figure 5-9 December 2010 triangulated rainfall totals

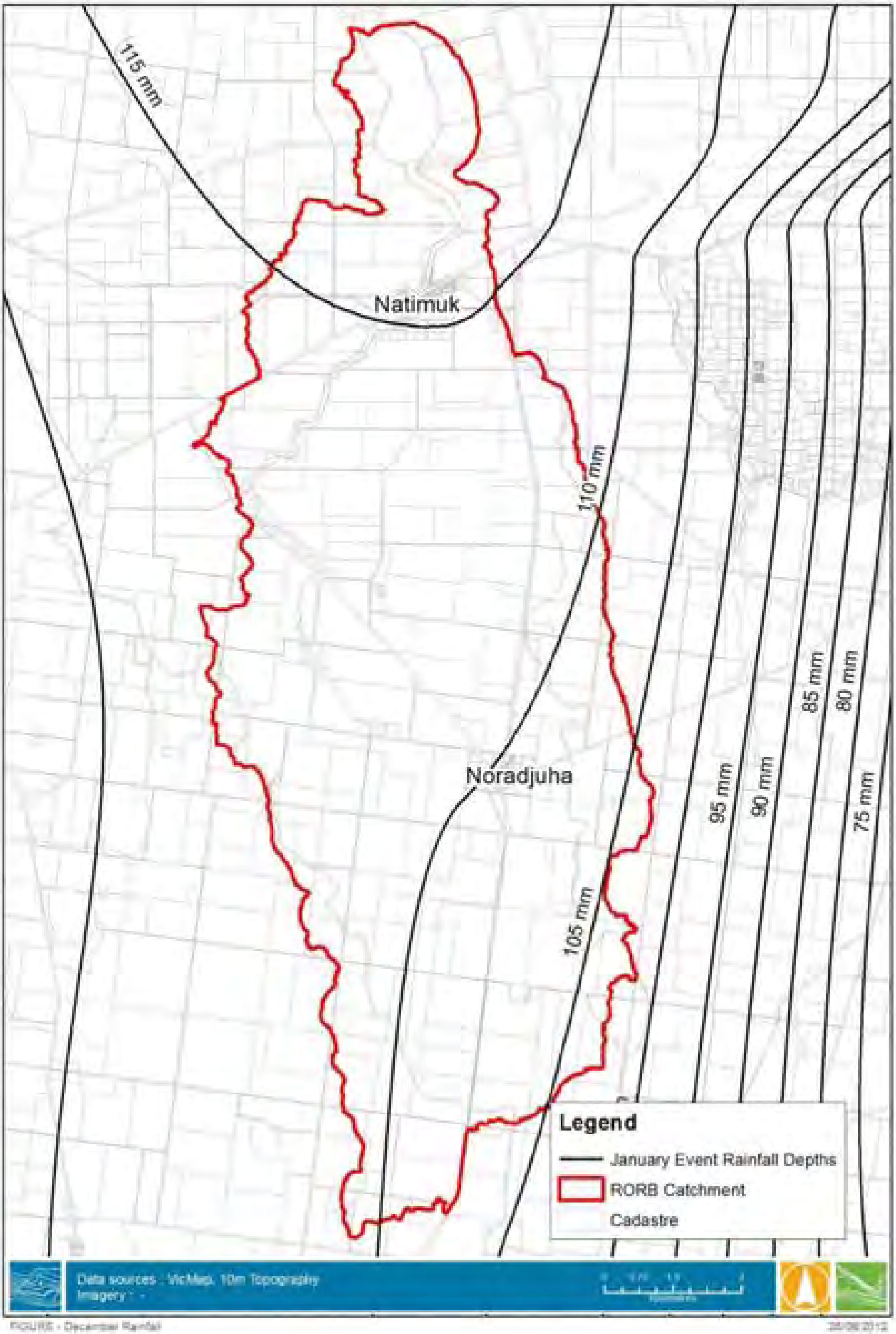

Figure 5-10 January 2011 triangulated rainfall totals

5.1.3 Model Parameters

Overview

There are several model parameters used in RORB that control the resulting peak flow rate and volume of runoff, these are – kc, m and losses. In gauged catchments these parameters are used to calibrate the modelled flow to gauged hydrographs. As no gauged streamflow data was available for Natimuk the above parameters were adjusted to generate a hydrograph that was then run through the hydraulic model, with the flood extent, water level and timing used to verify the RORB model parameter selection.

This section describes the method adopted for RORB model verification and presents the range of parameter values tested along with the final parameter values adopted. As the RORB model verification was run in series with the hydraulic model verification, the results of the iterative verification process are presented along with the hydraulic modelling results in Section 5.2.

m

The RORB *m* value is typically set at 0.80. This value remains unchanged and is an acceptable value for the degree of non-linearity of catchment response (Australian Rainfall and Runoff, 1987)[16]. There are alternate methods for determining *m*, such as Weeks (1980),[17] which uses multiple calibration events to select *kc* and *m*. However, given the absence of streamflow data and uncertainty surrounding the temporal and spatial distribution of rainfall across the Natimuk Creek catchment during the calibration events, a change to the *m* value from 0.8 would be difficult to justify.

kc

The RORB model *kc* value was estimated using a range of prediction equations as shown below in Table 5-3. These equations generally use catchment area or D_{av}, (the average flow distance in the channel network of sub area inflows) to describe the model, and were developed using different data sets (or subsets of the same data set).

Table 5-3 Method of kc value calculation

Method	Equation	Predicted kc
Default RORB	$kc = 2.2*A^{0.5}$	27.5
Vic MAR<800 mm - Eq 3.21 ARR (BkV) [16]	$kc=0.49*A^{0.65}$	13.1
Victoria data (Pearse et al, 2002)[18]	$kc=1.25*D_{av}$	26.6
Aust wide Dyer (1994) (Pearse et al 2002) [18]	$kc=1.14*D_{av}$	24.3
Aust wide Yu (1989) (Pearse et al 2002)[18]	$kc=0.96*D_{av}$	20.4
Andrew's Method (1972) (Dyer et al 1994)[19]	Fourier plot	7.0

[16] AR&R, 1987 – Australian Rainfall and Runoff

[17] Weeks, W. D. (1980). Using the Laurenson model: traps for young players. Hydrology and Water Resources Symposium, Adelaide, Institution of Engineers Australia

[18] Pearse et al, 2002 – A Simple Method for Estimating RORB Model Parameters for Ungauged Rural Catchments, Water Challenge: Balancing the Risks: Hydrology and Water Resources Symposium 2002, 2002

[19] Dyer et al, 1994 – Development of Regional Predictions Equations for the RORB Runoff Routing Model

Several *kc* values were trialled during verification, with the results presented in more detail below. The final adopted *kc* value for the December 2010 and January 2011 verification events was 26.6.

Losses

An initial and continuing loss model was chosen for the Natimuk RORB model. The initial and continuing loss model has traditionally been used for rural flood investigations in Victoria and was again adopted for this study. This method allows a better match in a rural setting with antecedent conditions impacting on the initial loss more heavily than continuing loss. After a sustained dry period the Natimuk Creek catchment may be dry, and with the onset of rain, a large portion of the initial rainfall may infiltrate into the soil. Alternatively, with significant rainfall in the lead up to an event the catchment may be wet, with the initial infiltration loss much lower. This process is modelled using an initial loss parameter. After the initial loss, the infiltration rate will slow to a relatively constant continuing loss closer to the saturated hydraulic conductivity of the soil, this is represented by the continuing loss in RORB.

For the December 2010 and January 2011 verification events, the RORB losses were chosen along with a *kc* value, hydrographs extracted from RORB and modelled in the hydraulic model, with results compared to observed flooding. The losses were then adjusted and the process repeated until the modelled flooding replicated the observed flooding in Natimuk.

The selection of losses has also considered the antecedent conditions for the selected events.

Several methods of loss estimation were also investigated to provide an understanding of typical values for the catchment. These included methods from Hill et al (1996)[20], and Australian Rainfall and Runoff[21].

Hill et al (1996)[20]

Storm Initial Loss:

$$IL_s = -25.8 \times BFI + 33.8$$

Continuing Loss:

$$CL = (7.97 * BFI) + (0.00659 * PET) - 6$$

Where: BFI is the baseflow index (0.08) and PET is the mean annual potential evaporation (1500 mm)

The Base Flow Index has is lowest recommended value in Hill et al 1998[22]. This value was used as Natimuk Creek is an ephemeral waterway that only flows after rainfall and has no baseflow.

The Potential Mean Evaporation was determined by Bureau of Meteorology average annual pan evaporation maps[23].

Australian Rainfall and Runoff Design Loss Rates [21]

Derived loss rates for numerous catchments are separated into States, with loss rates for areas of Victoria north and west of the Great Dividing Range given as similar to areas of New South Wales. These values for New South Wales are separated into east of the western slopes and arid zone with mean annual rainfall less than 300 mm. The values for east of the western slopes were adopted as

[20] Hill et al, 1996 – Empirical analysis of data to derive losses from design flood estimation in South Eastern Australia

[21] AR&R, 1987 – Australian Rainfall and Runoff - Volume 1, Book II, Chapter 6

[22] Hill et al, 1998 – How Much Rainfall Becomes Runoff? Loss Modelling for Flood Estimation, CRC for Catchment Hydrology

[23] BoM Website - http://www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp Accessed: September 2012

an indicative guide to the loss values which may be expected for the Natimuk catchment as the annual rainfall is greater than 300mm.

Table 5-4 Summary of losses from prediction equations

Method	Initial loss (mm)	Continuing loss (mm/hr)
Hill et al (1996)	31.7	4.5
ARR (1987)	10 to 35	2.5

In combination with *kc*, a range of loss values were trialled for both the December 2010 and January 2011 verification events. These trials are described in more detail below in Section 5.2, with the final loss values for the two historic events shown below in Table 5-5.

Table 5-5 Adopted loss values for verification events

Event	Initial loss (mm)	Continuing loss (mm/hr)
December 2010	35	4.5
January 2011	10	4.5

5.2 Hydraulic Model

5.2.1 Overview

The RORB model verification discussed above generated a range of inflow hydrographs which were taken as input to the hydraulic model. The results from the many model simulations were then compared to observations of the December 2010 and January 2011 flood events. The final RORB and hydraulic model parameters were then chosen based on the best fit to observed information.

The verification scenarios are fully described below.

5.2.2 January 2011

Antecedent conditions

The January 2011 event occurred between the 12th and 14th of January. Although over many months the rainfall in the catchment was above average, in the three weeks prior to the event the catchment received close to zero rainfall. Combined with hot conditions over the summer period, it is likely that the soil moisture stores were not particularly high.

Due to the significant rainfall events during 2010, Natimuk Lake was assumed to be at full operational level at the start of the January 2011 model simulation. Sensitivity testing carried out during the project confirmed that flood levels in Natimuk are insensitive to lake level given the distance from town and the available fall in topography between the town and the lake.

Model simulations

The verification process involved running a large number of RORB simulations with a range of *kc*, and loss values. The parameter values trialled are shown below in Table 5-6, with the resulting peak flows generated for all simulations shown in Appendix H.

Model results from six simulations were routed through the hydraulic model based on the range of RORB model predictions. The runs were completed to develop an understanding of how the catchment responds to changes in each parameter. The results of this sensitivity analysis are shown in Appendix A.

Table 5-6 January 2011 Model verification simulations

kc	IL (mm)	CL (mm/hr)	Comment
21.1	10	2.5	Average imperical Kc (discluding the highest and lowest) and lowest initial loss and continuing loss
24.71	10	2.5	Average imperical Kc (discluding the two outlying low values) and lowest initial loss and continuing loss
27.53	10	2.5	Default RORB and lowest initial loss and continuing loss
26.61	10	2.5	Victoria data (Pearse et al, 2002) and lowest initial loss and continuing loss
21.1	37.7	4.5	Average imperical Kc (discluding the highest and lowest) and Hill et al
24.71	37.7	4.5	Average imperical Kc (discluding the two outlying low values) and Hill et al
27.53	37.7	4.5	Default RORB and Hill et al
26.61	37.7	4.5	Victoria data (Pearse et al, 2002) and Hill et al
26.61	15	2.5	Victoria data (Pearse et al, 2002) and ARR initial loss and continuing loss
26.61	20	2.5	Victoria data (Pearse et al, 2002) and ARR initial loss and continuing loss
26.61	25	2.5	Victoria data (Pearse et al, 2002) and ARR initial loss and continuing loss
26.61	30	2.5	Victoria data (Pearse et al, 2002) and ARR initial loss and continuing loss
26.61	35	2.5	Victoria data (Pearse et al, 2002) and ARR initial loss and continuing loss
24.71	25	4.5	Average imperical Kc (discluding the two outlying low values) and ARR initial loss and Hill et al continu
26.61	25	4.5	Victoria data (Pearse et al, 2002) and ARR initial loss and continuing loss
24.71	30	4.5	Average imperical Kc (discluding the two outlying low values) and Hill et al
26.61	30	4.5	Victoria data (Pearse et al, 2002) and ARR initial loss and continuing loss
24.71	30	3.5	Average imperical Kc (discluding the two outlying low values) and Hill et al
24.71	35	4.5	Average imperical Kc (discluding the two outlying low values) and Hill et al
26.61	35	4.5	Victoria data (Pearse et al, 2002) and ARR initial loss and

			continuing loss

Results

Table 5-7 below shows the *kc* value, initial loss and continuing loss combination which generated the best fit to observed flood extents and surveyed water levels for temporal rainfall patterns at the two nearby pluviograph rainfall gauges. It also shows the corresponding peak flow in Natimuk and Little Natimuk creeks immediately upstream of the. The parameters and peak flows shown in Table 5-7 correspond with the hydraulic model inflow hydrographs shown below in Figure 5-11 and Figure 5-11.

Table 5-7 RORB Calibration Parameters – January 2011

	kc	IL	CL	Peak flow (m^3/s)	
				Natimuk Creek	Little Natimuk Creek
Polkemmet Road	26.6	35	4.5	99.6	36.8
Horsham AWS	26.6	35	4.5	90.7	30.0

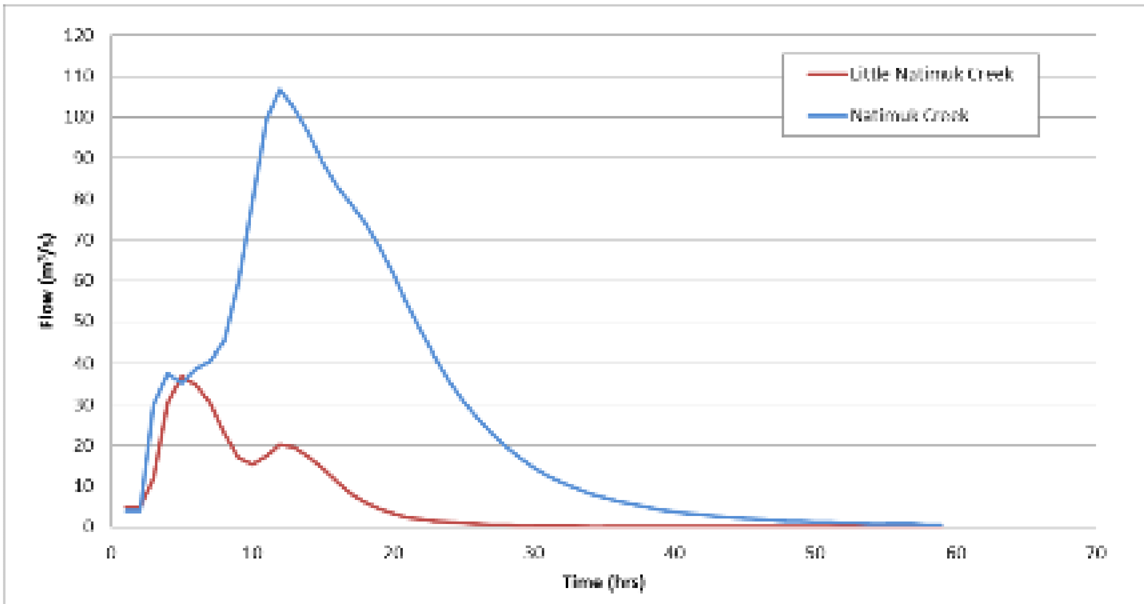

Figure 5-11 January inflow hydrographs extracted from RORB using the Polkemmet Road temporal pattern

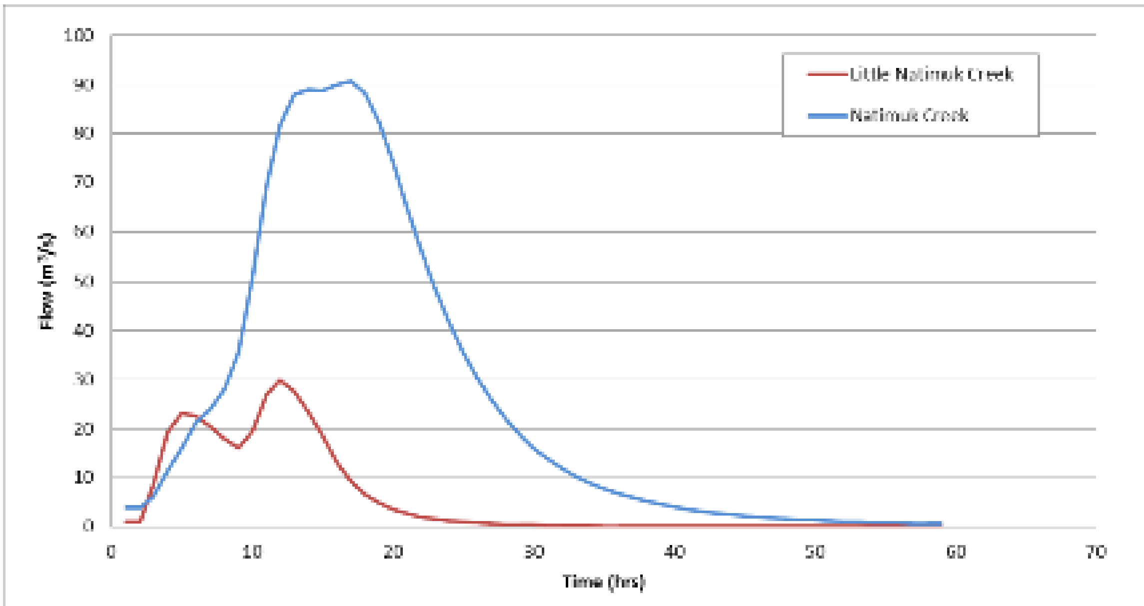

Figure 5-12 January inflow hydrographs extracted from RORB using the Horsham AWS temporal pattern

The peak water levels estimated by the hydraulic model with the above final verification flows were compared to the available 25 surveyed flood heights within Natimuk. At 20 of the 25 surveyed flood heights the modelled peak water levels were within 0.15 m, using the Polkemmet Road temporal pattern. Using the Horsham AWS temporal pattern 18 of the 25 surveyed flood marks were within 0.15 m. This was considered to be within the level of accuracy deemed appropriate for the study. Figure 5-13 and Figure 5-14 below show the modelled and observed flood extents as well as the accuracy in level at each of the 25 surveyed flood height locations. Positive values at these surveyed points indicate model estimations are higher than surveyed levels with negative values indicating model estimations are lower.

Four points outside the ±0.15 m range were clustered on Little Natimuk Creek around Schmidt Street. These points are shown below in Figure 5-15. Points upstream of this area matched within ±0.15 m and downstream points matched within 0.05 m. Of the four points, three show model results to be higher and one lower. The two points on Schmidt Street and Depot Lane are both described in the survey as 'ground level', meaning they were pegged at the extent of inundation. However, the aerial photography of the event contradicts this information suggesting the flood extent was greater than the pegged location, suggesting these survey points may be in error.

The aerial flood photograph shown in the below figures was taken during the flood event on the 12th January 2011 between 5:28 and 6.35 pm (3.5-4.5 hrs after the peak water level had passed on Natimuk Creek). Anecdotal evidence and RORB modelling suggests Little Natimuk Creek peaked before Natimuk Creek, supported by the drained areas shown in the aerial flood photograph.

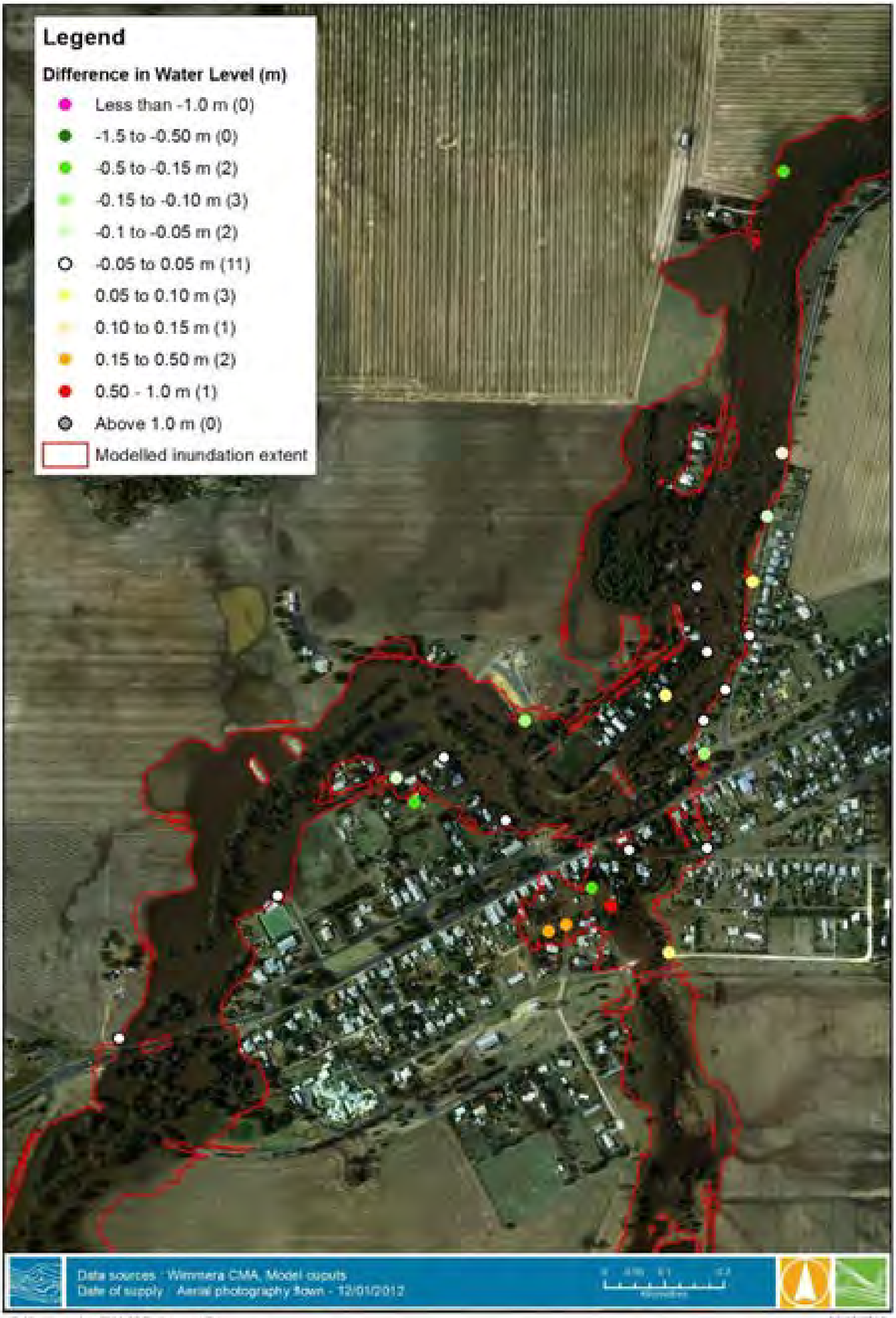

Figure 5-13 January 2011 hydraulic model results using the Polkemmet Road temporal pattern

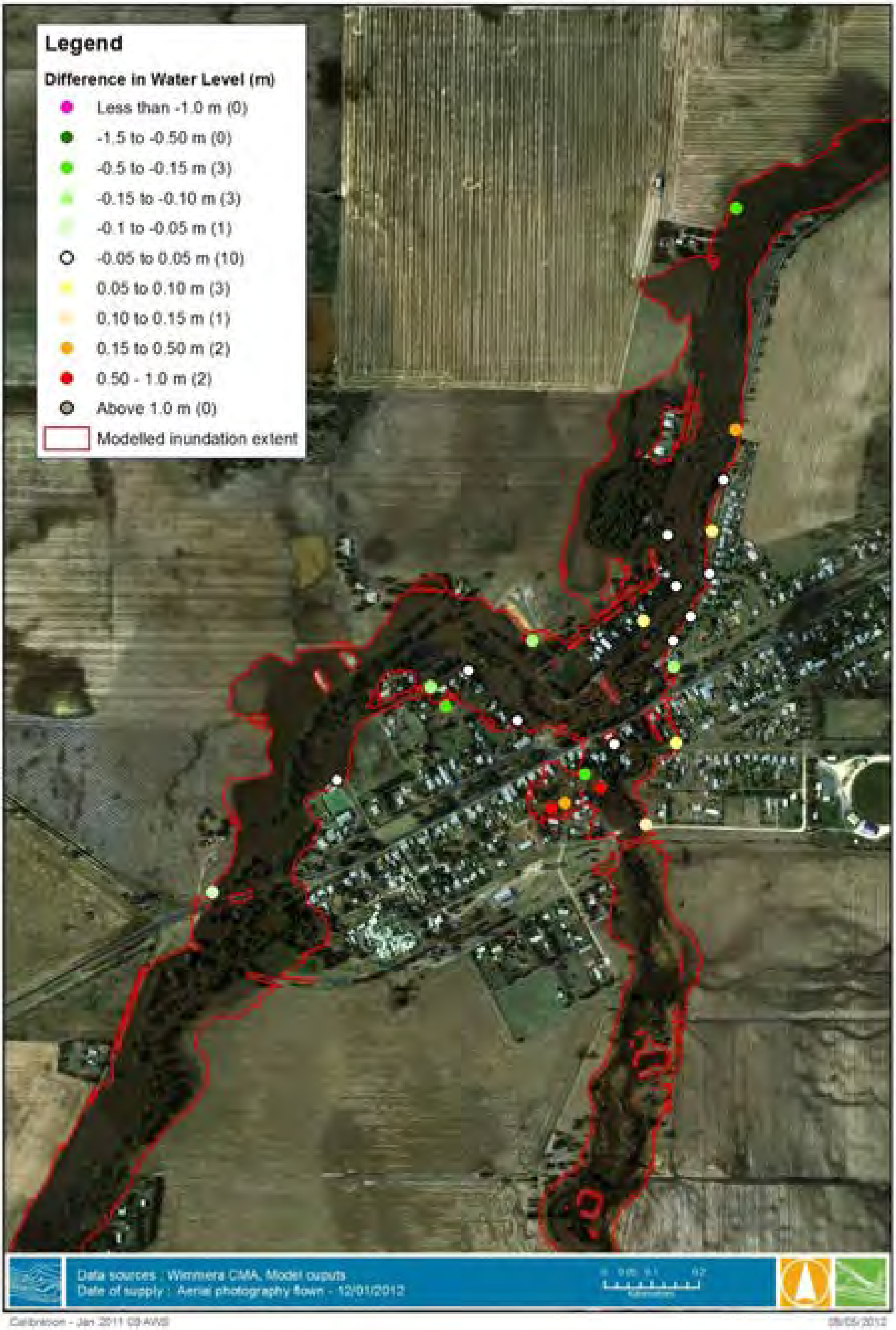

Figure 5-14 January 2011 hydraulic model results using the Horsham AWS temporal pattern

Figure 5-15 **January 2011 hydraulic model results on Little Natimuk Creek using the Horsham AWS temporal pattern**

Discussion

Hydraulic model predictions using the Polkemmet Road temporal pattern was shown to match 20 of the 25 surveyed flood heights within 150 mm. Similarly, model predictions using the Horsham AWS temporal pattern show 18 of the surveyed flood heights within 150 mm.

The Horsham AWS temporal pattern resulted in slightly lower peak water levels recorded in Natimuk Creek prior to the confluence with Little Natimuk Creek, and slightly higher peak water levels downstream of this point. This was due to the peaks of Natimuk Creek and Little Natimuk Creek event coinciding. The second peak of the Little Natimuk Creek hydrograph occurs later in concurrence with the Natimuk Creek peak flow when the Horsham AWS temporal pattern is adopted. This demonstrates why every flood is different, as slight changes to the spatial and temporal distribution of the rainfall can result in very different runoff hydrographs, resulting in different flood behaviour.

A survey was distributed to the community during the initial community engagement, requesting details and experiences of the January 2011 event. Comments received indicated Little Natimuk Creek and Natimuk Creek recorded maximum water levels at 11am and 2pm on 12th January respectively.

Table 5-8 below shows the timing of the observed and modelled peaks for both the Polkemmet Road and Horsham AWS temporal rainfall patterns, as well as the timing of the aerial photography.

Table 5-8 Modelled, observed and aerial photograph timing

Scenario	Timing of peak level	
	Little Natimuk Creek	Natimuk Creek
Observed	11 am 12th January	2.30 pm 12th January
Modelled – Polkemmet Road	3 am 12th January	10 am 12th January
Modelled – Horsham AWS	11 am 12th January	3.00 pm 12th January
Aerial photography flown	5:28-6:35 pm 12 January	

The modelled extent of inundation closely matches the extent shown by the aerial photography. The exception to this is Little Natimuk Creek, however it is known that the aerial photography used to compare the modelled and observed flood extent was flown after the peak level in the waterway. The extent in the aerial photo clearly shows signs of a larger flood extent earlier in the flood, with inundation on some sealed roads receded and upstream paddocks drained. The Horsham AWS temporal pattern provides the best fit to the observed flooding in terms of timing of the peak of the flood.

The January 2011 event was tested using a uniform spatial pattern and the Natimuk rainfall gauge total event depth. This showed changes in the peak flow in Natimuk Creek and Little Natimuk Creek to be 18.8 and 3.5 m^3/s respectively, whilst using the Horsham AWS temporal pattern. This again demonstrates that every flood is different, with a change in spatial distribution of rainfall in the January 2011 event reducing the peak flow in Natimuk Creek to a flow closer to the December 2010 event.

The January 2011 event was also tested with an increased roughness value of 0.1 in the 1D branch of Natimuk Creek all the way through to the lake. This increased the water level in the creek at 77 Lake Avenue by only 0.1 m, with even less impact on water level in town. This shows that the flood levels within the township are relatively insensitive to roughness in the creek downstream of town and through to the lake.

5.2.3 December 2010

Antecedent conditions

The December 2010 event occurred between the 6th and 8th of December. Over the week prior to this event the catchment received over 10 mm of rainfall, with approximately another 30 mm in the last week of November. This rainfall in the lead up to the December 2010 event ensured that catchments were sufficiently wet to generate a higher proportion of runoff with the events rainfall, with the catchment runoff responding quickly.

From this information it could be expected that the December 2010 event would have a lower initial loss than the January 2011 flood event.

Model simulations

The RORB model was run with eleven different combinations of initial and continuing loss, with a *kc* of 26.61 (adopted from the January 2011 verification), remaining constant for all simulations. Table 5-9 below summarises the range and combination of initial and continuing loss values trialled.

Table 5-9 December 2010 model verification simulations

Il (mm)	Cl (mm/hr)	Comment
10	2.5	Lowest recommended ARR initial and continuing loss
31.7	4.5	Losses recommended by Hill et al
15	2.5	Losses within the range recommended by ARR
20	2.5	Losses within the range recommended by ARR
25	2.5	Losses within the range recommended by ARR
30	2.5	Losses within the range recommended by ARR
35	2.5	Highest recommended ARR initial and continuing loss
25	4.5	ARR initial loss and Hill et al continuing loss
30	4.5	ARR initial loss and Hill et al continuing loss
30	3.5	ARR initial loss and continuing loss between Hill et al and ARR
35	4.5	Highest recommended ARR initial loss and Hill et al continuing loss

The results of this sensitivity analysis are shown in Appendix H.

Results

Table 5-10 below shows the *kc* value, initial loss and continuing loss which generated the best fit to the limited observed information for the December 2010 flood event. The final adopted parameter values and peak flows for the December 2010 verification shown in Table 5-10 correspond with the hydraulic model inflow hydrographs shown below in Figure 5-16. These hydrographs were used as inflow boundaries in the hydraulic model, producing the flood inundation shown in Figure 5-17 for the December 2010 flood event.

Table 5-10 RORB Calibration Parameters – December 2010

December 2010	kc	IL	CL	Peak flow (m^3/s)	
				Natimuk Creek	Little Natimuk Creek
	26.6	10	4.5	71.7	28.9

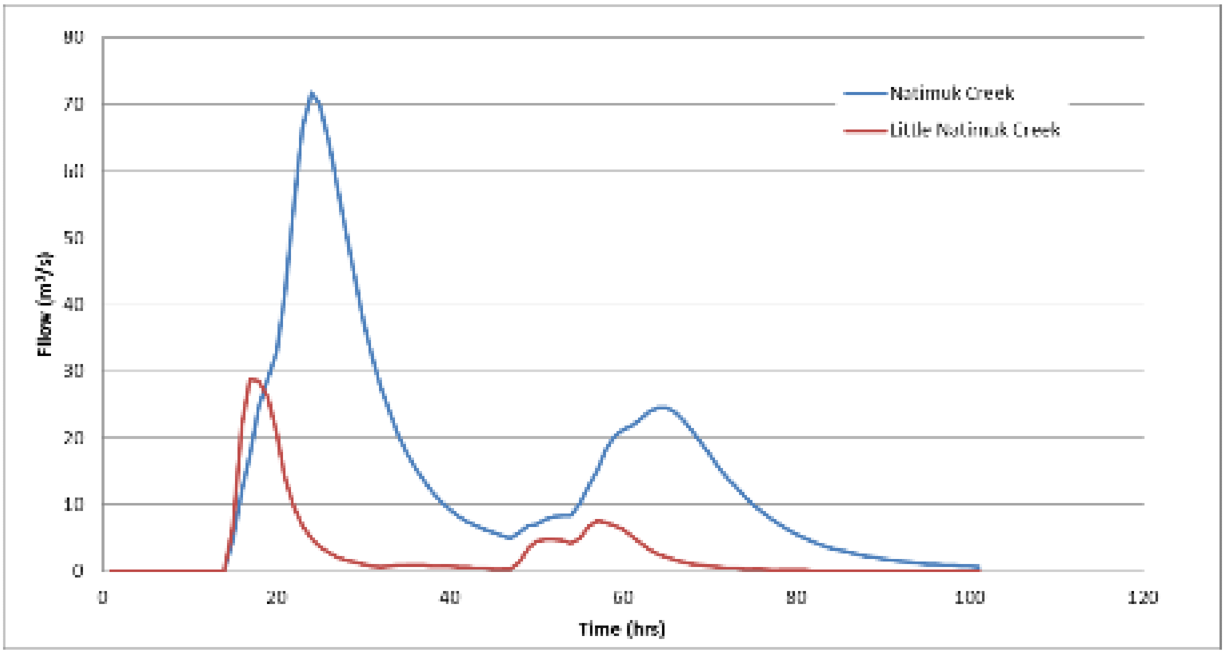

Figure 5-16 December inflow hydrographs

Figure 5-17 December hydraulic model results

Discussion

The final adopted initial loss value for the December 2010 event was considerably less than that of the January 2011 event, as was expected from the analysis of the antecedent conditions. In January 2011 close to no rain was recorded in the three weeks prior to the event, as compared to significant rainfall over the two weeks prior to the event.

The December 2010 flood event had considerably less information available to calibrate to as compared to the January 2011 event. Despite the lack of data, efforts were made to verify the hydraulic model results to anecdotal comments and photography of the December 2010 event.

A member of the Natimuk Flood Investigation Steering Committee submitted a marked aerial photograph demonstrating where he believed the December 2010 flood waters reached on Elmes Street. This matched closely to the modelled flood extent as shown in Figure 5-18.

Other anecdotal comments relating to the December 2010 event and how they compare to the model results are discussed below in Table 5-11.

Additional figures showing the hydraulic model results are shown in Appendix H.

Figure 5-18 December 2010 anecdotal flood extent on Elmes Street

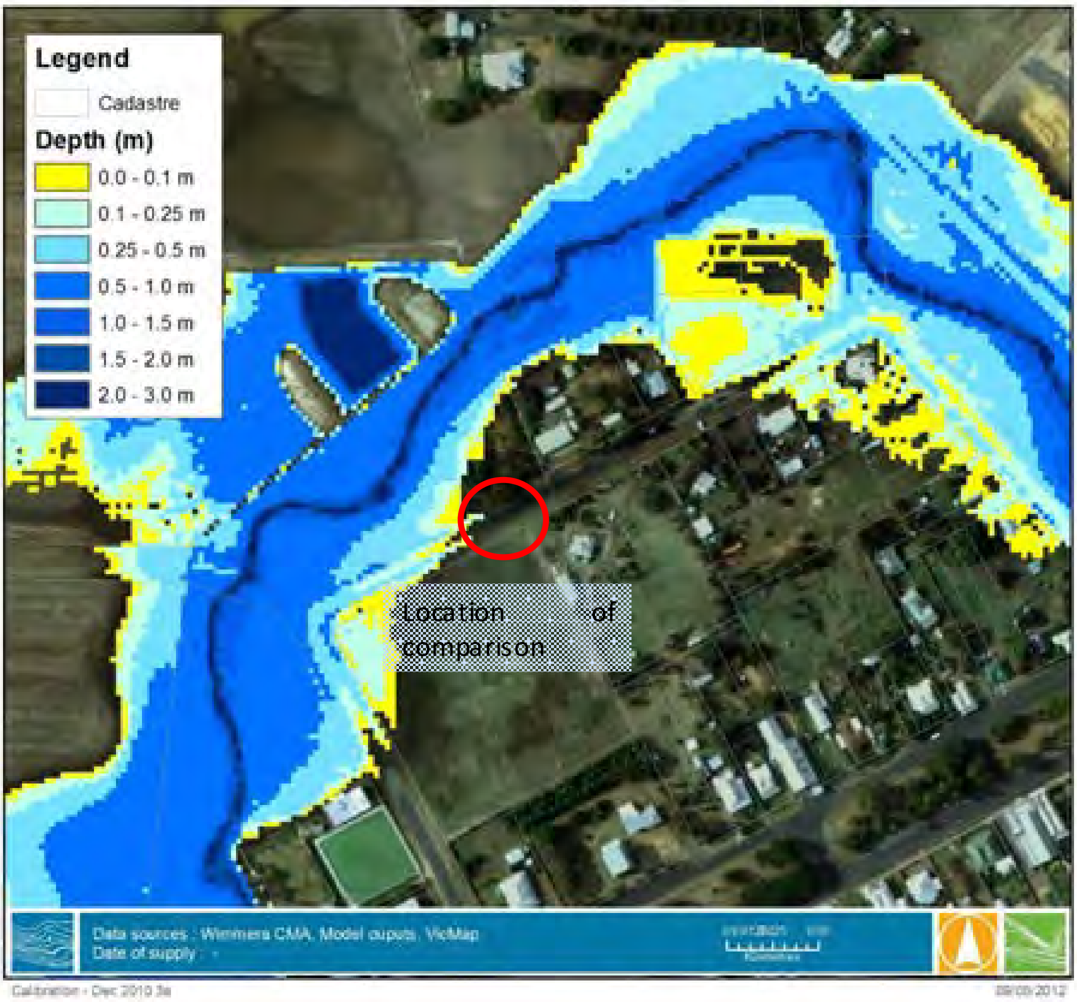

Figure 5-19 December 2010 modelled flood extent on Elmes Street

Table 5-11 Anecdotal comments and model comparisons

Comment	Model representation
'January was worse'	Model predictions have shown the January event to be have higher inundation than December
'Water did not overtop the Main Street in Natimuk'	Modelled water levels are not overtopping the Main Street
'January was 40 cm higher' – comment was made in reference to 19 Elmes Street	Difference in the two modelled events is 0.27 m
January was 20 cm higher' – comment was made in reference to 59 Lake Avenue	Difference in the two modelled events is 0.32 m
January was 61 cm higher' – comment was made in reference to Natimuk Main Street	Difference in the two modelled events ranges between 0.4-0.5 cm
Water covered the back of the property and entered the shed – comment was made in reference to 87 Main Street	Water from Little Natimuk Creek does not quite reach the property but owners have stated they were affected by overland flow from the west. See Figure 5-19.

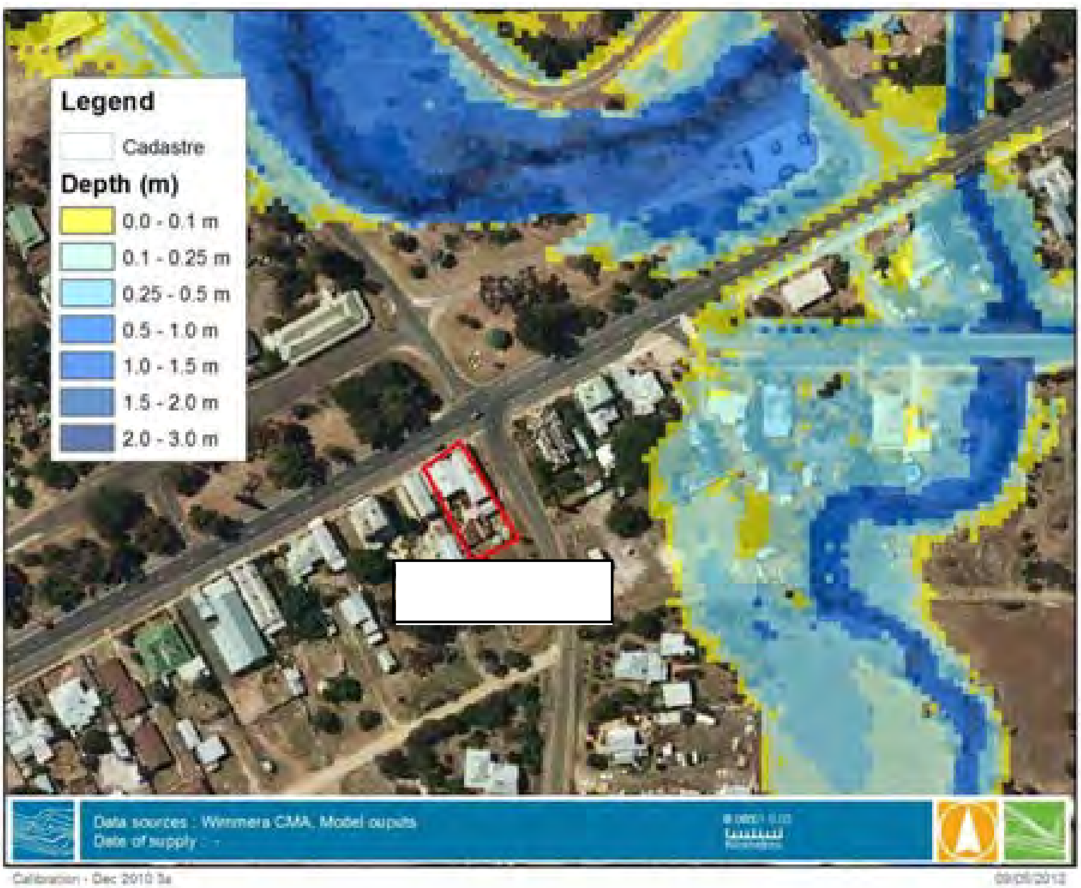

Figure 5-20 December 2010 modelled flood extent at 87 Main Street

6. DESIGN EVENT MODELLING

Following on from the successful RORB model and hydraulic model verification, a series of design events were modelled. This required the adoption of various design parameters to be included within RORB to generate design hydrographs for input into the hydraulic model.

This section presents the design parameter selection and subsequent flows generated within RORB, presents the hydraulic model results.

6.1 RORB Design Methodology

6.1.1 Design Rainfall Depths

Design rainfall depths were determined using the Bureau of Meteorology online IFD tool[24]. The rainfall Intensity Frequency Duration (IFD) parameters were generated for a location in Natimuk (141.950E, 36.750S) and are shown in Table 6-1 below.

Table 6-1 Catchment IFD Parameters

$2I_1$ (mm/hr)	$2I_{12}$ (mm/hr)	$2I_{72}$ (mm/hr)	$50I_1$ (mm/hr)	$50I_{12}$ (mm/hr)	$50I_{72}$ (mm/hr)	G	F2	F50	Zone
17.1	3.04	0.829	37.4	6.47	1.65	0.34	4.39	14.83	2

6.1.2 Design Temporal Pattern

Design temporal patterns were taken from the Generalised Short Duration Method (GSDM)[25] and Generalised South East Australian Method (GSAM)[26] as well as Australian Rainfall and Runoff (1987) in order to understand the sensitivity of the flood estimates to temporal pattern. For events greater than 100 year ARI GSDM patterns were used for durations up to and including 12 hours and unsmoothed GSAM patterns for durations greater than 12 hours.

The Natimuk catchment is located within Zone 2 of the temporal pattern map as defined in Australian Rainfall and Runoff (1987); however it is located close to the boundary between Zone 2 and Zone 6. For this reason temporal patterns from both zones were tested against the temporal patterns from observed events.

A comparison of the design temporal patterns was made with the December 2010 and January 2011 observed temporal patterns. The temporal pattern from the Longerenong gauge was used for December 2010 and the Polkemmet Road gauge for January 2011. The 48 hour duration was selected for the design temporal patterns for Zone 2 and 6 for comparison with the observed temporal. A comparison of the temporal patterns is shown in Figure 6-1 below and indicates that the Zone 2 temporal pattern is more indicative of the observations made during December 2010 and January 2011. The Zone 6 temporal pattern was therefore not adopted for further analysis.

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[24] BoM Online IFD Tool - http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml *Accessed: December 2011*

[25] BoM, 2003 – The estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method

[26] BoM, 2006 – Guidebook to the Estimation of Probable Maximum Precipitation: GENERALISED SOUTHEAST AUSTRALIA METHOD

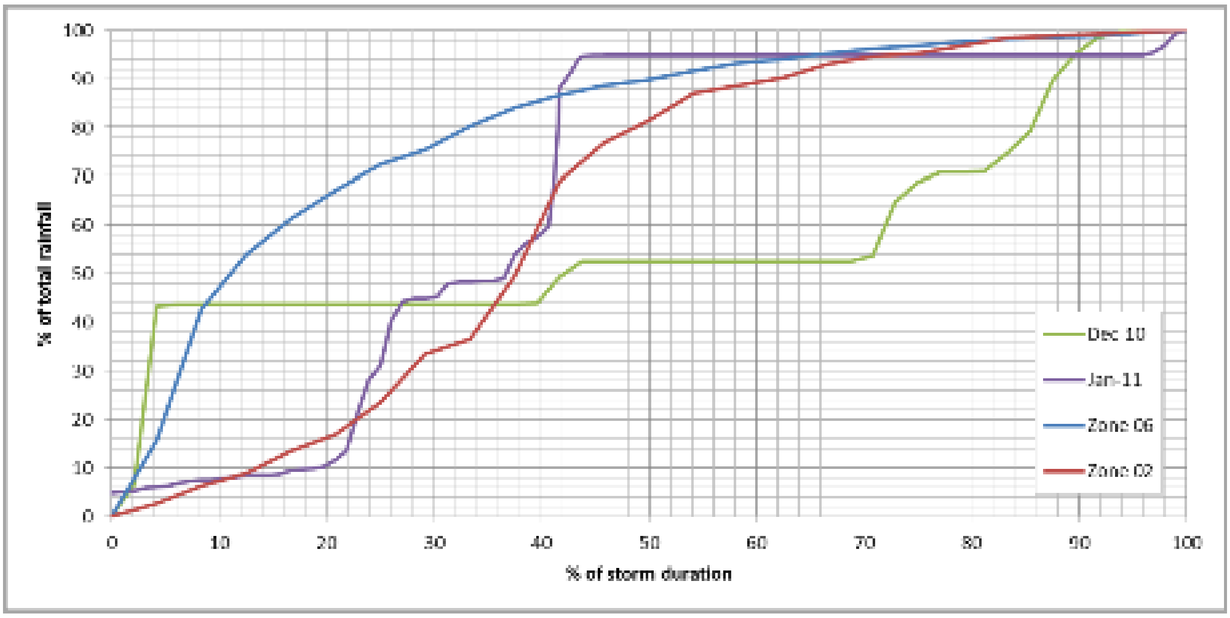

Figure 6-1 Design and observed temporal patterns

6.1.3 Design Spatial Pattern

A uniform spatial rainfall pattern (i.e. the same rainfall depths applied to the entire catchment) were adopted for the generation of design flood hydrographs for events up to the 100 year ARI event. This is considered to be appropriate given the size of the catchment (157 km^2) and topography (i.e. no mountain ranges). For the 200 year ARI event the possible spatial variation in rainfall was explored. The GSAM spatial pattern for the catchment of the Natimuk Creek catchment upstream of Natimuk was obtained using the method outlined by the Bureau of Meteorology[27].

6.1.4 Areal Reduction Factors

Areal reduction factors were used to convert point rainfall to areal estimates and are used to account for the variation of rainfall intensities over a large catchment. Siriwardena and Weinmann (1996)[28] areal reduction factors were applied to the catchment area upstream of Natimuk as recommended in Australian Rainfall and Runoff (1987)[29].

6.1.5 Design Model Parameters

Routing Parameters

Various regional *kc* estimation equations were trialled for the verification process and a value of 26.6 was found to provide a good fit to the observed flood information for the December 2010 and January 2011 flood events. Table 5-3 shows a comparison between this study's adopted *kc* value and regional *kc* estimates. A final *kc* value of 26.6 and m value of 0.8 was also adopted as routing parameters for design flood estimation. The adopted *kc* value of 26.6 is the same as that predicted by the regional prediction equation from Pearse et al (2002)[18] and is consistent with a number of other regional prediction equations.

[27] BoM, 2003 – The estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method
[28] Siriwardena and Weinmanm, 1996 - Derivation of Areal Reduction Factors For Design Rainfalls (18 - 120 hours) in Victoria
[29] ARR 1987 – Australian Rainfall and Runoff

Design Losses

This study adopted an initial loss of 20 mm and a continuing loss of 3 mm as the design loss parameters. The loss parameters were applied across all ARI events and durations. The loss parameters adopted are in the mid-range of the design loss parameters as set out within AR&R 1987[30] but are less than that recommended in Hill et al[31].

The design losses were not based on the losses adopted in the calibration events. Losses applied for the December 2010 and January 2011 are highly dependent on antecedent catchment conditions and are not suitable for design flood estimation. However they did provide guidance to the potential range of losses that may be applied.

Other studies in the Wimmera catchment have used similar loss values for design purposes. A summary of these values is shown below in Table 6-2. The design losses were less than that adopted for the January 2011 model verification process.

Table 6-2 Loss values for other Wimmera flood investigations

Study	Initial Loss (mm)	Continuing loss (mm/hr)
Yarriambiack Creek Flows Study (Water Technology, 2009)	20	2.5
Warracknabeal and Beulah Flood Study (Water Technology, 2007)	15	3.0
Halls Gap Flood Study (Water Technology, 2008)	20	2

Figure 6-2, Figure 6-3 and Table 6-3 below shows the change in peak flow rate for Natimuk Creek upstream of the Natimuk township with increasing initial losses for a range of design floods. Continuing losses have remained constant as has the uniform spatial pattern and ARR, Zone 2 temporal patterns. As expected, as the initial loss increases the peak flow rate decreases. There is significant variation in the magnitude of the peak flow reduction for a given reduction in initial loss over the range of design events considered. This is driven by the depth of rainfall at each ARI and the temporal pattern of the design event. The lower ARI (5, 10, 20 year) events lose a greater proportion of their total depth than the larger events (50, 100 year). The lower ARI events also all have temporal patterns that are slightly weighted toward the front of the event, so the loss impacts on the peak of the event more heavily, as opposed to the slightly back loaded 50, 100 and 200 year ARI events, as shown in Figure 6-3.

[30] ARR 1987 – Australian Rainfall and Runoff

[31] Hill et al, 1996 – Empirical analysis of data to derive losses from design flood estimation in South Eastern Australia

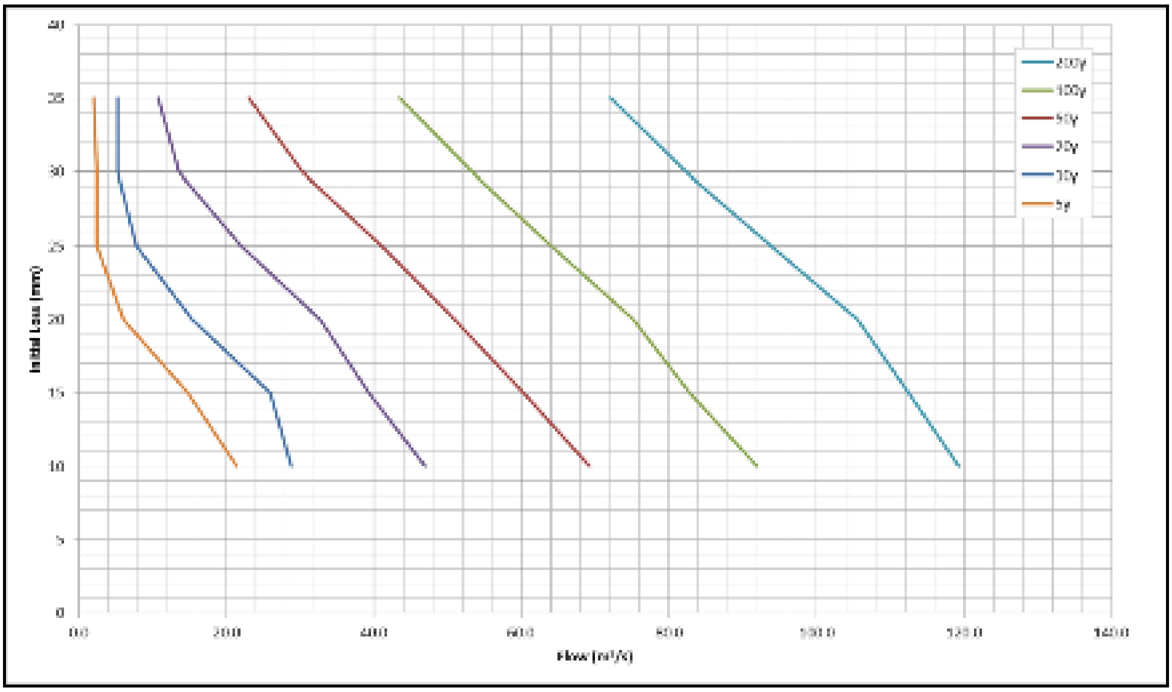

Figure 6-2 Impact of initial loss on peak flow

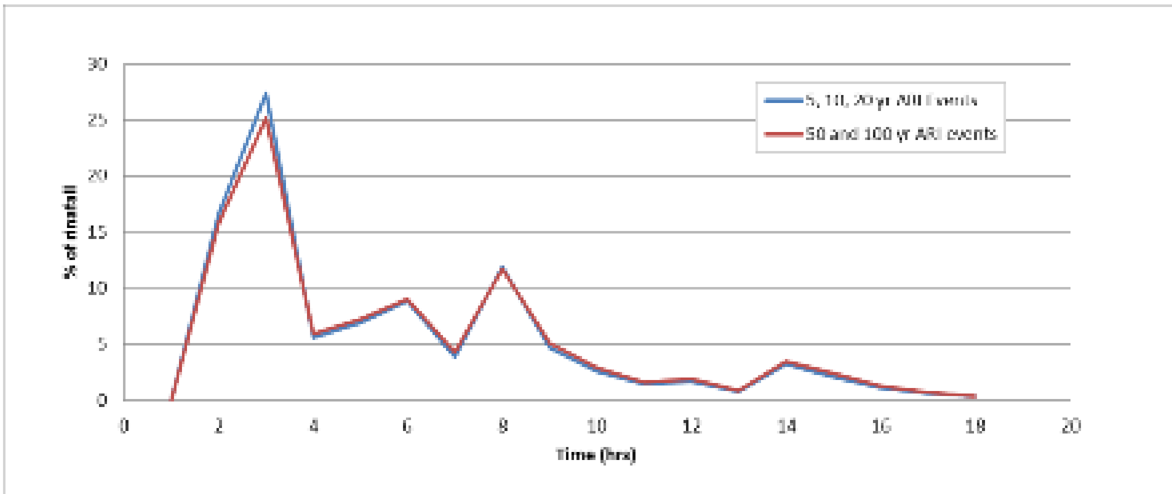

Figure 6-3 Temporal Patterns across the range of modelled events

Table 6-3 Impact of initial loss on peak flow

	Initial Loss (mm)					
ARI Peak Flow (m^3/s)	10	15	20	25	30	35
200 year ARI	119.3	112.5	105.6	93.9	82.3	72.0
100 year ARI	91.9	82.8	75.1	64.1	53.3	43.5
50 year ARI	69.2	60.3	51.0	41.0	30.3	22.9
20 year ARI	46.9	39.4	32.7	22.0	13.5	10.8
10 year ARI	28.7	26.0	15.4	7.8	5.3	5.3
5 year ARI	21.3	14.8	6.1	2.5	2.5	2.0

A common method of verifying the design losses adopted is to compare the resultant modelled peak flows to that of flood frequency analysis. As there are no streamflow gauges in the catchment, flood frequency analysis cannot be used to verify design losses for Natimuk Creek.

6.1.6 Design Flood Hydrographs

Existing Conditions

Design flood hydrographs were determined at input locations into the hydraulic model. A range of storm durations were run (10 min – 72 hours) to ensure that the critical storm durations of the large branches and smaller tributaries were determined. Table 6-4 displays the calculated design peak flows and critical storm durations for various ARI events.

Table 6-4 RORB model design peak flows and critical storm durations at selected locations

	Natimuk Creek at Natimuk		Little Natimuk Creek US of Natimuk	
ARI	**Peak flow (m^3/s)**	**Duration (hrs)**	**Peak flow (m^3/s)**	**Duration (hrs)**
5	16.2	72h	6.5	72h
10	28.4	72h	11.1	72h
20	47.6	30h	18.3	30h
50	71.6	30h	26.5	30h
100	99.9	18h	33.5	30h
200	122.0	12h	43	6h

The design flows indicate that the December 2010 and January 2011 flood events were approximately a 50 year ARI event and slightly below a 100 year ARI event respectively in both Natimuk Creek at Natimuk and Little Natimuk Creek at Natimuk.

Table 6-4 shows longer than expected critical durations for the more frequent rainfall events. These design events have adopted a uniform spatial pattern and a Zone 2 Australian Rainfall and Runoff temporal pattern. Temporal rainfall patterns can be 'filtered' to remove the occurrence of imbedded bursts of higher rainfall intensity which have a higher ARI than the event modelled. Figure 6-4 and Figure 6-5 show the 5 year ARI unfiltered and filtered temporal patterns respectively. In both sets of temporal patterns the 72 hour storm has the highest percentage of depth over the shortest percentage of time. A comparison of the unfiltered and filtered temporal patterns for the 72 hour and 6 hour events is shown below in Figure 6-6. The figure shows filtering of the temporal pattern has reduced the rainfall intensity in both the 72 hour and 6 hour events. This reduction is greater in the 72 hour storm.

The full list of RORB model peak flows and durations for Natimuk Creek and Little Natimuk Creek are shown in Appendix B. This analysis shows that the 72 hour duration for the 5 year ARI event produces a peak flow that is roughly double that of the 6 hour duration. The critical design storm duration was assumed to be significantly less than 72 hours due to the size of the catchment and the known response time from recent floods, but the recommended design storm temporal patterns generate higher peak flows for these longer durations. The 72 hour duration event was included in the design modelling along with other shorter durations, with the resulting flood levels from the hydraulic model enveloped to produce the maximum water level across multiple duration events. This is a conservative approach and was approved by the Steering Committee prior to adoption.

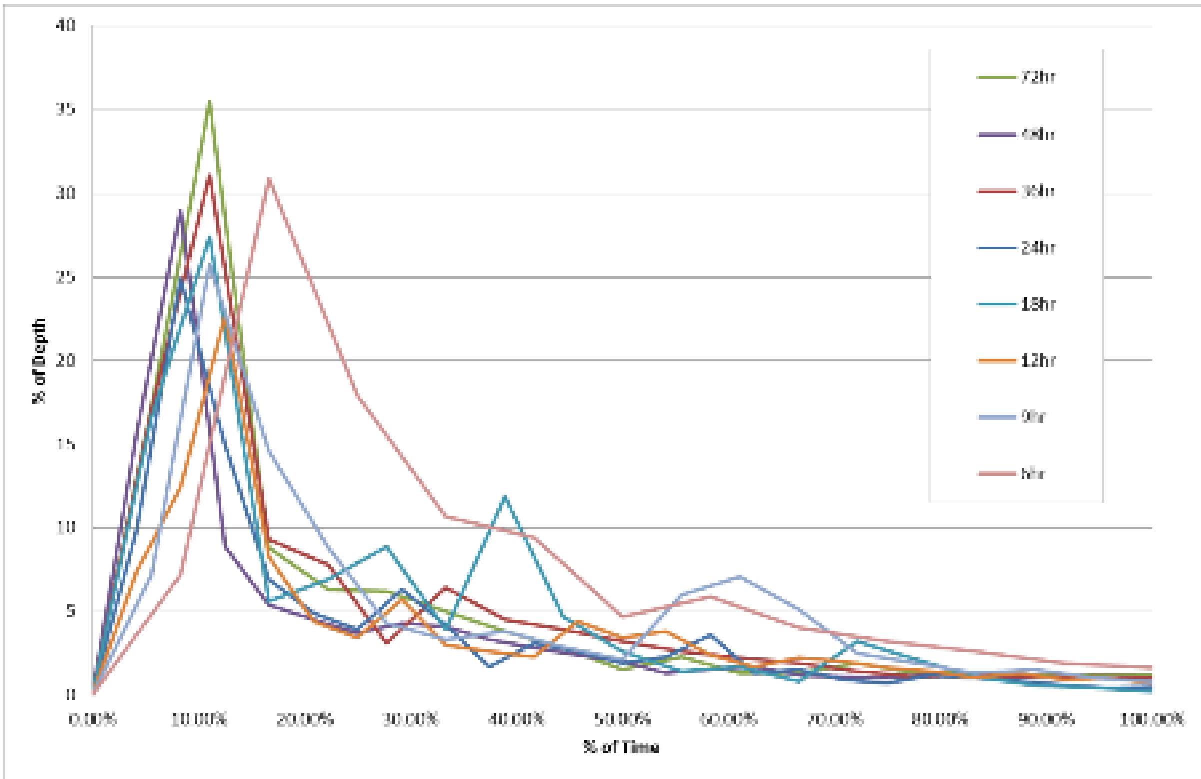

Figure 6-4 Unfiltered temporal patterns for the 5 year ARI

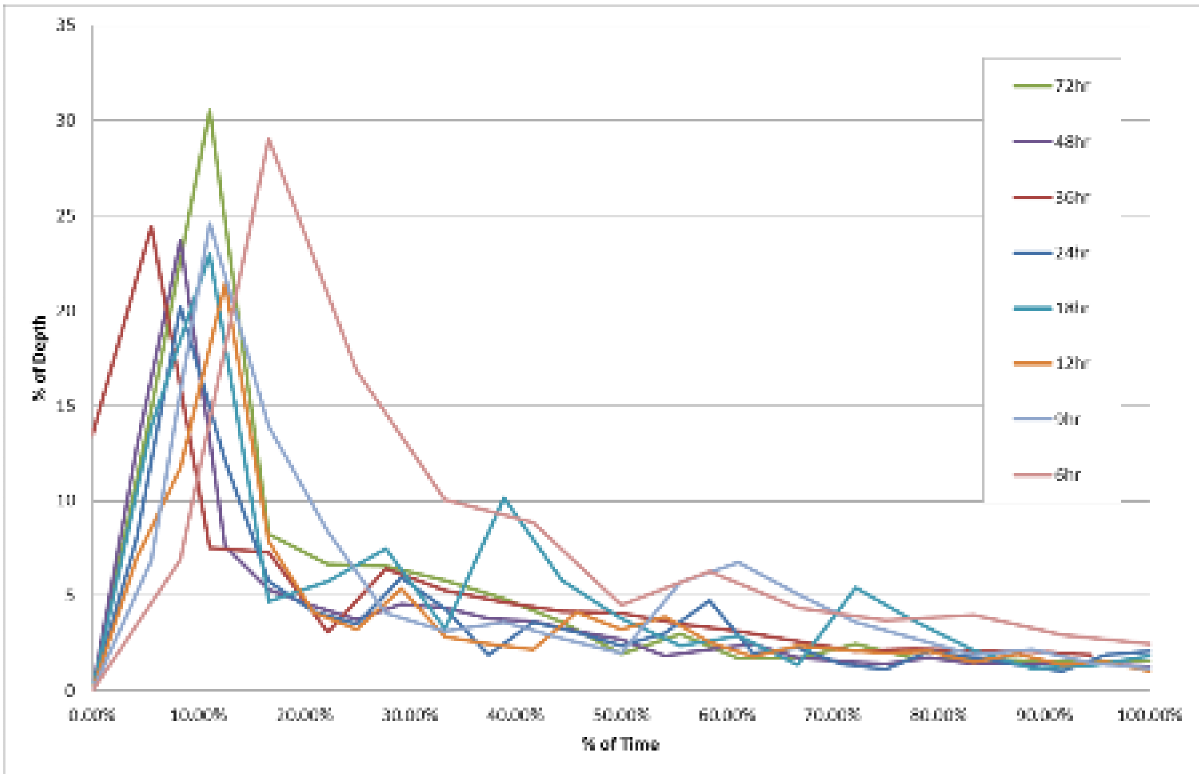

Figure 6-5 Filtered temporal patterns for the 5 year ARI

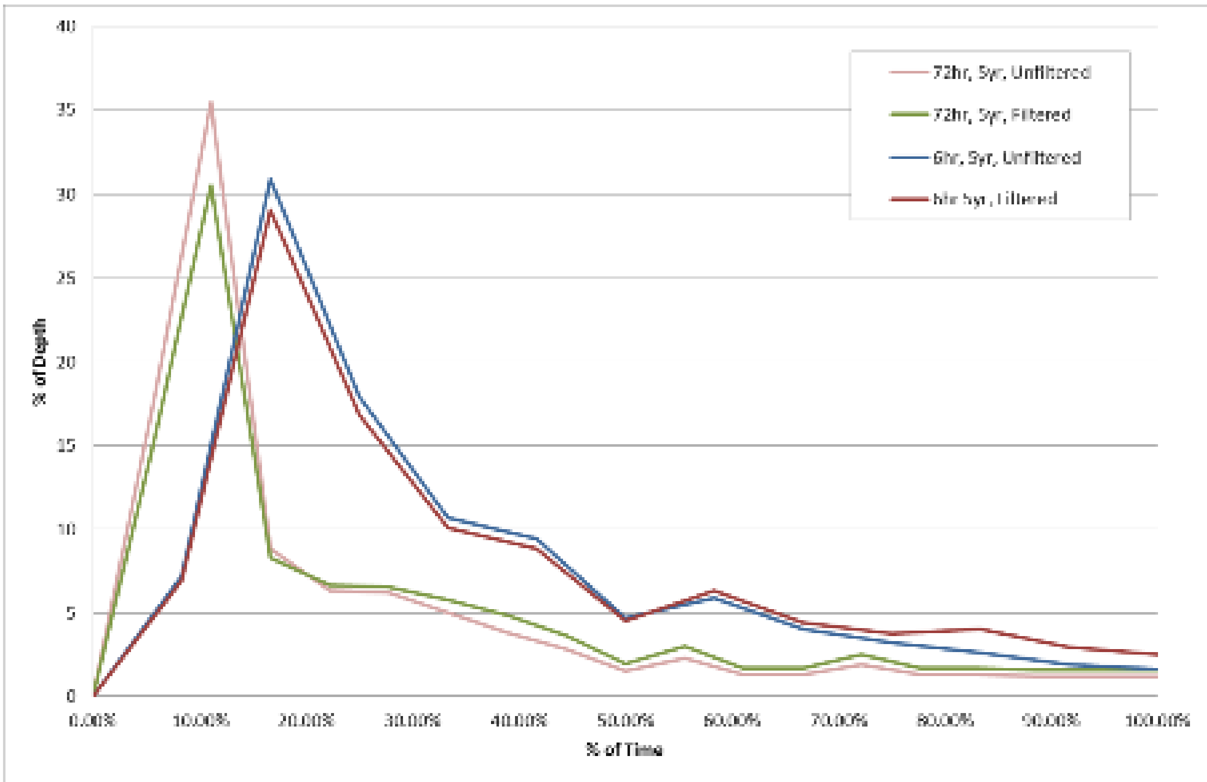

Figure 6-6 **Comparison of filtered and unfiltered temporal patterns for the 72 and 6 hour duration events**

6.1.7 Design Flow Validation

Rational Method

Probabilistic Rational Method[32] calculations were performed as a comparison to the RORB generated peak flows. The Rational Method estimated a higher 100 year ARI peak flow of 136.6 m^3/s, compared to the design 100 year flow (99.9 m^3/s) on Natimuk Creek at Natimuk. It also estimated a higher 100 year flow of 45.9 m^3/s compared to the design flow (33.5 m^3/s) on Little Natimuk Creek at Natimuk. The method of calculation is shown below:

$$Q_{100} = C_y \times I \times A$$

Where,

$$C_y = F_y \times C_{10}$$

$$I = Rainfall\ intensity\ (\frac{mm}{hr})$$

$$A = Area\ (km^2)$$

And;

$$F_y = 1.2$$

$$C_{10} = 0.9 \times f + C_{10}^1 \times (1 - f) = 10yr\ runoff\ coefficient = 0.21$$

$$F = Fraction\ Impervious$$

[32] ARR 1987 – Australian Rainfall and Runoff

$$C_{10}^{1} = the\ pervious\ area\ runoff\ coefficient = 0.126$$

Regional Method

A regional method for estimating a 100 year ARI peak flow in rural catchments (Grayson et al, 1996)[33] was applied to Natimuk. The peak 100 year ARI flow on Natimuk Creek at Natimuk was estimated as 173.3 m^3/s, much higher than the adopted design 100 year ARI peak flow (99.9 m^3/s). The regional method estimated peak 100 year ARI flows for Little Natimuk Creek at Natimuk as 54.4 m^3/s, again much higher than the adopted design 100 year ARI peak flow of 33.5 m^3/s. The method of calculation is shown below:

$$Q_{100} = 4.67\ A^{1.763}$$

6.1.8 Probable Maximum Flood

The Probable Maximum Flood (PMF) was determined using the rapid assessment method. This method is obtained from a study by Nathan et al (1994)[34], and uses a prediction equation based on a sample of 56 catchments in South Eastern Australia, ranging in size from 1 km^2 to 10,000 km^2. The equation derived by Nathan et al (1994) was as follows:

$$Q_p = 129.1\ A^{0.616}$$

$$V = 497.7\ A^{0.984}$$

$$T_P = 1.062\times10^{-4}\ A^{-1.057}\ V^{1.446}$$

Where Q_p is the PMF peak flow (m^3/s), A is the catchment area (km^2), V is the hydrograph volume (ML) and T_P is the time to peak of the hydrograph (h).

This method was considered appropriate given the uncertainty associated with the extrapolation of an uncalibrated model beyond the credible limit. It is also considered appropriate as we note that PMF estimates, by their nature, have an extreme degree of uncertainty. It should be noted that the total catchment area and location of the catchment are within the specified range for application of this equation.

The Nathan et al (1994)[35] method includes regression equations that can be used to obtain preliminary estimates of the peak, volume, and time to peak of Probable Maximum Floods (PMFs). Following calibration of the hydraulic model, some consideration was given to the timing and hydrograph shape of PMF flows.

The estimated peak flow rate for the Natimuk and Little Natimuk creek catchments was 2,388 m^3/s and 938 m^3/s respectively.

6.1.9 Climate Change

An understanding of the impact of climate change was determined for the 10, 100 and 200 year ARI events. Rainfall intensities were increased by 32% to produce revised peak flows and hydrographs

[33] Grayson et al, 1996 - Estimation Techniques in Australian Hydrology

[34] Nathan. R. J., Weinmann, P. E. and Gato, S. A. (1994), 'A Quick Method for Estimating Probable Maximum Flood in South Eastern Australia', Water Down Under 94 Conference Proc., Adelaide, November, 1994, pp. 229-234.

[35] Nathan. R. J., Weinmann, P. E. and Gato, S. A. (1994), 'A Quick Method for Estimating Probable Maximum Flood in South Eastern Australia', Water Down Under 94 Conference Proc., Adelaide, November, 1994, pp. 229-234

for these events. This increase is consistent with recommendations from the CSIRO publication Climate Change in Australia (CSIRO, 2007)[36].

The increase of 32% in design rainfall intensity was shown to increase peak flows by approximately 100% at a 10 year ARI event and between 50 to 60% at the 100 and 200 year ARI events, as shown in Table 6-5.

Table 6-5 RORB model design peak flows and critical storm durations with climate change

ARI	Natimuk Creek at Natimuk			Little Natimuk Creek US of Natimuk		
	Peak flow (m^3/s)			Peak flow (m^3/s)		
	Existing	Climate Change	Duration (hrs)	Existing	Climate Change	Duration (hrs)
10	28.4	57.8	72h	11.1	21.7	72h
100	99.9	166.8	18h	33.5	52.8	30h
200	122.0	200.8	12h	43	69.5	6h

6.1.10 Adopted Design Hydrology Summary

Based on the hydrological analysis undertaken the following parameters and assumptions were adopted for design purposes:

- Design rainfall depths from IFD analysis of Natimuk location
- Zone 2 design temporal patterns for events up to the 100 year ARI
- GSDM temporal patterns for 200 year ARI events with a duration less than 12hrs
- GSAM temporal patters for 200 year ARI events with a duration greater than 12rhs
- Siriwardena and Weinmann areal reduction factors for area upstream of Natimuk
- Uniform spatial rainfall pattern across the entire catchment for the events up to the 100 year ARI
- GSDM spatial patterns for 200yr ARI events less than 12hrs
- GSAM spatial patterns for 200yr ARI events greater than 12hrs
- Design losses; an initial loss of 20 mm and a continuing loss of 3 mm
- *kc* of 26.6 and *m* of 0.8
- Storm durations from 2hr to 72hr modelled

6.2 Hydraulic Design Flood Modelling

Design flood modelling for the 5, 10, 20, 50, 100 and 200 year ARI and PMF events was completed using the hydraulic model parameters determined during the hydraulic model calibration. The sensitivity of the Natimuk Creek catchment to climate change was also modelled using a 32% increase in rainfall intensity with results shown in Appendix A.

After the January 2011 flood event a damaged foot bridge was removed from Little Natimuk Creek on the upstream side of Jory Street, and was replaced with an extension of the road culvert. This change did not make any significant impact to the hydraulic capacity of the structure (with the same size culverts in place), particularly for large floods where Jory St is overtopped, but the revised structure arrangement was included in the design modelling.

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

The design event modelling assumed Natimuk Lake to be full prior to the design event. The sensitivity of this assumption was tested on the 100 year ARI event and was shown to be negligible, with the difference in water level through Natimuk only 1-2 mm with the lake empty and full at the start of the event.

Utilizing the updated hydraulic model, the design flood events were mapped for the 5, 10, 20, 50, 100 and 200 year ARI events along with the Probable Maximum Flood (PMF). Each design event was run for the critical duration events for Natimuk Creek and Little Natimuk Creek; this included the 6, 12, 18, 30 and 72 hour events. The results for each ARI event were then combined taking the maximum water levels and a suite of flood maps produced, as shown in Appendix A. Figure 6-7 shows all design flood extents overlayed on the one figure for comparison.

Long-sections of both Natimuk and Little Natimuk Creek were developed to show the impact of structures on the range of ARI events. These are shown below in Figure 6-9 and Figure 6-10. The long sections were extracted along the centreline of each waterway as shown below in Figure 6-8.

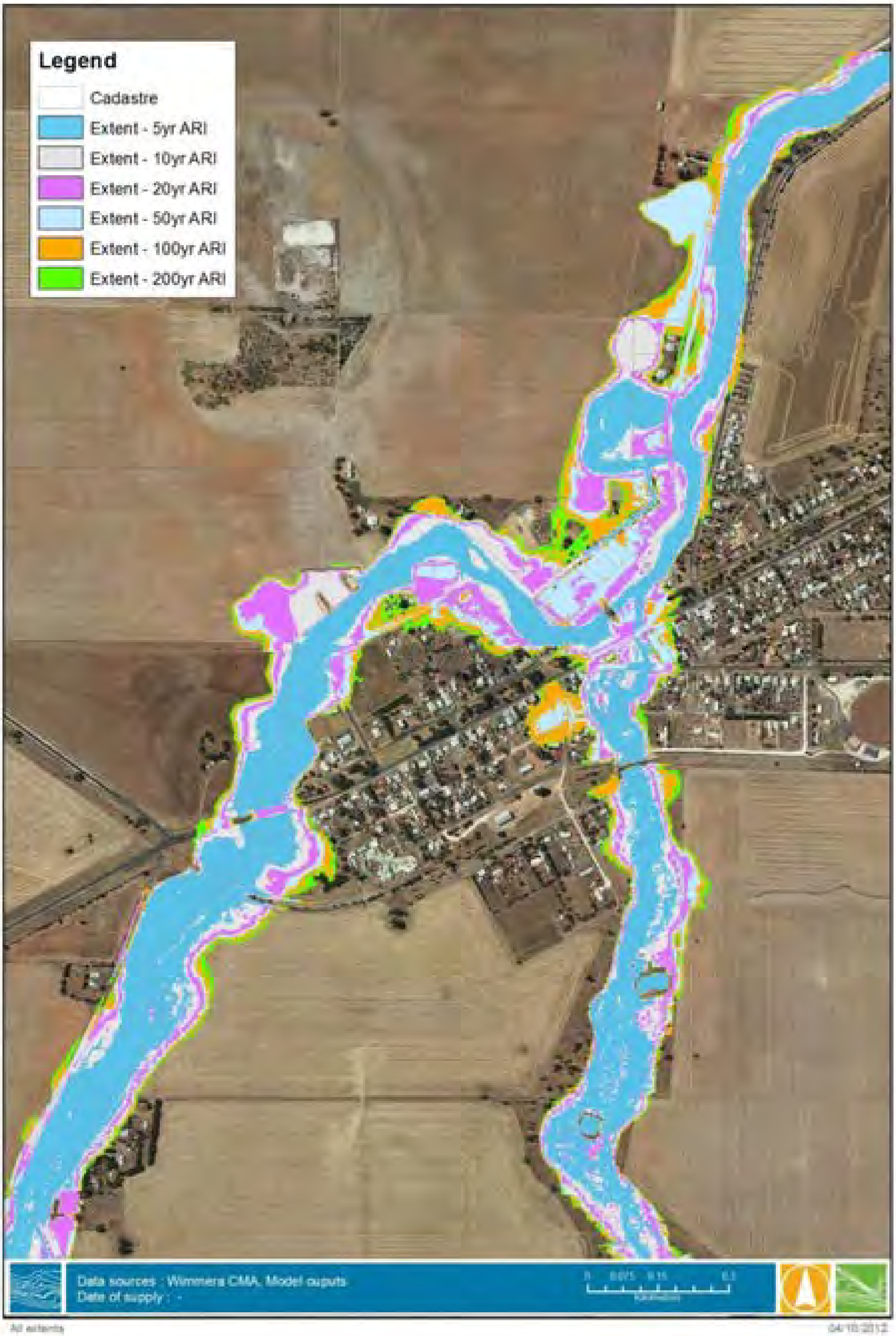

Figure 6-7 Hydraulic modelling design flood extents.

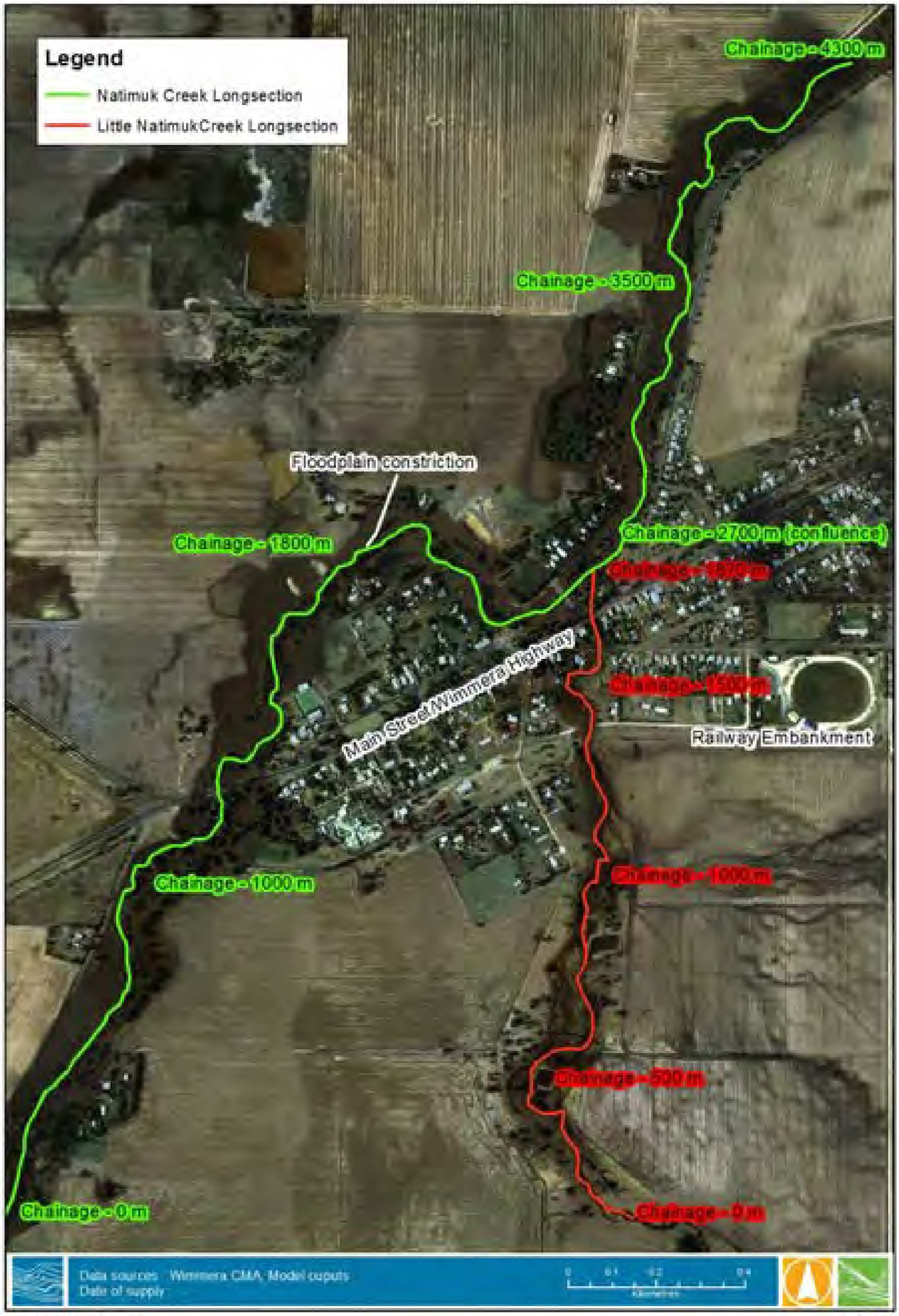

Figure 6-8 **Long-section locations along Natimuk Creek and Little Natimuk Creek**

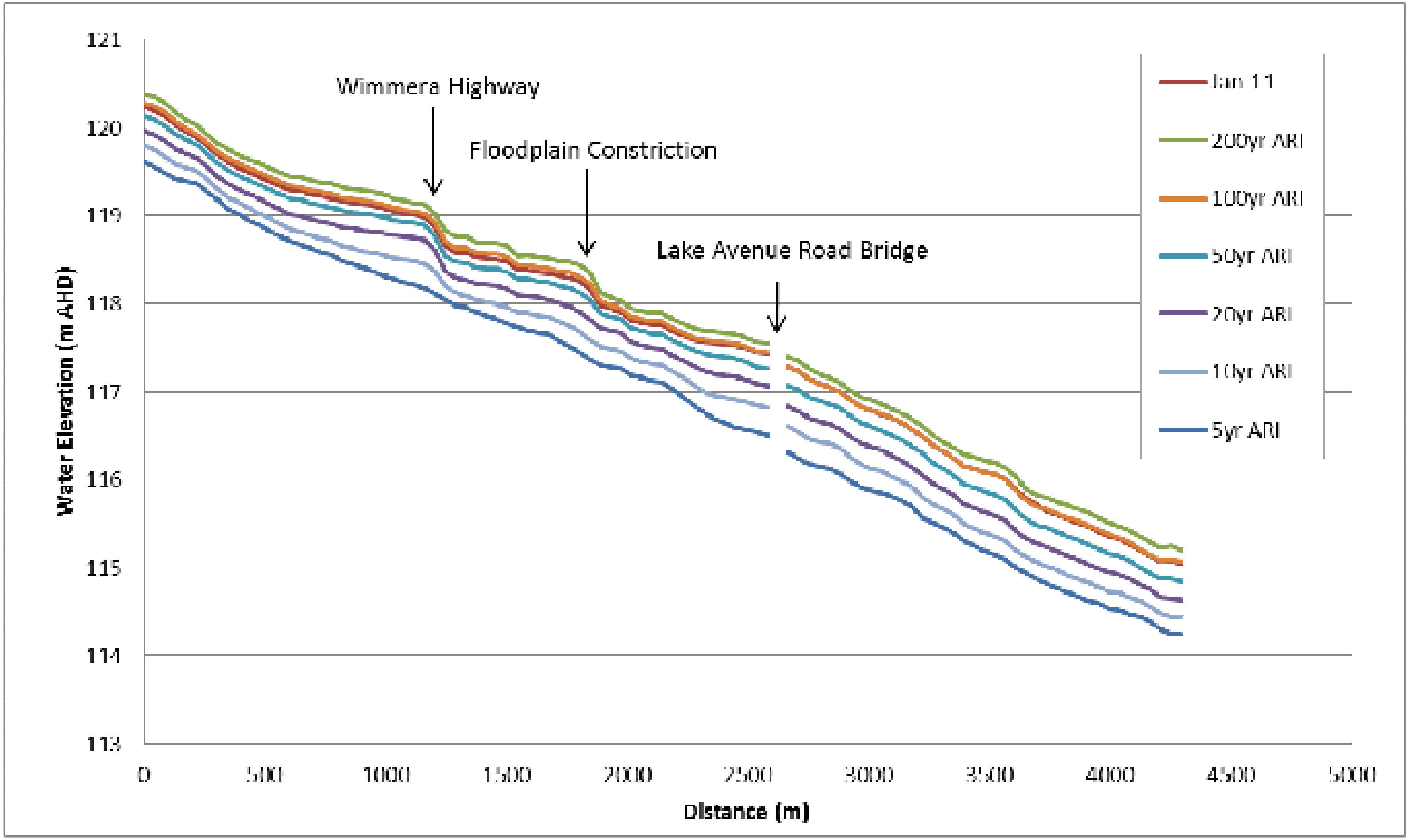

Figure 6-9 Longitudinal sections of Natimuk Creek hydraulic model predictions for the range of design events considered

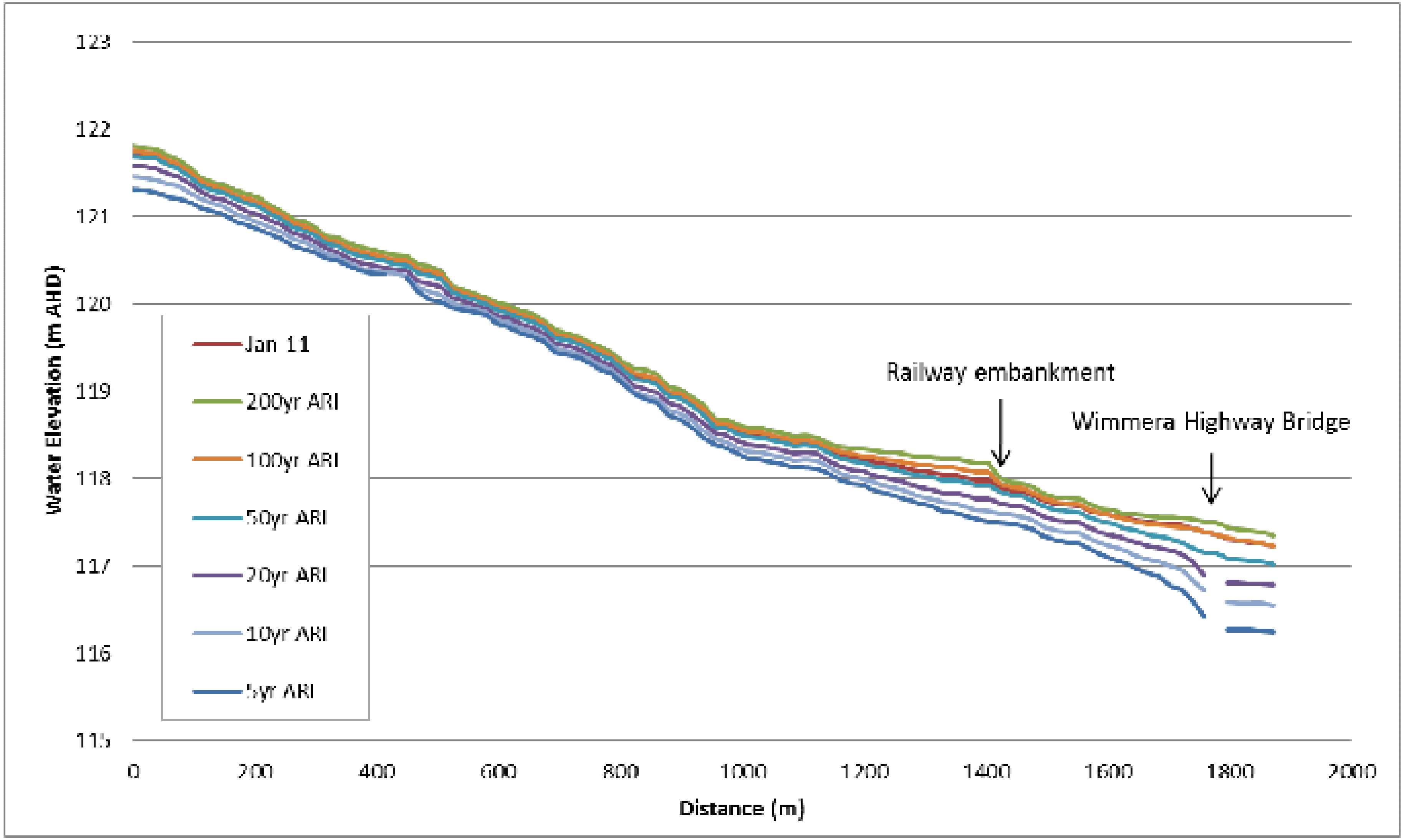

Figure 6-10 Longitudinal sections of Little Natimuk Creek hydraulic model predictions for the range of ARIs considered

6.3 Design Flood Behaviour

The following comments describe the key flood characteristics in Natimuk Creek and Little Natimuk Creek for each design event.

5 Year ARI Event

- Natimuk Creek
  - The Wimmera Highway is not inundated by Natimuk Creek;
  - The corner of Sudholz Street and Elmes Street inundated up to 0.3 m;
  - Water in close proximity to Lake Avenue; and
  - Water backing up from Natimuk Creek into the Lake Avenue bywash channel and entering lower sections of land to the east of Lake Avenue.
- Little Natimuk Creek
  - Downstream of the railway culverts, water inundates Station Street to a depth up to 0.5 m;
  - Jory Street is overtopped to a depth less than 0.1 m;
  - The Wimmera Highway does not become inundated by Little Natimuk Creek;
  - Some Jory Street properties at risk of above ground inundation (2-12 Jory Street); and

10 Year ARI Event

- Natimuk Creek
  - Areas of Creek Road becoming inundated to maximum depth of approximately 0.3 m;
  - The Wimmera Highway remains dry;
  - Further inundation of the corner of Sudholz Street and Elmes Street;
  - Inundation beginning to impact on the northern most corner of Elmes Street;
  - Water entering both ends of the Lake Avenue bywash channel; and
  - Water inundating Lake Avenue to a depth of approximately 0.2 m, in the area of 47-61 Lake Avenue.
- Little Natimuk Creek
  - Increase in depth along Station Street immediately downstream of the culverts underneath the railway embankment;
  - Jory Street is overtopped to a depth of approximately 0.25 m;
  - The Wimmera Highway does not become inundated;
  - Further Jory Street properties at risk of above ground inundation (2-14 Jory Street); and
  - Properties located at 83 Mains Street and 3 Schmidt Street may also receive some above ground inundation.

20 Year ARI Event

- Natimuk Creek
  - Areas of Creek Road becoming inundated to maximum depth of approximately 0.4 m;
  - The Wimmera Highway becomes inundated to a depth of approximately 0.1 m
  - Inundation of the corner of Sudholz Street and Elmes Street and the northern most corner of Elmes Street, this may impact on access to homes along Elmes Street with depths reaching up to 0.2 m;
  - Water entering both ends of the Lake Avenue bywash channel, overtopping the channel outlet on Lake Avenue;

- Water inundating Lake Avenue to a depth of approximately 0.3 m in several areas; and
- Properties along Lake Avenue inundated above ground level (47-65 Lake Avenue).

- Little Natimuk Creek
  - Increase in depth to 0.5 m along Station Street immediately downstream of the culverts underneath the railway embankment;
  - Jory Street is overtopped to a depth of approximately 0.4 m;
  - The Wimmera Highway does not become inundated;
  - Further Jory Street properties at risk of above ground inundation (2-14 Jory Street); and
  - Properties located at 81, 75-79, 71, 83 and 85 Main Street and 3-7 Schmidt Street also receive some above ground inundation.

50 Year ARI Event

- Natimuk Creek
  - Areas of Creek Road becoming inundated to maximum depth of approximately 0.4 m;
  - The Wimmera Highway becomes inundated to a depth of approximately 0.1 m;
  - Inundation of the corner of Sudholz Street and Elmes Street and the northern most corner of Elmes Street, this may impact on access to homes along Elmes Street with depths reaching up to 0.2 m;
  - Water entering both ends of the Lake Avenue bywash channel, overtopping the channel outlet on Lake Avenue;
  - Water inundating Lake Avenue to a depth of approximately 0.3 m in several areas; and
  - Properties along Lake Avenue inundated above ground level (47-65 Lake Avenue).
- Little Natimuk Creek
  - Increase in depth to 0.75 m along Station Street immediately downstream of the culverts underneath the railway embankment;
  - Jory Street is overtopped to a depth of approximately 0.5 m;
  - The Wimmera Highway becomes inundated to a depth 0.1-0.2 m;
  - Further Jory Street properties at risk of above ground inundation (2-16 Jory Street);
  - Properties located at 81, 75-79, 71, 83 and 85 Main Street may observe above ground inundation; and
  - Schmidt Street overtopped to a very shallow depth, properties at 3-7 Schmidt Street and the rear of 95 and 97 Main Street may also see some ground inundation.

100 Year ARI Event – peak approximately resembles the January 2011 event

- Natimuk Creek
  - Areas of Creek Road becoming inundated to maximum depth of approximately 0.5 m;
  - The Wimmera Highway becomes inundated to a depth of approximately 0.2-0.3 m;
  - Significant inundation of Sudholz Street and Elmes Street, access to homes along Elmes Street is limited with depths reaching up to 0.3-0.4 m;
  - Properties along Elmes Street inundated above ground level (3-27 Elmes Street);
  - Water entering both ends of the Lake Avenue bywash channel, overtopping the channel outlet on Lake Avenue;
  - Significant inundation of Lake Avenue to a depth exceeding 0.5 m in several areas; and
  - Properties along Lake Avenue inundated above ground level (27-75 Lake Avenue).
- Little Natimuk Creek

- Properties along Duncan Street in close proximity to Little Natimuk Creek may be at risk of above ground inundation;
- Increase in depth to 0.8 m along Station Street immediately downstream of the culverts underneath the railway embankment;
- Jory Street is overtopped to a depth of approximately 0.6 m;
- The Wimmera Highway becomes inundated to a depth 0.2-0.3 m;
- Jory Street properties at risk of above ground inundation (2-16 Jory Street);
- Properties located at 81, 75-79, 71, 83 and 85 Main Street may observe above ground inundation; and
- Schmidt Street overtopped to a depth of approximately 0.3 m, properties at 3-7 Schmidt Street and the rear of 95 and 97 Main Street may also receive some above ground inundation.

200 Year ARI Event

- Natimuk Creek
  - Areas of Creek Road becoming inundated to maximum depth of approximately 0.5-0.6 m;
  - The Wimmera Highway becomes inundated to a depth of in excess of 0.3 m;
  - Significant inundation of Sudholz Street;
  - Elmes Street almost entirely inundated, access to homes along Elmes Street is limited with depths reaching up to 0.5 m;
  - Properties along Elmes Street inundated above ground level (3-31 Elmes Street);
  - Water entering both ends of the Lake Avenue bywash channel, overtopping the channel outlet on Lake Avenue;
  - Significant inundation of Lake Avenue to a depth exceeding 0.6 m in several areas; and
  - Properties along Lake Avenue inundated above ground level (27-75 Lake Avenue).
- Little Natimuk Creek
  - Properties along Duncan Street in close proximity to Little Natimuk Creek may be at risk of above ground inundation;
  - Increase in depth to in excess of 0.8 m along Station Street immediately downstream of the culverts underneath the railway embankment;
  - Jory Street is overtopped to a depth of approximately 0.8 m;
  - The Wimmera Highway becomes inundated to a depth 0.5 m;
  - Jory Street properties at risk of above ground inundation (2-16 Jory Street);
  - Properties located at 73-79, 81, 71, 83 and 85 Main Street may receive above ground inundation with some allotments completely inundated; and
  - Schmidt Street overtopped to a depth of approximately 0.6 m, properties at 3-7 Schmidt Street and the rear of 95 and 97 Main Street may also receive some above ground inundation.

This summary of flood behaviour for each design flood event was prepared with a number of other flood intelligence outputs, with the aim of providing a condensed summary of flood behaviour in order to assist in emergency response when a flood occurs.

7. CATCHMENT RAINFALL-ON-GRID MODELLING

7.1 Overview

To model the entire Natimuk Creek Catchment a 'rainfall-on-grid' model was developed. The purpose of the model was to generate a coarse 100 year ARI extent which the Wimmera CMA could use to assist in the planning referral process where they currently have a limited amount of data.

The model extent and estimated drainage lines are the same as were developed during the RORB model construction, discussed in detail in Section 4.2.1.

7.2 Model Construction

7.2.1 Rainfall

The rainfall-on-grid model covering the Natimuk Creek catchment was run for the 100 year ARI event only. The catchment response to rainfall is different depending on the location within the catchment. Higher in the catchment the peak flood level is typically generated by intense short duration rainfall events. Further down the catchment the storm that produces the peak flood level may typically have a longer duration. The 2 hour and 18 hour duration events were simulated and enveloped for the rainfall-on-grid modelling.

Zone 2 temporal rainfall patterns were adopted from AR&R, Book 2[37], and total rainfall depths were extracted using the BoM Online IFD Tool[38] extracted at the Natimuk rainfall gauge.

7.2.2 Topography

The hydraulic model topography was constructed using a combination of LiDAR data sets flown in 2004 and 2011. The areas covered by each dataset are shown Figure 2-8 earlier in this report. In the areas of overlap the 2011 dataset was used in preference to 2004 as it was considered to be more up to date and more accurate as detailed in Section 2.4.

The combined LiDAR data sets were re-sampled to a 15 m grid resolution for the creation of the model topography to allow for reasonable run times and resolution of results.

7.2.3 Boundary conditions

The hydraulic model contained one boundary at the downstream end of Natimuk Lake, this was a fixed water level boundary set at the full operational level of the Lake. Similar to the other hydraulic model simulations completed as part of this project Natimuk Lake was assumed to be at full supply level during the modelling.

[37] AR&R, 1987 – Australian Rainfall and Runoff
[38] BoM Online IFD Tool - http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml *Accessed: December 2011*

7.3 Model Verification

7.3.1 Overview

The rainfall-on-grid model was verified by comparing to 100 year ARI flows and water levels produced during the RORB modelling and detailed hydraulic modelling of the Natimuk township.

To verify the rainfall-on-grid model predictions, rainfall losses and hydraulic roughness values applied to the model were altered until results reflected that of the detailed hydraulic modelling for the Natimuk township. Changes in rainfall losses and hydraulic roughness were shown to have significant impacts on the model results throughout the catchment.

7.3.2 Losses and Mannings 'n'

Losses were applied to the rainfall-on-grid model in a similar fashion to the RORB model, using an initial and continuing loss model. These losses were changed throughout the verification process.

A uniform value of Mannings 'n' was applied to the model extent, this value was also altered to change the peak flow rate, timing of the peak and predicted water levels and extents.

Table 7-1 and Table 7-2 below show the impact on peak flow at Natimuk for various combinations of rainfall losses and Mannings 'n' roughness, with comparison to the adopted RORB model peak flows.

7.3.3 Results

As discussed previously the rainfall-on-grid model was run for the 100 year ARI event for 2 hour and 18 hour durations to simulate the maximum water level and extent across the Natimuk Creek catchment. The Natimuk Creek flow was extracted at the Western Highway, and the Little Natimuk Creek flow was extracted at the railway embankment.

The results are presented below in a series of tables and figures.

Table 7-1 Estimated 100 year ARI 2 hour duration event peak flows

Model simulation	Losses	Mannings 'n'	Natimuk Creek peak flow (m^3/s)	Little Natimuk Creek peak flow (m^3/s)
RORB	IL – 20 mm CL – 3 mm	-	54.0	23.5
ROG 01	IL – 0 mm CL – 0 mm	0.03	161.6	94.1
ROG 02	IL – 20 mm CL – 3 mm	0.03	41.6	23.7
ROG 03	IL – 12mm, CL – 3mm	0.03	54.9	35.6
ROG 04	IL – 12mm, CL – 3mm	0.04	42.5	29.8
ROG 05	IL – 10 mm CL -3 mm	0.05	44.1	26.9

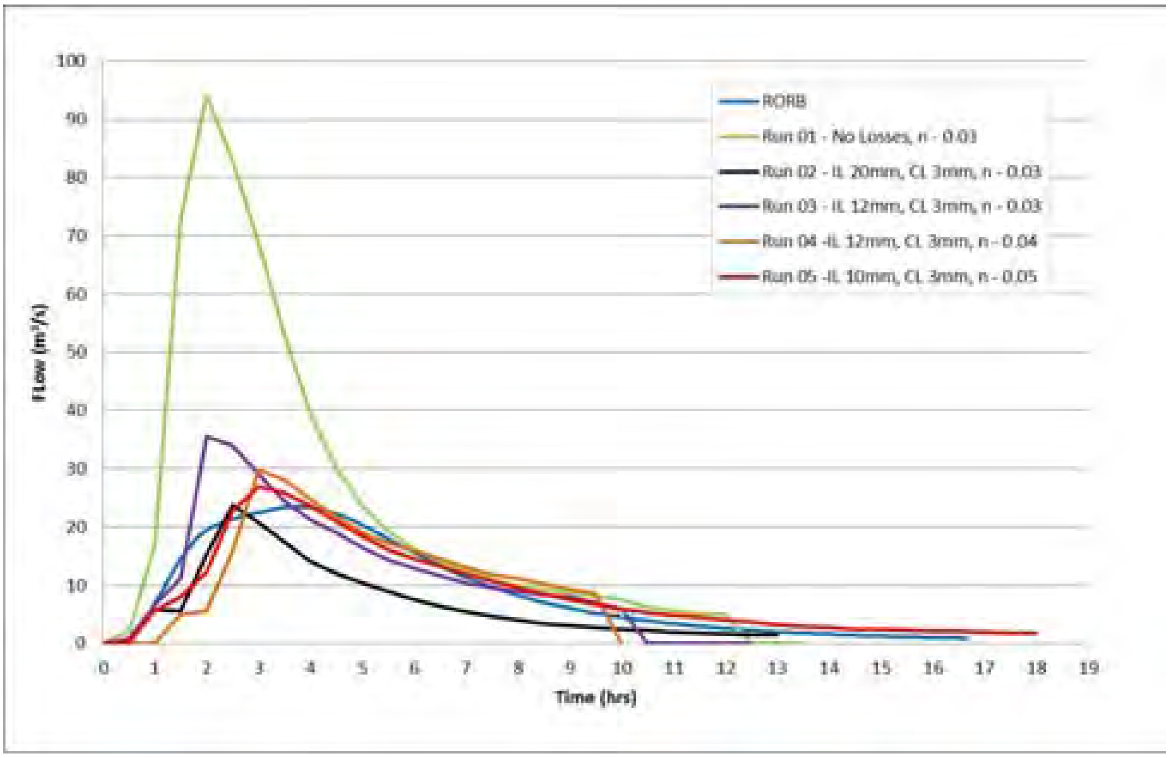

Figure 7-1 **Little Natimuk Creek 100 year ARI 2 hour duration event rainfall-on-grid and RORB hydrographs**

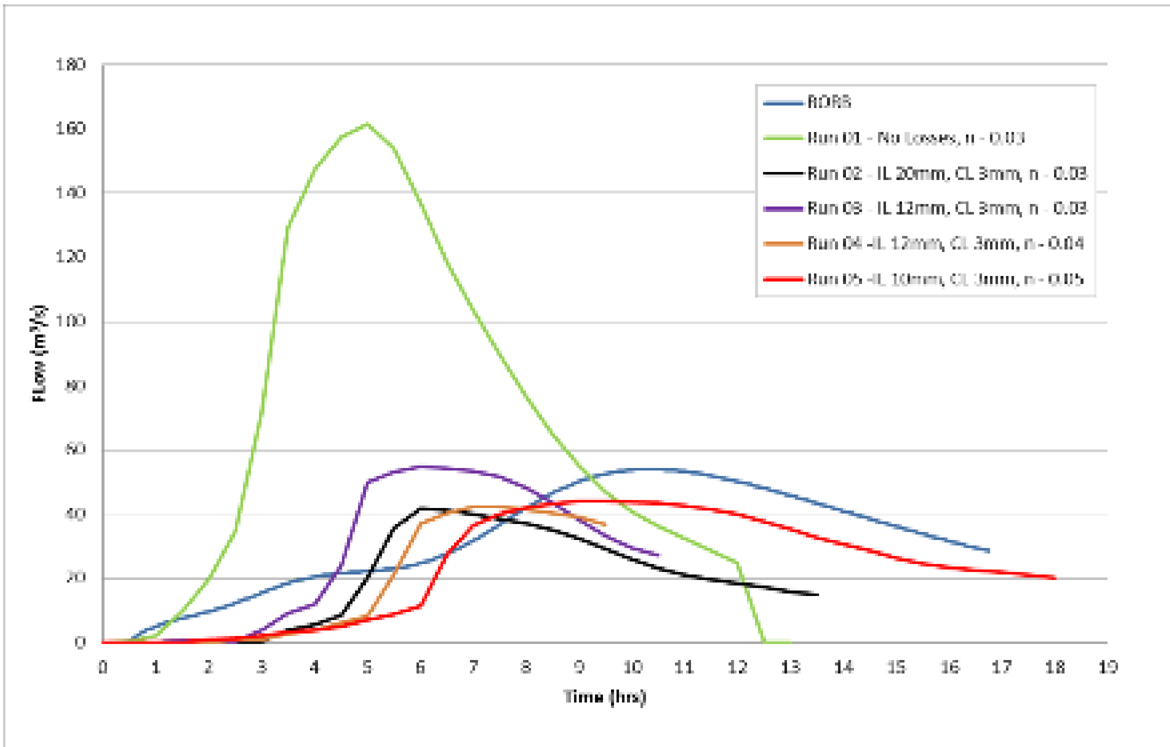

Figure 7-2 **Natimuk Creek 100 year ARI 2 hour duration event rainfall-on-grid and RORB hydrographs**

The rainfall-on-grid run 05 showed the best fit to the RORB hydrograph (both timing and peak flow) at Natimuk and Little Natimuk creeks. The rainfall-on-grid run 05 and RORB hydrographs are shown in Figure 7-3 and Figure 7-4.

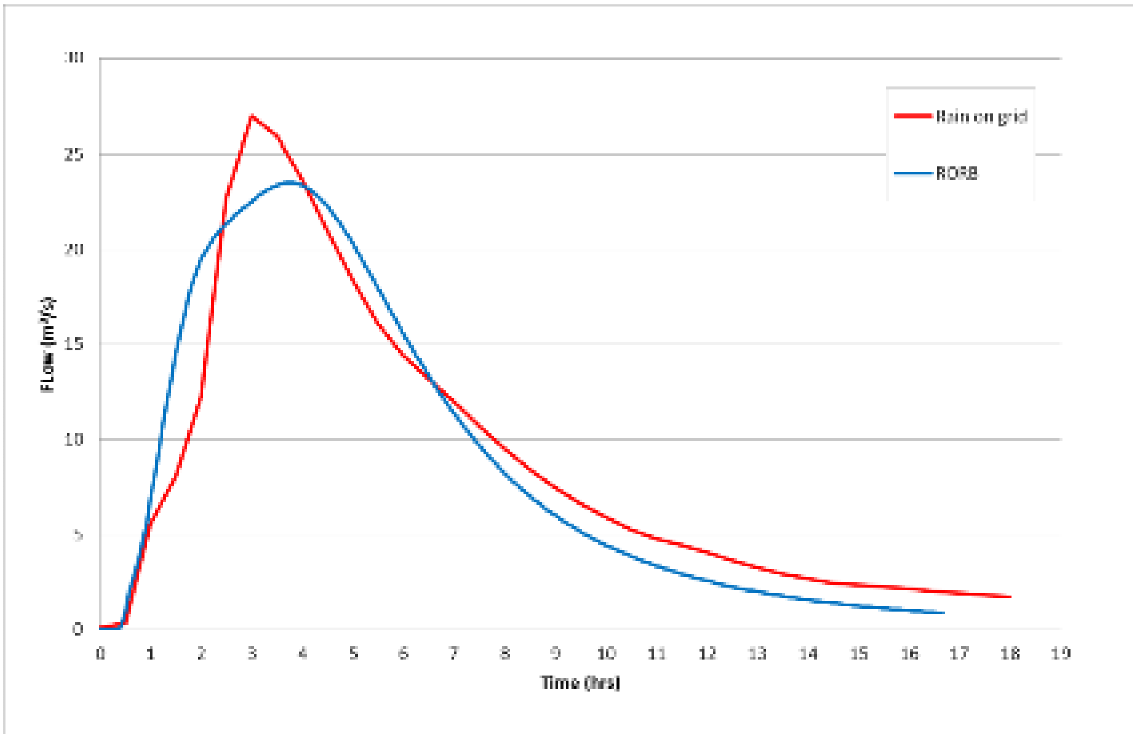

Figure 7-3 Adopted Little Natimuk Creek 100 year ARI 2 hour duration event rainfall-on-grid and RORB hydrographs

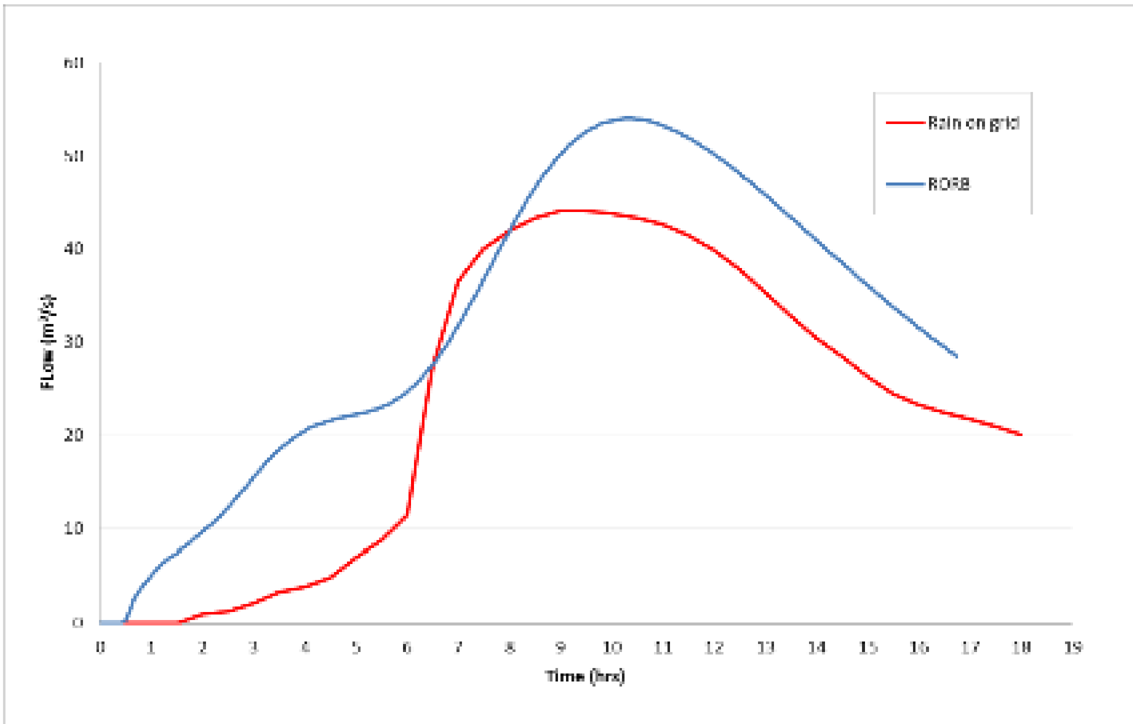

Figure 7-4 Adopted Natimuk Creek 100 year ARI 2 hour duration rainfall-on-grid and RORB hydrographs

The 100 year ARI 2 hour duration event matched best with an initial loss of 10 mm, continuing loss of 3 mm and Mannings 'n' of 0.05. The 100 year ARI 18 hour duration event was run using these parameters also; Table 7-2 shows the estimated peak flow rates.

Table 7-2 Estimated 100 year ARI 18 hour duration event peak flows

Model simulation	Losses	Mannings 'n'	Natimuk Creek peak flow (m^3/s)	Little Natimuk Creek peak flow (m^3/s)
RORB	IL – 20 mm CL – 3 mm	-	99.8	31.7
ROG 01	IL – 10 mm CL – 3 mm	0.05	87.6	38.0

The peak flow and timing of the 100 year ARI hydrographs underestimate the RORB flows on Natimuk Creek and over estimate on Little Natimuk Creek for both the 2 and 18 hour durations.

Figure 7-7 shows a comparison of the MikeFlood detailed hydraulic modelling of Natimuk township and the rainfall-on-grid model results. The results showed a close match in extent with the rainfall-on-grid model. The rainfall-on-grid modelling predicted slightly higher water levels and extent as compared to the detailed modelling. This can be explained by differences in the flow routing, the roughness adopted and the courser 15 m model grid. The average difference ranged from 0 to 0.2 m over the overlapping model domains.

Figure 7-8 shows the estimated 100 year ARI flood extent using an envelope of the 18 and 2hr events. The 18 hour duration event generated a greater flood almost all areas; this is due to the proportion of the 2hr rainfall peak being absorbed by the initial loss and greater depth in the 18hr event. The 18hr event is impacted by the initial loss but the influence on peak flow is not as great. These model results will allow Wimmera CMA and Council to make informed decisions regarding development applications in the Natimuk Creek catchment regarding flood risk.

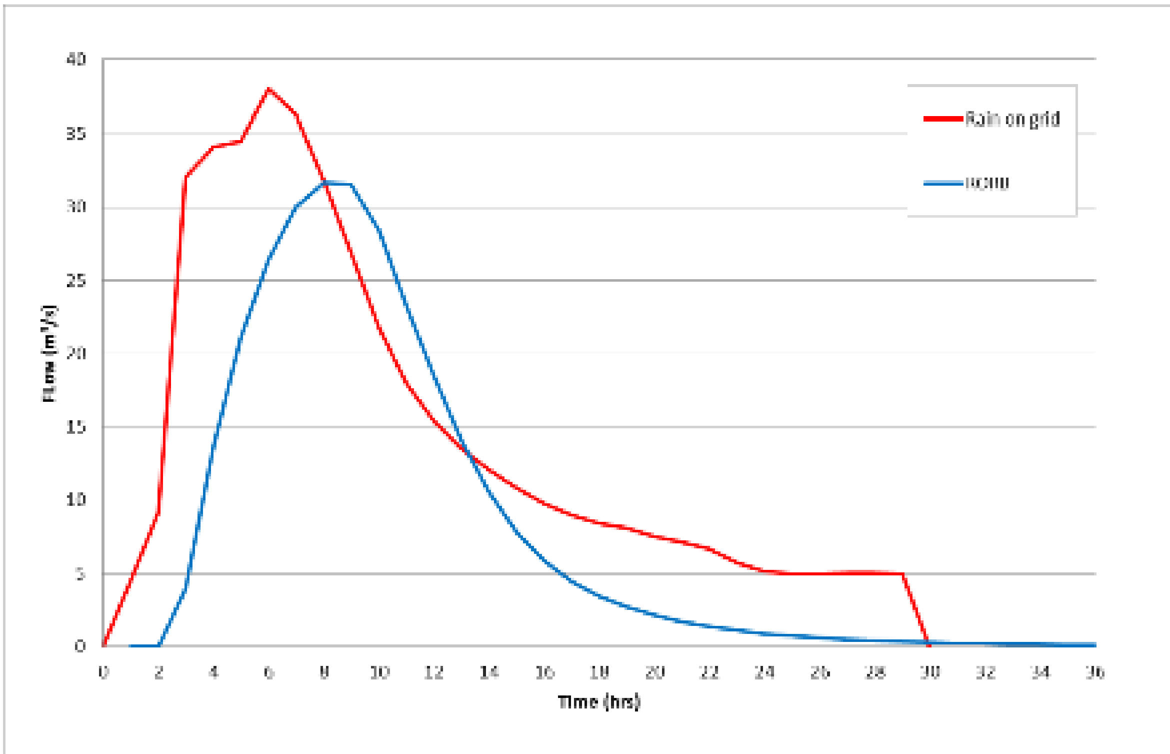

Figure 7-5 **Adopted Little Natimuk Creek 100 year ARI 18 hour duration event rainfall-on-grid and RORB hydrographs**

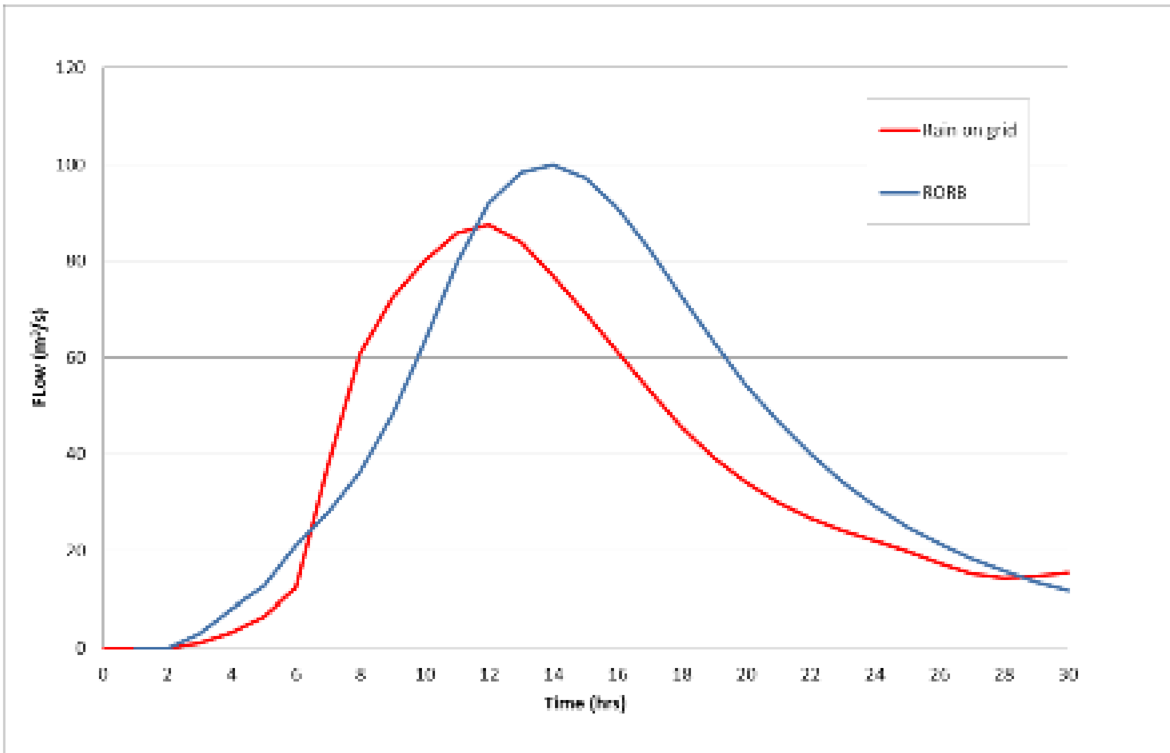

Figure 7-6 **Adopted Natimuk Creek 100 year ARI 18 hour duration event rainfall-on-grid and RORB hydrographs**

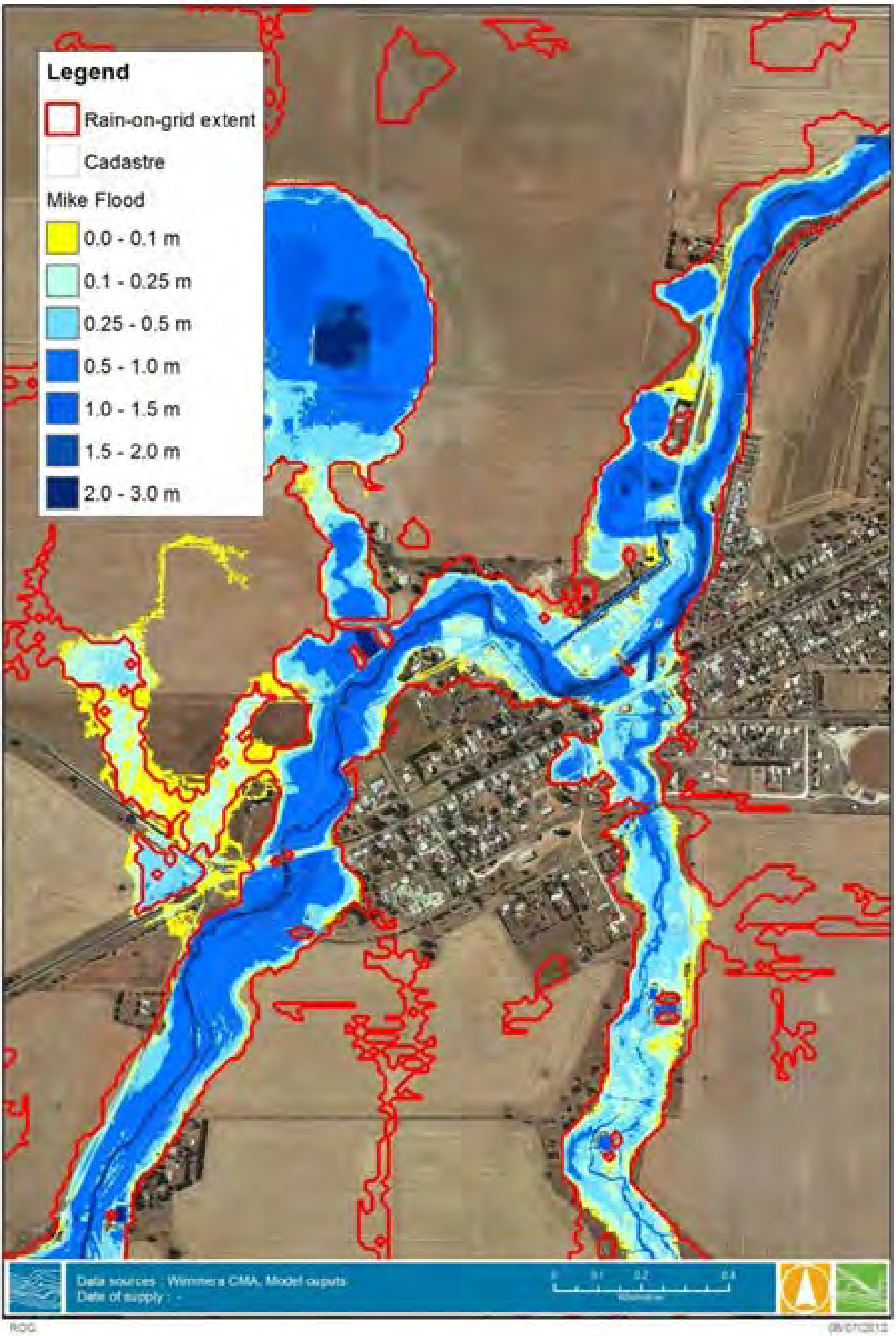

Figure 7-7 **100 year ARI rainfall-on-grid using an envelope of the 2 and 18hr duration and MikeFlood detailed model comparison**

Figure 7-8 **100 year ARI rainfall-on-grid flood extent using an envelope of the 18 and 2 hour durations**

8. FLOOD MITIGATION

8.1 Overview

This section provides an overview of the flood mitigation options available to reduce flood risk and flood damages in Natimuk. The options are divided into structural and non-structural mitigation options. The list of structural mitigation options was developed during community meetings, questionaries and Steering Committee meetings. The list was assessed with a prefeasibility assessment, selecting several options to be further tested using the hydraulic model. Hydraulic modelling was used to eliminate options which were not suitable, and to provide hydraulic results that the Natimuk community could see and use to decide on the preferred final options.

8.2 Structural Mitigation Options

8.2.1 Overview

A list of potential structural flood mitigation measures for Natimuk was developed based on options suggested by the community as well as options suggested by Wimmera CMA, Horsham Rural City Council or Water Technology.

Each option was assessed to determine its feasibility and to highlight any property allotments which may be directly impacted by the option's construction or implementation.

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

- 01 - Properties south of the Wimmera Highway (largely impacted by Little Natimuk Creek);
- 02 - Properties on Elmes Street; and
- 03 - Properties on Lake Avenue.

These divisions are based on the location of above floor flooded properties and also the different flood mechanisms that cause the flooding at those properties. The three divisions are highlighted in Figure 8-1, showing the dwellings impacted above floor during January 2011.

Figure 8-1 Natimuk hydraulic divisions, showing properties flooded above floor during January 2011 (Wimmera CMA)

The list of suggested mitigation measures and the source of the suggestion is shown below in Table 8-1.

Table 8-1 Suggested structural mitigation options

Option No.	Detail	Source
1	Straighten and widen Natimuk Creek	Natimuk Flood Investigation – Flood Questionnaire
2	Place storages upstream of Natimuk	Natimuk Flood Investigation – Flood Questionnaire
3	Open the overflow to allow filling of the wetland to the north west of Natimuk	Natimuk Flood Investigation – Flood Questionnaire
4	Raise houses that are at ground level	Natimuk Flood Investigation – Flood Questionnaire
5	Straighten Little Natimuk Creek	Conversation during community meeting
6	Lake Avenue levee	Water Technology
7	Elmes Street levee	Water Technology
8	Place storages upstream of Natimuk on Little Natimuk Creek	Conversation during community meeting
9	Open the by wash channel behind Lake Avenue	Natimuk Flood Investigation – Flood Questionnaire
10	Removing vegetation from the creek to increase capacity	Conversation during community meeting
11	Increase the capacity of bridge structures on Little Natimuk Creek	Water Technology
12	Reduced the water level in Natimuk Lake	Conversation during community meeting

8.2.2 Prefeasibility Assessment

Each mitigation option was assessed against a number of criteria; potential reduction in flood damage, cost of construction, feasibility of construction and environmental impact. The score for each criterion was based on a ranking system of 1 to 5, with 1 being the worst score and 5 the best. Each criteria score was then weighted according to the weighting shown in Table 8-2 below. The reduction in flood damage was the most heavily weighted criteria as this is the main objective for all flood mitigation. Table 8-3 reviews and scores each mitigation option against the four criteria and calculates a total score for each option. The options with the higher scores indicate the most appropriate mitigation solutions for Natimuk. While these options were reviewed and assessed individually it is important to consider a combination of options when developing a complete flood mitigation scheme.

Table 8-2 Prefeasibility assessment criteria

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

Table 8-3 Structural mitigation prefeasibility assessment

No.	Works Location	Mitigation Option	Criteria					Score
			Reduction in Flood Damages	Cost ($)	Feasibility/ Constructability	Environmental Impact	Comments	
1	Natimuk Creek downstream of the Wimmera Highway Bridge	Straighten and widen Natimuk Creek	3	3	3	1	Straightening and widening Natimuk Creek is likely to cause significant negative environmental impact, decrease the amenity and aesthetics of the Natimuk township and has the potential for ongoing erosion issues. The impact on water levels by a reduction in roughness in Natimuk Creek is likely to be minimal.	11
2	On Natimuk Creek	Place storages upstream of Natimuk on Natimuk Creek	4	1	2	3	Storages constructed upstream of Natimuk on Natimuk Creek would have to be of significant size to reduced flow of water through the township. The required size of the storages can be assessed on approval of design flows. The options may vary from a small retarding basin up to large storages further along Little Natimuk Creek.	11.5
3	Downstream of the Wimmera Highway Bridge west of the Natimuk township	Open the overflow to allow filling of the wetland to the north west of Natimuk	4	5	3	5	A constructed earthen embankment causes a significant blockage to overflows from Natimuk Creek into a wetland to the north of Natimuk; however the embankment and swamp are privately owned. The potential flow rate and volume the wetland is capable of receiving is unknown.	17

4	Natimuk township	Raise houses that are at ground level to above flood level	5	1	1	5	Raising house floor levels would significantly reduce the damage to private infrastructure but would be very cost prohibitive.	14
5	Little Natimuk Creek between the railway culverts and Jory Street	Straighten Little Natimuk Creek	2	4	3	3	Straightening Little Natimuk Creek would have less environmental impact than if similar works were suggested on Natimuk Creek as there is less significant vegetation and far less amenity provided to the township. However, the land is privately owned. The impact of a reduction in roughness in Little Natimuk Creek is likely to be relatively small.	11
6	Lake Avenue	Lake Avenue levee	4	4	4	5	An increase in the Lake Avenue Road crest height or an earthen levee has the potential to prevent some properties from becoming inundated, however it may increase the flood level through Natimuk in other locations An assessment of the levee would be required using the hydraulic model to determine the overall change in flood levels.	16.5
7	Elmes Street	Elmes Street levee	4	4	5	5	An increase in the Elmes Street crest height or an earthen levee has the potential to prevent some properties from becoming inundated, however it may increase the flood level through Natimuk in other locations, this change is expected to be less than that of the Lake Avenue levee. An assessment of the levee would be required using the hydraulic model to determine the overall change in flood levels.	17
8	Railway embankment on Little Natimuk Creek and Natimuk Creek	Place storages utilising the railway embankment upstream of Natimuk	4	4	3	4	The construction of retarding basins on Little Natimuk Creek is likely to be a more viable option than Natimuk Creek as the Little Natimuk Creek catchment has significantly less contributing area and would therefore have a lower volume to store. Both scenarios can be tested simultaneously. The required size of the storages can be assessed on approval of	15.5

							design flows.	
9	Bywash channel behind Lake Avenue	Open the bywash channel behind Lake Avenue	3	5	5	5	Opening the by wash channel with a culvert may reduce flood levels in the township but its full impact on flood levels is unknown. An assessment of the culvert would be required using the hydraulic model to determine the overall change in flood levels	16
10	Natimuk Creek	Removing vegetation from Natimuk Creek to increase capacity	2	4	1	1	Removing vegetation from Natimuk Creek would marginally impact on water level though town, but likely to be insignificant, Natimuk Creek is already very open and clear of debris. The removal of vegetation is likely to have significant negative environmental impact and may cause erosion issues into the future. It would also decrease the amenity and aesthetics of the township.	9
11	Little Natimuk Creek structures at Jory Street and the Wimmera Highway	Increase the capacity of bridge structures on Little Natimuk Creek	4	2	3	5	An increase in the capacity of culverts on Little Natimuk Creek at Jory Street and the Wimmera Highway may have an impact at mid-range ARIs. During January 2011 both structures overtopped and preliminary modelling has shown they had a minor impact on water level. Their replacement would be relatively costly, causing closure or partial closure of the Wimmera Highway.	14
12	Natimuk Lake	Reduce the water level in Natimuk Lake	2	5	4	5	A reduction in the operational water level in Natimuk Lake may influence water level at the very downstream end of town but this influence is expected to be relatively minor. A reduction in the operational level may cause some decreased ability to use the lake, this would be dependent on the reduction from the current operational level.	13.5

Using the prefeasibility assessment above, the twelve mitigation options were ranked by weighted score. Their ranking is shown below in Table 8-4

Table 8-4 Weighted prefeasibility mitigation Scores

Rank	Option No.	Mitigation Option	Weighted Score
1	7	Elmes Street levee	17
2	6	Lake Avenue levee	16.5
3	9	Open the bywash channel behind Lake Avenue	16
4	3	Open the overflow to allow filling of the wetland to the north west of Natimuk	15.5
5	8	Place storages upstream of Natimuk on Little Natimuk Creek	15.5
6	11	Increase the capacity of bridge structures on Little Natimuk Creek	14
7	4	Raise houses that are at ground level to above flood level	14
8	12	Reduce the water level in Natimuk Lake	13.5
9	2	Place storages upstream of Natimuk	11.5
10	5	Straighten Little Natimuk Creek	11
11	1	Straighten and widen Natimuk Creek	11
12	10	Removing vegetation from Natimuk Creek to increase capacity	9

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

These are:

- Reduce the operational water level in Natimuk Lake
- Remove vegetation from Natimuk Creek to increase capacity
- Place storages upstream of Natimuk on Natimuk Creek
- Straighten Little Natimuk Creek
- Straighten and widen Natimuk Creek

As the level of community interest was very high surrounding the options to remove vegetation from Natimuk Creek and also lowering the lake level and increasing the inlet capacity, these options were tested with a single model run for the 100 year ARI 18 hour duration event. The results for these options are shown below in Figure 8-2 and Figure 8-3 with a longitudinal section of water level between upstream of Natimuk and the Lake. The longitudinal section demonstrates that the impact of these options is minimal at Natimuk and these options were not progressed for further modelling.

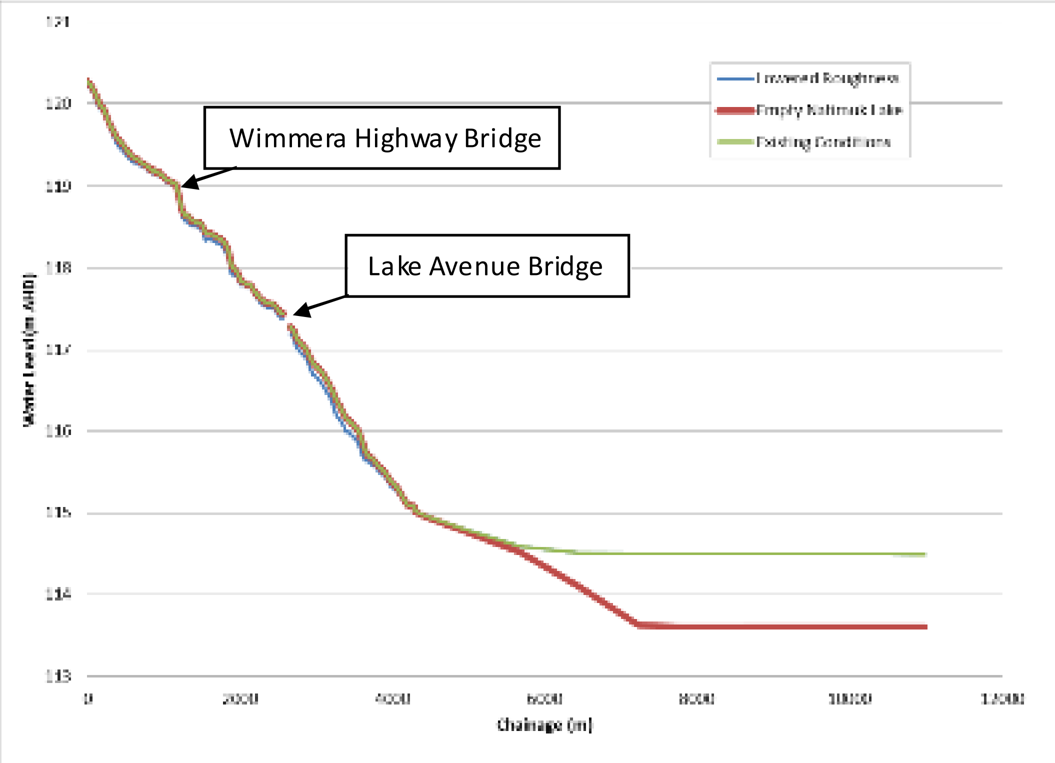

Figure 8-2 **Longitudinal section of water surface elevation for various mitigation options (upstream of Natimuk to downstream of Natimuk Lake)**

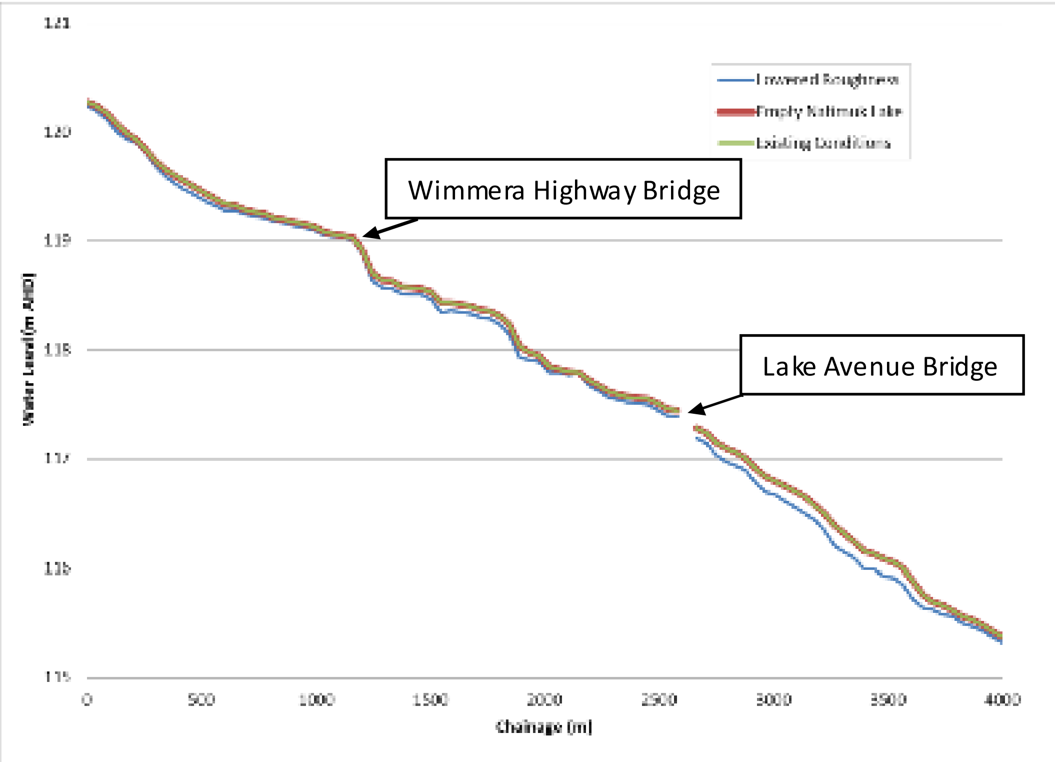

Figure 8-3 **Longitudinal section of water surface elevation for various mitigation options (upstream of Natimuk to approximately 1500m downstream of the Lake Avenue Bridge)**

Based on the prefeasibility assessment six options were identified as viable and considered for further investigation.

- Elmes Street Levee – A levee on along Elmes Street
- Lake Avenue Levee – A levee along Lake Avenue
- Lake Avenue Bywash Channel – Opening the bywash channel along the back of Lake Avenue properties
- Depression Overflow – Opening a natural overflow point from Natimuk Creek into a privately owned depression
- Little Natimuk and Natimuk Creek Storages – Place a storage upstream of the railway embankment on Little Natimuk Creek
- Increase the capacity of culverts along Little Natimuk Creek – Increase the capacity of Jory Street and Wimmera Highway culverts

As part of this process properties that would be directly impacted by the construction of each option were highlighted for Wimmera CMA and Horsham Rural City Council consideration. Properties potentially impacted by the construction of each of the prefeasibility mitigation options are shown as red dots in each of the below Figures.

8.2.3 Property/Allotments Affected

Option 07 – Elmes Street Levee (Rank 1)

A levee along Elmes Street was assessed to prevent water entering the properties from Natimuk Creek to the north and east. During January 2011 five properties were impacted above floor level along Elmes Street. Figure 8-4 shows the potential location of the Elmes Street levee and the properties which may be directly impacted by its construction.

Figure 8-4 Potential location for Elmes Street Levee

Option 06 – Lake Avenue Levee (Rank 2)

A levee along Lake Avenue was assessed, preventing water entering properties from Natimuk Creek. The levee was assessed on the Natimuk Creek side of Lake Avenue. During January 2011 eleven properties were impacted above floor level along Lake Avenue. Structural arrangements of the bywash channel to the north of Lake Avenue would also need to be investigated during this option. Figure 8-5 shows the potential location of the Lake Avenue levee.

Figure 8-5 Potential location for Lake Avenue Levee

Option 09 – Lake Avenue bywash channel (Rank 3)

A channel exists to the rear of Lake Avenue. Anecdotally the channels original purpose was to bypass flood water around the Main Street of Natimuk. Since its construction the channel was blocked by Lake Avenue. A culvert previously existed under Lake Avenue but this was not reinstated during road works, this culvert could be reinstated bypassing flow around Natimuk. If the culvert were to be reinstated it is likely the channel would also require some maintenance. Figure 8-6 shows the location of the existing channel, location of the potential culvert.

Figure 8-6 Lake Avenue bywash

Option 03 – Overflow to privately owned depression (Rank 4)

A privately owned depression to the north-west of Natimuk appears to have once been a swamp/wetland connected to Natimuk Creek. Historically, the wetland would have received flow once Natimuk Creek exceeded its bank capacity at the offtake location. There is currently an earthen embankment blocking water passage, which appears to have been constructed as part of a private water supply dam. Opening of the overland flow path can reduce water levels in Natimuk, but will cause additional inundation through private property. Figure 8-7 shows the location of the earthen embankment.

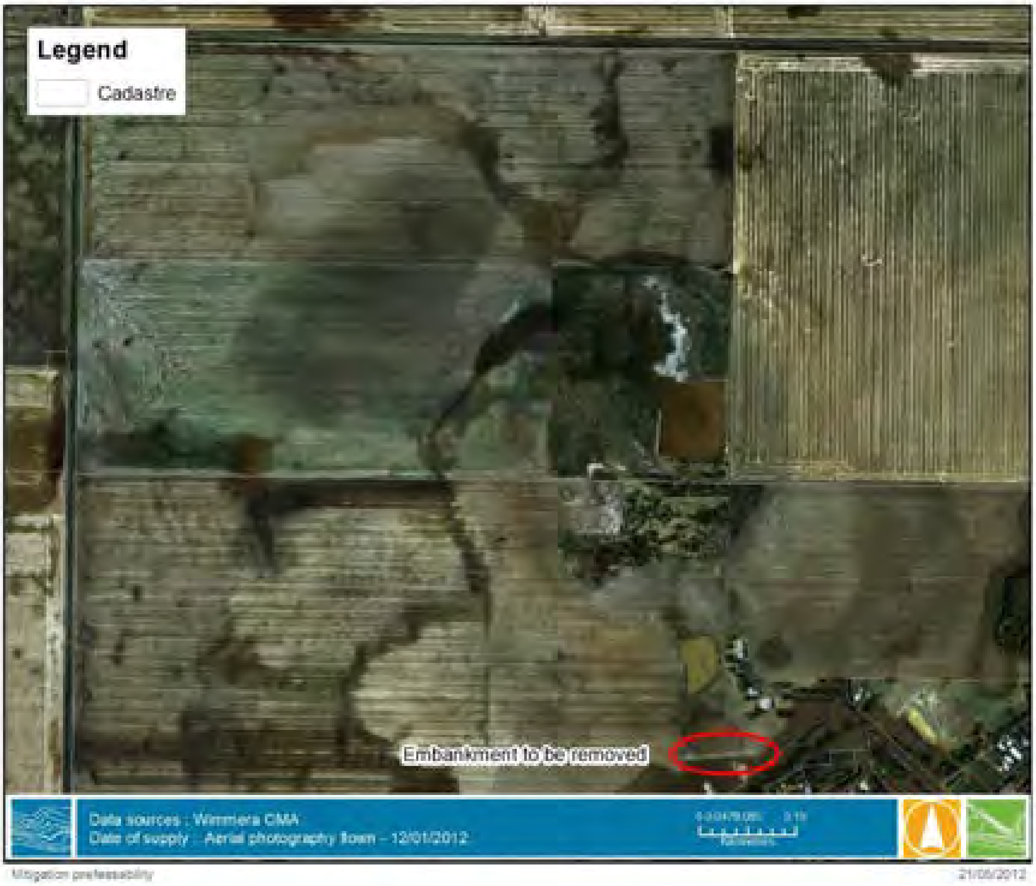

Figure 8-7 Location of earthen embankment and properties impacted

Option 08 – Place storages utilising the railway embankment upstream of Natimuk (Rank 5)

Potential exists to place retarding basins upstream of the Natimuk township on Little Natimuk Creek. These storages could be located upstream of the railway embankments and could use the embankment to retain water. The current culverts under the railway embankment could be modified to allow water to drain from the retarding basin at lower flows while a spillway would be required for overtopping of flood flows.

The impact of the storages would rely heavily on the duration and volume of a flood event. If the storages were to fill prior to the peak flow rate arriving at the township there would most likely be a negative impact as the raised level in the storages could potentially inundated nearby properties to a higher degree as compared to current conditions.

Figure 8-8 shows areas which may be suitable for a retarding basin a Little Natimuk Creek

Figure 8-8 Location of potential retarding basins on Little Natimuk Creek

Option 11 – Increase the capacity of bridge structures on Little Natimuk Creek (Rank 6).

An increase to the capacity of Little Natimuk Creek structures on the Wimmera Highway and Jory Street may allow more water to pass under the roadways and reduce the back water behind them.

During January 2011 seven properties were impacted above floor level on the southern side of the Wimmera Highway, the majority of these were flooded by Little Natimuk Creek. Four of the properties are directly upstream of the Wimmera Highway culverts.

Figure 8-9 shows the locations of the culverts on Jory Street and the Wimmera Highway that have the potential to be enlarged.

Figure 8-9 Location of the Jory Street and Wimmera Highway culverts

8.3 Flood Mitigation Modelling Assessment

8.3.1 Overview

Of the six options investigated using the hydraulic model five were modelled in detail by incorporating the option into the hydraulic model and running the 100 year ARI 18 hour duration event. The sixth option to increase the size of the Little Natimuk Creek culverts was assessed based on the influence of the culverts on flood levels for the design and calibration modelling.

Comparisons are shown throughout this section using the colour scale shown below in

Figure 8-10 and the number of buildings that are inundated above and below floor level.

The Pink '*Was wet now dry*' indicates areas which have become dry in the mitigation scenario, this will be most apparent in areas which are protected by a levee. The negative numbers are all shown in Green. These numbers indicate areas which have decreased in depth due to the construction of the mitigation option with the darker shades a greater reduction.

The Blue 'Was *dry now wet*' indicates areas which are now inundated in the mitigation scenario. The positive numbers are shown in Yellow through to Orange. They indicate areas which have increased in depth due to the construction of the mitigation option.

Areas which have not changed are shown in light Blue.

The existing conditions 100 year ARI event model results are shown below in Figure 8-11.

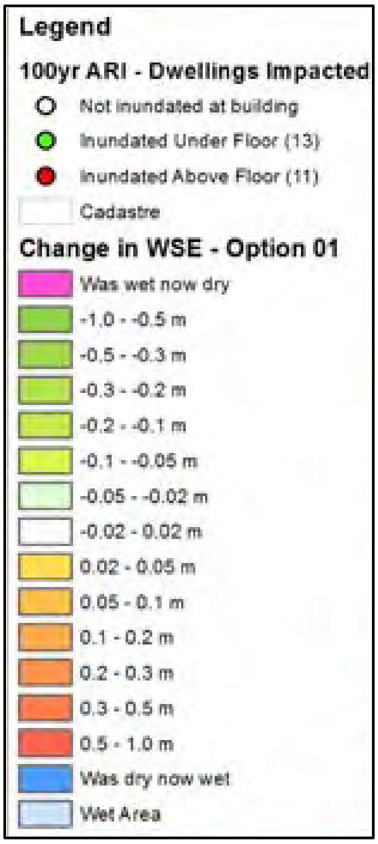

Figure 8-10 Mitigation Option assessment legend

Figure 8-11 Existing 100 year ARI event model results

8.3.2 Elmes Street Levee

The proposed Elmes Street levee as modelled is located along the centreline of Elmes Street. This could be achieved by road raising but would be more expensive given the height of raising required. The levee protected all buildings in Elmes Street and could be located on either side of the road.

However, it would be preferable for the levee to be on the south west side of the road so it would not need to cross the road, also allowing maximum flow area on the creek side of the levee. To prevent inundation at a 100 year ARI the levee would be required to be approximately 0.3 m higher than the existing road level. If the levee were to be on the southern side of Lake Avenue, including a 300mm freeboard it would have a maximum height of 0.8 m, average height of 0.6 m and length of 400 m.

Modelling of the proposed Elmes Street levee is shown below in Figure 8-12. Modelling of the proposed Elmes Street levee showed six buildings to be removed from flooding entirely, three which were inundated above floor and three that were inundated below floor under existing conditions during a 100 year ARI event.

The levee caused an increase in water level on the northern side of the levee. This increase was approximately 0.05-0.10 m immediately upstream of the levee and 0.02-0.05 m for the larger area. The increase in water level inundates some private property to higher depths, but not at buildings, and does not inundate any significant additional area due to the steep slopes of the floodplain. The exception is the Tennis Clubrooms. They were excluded from the damage assessment and consideration for mitigation options as they are due for demolition.

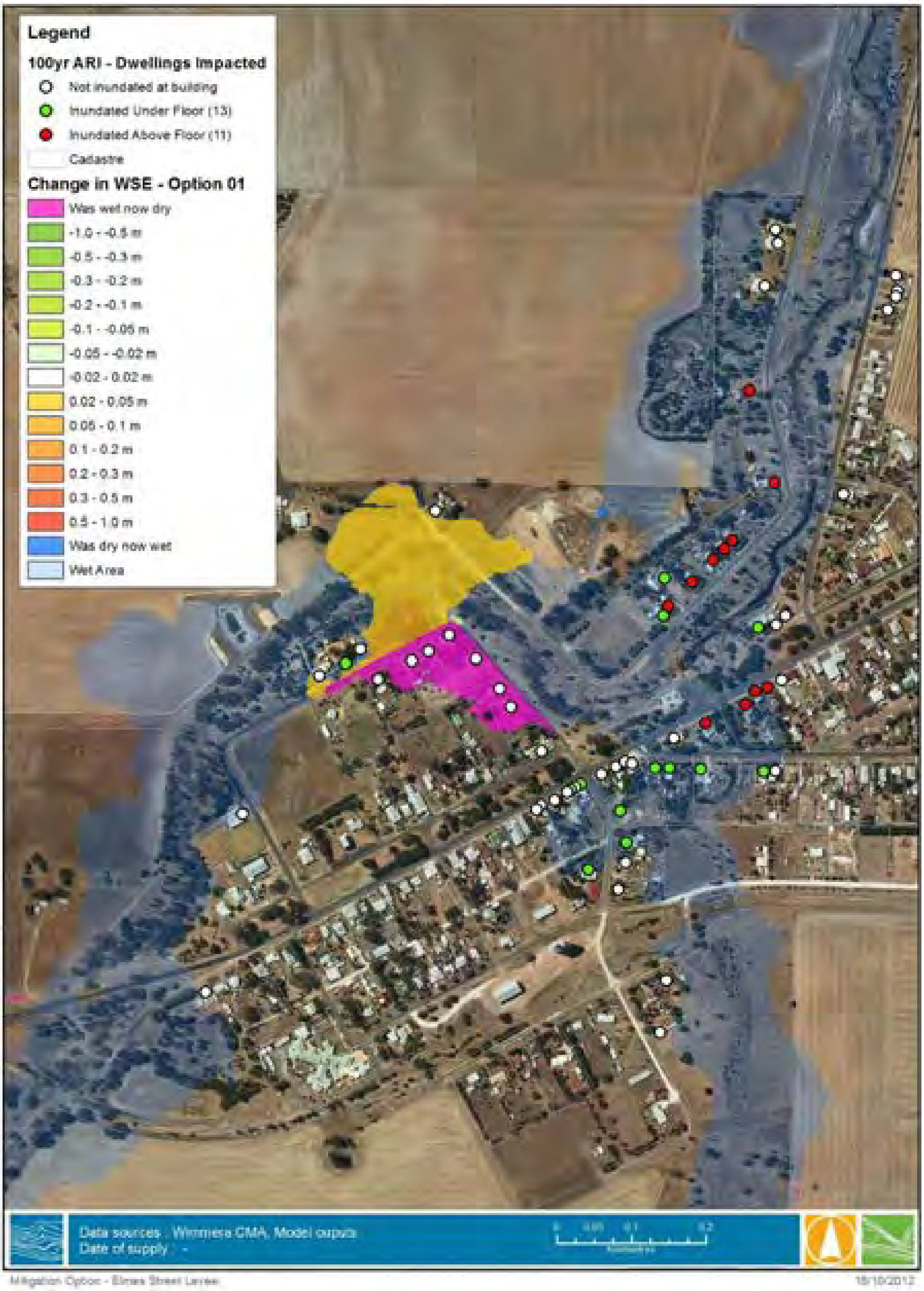

Figure 8-12 Elmes Street levee 100 year ARI event difference plot

8.3.3 Lake Avenue Levee

The proposed Lake Avenue levee stretched from the western end of Lake Avenue, to past the extent of the township. The levee was situated on the Natimuk Creek side of Lake Avenue. The levee protected nine buildings from inundation during the 100 year ARI event, seven above floor and two below floor.

Modelling of the Lake Avenue levee is shown below in Figure 8-13. The levee completely prevented inundation of the north-west side of Lake Avenue protecting seven buildings from above floor and two from below floor inundation. The levee did however significantly reduce the available floodplain flow area available, increasing water levels upstream and along its length. The levee caused increases in water level of up to 0.2-0.3 m. There are buildings already inundated above floor within these areas indicating that if the levee were constructed they would be inundated to a greater depth during a 100 year ARI event.

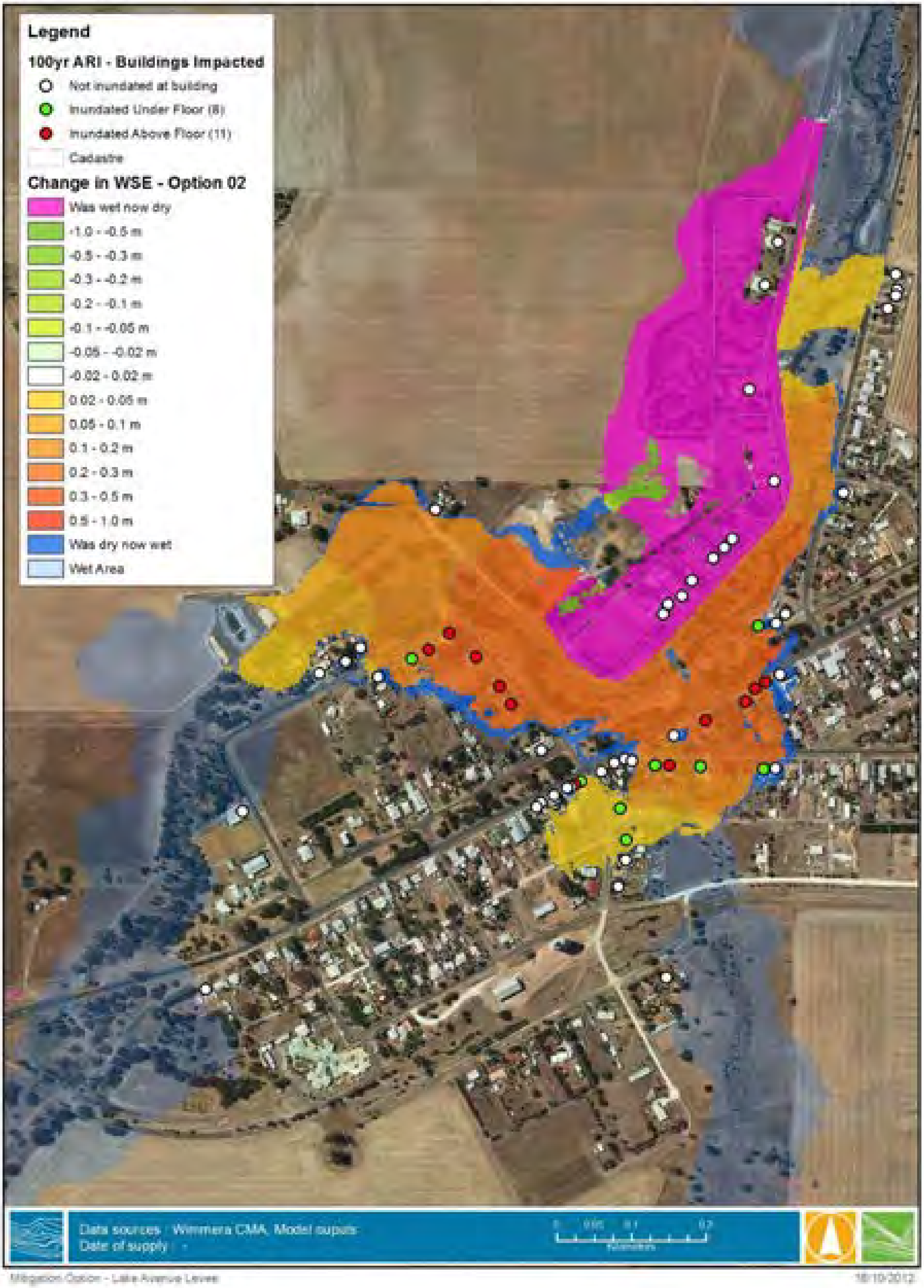

Figure 8-13 Lake Avenue levee 100 year ARI event difference plot

8.3.4 Lake Avenue Bywash Channel

Opening the Lake Avenue bywash channel at the northern and southern ends was modelled. However during a 100 year ARI event there were no changes in the maximum observed water levels outside the -0.02 to 0.02 m range, as such no difference plots are presented.

8.3.5 Wetland overflow

Opening the overland flow path into the privately owned depression to the north of Natimuk was modelled using two scenarios; one with localised catchment runoff accumulating into the depression prior to Natimuk Creek and Little Natimuk Creek flooding, and the second with no localised runoff accumulating in the depression.

These model simulations were used to assess the lowest and highest levels of impact opening the depression may have on water levels in the Natimuk township.

Figure 8-14 and Figure 8-15 show the impact of opening the depression to Natimuk Creek with and without localised catchment runoff entering the depression respectively.

Whilst local catchment runoff is entering the depression it takes up storage, reducing the amount of water diverted from Natimuk Creek. With the depression open to inundation from Natimuk Creek it is likely water would remain in there forming a swamp/wetland for an extended period of time, meaning the land would not be able to be farmed as is the current practice with Lucerne cropping.

With local catchment runoff draining into the depression and having it open to overflows from Natimuk Creek, modelling showed that water levels through town could be reduced by a maximum of 0.1 m. This reduction in water level does reduce the number of buildings inundated above floor by two in a 100 year ARI event.

With no localised catchment inflow entering the swamp there is greater storage available for Natimuk Creek to fill, and modelling showed reduction in water levels through town of up to 0.2-0.3 m, with the number of above floor flooded building reduced by three from existing conditions.

Inundation within the depression was up to 3 m deep, with 2.4 m remaining in the depression after draining. This inundation has the potential to remain for extended periods of time.

Opening the privately owned depression to allow an overflow point for Natimuk Creek has the potential to have a lower impact on flood levels through Natimuk if the depression contains water prior to a flood event. This is also the case if a longer duration event occurs, which fills the depression prior to the peak discharge on Natimuk Creek.

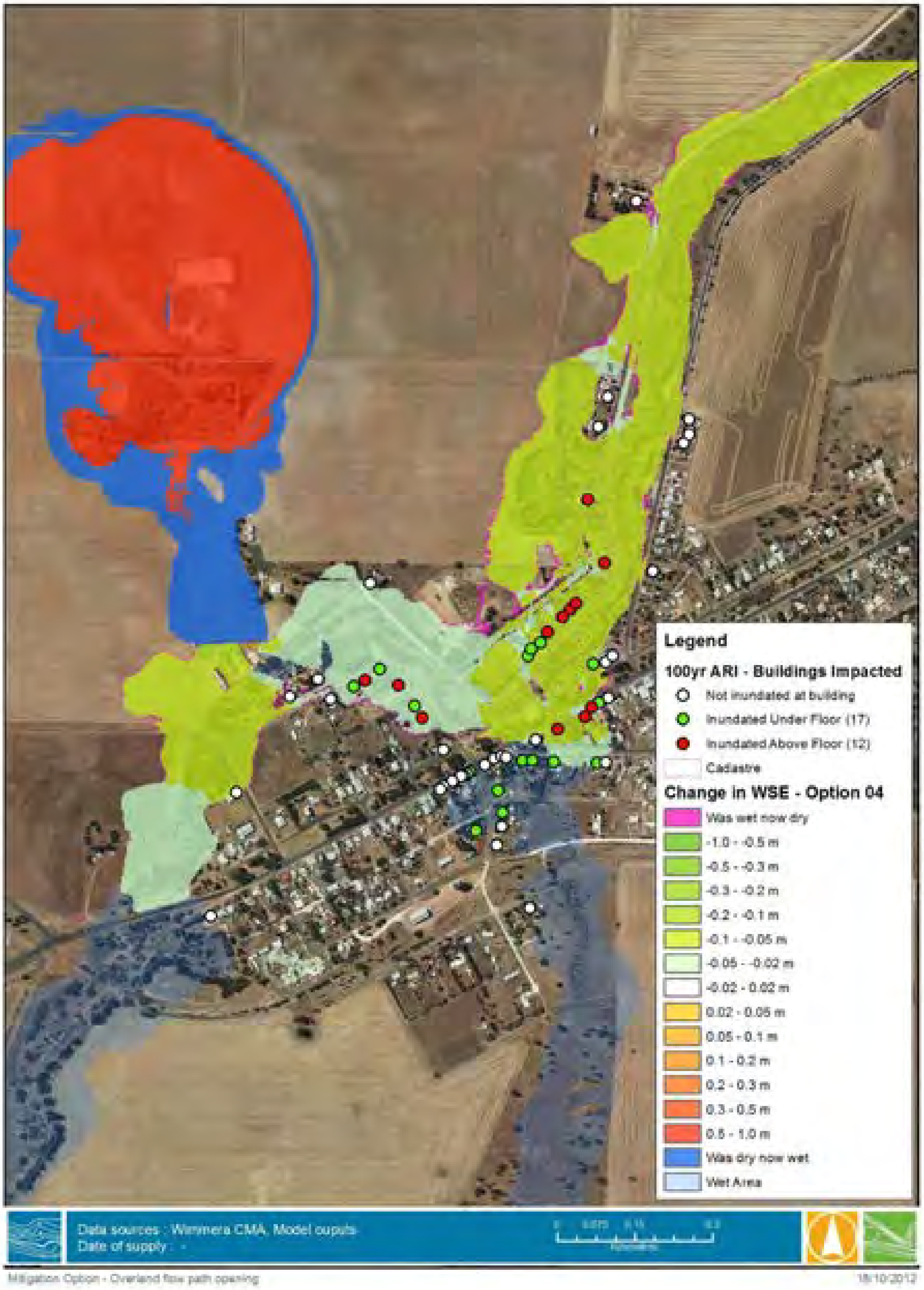

Figure 8-14 Wetland overflow with localised catchment inflow 100 year ARI event difference plot

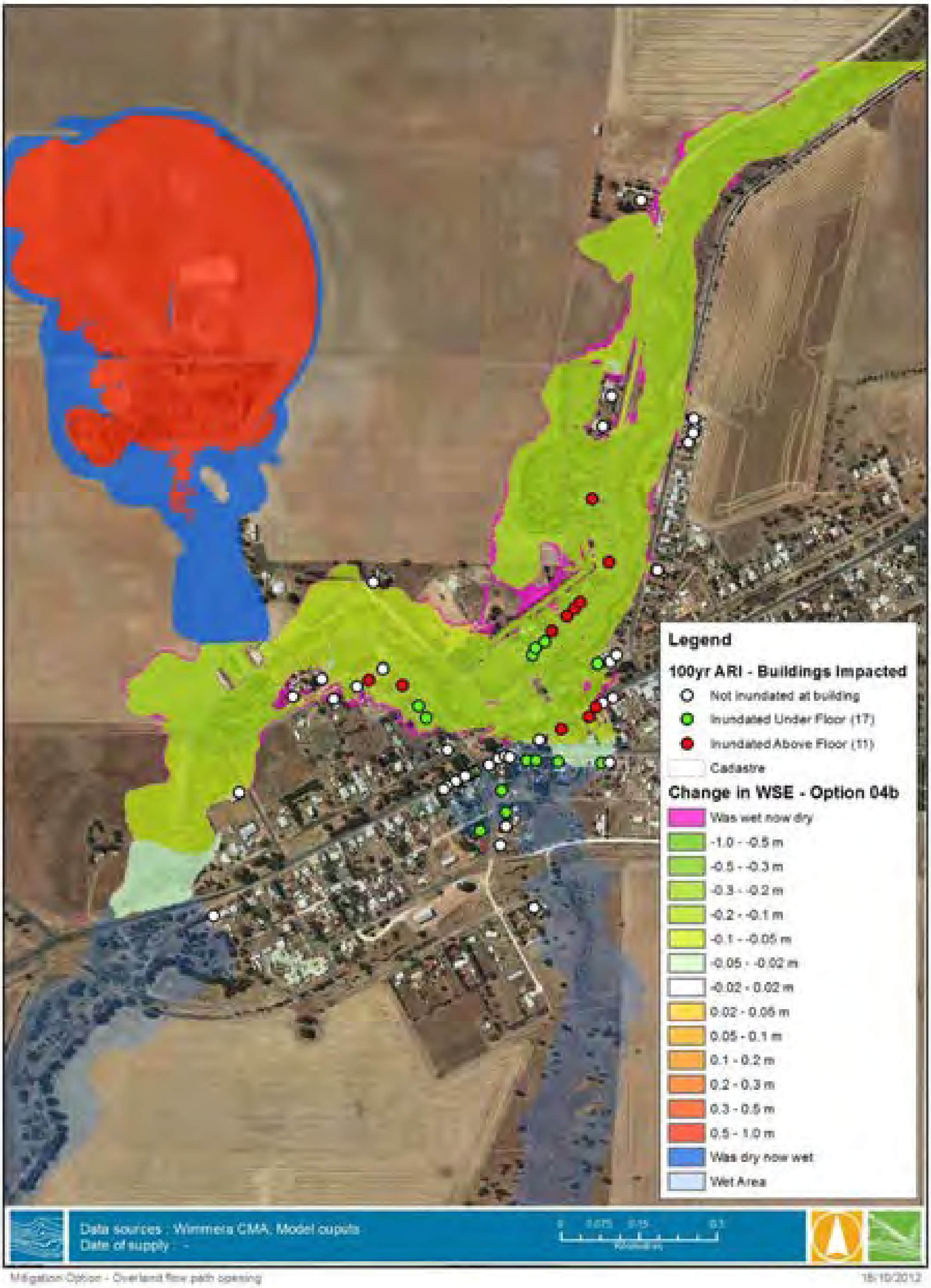

Figure 8-15 Wetland overflow with no localised catchment inflow 100 year ARI event difference plot

8.3.6 Place storages utilising the railway embankment upstream of Natimuk

Utilising the existing railway embankment for a retarding basin was modelled by removing the existing pipe culverts and lowering the bank level to 118.6 m AHD, allowing the storage to fill then spill over.

Figure 8-16 shows the impact of removing the railway culverts and lowering the sill-level of the embankment.

Removal of the culverts caused additional areas to become inundated, including one dwelling. During a 100 year ARI event the storage created was completely filled prior to the peak flow rate on Little Natimuk Creek. This means any benefit downstream of the storage is removed. Water was forced to overtop the embankment on a lower section to the east where it inundated previously flood free land.

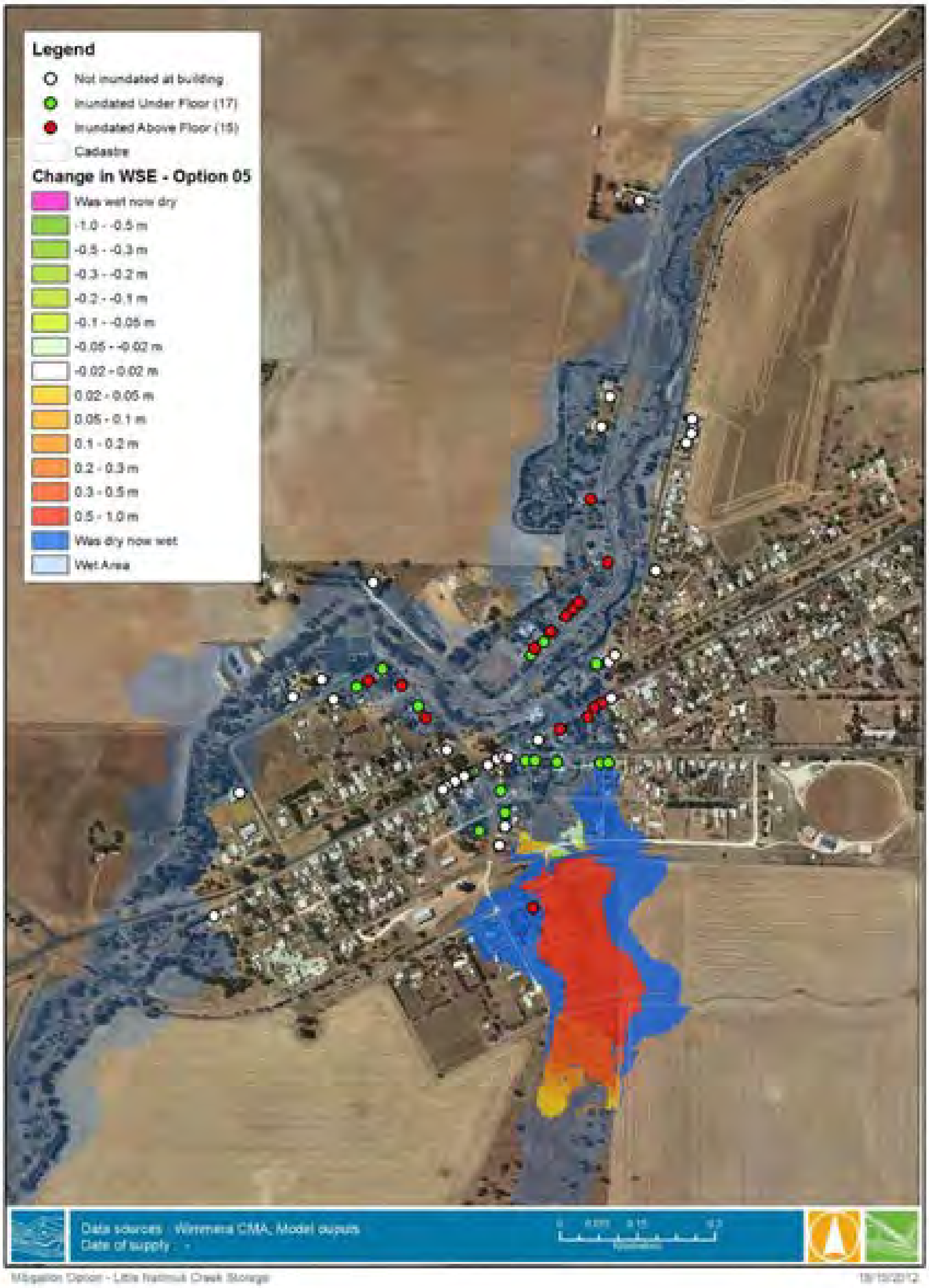

Figure 8-16 Little Natimuk Creek storages 100 year ARI event difference plot

8.3.7 Increase the capacity of bridge structures on Little Natimuk Creek

Increasing the capacity of the Little Natimuk Creek culverts was assessed using the design and calibration model results by assessing the head loss across the structures over the range of modelled events. Long sections of the water level in Little Natimuk Creek were extracted showing the head loss across the structures. A high head loss across a structure indicates that the structure forms a constriction in flow, raising upstream water levels.

Figure 8-17 shows a longitudinal section of the waterway from the beginning of the 2D model extent, with Figure 8-18 a zoom of the reach with the railway embankment and Wimmera Highway Bridge. A plan view of the long sections is shown in Figure 6-8, earlier in the report.

The longitudinal sections showed the railway embankment constricts flow at the higher flow rates, this is most apparent in the 200 year ARI event with a head loss of approximately 0.2 m. The Wimmera Highway Bridge also causes come constriction, however this is only to the effect of approximately 0.05 m in a 200 year ARI event.

These results suggest that the culverts on Jory St and the Wimmera Highway do not present significant constrictions to Little Natimuk Creek flood flows. This is due to the fact that during the peak of a large flood event these structures are overtopped, with the waterway area above the road deck significant enough to provide capacity for flood flows to pass.

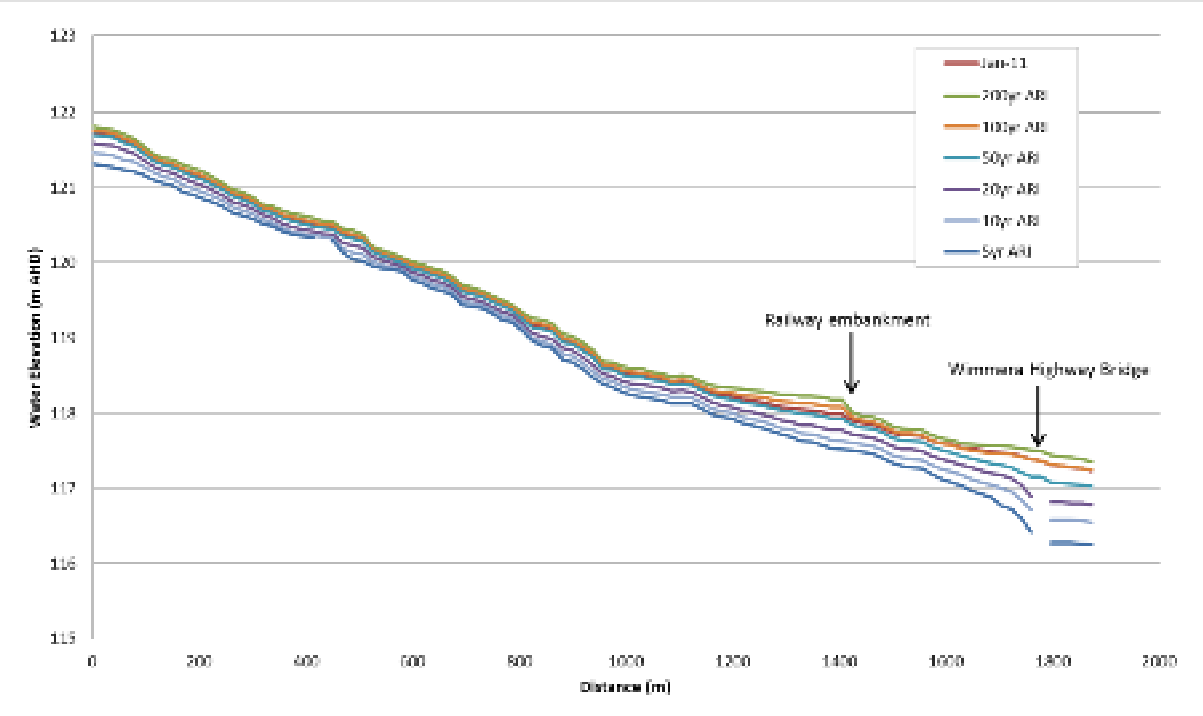

Figure 8-17 Little Natimuk Creek water surface elevation profiles

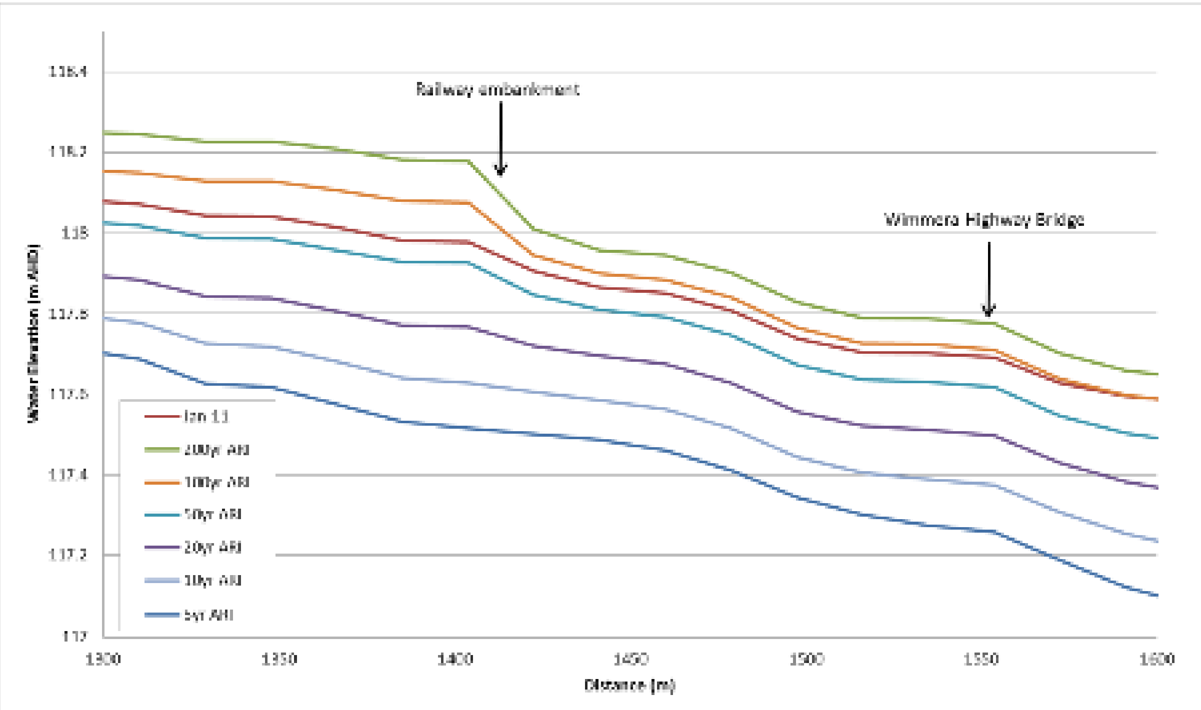

Figure 8-18 Little Natimuk Creek water surface elevation profiles between the railway embankment and the Wimmera Highway bridge.

8.3.8 Mitigation Option Packages

Overview

Once all mitigation options were assessed for their individual impact a series of mitigation packages were modelled, combining a number of individual measures. These options were focused on the Elmes Street and Lake Avenue levees as they were able to reduce damages in Natimuk to the highest degree, and during initial community consultation were feasible options that the community were interested in.

Combined Option 01

Combined Option 01 was made up of the Elmes Street levee and a series of levees along Lake Avenue. The Lake Avenue levee protected all the same properties but was split into three separate levees rather than a single levee to allow flood flows to pass around the bywash channel and back to the creek. The levees along Lake Avenue were placed on the private property boundary to allow the greatest floodplain area to be available.

All levees are 'ring levees' preventing water from inundating the allotments from any direction. The first of the levees protects the majority of properties, the second levee protects one property and the third levee protects two properties. The dwellings behind the third levee are not impacted above floor level in a 100 year ARI event but are impacted below floor. The levee has been included in modelling to ensure the potential changes to water levels due to the levee are conservative.

Combined Option 01 reduced the number of buildings flooded above floor to four. The option increased water levels by a maximum of 0.2-0.3 m, with the water level increasing between 0.1-0.2 m at some buildings already inundated above floor in existing conditions.

Combined Option 02

Combined Option 02 was a similar levee arrangement to Combined Option 01, but with the major length of Lake Avenue levee on the Natimuk Creek side of Lake Avenue instead of the property boundary.

This realignment of the levee location resulted in a reduction in the available flow area of Natimuk Creek and caused further increases in water levels. The model results show increases of approximately 0.2 m in depth along the levee and around properties on Main Street. The number of houses inundated above floor did not change from Combined Option 01 but they were inundated to a greater depth.

Combined Option 03

Combined Option 03 used the same levee arrangement as Combined Option 02 but attempted to mitigate the increases in water level by an expansion to the bywash Channel to the rear (north) of Lake Avenue.

The channel was widened to approximately 18 m wide, which would encroach on Council owned land to the north. In the cost of construction it was assumed the Horsham Rural City Council would not charge for the acquisition of this land. A levee would be required along the channel to ensure properties were not inundated from the channel.

The model results show the enlarged bywash channel is capable of transferring enough of the peak flow to mitigate against the increases in water level caused by the levees. Some increases in flood level were still observed but importantly there were no increases in water level at properties already flooded above floor in existing conditions.

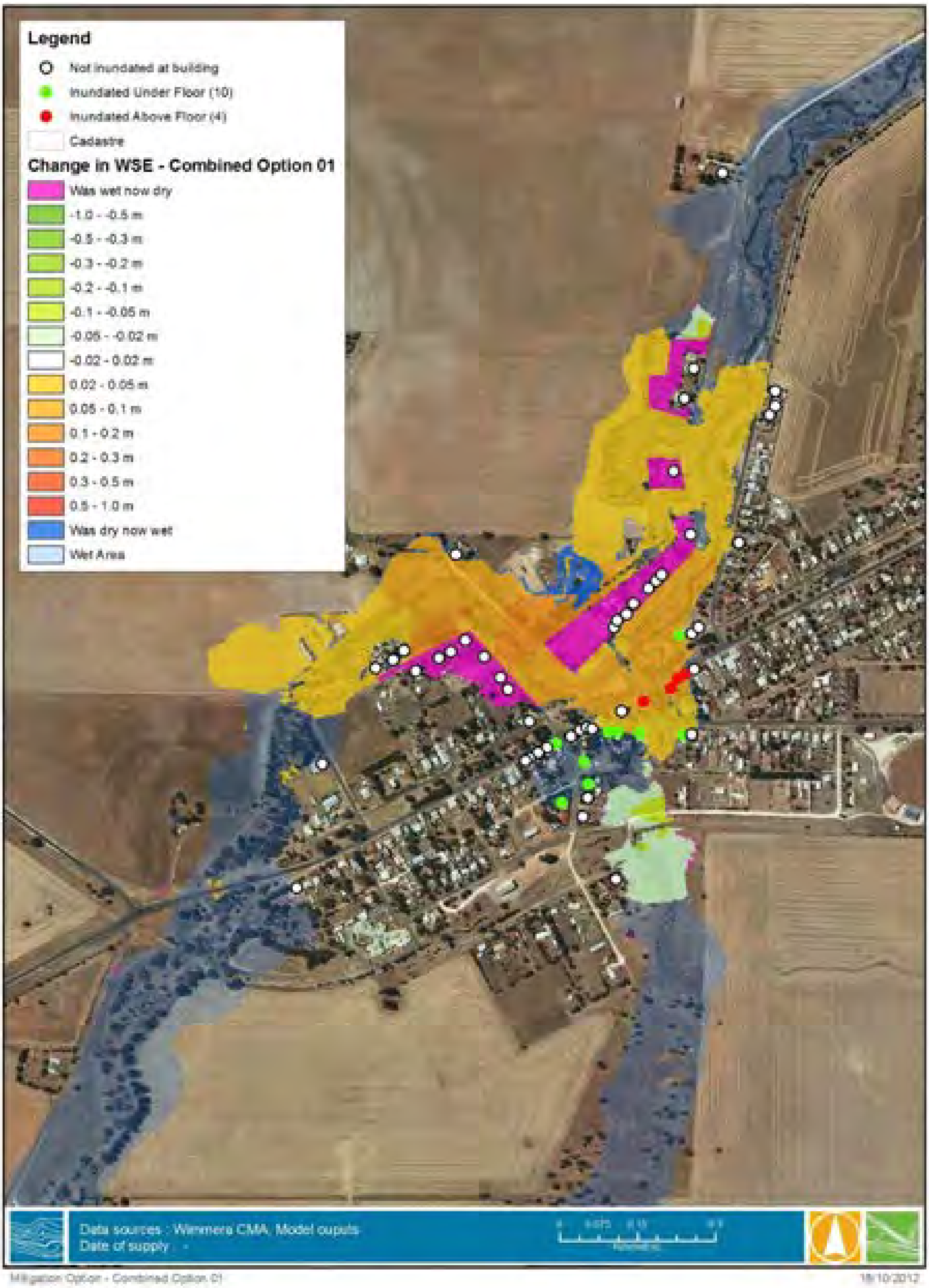

Figure 8-19 Combined option 01 100 year ARI event difference plot

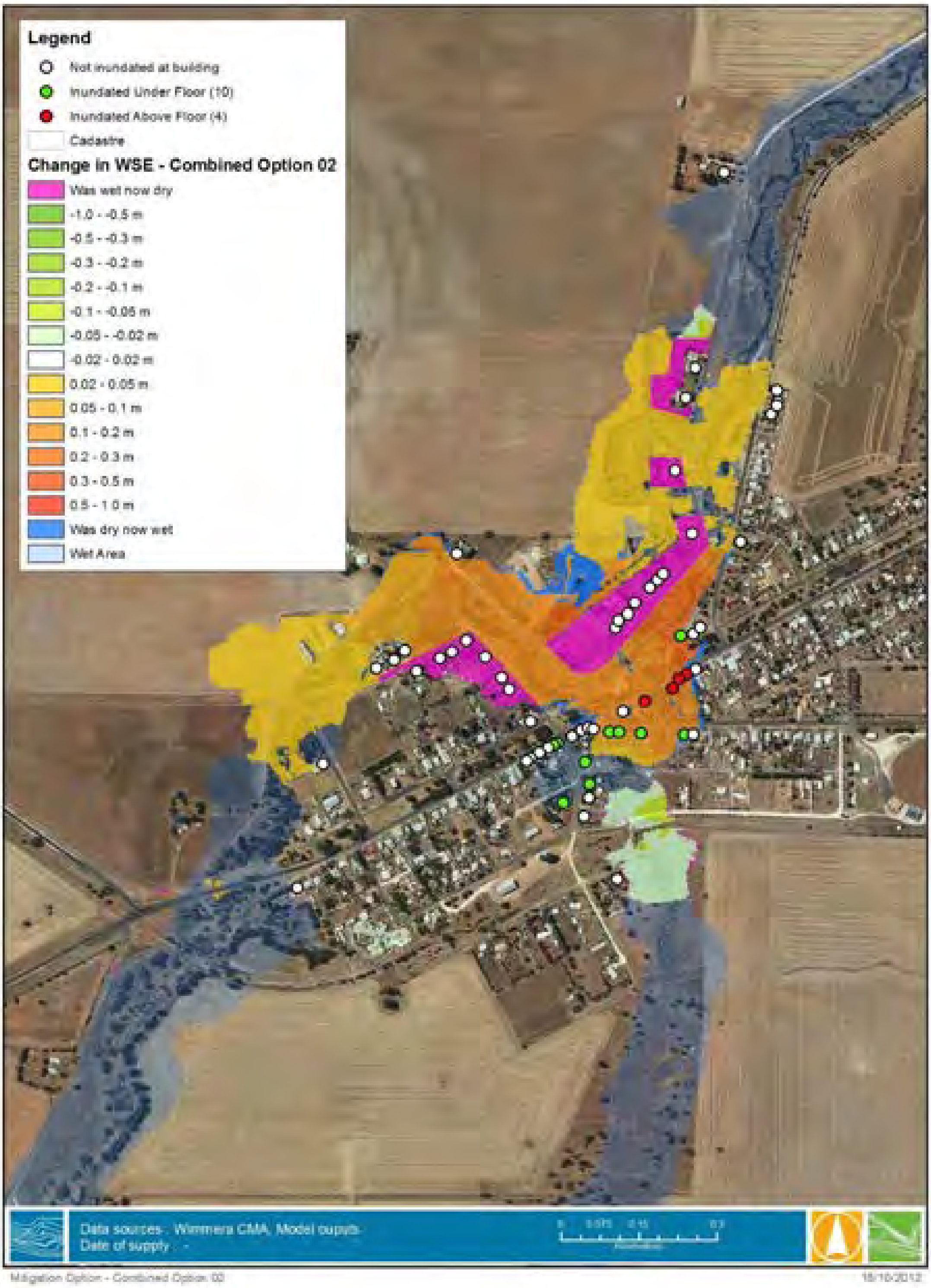

Figure 8-20 Combined option 02 100 year ARI event difference plot

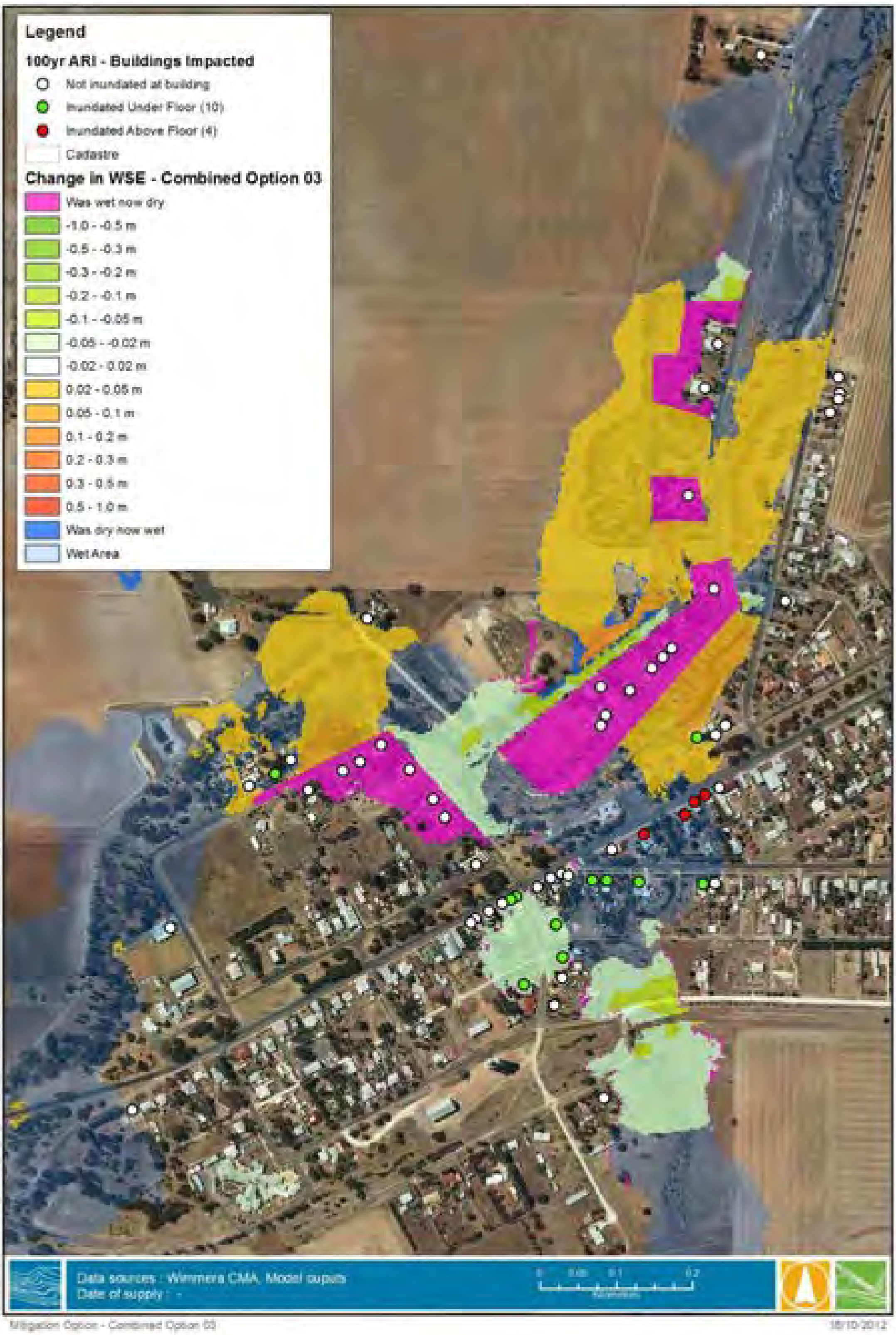

Figure 8-21 Combined option 03 100 year ARI event difference plot

8.3.9 Summary

Of all the options investigated there was no feasible solution that could be implemented that would reduce all above floor flooding within town. A number of options performed well hydraulically, however other considerations made them less attractive to the Steering Committee and with the community who were consulted on the selection of a preferred option. Table 8-5 below shows a brief summary of each option.

Table 8-5 Summary of mitigation options

Mitigation Option	Summary
Elmes Street levee	Protected 6 buildings (3 that were flooded above floor), very minor additional inundation on private land. However, no buildings adversely impacted.
Lake Avenue levee	Protect 9 buildings (7 that were flooded above floor). Flood levels increased by 0.2-0.3 m in areas where buildings were already impacted above floor.
Lake Avenue bywash channel	No significant impact on flood levels
Wetland overflow	Opening Natimuk Creek to the natural depression to the north of Natimuk reduced water levels in Natimuk by up to 0.1-0.2 m. This reduction reduced the number of buildings flooded above floor by 3. After the flood has passed the depression would remain inundated for an extended period of time, with the land not able to be farmed.
Little Natimuk Creek storages	Utilising the existing railway embankment for a retarding basin had no positive impacts on flood levels, it in fact increased flooding at nearby properties. In a 100 year ARI event the storage does not have the capacity to reduce the peak flow rate.
Increase the capacity of Little Natimuk Creek culverts	The culverts on Little Natimuk Creek do not significantly constrict flow in a large flood. The road heights (Jory Street and the Wimmera Highway) are close to the top of the culverts and once the culvert capacity is exceeded they overtop, with the flow area above the road deck providing sufficient flow capacity.
Combined option 01	Reduced number of buildings flooded above floor to 4 with all buildings impacted by Natimuk Creek free of inundation. Causes increase in flood levels by 0.1-0.2 m in the area of buildings impacted above floor.
Combined option 02	Reduction in buildings flooded above floor to 4 with all buildings impacted by Natimuk Creek free of inundation. Causes increase in flood levels by 0.2-0.3 m in the area of buildings impacted above floor level.
Combined option 03	Reduction in buildings flooded above floor to 4 with all buildings impacted by Natimuk Creek free of inundation. No buildings adversely impacted.

8.4 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.

8.4.1 Land Use Planning

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

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

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

Planning Schemes can be viewed online at http://services.land.vic.gov.au/maps/pmo.jsp. It is recommended that the planning scheme for Natimuk is amended to reflect the flood risk identified by this project. Figure 8-23 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 Natimuk.

Flood hazard - Combines the flood depth and flow speed for a given design flood event. The advisory notes suggest the use of Figure 8-22 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.

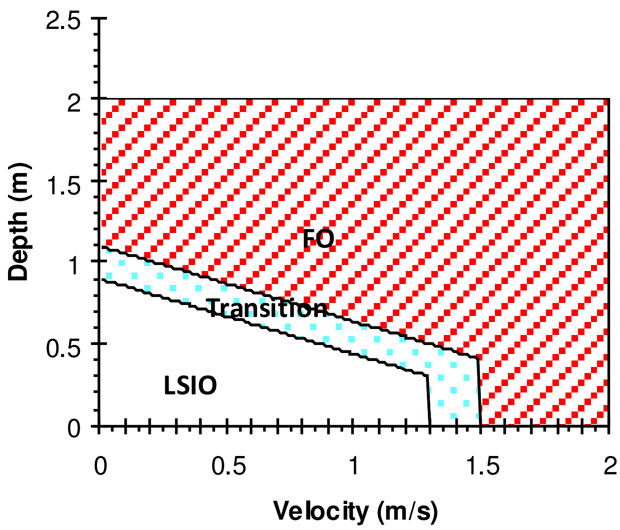

Figure 8-22 Flood Hazard Delineation of FO

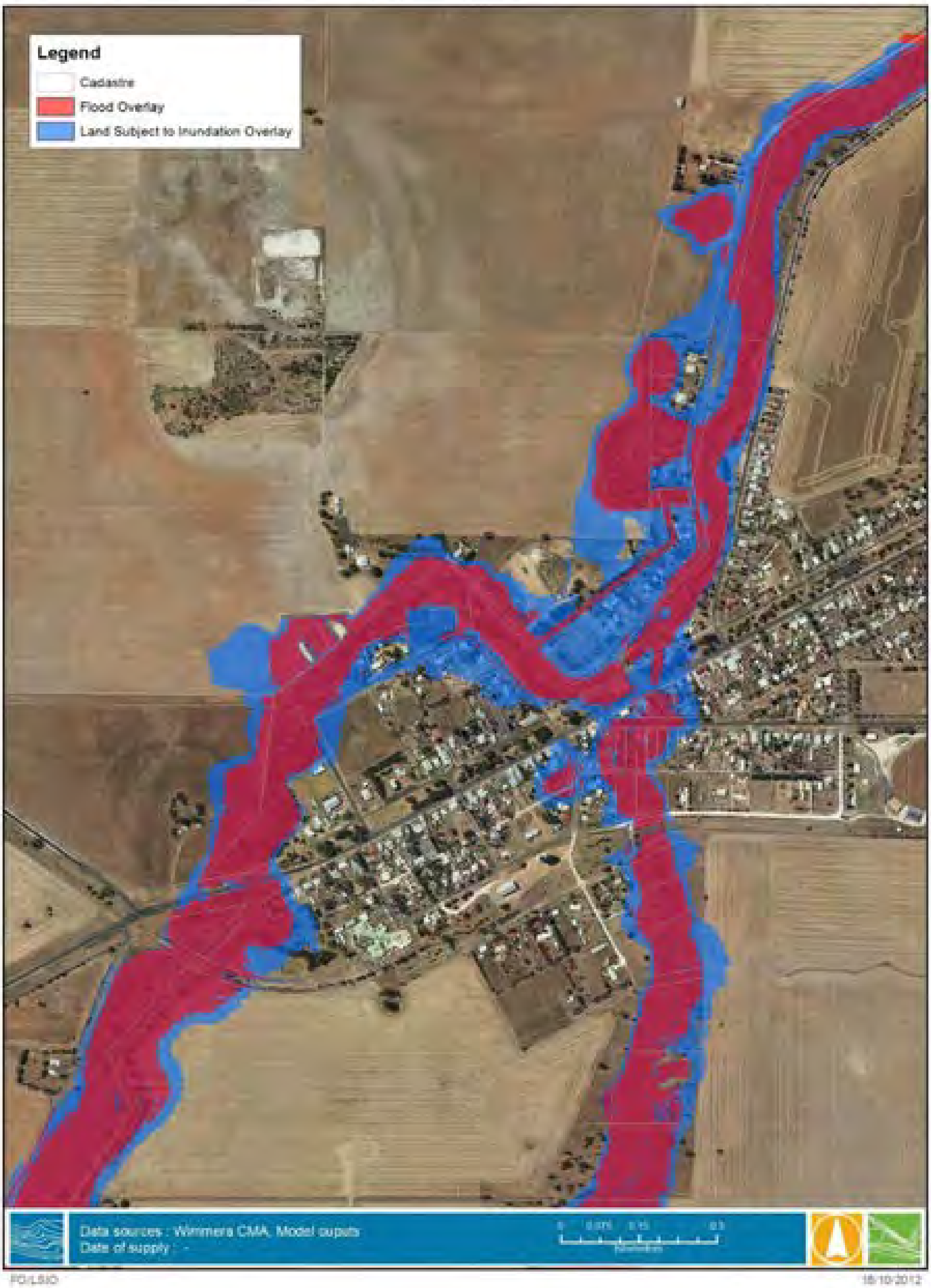

Figure 8-23 Draft LSIO and FO Map for Existing Conditions

9. FLOOD WARNING

9.1 Flood Warning as part of a Floodplain Management Strategy

Put simply, flood warning systems provide a means of gathering information about impending floods, communicating that information to those who need it (those at risk) and facilitating an effective and timely response. Thus flood warning systems aim to enable and persuade people and organisations to take action to increase personal safety and reduce the damage caused by flooding[39]. Effective flood warning systems maximise the opportunity for the implementation of public and private response strategies aimed at enhancing the safety of life and property and reducing avoidable flood damage.

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

9.2 Limitations of Flood Warning Systems

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

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

It is not surprising, given the above, that flood warning systems often work imperfectly and have, on occasions, failed. Indeed, as Handmer[40] points out, "*flood warnings often don't work well and too frequently fail completely – and this despite great effort by the responsible authorities*." While in some cases the problem is the result of a physical mechanical or technical failure (for example of gauges or telemetry or of communications equipment during a flood event), or perhaps in defining what constitutes success (or failure), the more common reason is that the systems have not been properly conceptualised at the design stage and in terms of their operation, despite the considerable and conscientious efforts of those involved. All too often, too little attention has been paid to issues of risk communication. In particular:

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

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

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

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

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

In numerous cases where flood warning systems have been developed, the bulk of the effort has been devoted to creating and strengthening data collection networks, devising and upgrading forecasting tools and facilities and utilising new dissemination technologies to distribute the forecast to at-risk communities. While all these things are important, they are never sufficient by themselves to ensure that flood warnings are heeded by those who receive them. Other equally vital elements of the system such as risk communication and the comprehension that people have of the flood problems they may face (and the value that warnings can offer) need at least as much attention at the design stage and in system operation. The lesson from many studies of flood warning systems (e.g. Smith and Handmer (1986)[41]; Phillips (1998)[42]; Handmer (1997)[43], (2000)[44], (2001)[45], (2002)[46]; Comrie, (2011)[47] is that the status of all elements of the system must be given appropriate resourcing if the system is to be made capable of functioning effectively.

Studies of flood warning system failures (e.g. Brisbane in 1974, Charleville and Nyngan in 1990, Benalla in 1993, Canada in 1997, England in 1998, Kempsey and Grafton in 2001, New Zealand in 2005) suggest that the most common reasons for poor system performance are that those in the path of floods, whether emergency responders, householders, the owners of businesses or the operators of infrastructural assets, have either not understood the significance of the warnings they have received or have not known that there were things (or the most appropriate things) they could do to mitigate the effects of flooding. The result has all too often been unnecessary loss of private belongings and commercial and industrial plant, stock and records (for example, through late or non-existent responses) and / or unnecessary risk to life (for example, due to evacuation after it became dangerous rather than when it was relatively safe). Most studies report that warnings were of an adequate technical standard (that is, they were accurate and delivered with good lead times), but the information was poorly communicated and not understood by the target communities. As reported by Anderson-Berry[48] and Soste & Glass[49] , there is often insufficient attention to ensuring that people in flood liable areas understand the flood gauge or forecast heights which are incorporated in warning messages. The result is that those who have been warned fail to appreciate that the information contained in the message has meaning for their own circumstances. Consequently, they fail to take appropriate or adequate protective measures. Such people often claim afterwards that

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

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

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

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

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

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

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

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

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

they received no flood warnings. In many cases warnings were issued but the gap between the information provided and what was understood by those at risk was too large. The problem is one of poor communication.

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

9.3 The Total Flood Warning System

In 1995 the Australian Emergency Management Institute, following a national review of flood warning practices after disastrous flooding in the eastern states in 1990, published a best-practice manual entitled '*Flood Warning: an Australian Guide*'[50]. In describing practices for the design, implementation and operation of flood warning systems in Australia, the manual introduced the concept of the 'total flood warning system' (TFWS). It also re-focused attention on flood warning as an effective and credible flood mitigation measure but made it clear that successful system implementation required the development of some elements that hitherto had been given little attention as well as the striking of an appropriate balance between each of the elements. In particular, it was noted that more attention needed to be given to risk communication and the education of communities about the flood risk, the measures which people could take to alleviate the problems that flooding causes and the place of warnings in triggering appropriate actions and behaviours. It also clearly enunciated the need for several agencies to play a part, with clearly-defined roles and with the various elements carefully integrated, and for the members of flood liable communities to be involved. Put another way, "*effective warning systems rely on the close cooperation and coordination of a range of agencies, organisations and the community*"[51] .

While the original manual has been updated and republished as Manual 21 of the Australian Emergency Manuals Series[52], the concepts, practices and key messages from the original manual endure.

9.4 Total Flood Warning System Building Blocks

An effective flood warning system is made up of several building blocks. Each building block represents an element of the Total Flood Warning System. The blocks (derived from EMA, 2009[53]) along with the basic tools to facilitate delivery against each of the TFWS elements are presented in Table 1.

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

[50] Australian Emergency Management Institute (AEMI) (1995): *Flood Warning: An Australian Guide*.
[51] Department of Transport and Regional Services (DoTARS) on behalf of the Council of Australian Governments (CoAG) (2002): *Natural Disasters in Australia. Reforming Mitigation, Relief and Recovery Arrangements: A report to the Council of Australian Governments by a high level officials' group.* August 2002 published 2004.
[52] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*
[53] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

community, who need to respond in an appropriate manner. A community that is informed and flood aware is more likely to receive the full benefits of a warning system.

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

9.5 The Task for Natimuk

9.5.1 Introduction

Attention will need to be given to each of the TFWS building blocks if an effective flash flood warning system is to be established for Natimuk.

9.5.2 Data Collection, Collation and Flood Detection and Prediction

Introduction

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

Possible Data Collection Sites

It is suggested that two creek level sites should be instrumented: both immediately upstream of the Wimmera Highway, at the Little Natimuk Creek crossing and at the Natimuk Creek crossing. Additional creek level monitoring sites could be instrumented but would provide limited benefit. For example, upstream gauges would need to be located a good distance upstream from Natimuk in order to provide useful lead time. The size of the Little Natimuk Creek catchment and the associated stream network (a number of quite small sub-catchments that come together around 3 km to 4 km upstream of Natimuk) mitigates against a useful (from a flood perspective) site being identified. Similarly, the Natimuk Creek catchment effectively splits in half around 5 km to 6 km upstream of Natimuk with many small creeks and drainage lines contributing to flows within each branch of the creek.

While a relationship may be able to be developed between sites established further up the catchment with additional modelling effort, it is suggested that lead times will be short, the error band on likely outcomes will be quite large and the benefit to Natimuk will be limited.

The Bureau of Meteorology maintains a daily-read rain gauge at Natimuk and operates an AWS with rain gauge nearby at Horsham. Data from the AWS is available from the BoM website every 30 minutes. During heavy rain events, rainfall data is reported more frequently.

Additional rain gauges could be located further up the catchment. For example, towards the top end of the Little Natimuk Creek catchment, around or upstream of Noradjuha in the Natimuk Creek east branch catchment and in the same general vicinity but further to the west in the catchment of the west branch.

Turnkey Data Collection and Alerting Systems

Introduction

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

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

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

- Sipan Sihaporas Hydro Electric Power Scheme in Indonesia;
- San Roque Dam and Hydro Power Scheme in the Philippines;
- SMART (Stormwater Management and Road Tunnel) in Kuala Lumpur in Malaysia;
- Public protection system for the Bruce Highway at Proserpine for Queensland Main Roads;
- Flash flood warning system for Warringah Mall in Brookevale in NSW.

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

Other Automated Data Collection and Alerting Systems

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

Campbell Data Logger
Campbell data loggers provide a level of functionality and reliability that has seen them installed at many water resources sites across Victoria over the past 10 years or so. They generally collect data at a combination of predetermined frequencies and exceedance criteria. They can be interrogated by computer via the telephone system (fixed and mobile) and can also be set to dial out or SMS to one of a number of pre-determined telephone numbers when simple alarm criteria are exceeded (i.e. alerting to the likelihood of or detection of flooding). A number of these loggers are installed in the Wimmera catchment. Quality control of data is an end-user responsibility.

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

Event-Reporting Radio Telemetry System
Event-Reporting Radio Telemetry System (ERTS) equipment is also installed at a number of sites across the Wimmera catchment. Base stations are operational at the Wimmera CMA's office in Horsham and at the Bureau of Meteorology's office in Melbourne. Both base stations host BoM supplied and maintained Enviromon software. This software manages all the data checking, collation and alerting functions.

Each ERTS flood monitoring system installation sends a signal by radio to one or more base stations every time there is a change in state of the parameter being measured – each increment of rainfall (can be 0.2mm, 0.5mm or 1mm) and a predetermined rise in stream level (usually every 10mm). Quality and other checks are performed automatically on the data as it is received in real-time at each base station. These checks include a comparison of rainfall and river level data received from each of the stations against a pre-set rainfall amount in a specified time period and / or against a pre-set river level threshold. The values selected reflect typical catchment response times as well as catchment and stream characteristics. For Natimuk, a useful rainfall trigger may be the rainfall intensity over the time of concentration for the catchment or the critical duration that produces the first overbank flows in the vicinity of the town. Any creek height thresholds would be set based on consideration of a range of factors particular to each gauge location. Trigger values can be adjusted based on experience so that alarms do not trigger unnecessarily or too often but do provide sufficient lead time on a potential flash flood event. As soon as the trigger rate is exceeded, the base station can be programmed to initiate an SMS message to the mobile phone (or pager) of key personnel.

The SMS alert provides a 'heads up' to a possible flash flood event. It is aimed at flagging the need for people to more closely monitor rainfall and other flood indicators (e.g. continuing heavy rain and other local indicators of a developing flood, radar imagery and rainfall data available from the Bureau's website, etc.), and at enabling early activation of flood response and related plans in order to minimise the risk to life and property. For Natimuk, the 'heads up' would also provide the trigger to use an indicative quick look 'flood / no-flood' tool developed for Natimuk and included in Appendix C4 of the Horsham Rural City's Municipal Flood Emergency Plan.

A more detailed explanation of ERTS systems and their benefits when used in flash flood situations is provided by Wright[54].

Manual Data Collection and Alerting

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

The simplest data collection system would comprise a set of staff gauges immediately upstream of the Wimmera Highway at the Little Natimuk and Natimuk creek crossings. The gauges would need to be either set to AHD (refer to discussion on page 56 of the Comrie Review Report[55]) or to a local datum with the correction to AHD determined as part of installation. This will enable the flood extent and depth maps delivered by the Natimuk Flood Investigation to be used to inform future flood response activities. Local residents would also need to be instructed on how to read the gauges so as to avoid possible confusion over water levels. In addition, a person (or group – see Section 7.4.1.5 below regarding the establishment of a community flash flood action group, or similar) would need to be nominated to read the gauges during heavy rain events and initiate local actions in the event of trigger levels being exceeded. These trigger levels should be set by the Natimuk community. It is suggested that a level 100mm or so below the 5-year ARI flood level might be a useful initial alerting level[56] but that the indicative quick look 'flood / no-flood' tool located in Appendix C4 of the MFEP would provide additional guidance on the need to initiate a local response.

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

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

[56] An initial alerting level of 100mm or so below the 5-year ARI level is suggested because at the 5-year level there are 2 properties flooded below-floor plus 18 land parcels flooded. Further, creek levels will rise quickly if the flood is going to be higher than a 5-year event and while it is appreciated that the first floor does not get flooded until a bit below the 20-year ARI level, the initial alert is aimed at providing the community with good lead time of possible flooding. As a minimum this will enable the mobilisation of local resources for sandbagging and other activities. The suggested initial alert level is between 500 and 600 mm below the 20-year ARI level (see Section 6.3 of the Natimuk Flood Intelligence Report). The initial alert level to be used should be established in consultation with the Natimuk community.

It should be noted that even if an automated data collection system is installed, staff gauges will need to be installed at all creek level monitoring sites.

A more developed data collection system would include manually read rain gauges as discussed in Section 7.2.2. Again, a person would need to be nominated to read each gauge at short time intervals during heavy rain events and provide each reading to a nominated person, possibly the same person reading the staff gauges at the Highway Bridge in Natimuk. Note that the owners of existing private rain gauges within these general areas may be willing to take on this task.

9.5.3 Interpretation

The flood inundation maps and Municipal Flood Emergency Plan Appendices developed as part of the Natimuk Flood Investigation provide the base information to enable the community and stakeholder agencies to determine the likely effects of a potential flood. This means however that the flood inundation maps and the relevant Appendices of the MFEP will need to be readily available to the Natimuk community.

9.5.4 Message Construction and Dissemination

Discussion - Available Alerting and Notification Tools and Technologies

According to Rogers and Sorensen[57], warning people of impending danger encompasses two conceptually distinct aspects—alerting and notification. Alerting deals with the ability of emergency officials to make people aware of an imminent hazard. Alerting frequently involves the technical ability to break routine acoustic environments to cue people to seek additional information. In contrast, notification focuses on how people interpret the warning message. It is the process by which people are provided with a warning message and information.

There are a number of alerting and notification tools and technologies available, some of which both alert and notify. Molino et al[58] provide a summary worth considering in the context of Natimuk and flash flooding. Only those that can very quickly provide property owners and occupiers with an alert or notification have been considered herein due to the quick response time associated with flooding at Natimuk.

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

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

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

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

- Enhanced dial-out system – similar to above but more expensive and reliant on local power supply.
- Paging and mobile phones – potential if local community is flood aware.

- Those that provide notification only:
  - Mass media (radio, television) - already used, for example ABC radio (1026AM and 774AM).
  - Internet – Bureau website displays warnings[59] and data from local rain and river sites[60].
  - FM-88 with community awareness program – being implemented.

From the above it can be seen that while information about flooding is available to the community through the internet there is need to, as a minimum, alert the Natimuk community in a timely manner to the likely on-set of flooding so that they can obtain the necessary notifications.

The need to alert communities to flash flooding is not restricted to Natimuk. A number of flash flood warning systems have been installed in NSW. Where time permits, the community alerting task is often achieved via local radio announcements. Active alerting is only undertaken occasionally and generally involves door knocking and loud hailer street announcements by SES. Other States, with the exception of Victoria and to some extent South Australia and Queensland, do not appear to have as yet addressed the issue. In South Australia and Queensland, the Bureau of Meteorology alerts and notifies selected stakeholder agency staff using an SMS message system provided by StreetData. Within Victoria, many of the Councils involved in flood warning system upgrades in recent years have implemented Premier Global Services' Xpedite VoiceREACH system to alert and notify residents and property owners in flood-prone urban areas. Melbourne Water are piloting an in-house developed SMS alerting system for residents in an area subject to flash flooding alongside Brushy Creek in the City of Maroondah which is triggered by the exceedance of rain or water level alarm criteria[61].

Both Xpedite (www.premiereglobal.com.au/voicereach/voicereach_broadcasting.htm) and StreetData (www.streetdata.com.au) are available and operational within Victoria. Both use existing technology, are quick and effective, are relatively cheap to implement and maintain, but require good quality broadband internet access from the host computer. For either to be truly effective, the at-risk or target community needs to be flood aware.

The national Emergency Alert (EA) system provides VICSES with a means of providing short messages to selected areas. While the EA has application for emergency situations, given the short lead times available it may not be suitable to warn Natimuk residents of possible flash flooding.

Expedite VoiceREACH

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

VoiceREACH is simple to set up, implement, use and maintain. When flooding is likely, a message is scripted by Council staff and, following log-in (from any computer with broadband internet access) to the VoiceREACH website, is read into a file by the user. The message is confirmed via playback and

[59] While the Bureau does not provide a flash flood warning service for the Natimuk catchment, it does issue warnings of severe storms and thunderstorms, phenomena that often lead to flash flooding in similar catchments.

[60] Rain and water level data from all Wimmera catchment ERTS sites are available in near real-time.

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

either edited or accepted for transmission. On acceptance for transmission, VoiceREACH delivers the voice message almost simultaneously to all telephone numbers in the user-managed telephone number file[62] located on the VoiceREACH website.

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

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

StreetData

StreetData offers an SMS delivery service[63]. The disadvantage of StreetData is that it can only deliver an SMS message. This means that unless a telephone handset recognises SMS protocols, only mobile phone owners can receive the message[64]. Further, there is no guarantee of delivery, delivery is not necessarily immediate and there is no confirmation that the message has been received: it is essentially a "fire and forget" system.

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

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

Enviromon can be set up to send the message to StreetData with a single, block of or all listed telephone numbers[65]. The Bureau recommends however that the message is sent to StreetData for each telephone number. This reduces the risk of message loss as, if there is a failure, only single, rather than many recipients fail to receive the message.

Enviromon can be configured to automatically drive the alerting process. It will monitor data from each sensor at each site[66] and can drop real time data into the pre-scripted messages.

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

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

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

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

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

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

The Bureau is in the process of finalising documentation for the use of StreetData with Enviromon[67].

Community Involvement

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

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

9.5.5 Response

The Natimuk Flood Intelligence Report has been produced as part of this study. The Intelligence report will allow the Horsham Rural City's Municipal Flood Emergency Plan (MFEP) to be updated for flooding and response at Natimuk.

Information to be incorporated into the revised MFEP should include all available intelligence relating to flooding at Natimuk from the Little Natimuk and Natimuk creeks along with the indicative quick look 'flood / no-flood' tool which utilises local rainfall depths. Flood inundation extent and depth maps should also be included along with a list of properties likely to be flooded and the expected depth of that flooding at each property. This information is presented in the Natimuk Flood Intelligence Report and should be able to be cut across into the existing MFEP with relative ease.

A critical issue for flood response at Natimuk is the timely availability of sandbags and sand within the town with sufficient lead time to enable buildings at risk of flooding over-floor (see Appendix C4 of the MFEP) to be sandbagged / protected. Arrangements established in conjunction with Council should be detailed in the MFEP.

9.5.6 Community Flood Awareness

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

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

Studies repeatedly show that communities that are not aware of flood hazard are less capable of responding appropriately to flood warnings or alerts and experience a more difficult recovery than a

[67] Enviromon can accommodate other programs that initiate other actions provided that an interface is available or developed. This means that if the Rural City of Horsham wished to initiate a siren (say) on exceedance of alarm criteria, provided there was a program available to activate the siren and provided that an interface was prepared, the Enviromon alarm function could be used to sound the siren.

flood-aware community. Plain language flood awareness campaigns should aim to erase these misconceptions

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

- Making the MFEP publicly available (Council offices, library, website) with a summary provided in Council welcome packages for new residents and business owners and with annual rate notices;
- Championing a community flash flood action group and the establishment of volunteer community based flood wardens (or similar);
- Periodically providing feature articles to local media on previous flood events and their effects on the community;
- Installing flood markers indicating the heights of previous floodwaters (e.g. on power poles, street signs, public buildings, sides of bridges, etc);
- Preparing and distributing property specific flood depth charts for all properties likely to be affected by flooding within Natimuk (the data to inform the charts can be extracted from the hydraulic model developed for the Natimuk Flood Investigation);
- Installing flood depth indicators where there is appreciable danger to human life due to flood depth and / or velocity (e.g. where Station Street and Jory Street cross Little Natimuk Creek, at strategic locations along Elmes Street, Lake Avenue and Creek Road, etc);
- Photo displays of past flood events in local venues (these could be permanent); and.
- Preparing and distributing (as an on-going program) a flash flood action guide or brochure (e.g. FloodSafe brochure and as described by Crapper et al[68], in relation to Shepparton and Mooroopna) aimed specifically at encouraging local residents and businesses to take a pro-active role in preparing their property and themselves for a flood as well as describing what people need to do in a flood event. These could be given out at local events and with council rate notices and / or other council communications.

9.6 Suggested System

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

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

Table 9-1 Flash Flood Warning System Building Blocks and Possible Solution for Natimuk with due regard for the EMMV, Commonwealth-State arrangements for flood warning service provision (BoM[69], VFWCC[70] and EMA[71])

Building Blocks of a Flash Flood Warning System	Basic Tools	Possible Solution for Natimuk
DATA COLLECTION & COLLATION	Data collection network (e.g. rain and stream gauges)	INITIALLY: Install 2 x staff gauge sets at Natimuk plus 2 x rainfall gauges further up the catchment and nominate a person or group to collect and collate data, and make initial assessments of the likelihood of flooding.
	System to convey data from field to central location and / or forecast centre (e.g. radio or phone telemetry).	AT SAME TIME OR LATER: Install ERTS - ALERT flood monitoring system. ERTS is a commercially available radio telemetry system that reports by radio in real-time to a base station. A number of sites already installed in Wimmera catchment and base station at WCMA office. Existing base station as well as Bureau offices will receive data.
	Data management system to check, store, display data.	ENVIROMON – software provided and maintained by the Bureau.
	Arrangements and facilities for system / equipment maintenance and calibration. For example, the Regional Surface Water Monitoring Partnership, data warehousing, etc.	Commercial arrangement between Council and a service provider for maintenance. Ideally this would be through the Surface Water Monitoring Partnership. Include all capitalised system components on Council's asset management register.
DETECTION & PREDICTION (i.e. Forecasting)	Rainfall rates and depths likely to cause flooding together with information on critical levels / effects at key and other locations.	INITIALLY: Using data from the Horsham AWS, Natimuk daily-read gauge (if available) and upstream rain gauges (if available) together with water levels and trends at Natimuk (if available), determine likelihood and scale of possible flooding using the tool described below.
	Appropriately representative flood class levels at key locations plus information on critical levels / effects.	LATER: Use rainfall rates and depths from Flood Intelligence tool to set alarm criteria (on rainfall) at gauges and to initiate local alerting of potential flooding. This may lead to the establishment of flood class levels if desirable.
	Flood forecast techniques (e.g. hydrologic rainfall - runoff model, stream flow and / or height correlations, simple nomograms based on rainfall).	The indicative quick look 'flood / no-flood' tool developed for Natimuk and included in Section 6.5 of the Natimuk Flood Intelligence Report provides guidance on the likelihood and scale of possible flooding. Council responsible for maintaining the tool. Decide how this tool is to be used and who by – Council, VICSES, WCMA, community?

[69] Bureau of Meteorology (1987): *Flood Warning Arrangements - Papers prepared for discussions with Victorian Agencies,* December 1987
[70] Victorian Flood Warning Consultative Committee (VFWCC) (2001): *Arrangements for Flood Warning Services in Victoria.* February 2001.
[71] Emergency Management Australia (EMA) (2009): *Manual 21: Flood Warning.*

Building Blocks of a Flash Flood Warning System	Basic Tools	Possible Solution for Natimuk
INTERPRETATION (i.e. an ability to answer the question *"what does this mean for me - will I be flooded and to what depth"*.	Interpretative tools (i.e. flood inundation maps, flood information cards, flood histories, local knowledge, flood response plans that have tapped community knowledge and experience, flood related studies and other sources, etc).	Deliverables and intell arising from the Natimuk Flood Investigation have been captured to the MFEP. The quick look tool described above together with the MFEP enable those at risk to determine whether they are likely to be flooded with some lead time. After gauges installed, access the hydraulic model to provide exact levels at each gauge location for the modelled flood events. Add intell into the MFEP
MESSAGE CONSTRUCTION	Warning messages / products and message dissemination system.	Short hydrologic response time hence simple automated messaging is likely to work best. There would be a role for the Emergency Alert during a severe flood event.
MESSAGE DISSEMINATION (i.e. Communication and Alerting)	**Formal media channels[72] – TV, radio and print.** Fax / faxstream, phone / pager (e.g. SMS, voice), voice messaging systems (e.g. Xpedite), tape message services, community radio, internet (e.g. BoM & VICSES websites, email, social media), national Emergency Alert system. Flood wardens Door knocking Informal local message / information dissemination systems or 'trees'. Opportunity for at-risk communities to confirm warning details.	In the lead up to system implementation, establish a Council championed community flash flood action group. On exceedance of alarm criteria ENVIROMON will send an SMS message to key Municipal and / or VICSES personnel as well as perhaps to key community members who could then initiate a local phone-based information dissemination tree. An opt-in system that must be heavily community drive.
RESPONSE	Flood management tools (e.g. Municipal Flood Emergency Plan complete with inundation maps and 'intelligence', effective public dissemination of flood information, local flood awareness, individual and business flood action plans, etc). Flood response guidelines and related information (e.g. Standing Operating Procedures).	Establish arrangements for the timely supply of sandbags and sand within Natimuk with sufficient lead time to enable buildings at risk of flooding over-floor (see Appendix C4 of the MFEP) to be sandbagged / protected. Arrangements established in conjunction with Council should be detailed in the MFEP. Following (or perhaps in concert with) acceptance of the MFEP, encourage and assist residents and businesses to develop individual flood response plans. A package that assists businesses and individuals is available from VICSES and provides an excellent

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

Building Blocks of a Flash Flood Warning System	Basic Tools	Possible Solution for Natimuk
	Comprehensive use of available experience, knowledge and information.	model for community use.
REVIEW	Post-event debriefs (agency, community), etc. Data from Rapid Impact Assessments. Flood 'intelligence' and flood damage data from the event collected by residents, Council, WCMA, etc. Review and update of personal, business and other flood action plans.	Review and update of alarm criteria, local flood intelligence (i.e. flood characteristics, impacts, etc), local alerting arrangements, response plans, local flood awareness material, etc (initially) after every flood that triggers an alarm. Best done by Council with input from VICSES, WCMA and the Council championed community flash flood action group. Council to develop review and update protocols => who does what when and process to be followed to update material consistently across all parts of the flash flood warning and response system, including the MFEP.
AWARENESS	Identification of vulnerable communities and properties (i.e. flood inundation maps, information on flood levels / depths and extents, etc). Activities and tools (e.g. participative community flood education, flood awareness raising, flood risk communication) that aim to build flood resilient communities (i.e. communities that can anticipate, prepare for, respond to and recover quickly from floods while also learning from and improving after flood events). Community education and flood awareness raising including VICSES FloodSafe and StormSafe programs. Local flood education plans – developed, implemented and evaluated locally (e.g. Cities of Maroondah, Whitehorse, Wodonga, Benalla and Greater Geelong). Flood response guidelines, residents' kits, flood markers, flood depth indicators, flood inundation maps and property listings, property specific flood depth charts, flood levels in meter boxes and on rate notices, etc for properties identified as being subject to flooding through the Natimuk Flood Investigation.	Develop, print and distribute flood awareness material (FloodSafe brochures, property specific flood depth charts, etc), including information on how the flash flood warning system operates using information collated for the MFEP and available within the Natimuk Flood Investigation report and from the web. Load and maintain material (including the MFEP) on Council's website with appropriate links to relevant useful sites (e.g. the Flood Victoria website http://www.floodvictoria.vic.gov.au/centric/home.jsp). Routinely revisit and update awareness material to accommodate lesson leant, additional or improved material and to reflect advances in good practice. Routinely repeat distribution of awareness material and consider other measures. Decide whether to alert residents and visitors to the risk of flooding in more direct ways. This could include the installation of flood depth indicator boards at key locations (e.g. where Station Street and Jory Street cross Little Natimuk Creek, at strategic locations along Elmes Street, Lake Avenue and Creek Road, etc).

9.7 Estimated costs

Table 9-2 Estimated cost associated with the Flood Warning System Options

Item	Estimated cost as at 2012 (excl GST)	Comments
9.7.1 Data Collection, Collation and Flood Detection and Prediction		
4 x staff gauges immediately upstream of the Wimmera Highway at Little Natimuk Creek and Natimuk Creek. Set either to AHD or local datum and including survey to AHD.	$2,500 per site $5,000 for both	Cost covers supply, installation and commissioning of equipment. It also includes estimated allowances for cultural heritage assessment and service checks and marking at both sites.
2 x ERTS river only installations immediately upstream of the Wimmera Highway at Little Natimuk Creek and Natimuk Creek. Includes concrete instrument housing on concrete pad, HS dry bubbler and pressure transducer, ERTS canister, solar panel, antenna, cabling.	$24,000 per site $48,000 for both	
3 x manually read rain gauges: ➢ Top end of the Little Natimuk Creek. ➢ EITHER around or upstream of Noradjuha in the Natimuk Creek east branch catchment. ➢ OR in the same general vicinity but further to the west in the west branch catchment	~$150 per site ~$300 total	
2 x ERTS rain only installations at locations as indicated for the manually read gauges. Includes steel instrument housing, BoM spec TBRG, ERTS canister, solar panel, antenna, cabling.	$13,000 per site $26,000 total	Cost covers supply, installation and commissioning of equipment.
Addition of rain gauge to one of the ERTS river level monitoring sites at Natimuk.	$2,500 per site	Only required if rainfall data is required from Natimuk rather than from the Horsham AWS.
Input from the Bureau of Meteorology, comprising assistance with site selection, radio path testing, advice on necessary and appropriate equipment, base station computer set up and input to development of protocols for on-going support.	In-kind	Subject to operational and other workloads.
Recurrent costs: ➢ Staff gauge site. ➢ Manual rain gauge site. ➢ ERTS river site (no gauging). ➢ ERTS rain gauge only site.	$1,000/year/site nil $3,000/year/site $2,500/year/site	Indicative costs only and dependent on the work scope and whether the sites are brought into the Surface Water Monitoring Partnership.
Council to champion and oversee the establishment of a flash flood action or flood warden group for Natimuk. This group would collect and collate rain and river data and undertake the initial assessment of the likelihood and scale of possible flooding within Natimuk.		Will need to clearly establish the role for this group along with its authority.

Item	Estimated cost as at 2012 (excl GST)	Comments
Use the indicative quick look 'flood / no-flood' tool developed for Natimuk to determine the likelihood and scale of possible flooding.	In-kind	Council to maintain the tool. This could be done by plotting flood producing rainfall events and resulting flooding on the chart along with the event date. This may allow some refinement of the tool over time.
9.7.2 Interpretation		
The indicative quick look 'flood / no-flood' tool together with the MFEP enable those at risk to determine whether they are likely to be flooded with some lead time.	In-kind	MFEP intell will need to updated following flooding at Natimuk.
Assess the hydraulic model results for the Natimuk Flood Investigation in order to provide exact levels at each gauge location for the modelled flood events. Add intell into the MFEP.	$2,000	Cannot be done until staff gauges installed.
9.7.3 Message Construction and Dissemination		
Council to champion and oversee the establishment of a flash flood action or flood warden group for Natimuk. This group to initiate advice of the likelihood and scale of likely flooding within Natimuk.		Will need to clearly establish the role for this group along with its authority. Establish a local telephone-based information dissemination tree.
Longer term and to coincide with the installation of ERTS equipment, implement a system utilising either StreetData or Xpedite to alert the Natimuk community to the exceedance of alarm criteria. Some recurrent costs.	~$15,000 plus some in-kind Allow $1,000/yr for recurrent costs	Cost will depend on approach selected, BoM workloads and how much of system set up (e.g. informing the community of the system, collating responses, establishing contact numbers, documentation, etc) is out-sourced.
9.7.4 Response		
Council to share relevant parts of the MFEP with the Natimuk community.	In-kind	Will assist the implementation of an informed local response when it next floods.
Council to establish arrangements for the timely supply of sandbags and sand within Natimuk.	In-kind	
Encourage and assist residents and businesses to develop individual flood response plans.	In-kind	Council and VICSES.
9.7.5 Review and Keeping the System Alive		
Post-event review and on-going maintenance of the system in order to keep it alive within the community (e.g. exercises to test procedures, maintenance of the website, asset replacement, SMS call costs, involvement with a community	In-kind except SMS costs.	SMS costs will vary year to year and will depend on rainfall and seasonal conditions.

Item	Estimated cost as at 2012 (excl GST)	Comments
flash flood action group and so on).		
9.7.6 Community Flood Awareness		
Develop and distribute a FloodSafe brochure for Natimuk	Up to $12,000 but expected to be covered by other funding through VICSES	Cost will depend on how much of the work is out-sourced and how much is done by VICSES as an in-kind contribution.
Develop, print and distribute property-specific flood depth charts for properties within Natimuk.	$5,000	Cost will depend on how much of chart build is out-sourced.
Load and maintain flood related material (including the MFEP) to Council's website.	In-kind	
Install flood depth indicator boards at key locations in and around Natimuk.	$1,000/board	

9.8 Recommendations

A staged approach to the development of a flash flood warning system for Natimuk is proposed as follows.

Stage 1

1. Council, Wimmera CMA, VICSES and other entities to determine the responsible entity in relation to "ownership" of the flash flood warning system for Natimuk, where ownership is considered to denote overall responsibility for the functioning of all system elements and, in the event of failure, either fault-fix or the organisation of appropriate fault-fix actions and payments. VFWCC[73] provides guidance on this matter although recommendation 5 from the Comrie Review Report[74] suggests that some clarifications may be required.

Stage 2

1. Council to champion and oversee the establishment of a flash flood action or flood warden group for Natimuk. Clearly establish the role for this group along with its authority. Essentially the group would:
   - Collect and collate rain and creek data.
   - Make initial assessments of the likelihood of flooding based on available rainfall data and the indicative quick look 'flood / no-flood' tool developed for Natimuk and included in Section 6.5 of the Natimuk Flood Intelligence Report.
   - Initiate flood response within Natimuk (door knocking and through the MFEP, identification of roads and properties likely to be impacted) when conditions indicated it is warranted or necessary and thereafter work closely with VICSES, CFA and Council.

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

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

- Maintain a watching brief on arrangements for and the availability of sandbags and sand within Natimuk and provide feedback to Council on the adequacy and efficacy of arrangements in place at the time.

2. Council to share the MFEP with the Natimuk community.

3. Council to establish arrangements for the timely supply of sandbags and sand within Natimuk.

4. Council and VICSES to encourage and assist residents and businesses to develop individual flood response plans.

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

6. Council with the support of VICSES, WCMA and the Natimuk community to submit an application for funding under the Australian Government Natural Disaster Resilience Grants Scheme (or similar) for all outstanding elements of a TFWS for Natimuk.

7. Install 2 x staff gauge sets (up to 4 staff gauges each) immediately upstream of the Wimmera Highway at Little Natimuk Creek and Natimuk Creek. Set to either AHD or local datum and survey to AHD. Mark January 2011 and December 2010 flood levels on the gauges, as well as the design flood levels determined through the Natimuk Flood Investigation. Establish on-going maintenance arrangements, ideally through the Surface Water Monitoring Partnership.

8. Update the MFEP with staff gauge datums and levels for the 6 x design events.

Stage 3

1. Determine the location of private rain gauges within or in close vicinity to the Natimuk Creek catchment upstream of Natimuk and establish arrangements for the provision of rainfall data to the flash flood action or flood warden group at frequent intervals during heavy rain events.

   Alternatively, source two rain gauges and distribute to local residents willing to provide rainfall data at frequent intervals during heavy rain events in the general vicinity of:
   - EITHER around or upstream of Noradjuha in the Natimuk Creek east branch catchment,
   - OR in the same general vicinity but further to the west in the west branch catchment,
   - Top end of the Little Natimuk Creek.

2. Either directly with the reader or possibly through BoM, arrange for access to as-required rainfall data from the BoM daily-read rain gauge at Natimuk. Ideally this will involve the reader in providing data directly to the flash flood action or flood warden group at frequent intervals during heavy rain events.

Stage 4

1. Install an ERTS - ALERT flood monitoring system comprising:
   - 2 x ERTS rain only installations in the general vicinity of:
     - EITHER around or upstream of Noradjuha in the Natimuk Creek east branch catchment,
     - OR in the same general vicinity but further to the west in the west branch catchment,
     - Top end of the Little Natimuk Creek.

2. Establish on-going maintenance arrangements for all installed equipment, ideally through the Surface Water Monitoring Partnership.

3. Implement a community flash flood alerting system utilising either StreetData or Xpedite and the existing ERTS base station (currently located in the WCAM offices) to alert the Natimuk

community to the exceedance of alarm criteria at the ERTS rain and / or river sites and the likelihood of flooding.

4. VICSES to develop and distribute a FloodSafe brochure for Natimuk

5. Council to oversee the development, printing and distribution of property-specific flood depth charts for properties within Natimuk.

Stage 5

1. Install flood depth indicator boards at key locations in and around Natimuk (e.g. where Station Street and Jory Street cross Little Natimuk Creek, at strategic locations along Elmes Street, Lake Avenue and Creek Road, etc.).

Stage 6 – an optional later activity dependent on available funding and FWS development path

1. In order to fully complete the TFWS and provide a basis for automation of flood monitoring, forecasting and warning, augment the ERTS - ALERT flood monitoring system through installation of:
   - 2 x ERTS river only stations immediately upstream of the Wimmera Highway at Little Natimuk Creek and Natimuk Creek at the same location as the staff gauges;
   - 1 x TBRG at one of the ERTS river only stations at Natimuk.

10. FLOOD DAMAGE ASSESSMENT

10.1 Overview

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

The flood damage assessment was also undertaken for two flood mitigation options chosen by the Natimuk Flood Investigation Steering Committee (Elmes Street Levee and Combined Option 03).

Water Technology has developed an industry best practice flood damage assessment methodology that has been previously 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 C.

10.2 Existing Conditions

The flood damage assessment for existing conditions is shown below in Table 10-1. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$37,250**. 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 for the occurrence of a future flood event.

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

Table 10-1 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	17	14	4	1	0	0
Properties Flooded Below Floor	46	49	47	31	19	16
Total Properties Flooded	**63**	**61**	**51**	**32**	**19**	**16**
Direct Potential External Damage Cost	$231,571	$227,739	$198,428	$121,254	$80,253	$40,141
Direct Potential Residential Damage Cost	$222,903	$148,522	$38,904	$0	$0	$0
Direct Potential Commercial Damage Cost	$58,315	$39,968	$20,105	$10,508	$0	$0
Total Direct Potential Damage Cost	**$512,788**	**$416,229**	**$257,437**	**$131,762**	**$80,253**	**$40,141**
Total Actual Damage Cost *(0.8*Potential)*	**$410,231**	**$332,983**	**$205,950**	**$105,410**	**$64,202**	**$32,113**
Infrastructure Damage Cost	**$145,673**	**$132,566**	**$103,866**	**$60,082**	**$27,224**	**$10,370**
Indirect Clean Up Cost	$83,050	$59,639	$19,880	$3,531	$0	$0
Indirect Residential Relocation Cost	$9,290	$6,968	$2,323	$0	$0	$0
Indirect Emergency Response Cost	$23,269	$23,269	$23,269	$13,961	$9,308	$4,654
Total Indirect Cost	**$115,609**	**$89,875**	**$45,471**	**$17,492**	**$9,308**	**$4,654**
Total Cost	**$671,512**	**$555,424**	**$355,287**	**$182,984**	**$100,733**	**$47,137**
Average Annual Damage (AAD)	**$37,252**					

10.3 Elmes Street Levee

The AAD for the Elmes Street levee mitigation option was calculated to be approximately **$34,500**. The Elmes Street levee only protects properties on Elmes Street. The levee increases the ARI at which the first building becomes inundated above floor to a 50 year ARI. It also reduces the number of buildings inundated above floor by 3 in a 100 year ARI event and 5 in a 200 year ARI event.

Table 10-2 Flood Damage Assessment for the Elmes Street Levee

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	12	9	3	0	0	0
Properties Flooded Below Floor	42	42	38	24	16	13
Total Properties Flooded	**54**	**51**	**41**	**24**	**16**	**13**
Direct Potential External Damage Cost	$237,721	$211,181	$153,203	$100,580	$68,598	$36,131
Direct Potential Residential Damage Cost	$169,443	$125,059	$37,527	$0	$0	$0
Direct Potential Commercial Damage Cost	$26,199	$12,491	$0	$0	$0	$0
Total Direct Potential Damage Cost	**$433,363**	**$348,731**	**$190,730**	**$100,580**	**$68,598**	**$36,131**
Total Actual Damage Cost (0.8*Potential)	**$346,691**	**$278,985**	**$152,584**	**$80,464**	**$54,878**	**$28,905**
Infrastructure Damage Cost	**$147,034**	**$136,162**	**$105,249**	**$64,620**	**$32,341**	**$15,351**
Indirect Clean Up Cost	$57,720	$45,209	$16,349	$0	$0	$0
Indirect Residential Relocation Cost	$6,193	$5,419	$2,323	$0	$0	$0
Indirect Emergency Response Cost	$23,269	$23,269	$23,269	$13,961	$9,308	$4,654
Total Indirect Cost	**$87,183**	**$73,897**	**$41,940**	**$13,961**	**$9,308**	**$4,654**
Total Cost	**$580,907**	**$489,044**	**$299,773**	**$159,045**	**$96,527**	**$48,910**

Average Annual Damage (AAD)	$34,499

10.4 Combined Option 03

Combined Option 03 involved the construction of three levees. Lake Avenue Levee 02 protected one house, while Lake Avenue Levee 03 protected two houses. As these levees are likely to be uneconomical to build for the number of houses they protect, flood damages were calculated with and without their inclusion. Combined Option 03a included the levees protecting the properties and Combined Option 03b raised the floor level of one property. This property was protected by the second Lake Avenue levee. Properties protected by the third Lake Avenue Levee, although impacted below floor, have a floor level at more than the 300mm above the 100 year ARI water level. Combined Option 03b used the existing conditions damages for an assessment of external damages but without above floor building damages.

Figure 10-1 and Figure 10-2 show the location of the levees and impacted flood levels for Combined Option 3a and 3b respectively.

Figure 10-1 Combined option 03a

Figure 10-2 Combined option 03b

10.4.1 Combined Option 03a

The AAD for Combined Option 03a was calculated to be approximately **$27,316**. Combined Mitigation Option 3 is effective in reducing the damage cost because it protects all dwellings that would become inundated by Natimuk Creek. It is by far the best option for reducing flood risk with 3 buildings inundated by floodwater during a 100 year ARI event and 5 in a 200 year ARI event. However as discussed in Section 10.7 it is an extremely costly option to construct.

Table 10-3 Flood Damage Assessment for Combined Option 03a

ARI (years)	200yr	100yr	50yr	20yr	10yr	5yr
AEP	0.005	0.01	0.02	0.05	0.1	0.2
Buildings Flooded Above Floor	5	3	1	0	0	0
Properties Flooded Below Floor	43	42	26	22	17	13
Total Properties Flooded	**48**	**45**	**27**	**22**	**17**	**13**
Direct Potential External Damage Cost	$203,312	$173,293	$107,274	$88,890	$57,892	$25,035
Direct Potential Residential Damage Cost	$26,731	$22,015	$14,670	$0	$0	$0
Direct Potential Commercial Damage Cost	$26,225	$12,495	$0	$0	$0	$0
Total Direct Potential Damage Cost	**$256,268**	**$207,802**	**$121,944**	**$88,890**	**$57,892**	**$25,035**
Total Actual Damage Cost (0.8*Potential)	**$205,015**	**$166,242**	**$97,555**	**$71,112**	**$46,314**	**$20,028**

Infrastructure Damage Cost	**$134,649**	**$124,604**	**$91,498**	**$54,492**	**$26,516**	**$14,263**
Indirect Clean Up Cost	$19,574	$12,512	$5,450	$0	$0	$0
Indirect Residential Relocation Cost	$774	$774	$774	$0	$0	$0
Indirect Emergency Response Cost	$23,269	$23,269	$23,269	$13,961	$9,308	$4,654
Total Indirect Cost	**$43,617**	**$36,555**	**$29,492**	**$13,961**	**$9,308**	**$4,654**
Total Cost	**$383,281**	**$327,401**	**$218,546**	**$139,566**	**$82,137**	**$38,944**

Average Annual Damage (AAD)	$27,316

10.4.2 Combined Option 03b

The AAD for Combined Option 03b was calculated to be approximately **$27,860**. Combined Mitigation Option 3 is effective in reducing the damage cost because it protects all dwellings that would become inundated by Natimuk Creek. It is by far the best option for reducing flood risk with 3 buildings inundated by floodwater during a 100 year ARI event and 5 in a 200 year ARI event. However as discussed in Section 10.7 it is an extremely costly option to construct.

Table 10-4 Flood Damage Assessment for Combined Option 03

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	5	3	1	0	0	0
Properties Flooded Below Floor	39	38	26	22	17	14
Total Properties Flooded	**44**	**41**	**27**	**22**	**17**	**14**
Direct Potential External Damage Cost	$214,500	$186,123	$118,976	$95,040	$58,862	$25,054
Direct Potential Residential Damage Cost	$26,731	$22,015	$14,670	$0	$0	$0
Direct Potential Commercial Damage Cost	$26,225	$12,495	$0	$0	$0	$0
Total Direct Potential Damage Cost	**$267,456**	**$220,633**	**$133,646**	**$95,040**	**$58,862**	**$25,054**
Total Actual Damage Cost (0.8*Potential)	**$213,965**	**$176,506**	**$106,917**	**$76,032**	**$47,090**	**$20,043**
Infrastructure Damage Cost	**$134,649**	**$124,604**	**$91,498**	**$54,492**	**$26,516**	**$14,263**
Indirect Clean Up Cost	$19,574	$12,512	$5,450	$0	$0	$0
Indirect Residential Relocation Cost	$774	$774	$774	$0	$0	$0
Indirect Emergency Response Cost	$23,269	$23,269	$23,269	$13,961	$9,308	$4,654
Total Indirect Cost	**$43,617**	**$36,555**	**$29,492**	**$13,961**	**$9,308**	**$4,654**
Total Cost	**$392,231**	**$337,665**	**$227,908**	**$144,485**	**$82,913**	**$38,959**

Average Annual Damage (AAD)	$27,861

10.5 Average Annual Damage Summary

The flood damage assessment showed that the Elmes Street Levee had a minor impact on reducing the AAD in Natimuk. This was primarily because there are very few properties impacted from the frequent, lower magnitude flood events, and only 3 and 5 properties protected at 100 and 200 year ARI events respectively. Combined Option 03 has a moderate impact on reducing the AAD in Natimuk, with significant below floor flood damage remaining and 5 above floor flooded properties in a 200 year ARI event.

Table 10-5 Average Annual Damage Summary for Natimuk

Scenario	Average Annual Damage
Existing Conditions	$37,250
Elmes Street Levee	$34,500
Combined Option 03a	$27,320
Combined Option 03b	$27,860

10.6 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 Natimuk have experienced emotional trauma with some reports of physical injuries caused by the floods.

There is no doubt that the intangible non-monetary flood related damage in Natimuk 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 Natimuk 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 Natimuk.

10.7 Benefit Cost Analysis

10.7.1 Overview

A benefit cost analysis was undertaken to assess the economic viability of the two mitigation options (combined mitigation option 3 has 'a' and 'b' variants). Indicative benefit cost ratios were based on the construction cost estimates and Average Annual Damages calculated.

The cost of lifting dwelling floor levels has also been assessed as a standalone measure and in combination with Combined Option 03.

10.7.2 Increasing dwelling floor levels

The ability to lift a dwellings floor level is dependent on its construction method, the level it has to be raised and its condition. A recent floor level assessment for Glenorchy considered the feasibility of lifting existing floor levels 300 mm above the 100 year ARI flood level[75]. Estimates of the cost of floor level raising were taken from the findings of this report, and were used to assess the potential cost of raising houses in Natimuk.

The report based the feasibility of lifting houses 300 mm above the 100 year ARI flood level by a comparison of the floor level raising cost and mean dwelling value as per Northern Grampians Shire valuations. The mean valuation of the dwellings requiring their floor level increased in Glenorchy was $57,500 as at the July 2012 valuation.

Table 10-6 below shows the estimated average cost of raising floor levels in Glenorchy.

Table 10-6 Average cost of floor level raising at Glenorchy for a range of building types

Building Type	Average Cost of Raising
Very low timber framed dwelling with significant verandahs and built in porches	$34,700
Timber Framed Dwelling with reasonable sub-floor clearance with some verandah	$19,700
Timber framed dwelling with significant annex based on a concrete slab floor	$48,200
Steel Framed Building on a slab floor base	$31,300
Solid Brick Building with a Timber Floor	$22,650

In Natimuk there are 14 buildings flooded above floor level during a 100 year ARI event, of these buildings one is a commercial shed, three are commercial shopfronts and 10 dwellings.

If an additional 300 mm freeboard is added to the 100 year ARI event flood level, there are an additional 14 buildings impacted bringing the total to 28.

To determine the cost of raising the required buildings 300 mm above the 100 year ARI event flood level, some buildings were removed from the cost calculation because of the viability of increasing their floor level. These include four sheds which would not be raised and a large commercial building which has a calculated increase in floor level of 0.01 m. Using generalisations of building type and the average cost of floor level raising shown in Table 10-6 the estimated cost of raising the remaining buildings to 300 mm above the 100 year ARI flood level is approximately $700,000. This does not take into account difficulties which may arise due to the age or condition of the buildings.

The Horsham Rural City Council has calculated the mean value of the dwellings which require an increase in floor level to be $66,385 as at July 2012. The average cost of floor level raising per dwelling is approximately $25,000.

10.7.3 Mitigation Option Costs

The cost estimates for the two major mitigation options are shown in Table 10-7 and Table 10-8. Table 10-9 shows a variation of Combined Option 03. A 30% contingency cost was included along with engineering and administration costs. It should be noted that these costs are based on estimated rates and should be checked during the detailed design phase.

[75] Glenorchy Feasibility Study, CT Management Group for the Northern Grampians Shire Council – August 2012.

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; 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 has also been included.

The breakdown of costs for Elmes Street Levee is shown below in Table 10-8 with Combined Option 03 shown in Table 10-9.

Table 10-7 Mitigation Option Cost Breakdown – Elmes Street Levee

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Elmes Street Levee	$21,242	$319
Sub-total 'A'	$21,242	$319
'A' x Engineering Fee @ 15%	$3,186	$48
Sub-total 'B'	$24,429	$366
'B' x Administration Fee @ 9%	$2,199	$33
Sub-total 'C'	$26,627	$399
'A' x Contingencies @ 30%	$6,373	$96
FORECAST EXPENDITURE	$33,000	$495

Table 10-8 Mitigation Option Cost Breakdown – Combined Option 03a

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Elmes Street Levee	$21,187	$318
Lake Avenue Levee 01	$84,198	$1,263
Lake Avenue Levee 02	$119,166	$1,787
Lake Avenue Levee 03	$150,800	$2,262
Channel Construction	$106,270	$1,594
Culverts Under Lake Av.	$57,793	N/A
Sub-total 'A'	$388,614	$4,962
'A' x Engineering Fee @ 15%	$58,292	$744
Sub-total 'B'	$446,906	$5,707
'B' x Administration Fee @ 9%	$40,222	$514

Sub-total 'C'	$487,127	$6,220
'A' x Contingencies @ 30%	$116,584	$1,489
FORECAST EXPENDITURE	$837,980	$11,223

The construction costs show the Lake Avenue Levees 02 and Lake Avenue 03 made up a significant proportion of the overall construction cost ($270,000 approx.) and protect three dwellings. This levee was more costly than the Elmes Street Levee and Lake Avenue Levee 01 because it passed through low areas of land and would require large amounts of fill to construct a high elevation levee.

Rather than construct levees around the properties in the second and third sections of the Lake Avenue levee it was considered more cost effective to raise one house 300 mm above the 100 year ARI event flood level. The dwelling is of iron clad construction, built on stumps. The estimated cost of raising this building was $19,700 and would be a more cost effective option for protection of the dwelling alone.

The dwellings protected by the second levee are already 300mm above the 100yr ARI level.

This would reduce the cost of Combined Option 03 as shown below in Table 10-9

Table 10-9 Mitigation Option Cost Breakdown – Combined Option 03b

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Elmes Street Levee	$21,187	$318
Lake Avenue 01	$84,198	$1,263
Floor Level Raising	$19,700	$0
Channel Construction	$106,270	$1,594
Culverts Under Lake Av.	$57,793	N/A
Sub-total 'A'	$289,149	$3,175
'A' x Engineering Fee @ 15%	$43,372	$476
Sub-total 'B'	$332,521	$3,651
'B' x Administration Fee @ 9%	$29,927	$329
Sub-total 'C'	$362,448	$3,980
'A' x Contingencies @ 30%	$86,745	$952
FORECAST EXPENDITURE	$449,192	$4,932

10.7.4 Benefit Cost Ratio

The results of the benefit-cost analysis are shown below in Table 10-10. 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, meaning that the long term benefit of flood mitigation equals or exceeds the long term costs. The Elmes Street levee is clearly a cost effective solution with a benefit cost ratio of 0.96. However, the Combined Option 03 even with the more cost effective floor level raising instead of the second and third levee components has a very low benefit cost ratio of 0.16. Raising floor levels as a standalone measure is also not cost effective, with a benefit cost ratio of 0.04.

Table 10-10 Benefit Cost Analysis

	Existing Conditions	Raising Floor Levels	Elmes Street Levee	Combined Mitigation Option 03a	Combined Mitigation Option 03b
Average Annual Damage	$37,252	$35,405	$35,499	$27,316	$27,861
Annual Maintenance Cost	-	-	$495	$11,223	$4,932
Annual Cost Savings	-	$1,847	$2,258	$1,287	$4,459
Net Present Value	-	$25,973	$31,753	$18,098	$78,717
Capital Cost of Mitigation	-	$700,000	$33,000	$837,982	$449,192
Benefit-Cost Ratio	**-**	**0.04**	**0.96**	**-0.02**	**0.14**

11. CONCLUSIONS AND RECOMMENDATIONS

Following the recent flood events in December 2010 and January 2011, Natimuk was identified as a high flood risk community and funding was approved for a flood investigation of the township. The Natimuk Flood Investigation was run by Wimmera CMA in conjunction with Horsham Rural City Council.

The study involved the development of a hydrologic model of the Natimuk Creek catchment and separate hydraulic models of the entire catchment and the township, successful verification to the December 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. It must be noted that the community participation and interest in the study was excellent, with flood observations, local information, feedback on the study greatly improving the outcomes from the study.

An initial prefeasibility assessment of twelve structural mitigation options was undertaken. From the prefeasibility assessment six options were selected for further analysis using the developed hydraulic model, these were:

- Elmes Street levee;
- Lake Avenue levee;
- Lake Avenue bywash channel;
- Wetland overflow;
- Little Natimuk Creek storages; and
- Little Natimuk Creek bridge structure capacity increase.

A series of combined options were also assessed for their impact on flood inundation through the town.

Following hydraulic investigation two mitigation options were developed and investigated in detail, these were the Elmes Street levee and Combined Option 03. The Elmes Street levee protects property along Elmes Street only, while Combined Option 03 protects properties along Elmes Street and Lake Avenue. The potential to raise dwelling floor levels 300 mm above the 100 year ARI event flood level was assessed also.

The Elmes Street and Combined Option 03 structural mitigation options and floor level increases had a full benefit cost analysis undertaken.

The Elmes Street levee option was the only option to return a reasonable benefit cost ratio at 0.96. All other options assessed were found to be not economically viable. The true benefit cost ratio is likely to be 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, no option is likely to be considered unless it has the strong support of the community. Through extensive community consultation it is suggested that of all community members who have been involved in the development of this study, the majority supported the Elmes Street levee option. Some residents were interested in the Combined Option 03 as it protected more properties, but there was consensus that this option would greatly impact the amenity of Lake Avenue residents, and the decision whether to pursue this option should be made by the Lake Avenue residents themselves.

11.1 Plan Recommendations

Following significant consultation with the Natimuk community the Natimuk Flood Investigation Steering Committee recommends the following actions:

- The staged implementation of a flood warning system for Natimuk requiring two new rainfall gauges (one in the Little Natimuk Creek catchment and one Natimuk Creek catchment) and two new stream flow gauge boards to be installed (on the Wimmera Highway at both Natimuk Creek and Little Natimuk Creek).
- The flood warning system should be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system;
- It is recommended that a flood response plan be adopted into the Municipal Flood Emergency Plan and the community is engaged along with the responsible agencies (BoM, SES, HRCC, Wimmera CMA etc.) in developing appropriate actions.
- It is recommended that the planning scheme for Natimuk is amended to reflect the flood risk identified by this project;
- It is recommended that HRCC worth with Natimuk residents and in particular residents of Elmes Street and Lake Avenue to resolve any issues regarding the visual concerns of the proposed levees options; and
- The Elmes Street levee option should be submitted for funding for detailed design with further consultation with Elmes Street residents.