Quambatook Flood Management Plan

April 2014

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PROJECT DETAILS

Project Name	Quambatook Flood Management Plan
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Cover Photo: Flooding in Quambatook, 11 September 2010. Provided by North Central CMA.

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GLOSSARY OF TERMS

Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10 year ARI flood is expected to be exceeded on average once every 10 years. A 100 year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage. The ARI definition is often poorly understood and misrepresented.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Design flood	A design flood is a probabilistic or statistical estimate, being generally based on some form of probability analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which causes it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood damage	The tangible and intangible costs of flooding.
Flood frequency analysis	A statistical analysis of observed flood magnitudes to determine the probability of a given flood magnitude.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.
Flood mitigation	A series of works to prevent or reduce the impact of flooding. This includes structural options such as levees and non-structural options such as planning schemes and flood warning systems.

Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Flood storages	Those parts of the floodplain that are important for the temporary storage, of floodwaters during the passage of a flood.
Freeboard	A factor of safety above design flood levels typically used in relation to the setting of floor levels or crest heights of flood levees. It is usually expressed as a height above the level of the design flood event.
Geographical information systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
Intensity frequency duration (IFD) analysis	Statistical analysis of rainfall, describing the rainfall intensity (mm/hr), frequency (probability measured by the AEP), duration (hrs). This analysis is used to generate design rainfall estimates.
m^3/s	Cubic metres per second or 'cumecs', a standard measure of discharge, which can be converted to megalitres per day by multiplying by 86.4.
MIKE FLOOD	A hydraulic modelling tool used in this study to simulate the flow of flood water through the floodplain. The model uses numerical equations to describe the water movement.
Ortho-photography	Aerial photography which has been adjusted to account for topography. Distance measures on the ortho-photography are true distances on the ground.
Peak flow	The maximum discharge occurring during a flood event.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a fuller explanation see Average Recurrence Interval.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequence and likelihood. For this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
RORB	A hydrological modelling tool used in this study to calculate the runoff generated from historic and design rainfall events.
Runoff	The amount of rainfall that actually ends up as stream or pipe flow, also known as rainfall excess.
Stage	Equivalent to 'water level'. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level changes with time. It must be referenced to a particular location and datum.
Topography	A surface which defines the ground level of a chosen area.

EXECUTIVE SUMMARY

Overview

Quambatook was affected by flooding from the Avoca River in September 2010 and January 2011. The flooding event that began on the 16th of January was the largest flood on record. In the lead-up to the flooding, approximately three kilometres of temporary levee bank was constructed to protect the town. The levees held throughout the flood event, and catastrophic damage to the town was averted. Had these works not been undertaken, or had they failed, almost all the properties in the town would have been inundated, causing millions of dollars of damage, displacing hundreds of people and causing significant social disruption.

Following the flood events, The Minister for Water announced funding for the Quambatook Flood Management Plan, to be led by Gannawarra Shire Council in partnership with the North Central Catchment Management Authority (CMA). Water Technology was commissioned by Gannawarra Shire Council to develop the Flood Management Plan. The objectives of the study were to understand flood behaviour for a range of flood events within the study area and investigate and recommend a number of possible structural and non-structural mitigation measures to reduce future flood risk to the residents of Quambatook.

The study included detailed hydrological and hydraulic modelling of the Avoca River, flood mapping of the Quambatook township and broader floodplain, and assessment of potential flood mitigation works.

Community Consultation and Feedback

A key objective of the Plan was to ensure strong community engagement and to demonstrate strong community support for the final Plan. A number of local flood wardens and other community members were involved in the steering committee, providing community-based guidance for the project from start to finish. A key aspect of all community engagement was to provide information to ensure community understanding and then to seek feedback verbally at meetings and through more formal feedback methods. Two public meetings were held as part of the consultation process. The first was to present initial results of the flood modelling and to seek community feedback on the flood modelling results and their preference/suggestions for flood mitigation options. The second was to present the outcomes of the study and to gather community feedback on the flood management plan. The recommended mitigation package was guided by a proposed package of works developed by the local flood wardens following the 2011 flood. Feedback from the wider community indicated strong support for the mitigation measures, as long as key concerns could be addressed, such as ensuring adequate compensatory measures for the few properties affected by increased flood impacts, and ensuring the levees do not become a visual barrier between the town and river.

Hydrologic Assessment

A hydrologic analysis of the Avoca River was undertaken to determine design flood hydrographs for the 20%, 10%, 5%, 2%, 1% and 0.5% annual exceedance probability (AEP) flood events. The estimates were obtained through a flood frequency analysis at the Quambatook South gauge and confirmed through calibration of the hydraulic model. The adopted design flood flows listed in Table 2 are considered appropriate for the definition of flood risk in the study area.

Hydraulic Assessment

A hydraulic model was developed from a digital terrain model (DTM) of the study area, to simulated flood behaviour in the Avoca River and floodplain. The hydraulic model was calibrated to two historic flood events (January 2011 and September 2010). There was a good level of calibration data available for these recent events which enabled a high level of model calibration to be achieved. The outputs of the hydraulic modelling are considered appropriate for the definition of flood risk in the study area.

A flood risk assessment was undertaken which involved the estimation of tangible flood damages for a range of design events. The average annual damage (AAD) was then calculated to be approximately $159,115 per year with current floodplain conditions and flows.

Table 2 Peak flows for historic and design events

Event	Peak Flow in Avoca River		Peak Flow in Eastern Flood Course	
	m^3/s	ML/day[1]	m^3/s	ML/day[1]
Sep 2010	31	2,700	5	400
Jan 2011	166	14,400	40	3,500
20% AEP	27	2,300	4	300
10% AEP	42	3,600	8	700
5% AEP	61	5,200	13	1,100
2% AEP	90	7,800	20	1,700
1% AEP	118	10,200	27	2,300
0.5% AEP	152	13,200	36	3,100

[1] *Reported to nearest 100 ML/day*

Plan Recommendations

A detailed assessment of a range of mitigation options has been undertaken. Following an initial prefeasibility assessment, and detailed hydraulic investigation, a final recommended mitigation package was developed. The indicative construction cost of the mitigation package was estimated to be $886,952, with a benefit-cost ratio over a period of 30 years of 1.9, and a likely pay-back period of 9-10 years. This is a high benefit-cost ratio, providing a very strong case for funding of the recommended mitigation works.

The package consisted of the following structural mitigation works:

- Levee from Ninyeunook Rd bend, east of Lawn Cemetery, to meet with the Reservoir bank. Ensure levee accommodates future expansion of Lawn Cemetery
- Levee from reservoir bank to the Rail Bridge
- Levee on east side of River St and south side of Kerang Rd. Alignment to go around tennis courts, bowling club, swimming pool and drainage pump house.
- Temporary sandbagging across Boort Road bridge and at north end of levee to road crest
- Fill in GWM Water Channel that runs east/west down Meering Rd
- Remove channel banks on south side of Golf Club
- Levees at 5% AEP level for Caravan Park along the river

The proposed works in effect replicate the emergency works undertaken in the January 2011 flood event, however some additional small scale works may be required to offset adverse impacts on three identified residences on the east side of the floodplain.

The following non-structural mitigation works are also recommended:

- A formalised flood warning system should be developed for Quambatook bringing together the relationships identified in this study between Yawong Weir, Quambatook South Gauge and Quambatook town, and considering recommendations for new gauges in Quambatook Town and on the Eastern Flood Course.
- The stream gauge information should be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system;

- A flood response plan should be adopted into the Municipal Flood Emergency Plan and the community is engaged along with the responsible agencies (BoM, SES, Gannawarra Shire Council, North Central CMA etc.) in developing appropriate actions.
- The planning scheme for Quambatook should be amended to reflect the flood risk identified by this project, for example by implementation of the recommended draft Land Subject to Inundation Overlay and Flood Overlay.

Next Steps

The recommended mitigation works package should be submitted for funding for detailed design and construction with further consultation with the Quambatook community, particularly impacted properties identified and users of the channel in the Quambatook-Boort Road reserve.

ACKNOWLEDGEMENTS

Numerous organisations and individuals have contributed both time and valuable information to the Quambatook Flood Management Plan. The study team acknowledges the contributions made by these groups and individuals, in particular:

- Leo Parker, Malcolm Knight, John Knight, Norma Bennett, Merril Kelly, Jim Free, David Hosking, Shane Pilgrim and Cr Neil Gannon (Steering Committee)
- Stuart Patterson (Gannawarra Shire Council Project Manager)
- Camille White and Julie Bennett (North Central CMA)

The study team also wishes to thank all those stakeholders and members of the public who participated in the steering group and community information sessions and provided valuable records (including flood photos) and discussed their experiences and views on flooding in and around Quambatook.

Funding for the study was provided by the Victorian Government Department of Environment and Primary Industries (DEPI) and the Australian Government.

Valuable feedback on technical aspects of the report have been provided by the DEPI technical review panel.

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1. INTRODUCTION

1.1 Overview

Quambatook was affected by flooding from the Avoca River in September 2010 and January 2011. Following the flood events, The Minister for Water announced funding for the Quambatook Flood Management Plan, to be led by Gannawarra Shire Council in partnership with the North Central Catchment Management Authority (CMA). Water Technology was commissioned by Gannawarra Shire Council to develop the Flood Management Plan. This included detailed hydrological and hydraulic modelling of the Avoca River, flood mapping of the Quambatook township and broader floodplain, and also provided recommendations for flood mitigation works.

1.2 Objectives

The study objectives are to understand flood behaviour for a range of flood events within the study area and investigate and recommend a number of possible structural and non-structural mitigation measures to reduce future flood risk to the residents of Quambatook.

1.3 Scope

The study scope includes the following:

- Review historic flood data and information
- Review the rating curve at Quambatook South gauge and revise if necessary
- Undertake a flood frequency analysis at Quambatook South gauge and determine Annual Exceedance Probabilities (AEP) for the gauge levels.
- Develop and calibrate a detailed 1D-2D hydraulic model of the Quambatook study area
- Model a series of design flood events (0.5%, 1%, 2%, 5%, 10% and 20% AEP events) through Quambatook
- Assess the effectiveness of flood mitigation options proposed by the Quambatook Flood Wardens and recommend a package of works to prevent flood inundation in future events
- Determine any local drainage works that would need to be actioned to offset the impact of undertaking the proposed mitigation works
- Undertake a flood damage assessment of the proposed mitigation works
- Undertake a cost-benefit analysis of the proposed mitigation works
- Throughout the process, consult with Council and North Central CMA to clearly communicate study progress/results and receive feedback.

It is noted that Quambatook was subject to stormwater inundation in early January 2011 due to intense local rainfall, however this study is focused on riverine flooding from the Avoca River and does not include an assessment of local stormwater inundation or suggest improvements to the local stormwater drainage network to better cope with local rainfall events.

1.4 Previous reporting

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 Quambatook Flood Management Plan, including the following staged reports:

- Data Review and Model Scoping Memo (28/06/2013)
- Hydrology Memo (19/07/2013)
- Hydraulic Model Development and Calibration Memo (12/08/2013)
- Mitigation Options Memo (20/09/2013)
- Mitigation Package – 1% AEP Modelling Results Memo (25/10/2013)

All report stages are included within the body of this Study Report.

1.5 Study Area

Quambatook is a small township with a population of 230 and is located on the banks of the Avoca River 40 km south-west of Kerang. Quambatook was severely affected by flooding in September 2010 and January 2011. The study area for the purpose of the Quambatook Flood Management Plan covers the township, the Avoca River and its broader floodplain. The study area extends from the Quambatook South gauge, approximately 6 km south (upstream) of Quambatook, to the Budgerum Bridge approximately 6 km north-east (downstream) of Quambatook (Figure 1-1).

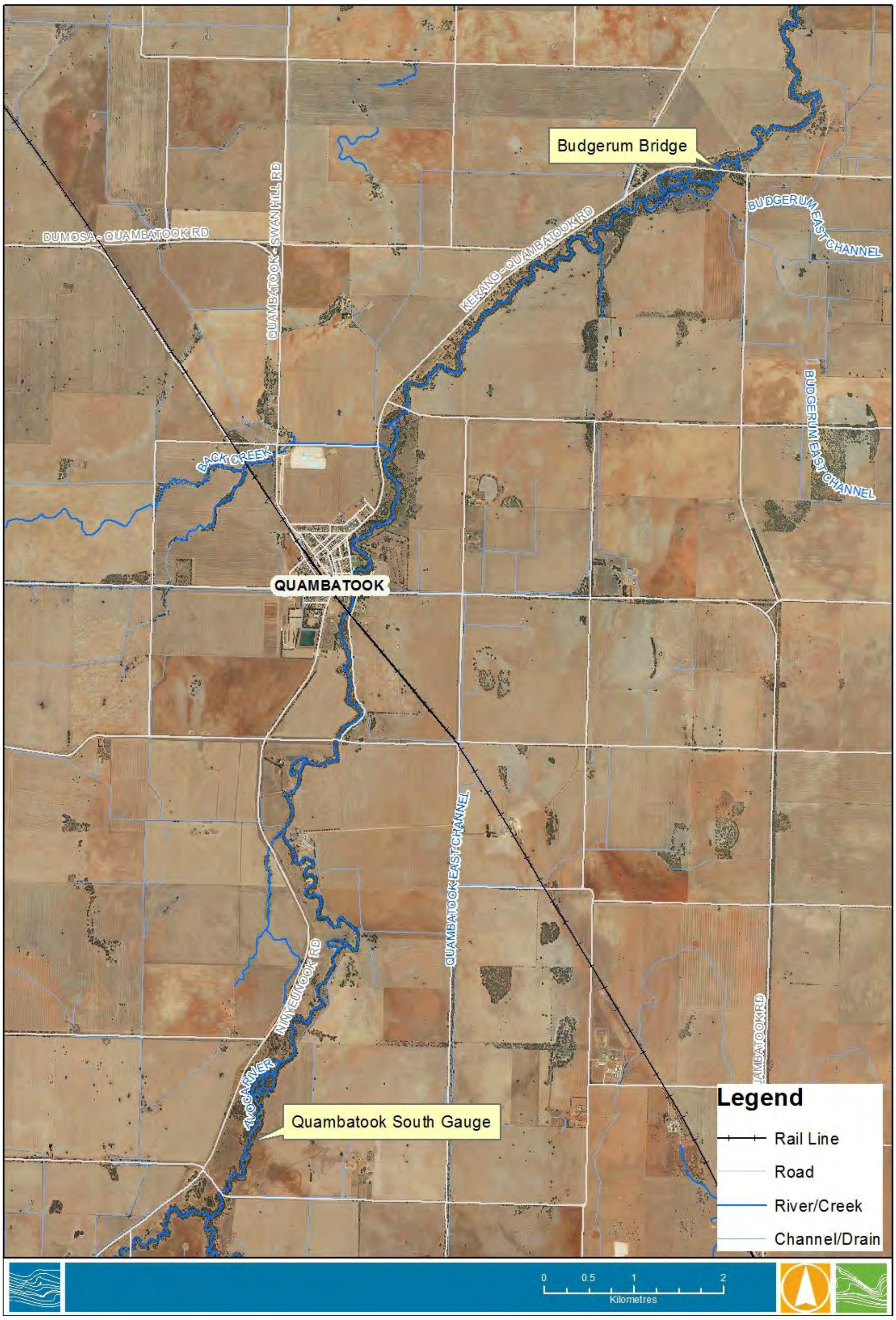


Figure 1-1 Study Area

1.6 Recent and Historical Flood Events

Three severe flood events occurred over the 2010-2011 period. The first was in September 2010, when the Avoca River rose but was largely contained within the channel and low-lying floodplain areas (Figure 1-2). This event did not impact upon the town.

On the 9th of January, the town was impacted by stormwater inundation following a severe rainfall event in which over 100 mm of rain fell on the town. The rainfall overwhelmed the drainage infrastructure and pooled in low-lying areas of the town. Around 20 properties were flooded in Kerang Rd, Paterson St and River St, and at least two were flooded above floor level. Cellars and septic tanks were filled and the shire had to install portable toilets and showers for residents to use. The grain bunkers north of the town were not fully covered and sustained significant losses of grain.

The riverine flooding event that commenced the following week was the largest flood on record. The river started to rise on the 15th of January and flooding began on the 16th of January. The floodwaters peaked on the 18th of January and had subsided by around the 23rd of January. In the lead-up to the flooding, approximately three kilometres of temporary levee bank was constructed to protect the town (Figure 1-4). The levees held throughout the flood event, and catastrophic damage to the town was averted. Had these works not been undertaken, or had they failed, almost all the properties in the town would have been inundated, causing millions of dollars of damage, displacing hundreds of people and causing significant social disruption.

Prior to 2011, the largest flood on record was in 1983. Anecdotal evidence and data from regional gauges suggests that prior to the beginning of gauged records in 1964, large flood events greater than the 1983 events occurred in 1909 and 1956. A photo of the 1909 flood event provided by North Central CMA is shown in Figure 1-5.

Figure 1-2 September 2010 Flood Event in Quambatook, River Street looking upstream toward Quambatook-Boort Road Bridge (source: North Central CMA)

Figure 1-3 January 2011 Stormwater Inundation Event in Quambatook, looking towards Kerang Rd from Mildred St (source: Jodie Russ)

Figure 1-4 January 2011 Flood Event in Quambatook, River Street showing temporary levee bank (source: Merril Kelly)

Figure 1-5 1909 Flood Event in Quambatook, Adamthwaite homestead

2. DATA REVIEW

2.1 Previous Studies

The Avoca Floodplain Management Study was completed by Camp Scott Furphy for RWC in 1985. This covered the Avoca River, Tyrell Creek, Lalbert Creek, Eastern Streams and Avoca Outfall systems and the towns of Charlton, Quambatook and Wycheproof. The study was followed by a flood mitigation study completed in 1987. A number of mitigation works were proposed, however at 2006 (GHD 2006), very few had been implemented.

GHD undertook the Lower Avoca Hydrologic Study in 2006 to describe and understand the hydrology of the Lower Avoca River system as a whole. A series of flood frequency analyses were undertaken at a number of gauged and ungauged locations throughout the system. The study also identified floodplain changes which may have an impact on wetland water regimes and to reassess the merits of the works proposed in the 1987 flood mitigation study.

Water Technology undertook the Quambatook Weir Replacement Study in 2011-12 for which hydrological analysis and flood modelling of the Avoca River at Quambatook was undertaken.

2.2 Site Visit

A site visit was undertaken by Ben Tate and Kathy Russell of Water Technology on 2 July 2013. The following sites were visited:

- Rail bridges at Avoca River and Back Creek
- Quambatook-Boort Road Bridge
- Quambatook-Boort Road Culvert at Eastern Floodway
- Budgerum Bridge
- Quambatook Weir
- Meering Road channel
- Decommissioned Goschen Channel site
- Temporary levees
- Flood marks at swimming pool, railway pedestrian crossing, rail bridge

2.3 Digital Elevation Models and Survey

Three Digital Elevation Models (DEMs) were available covering or partially covering the study area (Table 2-1). The extent of the three datasets is shown in Figure 2-1.

Table 2-1 Available DEMs

Name	Date	Grid Size	Vertical Accuracy
2009-10 Victorian State Wide Floodplains LiDAR Project	Dec 2009-Aug 2011	1 m	+/- 10 cm
2010-11 North Central CMA Stage 2 Floodplains LiDAR	Jul-Aug 2011	1 m	+/- 10 cm
North Central CMA ISC LiDAR	Dec 2009-Oct 2010	1 m	+/- 10 cm

The DEMs were checked against each other and against available survey for offsets and other errors (Figure 2-2, Figure 2-3 and Table 2-2).

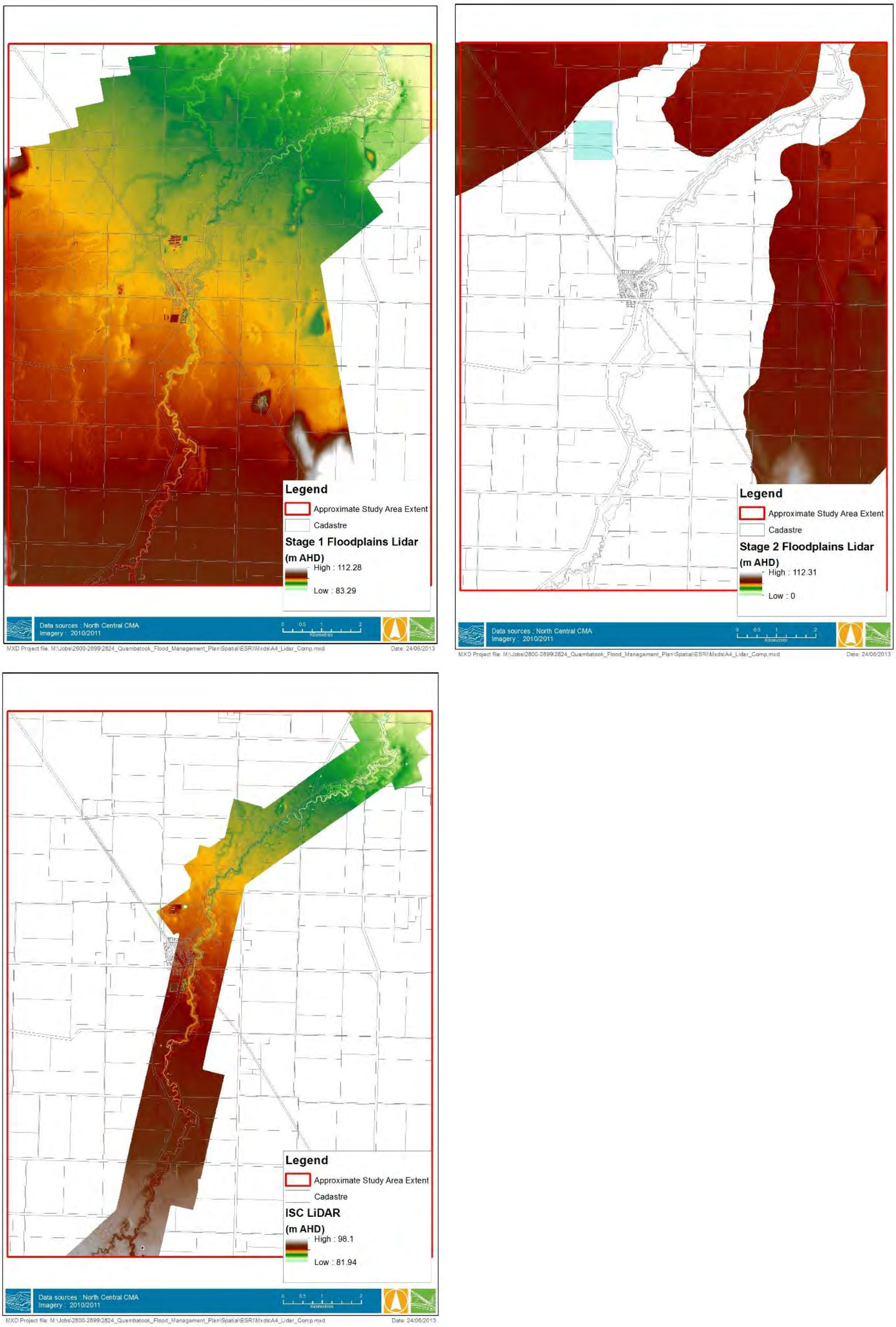


Figure 2-1 Extent of LiDAR datasets

Available field survey was collected for the Quambatook weir replacement project and included the following:

- 6 river cross-sections downstream of Quambatook
- Feature survey of Quambatook Weir

Table 2-2 Comparison between LiDAR and survey datasets

Comparison	Mean difference	St. dev. of differences	Comment
ISC LiDAR minus Stage 1 Floodplain LiDAR	-0.011 m (ISC LiDAR is lower)	0.232 m	ISC LiDAR tended to be lower south of the weir and higher north of the weir
ISC LiDAR minus Stage 2 Floodplain LiDAR	-0.109 m (ISC LiDAR is lower)	0.079 m	Systematic offset identified in Stage 2 dataset
Stage 2 minus Stage 1 Floodplain LiDAR	0.132 m (Stage 1 is lower	0.097 m	Systematic offset identified in Stage 2 dataset
Surveyed natural surface points minus ISC LiDAR	-0.066 (Survey is lower)	0.077 m	
Surveyed cross section points minus ISC LiDAR	-0.088 m (Survey is lower)	0.135 m	

There appeared to be a significant systematic offset of approximately 0.1 m in the Stage 2 Floodplain LiDAR. The other two datasets were broadly consistent with each other but the Stage 2 LiDAR was offset from both of them. The comparison also suggested that the vertical accuracy reported for the LiDAR datasets (+/- 0.1 m) was likely to be an underestimate.

The two floodplain LiDAR datasets were captured when there was water in the river, while the ISC LiDAR was captured when the river was dry. However the ISC dataset only covered a narrow (1,300 m) swathe along the river and didn't include the whole floodplain. The DEMs were used as follows for construction of the hydraulic model:

- North Central CMA ISC LiDAR (in-channel detail only, first choice DEM)
- 2009-10 Victorian State Wide Floodplains LiDAR Project (second choice DEM)
- 2010-11 North Central CMA Stage 2 Floodplains LiDAR (third choice DEM)

The Stage 2 LiDAR was only used where no other data existed. The offset identified in the Stage 2 LiDAR was corrected by lowering the whole dataset to match the Stage 1 LiDAR.

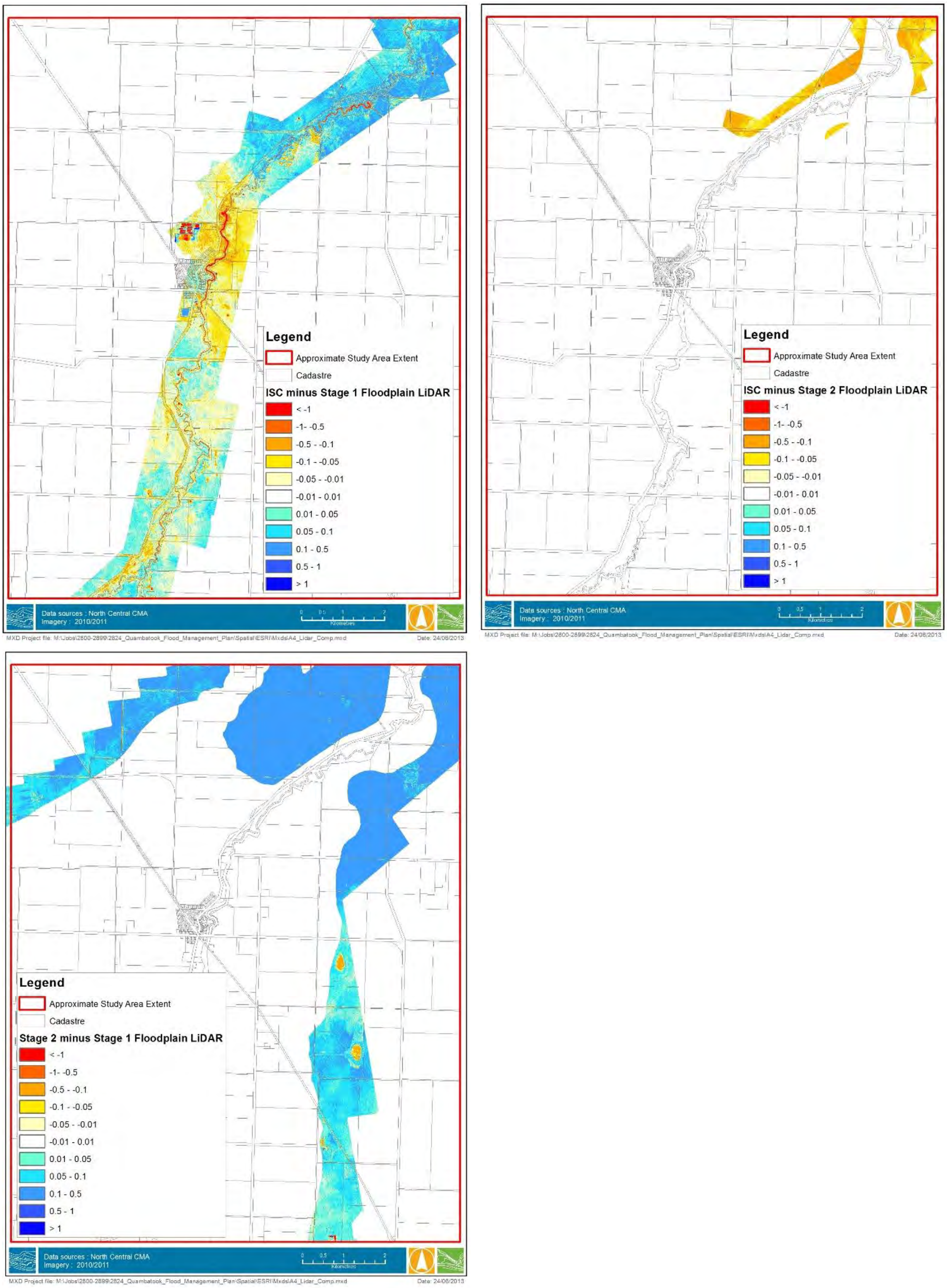


Figure 2-2 Comparison between LiDAR datasets

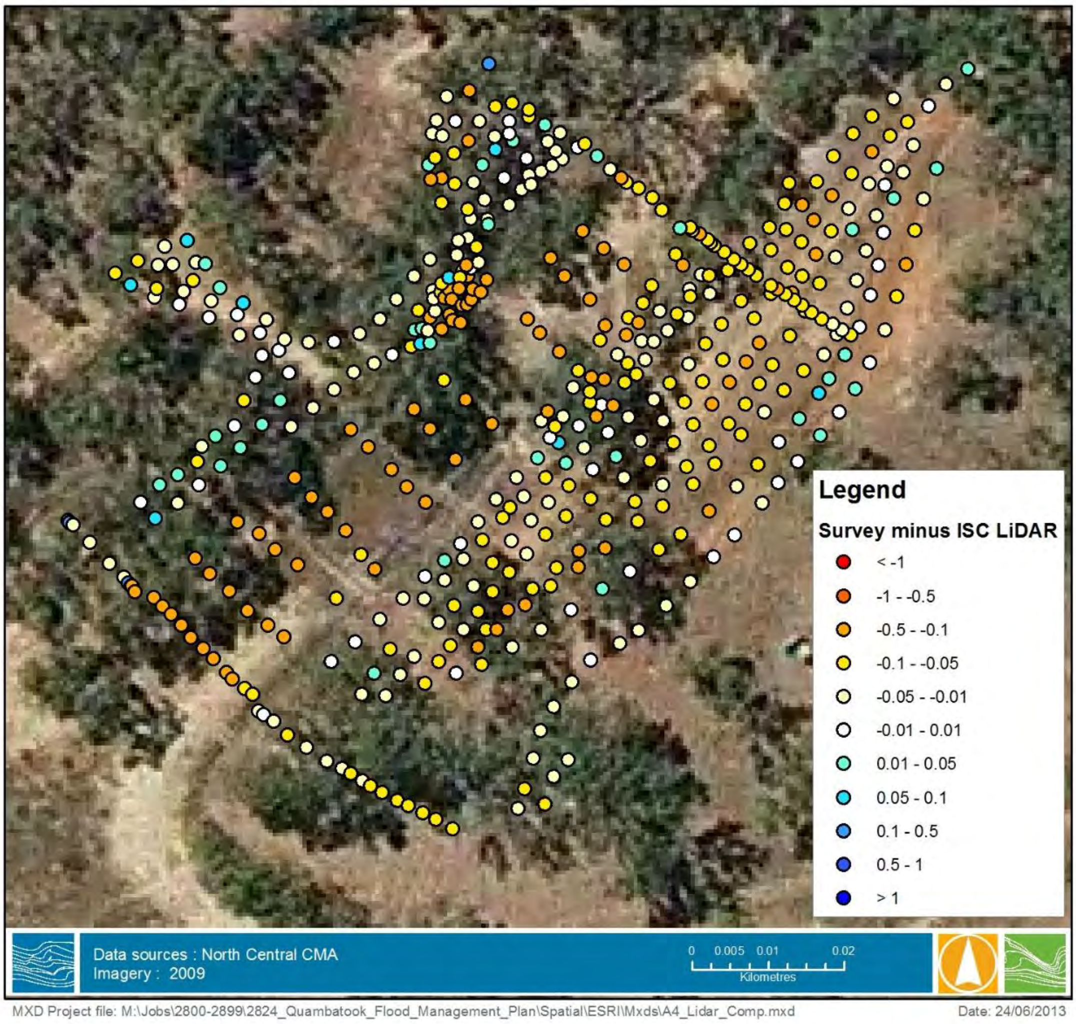


Figure 2-3 Comparison between ISC LiDAR and surveyed natural surface and roadway levels around Quambatook Weir

2.4 Structures

2.4.1 Bridges and Culverts

Key structures in the study area were identified and drawings or survey of these structures were requested from VicTrack, VicRoads and Gannawarra Shire Council. Gannawarra Shire Council provided a GIS layer of culverts containing information on type, diameter/width and number of culverts, and VicRoads and VicTrack provided PDF bridge drawings. Remaining culverts and bridges that were identified but for which details were not provided were surveyed by Gannawarra Shire Council.

The location of the key structures is shown in Figure 2-4. Drawings of each bridge are shown in Table 2-3. Dimensions of the culverts are included in Table 2-4 below.

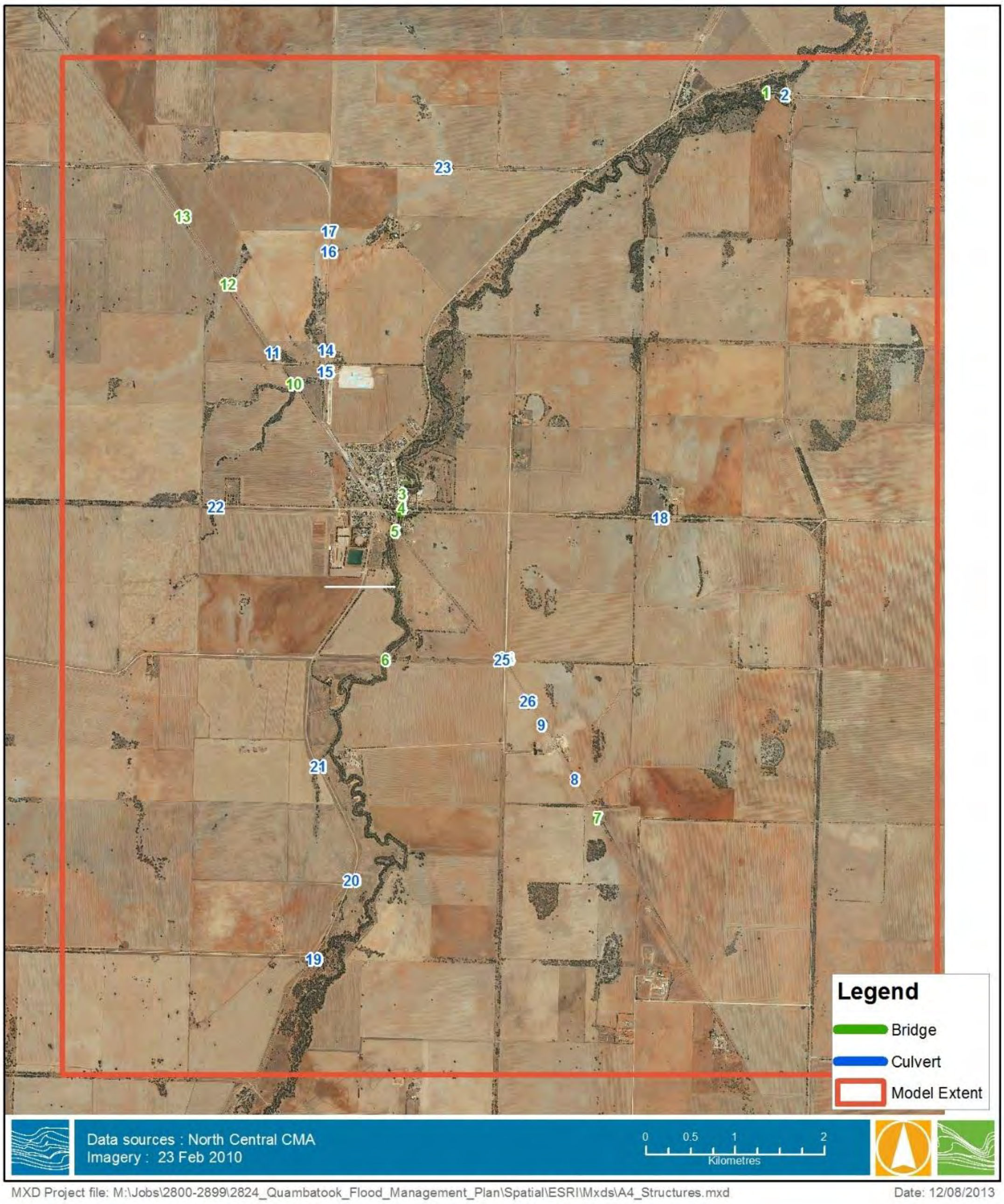
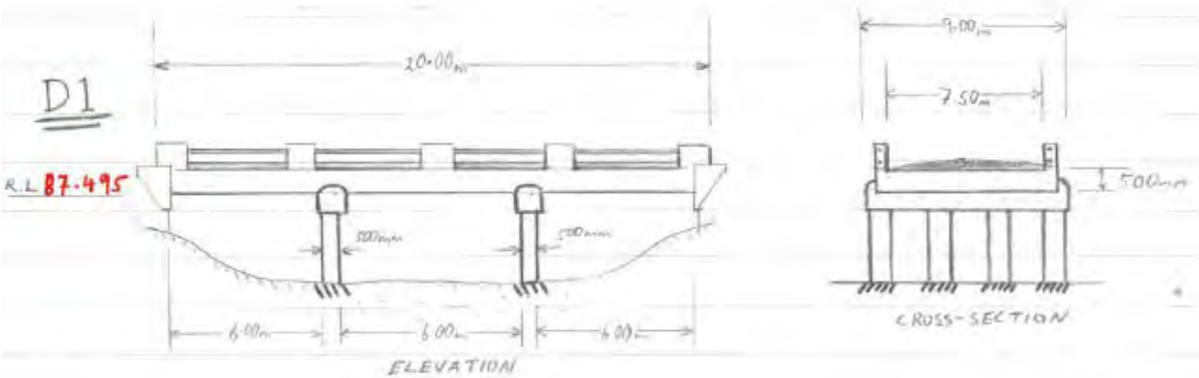
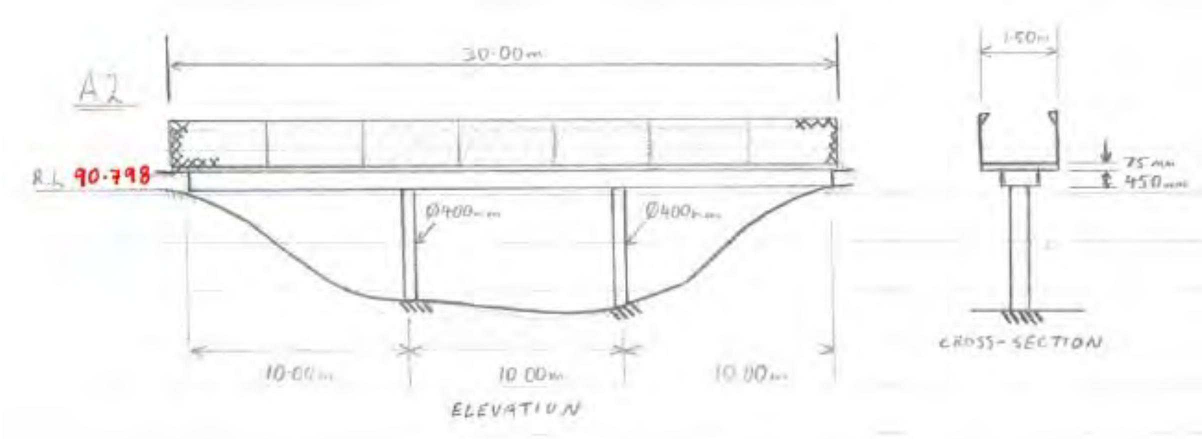
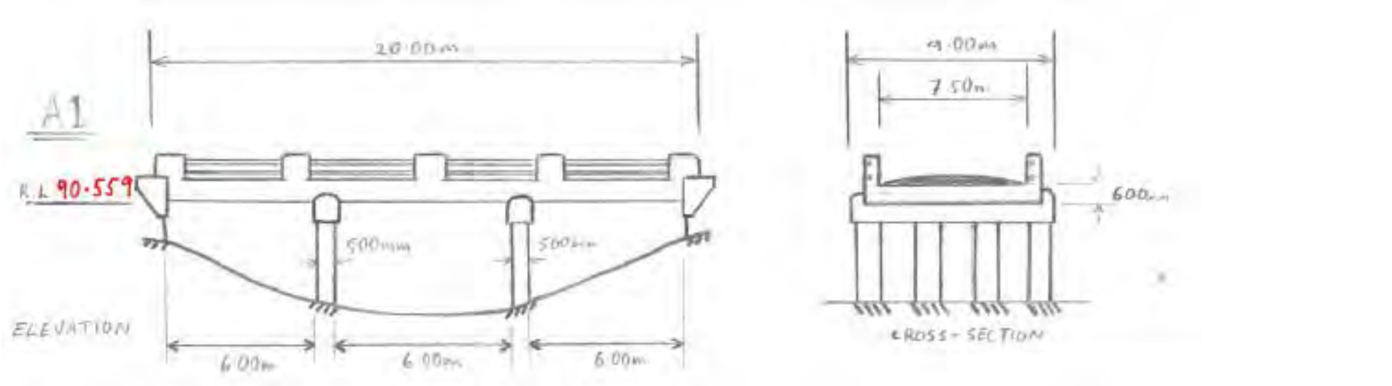
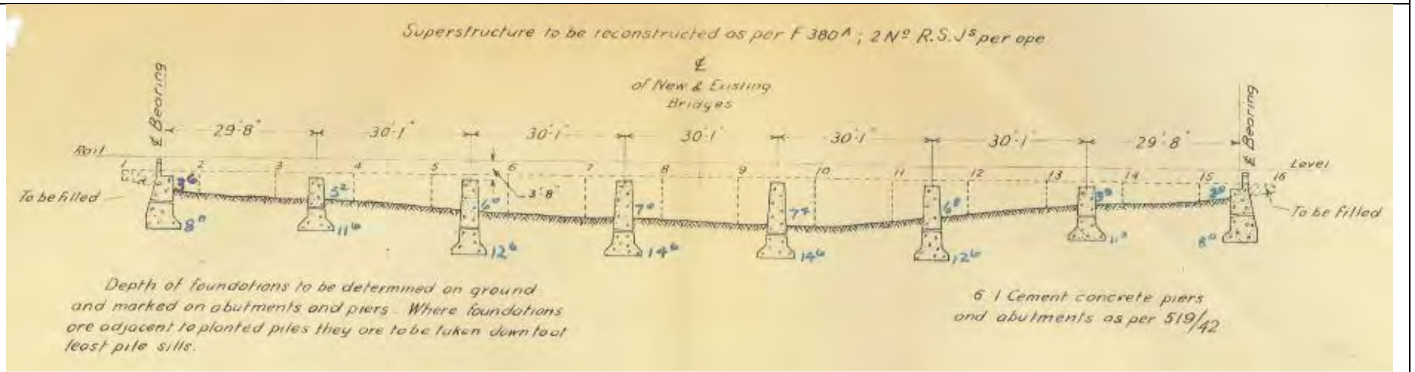
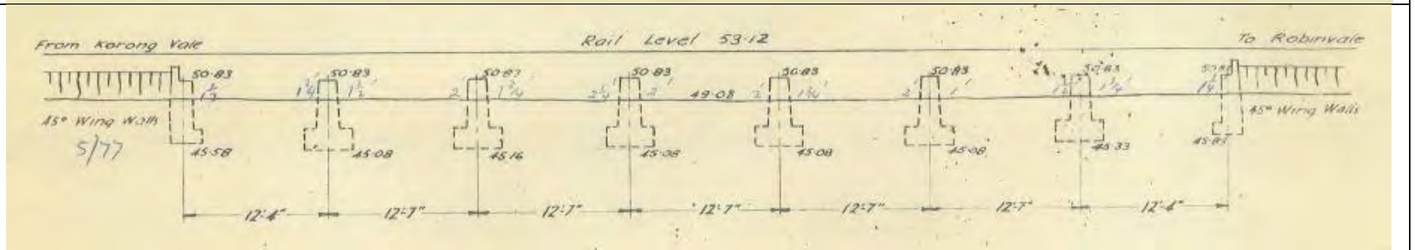


Figure 2-4 Bridge and Pipe/Culvert locations

Table 2-3 Modelled bridges

ID	Name	Drawing
1	Budgerum Bridge	
3	Footbridge	

4	Quambatook-Boort Road Bridge	
5	Rail Bridge 344.651 km	
7	Rail Bridge 340.736 km	

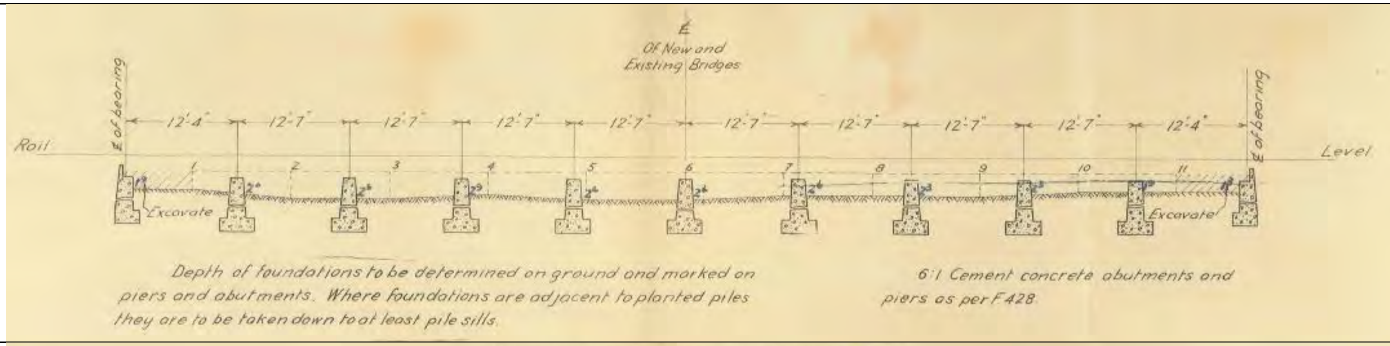
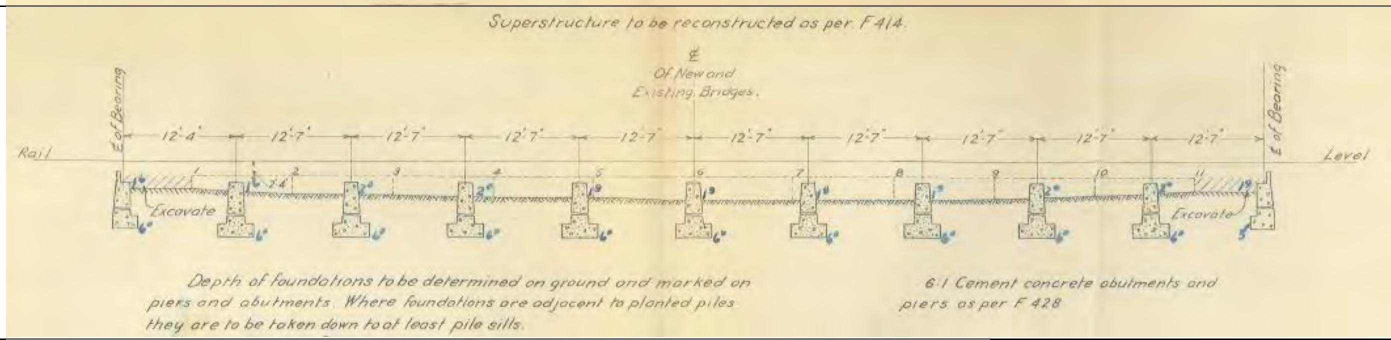
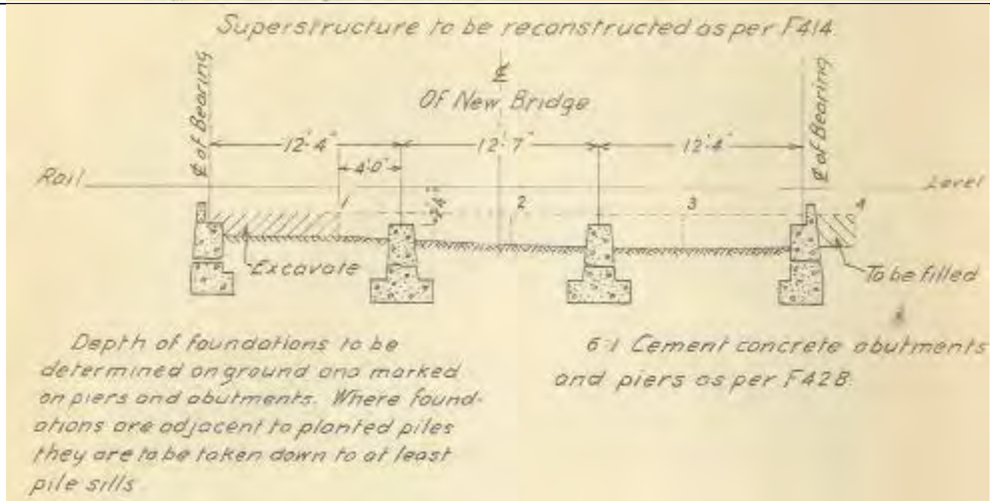
10	Rail Bridge 346.682 km	
12	Rail Bridge 348.018 km	
13	Rail Bridge 348.956 km	

Table 2-4 Modelled culvert dimensions

ID	Name	Shape	No. of culverts	Width/ Diameter (m)	Height (m)	Length (m)	Invert (m)
2	Quambatook Kerang Road Culvert 1	Pipe	1	1.5	-	15	85
6	Knight Road Bridge	Box	1	1.23	0.95	7	88.59
8	Rail Culvert 341.24 km	Box	1	3.2	1.15	7	91.71
9	Rail Culvert 341.96 km	Pipe	2	0.6	-	7	91.22
11	Rail Culvert 347.11 km	Pipe	1	0.6	-	3.3	89.17
15	Quambatook-Swan Hill Road 1	Box	2	1.2	0.45	10	88.53
		Box	2	1.2	0.9	10	88.53
14	Quambatook-Swan Hill Road 2	Pipe	1	0.65	-	10	88.70
16	Quambatook-Swan Hill Road 3	Box	3	1.2	0.45	10	87.97
		Pipe	2	0.75	-	10	87.97
17	Quambatook-Swan Hill Road 4	Box	1	1.2	0.6	10	88.28
18	Quambatook-Boort Road Culvert	Box	1	4.3	2	10	88.1
19	Ninyeunook Road 1	Pipe	1	0.3	-	14	93.1
20	Ninyeunook Road 2	Pipe	1	0.9	-	21	91.4
21	Ninyeunook Road 3	Pipe	1	0.9	-	21	91.2
22	Meering Road	Pipe	2	0.45	-	12	90
23	Suttie Road	Pipe	3	0.6	-	12	87.2
24	Cemetery Road	Pipe	1	0.75	-	9	90.02
25	Rail Culvert 342.81 km	Pipe	2	0.6	-	7	90.94
26	Rail Culvert 342.27 km	Pipe	2	0.53	-	7	90.66

2.4.2 Stormwater Pits and Pipes

GIS Layers of the stormwater network were provided by Gannawarra Shire Council. The stormwater network flows to a low point just south of the swimming pool on the eastern edge of Quambatook, where it is pumped to the river. The pump station is not formally protected from flooding and was inundated in the January 2011 event. The pump stopped working in this event causing drainage impacts within the town. Except for the potential for inundation and breakdown of the pumping infrastructure, the stormwater network is not expected to be a significant contributor to flooding impacts, although it is acknowledged that areas of low relief may accumulate stormwater prior to any riverine flooding being experienced.

2.4.3 Floor Levels

No floor level data has been captured for the town.

2.4.4 Levees

Levees appear to be well-represented in the LiDAR DEMs.

A map of the temporary works undertaken in the January 2011 event was provided by NCCMA (Figure 2-5).

Figure 2-5 Temporary levees in Jan 2011 event

2.4.5 Quambatook Weir

The Quambatook weir was recently replaced with a new structure. The replacement weir was observed during the site visit on 2 July 2013 (Figure 2-6). The weir has the same width and crest height as the old weir. The weir is 14.33 m wide with a variable crest level. For all flood modelling it was assumed the crest level was lowered to its minimum level (89.02 m AHD) during flood events.

Survey of the pre-2013 weir was obtained in the Quambatook Weir Replacement Study, Figure 2-7.

Figure 2-6 New Quambatook weir, 2 July 2013

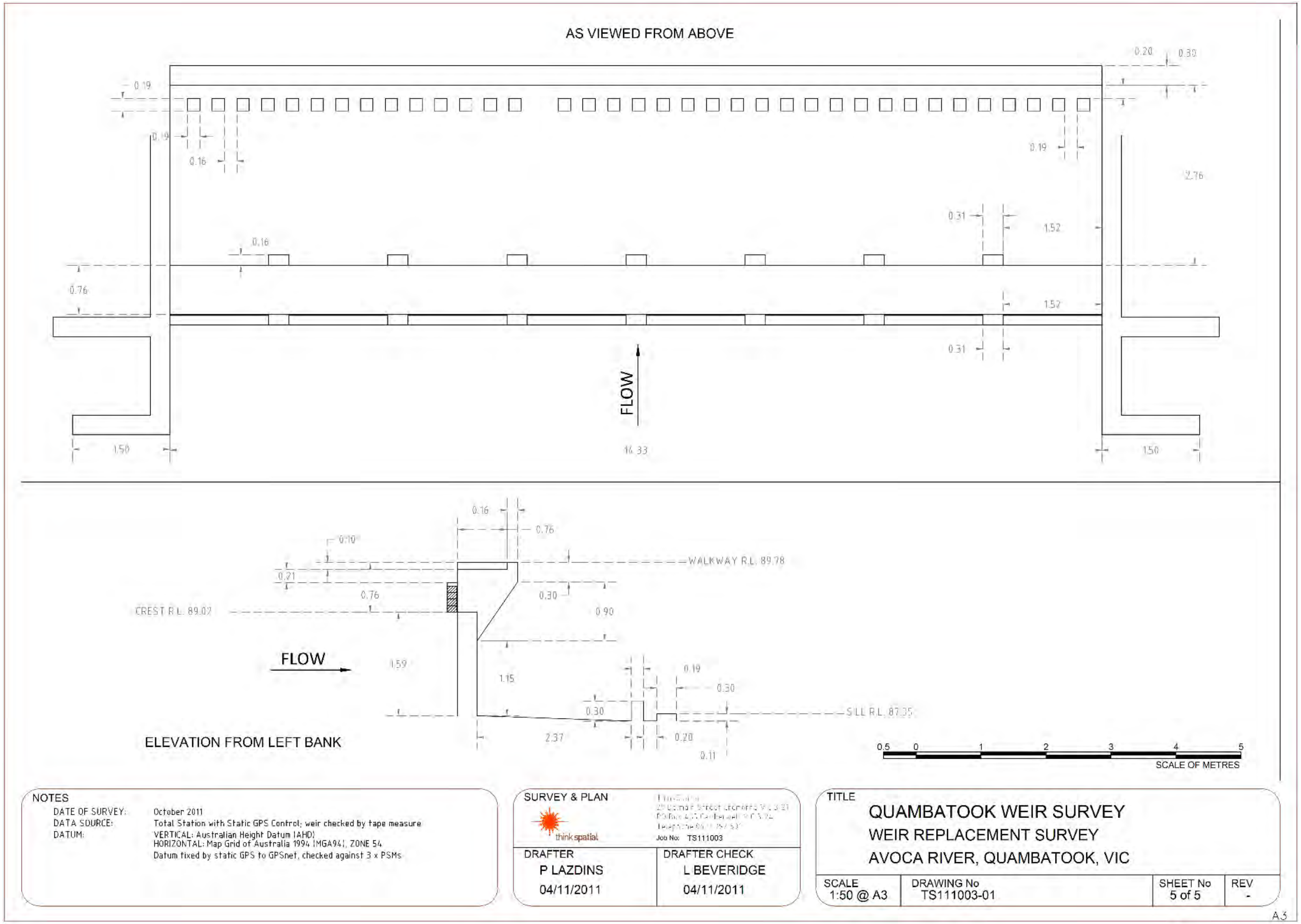


Figure 2-7 Old Weir Details

2.5 Imagery

Non-flood aerial photography was available for the study area, captured on 14 January 2009.

2.6 Observed Flood Data

Surveyed flood pegging and aerial photography were available for the September 2010 and January 2011 events, as shown in Table 2-5, Figure 2-8 and Figure 2-9. The January 2011 flood pegs were never surveyed, however flood photos including photos of the flood pegs were supplied by NCCMA.

VFD flood extents were available for the 1973, 1983, 1988 and 1995 floods within the study area, however most of these extents were fragmented and cover only a small portion of the total study area. The 1983 flood extent fully covered the study area. Digitised extents were supplied for the 2010 and 2011 events, but upon review of the extents against the available aerial flood photography and line scan imagery[1], the extents were found to be inaccurate.

Table 2-5 Observed flood data for recent flood events

Flood Event	Flood Marks	Flood Photography
September 2010	12 flood pegs (surveyed to AHD)	Visible Aerial Photograph 9 Sep 2010 Colour Infrared Aerial Photograph 9 Sep 2010
January 2011	11 flood pegs (not surveyed)	Visible aerial photograph 19 Jan 2011 Line scan imagery 18 Jan 2011

[1] Line scan imagery is captured by an airborne infrared sensor which scans back and forth along the flight path, providing a thermal image of the ground surface. Flooded areas are cold and show up as dark patches, while dry areas remain warmer and show up as lighter shades.

Figure 2-8 Flood pegging and colour infrared aerial photography – 9 September 2010

Figure 2-9 Flood pegging and visible aerial photography – 19 January 2011

Figure 2-10 Line scan imagery – 18 January 2011

2.7 Streamflow Data

Streamflow data has been provided by DEPI for the Quambatook gauge (also known as Quambatook South), located 6 km south of Quambatook, and the Coonooer gauge at Yawong Weir (Table 2-6). The rating curves for both gauges were extrapolated for the January 2011 event. The gauge zero for the Quambatook gauge is provided by Thiess as 91.408 m AHD.

Table 2-6 Streamflow data obtained

Site	Data Items	Date	Purpose
408203 AVOCA RIVER @ QUAMBATOOK	• Rating curve • Instantaneous flow • Average daily flow	1967-2013	Rating curve review, flood frequency analysis, Model calibration
408200 AVOCA RIVER @ COONOOER	• Instantaneous flow • Average daily flow	1964-2013	Investigation of relationship between flow at Yawong Weir and flow at Quambatook for flood warning purposes

The rating curve for 408203 Avoca River at Quambatook is shown in Figure 2-11. The rating curve is coded as 'reliable' for levels below 2.6 m. Above that level the rating curve is extrapolated, with the generated flows having a higher degree of uncertainty.

The instantaneous flow records for 408203 Avoca River at Quambatook and 408200 Avoca River at Coonooer are shown in Figure 2-12 and Figure 2-13. These plots clearly show that the January 2011 event was significantly larger than any other events on record at the two gauges.

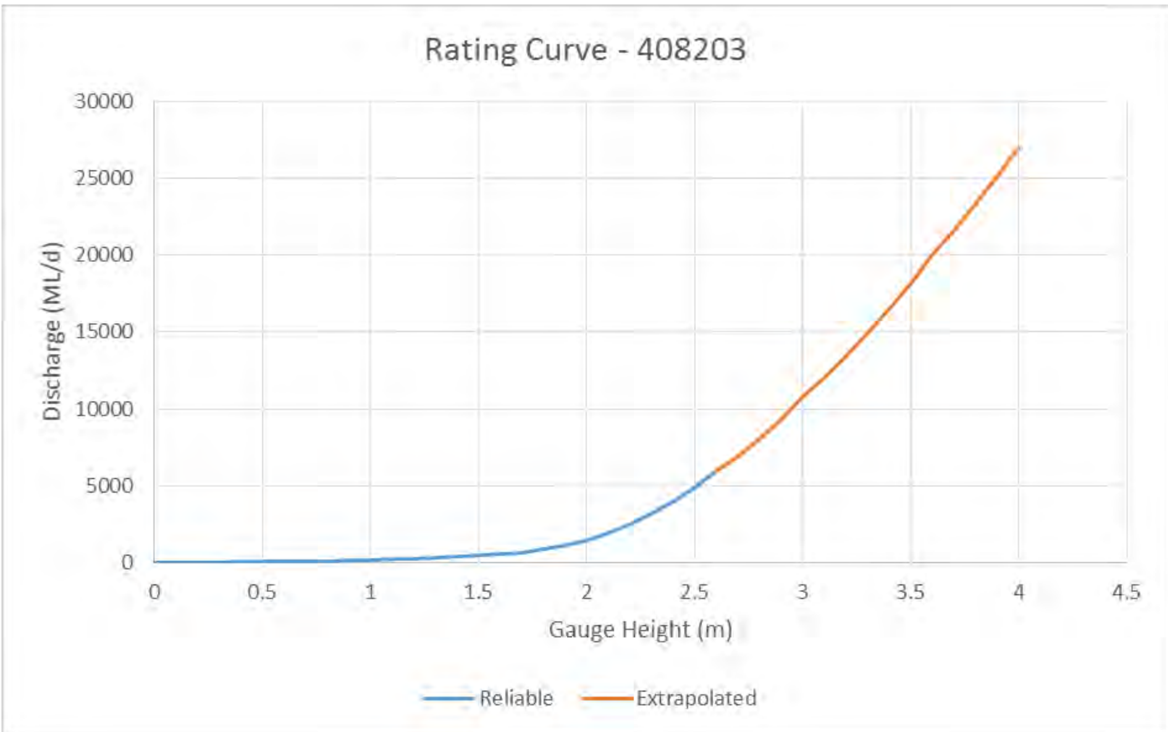


Figure 2-11 Rating Curve – 408203 Avoca River @ Quambatook

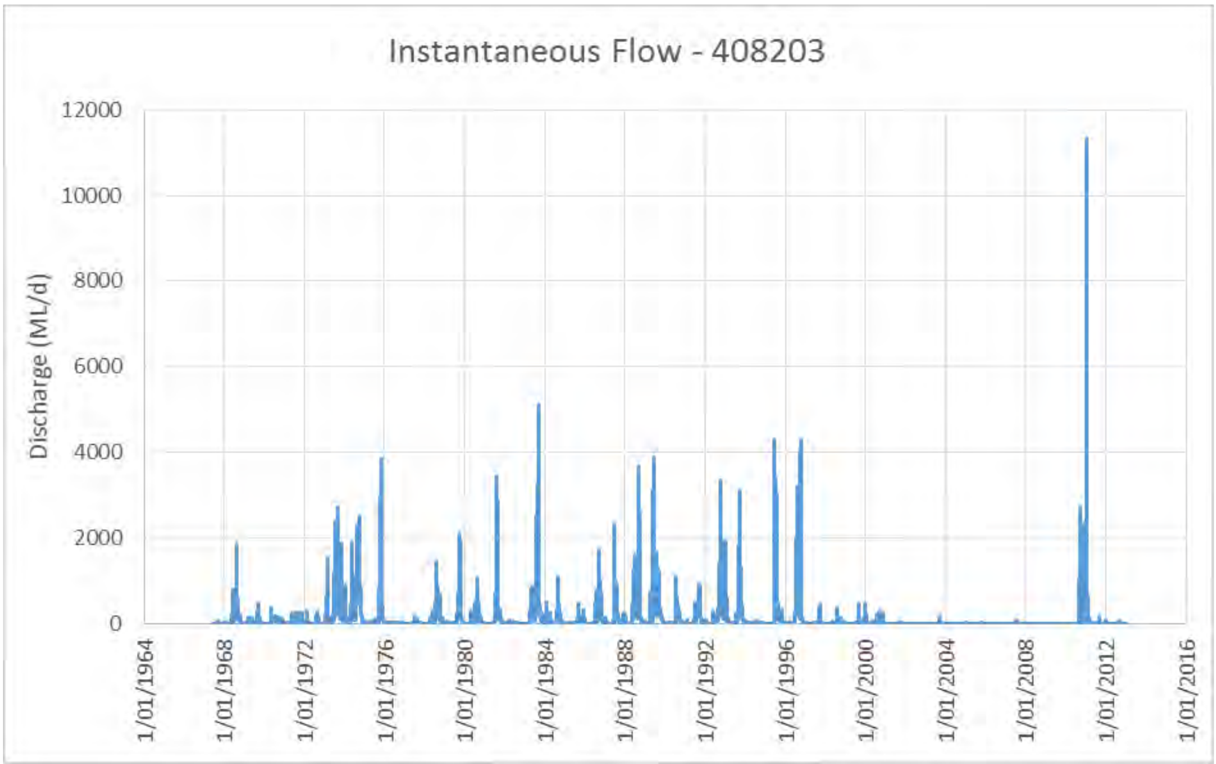


Figure 2-12 Instantaneous Flow – 408203 Avoca River @ Quambatook

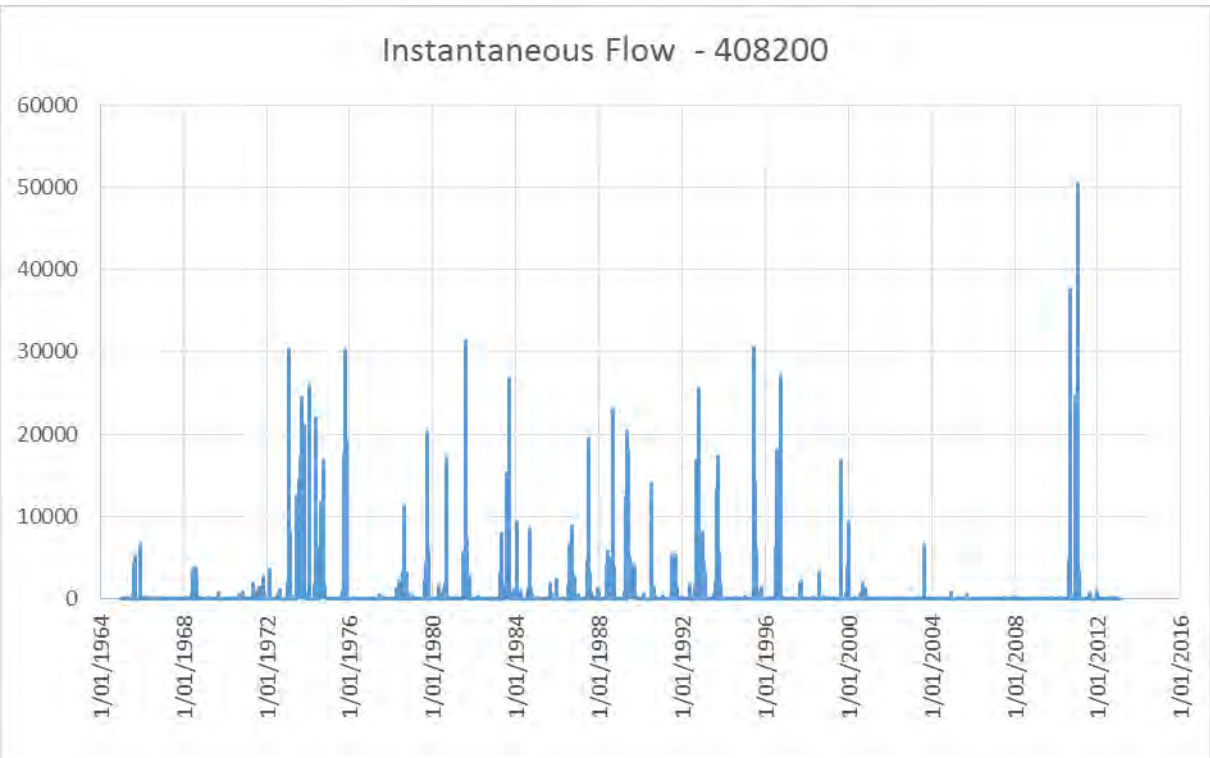


Figure 2-13 Instantaneous Flow – 408200 Avoca River @ Coonooer (Yawong Weir)

2.8 Flood Mitigation Options

Recommendations for flood mitigation works were compiled by flood wardens involved in the January 2011 flood event (Table 2-7). The locations of each of the options are shown in Figure 2-14 and Figure 2-15.

Table 2-7 Recommendations for works arising from 2011 flood, compiled by Flood Wardens

ID	Recommendation
1	Levee be constructed from Ninyeunook Rd bend, east of Lawn Cemetery, to meet with the Reservoir bank. Recommend Levee to be at least 1.5 metres high.
2	Levee from Reservoir bank to the Rail Bridge. Recommend Levee to be at least as high as Rail Lines
3	Clean out under Quambatook Rail Bridge
4	Extra culvert to be placed under Rail Line between Cemetery Rd and Fox Rd, where floodwater ran over rail line
5	Levee be constructed from Reservoir to Meering Rd, to protect houses on south west corner of town
6	Levee on east side of River St and south side of Kerang Rd to be increased by a metre to bend
7	Boort Rd bridge to be banked (temporary sandbags to be placed across opening between levees on road)
8	Section of channel banks on south side of Golf Club to be removed. Recommend 2 x 10 metre sections
9	Banks on east side of river, that protect Golf and Football Clubs, to be maintained at current level
10	Levee be constructed travelling north/south along the west side of McKissack Rd
11	Extra culvert in flood way on Boort – Quambatook Rd
12	Extra culvert (larger than existing size) on Kerang/Quambatook Rd at Budgerum Bridge
13	Quambatook BOM Gauge needs to be renamed Quambatook South Gauge to reflect its correct location and be recalibrated to AHD. Gauge ceiling of 3 metres need to be increased. It is imperative that this gauge remains at its current site.
14	A new river depth measure is needed in Quambatook. To be located between Boort Rd Bridge and Pedestrian Bridge. Gauge to be in AHD and preferably automated through BOM.
15	The town Drainage Pumps need to be upgraded
16	A bank is not needed from Meering Rd, behind Shire Depot, to Wheat Sub Terminal (Million Bushell) as there is a natural hill protecting the town
17	Fill in GWM Water Channel that runs east/west down Meering Rd. Channel located west of Quambatook
18	A bank at south end of Quambatook School between the Reservoirs is not needed if the Levee behind the cemetery is in place
19	Phone and Power services are a must and need to be protected from flood
20	Keatings Corner (Boort – Quambatook Rd) needs extra pipe to assist with flood water
21	Pipe is needed at Cameron Rd and Kerang Rd to assist with flood water
22	Pipes are needed at floodway on Kerang Rd at Gilmours Lake
23	Recommend that Charlton D/S BOM Gauge Minor Flood Level be reduced to 3.5 metres, Moderate Flood Level to 5 metres and Major Flood Level 7 metres. This gives residents north of this location a realistic idea what to expect.

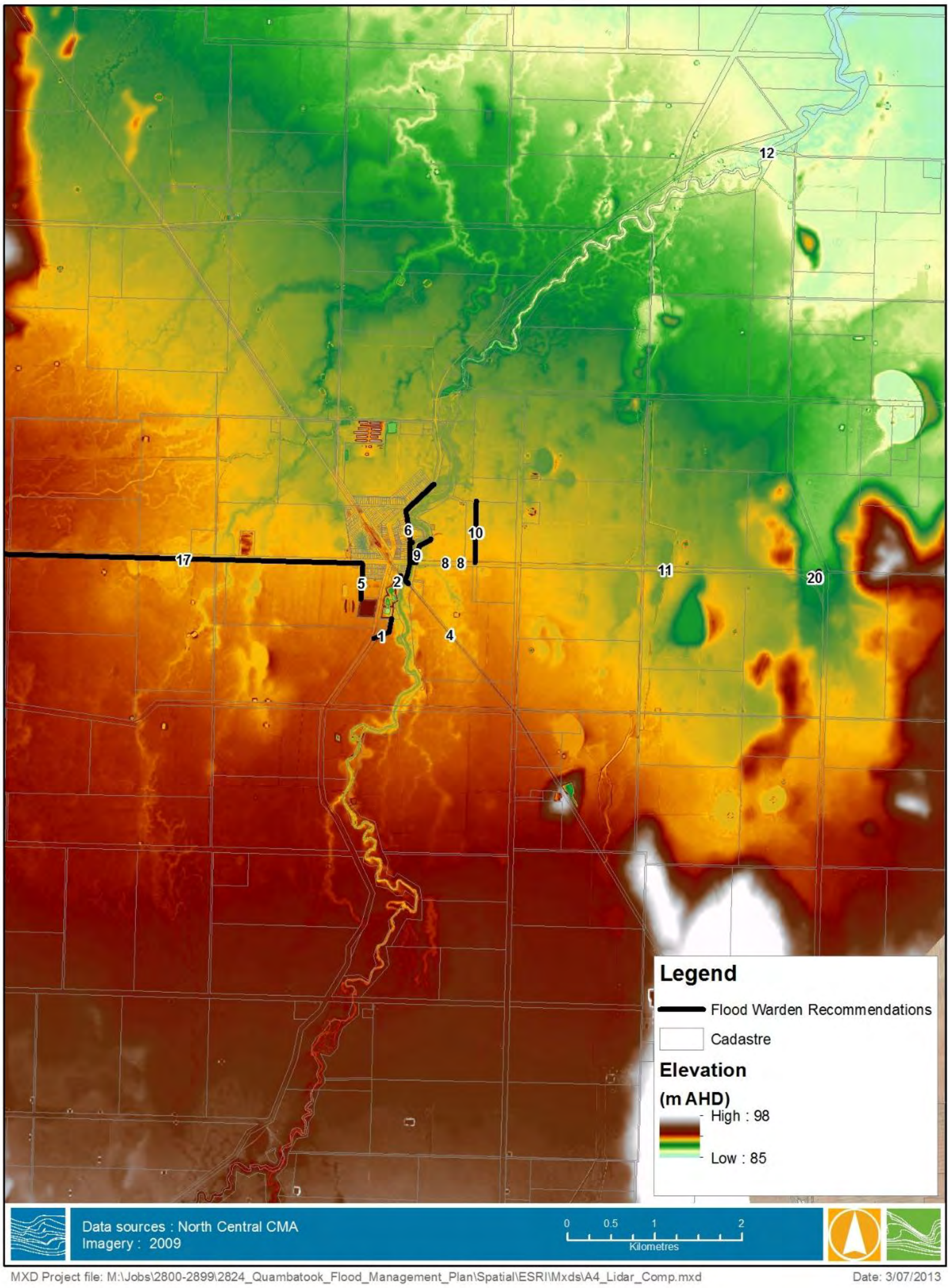


Figure 2-14 Location of proposed mitigation options provided by Flood Wardens, whole study area

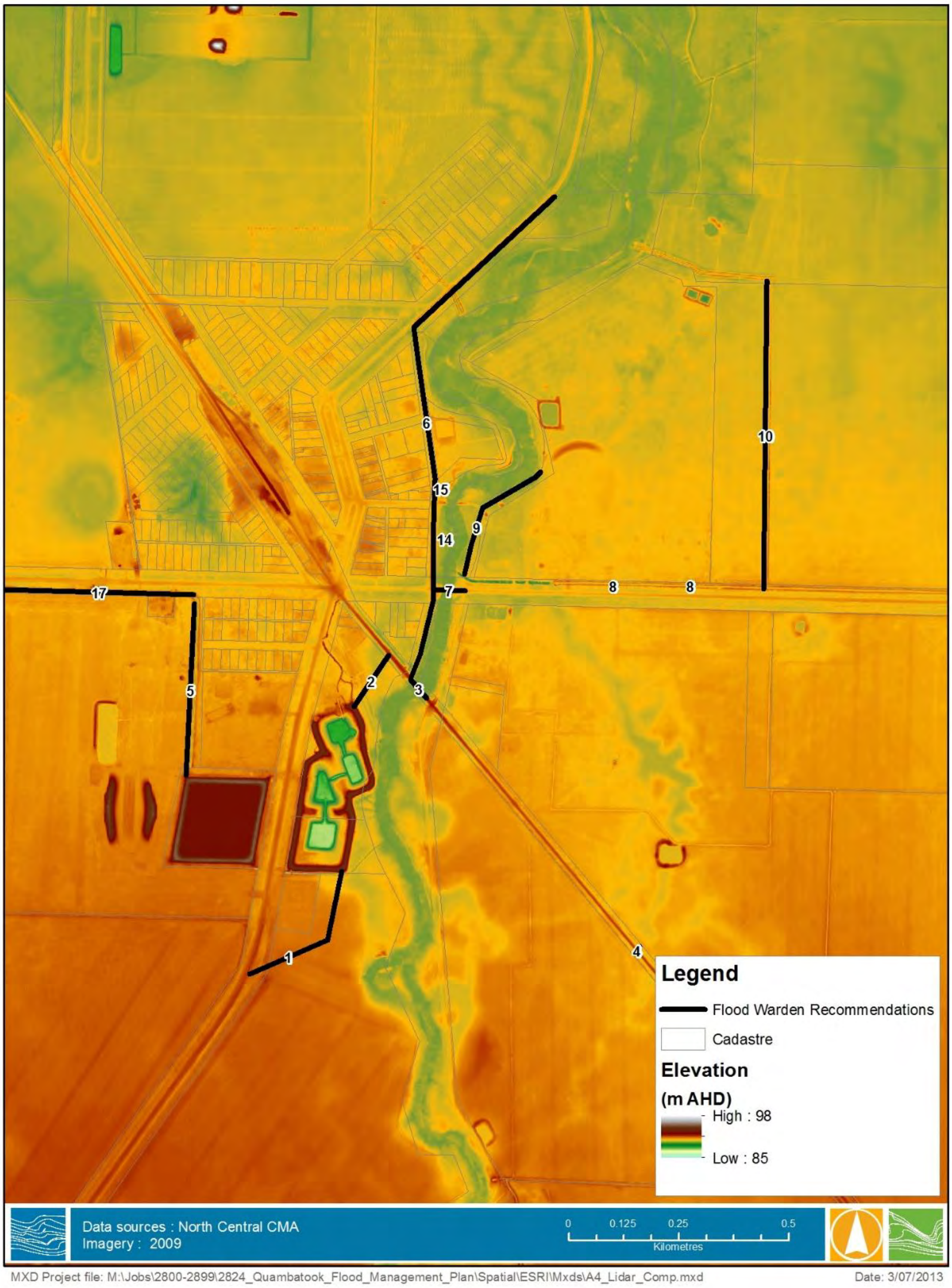


Figure 2-15 Location of proposed mitigation options provided by Flood Wardens, town detail

3. PROJECT CONSULTATION

3.1 Overview

A key element in the development of this flood management plan 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 including several members of the community. 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

The Flood Management Plan was led by a Steering Committee consisting of representatives from SES (Quambatook Flood Wardens), Victoria Police, Gannawarra Shire Council, North Central Catchment Management Authority, Water Technology and the wider Quambatook community. The steering committee included community members who had a great deal of local knowledge about flooding and who had been involved in implementing the emergency works during the September 2010 and January 2011 events. The mitigation options assessed under this flood management plan and the final recommended mitigation package was guided by a list of proposed measures developed by the flood wardens following the January 2011 flood.

The Steering Committee met on 3 occasions at key points throughout the study, to manage the development of the plan.

3.3 Community Consultation

The main aim of the community engagement process was to provide information regarding the development of the plan and to seek feedback, both verbally and through more formal feedback methods. The community meetings were advertised in the Northern Times.

The public consultation process was led by the Gannawarra Shire Council and North Central Catchment Management Authority. Two community meetings were held as part of the consultation process:

- Initial community meeting, 27 August 2013 – 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.
- Final community meeting, 18 February 2014 – This meeting presented the final flood mapping and the recommended flood mitigation package. A question and answer session after the presentation allowed the community and steering committee to discuss the benefits and impacts of the proposed works.

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 Quambatook. The following twelve questions were listed on the questionnaire:

- Name, address and contact details
- How long have you lived at the above address
- Major flooding occurred most recently in the study area in January 2011. Were you impacted by either local stormwater runoff or riverine flooding in this event or any other historic floods? If so, when?
- If your property was flooded or stormwater runoff in January 2011 can you estimate the height of the water level above or below the 'floorboards' of your home?
- What property damage did you personally sustain from the recent floods?
- Were you notified that a flood was imminent for any of the flood events? (Yes/No). If so, how were you notified? E.g. SES, CFA, Council, Radio, TV, Word of Mouth, other?
- If you did receive warning, how much time did you have before the flood waters arrived?
- Were there any significant differences in flooding between the January 2011 flood event and past flood events, if so, what did you notice?
- Do you have any information about the recent floods? E.g. local rainfall records, photos or known points of flood extent/height?
- What do you think are the major flooding issues in your area?
- What do you think could be done to improve the flood situation in your area?
- Any additional comments/information?

Six feedback forms were filled in and returned to North Central CMA. Feedback from the questionnaires indicated what the community saw as potential flood mitigation and provided data for model validation.

The following common themes were raised in the questionnaire responses:

- The January 2011 event was the largest event in living memory
- Many people were affected by stormwater flooding a number of days before the main riverine flood peak
- Flood warning for riverine flooding was reported as being provided 3-5 days in advance, and was adequate for people to prepare for the flooding.

3.5 Community Feedback on Flood Management Plan

At the final community meeting the following feedback was given on the flood mapping and proposed flood management works:

- There was concern that the main levee along River Street may be too high and provide an amenity/aesthetic barrier. The road from Boort Road to the stormwater pumping station is thought to be high enough to protect against most floods and could be temporarily banked for larger floods.
- Where it is permanent, the main levee should be integrated into the "look and feel" of the reserve and could have a walking track along it.
- The main levee could cut straight through the tennis courts rather than skirting around them, to provide a simpler, shorter alignment and leave part of the tennis court as a floodway
- There was concern that cutting the Golf Course Bank may make flooding worse for McKissack Road properties. It was also suggested that McKissack Road needs a longer bank along the road to protect local properties
- The community members who had properties on the eastern side of the river sought assurances that appropriate compensatory measures would be undertaken to ensure they were not adversely affected by the proposed works

A community questionnaire was in preparation by North Central Catchment Management Authority following the final community meeting for distribution to residents.

4. HYDROLOGY

4.1 River and Floodplain systems

The complex nature of channel and floodplain flows affecting Quambatook was reviewed through a combination of aerial photography, survey data, historic flood data and local knowledge. There are three major flood paths through the study area, the Avoca River and floodplain, the Back Creek system, and the Eastern Flood Course (Figure 4-1). The town is affected primarily by the Avoca River which skirts the eastern side of the town. The Eastern Flood Course is a constructed floodway flanked by levees at the eastern edge of the floodplain. Back Creek lies to the west of the town, and is fed by anabranch flows leaving the Avoca River at various points upstream, as well as its own local catchment.

Under moderate flow conditions, flow is restricted to the three distinct flow paths of Back Creek, Avoca River and Eastern Flood Course. Under extreme flows such as the January 2011 event, the three flow paths interact, through overflows from the Avoca River into Back Creek, and through overflows from Avoca River and the Eastern Flood Course meeting at various points in the floodplain.

A railway embankment running diagonally through the floodplain from south-east to north-west provides a control for upstream flood levels and downstream flow paths. Other embankments on roads and irrigation/drainage channels also provide important controls on flood behaviour.

The Quambatook South gauge (408203) is located approximately 6.5 km south (upstream) of Quambatook on the Avoca River, and has been used as the basis of the hydrological analysis for this study. The Eastern Flood Course and Back Creek are ungauged. Back Creek is considered to be essentially a separate system to the Avoca floodplain. Overflow from the Avoca River enters Back Creek south of the railway line under high flow conditions, but this flow remains separate from the main floodplain for the rest of the study area. The January 2011 flood extent in Figure 4-1 shows that Back Creek did not cause widespread flooding or impact upon the town. Therefore it was concluded that Back Creek could be excluded from the study.

The Eastern Flood Course interacts with the main Avoca Floodplain under extreme flow conditions, however the flow path is ungauged and little is known about the flood magnitudes. Under low flows the Eastern Flood Course is likely to remain within its confined floodway and not impact upon Quambatook. The Lower Avoca Hydrologic Study (GHD 2006) reported design flows for the Eastern Flood Course (approximated from a relationship with the Quambatook gauge) as 12 m^3/s, 17 m^3/s and 23 m^3/s for the 20%, 10% and 1% AEPs respectively. New flow estimates for the Eastern Flood Course were developed for this study through the model calibration process.

Figure 4-1 Floodplain and channel systems within study area, 19 January 2011 aerial imagery

4.2 Gauge Review

4.2.1 Independent assessment of gauge extrapolation

The quality of flow estimation at the Quambatook South Gauge (408203) was reviewed through a review of the flow data, rating curve and quality codes. The rating curve and a summary of the flow record is shown in Section 2.7. The rating curve has been extrapolated above a level of 2.6 m gauge height or a flow of 69 m^3/s. The January 2011 peak flow was estimated using the extrapolated section of the rating curve, and therefore has low reliability in the flow record. All other recorded events sit within the "reliable" section of the rating curve.

Given the likely uncertainty in the extrapolated rating curve, an independent assessment was undertaken in order to verify or revise the rating curve. This assessment consisted of 2D hydraulic modelling of the channel and floodplain in the gauge location. The model was calibrated by modelling a range of flows in the reliable range of the rating curve and ensuring good replication of the rating curve levels. The rating curve was then extrapolated by running a range of flows from 100 to 350 m^3/s and recording the water levels at the gauge location.

Model Elements

The model was schematised as a two dimensional MIKE 21 hydraulic model.

Grid extent, resolution and topography
The grid extent is shown in Figure 4-2. Based on the grid extent and the channel geometry, a 5 m grid resolution was selected to provide a good representation of the channel, while ensuring reasonable model run times.

The topography was based on the following LiDAR datasets:

- North Central CMA ISC LiDAR (in-channel detail only)
- 2009-10 Victorian State Wide Floodplains LiDAR Project (floodplain)

The LiDAR datasets were resampled from the 1 m DEM to a 5 m grid size. Significant levee and road embankments were manually "stamped" onto the grid to ensure their crest levels were well-represented.

Boundary conditions
An inflow boundary was delineated at the upstream (southern) extent of the model and a water level boundary at the downstream (northern) extent (Figure 4-2). The water level was set to a constant height at approximately bankfull level, to allow free draining of floodwaters from the model. The grid extent was adequate to ensure the boundary condition at the downstream end did not impact on water levels at the gauge.

Roughness
Roughness values were applied to the channel, vegetated riparian zone, and floodplain. These values were refined through the calibration process and the final values are provided below.

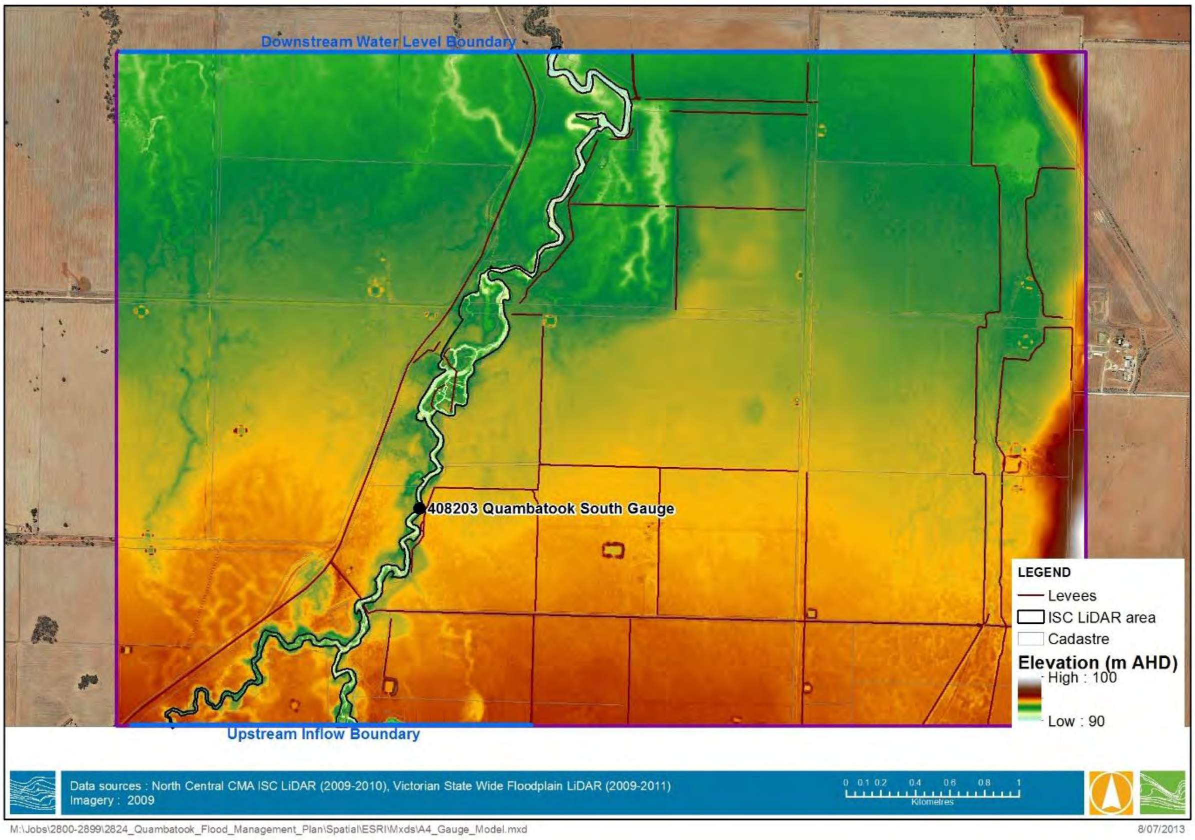


Figure 4-2 Grid extent, topography and boundaries for rating curve review

Calibration

Three roughness parameter sets were trialled for calibration of the model to the reliable section of the Thiess rating curve, as shown in Table 4-1. Three flow rates were run through the model, from 17 to 69 m^3/s, and including the September 2010 peak flow of 31 m^3/s. The resulting gauge heights are given in Table 4-2 in comparison to the gauge height from the Thiess rating curve.

The September 2010 gauge height was best replicated by the high roughness parameter set, but the upper limit of the reliable section of the Thiess rating curve was best replicated by the moderate roughness parameter set. The results suggest that the channel and riparian zone roughness decreases as flow increases. Therefore, for the extrapolation of the rating curve, the moderate roughness parameter set was considered more appropriate, and was adopted for the extrapolation.

Table 4-1 Roughness parameter sets (Manning's n) trialled for calibration

Category	Low roughness	Moderate roughness	High roughness
Channel	0.03	0.04	0.05
Riparian	0.05	0.06	0.07
Floodplain	0.04	0.04	0.04

Table 4-2 Calibration of gauge height to reliable section of Thiess rating curve

Flow (m3/s)	Gauge Height (m)	Modelled Gauge Height (m)		
		Low roughness	Moderate roughness	High roughness
17	2	1.70	1.79	1.86
31	2.23	2.06	2.14	2.22
69	2.6	2.48	2.61	2.70

Extrapolation and Sensitivity

The modelled rating curves were extrapolated to a flow of 350 m^3/s using the adopted (moderate) roughness values.

The extrapolation was also undertaken using the low and high roughness parameter sets to test the sensitivity of the modelled rating curve in its extrapolated section. The resulting curves are shown in Figure 4-3. The results show that the sensitivity to roughness is low, with the envelope of the three curves showing a maximum variance of approximately 50 m^3/s in flow and 0.2 m in water level.

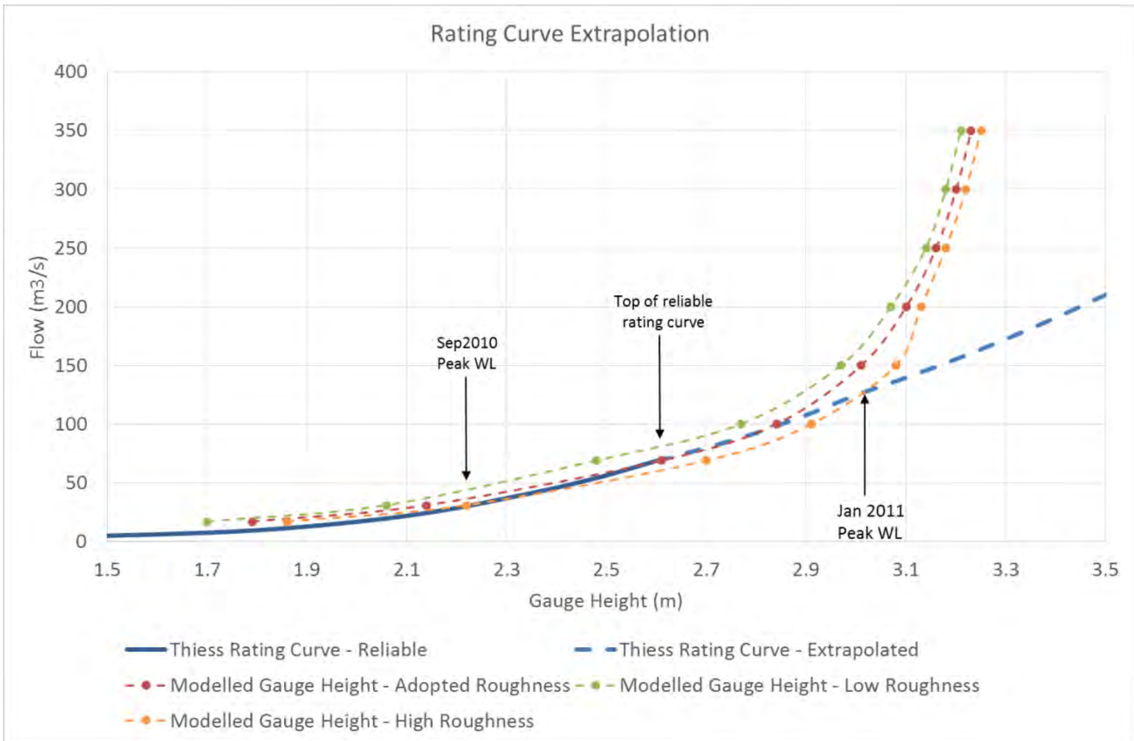


Figure 4-3 Extrapolation of Rating Curve – 408203 Avoca River @ Quambatook

4.2.2 Revised Rating Curve

A revised rating curve was constructed using the Thiess rating curve in its reliable section, and the newly developed extrapolation (Figure 4-4).

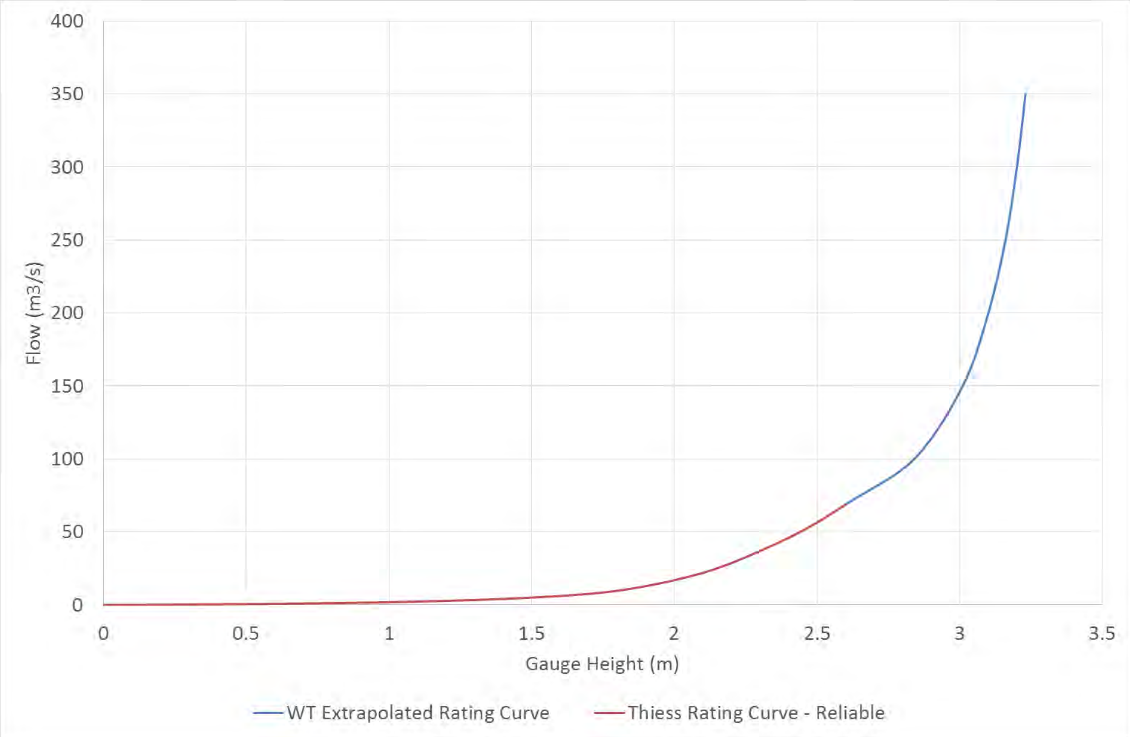


Figure 4-4 Revised Rating Curve – 408203 Avoca River @ Quambatook

Using this rating curve the January 2011 peak flow is estimated to be 166 m^3/s (27% higher than the flow in the gauge record). For all subsequent hydrological analysis, the gauge record for the January 2011 event was amended using the revised rating curve.

4.3 Flood Frequency Analysis

4.3.1 Annual Series Analysis – Peak Flow

An annual series of peak flows at the Quambatook South gauge (408203) was constructed from the flow record as shown in Table 4-3. The annual series is shown graphically in Figure 4-5. The record spanned 49 years from 1964 to 2012 with one year of missing data (1966). Historic flood information was available for the gauge upstream at Coonooer (408200) from 1889. The record indicated that there were flows exceeding the 1983 peak flow (largest flow on record prior to 2011) in 1909 and 1956 (Table 4-4).

Table 4-3 Annual series of peak flows at Quambatook South gauge (408203).

Year	Peak Flow (m^3/s)	Source	Year	Peak Flow (m^3/s)	Source
1964	20	RWC	1989	45	DEPI
1965	7	RWC	1990	13	DEPI
1966	No data		1991	11	DEPI
1967	0	DEPI	1992	39	DEPI
1968	22	DEPI	1993	36	DEPI
1969	5	DEPI	1994	1	DEPI
1970	5	DEPI	1995	50	DEPI
1971	3	DEPI	1996	50	DEPI
1972	3	DEPI	1997	5	DEPI

Year	Peak Flow (m^3/s)	Source	Year	Peak Flow (m^3/s)	Source
1973	31	DEPI	1998	4	DEPI
1974	29	DEPI	1999	5	DEPI
1975	45	DEPI	2000	6	DEPI
1976	1	DEPI	2001	1	DEPI
1977	2	DEPI	2002	0	DEPI
1978	17	DEPI	2003	2	DEPI
1979	24	DEPI	2004	0	DEPI
1980	12	DEPI	2005	0	DEPI
1981	40	DEPI	2006	0	DEPI
1982	1	DEPI	2007	1	DEPI
1983	59	DEPI	2008	0	DEPI
1984	13	DEPI	2009	0	DEPI
1985	5	DEPI	2010	31	DEPI
1986	20	DEPI	2011	166	DEPI (WT revised rating curve)
1987	27	DEPI			
1988	43	DEPI	2012	1	DEPI

DEPI: Provided by Department of Environment and Primary Industries

RWC: Rural Water Commission of Victoria (1990) Victorian Surface Water Information to 1987 (Blue Book).

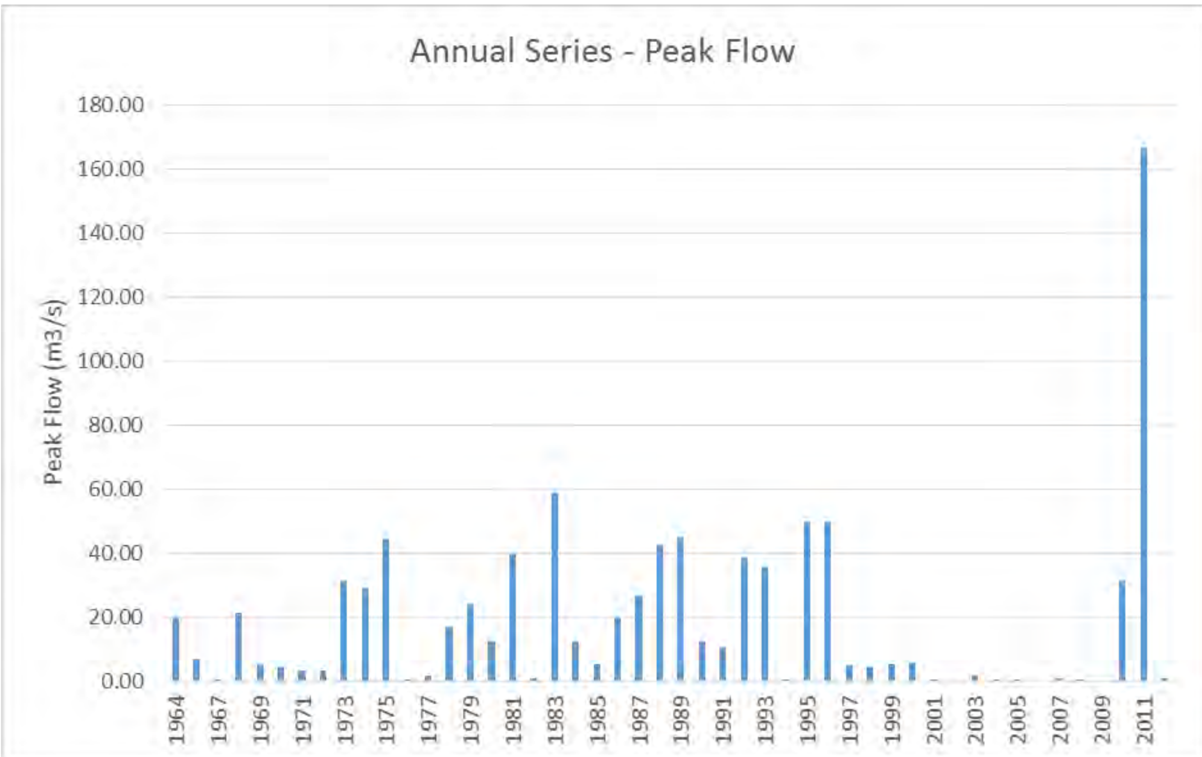


Figure 4-5 Annual series of peak flows at Quambatook South gauge (408203)

Table 4-4 Inferred Historic Flows 1989-1963, based on flow record at Yawong Weir (408200 Avoca River @ Coonooer)

Year	Above threshold m^3/s	Comment
1909	59	Largest flow on record at Yawong Weir
1956	59	Larger than 1983 at Yawong Weir

Design flows can be estimated from an annual series by fitting a distribution to the series of peak flows. Distributions were fitted to the annual peak flow series using the FLIKE software, which uses a Bayesian approach to parameter fitting and allows the fitting of five different distribution types.

Many years in the series had extremely low flows that could not be considered part of the flood series. Fifteen peak flows below a threshold of 3 m^3/s were censored from the analysis. These low flows were retained in the annual series but removed from the statistical fit (such that the duration of the annual series was unchanged). The Generalised Extreme Value distribution was found to provide the best fit to the series (Figure 4-6). The design peak flows resulting from the analysis are given in Table 4-5.

The effect of including the two inferred historic flows was tested and was found to decrease the predicted 1% AEP flow from 180 to 118 m^3/s (see Figure 4-7 and Table 4-6). Including the historic flows also resulted in narrower confidence limits on the predicted design flows. The historical record shows that the January 2011 peak flow was an extremely rare event, therefore including the historic peak flows provides a more reasonable estimate of the magnitude of AEP design flows. The best estimate of the AEP of the January 2011 event is 0.4%. The confidence limits indicate that the January 2011 event has a 95% chance of having an AEP between 1.7% (1 in 60) and 0.02% (1 in 5000). This is consistent with the preliminary finding of the Charlton Flood and Drainage Management Plan (Draft Hydrology Report, BMT WBM 2011) that the January 2011 event at Yawong Weir had an AEP of less than 0.5%.

The September 2010 event was a more common event with an AEP of approximately 17% (1 in 6) with 95% confidence limits of 11%-23% (1 in 4 to 1 in 9).

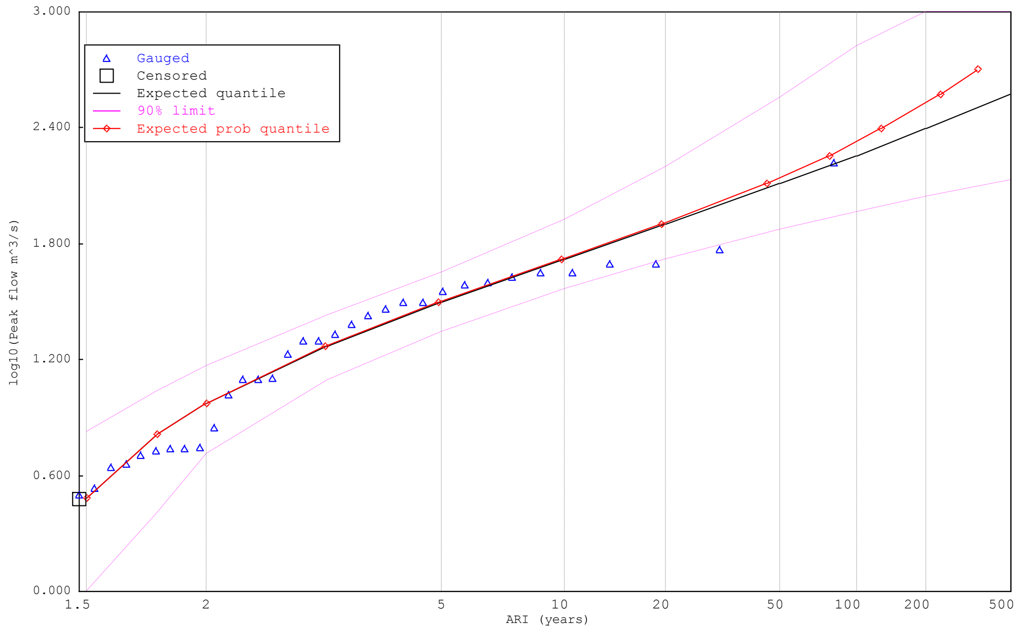


Figure 4-6 Generalised Extreme Value distribution fitted to annual series with no historic peaks over 59 m^3/s and 15 low flow years excluded

Table 4-5 Design peak flow estimates from Generalised Extreme Value distribution fitted to annual series with no historic peaks over 59 m^3/s and 15 low flow years excluded

AEP	GEV Peak Flows (m^3/s)	90% Confidence Interval (m^3/s)
20%	31	22-45
10%	52	37-84
5%	80	53-159
2%	129	75-358
1%	180	92-668
0.5%	249	110-1243

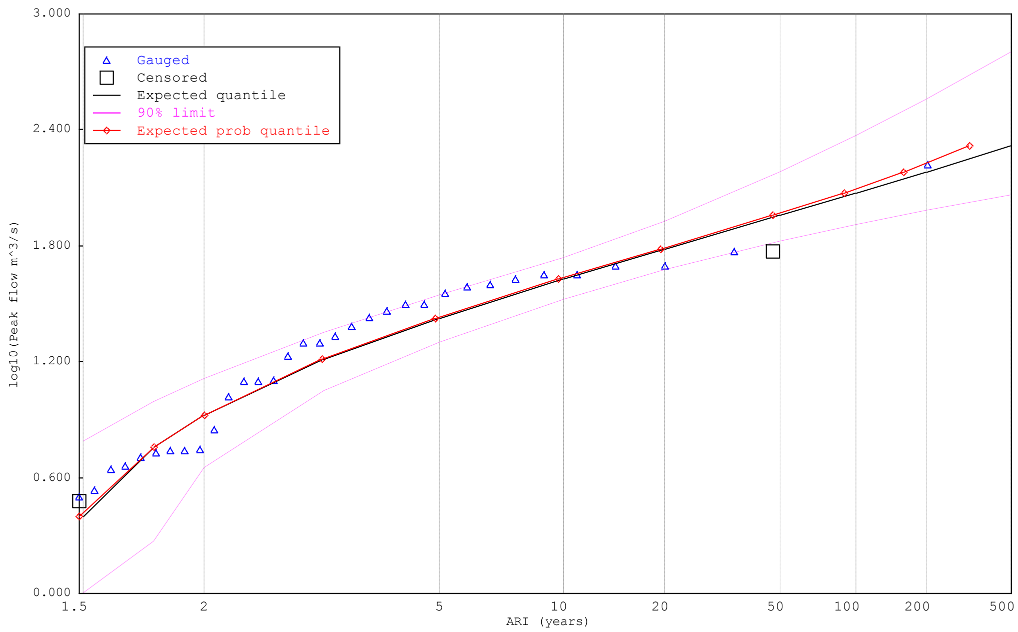


Figure 4-7 Generalised Extreme Value distribution fitted to annual series with two historic peaks over 59 m^3/s and 15 low flow years excluded

Table 4-6 Design peak flow estimates from Generalised Extreme Value distribution fitted to annual series with two historic peaks over 59 m^3/s and 15 low flow years excluded

AEP	GEV Peak Flows (m^3/s)	90% Confidence Interval (m^3/s)
20%	27	20-35
10%	42	33-55
5%	61	47-84
2%	90	66-151
1%	118	81-232
0.5%	152	95-358

4.3.2 Annual Series Analysis – Flood Volume

In order to estimate design flow hydrographs, a flood frequency analysis on flood volume was undertaken. A review of significant events in the flow record revealed that the average flood event duration was approximately 15 days. The maximum 15 day flood volume was calculated for each year (from 46 years of data provided by DEPI) as shown in Table 4-7. The annual series of 15 day flood volumes is shown in Figure 4-8.

Table 4-7 Annual series of 15 day volumes at Quambatook South gauge (408203)

Year	Max 15 day volume (ML)	Year	Max 15 day volume (ML)
1967	226	1990	5,872
1968	12,622	1991	9,047
1969	4,872	1992	25,132
1970	4,098	1993	16,114
1971	3,376	1994	868
1972	2,609	1995	30,654
1973	24,456	1996	24,469
1974	19,906	1997	4,804
1975	40,835	1998	2,767
1976	760	1999	3,218
1977	1,372	2000	3,268
1978	11,537	2001	548
1979	19,670	2002	-
1980	6,916	2003	1,433
1981	35,042	2004	16
1982	673	2005	292
1983	39,465	2006	-
1984	9,869	2007	632
1985	4,341	2008	37
1986	9,722	2009	-
1987	13,274	2010	15,779
1988	27,533	2011	57,980*
1989	26,978	2012	747

** from WT revised rating curve*

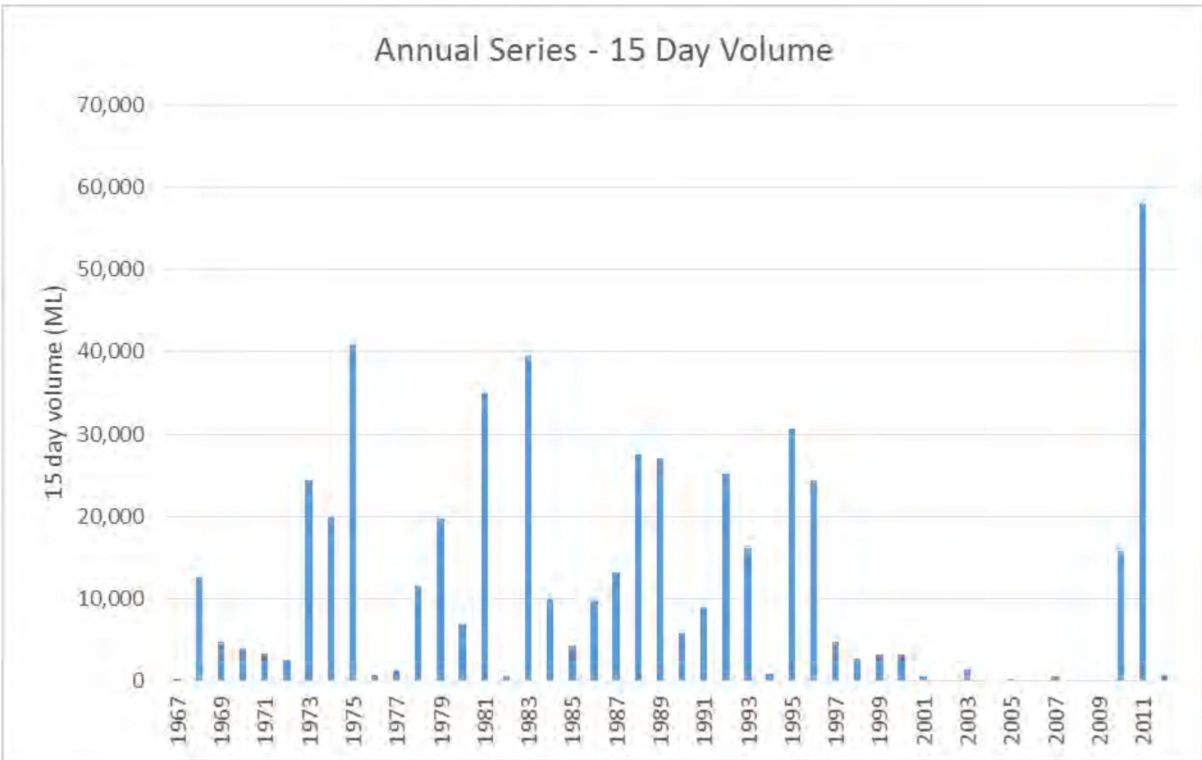


Figure 4-8 Annual series of 15 day volumes at Quambatook South gauge (408203)

Distributions were fitted to the annual flood volume series in FLIKE, and the Log Pearson III distribution was found to have the best fit. Fifteen low flow years with maximum flood volume less than 2,500 ML were excluded from the analysis. The resulting design flood volumes are given in Table 4-8.

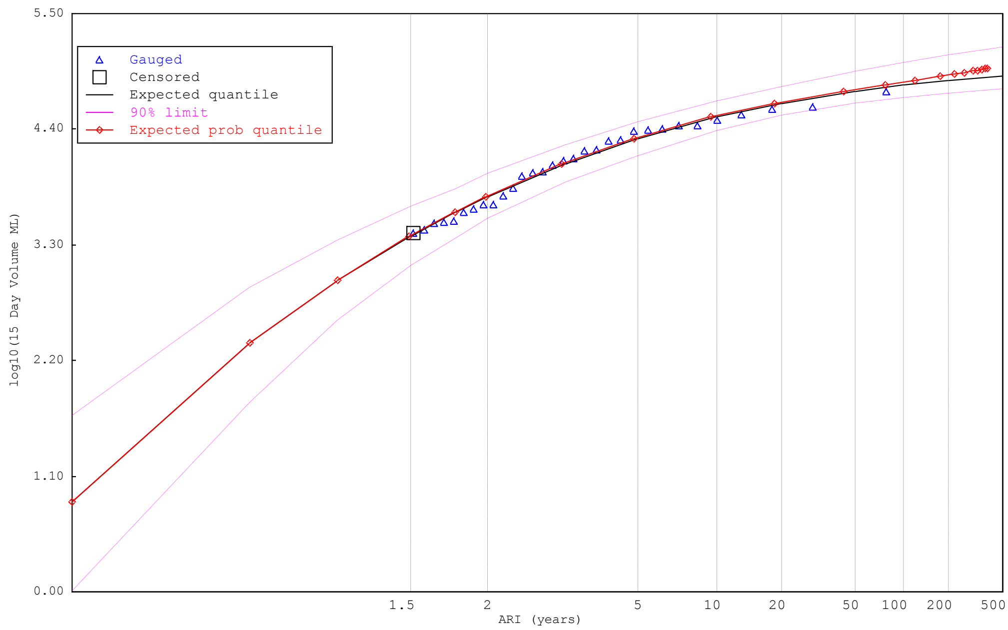


Figure 4-9 Log Pearson III distribution fitted to annual series with 15 low flow years excluded

Table 4-8 Design flood 15 day volume estimates from Log Pearson III distribution fitted to annual series with 15 low flow years excluded

AEP	LPIII (ML)	90% Confidence Interval (ML)
20%	21,000	14,000-29,000
10%	33,000	24,000-46,000
5%	45,000	34,000-63,000
2%	58,000	44,000-88,000
1%	66,000	50,000-106,000
0.5%	73,000	55,000-126,000

4.4 Design flow hydrographs and Gauge heights

Design hydrographs were constructed based on the peak flows and 15 day flood volumes estimated above. See Table 4-9 for a summary of design flows, gauge heights and volumes.

Table 4-9 Design peak flows, gauge heights and flood volumes for AEPs from 20% to 0.5% at Quambatook South (408203)

AEP	Peak flow (m3/s)	Peak gauge height (m)	15 day volume (ML)
20%	27	2.18	21,000
10%	42	2.36	33,000
5%	61	2.54	45,000
2%	90	2.76	58,000
1%	118	2.90	66,000
0.5%	152	3.01	73,000

An observed hydrograph was selected from the gauged record to be scaled by peak flow and volume to give the design flow hydrographs. The gauge record was inspected to identify 'simple' hydrographs appropriate for scaling – hydrographs that start and end at low flow values, have a single peak, and are regular in shape. Five gauged hydrographs were identified that were appropriate; 1986, 1987, 1995, 1996 and 2010. The ratio of volume to peak flow was calculated for the design flows and compared to the ratio for gauged hydrographs. The selected gauged hydrographs had a ratio that ranged from 330 to 496 (Table 4-10), while the ratio for the design flows ranged from 480 to 778 (Table 4-11). The 1996 hydrograph (Figure 4-10) was selected as it had a volume to peak flow ratio that lay close to the range of the design flow hydrographs, and a relatively high peak flow that lay in the middle of the range of design peak flows.

The hydrograph was scaled to each design peak flow and volume, first by a linear scaling of the flow magnitudes to match the design peak flow, than by a linear scaling of the time step. The time step was increased until the calculated 15 day volume was equal to the design volume listed in Table 4-9. The resulting design hydrographs are shown in Figure 4-11.

Table 4-10 Volume/peak flow ratio for selected gauged hydrographs

Historic Flow	Peak flow (m3/s)	15 day volume (ML)	Volume/Peak Flow Ratio
1995	50	16399	330
1996	50	23059	462
1986	20	9722	490
1987	27	13274	496
2010	31	13433	429

Table 4-11 Volume/peak flow ratio for design flow hydrographs

AEP	Peak flow (m3/s)	15 day volume (ML)	Volume/Peak Flow Ratio	Model Hydrograph
20%	27	21000	778	1996
10%	42	33000	786	1996
5%	61	45000	738	1996
2%	90	58000	644	1996
1%	118	66000	559	1996
0.5%	152	73000	480	1996

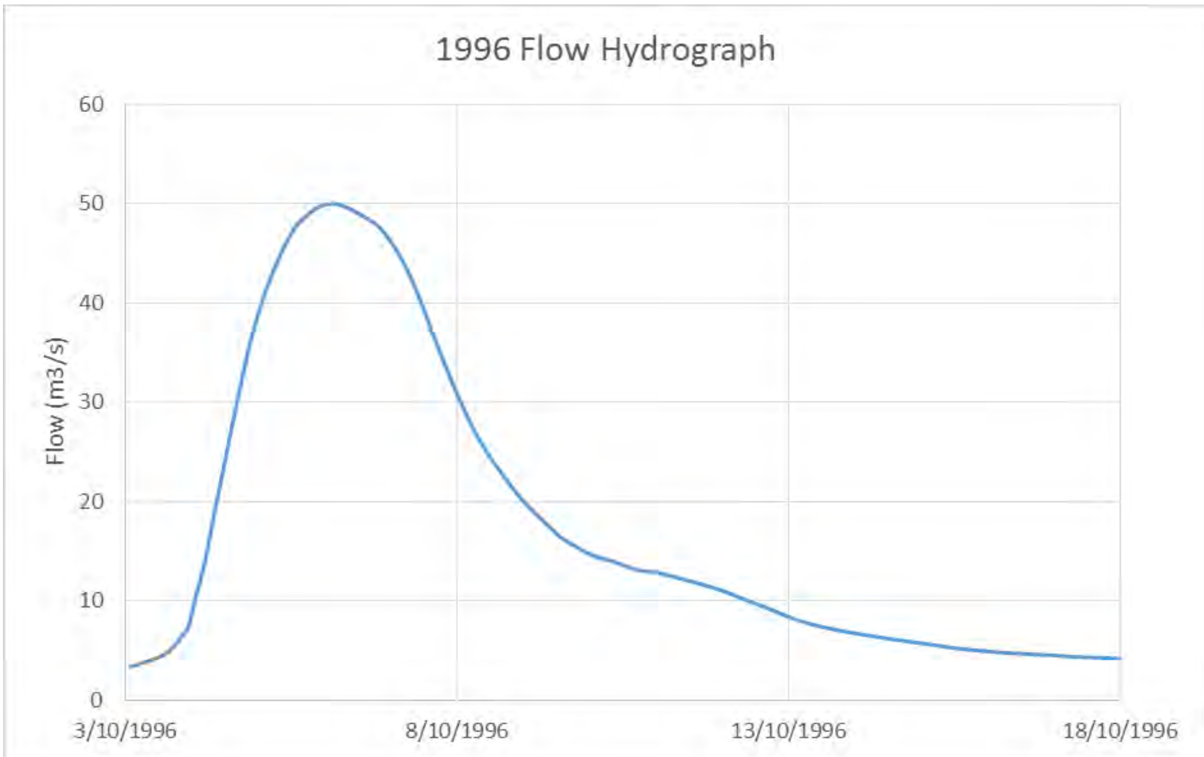


Figure 4-10 1996 flow hydrograph adopted as model hydrograph for design purposes

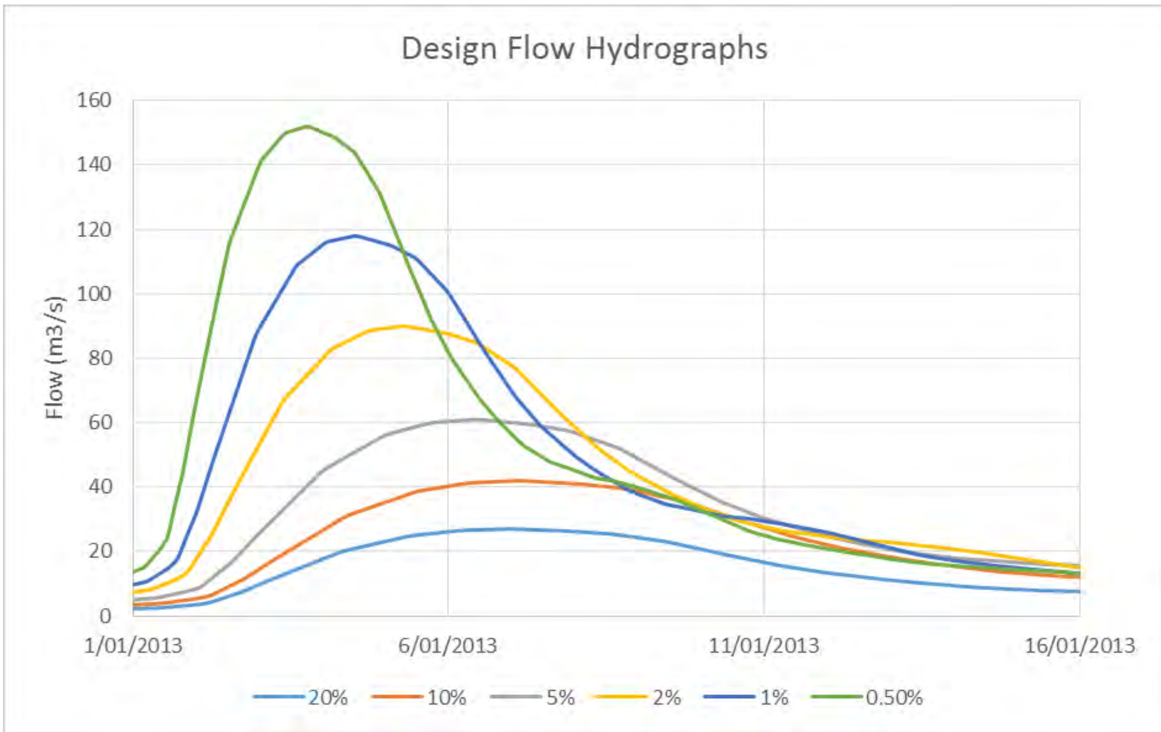


Figure 4-11 Scaled design flow hydrographs

4.5 Eastern Flood Course Design Flows

The flow in the Eastern Flood Course for the range of AEP events was estimated through the hydraulic model calibration process, as described in Section 5.3.1. From the two calibrated events, a linear relationship between peak flow in the Avoca River and peak flow in the Eastern Flood Course was estimated. The Eastern Flood Course for each AEP design flow was calculated from this relationship. The flow in the Eastern Flood Course was found to be between 15 and 24% of the Avoca River peak flow. It is acknowledged that this method provides very approximate estimates only, but this was deemed acceptable given that the Eastern Flood Course does not have a significant impact on the township of Quambatook. For comparison, the Lower Avoca Hydrologic Study (GHD 2006) listed design flows for the Eastern Flood Course approximated from a relationship with the Quambatook gauge. The reported design flows were 12 m^3/s, 17 m^3/s and 23 m^3/s for the 20%, 10% and 1% AEPs respectively. The current estimates are consistent with previous estimates.

Table 4-12 Estimated Design Flows for the Eastern Flood Course

Event	Peak flow in Avoca (m^3/s)	Flow in EFC (m^3/s)	EFC as a % of Avoca flow
Sep 2010	31	5	16%
Jan 2011	166	40*	24%
20%	27	4	15%
10%	42	8	19%
5%	61	13	21%
2%	90	20	22%
1%	118	27	23%
0.5%	152	36**	24%

** Applied as 30 m^3/s in main Flood Course and 10 m^3/s in breakout west of Flood Course*

*** Applied as 30 m^3/s in main Flood Course and 6 m^3/s in breakout west of Flood Course*

4.6 Gauge Height Increments

For a range of design gauge levels from 2 m to 3.2 m gauge height, the corresponding flow and AEP are given in Table 4-13.

Table 4-13 Peak flows corresponding to gauge height increments at Quambatook South (408203)

Peak gauge height (m)	Peak flow (m^3/s)	AEP
2.0	17	32%
2.2	29	18%
2.4	46	8.5%
2.6	69	3.8%
2.8	95	1.7%
3.0	147	0.55%
3.2	300	0.07%

4.7 Relationship between Yawong Weir and Quambatook South

Recorded flows from Quambatook South (408203) and Yawong Weir (Coonooer 408200) were analysed to determine the relationship between their peak flows. The flow records were compared over their overlapping period, from 24 May 1967 to 31 Jan 2013.

43 peak flows above 20 ML/day were found for Quambatook South, and each of these was paired the corresponding peak flow from Coonooer. The time lag between the two determined from each pair. Table 4-14,

Table 4-15, Figure 4-12 and Figure 4-13 summarise the findings.

The large peak flow rate from January 2011 is clearly shown as an outlier from the other points in both plots. This indicates that a greater proportion of the upstream peak was transferred downstream, and that the peak moved faster downstream than any other recorded flood event. Both of these findings may be explained by the initially wet catchment in January 2011, however they also suggest a significant difference in flood transmission behaviour under extreme flow conditions such as the January 2011 event.

A reference table for the prediction of flow ranges at Quambatook South from flow ranges at Yawong Weir is provided (Table 4-16), however its usefulness is limited by the significant amount of scatter in the relationship.

Table 4-14 Comparison for selected historical events

Flood Event	Flow at Yawong Weir (Q_{up}, m^3/s)	Flow at Quambatook South (Q_{down}, m^3/s)	Ratio (Q_{down} / Q_{up})	Time Lag (days)
Jan 2011	584	166	0.28	3.6
Sep 2010	434	31	0.07	5.2
Sep 1983	311	59	0.19	6.0
Oct 1996	313	50	0.16	5.1
Jun 1995	352	50	0.14	4.1
Jun 1989	209	45	0.21	4.3
Oct 1975	334	45	0.13	5.2

Table 4-15 Summary of Comparison

Statistics	Ratio (Q_{down} / Q_{up})	Time Lag (days)
Maximum	0.50	6.4
Minimum	0.07	3.6
Mean	0.21	5.0
Standard Deviation	0.11	0.7

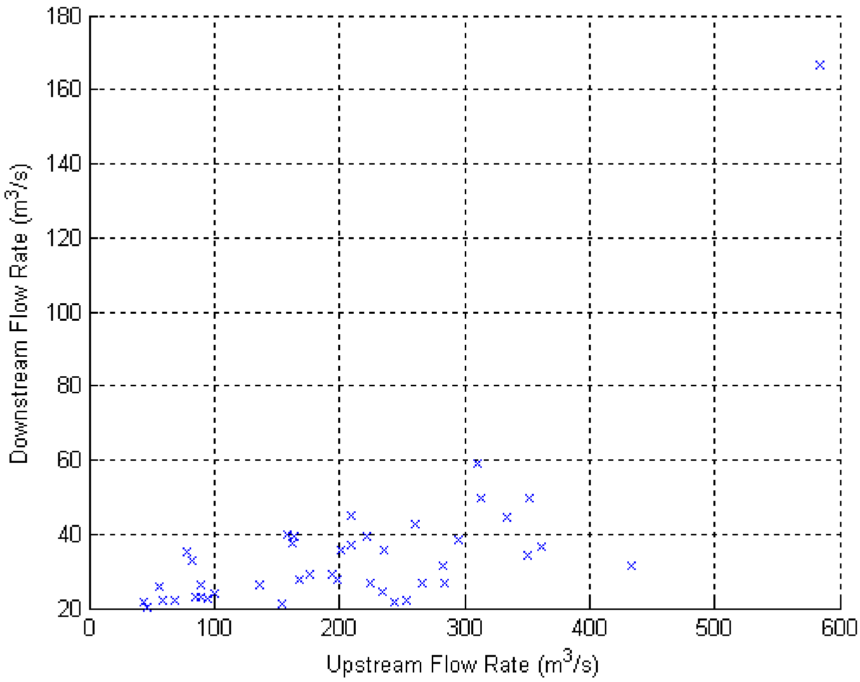


Figure 4-12 Downstream (Quambatook) Flow Rate (m^3/s) vs. Upstream (Yawong Weir) Flow Rate (m^3/s)

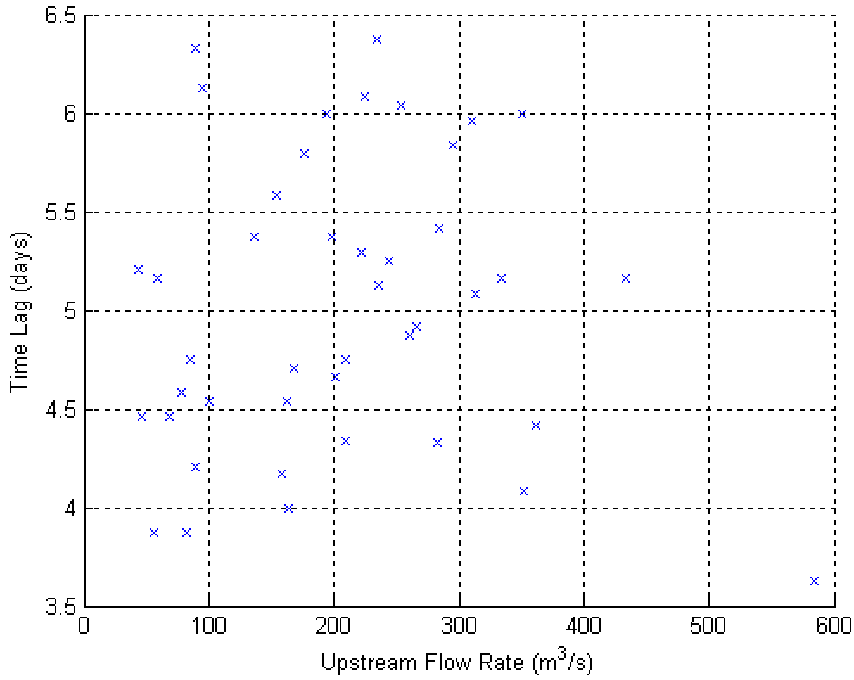


Figure 4-13 Time Lag vs. Upstream (Yawong Weir) Flow Rate (m^3/s)

Table 4-16 Reference table for flows at Quambatook South corresponding to flow ranges at Yawong Weir

Flow at Yawong Weir (m^3/s)	Flow at Quambatook South (m^3/s)	Approx. AEP at Quambatook South	Time lag (days)
0-100	0-35	> 14%	3.5-6.5
100-200	22-46	8-26%	3.5-6.5
200-300	24-60	5-23%	3.5-6.5
300-400	30-90	2-17%	3.5-6.5
400-600	30-180	0.3-17%	3.5-6.5

5. HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

5.1 Hydraulic modelling framework

5.1.1 Overview

This section discusses the philosophy underpinning the hydraulic modelling framework employed for this study. A comprehensive hydraulic modelling framework has been employed in this study, as discussed in Section 5.1.2. However, the outcomes of the hydraulic modelling must be viewed in the light of the hydraulic models' capabilities, limitations and uncertainties. These aspects are discussed in Section 5.1.3.

5.1.2 Hydraulic Model Elements

A hydraulic model was required to simulate the flow behaviour across the Quambatook floodplain balancing excessive model simulation times and topographic resolution. The final hydraulic modelling framework comprised a two-dimensional (2D) hydraulic model which represents broad scale channel floodplain features, coupled with one-dimensional (1D) representations of structures such as bridges and culverts.

The hydraulic modelling suite, MIKE11, MIKE21 and MIKE FLOOD, developed by the Danish Hydraulic Institute (DHI) was applied in this study. MIKE FLOOD is a state-of-the-art tool for floodplain modelling that combines the dynamic coupling of the one-dimensional MIKE 11 river model and MIKE 21 fully two-dimensional model systems. Further details on the capabilities of the MIKE modelling system can be found at http://www.dhisoftware.com.

5.1.3 Hydraulic Model Capabilities and Uncertainties

There are numerous contributing factors to the ultimate output uncertainty in a complex hydraulic modelling exercise such as that undertaken for this study. Some of the uncertainties relate to the data inputs, whilst others are dependent on the numerical modelling processes itself. Sources of output uncertainty related to the input data for the hydraulic modelling include:

- Topographic data
- Definition of hydraulic controls/structures
- Observed flows and water levels for model calibration

Sources of uncertainty related to the hydraulic modelling process include:

- Model schematisation and set-up (bridge and culvert representation, grid resolution)
- Model parameters such as computational time-steps, surface-friction and other energy-loss parameters (expansion/contraction coefficients and eddy viscosity for example)
- Model numerical and computational schemes – these relate to the ability of the model to replicate the physics of free-surface flow in channels and over land
- Floating point accuracy of computing resources (round-off error)

There is a wide variation in the magnitude of the impact associated with each source of uncertainty. In order to identify the most significant sources of uncertainty it is possible to consider items as either first or second order magnitude, where second order items are of a significantly smaller magnitude compared to first order items and can generally be ignored. The first order sources of error are survey data, definition of hydraulic controls/structures, flow gauging data, observed flood levels for calibration, model schematisation, and model parameters.

The model development process can only address uncertainties arising from the following aspects:

- Definition of hydraulic controls/structures
- Model schematisation and set-up (location and spacing of cross-sections, grid resolution)

- Model parameters such as computational time-steps, surface-friction and other energy-loss parameters

Section 5.2 discusses the consideration of these three aspects in the model development.

5.2 Model Development and Schematisation

This section defines the scope of the hydraulic analysis, details the hydraulic model construction, and discusses the hydraulic model calibration.

5.2.1 2D Hydraulic Model Schematisation

Grid Extent and Resolution

The 2D grid extent was delineated to extend far enough upstream and downstream of the study area to avoid the influence of boundary schematisation and conditions on results within the study area. The chosen grid extent is shown in Figure 5-1. The extent of the 2D grid area was approximately 110 km^2, meaning that a 10 m grid provided a good balance between accuracy and model run time.

Topography

The 2D model topography was based on a combination of the North Central CMA Index of Stream Condition (ISC) LiDAR, the 2009-10 Victorian State Wide Floodplains LiDAR and the 2010-11 North Central CMA Stage 2 Floodplains LiDAR. The two floodplain LiDAR datasets were captured when there was water in the river, while the ISC LiDAR was captured when the river was dry. However the ISC dataset only covers a narrow (1,300 m) swathe along the river and doesn't include the whole floodplain. The LiDAR datasets were mosaicked and used in priority order as shown below for construction of the hydraulic model:

1. North Central CMA ISC LiDAR (in-channel detail only)
2. 2009-10 Victorian State Wide Floodplains LiDAR Project
3. 2010-11 North Central CMA Stage 2 Floodplains LiDAR

There appeared to be a significant systematic offset of approximately 0.1 m in the Stage 2 Floodplain LiDAR. The other two datasets were broadly consistent with each other but the Stage 2 LiDAR was offset from both of them. This dataset was adjusted by a constant offset of -0.1 m prior to use. The Stage 2 LiDAR was only used where no other data existed.

Key hydraulic controls such as levees and road embankments were stamped into the model grid by sampling the local maximum heights from the 1 m LiDAR DEM data and applying them to the 10 m model grid.

A number of temporary levees were constructed prior to and during the September 2010 and January 2011 flood events. For calibration to these events, the temporary levees were added to the model grid

The model topography, including key hydraulic control lines and temporary levees is shown in Figure 5-1.

Boundary Conditions

Upstream boundaries were applied at the Avoca River inflow point, as well as the Eastern Flood Course. The hydrograph at the Quambatook South Gauge on the Avoca River was applied at the study area boundary. No hydrologic information was available for the Eastern Flood Course and a constant inflow was applied as required to achieve calibration. This is thought to be a reasonable assumption given the regulated, engineered and confined nature of the Eastern Flood Course. For the 2011 calibration event an additional inflow boundary was applied to the west of the Eastern Flood Course to apply overflows running parallel to the floodway observed in aerial photography.

The downstream boundaries were applied to the channel and floodplain downstream of Budgerum Bridge. Constant water levels were applied to these boundaries at approximately the bankfull or floodplain level.

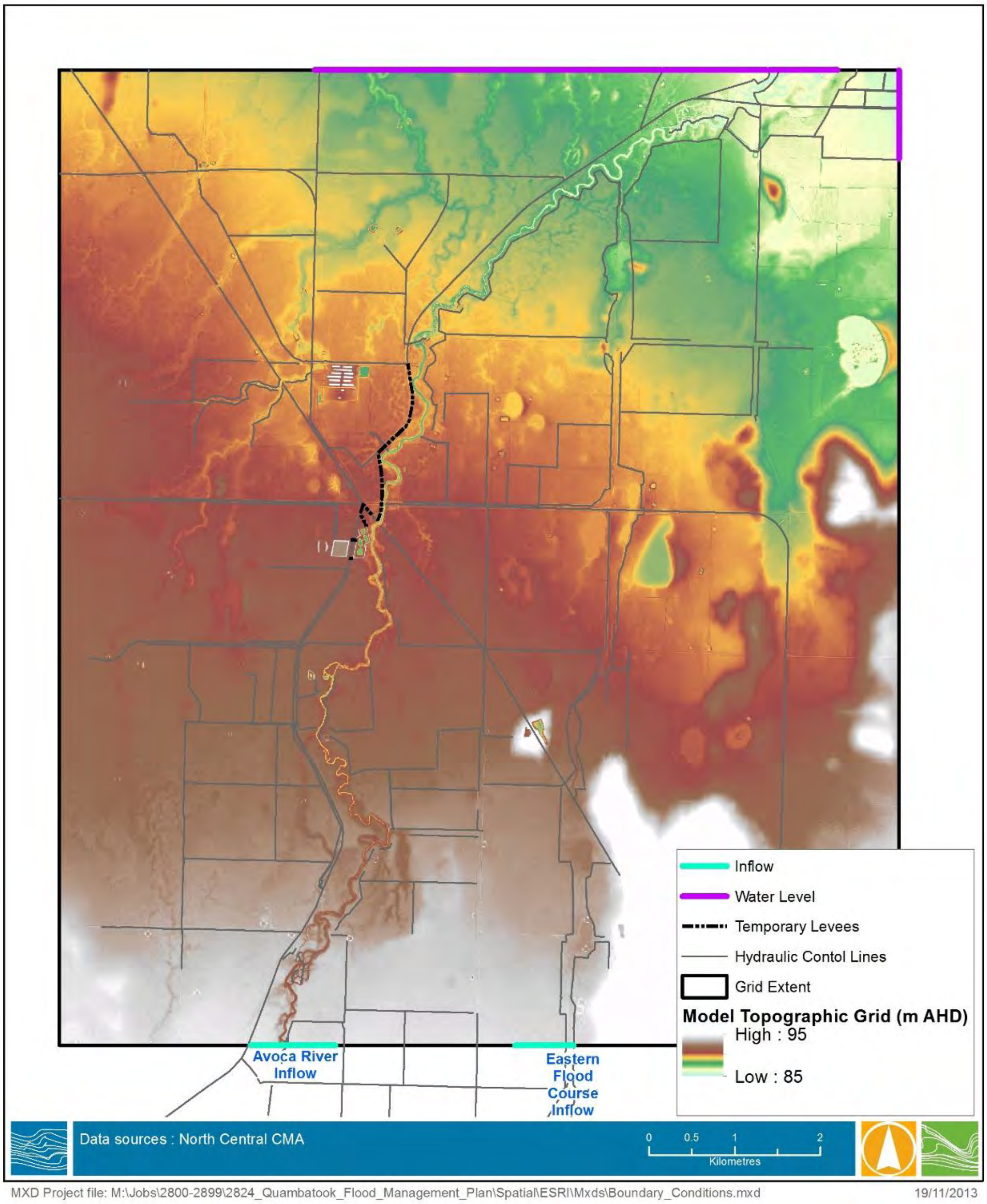


Figure 5-1 Grid extent, topography and boundary locations

Roughness

Hydraulic roughness within the 2D model was expressed as Manning's n. For the estimation of the floodplain Manning's n, this study assessed land use and vegetation cover. Hydraulic roughness parameters were adopted using industry standard values that represent the channel and floodplain cover, and adjusted as required to calibrate the models.

Hydraulic roughness values adopted for the 2D hydraulic model and confirmed in the model calibration are summarised in Table 5-1, which shows the different values adopted for each land use of ground cover. Figure 5-2 is a map of the roughness categories as used in the 2D model; a roughness category of "general floodplain" is used as default for the regions that do not have a roughness category overlay.

Table 5-1 2D Roughness Values

Land Use / Topographic Description	Manning's "n"
General Floodplain	0.04
Unvegetated River Channel	0.03
Dense Vegetation	0.06
Residential/Commerical/Industrial Town Areas	0.08

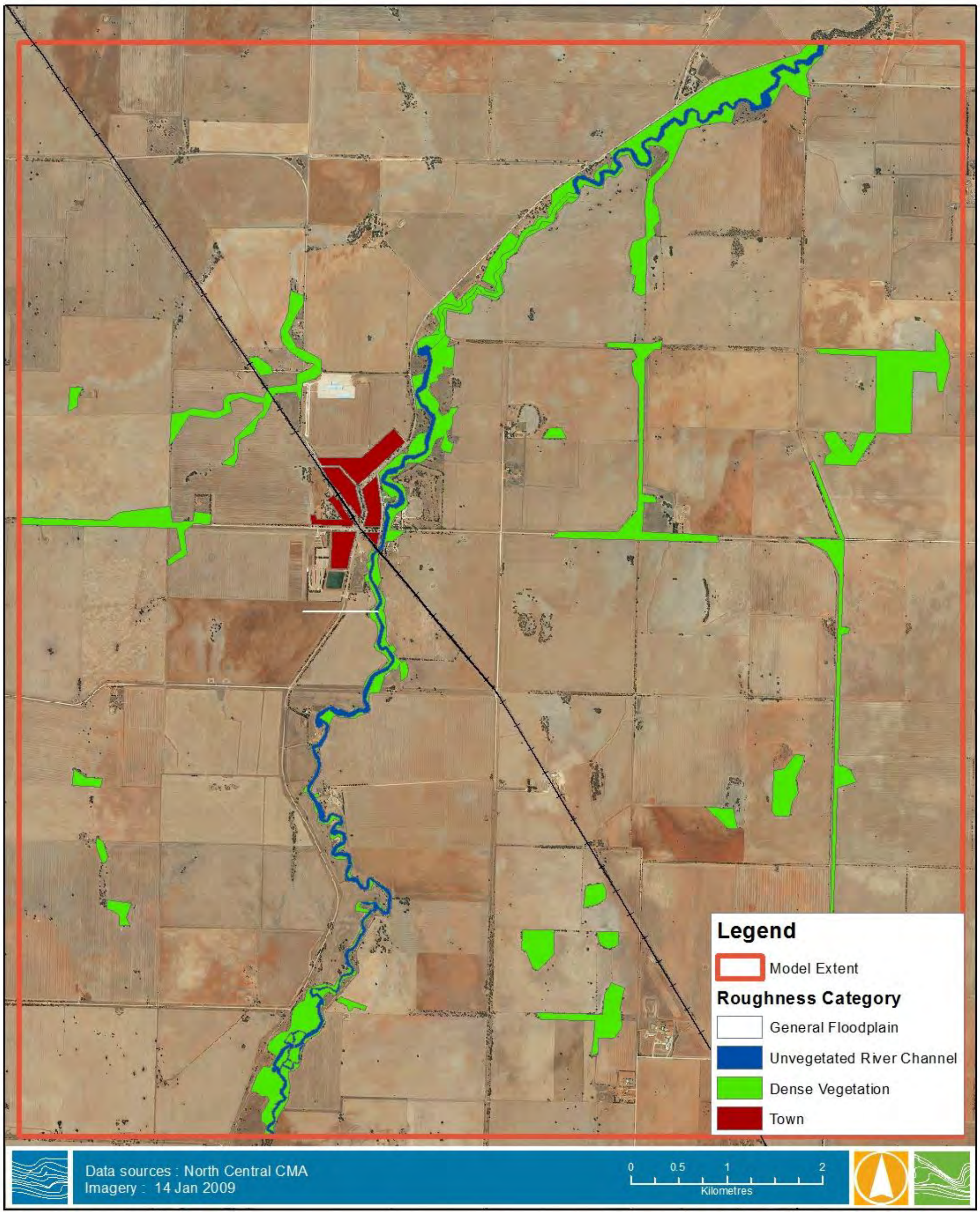


Figure 5-2 Roughness Categories

5.2.2 1D Hydraulic Model Schematisation

Bridges

The nine bridges within the study area were incorporated as MIKE 11 (1D) structures within the MIKE FLOOD (1D-2D) simulation program. The MIKE 11 (1D) model is linked to the 2D model grid upstream and downstream of each structure. The location and dimensions of the modelled bridges is detailed in Section 2.4.1.

Pipes and Culverts

Large culverts within the study area were surveyed and were incorporated into the hydraulic model as MIKE 11 structures within the MIKE FLOOD simulation program. The location and dimensions of the modelled culverts are detailed in Section 2.4.1.

Weir

The Quambatook Weir was included as a MIKE 11 structure within the MIKE FLOOD simulation program.

The weir was recently replaced with a new structure (see Section 2.4.5 for details). The new weir (14.33 m wide with a crest level of 89.02 m AHD with crest fully lowered) was adopted for design flood events.

The calibration events (September 2010 and January 2011) occurred when the old weir was still in place. The old weir was surveyed for the Quambatook weir replacement study (Figure 2-7) and a Q-H curve was developed to combine the flow regimes for sharp-crested weir flow or orifice flow under the walkway and broad crested weir flow over the walkway. The Q-H curve assumed all boards were removed under flood conditions. This Q-H curve was adopted for the calibration events.

Boundary Conditions

As all the 1D model components are linked within the 2D model grid structure specific boundaries for each component are not required. Flow on the 2D grid surface enters a grid cell linked to a 1D structure and that structure becomes active. Flow then passes through the structure and re-enters the 2D grid downstream.

Roughness

Hydraulic roughness was expressed as Manning's n values. Manning's n values were applied based on structure material (i.e. concrete, earth) for the 1D components (Table 5-2). Structure inlet/outlet losses were also applied as per MIKE 11 defaults.

Table 5-2 1D Roughness Values

Material Description	Manning's "n"
Earth	0.020
Earth with Bridge Piers	0.025
Concrete	0.013
Ribbed Wall Poly Pipe	0.024

5.3 Hydraulic Model Calibration and Validation

5.3.1 Calibration Approach

This section discusses the refinement of the hydraulic model parameters through calibration against observed flood levels, extents and stream flow data, and outlines the validation of adopted model parameters.

The calibration process consisted of an iterative comparison of observed and modelled flooding. The model parameters were adjusted to minimise the differences between the modelled and observed data. The validation process applied the calibrated model parameters to another flood event to assess model performance.

A robust calibration requires the comparison of modelled and observed flood behaviour across a range of flow magnitudes. The following observed data was required for a historical event to be considered in the model calibration:

- Well defined inflows and outflows (boundary conditions).
- Observed flood levels/extents over time providing a temporal distribution throughout the floodplain and along the river.
- Observed flood extents from aerial/satellite imagery providing a spatial distribution.

The historical flood events used to calibrate/validate the models were chosen on the basis of available observed flood information. The following sections detail the selection of events and the available data.

The calibration of the model centred on the representation of hydraulic controls (levees and road embankments) and determination of floodplain and river channel hydraulic roughness values (Manning's n values) to achieve a reasonable agreement between observed and modelled flood levels. Initial manning's n values were assigned to various land uses based on previous modelling experience, and where necessary to achieve a reasonable agreement, these initial Manning's n values were refined.

Available Observed Flood Data and Calibration/Validation Event Selection

The focus of the model calibration and validation was the general flood behaviour during large flood events, in line with the study focus (0.5% to 20% AEP events). Hence, the selection of calibration and validation events reflected large flood events with adequate available observed flood data suitable for this purpose.

The recent flood events in September 2010 and January 2011 were selected for model calibration, given their relatively large flood magnitude and reasonable abundance of observed flood information. Aerial photography was available for both events. Surveyed flood pegging was available for the September 2010 event and aerial infrared line scan imagery was available for the January 2011 event.

The flow record at the Quambatook South gauge was more reliable for the September 2010 event, with greater uncertainty in the gauged hydrograph for the January 2011 event due to the exceedance of the rating curve (relationship between level and flow). There was more observed calibration data available for the September 2010 event, therefore the calibration focussed initially on matching the observed flood levels and extents for the September 2010 event. The January 2011 event was then used for validation of the calibrated model.

Table 5-3 summarises the calibration/validation events. The approximate Annual Exceedance Probability (AEP) is based on the adopted design peak flows for the Quambatook South gauging station (408203) as detailed in Section 4.3.

Table 5-3 Hydraulic model calibration/validation events – Peak flows, approximate AEP, and available observed flood information

Event	Peak Flow (m^3/s)	Approximate AEP (%)	Available flood information	
			Flood Marks	Flood Photography
September 2010	31	20%	12 flood pegs surveyed to AHD	Visible aerial photograph 9 Sep 2010 Colour infrared aerial photograph 9 Sep 2010
January 2011	166	<0.5% AEP	11 flood pegs (not surveyed)	Visible aerial photograph 19 Jan 2011 Line scan (infrared) imagery 18 Jan 2011

Eastern Flood Course Flows

The steady state flow in the Eastern Flood Course for each of the calibration events was inferred iteratively through the calibration process. For the January 2011 event, it was found an additional flow needed to be applied just to the west of the Eastern Flood Course to account for overflows from upstream of the study area. The inferred flows are given in Table 5-4.

The purpose of the estimation of flows in the Eastern Flood Course is to understand the interaction they have with the main Avoca River flows. Given the considerable uncertainty in these estimates they are not considered adequate for flood level estimation in the eastern part of the floodplain. For design flood modelling, a relationship was developed between the Avoca River peak flow and the Eastern Flood Course flow, however it should be noted that these flows are not based on hydrological analysis and flood mapping should be treated as less accurate in the eastern part of the floodplain. Despite the uncertainties, we believe the inclusion of the Eastern Flood Course flow is necessary, and will improve the representation of flood levels through the town area in large events.

Table 5-4 Hydraulic model calibration/validation events – inferred flows in Eastern Flood Course

Event	Flows in Eastern Flood Course (m^3/s)	
	Eastern Flood Course	Overflow to west of EFC
September 2010	5	0
January 2011	30	10

5.3.2 Calibration and Validation Results

September 2010 Calibration Event

A comparison of modelled and surveyed peak flood levels is given in Figure 5-4 and Figure 5-5. A comparison of the modelled longitudinal section with the surveyed peak flood levels is shown in Figure 5-3. The comparison of peak flood levels shows an excellent calibration result, with 75% of points falling within 0.05 m of the surveyed level and all points within 0.12 m of the surveyed level (Table 5-5). This indicates that the model is capable of accurately representing flood levels through the area adjacent to the town.

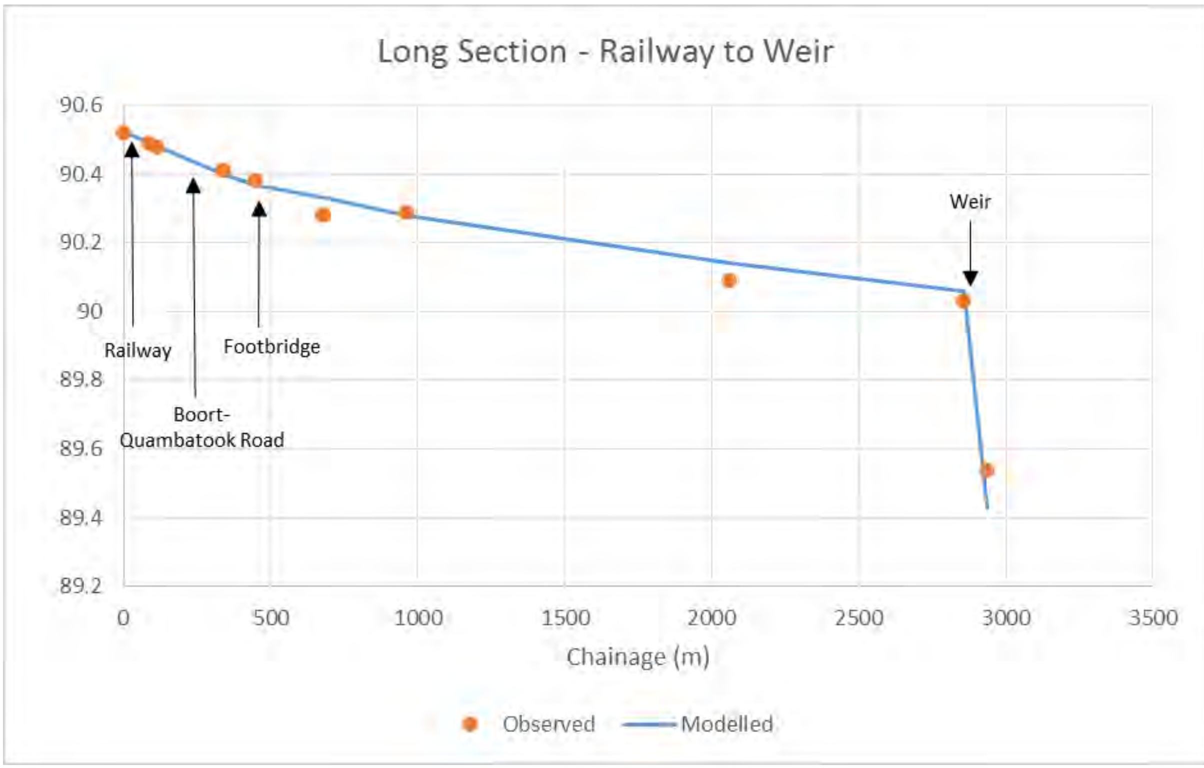


Figure 5-3 **Comparison of modelled Avoca River longitudinal section with observed peak flood levels**

Table 5-5 **Summary of calibration accuracy, September 2010 event**

	Total number of peak levels	Water level difference (modelled – observed)				
		< -0.1 m	-0.1 to -0.05	-0.05 to +0.05	+0.05 to +0.1	>+0.1
Number of surveyed points that fall within each category	12	2	0	9	1	0

A comparison of the flood extent on 9th September at 4pm with the colour infrared image captured on the same afternoon is shown in Figure 5-6. The replication of the flood extent is excellent through the town area (Figure 5-7). The flood extent is overestimated by the model to the west of the Eastern Flood Course. This is due to the representation of a breach in the west bank of the Eastern Flood Course shown in Figure 5-8. The breach is visible as a 5 m wide break in the levee in the September 2010 aerial photography. By the peak of the January 2011 event (19th January) the breach had grown to 10 m wide, and LiDAR data captured after the event showed that the breach was 13 m wide. It is uncertain when the breach initiated or what it looked like before the September 2010 event. The breach is represented in the model as a 5 m wide gap in the levee at the floodplain level from the start of the event. It is likely that the volume escaping the Eastern Flood Course is overestimated by this arrangement, which explains the discrepancy between the modelled and observed flood extents in this area.

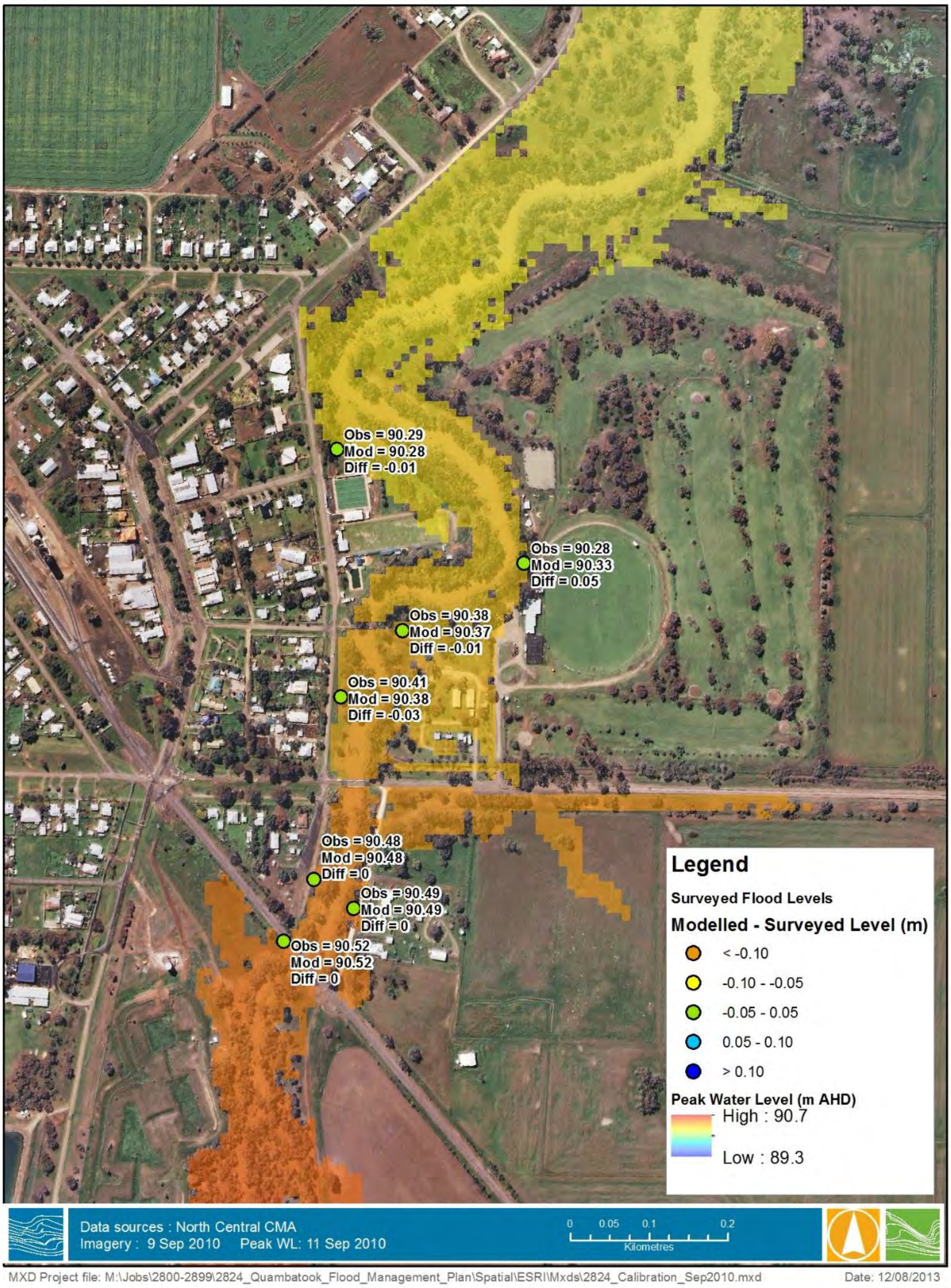


Figure 5-4 Comparison of modelled and surveyed peak flood levels - town

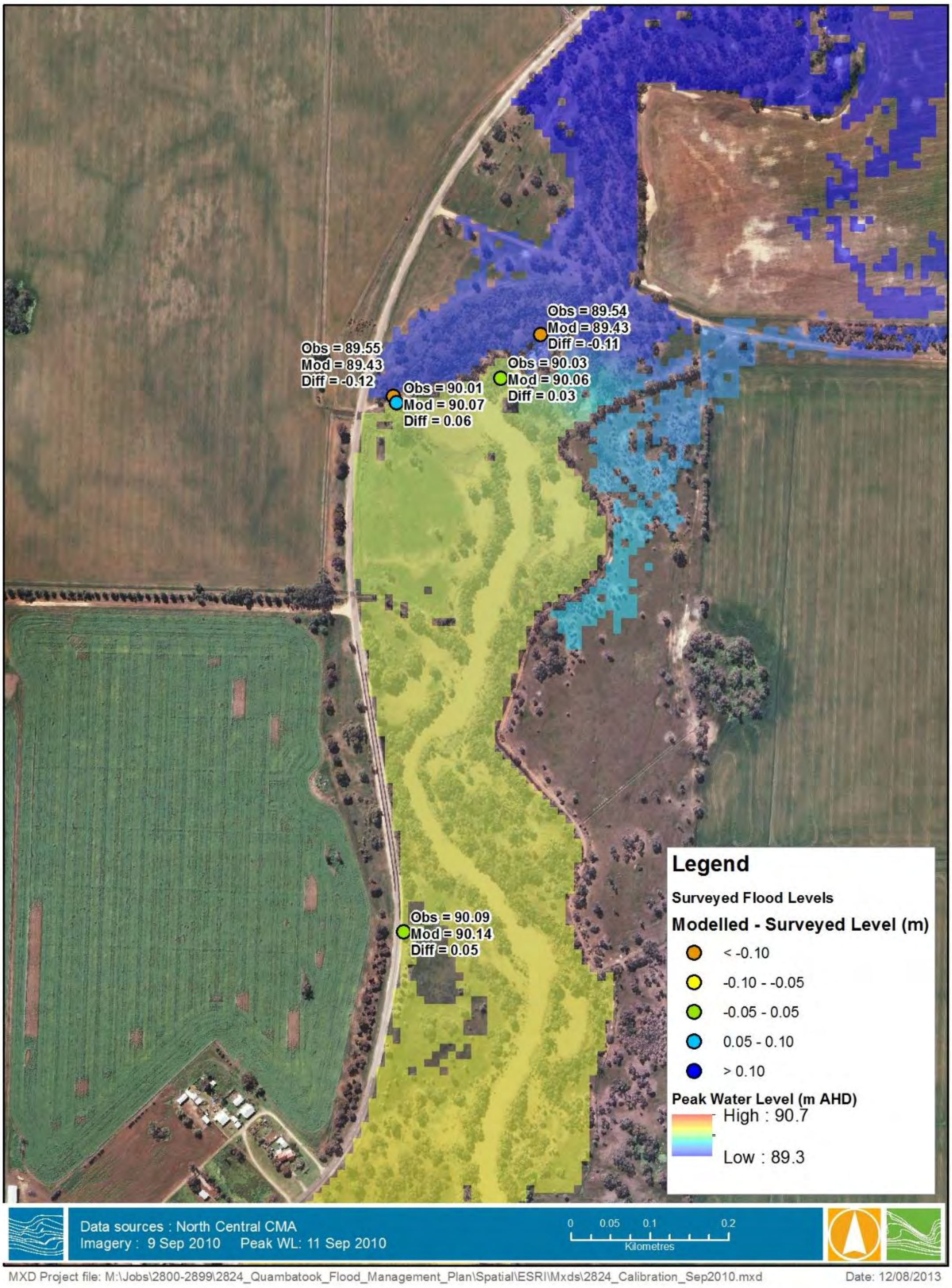


Figure 5-5 Comparison of modelled and surveyed peak flood levels - weir

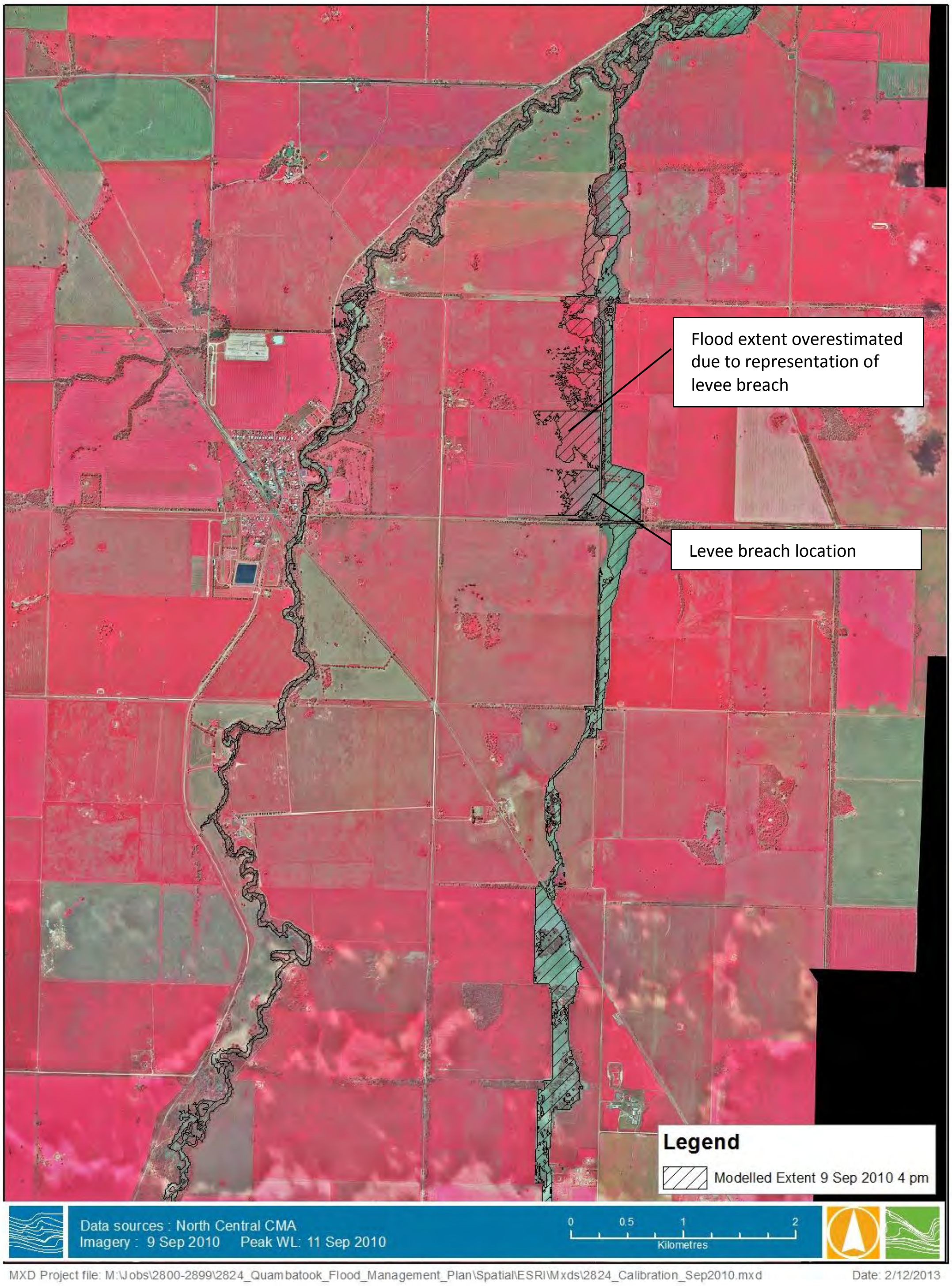


Figure 5-6 Comparison of aerial photographs with modelled flood extent (9 Sep 2010)

Figure 5-7 Comparison of aerial photographs with modelled flood extent (9 Sep 2010) over township

Figure 5-8 Comparison of aerial photographs with modelled flood extent (9 Sep 2010) at breached levee

January 2011 Validation Event

Comparisons between the modelled and observed extents on 18th and 19th January 2011 are shown in Figure 5-9 and Figure 5-10. The modelled extent replicates the observed extent well in the main Avoca River flow path, and reasonably well in the overflows from the Eastern Flood Course, particularly north of the railway. The volume overflowing to the western floodplain and Back Creek appears to be overestimated slightly. Key hydraulic controls such as culverts, levees and embankments in the western floodplain were checked and found to represent the surveyed conditions well. There is a possibility that some conditions (e.g. levee breaches) changed between the event and the LiDAR/structure survey, resulting in an inaccurate representation of the floodplain conditions for the event in the model.

Comparisons between the modelled depth at the flood pegs and photographs of each flood mark are given in Table 5-6. General agreement between the modelled depths and the apparent height of the flood marks above ground level was observed.

Given the hydrological uncertainty in the January 2011 hydrograph, this was considered to be a good quality validation result. The validation indicates that the calibrated model is capable of predicting flow paths and flood extents in extreme events exceeding the 0.5% AEP.

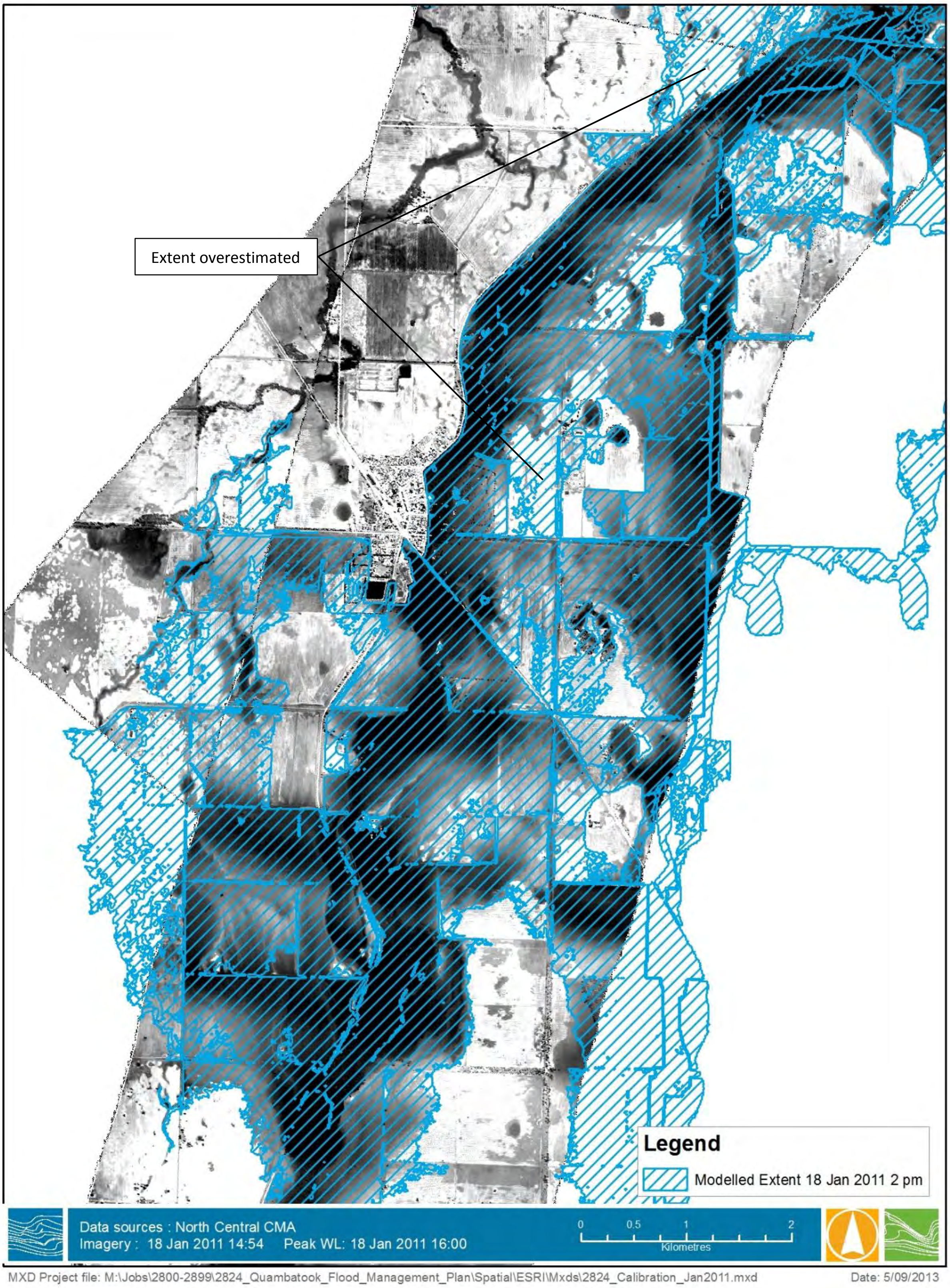


Figure 5-9 Comparison between modelled flood extent (18th January 2:00 pm) and aerial line scan image (18th January 2:54 pm)

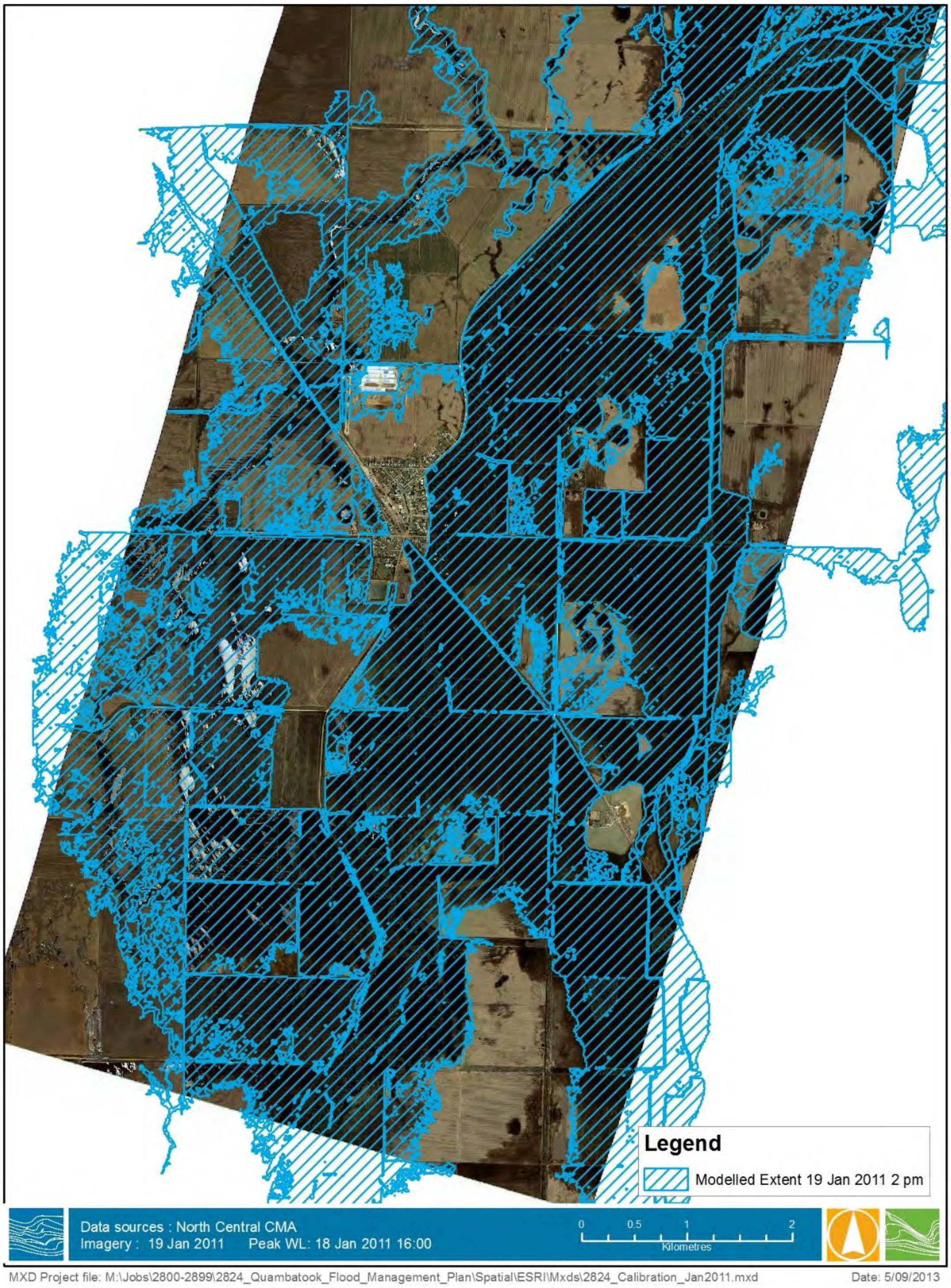


Figure 5-10 Comparison between modelled flood extent and aerial photography, 19th January 2:00 pm

Table 5-6 Comparison of modelled depths at flood pegs to photos

Peg	Modelled 2011 Flood Depth	Photo
Qt1	0.5 m	
Qt2	0.3 m	
Qt3	0.8 m	

Qt4	0.5 m	
Qt5	0 m (edge of flood extent)	
Qt6	0 m (edge of flood extent)	

Qt7	0.7 m	
Qt8	0.1 m	
Qt9	0.4 m	
Qt10	0.3 m	

Qt11	0.5 m	

5.3.3 Calibration Summary

The calibration to the September 2010 event demonstrated that the model is capable of accurately predicting flood levels and extents through the town area and broader floodplain. Seventy-five per cent of the observed flood levels in the town area were replicated to within 0.05 m by the model, indicating an excellent calibration quality. Overestimates in the flood extent adjacent to the Eastern Flood Course may be explained by the inclusion of a breach in the levee which may not have initiated until part-way through the event.

The validation with the January 2011 event showed that the calibrated model was capable of predicting flow paths and flood extents in extreme events exceeding the 0.5% AEP. Flood volumes overflowing to the Back Creek (western) floodplain appeared to be overestimated, however given the hydrological uncertainty in the estimated flow hydrograph for the January 2011 event, the validation results were considered to be of good quality.

The calibration and validation results demonstrated that the hydraulic model was fit for the purpose of predicting design flood levels and producing design flood maps. The hydraulic model is highly accurate through the main Avoca River flow path adjacent to the town, and is expected to be less accurate in the eastern and western flow paths. These flow paths do not directly impact upon the town.

5.4 Model Sensitivity

The sensitivity of the model results to parameters and estimated inputs such as roughness, downstream tailwater level and the inflow from the Eastern Flood Course was explored to understand how robust the model is in light of uncertainties in these values.

5.4.1 Roughness

The sensitivity to channel roughness was tested through the calibration process. The September 2010 and January 2011 events were tested with a channel roughness of 0.04 (slightly rougher than the adopted value of 0.03).

The September 2010 water levels were increased by up to 80 mm through the town area, and up to 100 mm further upstream. The effect on the longitudinal water surface profile through the town area is shown in Figure 5-11. The influence of the increased channel roughness was much greater on the September 2010 event (mostly in-channel flow) than the January 2011 event (broad floodplain flow). The January 2011 water levels were increased by generally less than 10 mm, with some areas increased by up to 20 mm.

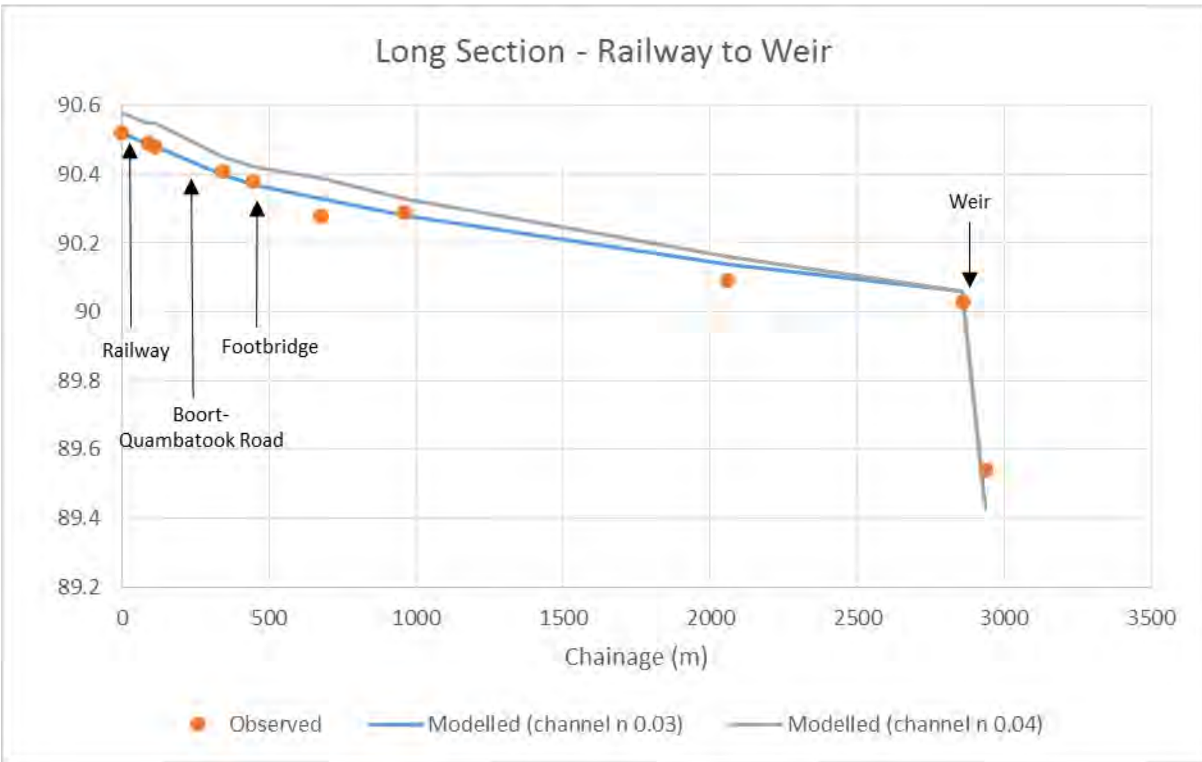


Figure 5-11 Sensitivity to channel roughness – longitudinal section from railway to weir, September 2010 event

5.4.2 Downstream Tailwater Level

To test the extent of influence of the downstream tailwater level, it was increased by one metre from its adopted level of 86 m AHD to 87 m AHD for the September 2010 event. The influence (defined by areas in which the water level was raised by 10 mm or more) extended approximately 1.5 km upstream.

The downstream boundary is located around 500 m downstream of Budgerum Bridge. Just upstream of Budgerum Bridge, the influence of the increased tailwater was up to 0.22 m, and there was some increased extent.

The tailwater level was also lowered by 1 m to 85 m AHD to test the influence of an unrealistically low tailwater level. The influence (where the water levels was lowered by 10 mm or more) extended approximately 400 m upstream of the boundary. The influence upstream of Budgerum Bridge was negligible.

A tailwater level of 87 m AHD appeared to be unrealistically high, particularly for the smaller events, as it produces a backwater pool up to the Budgerum Bridge. The adopted tailwater level of 86 m AHD produces a realistic water surface slope from Budgerum Bridge to the downstream boundary for the September 2010 event. The adopted tailwater level may be unrealistically low for larger events such as the January 2011 event, however it has been shown that a low tailwater level has negligible influence on water levels in the study area (upstream of Budgerum Bridge). Therefore a tailwater level of 86 m AHD was considered appropriate for the full range of calibration and design events, and the extent of the model boundary upstream of Budgerum Bridge is appropriate.

The downstream boundary is around 6 km downstream of the town, and the Quambatook Weir provides tailwater control for water levels through the town. Therefore the modelled tailwater level has no influence on flood levels in the vicinity of the town.

5.4.3 Eastern Flood Course Flow

Decreasing the Eastern Flood Course flow by 25% (from 40 to 30 m^3/s) caused significant local decreases in flood extent and levels adjacent to the Eastern Flood Course, however the effect was damped considerably in the town area. Upstream of the railway where overflows from the Eastern Flood Course interact with the main Avoca River floodplain, levels were increased by around 30-40 mm. Downstream of the railway through the town area, water levels were increased by up to 20 mm.

Doubling the Eastern Flood Course flow in the September 2010 event (from 5 to 10 m^3/s) caused local increases in level and extent in the Eastern Flood Course and its overflow paths, but had very little influence on levels in the Avoca River floodplain. Where the Eastern Flood Course joins the Avoca River just upstream of Budgerum Bridge, levels were raised by up to 55 mm, but there was no impact through the town reach.

5.5 Design Flood Modelling

The calibrated model was adopted for design flood modelling with the following changes:

- Temporary levees installed during the 2010-2011 flood events were removed and reinstated to pre-2010 levels.
- Breaches in permanent levees/channel banks that were present during the 2010-2011 events were filled in.

The 20%, 10%, 5%, 2%, 1% and 0.5% AEP design flood events were run. A suite of flood maps were developed across the range of flood magnitudes as shown in Appendix B.

5.6 Design Flood Behaviour

The extents of the design flood events are shown in Figure 5-12 and Figure 5-13. The modelling results show that the 20% and 10% AEP events are mostly contained within the Avoca River channel and the Eastern Flood Course. Breakouts into the town area and Back Creek (western floodplain) begin in the 5% AEP event. Widespread inundation of both eastern and western floodplains begins in the 2% AEP event. The inundation extents are incrementally increased, but the pattern of inundation is not greatly altered, in the 1% and 0.5% events.

The travel time of the flood peak from Quambatook South gauge to the Boort Road Bridge is 6-8 hours for all modelled events.

Detailed descriptions of the flood behaviour in the design events are given in Table 5-7.

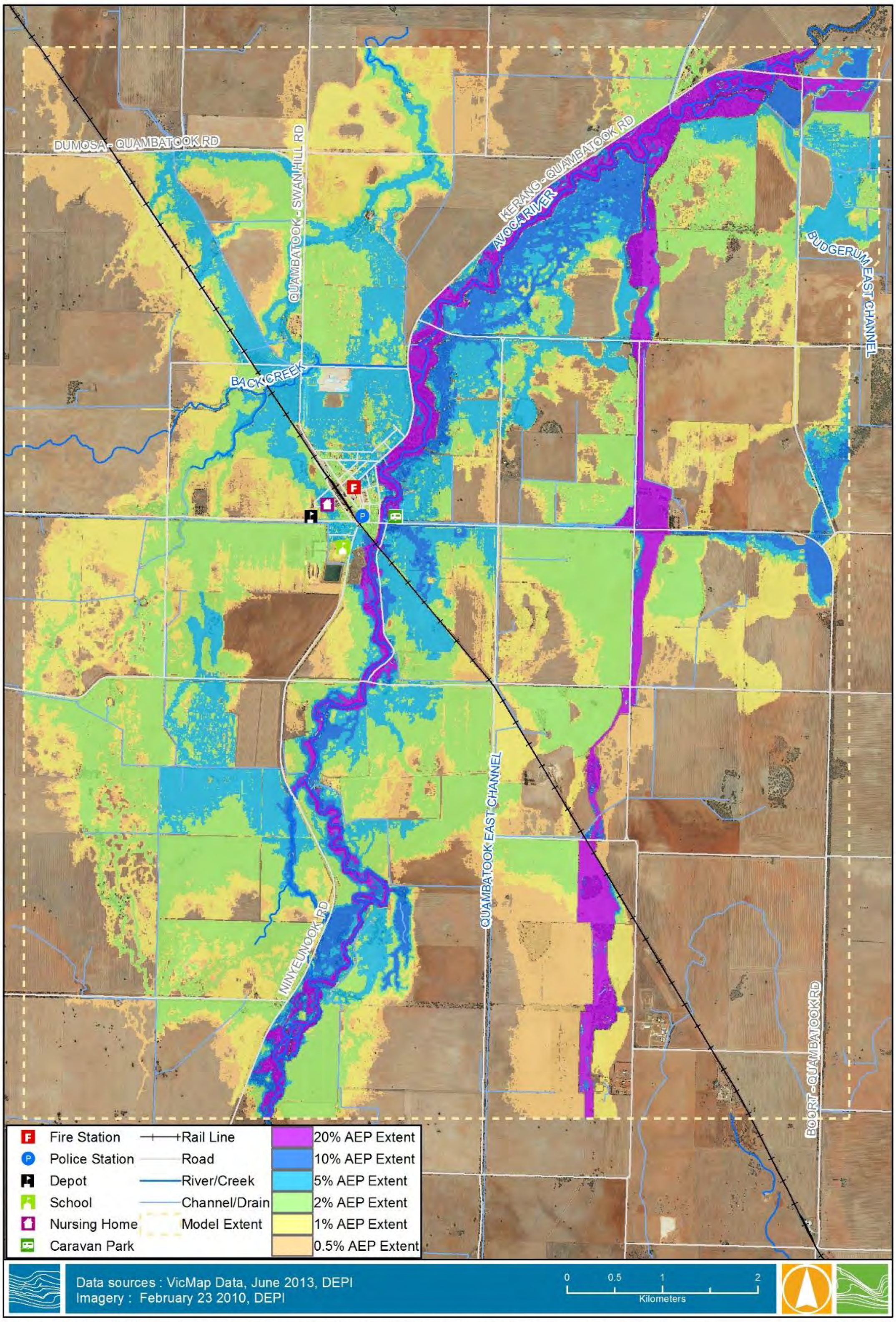


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Figure 5-12 Design flood extents, whole floodplain

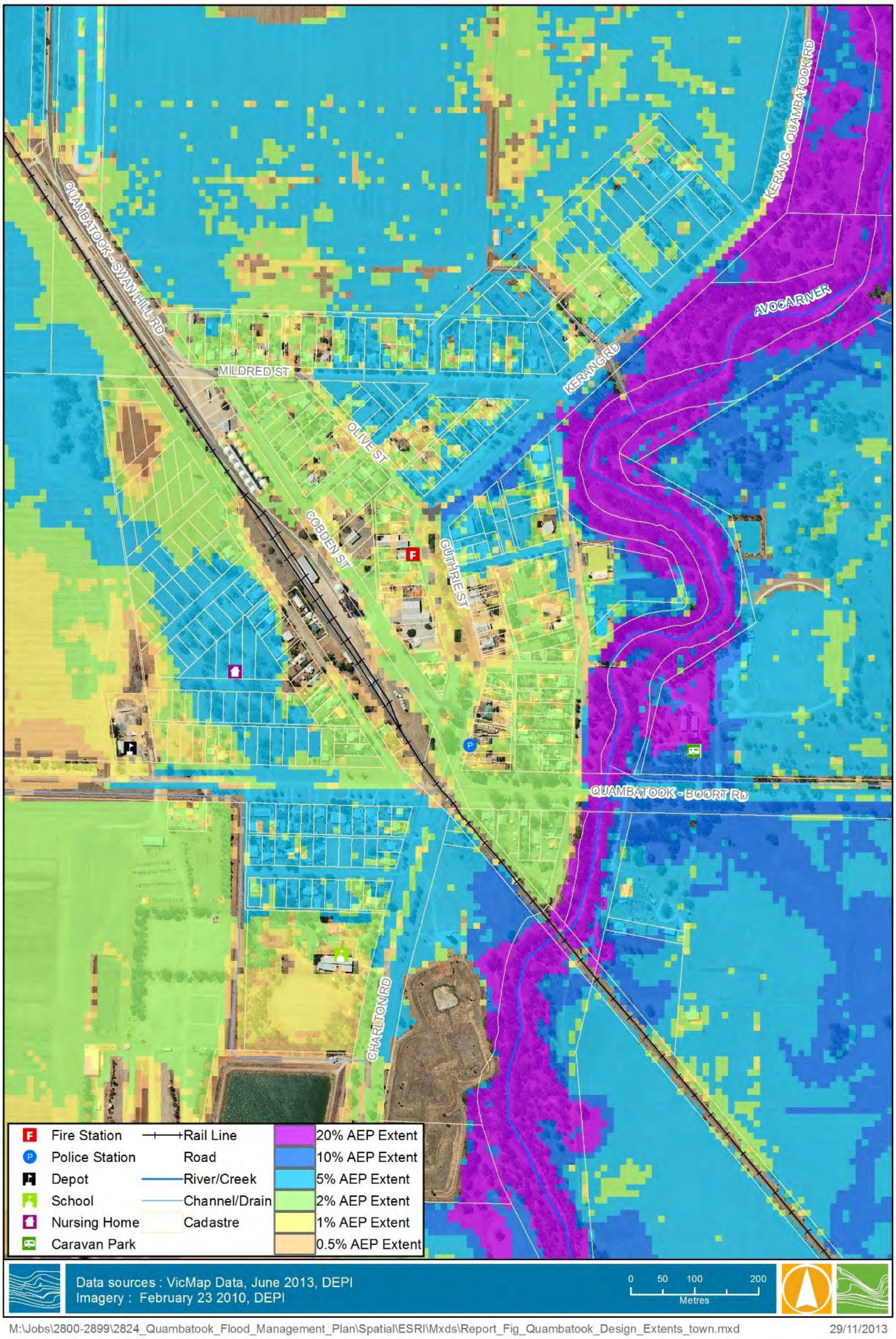

Figure 5-13 Design flood extents, town area

Table 5-7 Design Flood Behaviour

<table>
<tr><th>AEP</th><th>Town</th><th>Avoca Channel and Main Floodplain</th><th>Back Creek and Western Floodplain</th><th>Eastern Flood Course and Eastern Floodplain</th></tr>
<tr><td>20%</td><td>Low-lying parts of caravan park inundated</td><td rowspan="2">Flooding confined to isolated floodplain pockets adjacent to main channel. Floodplain inundation is more severe upstream of Quambatook Weir and Budgerum Bridge due to backwater effect</td><td>No flooding</td><td>Flows confined to EFC</td></tr>
<tr><td>10%</td><td>Caravan park and part of tennis club inundated
Parts of Fox Rd inundated</td><td>Minor breakout along anabranch which crosses Ninyeunook Rd and then re-joins Avoca River</td><td rowspan="2">Flows mainly confined to EFC, apart from minor breakout to east along Boort Rd</td></tr>
<tr><td>5%</td><td>Caravan park, football/netball club, tennis courts and swimming pool inundated
Numerous town properties inundated, mainly north of Church St and south of Railway Line
Partial inundation of grain bunkers</td><td>Widespread floodplain inundation begins in parts, particularly upstream of Rail Line, Boort Rd, and between Quambatook town and Eastern Flood Course inflow location</td><td>Breakouts from Avoca River to Back Creek and western floodplain begin</td></tr>
<tr><td>2%</td><td>Most town facilities and properties inundated including many in main street
Drainage pumps inundated
Partial inundation of grain bunkers</td><td rowspan="3">Widespread floodplain inundation across most of floodplain</td><td>Significant breakouts from Avoca River to Back Creek and western floodplain causing widespread flooding</td><td rowspan="3">Numerous breakouts from Eastern Flood Course causing widespread floodplain inundation</td></tr>
<tr><td>1%</td><td rowspan="2">Almost all town properties inundated including many in main street
Partial inundation of grain bunkers</td><td rowspan="2">Widespread breakouts across Ninyeunook Rd and through town causing widespread floodplain inundation</td></tr>
<tr><td>0.5%</td></tr>
</table>

6. MITIGATION OPTIONS ASSESSMENT

6.1 Overview

Mitigation measures provide a means to reduce the existing flood risk. Mitigation measures can reduce existing flood risk by lowering the likelihood of flooding and/or lowering the flood damages (consequences) for a given flood event. Mitigation measures can be categorised as:

- **Structural:** Physical barriers or works designed to prevent flooding up to a specific design flood standard. Structural measures aim to reduce existing flood risk by lowering flood likelihood at given locations. Structural works include levees, floodways, waterway works, drains, culverts, retarding basins, raising floor levels and improvements to existing hydraulic structures.
- **Non-structural:** Management and planning arrangements between relevant authorities designed to reduce flood related damages. Non-structural measures aim to reduce existing flood risk by lowering flood damage. Non-structural measures include land use planning, flood warning, flood response and flood awareness.

The following discussion outlines the preliminary assessment of structural mitigation measures for the study area. Non-structural mitigation measures are discussed in Section 6.3.1.

6.2 Structural Mitigation Measure Assessment

6.2.1 Structural Mitigation Options

Structural mitigation measures are physical works to reduce the likelihood of flooding in a given location. Recommendations for flood mitigation works were compiled by flood wardens involved in the 2010-11 flooding and have been added to by the Steering Committee. The structural mitigation options for Quambatook are listed in Table 2-7. The location of the options is shown in Figure 6-1 and Figure 6-2.

Table 6-1 Structural mitigation options

ID	Option	Source
1	Levee from Ninyeunook Rd bend, east of Lawn Cemetery, to meet with the Reservoir bank. Recommend levee to be at least 1.5 metres high.	Flood Wardens' Report
2	Levee from reservoir bank to the Rail Bridge. Recommend levee to be at least as high as rail lines	Flood Wardens' Report
3	Clean out under Quambatook Rail Bridge	Flood Wardens' Report
4	Extra culvert under Rail Line between Cemetery Rd and Fox Rd, where floodwater ran over rail line	Flood Wardens' Report
5	Levee from Reservoir to Meering Rd, to protect houses on south west corner of town	Flood Wardens' Report
6	Levee on east side of River St and south side of Kerang Rd to be increased by a metre to bend	Flood Wardens' Report
7	Boort Rd bridge to be banked (temporary sandbags to be placed across opening between levees on road)	Flood Wardens' Report
8	Section of channel banks on south side of Golf Club to be removed. Recommend 2 x 10 metre sections	Flood Wardens' Report
9	Banks on east side of river, that protect Golf and Football Clubs, to be maintained at current level	Flood Wardens' Report
10	Levee be constructed travelling north/south along the west side of McKissack Rd	Flood Wardens' Report
11	Extra culvert in flood way on Boort – Quambatook Rd	Flood Wardens' Report
12	Extra culvert (larger than existing size) on Kerang/Quambatook Rd at Budgerum Bridge	Flood Wardens' Report
13	The town Drainage Pumps need to be protected from floodwater up to the 0.5% AEP	Flood Wardens' Report
14	Fill in GWM Water Channel that runs east/west down Meering Rd. Channel located west of Quambatook	Flood Wardens' Report
15	Keatings Corner (Boort – Quambatook Rd) needs extra pipe to assist with flood water	Flood Wardens' Report
16	Levees providing 5% AEP protection for Caravan Park	Steering Committee Meeting 2
17	Levees providing 2% AEP protection for Tennis Courts and Bowling Club	Steering Committee Meeting 2
18	Protection of Optus and Telstra towers and repeater station	Steering Committee Meeting 2

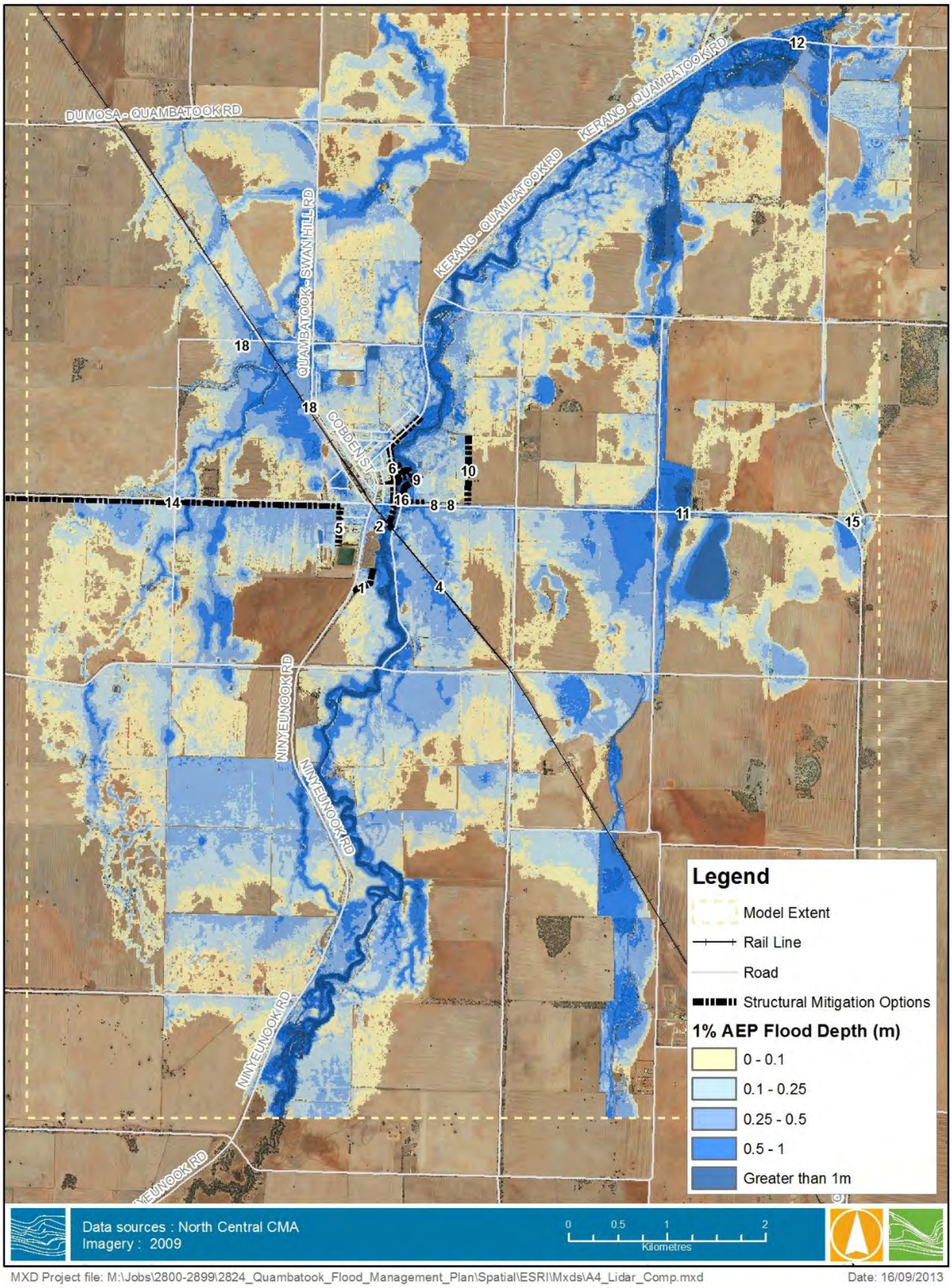

Figure 6-1 Location of structural mitigation options

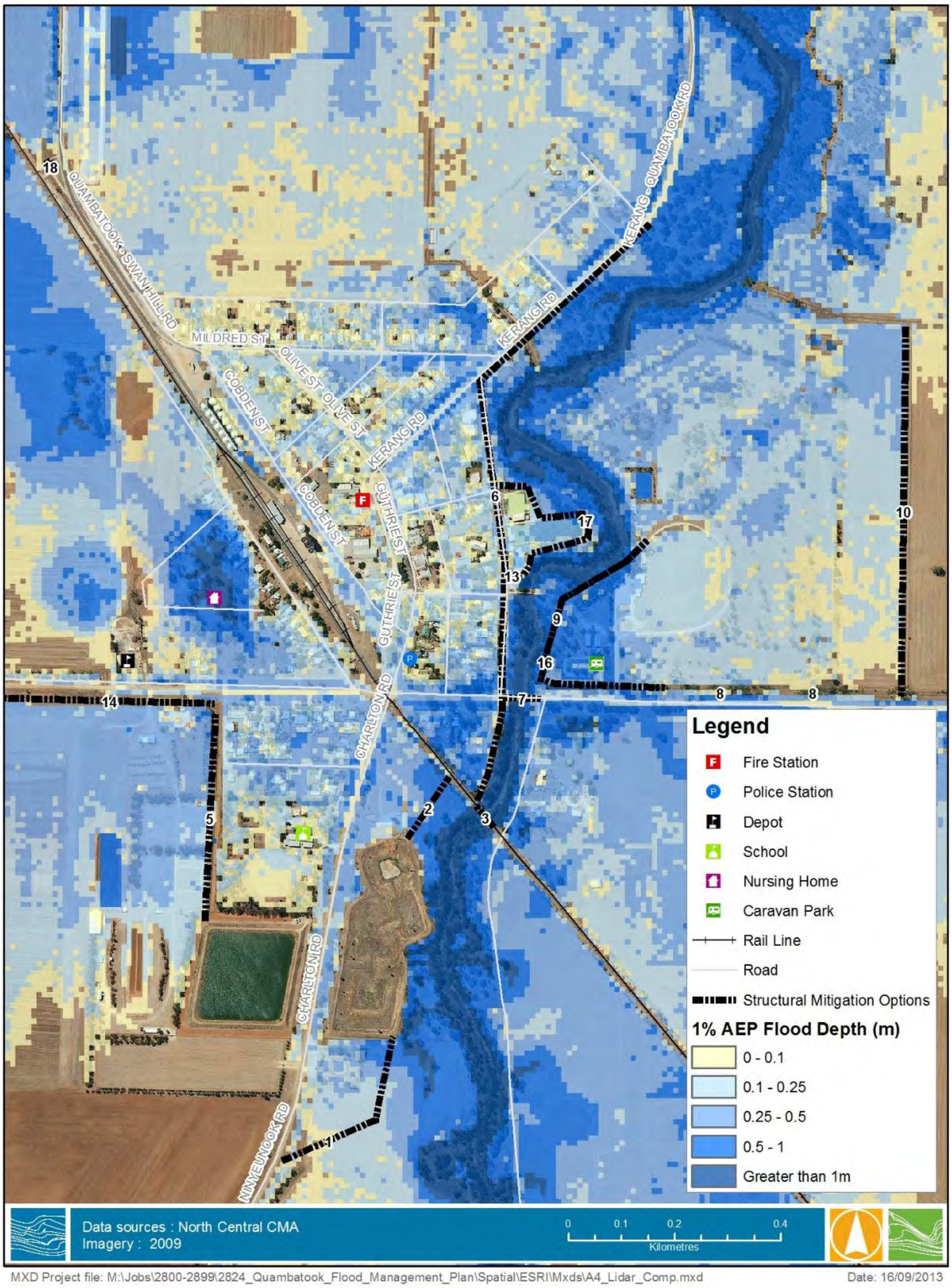

Figure 6-2 Location of structural mitigation options, town detail

6.2.2 Preliminary Assessment Criteria

Each mitigation option was assessed against a number of criteria; potential reduction in flood damage, cost of construction, feasibility of construction and environmental impact. The score for each criterion was based on a ranking system of 1 to 5, with 1 being the worst score and 5 the best. Each criteria score was then weighted according to the weighting shown in Table 6-2 below. The reduction in flood damage was the most heavily weighted criteria as it is the main objective for all flood mitigation. The environmental impact of mitigation options can include impacts from construction and operation, including habitat disturbance, physical barriers to wildlife movement, altered flow regimes, and other impacts. Table 6-3 reviews and scores each mitigation option against the four criteria and calculates a total score for each option. The options with the higher scores indicate the most appropriate mitigation solutions for Quambatook. While these options are reviewed individually, many are dependent upon each other and consideration has been given to combined options in the detailed review.

Table 6-2 Prefeasibility assessment criteria

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

6.2.3 Preliminary Assessment Overview

Each of the suggested mitigation options was assessed using the outlined assessment criteria as shown in Table 6-3.

Using the feasibility assessment above, the 18 mitigation options have been ranked by weighted score. The ranking of the top 10 options is shown below in Table 6-4. All other options were found to be unfeasible on the basis of low associated damage reduction, high costs and other constructability or environmental issues.

Discussion of these and other options reviewed and assessed are provided in the following sections.

Table 6-3 Prefeasibility assessment of individual options

No.	Mitigation Option	Criteria					Weighted Score
		Reduction in Flood Damages	Cost ($)	Feasibility/ Constructability	Environmental Impact	Comments	
1	Levee from Ninyeunook Rd bend, east of Lawn Cemetery, to meet with the Reservoir bank	4	5	5	4		17.5
2	Levee from reservoir bank to the Rail Bridge	5	5	5	4		19.5
3	Clean out under Quambatook Rail Bridge	3	5	4	3		14.5
4	Extra culvert under Rail Line between Cemetery Rd and Fox Rd	3	3	5	4	High cost due to works on rail line	13.5
5	Levee from Reservoir to Meering Rd, to protect houses on south west corner of town	2	5	5	4	Houses are not affected by flooding form the west up to the 0.5% AEP.	10.5
6	Levee on east side of River St and south side of Kerang Rd to be increased by a metre to bend	5	3	5	4		17.5
7	Boort Rd bridge to be banked (temporary sandbags to be placed across opening between levees on road)	5	5	5	5	Linked to option 6	20
8	Section of channel banks on south side of Golf Club to be removed. Recommend 2 x 10 metre sections	3	5	5	5		16
9	Banks on east side of river, that protect Golf and Football Clubs, to be maintained at current level	2	5	5	5		14

No.	Mitigation Option	Criteria					Weighted Score
		Reduction in Flood Damages	Cost ($)	Feasibility/ Constructability	Environmental Impact	Comments	
10	Levee north/south along the west side of McKissack Rd	2	4	5	4	There is little overtopping of McKissack Road as is. There are no significant assets that would be protected by this levee.	12.5
11	Extra culvert in flood way on Boort – Quambatook Rd	3	4	4	4	Extra culvert would improve flow of EFC and decrease overtopping of road but would have little effect on flooding in Quambatook. No significant assets would be protected apart from the road.	14
12	Extra culvert (larger than existing size) on Kerang/Quambatook Rd at Budgerum Bridge	3	4	3	4	Extra culvert would locally decrease flood levels upstream of bridge but would not affect flood levels in Quambatook. No significant assets would be protected. The road is flood-free up to the 1% AEP.	13.5
13	The town Drainage Pumps need to be protected from floodwater up to the 0.5% AEP	5	5	5	5		20
14	Fill in GWM Water Channel that runs east/west down Meering Rd	4	3	5	5	Allows water to follow natural Back Creek course rather than backing up south of Meering Road	16

No.	Mitigation Option	Criteria					Weighted Score
		Reduction in Flood Damages	Cost ($)	Feasibility/ Constructability	Environmental Impact	Comments	
15	Keatings Corner (Boort – Quambatook Rd) needs extra pipe to assist with flood water	2	4	5	5	No benefit to Quambatook or any major assets other than road.	13
16	Levees providing 5% AEP protection for Caravan Park	3	4	4	5	May increase flood levels in main Avoca channel by preventing flow on floodplain.	14.5
17	Levees providing 2% AEP protection for Tennis Courts and Bowling Club	4	4	5	4	Can be used to replace option 13 and part of option 6.	16.5
18	Protection of Optus and Telstra towers and repeater station	4	5	5	5	Low levees protecting the towers can be easily and cheaply installed.	18

Table 6-4 Ranked prefeasibility assessment on individual options

Rank	No.	Mitigation Option	Weighted Score
1	13	The town Drainage Pumps need to be protected from floodwater up to the 0.5% AEP	20
2	7	Boort Rd bridge to be banked (temporary sandbags to be placed across opening between levees on road)	20
3	2	Levee from reservoir bank to the Rail Bridge	19.5
4	18	Protection of Optus and Telstra towers and repeater station	18
5	1	Levee from Ninyeunook Rd bend, east of Lawn Cemetery, to meet with the Reservoir bank	17.5
6	6	Levee on east side of River St and south side of Kerang Rd to be increased by a metre to bend	17.5
7	17	Levees providing 2% AEP protection for Tennis Courts and Bowling Club	16.5

Rank	No.	Mitigation Option	Weighted Score
8	14	Fill in GWM Water Channel that runs east/west down Meering Rd	16
9	8	Section of channel banks on south side of Golf Club to be removed. Recommend 2 x 10 metre sections	16
10	16	Levees providing 5% AEP protection for Caravan Park	14.5

6.2.4 Option Review

Levee options

Levees have been suggested running along the western side of the Avoca River to protect the town from flooding. The levee locations that have been suggested include:

- From Ninyeunook Rd to reservoir bank running east of Lawn Cemetery
- From Reservoir bank to railway embankment
- On east side of River St and South Side of Kerang Road from railway embankment to bend
- Around tennis courts, bowling club and swimming pool
- Around caravan park
- Reservoir to Meering Road on west side of school
- Alongside McKissack Road

The first four locations protect the town area of Quambatook west of the Avoca River and would be constructed to the 1% AEP level plus 300 mm freeboard. The 300 mm freeboard allowance allows for uncertainty in the flood level estimates and minor changes to hydrologic/hydraulic conditions. Under current best estimates, the freeboard allowance would provide protection against another flood of the January 2011 magnitude. Temporary sandbagging would be required where breaks in the levees occur, including across Boort Road, at the northern end of the levee extending to the Kerang Road crest, and at the end of the cemetery levee extending to the Ninyeunook Road crest. Discussion is required regarding temporary and permanent levees through town. Through the community consultation process community members have expressed a concern that a permanent levee along River St may be too visually intrusive. This location (from Boort Road Bridge to the stormwater pumping station) is a good candidate for temporary levees as the road is relatively high and already protects against moderate floods. At its current level the road provides protection for the 10% AEP flood with 300mm freeboard, or the 2% AEP flood with no freeboard. At this concept stage, whether the levees are temporary or permanent is less important than the alignment and the crest level, but this will require consideration during detailed design.

The fifth location aimed to provide low level (5% AEP with zero freeboard) protection to the caravan park and football/netball club while still allowing conveyance of flows above the 5% AEP across the floodplain area. The impact of this levee was tested separately to ensure it did not raise water levels by restricting floodplain flow through the section of river immediately adjacent to the caravan park.

The last two locations suggested for levees were not considered necessary. There is no flooding of the school and surrounding residential areas under current conditions in the 1% AEP event due to flow from the west, therefore no levee is required to the west of this area. Other mitigation options (levelling the Meering Road channel) will lower the risk of inflow from the west. There is currently little overtopping of McKissack Road and a levee would not protect any significant assets.

Protection of Town Drainage Pumps

The town stormwater system drains to a sump to the south of the Swimming pool, and is then pumped to the river. In the January 2011 flood event, the drainage pumps were inundated and failed, compounding town drainage problems. The pump house needs to be protected from flooding to ensure pumping of the stormwater system can continue during flood events. This could be done by a small levee around the pump house itself, or the main town levee proposed could be aligned to protect the pump house.

Levelling of Channels and Banks

The levelling of the Meering Road channel was suggested to restore a more natural flow path to the Back Creek system. Under current conditions, the channel embankment causes backing up of large inundation areas to the south of Meering Road, which threatens the southern part of the town. Levelling the channel and embankments would mitigate the inundation to the south of Meering Road. Downstream of Meering Road flood waters would still back up behind the railway line to the north-west of town.

Another suggestion was to remove two 10 m sections of channel bank from the north side of Boort Road, south of the golf club. This channel bank currently forces flow west along Boort Road to the caravan park. Cutting the bank would allow flood flows to re-engage the floodplain through the golf club area.

Testing of this option separately indicated that its impact was very modest, and that a more significant reduction in flood levels south of Boort Road could be achieved by complete removal of the bank.

Increasing Capacity of Culverts and Bridges

Options to increase the capacity of bridges and culverts, including cleaning out sediment under the Quambatook Rail Bridge, and installing additional culverts on the Eastern Flood Course at Boort Road, the Avoca River at Budgerum Bridge and at Keatings Corner, were suggested.

The additional culverts have the potential to locally mitigated flood impacts upstream of the bridges and overtopping of the roadways. None of the options suggested will provide mitigation for the town area or any other key assets. These options are high-cost for only a modest benefit, so have not been considered further. There is nothing to stop Council implementing these local measures separately, but they have no significant benefit to the township, which is the primary objective of this study.

Cleaning out under the Quambatook Rail Bridge is unlikely to be effective as the bridge is in the backwater of the Quambatook weir (the bed level under the bridge is currently around 0.7 m below the weir crest) and its capacity is impeded more by the high tailwater level produced by the weir than the current level of sedimentation in the bed. Ongoing monitoring and future maintenance of sediment levels may be warranted if sediment continues to build up.

New Railway Culvert

A new rail culvert has been suggested between Cemetery Rd and Fox Rd. A flow path is visible crossing the floodplain at this point and re-entering the river at the caravan park. No existing culvert was identified under the railway line for this flow path. Some overtopping of the railway line occurred at this location in the January 2011 event. A culvert here would allow more flow to follow the floodplain flow path and take some of the pressure off the main railway bridge and the Avoca River through town. However it would direct more flood water across the caravan park and is likely to make minimal difference to flood levels in the Avoca River through the town area. In addition to these concerns, any works on the railway are likely to be expensive and difficult to manage. This option has therefore been ruled out of the final mitigation package, primarily due to the likely lack of benefit to the township.

Protection of Communication Towers

It is considered imperative that Optus and Telstra can ensure ongoing coverage during a flood event, in order to assist with the dissemination of flood information and warnings and to allow for communication with emergency services. Low levees can be constructed by Optus and Telstra if required to protect these services. Such levees will not significantly impact on flood storage and will not affect flooding in the town. This option has not been included in the mitigation works package but flood levels can be provided at tower locations to assist communications providers to ensure flood protection of their services. It is recommended that Council discuss protection of these assets with both Telstra and Optus.

6.2.5 Initial Testing of Options

Two options were identified as marginal and were tested separately in the hydraulic model for the 1% AEP flow. These were the caravan park levee and the removal of sections of channel bank on the south side of the Golf Course. The results of these tests are given below.

Removal of Sections of Golf Course Bank

A difference plot showing incremental increases and decreases in flood level and extent due to the removal of sections of the Golf Course bank) is given in Figure 6-3.

This option has the capacity to decrease flood levels between Boort Road and the Railway line by up to 0.02 m, with flow-on effects to breakout flow and extents in the east of the floodplain. The flood extent in rural land is likely to be reduced by around 3 ha by this option. Flood levels north of Boort Road are likely to be increased by up to 0.1 m, but no buildings or significant assets are likely to be affected by increased flood levels. The impact of this option on the five affected properties is given in Table 6-5.

Table 6-5 Incremental change in flood level at affected properties due to inclusion of removal of sections of Golf Course Bank in mitigation package in the 1% AEP event

Location	Incremental impact compared to base mitigation package
Fox Rd – north of no. 19	-0.01 m
19 Fox Rd	-0.01 m
100 McKissack Rd	No impact
Caravan Park	-0.01 m
Football Club	No impact

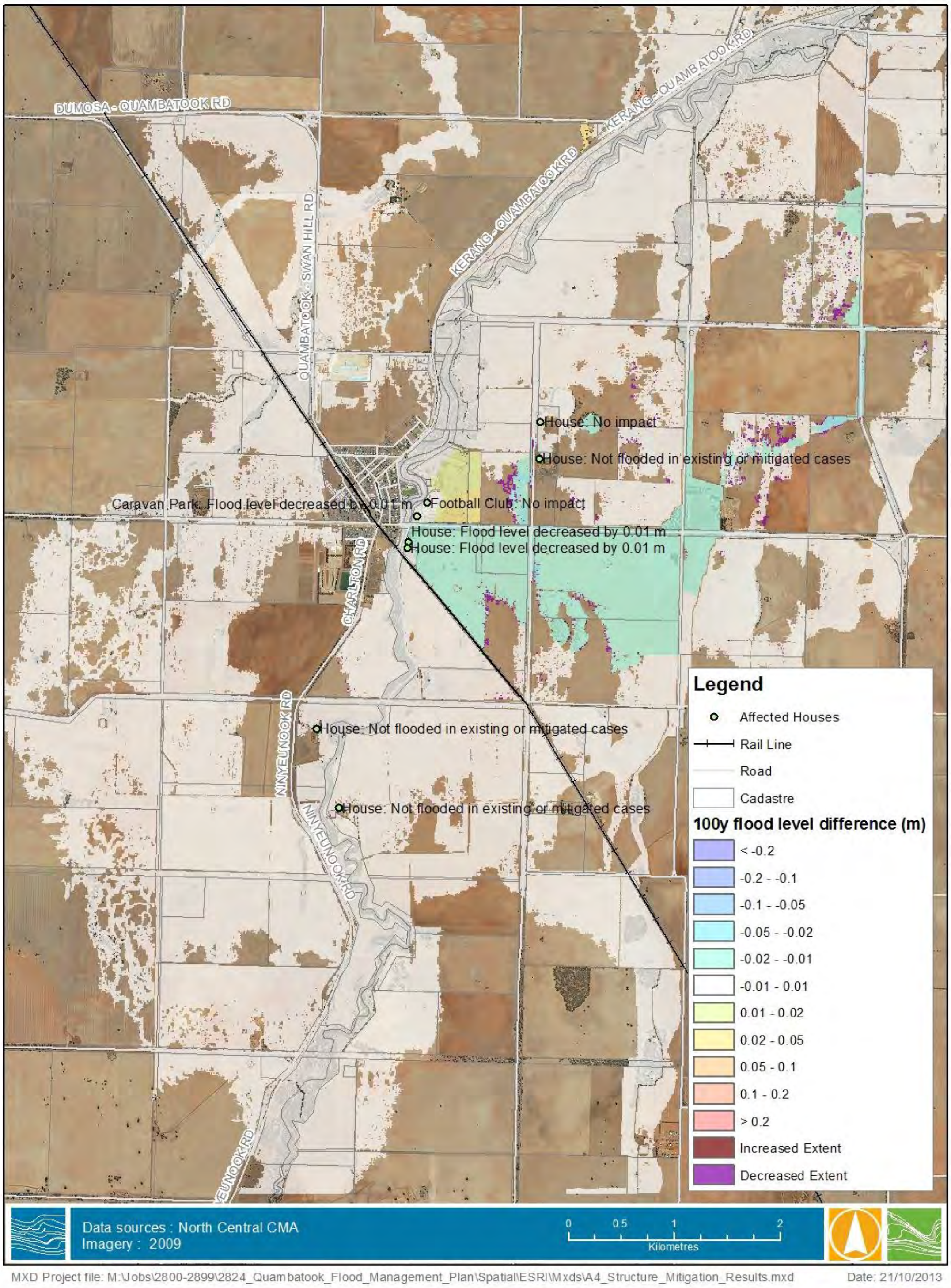

Figure 6-3 Difference plot showing incremental impact of removal of sections of Golf Course bank on 1% AEP flood level, compared to base mitigation package

Caravan Park Levees

A difference plot showing incremental increases and decreases in flood level and extent due to the addition of the Caravan Park levee (compared to the base mitigation package) is given in Figure 6-4.

This option has the capacity to increase flood levels between Boort Road and the Railway line by up to 0.02 m, with flow-on effects to breakout flow and extents in the east of the floodplain. The flood extent in rural land is likely to be increased by around 3 ha by this option. Flood levels north of Boort Road are likely to be decreased by up to 0.025 m. The caravan park levee was shown to actually slightly increase flood levels in the northern part of the caravan park, and in the football club. The levee was designed to the 5% AEP level, with floods above this magnitude overtopping the levee into the caravan park area. The water that overtops the levee is then blocked from following its existing flow path back to the river, and backs up behind the levee producing increased flood levels. A decision is required as to whether the protection of the caravan park to the 5% level merits slight increases in 1% AEP flood levels in the football club and Fox Rd areas. If it is decided that 5% AEP protection is warranted then an action for large flood events where the levee is overtopped from upstream would be to remove a section of the downstream levee to allow water to flow more freely.

The impact on the affected properties is given in Table 6-6.

Table 6-6 Incremental change in flood level at affected properties due to inclusion of Caravan Park levees in mitigation package in the 1% AEP event

Location	Incremental impact compared to base mitigation package
Fox Rd – north of no. 19	+0.01 m
19 Fox Rd	+0.01 m
100 McKissack Rd	No impact
Caravan Park	No impact at building locations (increases of up to 0.03 m at northern end)
Football Club	+0.02 m

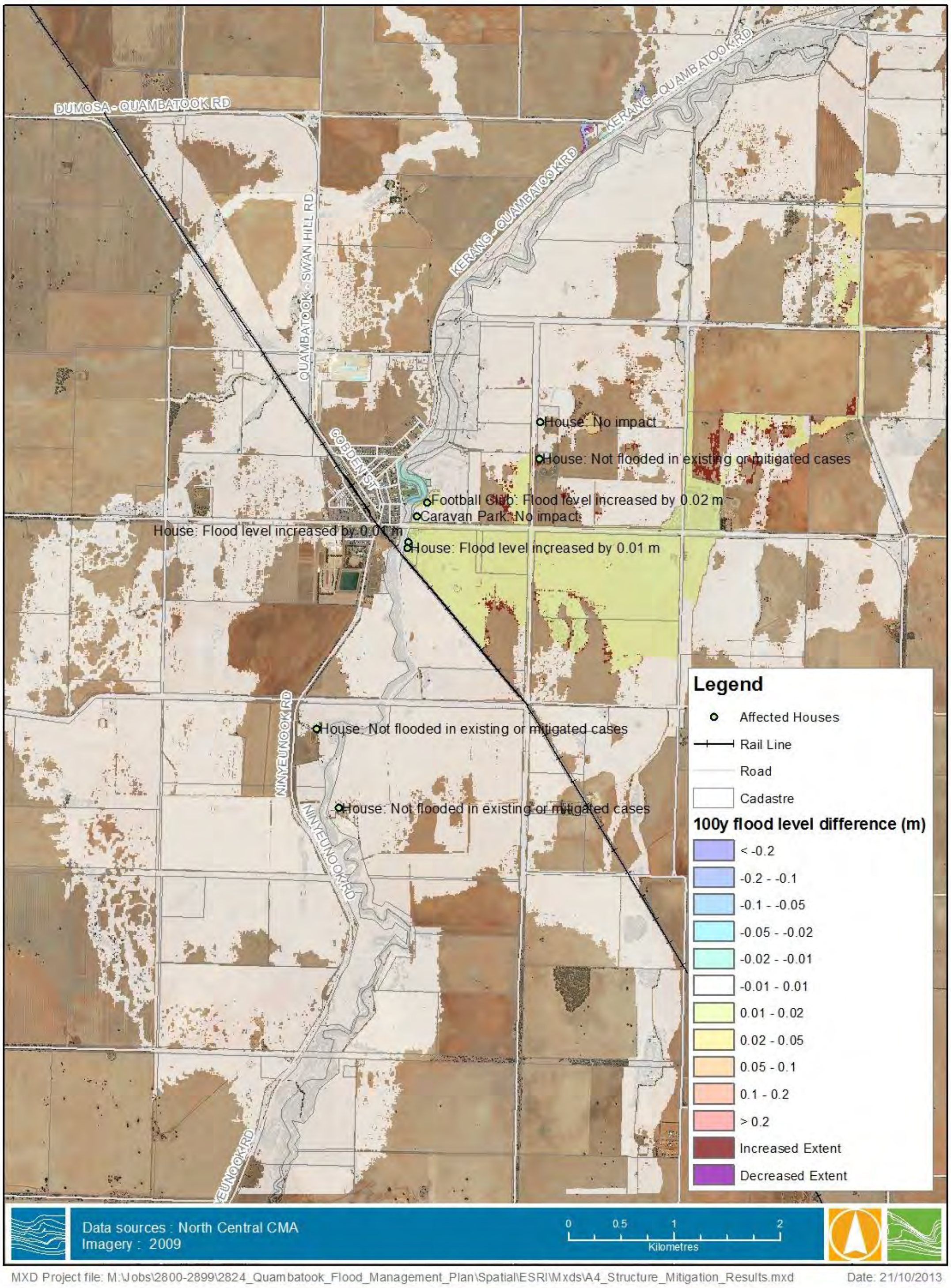

Figure 6-4 Difference plot showing incremental impact of removal of sections of Golf Course bank on 1% AEP flood level, compared to base mitigation package

Discussion

The caravan park levee only provides a benefit to the caravan park itself, and has minor detrimental impacts on upstream areas. These impacts are caused by the construction of the levee section alongside Boort Road, which is raised above the road level. The road level was previously the control for flood levels south of Boort Road, and the levee raises the control height and therefore the upstream flood level. This impact could be addressed by simply not constructing that section of levee. The road is not overtopped in the 10% AEP event, and flooding of the caravan park in this event is caused by the river backing up into the low lying areas. A levee along the river bank only, and not alongside Boort Rd, would provide effective protection against the 10% AEP flood. Overtopping of Boort Rd begins between the 10% and 5% AEP events. The caravan park cannot be protected against overtopping of Boort Rd without causing higher flood levels upstream. It is suggested that flood protection could be provided up to the 10% AEP by a levee along the river bank only, with flooding in the 5% AEP and above due to overtopping of Boort Rd should be accepted.

The removal of sections of the Boort Road bank alongside the golf course has been shown to have some merit, as it provides slight decreases in flood level south of Boort Road without any detrimental impacts, and is low cost. However, a more significant benefit could be afforded by complete removal of the bank in this section. A review of local topography suggests that this can be done without significant impact on downstream areas, apart from the football ground, golf course and localised rural areas. However it is understood that this channel is used to deliver water to a property to the east of town by pumping from the river. The channel is constructed on the road easement but consultation with the interested parties should occur prior to any final decision.

6.2.6 Recommended Mitigation Works Package

The recommended mitigation works package is detailed in Table 6-7.

Table 6-7 Recommended Mitigation Works Package

No.	Mitigation Works Package Component
1	Levee from Ninyeunook Rd bend, east of Lawn Cemetery, to meet with the Reservoir bank. Ensure levee accommodates future expansion of Lawn Cemetery 1% AEP protection + 300 mm freeboard
2	Levee from reservoir bank to the Rail Bridge 1% AEP protection + 300 mm freeboard
6, 13, 17	Levee on east side of River St and south side of Kerang Rd. Alignment to go around tennis courts, bowling club, swimming pool and drainage pump house. 1% AEP protection + 300 mm freeboard
7	Temporary sandbagging across Boort Road bridge and at north end of levee to road crest
14	Fill in GWM Water Channel that runs east/west down Meering Rd Level embankments by pushing into channel
8	Remove channel banks on south side of Golf Club, from caravan park to approx.. 100 m east of golf course
16	Levees at 5% AEP level for Caravan Park along river bank only, and not along Boort Rd, to provide at least 10% AEP protection to caravan park

Profiles for each levee are shown in Figure 6-5 and key dimensions are given in Table 6-8. The levees are, on average, 0.4 to 0.9 m high with maximum height of 1.6 m.

Figure 6-5 Levee bank profiles

Table 6-8 Key levee dimensions

Levee	Length (m)	Average height (m)	Maximum height (m)
Levee from Ninyeunook Rd bend, east of Lawn Cemetery	264	0.6	1.5
Levee from reservoir bank to the Rail Bridge	144	0.9	1.4
Levee on east side of River St and south side of Kerang Rd	2,270	0.8	1.5
Caravan Park Levee	378	0.4	1.6

It is assumed at this stage that the River Street levee alignment skirts around the entire tennis club. Feedback from the steering committee and community meeting indicated that it may be possible to cut through the tennis club to provide a simpler levee alignment and some additional floodway area. The modelling results indicate that the levee around the tennis courts does not cut off or deflect a significant amount of flow, therefore changing the alignment is not expected to materially affect the flood modelling results. However it could be considered at the detailed design stage as a way to simplify and shorten the levee alignment, if agreement can be reached with the tennis club.

Concerns have been raised by the community of the visual intrusiveness of a permanent levee along River Street and Kerang Road between homes and the river reserve. The height of the levee crest above the current visual barrier (the road or existing embankment crest) is reported in Table 6-9, to give an indication of the level of visual intrusiveness of the levees. For example, the levee along River Street from Boort Road to the stormwater pumping station, is to be up to 1.5 m above ground level and up to 0.5 m above the level of River Street. In all cases, levees between houses and the river reserve are to be no more than 0.7 m above the current level of the road or existing embankment.

Table 6-9 Measures of visual intrusiveness of levees between houses and river reserve

Levee	Height above Current Road/Embankment (m)	Height above Ground Level (m)
River St south of Boort Road	0.25-0.4	0.9-1.15
River St from Boort Road to stormwater pumping station	0.2-0.5	0.4-1.5
Behind swimming pool, tennis courts and bowls club	0.3-0.9	0.3-0.9
River St from Bowls Club to Kerang Road	0.3-0.7	0.3-1.1
Kerang Road from River St to bend	0.3-0.7	1.0-1.4

Where the levees meet or cross road reserves a number of options are available to ensure continuous protection in a flood event. The levee can be made continuous across the road by permanently raising the road surface to the levee crest height. Alternatively, the levee can be built to the edge of the road reserve and temporary sandbagging or earth banking can be undertaken across the gap when a flood event is imminent. Indicative lengths and heights of temporary banking/sandbagging sections are given in Table 6-10. Trigger levels and flows for commencing sandbagging or earth banking at the Quambatook South gauge are discussed in Section 6.3.2.

Table 6-10 Temporary earth banking/sandbagging indicative dimensions

Location	Length (m)	Average height (m)
Boort Road Bridge	20	0.6
Northern end of River St/Kerang Rd Levee to road crest	10	0.3
Southern end of Cemetery Levee to road crest	10	0.3

6.2.7 Modelling Results – Final Recommended Package

A difference plot showing increases and decreases in 1% AEP flood level and extent due to the final recommended mitigation package (compared to design flood conditions) is given in Figure 6-6. Dark purple area is where there is no longer any flooding, dark brown where there is new flooding, the blue shades is where depth is decreased and the beige colours is where depth is increased.

Benefits of Mitigation Package

The mitigation package will prevent flooding of almost all town properties in the 1% AEP flood. Flooding of over 100 houses as well as numerous businesses and public buildings will be prevented by the mitigation package. It will also lower flood levels by up to 0.33 m in rural areas in the western part of the floodplain (the Back Creek flow course). The mitigation works package is likely to reduce the 1% AEP flood extent by approximately 510 hectares, including 61 hectares within the town itself.

Impacts of Mitigation Package

Three houses have been identified that would be negatively impacted by the mitigation works package due to higher flood levels. The caravan park and football club are also likely to be affected by higher levels. The locations of the affected properties are marked on the difference plot in Figure 6-6. Three additional properties have been identified on the floodplain outside the town that are not directly affected under existing or mitigated conditions. Flood levels are increased on rural land mainly to the east of the Avoca River and also in an isolated area of the western floodplain (the Back Creek flow course) downstream of the proposed decommissioned channel on Meering Road. Around 122 hectares of rural land is likely to be inundated in the 1% AEP flood that was previously flood free.

The proposed mitigation works in effect replicate the emergency works undertaken in the Jan 2011 flood event, therefore the likely flood impacts in an extreme event with the works in place are known and have already been observed by the community. Nonetheless, the impact on residences in the eastern floodplain compared to unmitigated conditions merits the investigation of appropriate compensatory works or measures for these properties.

Flood level increases at the affected properties on the eastern floodplain under the final recommended mitigation package are given in Table 6-11.

Table 6-11 Impact of mitigation package on affected properties in 1% AEP event

Location	Approx. flood depth (m) above ground – existing conditions	Impact of mitigation package
Fox Rd – north of no. 19	0.3 m	Flood level increased by 0.06 m
19 Fox Rd	0.3 m	Flood level increased by 0.05 m
100 McKissack Rd	0.1 m	Flood level increased by 0.11 m
Caravan Park	0.7 m	Flood level increased by 0.06 m
Football Club	0.3 m	Flood level increased by 0.10 m

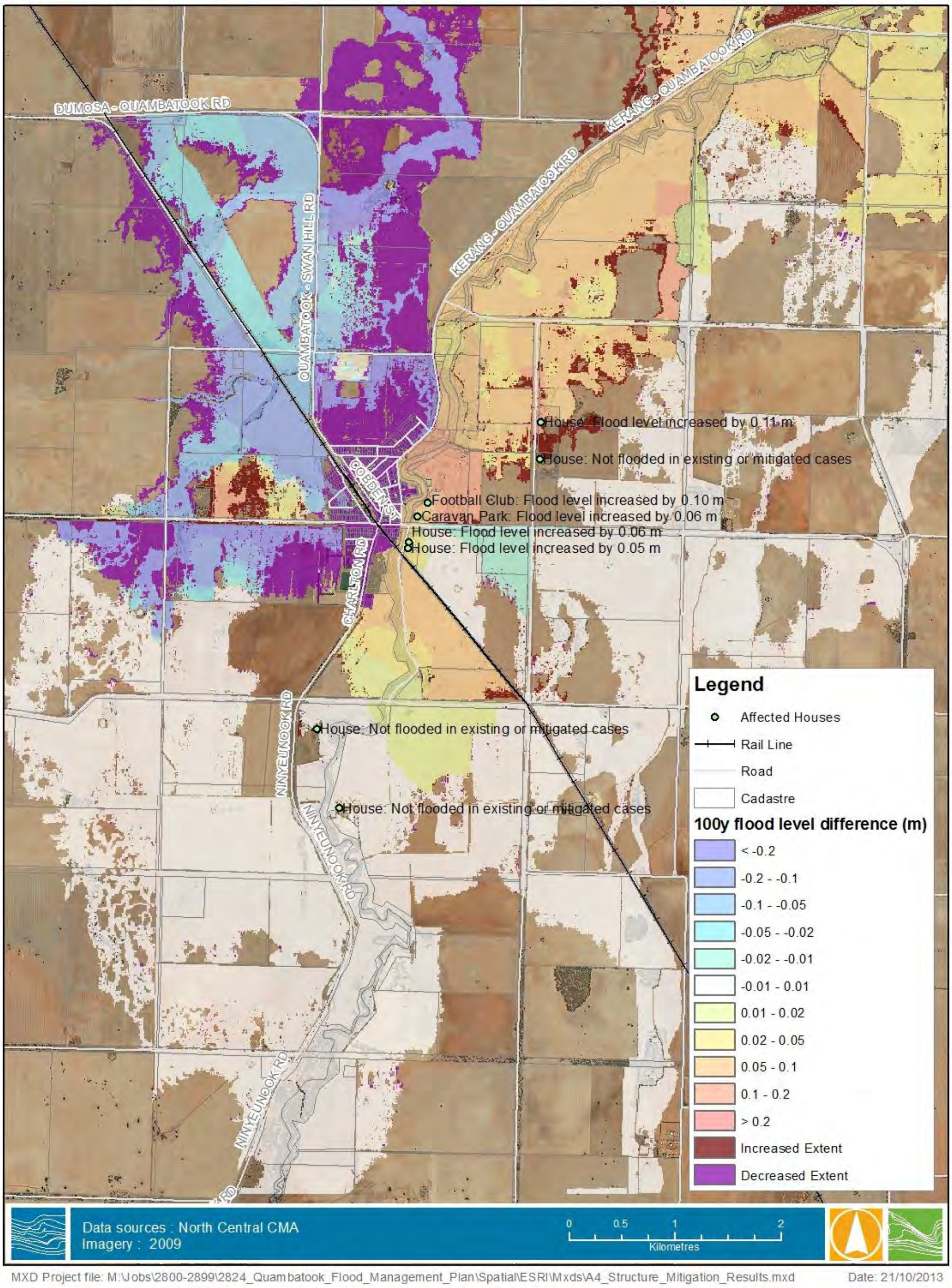

Figure 6-6 Difference plot showing impact of final recommended mitigation package on 1% AEP flood level

Modelling of the mitigation package in the remaining AEP events, and the January 2011 event, has also been undertaken for the purposes of flood damages assessment.

6.2.8 Summary – Structural Mitigation Assessment

The final recommended mitigation package has been tested and shown to provide a significant mitigation benefit to the town and western floodplain, while minimising impacts on the eastern floodplain as much as practicable. The mitigation works will produce increased flood extents and levels on some private rural land, including three dwellings, at which flood levels are increased by up to 0.11 m. It is strongly recommended that floor level survey be captured for these impacted dwellings to reveal if the dwellings are likely to be impacted above or below floor. If inundated above floor, consideration should be given to allowing these property owners to build local ring levees to protect their dwellings (subject to impact assessment), raising floor levels, or providing a once off compensation to purchase a flood easement for the increased flood damages they are likely to sustain. It should be noted that any flooding sustained by these properties in the January 2011 event was effectively "with mitigation" as temporary levees similar to the proposed mitigation levees were in place. Therefore, if floor levels were not exceeded in the January 2011 event, they would be highly unlikely to flood in the 1% AEP event with the mitigation levees in place. Consultation with these landowners is currently being undertaken to reach a mutually beneficial arrangement. On balance the mitigation package provides benefits which far outweigh any detrimental impacts.

6.3 Non-structural Mitigation Measures

Non-structural measures are floodplain management activities aimed at reducing future flood damages. Non-structural measures aim to reduce existing flood risk by lowering flood damages (consequences) at a given location (as opposed to structural measures which tend to reduce frequency or likelihood of flooding). Non-structural measures include:

- Catchment management
- Flood awareness, preparedness, warning and response
- Land use planning

Catchment management activities in the upstream catchment can influence the existing catchment runoff characteristics (flood peaks and volumes). Flood volumes and peaks are a function of the vegetation cover and land use within a catchment (in addition to topography). Land clearing and drainage works have significantly altered flood response in the catchment. Further drainage works may increase flood peaks and flood volumes resulting from significant rainfall events. Increases in peak flows and flood volumes in turn result in a higher flooding likelihood and flood risk. Catchment revegetation, over the longer term may reduce flood volumes. However, in major floods reductions in peak flow would be expected to be minimal.

Flood awareness, preparedness, warning and response aims to reduce the growth in future flood damages by improving community awareness of flooding and emergency services response. Flood awareness within a community reflects the frequency of significant flooding i.e. infrequent and insignificant flooding leads to lower community flood awareness. The most recent significant flooding events occurred in 2010/2011. Given the recent occurrence of significant flooding with associated damages to property, the community awareness of flooding in Quambatook is expected to be medium to high.

Land use planning aims to reduce flood damages by providing appropriate guidelines/controls for land use and development. The Victoria Planning Provisions (VPPs) allow for zoning of land and the application of controls on the type of land use and permitted activities in areas prone to flooding. The VPPs provide for the following zone and overlays:

- Land Subject to Inundation Overlay (LSIO)
- Floodway Overlay (FO)
- Urban Floodway Zones (UFZ)

The VPPs provide guidelines for the appropriate uses and/or development of land in LSIO, UFZ and FO areas.

6.3.1 Non-structural mitigation options

A number of non-structural mitigation options have been suggested in the Flood Wardens' Report and by the Steering Committee, focusing on improving flood warning. These options are summarised in Table 6-12. Two of these items are already being addressed by North Central CMA. The other two options will provide a benefit to flood warning and flood awareness in the town and should be considered for implementation by North Central CMA.

Other options, such as LSIO land-use controls and/or a formalised flood warning system, may be investigated following this study.

Table 6-12 Options for non-structural mitigation measures

Option	Source	Comment
Quambatook BOM Gauge needs to be renamed Quambatook South Gauge to reflect its correct location and be recalibrated to AHD. Gauge ceiling of 3 metres needs to be increased. It is imperative that this gauge remains at its current site.	Flood Wardens' Report	Being addressed by BOM in consultation with NCCMA
Recommend that Charlton D/S BOM Gauge Minor Flood Level be reduced to 3.5 metres, Moderate Flood Level to 5 metres and Major Flood Level 7 metres. This gives residents north of this location a realistic idea what to expect.	Flood Wardens' Report	Being addressed by BOM in consultation with NCCMA
A new river staff gauge is needed in Quambatook. To be located between Boort Rd Bridge and Pedestrian Bridge. Gauge to be surveyed to m AHD and preferably automated through BOM.	Flood Wardens' Report	This gauge should be tied to water levels from the flood modelling to allow forecasted level to be linked to a flood map
Gauge on Eastern Flood Course for flood warning	Steering Committee Meeting 2	Given the relatively low risk to the township from the EFC, this could perhaps be a manually read staff gauge
Flood Warning. Relationships to be developed with upstream flows in the Avoca River at Charlton to enable early warning for Quambatook.	Water Technology	Relationship with Yawong gauge proved weak
Municipal Floodplain Emergency Management Plan. VICSES should update the MFEP for Quambatook based on the information from this study.	Water Technology	Council and CMA should raise this with VICSES
Land use planning overlays. Council should consider updating the LSIO and FO overlays to ensure appropriate development within Quambatook.	Water Technology	

6.3.2 Flood warning

Flood warning arrangements for Quambatook based on currently operating gauges should be improved and formalised.

Early warning of possible floods can be obtained from the Yawong Weir gauge (Coonooer 408200). The flood peak travel time from Yawong Weir to Quambatook South gauge has been estimated to be 3.5-6.5 days across all event magnitudes. An approximate relationship has been developed between peak flows at Yawong Weir and Quambatook South, as described in Section 4.7, but the relationship has a high degree of uncertainty.

The reference table is reproduced in Table 6-13 below, with notes added on the interpretation of flood mapping for standard AEPs at Quambatook for each flow band at Yawong Weir. For flows up to 100 m^3/s at Yawong Weir, flooding at Quambatook above the 10% AEP is highly unlikely. For flows between 100 and 300 m^3/s at Yawong Weir, flooding at Quambatook is likely to exceed the 20% AEP but not the 5% AEP. For flows between 300 and 400 m^3/s at Yawong Weir, flooding at Quambatook is almost certain to exceed the 20% AEP but not the 2% AEP. Above this flow at Yawong Weir, flooding at Quambatook is almost certain to exceed the 20% AEP and has been recorded as high as the 0.3% AEP.

Table 6-13 Reference table for flows at Quambatook South corresponding to flow ranges at Yawong Weir

Flow at Yawong Weir (m^3/s)	Flow at Quambatook South (m^3/s)	Approx. AEP at Quambatook South	Interpretation of standard AEPs at Quambatook
0-100	0-35	> 14%	• Flooding above 10% AEP highly unlikely
100-200	22-46	8-26%	• Flooding above 20% AEP probable • Flooding above 5% AEP highly unlikely
200-300	24-60	5-23%	• Flooding above 20% AEP probable • Flooding above 5% AEP unlikely
300-400	30-90	2-17%	• Flooding above 20% AEP almost certain • Flooding above 2% AEP unlikely
400-600	30-180	0.3-17%	• Flooding above 20% AEP almost certain • Flooding up to 0.3% AEP has been recorded

A more concrete relationship exists between Quambatook South gauge and Quambatook township. The AEPs at Quambatook South gauge relate directly to the AEPs at Quambatook township. The flood peak travel time is estimated to be 6-8 hours from the gauge to the Boort Road Bridge. The peak flows, gauge heights and travel times for the modelled events are summarised in Table 4-16.

Table 6-14 Reference table for flows at Quambatook South corresponding to flow ranges at Yawong Weir

Event	Flow at Quambatook South (m^3/s)	Peak gauge height (m)	Flood peak travel time (hr)
Sep 2010	31	2.23	6-8
Jan 2011	166	3.04	6-8
20%	27	2.18	6-8
10%	42	2.36	6-8
5%	61	2.54	6-8
2%	90	2.76	6-8
1%	118	2.90	6-8
0.5%	152	3.01	6-8

It is noted that upgrades to the Quambatook South gauge and Charlton D/S gauge have been suggested by the Flood Wardens and are currently being addressed by BOM in consultation with North Central CMA. A new gauge on the Eastern Flood Course has also been suggested by the Steering Committee. This would provide valuable flood data on a watercourse about which very little is currently known, and which has a significant impact on flooding in Quambatook. However due to the minor flood impact on the township itself it is suggested that a manually read gauge or series of manually read gauges could be sufficient, with Flood Wardens instructed to monitor the gauges and record the peak levels post flood. Rating curves could be developed using the hydraulic model to transfer these levels into flows.

Trigger Levels for Temporary Mitigation Works

Depending on the detailed design of the levees, they may be continuous across road reserves (by raising of the road level to the levee crest level) or they may be discontinuous with gaps where they meet or cross road reserves. Temporary sandbagging or earth banking of any gaps in the levees will need to be undertaken in response to the gauge at Quambatook South exceeding certain trigger flows or levels.

Three locations have been identified which are likely to require temporary sandbagging or earth banking, if the road is not raised:

- Boort Road bridge
- Northern end of River St/Kerang Rd Levee to road crest
- Southern end of Cemetery Levee to road crest

The levees at these locations are likely to start to be outflanked at the 10% AEP level, or when the flow reaches 42 m^3/s and the level reaches 2.36 m at the Quambatook South gauge. When this level is reached at the gauge there is 6 to 8 hours warning time until the levees are likely to be outflanked at Quambatook. When this level is reached, sandbagging or earth banking should commence. The first two locations are more vulnerable to outflanking than the third and should be done as the priority.

At the northern end of the River St/Kerang Rd Levee and the southern end of the Cemetery Levee, sandbagging or earth banking to the road crest can be done without closing the road. Full sandbagging or earth banking of Boort Road will require closure of the road. It is suggested that the roadside drains and road verges can be banked first, leaving a carriageway clear. Then the carriageway can be filled in with sandbags when flooding is imminent to minimise the time of road closure.

The trigger flow/level should be confirmed in the detailed design phase of the mitigation works, as minor changes to the design or alignment of levees may result in different sandbagging requirements.

6.3.3 Land Use Planning Overlays

Draft recommended LSIO and FO layers have been developed for Council's consideration, as shown in Figure 6-7 and Appendix D.

The LSIO has been delineated based on the 1% AEP existing conditions flood extent. The FO has been delineated following the guidance of 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% AEP flood extent was considered an appropriate floodway delineation option for Rochester.

Flood depth - Regions with a flood depth in the 1% AEP event greater than 0.5 m were considered as FO based on the flood depth delineation option.

Flood hazard - Combines the flood depth and flow speed for a given design flood event. New flood hazard ratings based on depth-velocity product have been developed in Project 10 of the Australian Rainfall and Runoff Update (Engineers Australia 2010). Recent flood mapping studies by Water Technology (e.g. Burrumbeet Flood Study, 2013) have adopted a threshold of depth-velocity product greater than 0.4 for floodway delineation. On inspection it was found that all areas with flood depth less than 0.5 m in the 1% AEP event had depth-velocity product less than 0.4, therefore this criterion was redundant.

The flood frequency and depth regions were enveloped to provide the final proposed FO map. The extents were smoothed and the following filtering was undertaken:

- Islands (holes) less than 400 m^2 removed,
- Isolated pools less than 10,000 m^2 removed in Town Zone area, and
- All isolated pools not connected to Avoca River, Eastern Flood Course or Back Creek floodways removed outside Town Zone Area.

The community is not a high growth area, and any future development in the town zone, and particularly in the farm zone, is likely to be minimal and slow-paced. Therefore a pragmatic approach has been taken in applying the Floodway Overlay only in high-conveyance, connected areas. An exception has been made within the town zone, where two isolated areas of Floodway Overlay have been delineated due to high flood depths in the 1% AEP event making any further development of these areas undesirable. Consideration may be given to removing these areas from the floodway once levees are in place which prevent inundation of the town. The Land Subject to Inundation Overlay should remain in place over the town even after levees are in place, to ensure floor levels are built high enough in the case of a levee breach event. The delineation of the LSIO and FO may be further refined through discussions between the Gannawarra Shire Council Planning Department and North Central Catchment Management Authority.

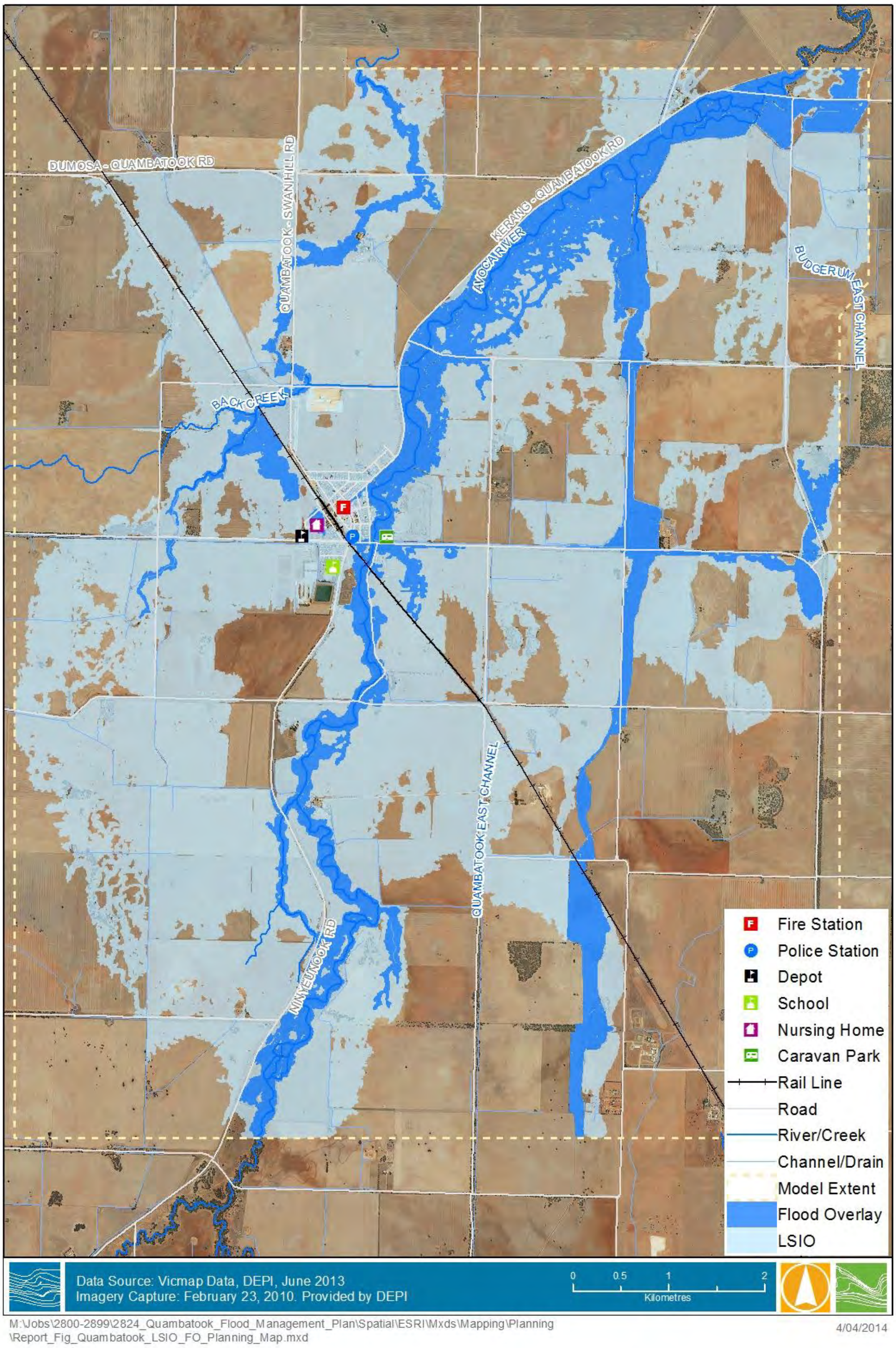

Figure 6-7 Draft recommended LSIO and FO layers

7. FLOOD DAMAGE COST ASSESSMENT

A flood damage assessment for Quambatook was undertaken using the range of design events modelled (20%, 10%, 5%, 2%, 1% and 0.5% AEP events). The damage assessment was used to determine the monetary flood damage for the design floods. The flood damage assessment was also undertaken for the mitigation works package detailed in Section 6.2.6.

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 and the lengths of flood-affected roads. Given that no floor level information was available for Quambatook, many of the aspects of a full damage assessment could not be applied, and the final assessment was mainly based on the Rapid Appraisal Methodology (RAM).

7.1 Assessment Method

The Rapid Appraisal Methodology (RAM) was published by Reed Sturgess and Associates (RSA) in 2000. The RAM provides an approach requiring a simple count of the total number of buildings within the flood extent. The Vicmap land parcels were used for this approach, and those that did not contain a residential or community/commercial building were removed from the analysis. The percentage of the land parcel inundated was also calculated to remove those properties that are on the edge of the flood extent (< 5 % inundated).

A damage estimate of $20,500 was recommended in 2000 for all buildings expect large non-residential buildings. Adjusted for CPI to June 2013 this equates to $30,500. No large non-residential buildings (> 1,000 m^2) were identified as flood affected in Quambatook.

Flood damage can be reduced by good preparation and response by the community, which is a function of the warning time and experience of the community in responding to floods (Table 7-1). An actual to potential damages ratio of 0.4 was adopted based on the extensive warning time provided by upstream gauges and high experience levels within the community.

Table 7-1 Actual to potential damages ratio (RAM, 2000).

Warning time	Experienced community	Inexperienced community
Less than 2 hour	0.8	0.9
2 to 12 hours	Linear reduction from 0.8 at 2 hours to 0.4 at 12 hours	0.8
Greater than 12 hours	0.4	0.7

The estimated damages for sealed roads was calculated by intersecting the Vicmap Roads data layer with the flood extents and calculating the length inundated. For minor sealed roads, a total cost of $27,517/km was applied (factored up from $18,500 in RAM (2000)). No major sealed roads were identified in the study area.

An indirect cost, accounting for clean-up, relocation and emergency response costs, of 20% of the total actual damage cost was applied.

The grain bunkers in the study area were identified as being at risk of partial inundation in the larger flood events considered. These were not included in the damage assessment but are very high value assets, that have been valued at $40 million when full of wheat. It has been estimated that up to

16% of the area and up to 0.3% of the full volume of the bunkers may be wetted in the 1% AEP event. Damages for the bunkers have not been included in the damage assessment because of uncertainty in their value due to the seasonal nature of the storages. However it is considered that these high value assets should lend more weight for the case of mitigation when considering the benefit-cost ratio presented in Section 7.5.

7.2 Existing Conditions

The flood damage assessment for existing conditions is shown below in Table 7-2. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$159,115**. 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 few properties are inundated in the lower magnitude events (20% and 10% AEP events) and there is a steep rise in the number of properties flooded from the 10% AEP to the 2% AEP event. Above the 2% AEP event the number of properties inundated and the damage total becomes fairly constant.

Table 7-2 Flood Damage Cost Assessment for Existing Conditions

Parameter	**Annual Exceedance Probability**					
	0.5%	**1%**	**2%**	**5%**	**10%**	**20%**
Large Buildings Flooded	0	0	0	0	0	0
Properties Flooded	178	173	162	90	8	3
Potential Large Buildings Damage Cost	$0	$0	$0	$0	$0	$0
Potential Property Damage Cost	**$5,429,000**	**$5,276,500**	**$4,941,000**	**$2,745,000**	**$244,000**	**$91,500**
Total Direct Potential Damage Cost	**$5,429,000**	**$5,276,500**	**$4,941,000**	**$2,745,000**	**$244,000**	**$91,500**
Total Actual Damage Cost *(0.4*Potential)*	**$2,171,600**	**$2,110,600**	**$1,976,400**	**$1,098,000**	**$97,600**	**$36,600**
Infrastructure Damage Cost	**$431,632**	**$346,852**	**$256,183**	**$108,527**	**$22,784**	**$5,228**
Total Indirect Cost *(0.2*Actual)*	**$434,320**	**$422,120**	**$395,280**	**$219,600**	**$19,520**	**$7,320**
Total Damage Cost	**$3,037,552**	**$2,879,572**	**$2,627,863**	**$1,426,127**	**$139,904**	**$49,148**

Average Annual Damage (AAD)	**$159,115**

7.3 Mitigation Works Package

The flood damage cost assessment was repeated for the mitigation package. The resulting flood damage costs for each AEP event are given in Table 7-3. The average annual damage cost (AAD) was decreased from $159,115 under existing conditions to **$31,522** under the recommended mitigation package conditions. The number of properties impacted with residential, commercial or public buildings in a 1% AEP event was reduced from 173 to just 19 by the recommended mitigation package. This means that the mitigation package will, on average, save the community $127,593 per year in flood damage costs.

Note that the damage to the grain bunkers was not included in the assessment, and that there are potential additional benefits due to higher levels of protection for these assets with the mitigation works in place, lending further weight to the case for flood mitigation at Quambatook.

Table 7-3 Total Actual Flood Damage Cost to Buildings for Mitigation Package Conditions

Parameter	Annual Exceedance Probability					
	0.5%	1%	2%	5%	10%	20%
Large Buildings Flooded	0	0	0	0	0	0
Properties Flooded	27	19	12	8	6	2
Potential Large Buildings Damage Cost	$0	$0	$0	$0	$0	$0
Potential Property Damage Cost	$823,500	$579,500	$366,000	$244,000	$183,000	$61,000
Total Direct Potential Damage Cost	**$823,500**	**$579,500**	**$366,000**	**$244,000**	**$183,000**	**$61,000**
Total Actual Damage Cost *(0.4*Potential)*	**$329,400**	**$231,800**	**$146,400**	**$97,600**	**$73,200**	**$24,400**
Infrastructure Damage Cost	**$237,829**	**$166,670**	**$96,310**	**$39,157**	**$18,822**	**$5,283**
Total Indirect Cost *(0.2*Actual)*	**$65,880**	**$46,360**	**$29,280**	**$19,520**	**$14,640**	**$4,880**
Total Damage Cost	**$633,109**	**$444,830**	**$271,990**	**$156,277**	**$106,662**	**$34,563**

Average Annual Damage (AAD)	**$31,522**

7.4 Non-Economic Flood Damages

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

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

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

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

The intangible non-monetary flood related damage in Quambatook, if flood mitigation works were not in place, would be very high. The benefit-cost analysis presented later in this report (section 7.5) 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 Quambatook is 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 Quambatook.

7.5 Benefit-Cost Assessment

7.5.1 Mitigation Package Indicative Costs

Costing has been undertaken for the mitigation works package as shown in Table 7-4 and Table 7-5. The earthworks, topsoiling and grassing have been costed for each component of the structural mitigation package. Costs of vegetation removal, and the cost of any compensation or compensatory works for properties where flooding has increased, have not been estimated, but a provisional allowance of $200,000 has been included in the current estimates. The levee alignments were chosen to avoid vegetation removal as much as possible, however it is expected some vegetation may need to be removed.

The total cost of the structural mitigation package, including allowances for engineering and administration fees and contingencies, is estimated to be **$886,952**. The estimated annual maintenance cost is **$5,378**.

Table 7-4 Unit cost estimates for mitigation works

Description		Qty	Unit	Rate ($/unit)	Estimated Cost $
Cemetery Levee					
	Construction and Compaction	971	m^3	$20	$19,429
	Topsoiling (100mm)	218	m^3	$17	$3,700
	Grassing	2,177	m^2	$1	$2,177
				Subtotal	**$25,306**
Caravan Park Levee					
	Construction and Compaction	815	m^3	$20	$16,294
	Topsoiling (100mm)	238	m^3	$17	$4,046
	Grassing	2,380	m^2	$1	$2,380
				Subtotal	**$22,719**
Reservoir-Railway Levee					
	Construction and Compaction	918	m^3	$20	$18,352
	Topsoiling (100mm)	148	m^3	$17	$2,508
	Grassing	1,475	m^2	$1	$1,475
				Subtotal	**$25,306**
River St Levee					
	Construction and Compaction	11,531	m^3	$20	$230,616
	Topsoiling (100mm)	2,132	m^3	$17	$36,250
	Grassing	21,323	m^2	$1	$21,323
				Subtotal	**$25,306**
Removal of GWM Water Channel banks along Meering Rd					
	Channel decommissioning	2,770	m	$3.80	$10,526
				Subtotal	**$10,526**
Removal of Boort Rd Bank alongside Golf Course					
	Channel decommissioning	490	m	$3.80	$1,862
				Subtotal	**$1,862**
Compensatory works or compensation for affected properties					
	Provisional allowance				$200,000
				Subtotal	**$200,000**

Table 7-5 Total Cost estimates for mitigation works

Works Description	Estimated Construction Cost	Estimated Annual Maintenance Cost
Levee from Ninyeunook Rd bend, east of Lawn Cemetery	$25,306	$380
Levee from reservoir bank to the Rail Bridge	$22,335	$335
Levee on east side of River St and south side of Kerang Rd	$288,189	$4,323
Caravan Park levee	$22,719	$341
Removal of GWM Water Channel banks along Meering Rd	$10,526	
Removal of Boort Rd Bank alongside Golf Course	$1,862	
Compensatory works or compensation for affected properties (provisional allowance)	$200,000	
Sub-total 'A'	**$570,938**	
'A' x Engineering Fee @ 15%	$85,641	
Sub-total 'B'	**$656,579**	
'B' x Administration Fee @ 9%	$59,092	
(Land Acq only) 'B' x Administration Fee @ 1%	-	
Sub-total 'C'	**$715,671**	
'A' x Contingencies @ 30%	$171,281	
FORECAST EXPENDITURE	**$886,952**	**$5,378**

7.5.2 Benefit-Cost Assessment

The construction cost of the mitigation package has been estimated at $886,952, and the annual maintenance cost at $5,378. The average annual flood damage benefit has been estimated to be $127,593. The benefit-cost ratio over a period of 30 years (assuming a discount rate of 6%) has been estimated to be 1.9. The likely pay-back period is 9-10 years. ***This is a high benefit-cost ratio, providing a very strong case for funding of the recommended mitigation works.***

8. CONCLUSIONS AND RECOMMENDATIONS

Quambatook was affected by flooding from the Avoca River in September 2010 and January 2011. Following the flood events, The Minister for Water announced funding for the Quambatook Flood Management Plan, to be led by Gannawarra Shire Council in partnership with the North Central Catchment Management Authority (CMA). Water Technology was commissioned by Gannawarra Shire Council to develop the Flood Management Plan. The study involved the development of flood estimates for the Avoca River and Eastern Flood Course at Quambatook, development of a hydraulic model of the township and floodplain, successful calibration and verification to the September 2010 and January 2011 flood events, simulation of a number of design flood events, design of potential flood mitigation options and a benefit-cost analysis.

Throughout the study, a range of community consultation activities were undertaken, including engagement and inclusion onto the Steering Committee of the Flood Warden group, community meetings and questionnaires to ensure that community issues were heard and the community ideas were considered in the development of potential flood mitigation options.

An initial prefeasibility assessment of 18 structural mitigation options was undertaken. From the prefeasibility assessment ten options were selected for further analysis using the hydraulic model. Following hydraulic investigation a final mitigation package was developed and investigated in detail. A package consisting of the following components was recommended:

- Levee from Ninyeunook Rd bend, east of Lawn Cemetery, to meet with the Reservoir bank. Ensure levee accommodates future expansion of Lawn Cemetery
- Levee from reservoir bank to the Rail Bridge
- Levee on east side of River St and south side of Kerang Rd. Alignment to go around tennis courts, bowling club, swimming pool and drainage pump house.
- Temporary sandbagging across Boort Road bridge and at north end of levee to road crest
- Fill in GWM Water Channel that runs east/west down Meering Rd
- Remove channel banks on south side of Golf Club
- Levees at 5% AEP level for Caravan Park along the river

The mitigation package had a full benefit-cost analysis undertaken. The package returned an excellent benefit-cost ratio of 1.9. 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 or the significant damage incurred by inundation of the grain bunkers.

Regardless of the benefit-cost ratio, no option is likely to be considered unless it has the strong support of the community. Feedback from the steering committee and community meetings indicated strong support for the mitigation measures, as long as key community concerns could be addressed, such as ensuring adequate compensatory measures for the few properties affected by increased flood impacts, and ensuring the levees do not become a visual barrier between the town and river.

8.1 Flood Management Plan Recommendations

The Quambatook Flood Management Plan Steering Committee recommends the following actions:

- A formalised flood warning system should be developed for Quambatook bringing together the relationships identified in this study between Yawong Weir, Quambatook South Gauge and Quambatook town, and considering recommendations for new gauges in Quambatook Town and on the Eastern Flood Course.
- The stream gauge information should be utilised in conjunction with the flood maps and flood intelligence produced from this study to form an effective flood warning system;
- A flood response plan should be adopted into the Municipal Flood Emergency Plan and the community is engaged along with the responsible agencies (BoM, SES, Gannawarra Shire Council, North Central CMA etc.) in developing appropriate actions.
- The planning scheme for Quambatook should be amended to reflect the flood risk identified by this project, for example by implementation of the recommended draft Land Subject to Inundation Overlay and Flood Overlay; and
- The recommended mitigation works package should be submitted for funding for detailed design and construction with further consultation with the Quambatook community, particularly impacted properties identified and users of the channel in the Quambatook-Boort Road reserve.

9. REFERENCES

Camp Scott Furphy (1985) Avoca River Floodplain Management Study, prepared by Camp Scott Furphy Pty Ltd for Rural Water Commission Victoria

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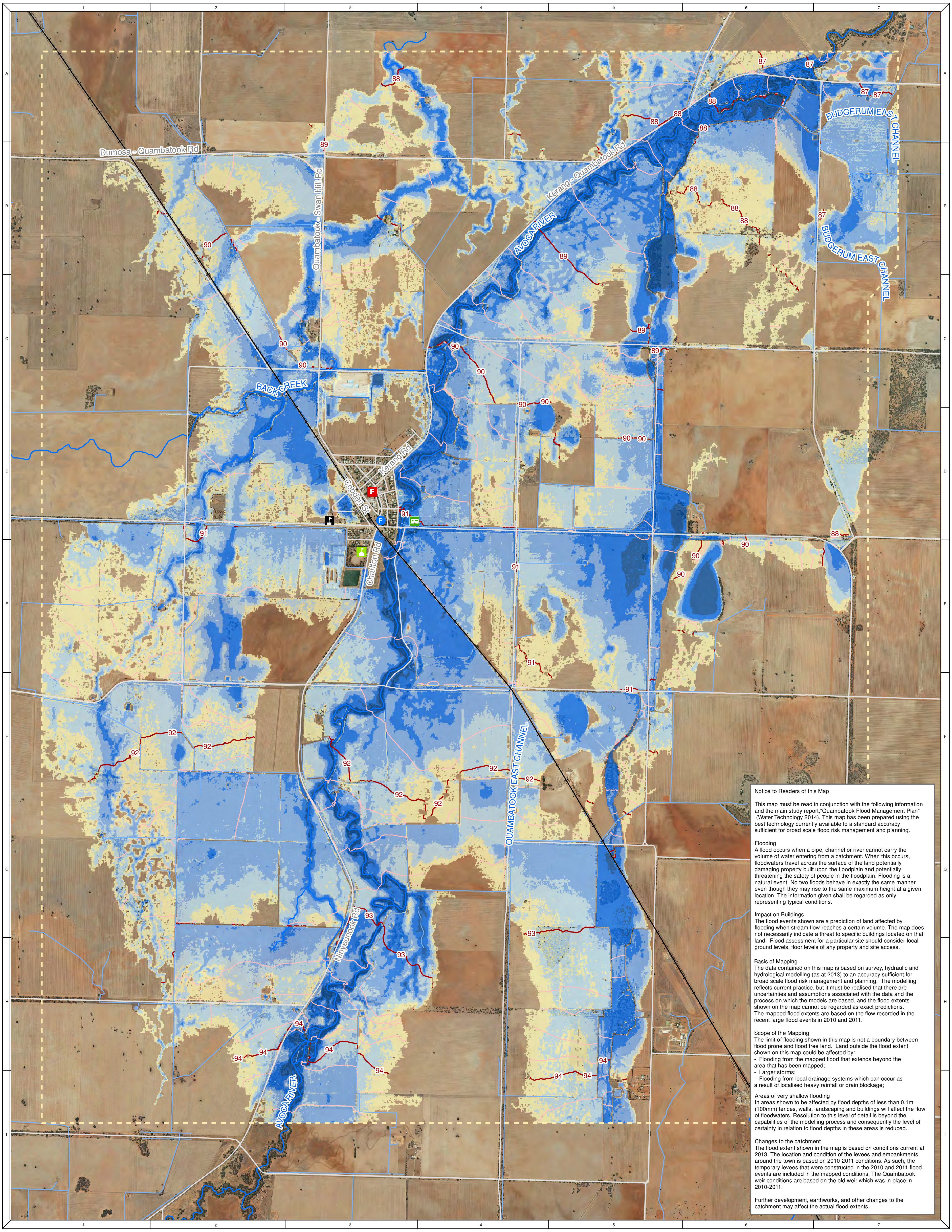
Water Technology (2013) Burrumbeet Flood Study [DRAFT] for Glenelg Hopkins Catchment Management Authority

APPENDIX A CALIBRATION MAPS



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Impact on Buildings
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Basis of Mapping
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The mapped flood extents are based on the flow recorded in the recent large flood events in 2010 and 2011.

Scope of the Mapping
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Areas of very shallow flooding
In areas shown to be affected by flood depths of less than 0.1m (100mm) fences, walls, landscaping and buildings will affect the flow of floodwaters. Resolution to this level of detail is beyond the capabilities of the modelling process and consequently the level of certainty in relation to flood depths in these areas is reduced.

Changes to the catchment
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Further development, earthworks, and other changes to the catchment may affect the actual flood extents.

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N
W E
S

Fire Station
Police Station
Depot
School
Caravan Park

Rail Line
Road
River/Creek
Channel/Drain
1m WSE Contours
20cm WSE Contours
Model Extent

Flood Depth (m)
0.005 - 0.1
0.1- 0.25
0.25 - 0.5
0.5 - 1
Greater than 1m

0 0.5 1 2 Kilometers 1:35,000 at A3

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan

DRAFT

January 2011 Calibration Depth Map

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Calibration \Quambatook_Jan2011_Calibration_Depth_Map.mxd

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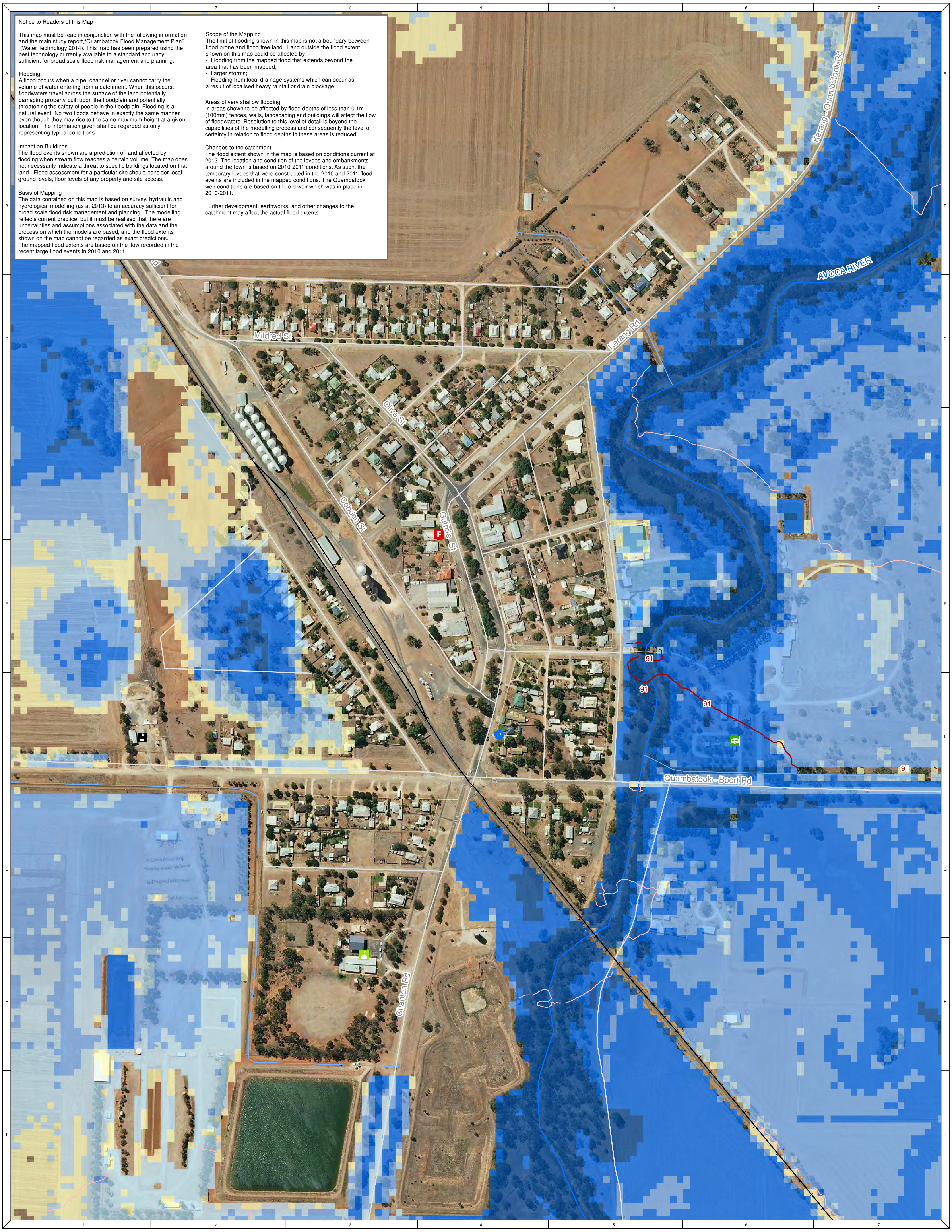

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1m WSE Contours
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Data Source: Vicmap Data, DEPI, June 2013
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Quambatook Flood Management Plan

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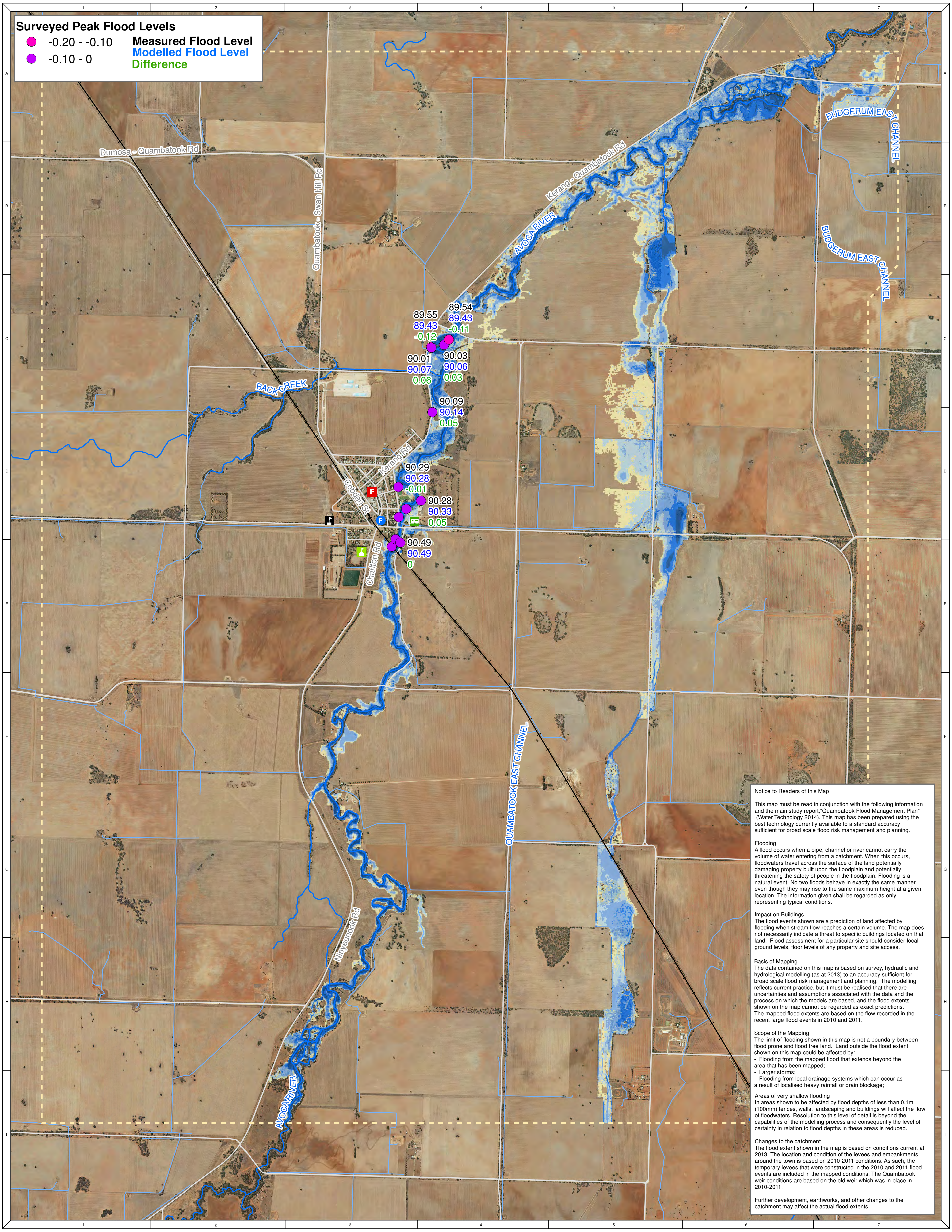

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Model Extent

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Greater than 1m

0 0.5 1 2 Kilometers
1:35,000 at A3

Data Source: Vicmap Data, DEPI, June 2013
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Quambatook Flood Management Plan

September 2010 Calibration Depth Map

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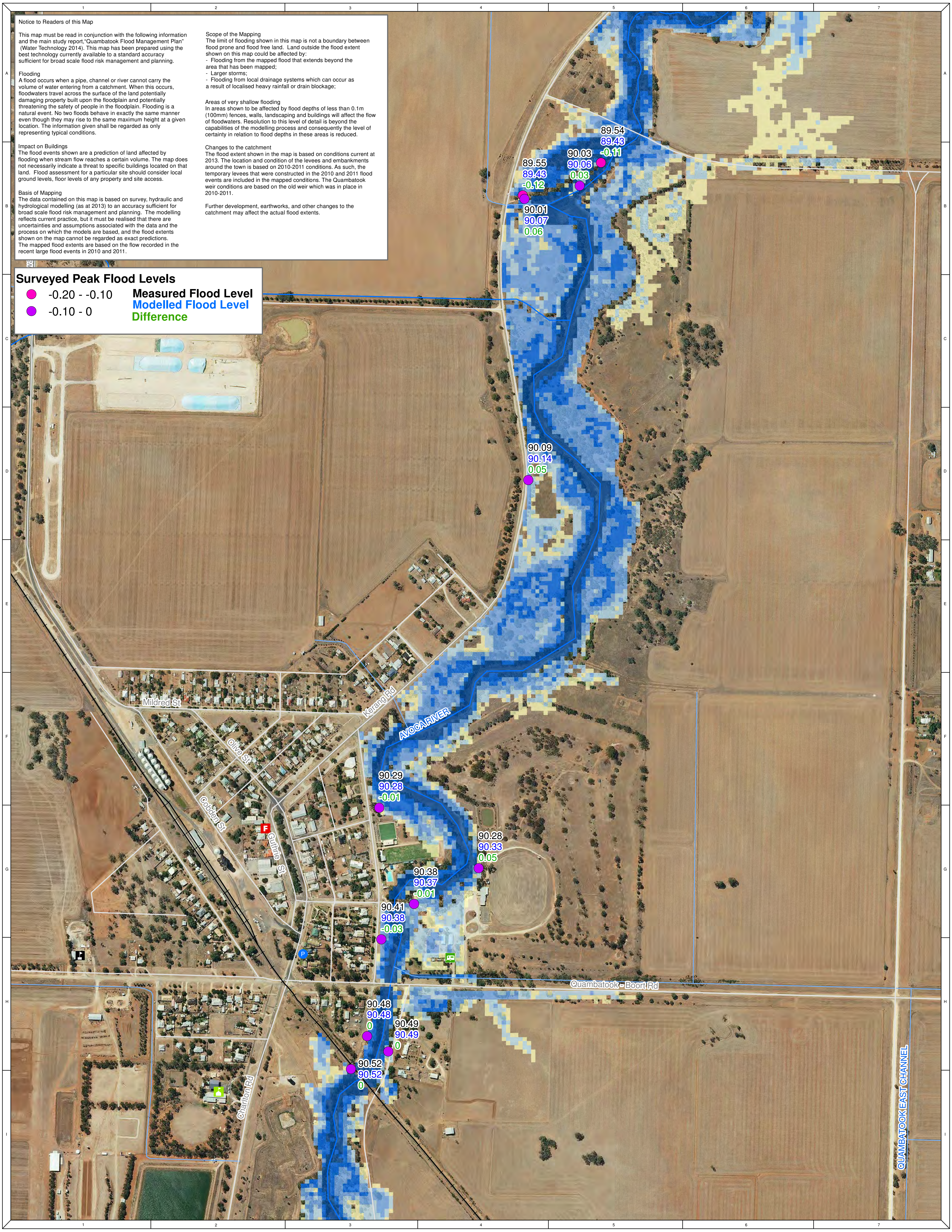
Surveyed Peak Flood Levels

- -0.20 - -0.10
- -0.10 - 0

Measured Flood Level
Modelled Flood Level
Difference



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- Rail Line
- Road
- River/Creek
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Flood Depth (m)
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- 0.1- 0.25
- 0.25 - 0.5
- 0.5 - 1
- Greater than 1m

0 100 200 400 Meters

1:8,000 at A3

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September 2010 Calibration Depth Map

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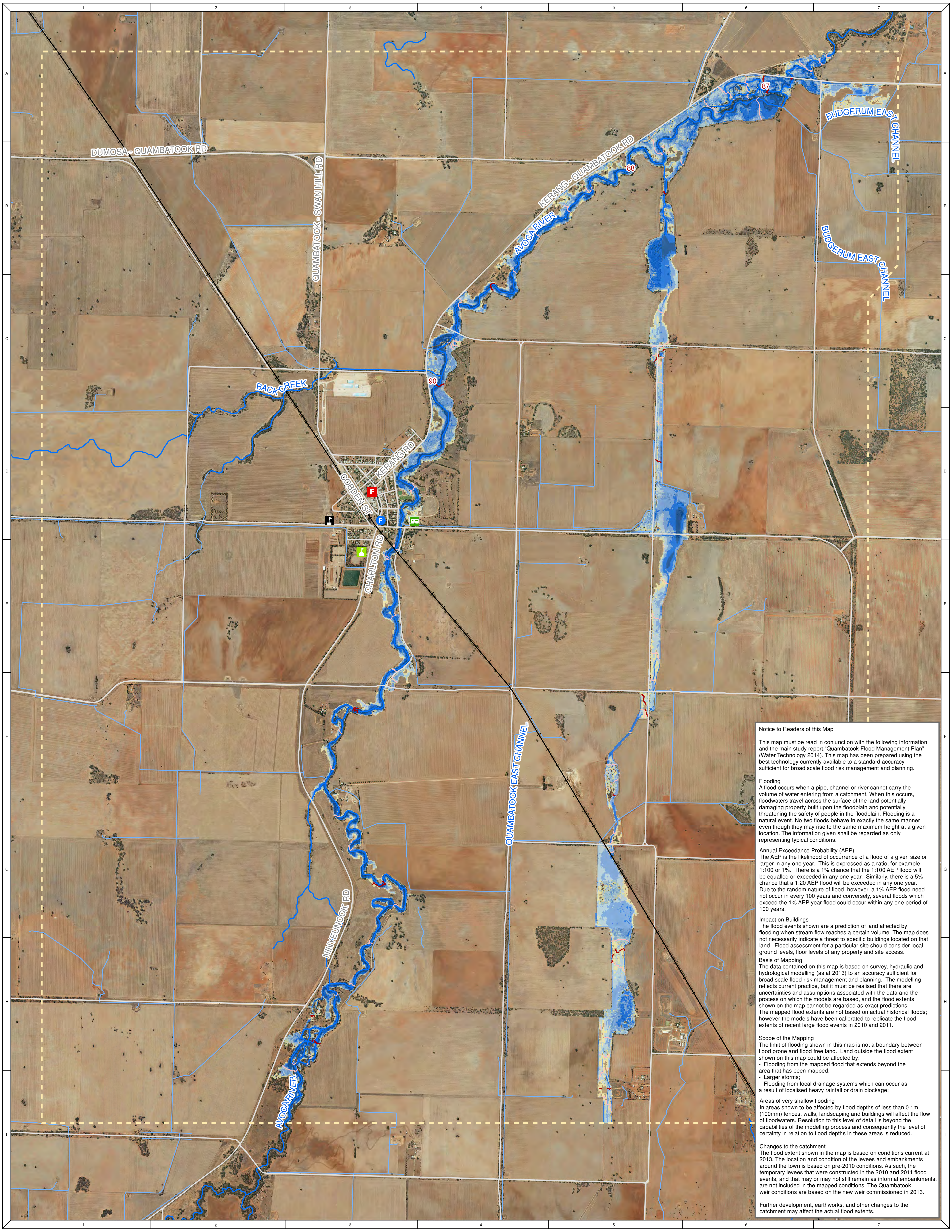
APPENDIX B DESIGN FLOOD MAPS



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Annual Exceedance Probability (AEP)
The AEP is the likelihood of occurrence of a flood of a given size or larger in any one year. This is expressed as a ratio, for example 1:100 or 1%. There is a 1% chance that the 1:100 AEP flood will be equalled or exceeded in any one year. Similarly, there is a 5% chance that a 1:20 AEP flood will be exceeded in any one year. Due to the random nature of flood, however, a 1% AEP flood need not occur in every 100 years and conversely, several floods which exceed the 1% AEP year flood could occur within any one period of 100 years.

Impact on Buildings
The flood events shown are a prediction of land affected by flooding when stream flow reaches a certain volume. The map does not necessarily indicate a threat to specific buildings located on that land. Flood assessment for a particular site should consider local ground levels, floor levels of any property and site access.

Basis of Mapping
The data contained on this map is based on survey, hydraulic and hydrological modelling (as at 2013) to an accuracy sufficient for broad scale flood risk management and planning. The modelling reflects current practice, but it must be realised that there are uncertainties and assumptions associated with the data and the process on which the models are based, and the flood extents shown on the map cannot be regarded as exact predictions.
The mapped flood extents are not based on actual historical floods; however the models have been calibrated to replicate the flood extents of recent large flood events in 2010 and 2011.

Scope of the Mapping
The limit of flooding shown in this map is not a boundary between flood prone and flood free land. Land outside the flood extent shown on this map could be affected by:
- Flooding from the mapped flood that extends beyond the area that has been mapped;
- Larger storms;
- Flooding from local drainage systems which can occur as a result of localised heavy rainfall or drain blockage;

Areas of very shallow flooding
In areas shown to be affected by flood depths of less than 0.1m (100mm) fences, walls, landscaping and buildings will affect the flow of floodwaters. Resolution to this level of detail is beyond the capabilities of the modelling process and consequently the level of certainty in relation to flood depths in these areas is reduced.

Changes to the catchment
The flood extent shown in the map is based on conditions current at 2013. The location and condition of the levees and embankments around the town is based on pre-2010 conditions. As such, the temporary levees that were constructed in the 2010 and 2011 flood events, and that may or may not still remain as informal embankments, are not included in the mapped conditions. The Quambatook weir conditions are based on the new weir commissioned in 2013.

Further development, earthworks, and other changes to the catchment may affect the actual flood extents.

NOTE
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N W E S

F Fire Station
P Police Station
Depot
School
Caravan Park

Rail Line
Road
River/Creek
Channel/Drain
1m WSE Contours
20cm WSE Contours
Model Extent

Flood Depth (m)
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
Greater than 1m

0 0.5 1 2 Kilometers
1:35,000 at A3

WATER TECHNOLOGY
NORTH CENTRAL Catchment Management Authority
GANNAWARRA SHIRE COUNCIL

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan
20% AEP Depth Map
No Temporary Levees

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design\Quambatook_5y_Depth_Map.mxd

DATE: 2/04/2014 | SHEET: 1 of 1 | DRAWING NUMBER: 1

Quambatook Flood Management Plan

20% AEP Depth Map - Town Extent
No Temporary Levees

Notice to Readers of this Map

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Flooding

A flood occurs when a pipe, channel or river cannot carry the volume of water entering from a catchment. When this occurs, floodwaters travel across the surface of the land potentially damaging property built upon the floodplain and potentially threatening the safety of people in the floodplain. Flooding is a natural event. No two floods behave in exactly the same manner even though they may rise to the same maximum height at a given location. The information given shall be regarded as only representing typical conditions.

Annual Exceedance Probability (AEP)

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Areas of very shallow flooding

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		Flood Depth (m)
Fire Station	Rail Line	0 - 0.1
Police Station	River/Creek	0.1 - 0.25
Depot	Channel/Drain	0.25 - 0.5
School	1m WSE Contours	0.5 - 1
Caravan Park	20cm WSE Contours	Greater than 1m
	Cadastre	

0 75 150 300 Meters — 1:5,000 at A3

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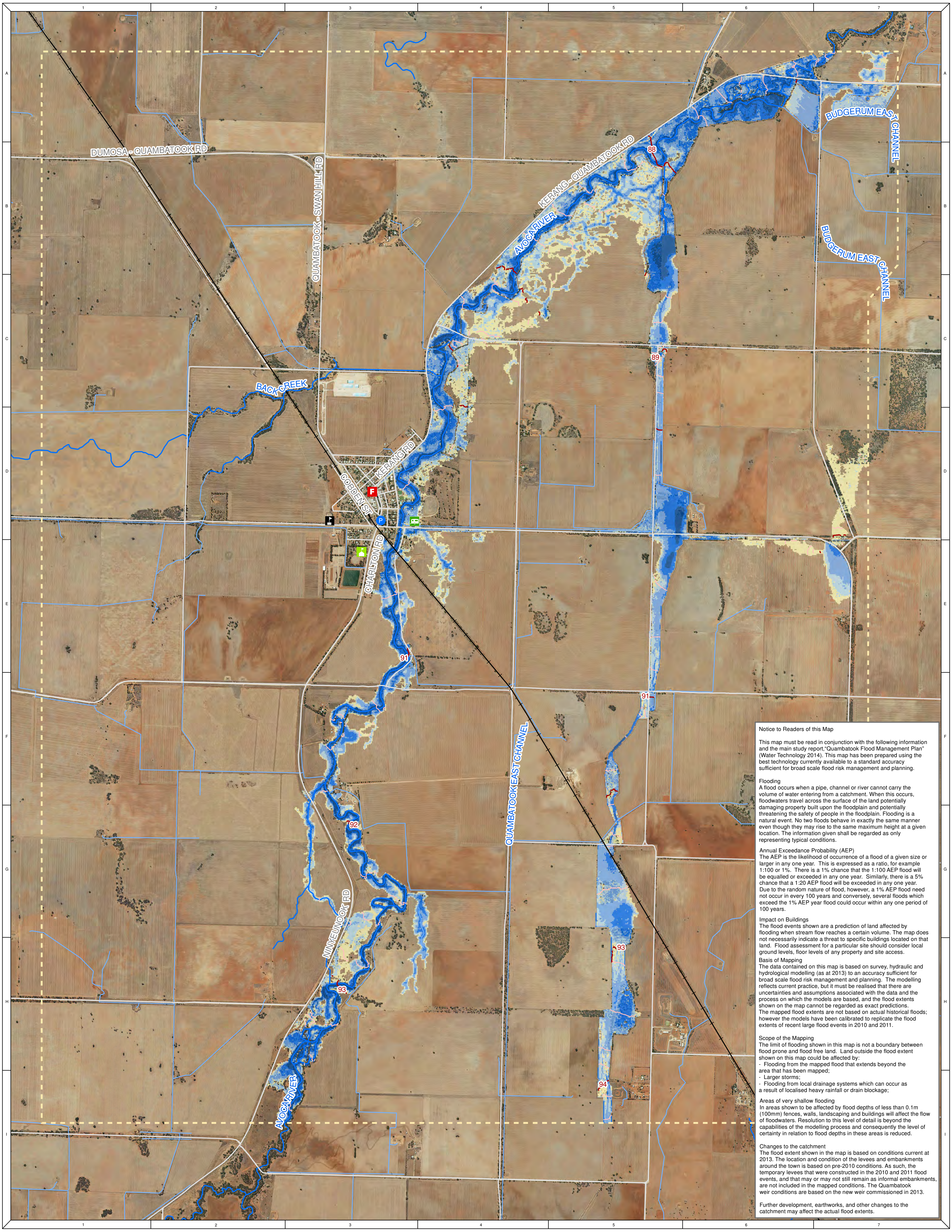
REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design\Quambatook_5y_Depth_Map_Town_Ext.mxd

DATE: 2/04/2013 | SHEET: 1 of 1 | DRAWING NUMBER: 1



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Fire Station
Police Station
Depot
School
Caravan Park

Rail Line
Road
River/Creek
Channel/Drain
1m WSE Contours
20cm WSE Contours
Model Extent

Flood Depth (m)
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
Greater than 1m

0 0.5 1 2 Kilometers 1:35,000 at A3

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan

10% AEP Depth Map
No Temporary Levees

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design \Quambatook_10y_Depth_Map.mxd

DATE: 2/04/2014 | SHEET: 1 of 1 | DRAWING NUMBER: 1

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- Fire Station
- Police Station
- Depot
- School
- Caravan Park
- Rail Line
- River/Creek
- Channel/Drain
- 1m WSE Contours
- 20cm WSE Contours
- Cadastre

Flood Depth (m)
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- Greater than 1m

0 75 150 300 Meters 1:5,000 at A3

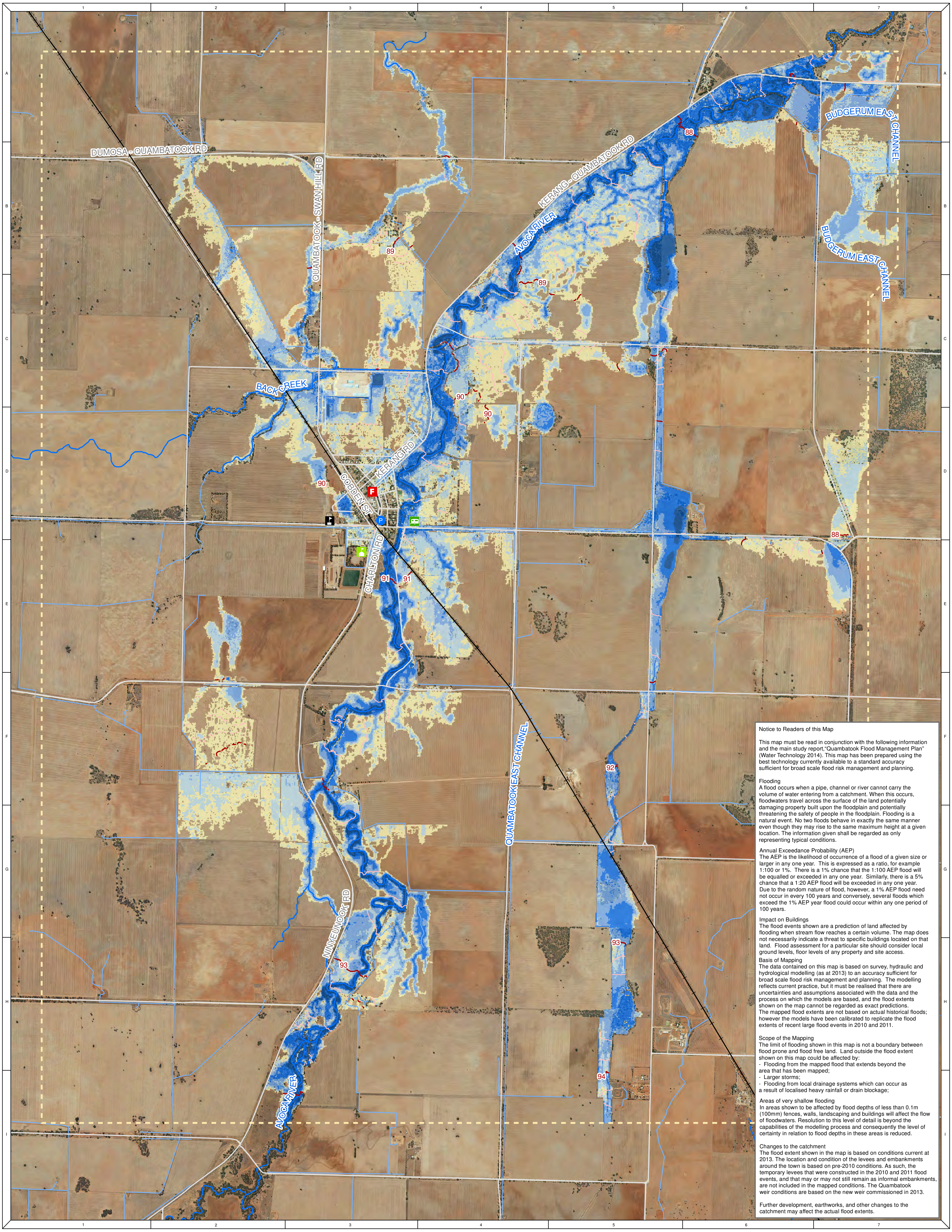
Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan

10% AEP Depth Map - Town Extent
No Temporary Levees

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design\Quambatook_10y_Depth_Map_Town_Ext.mxd

DATE: 2/04/2013 | SHEET: 1 of 1 | DRAWING NUMBER: 1



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Areas of very shallow flooding
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Changes to the catchment
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N
W E
S

Fire Station
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Road
River/Creek
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20cm WSE Contours
Model Extent

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Greater than 1m

0 0.5 1 2 Kilometers
1:35,000 at A3

WATER TECHNOLOGY
NORTH CENTRAL Catchment Management Authority
Connecting Rivers, Landscapes, People
GANNAWARRA SHIRE COUNCIL

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan
5% AEP Depth Map
No Temporary Levees

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design\Quambatook_20y_Depth_Map.mxd

DATE: 2/04/2014	SHEET: 1 of 1	DRAWING NUMBER: 1

Quambatook Flood Management Plan

5% AEP Depth Map - Town Extent
No Temporary Levees

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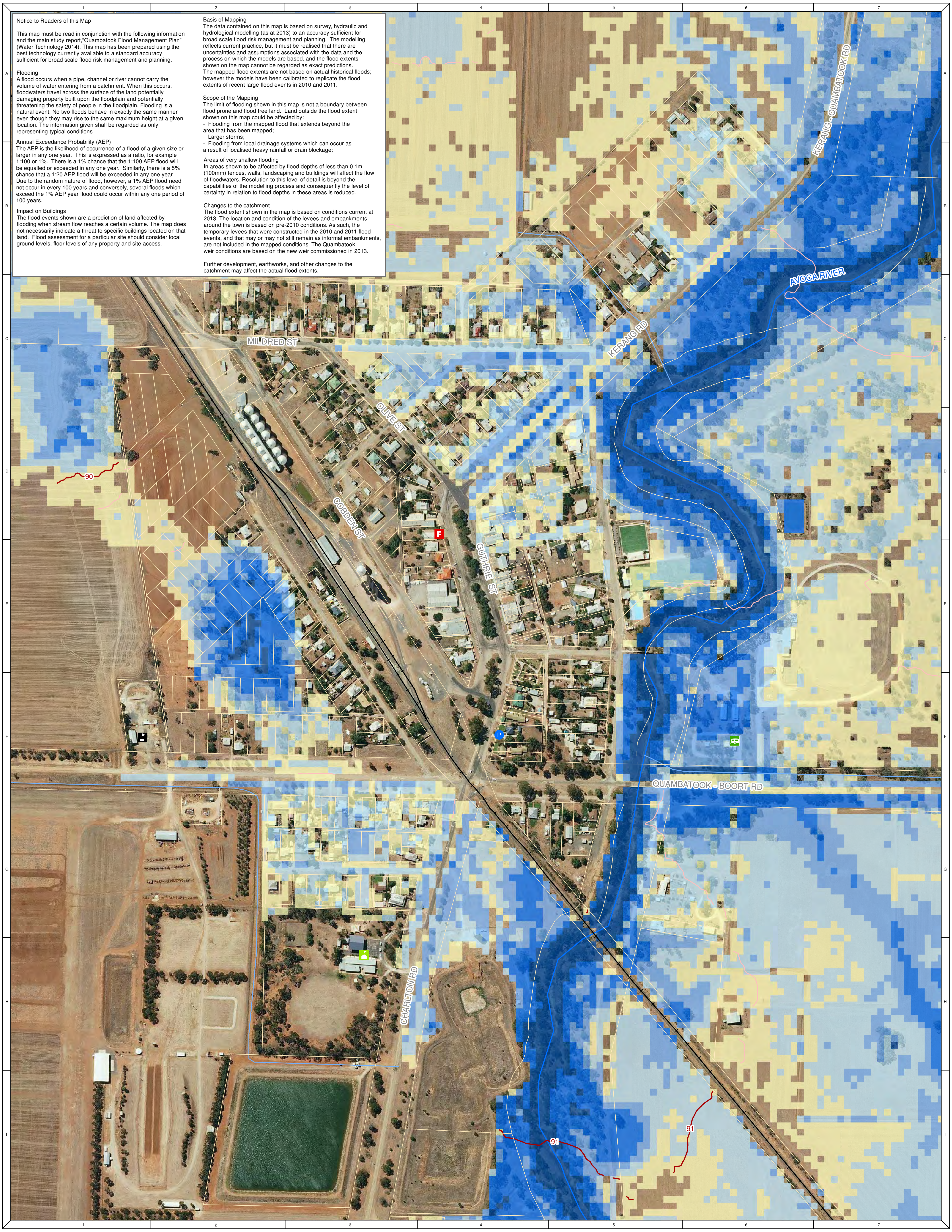

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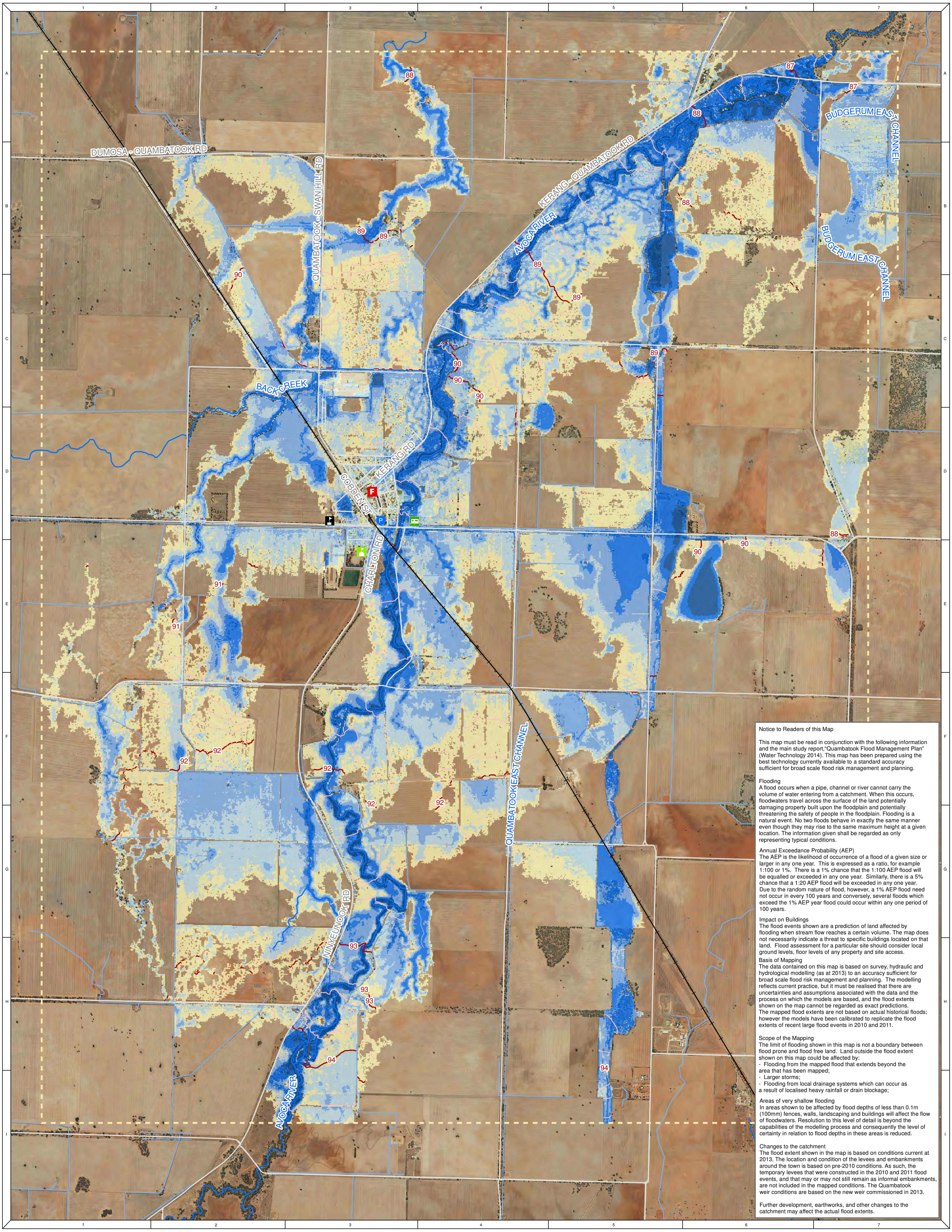
DATE: 2/04/2013 | SHEET: 1 of 1 | DRAWING NUMBER: 1



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NOTE
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N
W E
S

Fire Station
Police Station
Depot
School
Caravan Park

Rail Line
Road
River/Creek
Channel/Drain
1m WSE Contours
20cm WSE Contours
Model Extent

Flood Depth (m)
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
Greater than 1m

0 0.5 1 2 Kilometers
1:35,000 at A3

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan

2% AEP Depth Map
No Temporary Levees

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design \Quambatook_50y_Depth_Map.mxd

DATE: 2/04/2014 | SHEET: 1 of 1 | DRAWING NUMBER: 1

Quambatook Flood Management Plan

2% AEP Depth Map - Town Extent
No Temporary Levees

Notice to Readers of this Map

This map must be read in conjunction with the following information and the main study report,“Quambatook Flood Management Plan” (Water Technology 2014). This map has been prepared using the best technology currently available to a standard accuracy sufficient for broad scale flood risk management and planning.

Flooding

A flood occurs when a pipe, channel or river cannot carry the volume of water entering from a catchment. When this occurs, floodwaters travel across the surface of the land potentially damaging property built upon the floodplain and potentially threatening the safety of people in the floodplain. Flooding is a natural event. No two floods behave in exactly the same manner even though they may rise to the same maximum height at a given location. The information given shall be regarded as only representing typical conditions.

Annual Exceedance Probability (AEP)

The AEP is the likelihood of occurrence of a flood of a given size or larger in any one year. This is expressed as a ratio, for example 1:100 or 1%. There is a 1% chance that the 1:100 AEP flood will be equalled or exceeded in any one year. Similarly, there is a 5% chance that a 1:20 AEP flood will be exceeded in any one year. Due to the random nature of flood, however, a 1% AEP flood need not occur in every 100 years and conversely, several floods which exceed the 1% AEP year flood could occur within any one period of 100 years.

Impact on Buildings

The flood events shown are a prediction of land affected by flooding when stream flow reaches a certain volume. The map does not necessarily indicate a threat to specific buildings located on that land. Flood assessment for a particular site should consider local ground levels, floor levels of any property and site access.

Basis of Mapping

The data contained on this map is based on survey, hydraulic and hydrological modelling (as at 2013) to an accuracy sufficient for broad scale flood risk management and planning. The modelling reflects current practice, but it must be realised that there are uncertainties and assumptions associated with the data and the process on which the models are based, and the flood extents shown on the map cannot be regarded as exact predictions. The mapped flood extents are not based on actual historical floods; however the models have been calibrated to replicate the flood extents of recent large flood events in 2010 and 2011.

Scope of the Mapping

The limit of flooding shown in this map is not a boundary between flood prone and flood free land. Land outside the flood extent shown on this map could be affected by:

- Flooding from the mapped flood that extends beyond the area that has been mapped;
- Larger storms;
- Flooding from local drainage systems which can occur as a result of localised heavy rainfall or drain blockage;

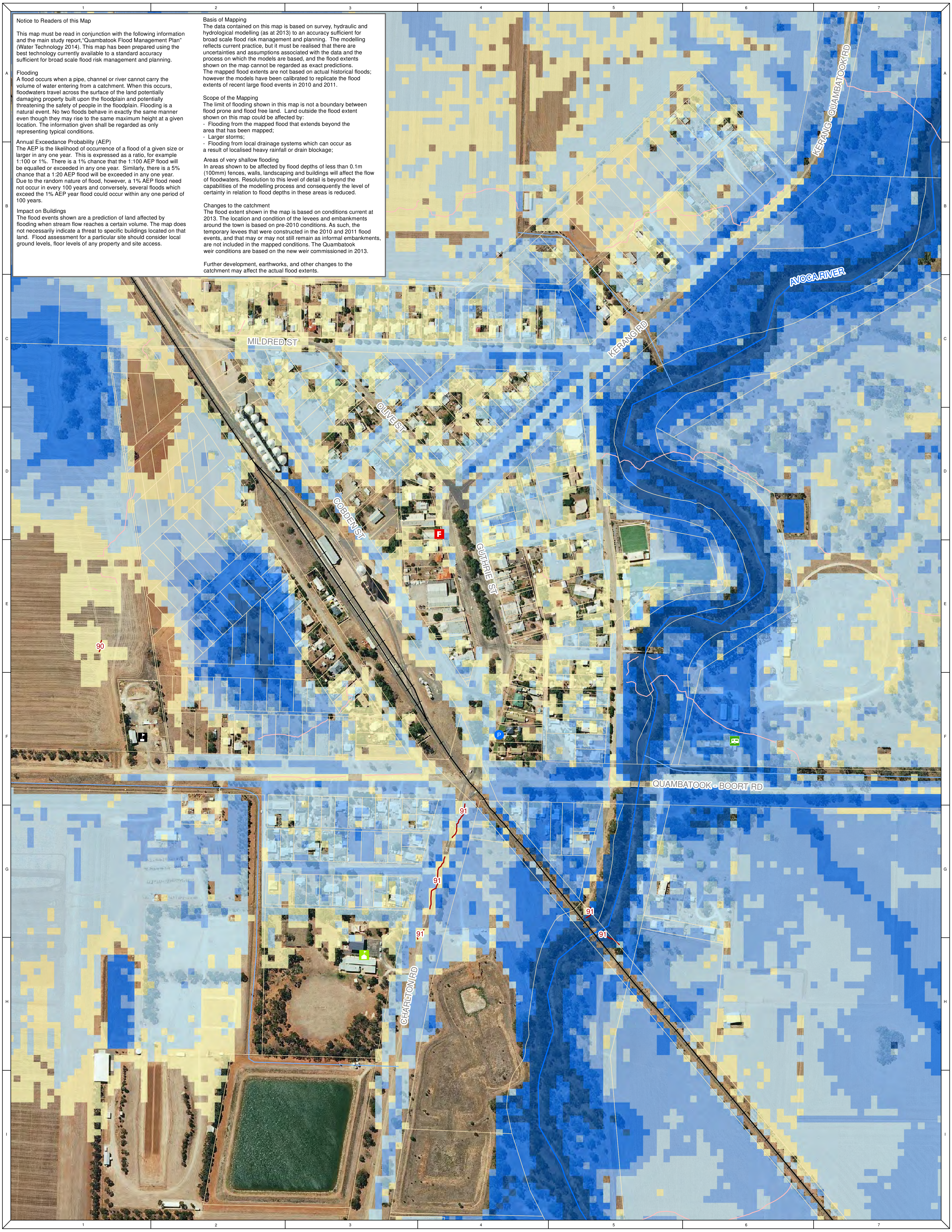
Areas of very shallow flooding

In areas shown to be affected by flood depths of less than 0.1m (100mm) fences, walls, landscaping and buildings will affect the flow of floodwaters. Resolution to this level of detail is beyond the capabilities of the modelling process and consequently the level of certainty in relation to flood depths in these areas is reduced.

Changes to the catchment

The flood extent shown in the map is based on conditions current at 2013. The location and condition of the levees and embankments around the town is based on pre-2010 conditions. As such, the temporary levees that were constructed in the 2010 and 2011 flood events, and that may or may not still remain as informal embankments, are not included in the mapped conditions. The Quambatook weir conditions are based on the new weir commissioned in 2013.

Further development, earthworks, and other changes to the catchment may affect the actual flood extents.



Fire Station	Rail Line	**Flood Depth (m)**
Police Station	River/Creek	0 - 0.1
Depot	Channel/Drain	0.1 - 0.25
School	1m WSE Contours	0.25 - 0.5
Caravan Park	20cm WSE Contours	0.5 - 1
	Cadastre	Greater than 1m

0 75 150 300 Meters 1:5,000 at A3

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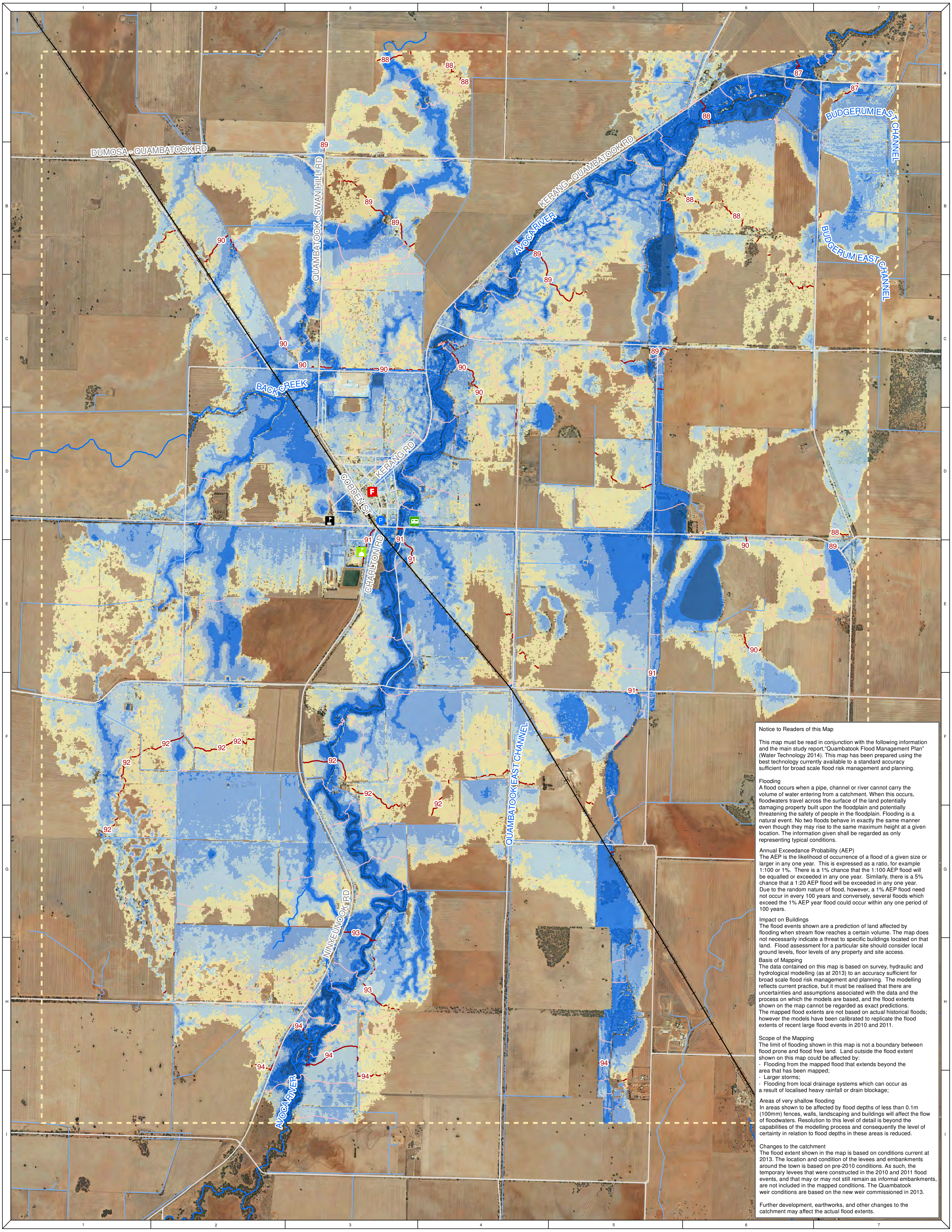
Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design\Quambatook_50y_Depth_Map_Town_Ext.mxd

DATE: 2/04/2013 | SHEET: 1 of 1 | DRAWING NUMBER: 1

Quambatook Flood Management Plan

1% AEP Depth Map
No Temporary Levees



Notice to Readers of this Map

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Flooding
A flood occurs when a pipe, channel or river cannot carry the volume of water entering from a catchment. When this occurs, floodwaters travel across the surface of the land potentially damaging property built upon the floodplain and potentially threatening the safety of people in the floodplain. Flooding is a natural event. No two floods behave in exactly the same manner even though they may rise to the same maximum height at a given location. The information given shall be regarded as only representing typical conditions.

Annual Exceedance Probability (AEP)
The AEP is the likelihood of occurrence of a flood of a given size or larger in any one year. This is expressed as a ratio, for example 1:100 or 1%. There is a 1% chance that the 1:100 AEP flood will be equalled or exceeded in any one year. Similarly, there is a 5% chance that a 1:20 AEP flood will be exceeded in any one year. Due to the random nature of flood, however, a 1% AEP flood need not occur in every 100 years and conversely, several floods which exceed the 1% AEP year flood could occur within any one period of 100 years.

Impact on Buildings
The flood events shown are a prediction of land affected by flooding when stream flow reaches a certain volume. The map does not necessarily indicate a threat to specific buildings located on that land. Flood assessment for a particular site should consider local ground levels, floor levels of any property and site access.

Basis of Mapping
The data contained on this map is based on survey, hydraulic and hydrological modelling (as at 2013) to an accuracy sufficient for broad scale flood risk management and planning. The modelling reflects current practice, but it must be realised that there are uncertainties and assumptions associated with the data and the process on which the models are based, and the flood extents shown on the map cannot be regarded as exact predictions.
The mapped flood extents are not based on actual historical floods; however the models have been calibrated to replicate the flood extents of recent large flood events in 2010 and 2011.

Scope of the Mapping
The limit of flooding shown in this map is not a boundary between flood prone and flood free land. Land outside the flood extent shown on this map could be affected by:
- Flooding from the mapped flood that extends beyond the area that has been mapped;
- Larger storms;
- Flooding from local drainage systems which can occur as a result of localised heavy rainfall or drain blockage;

Areas of very shallow flooding
In areas shown to be affected by flood depths of less than 0.1m (100mm) fences, walls, landscaping and buildings will affect the flow of floodwaters. Resolution to this level of detail is beyond the capabilities of the modelling process and consequently the level of certainty in relation to flood depths in these areas is reduced.

Changes to the catchment
The flood extent shown in the map is based on conditions current at 2013. The location and condition of the levees and embankments around the town is based on pre-2010 conditions. As such, the temporary levees that were constructed in the 2010 and 2011 flood events, and that may or may not still remain as informal embankments, are not included in the mapped conditions. The Quambatook weir conditions are based on the new weir commissioned in 2013.

Further development, earthworks, and other changes to the catchment may affect the actual flood extents.

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1m WSE Contours
20cm WSE Contours
Model Extent

Flood Depth (m)
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
Greater than 1m

0 0.5 1 2 Kilometers 1:35,000 at A3

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS
NORTH CENTRAL Catchment Management Authority
Connecting Rivers, Landscapes, People
GANNAWARRA SHIRE COUNCIL

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design \Quambatook_100y_Depth_Map.mxd

DATE: 2/04/2014 | SHEET: 1 of 1 | DRAWING NUMBER: 1

Notice to Readers of this Map

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Flooding
A flood occurs when a pipe, channel or river cannot carry the volume of water entering from a catchment. When this occurs, floodwaters travel across the surface of the land potentially damaging property built upon the floodplain and potentially threatening the safety of people in the floodplain. Flooding is a natural event. No two floods behave in exactly the same manner even though they may rise to the same maximum height at a given location. The information given shall be regarded as only representing typical conditions.

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Impact on Buildings
The flood events shown are a prediction of land affected by flooding when stream flow reaches a certain volume. The map does not necessarily indicate a threat to specific buildings located on that land. Flood assessment for a particular site should consider local ground levels, floor levels of any property and site access.

Basis of Mapping
The data contained on this map is based on survey, hydraulic and hydrological modelling (as at 2013) to an accuracy sufficient for broad scale flood risk management and planning. The modelling reflects current practice, but it must be realised that there are uncertainties and assumptions associated with the data and the process on which the models are based, and the flood extents shown on the map cannot be regarded as exact predictions.
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The limit of flooding shown in this map is not a boundary between flood prone and flood free land. Land outside the flood extent shown on this map could be affected by:
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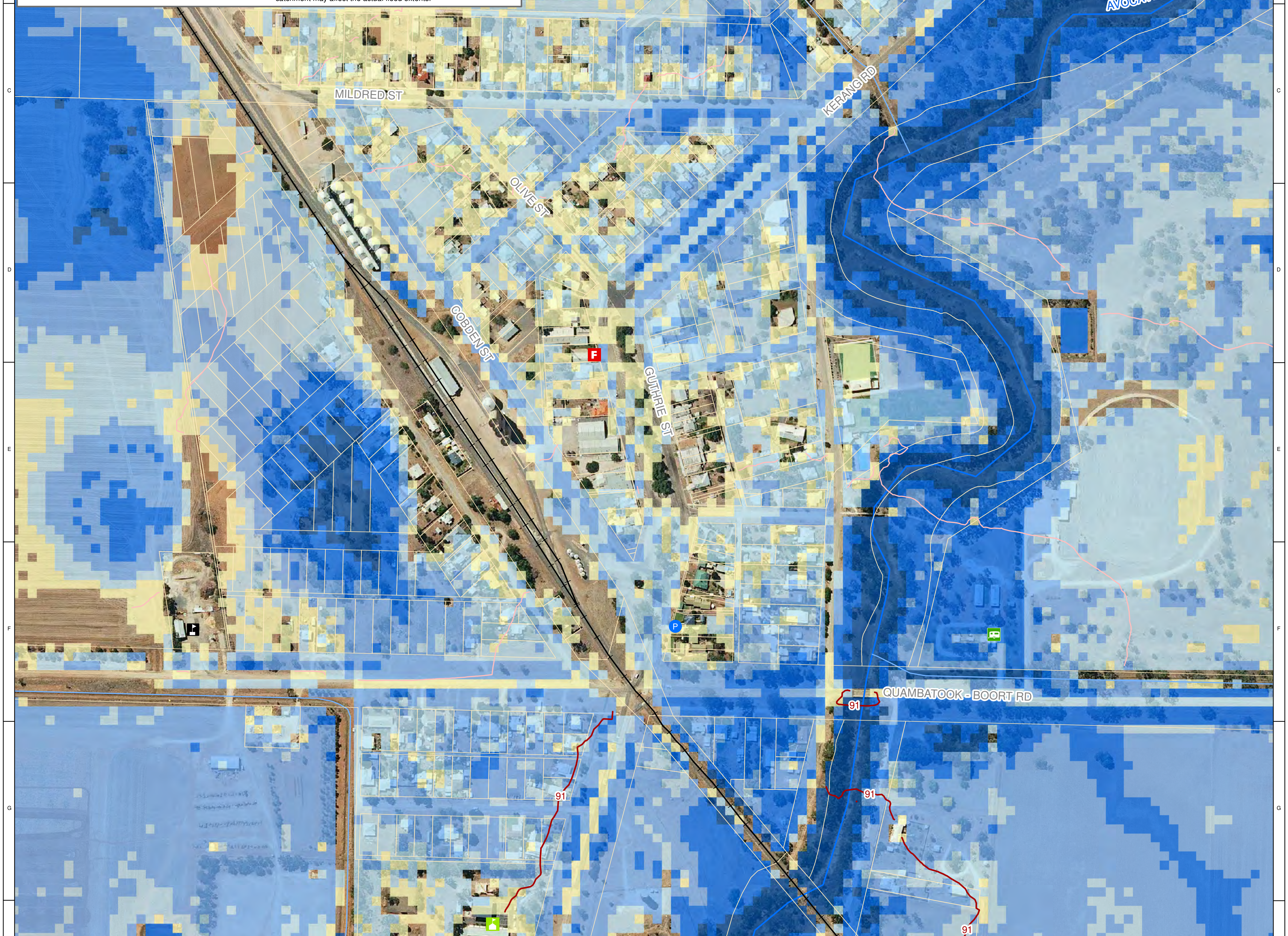
Changes to the catchment
The flood extent shown in the map is based on conditions current at 2013. The location and condition of the levees and embankments around the town is based on pre-2010 conditions. As such, the temporary levees that were constructed in the 2010 and 2011 flood events, and that may or may not still remain as informal embankments, are not included in the mapped conditions. The Quambatook weir conditions are based on the new weir commissioned in 2013.

Further development, earthworks, and other changes to the catchment may affect the actual flood extents.



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N S E W

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Caravan Park

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River/Creek
Channel/Drain
1m WSE Contours
20cm WSE Contours
Cadastre

Flood Depth (m)
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
Greater than 1m

0 75 150 300 Meters 1:5,000 at A3

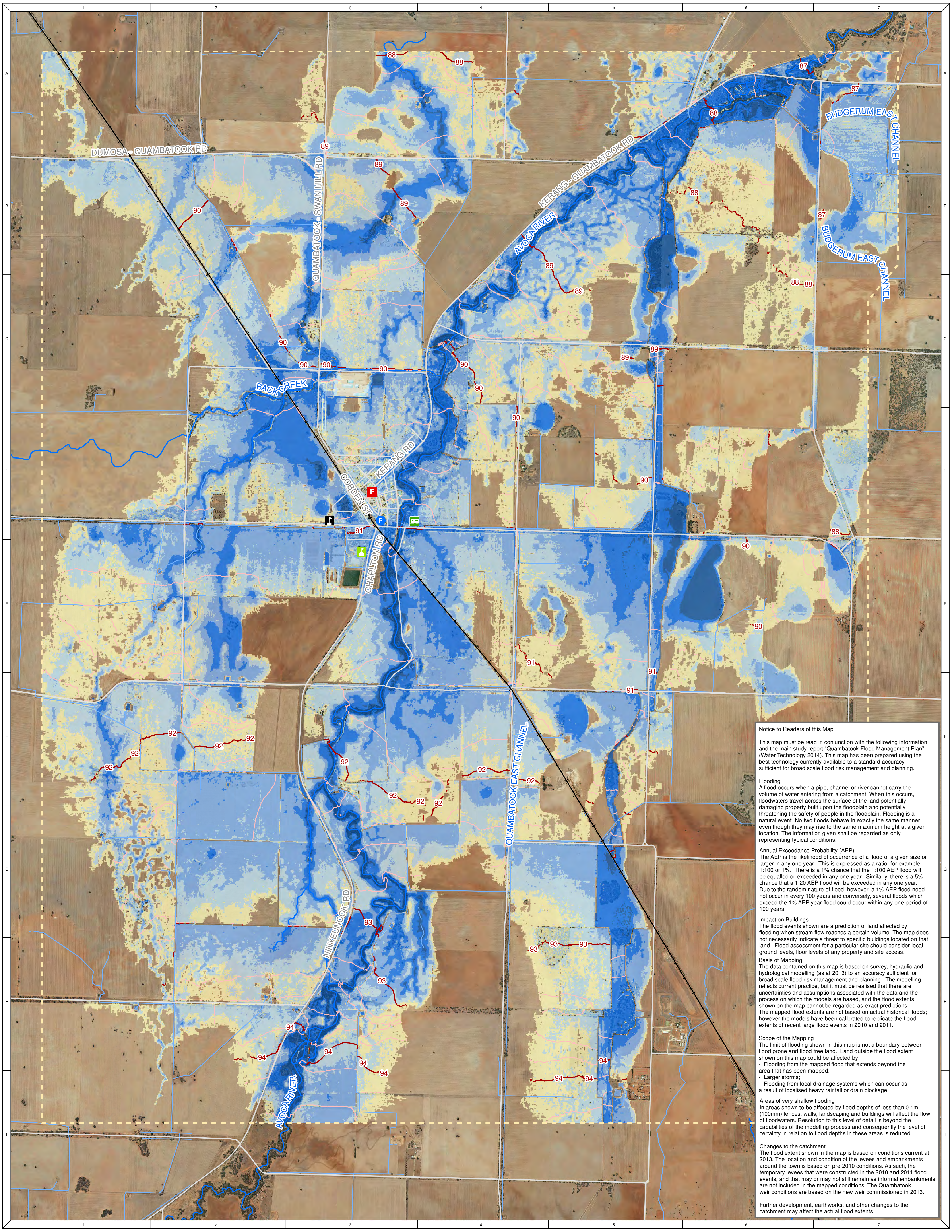
Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan

1% AEP Depth Map - Town Extent
No Temporary Levees

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design \Quambatook_100y_Depth_Map_Town_Ext.mxd

DATE: 2/04/2013 | SHEET: 1 of 1 | DRAWING NUMBER: 1



Notice to Readers of this Map

This map must be read in conjunction with the following information and the main study report,"Quambatook Flood Management Plan" (Water Technology 2014). This map has been prepared using the best technology currently available to a standard accuracy sufficient for broad scale flood risk management and planning.

Flooding

A flood occurs when a pipe, channel or river cannot carry the volume of water entering from a catchment. When this occurs, floodwaters travel across the surface of the land potentially damaging property built upon the floodplain and potentially threatening the safety of people in the floodplain. Flooding is a natural event. No two floods behave in exactly the same manner even though they may rise to the same maximum height at a given location. The information given shall be regarded as only representing typical conditions.

Annual Exceedance Probability (AEP)

The AEP is the likelihood of occurrence of a flood of a given size or larger in any one year. This is expressed as a ratio, for example 1:100 or 1%. There is a 1% chance that the 1:100 AEP flood will be equalled or exceeded in any one year. Similarly, there is a 5% chance that a 1:20 AEP flood will be exceeded in any one year. Due to the random nature of flood, however, a 1% AEP flood need not occur in every 100 years and conversely, several floods which exceed the 1% AEP year flood could occur within any one period of 100 years.

Impact on Buildings

The flood events shown are a prediction of land affected by flooding when stream flow reaches a certain volume. The map does not necessarily indicate a threat to specific buildings located on that land. Flood assessment for a particular site should consider local ground levels, floor levels of any property and site access.

Basis of Mapping

The data contained on this map is based on survey, hydraulic and hydrological modelling (as at 2013) to an accuracy sufficient for broad scale flood risk management and planning. The modelling reflects current practice, but it must be realised that there are uncertainties and assumptions associated with the data and the process on which the models are based, and the flood extents shown on the map cannot be regarded as exact predictions.
The mapped flood extents are not based on actual historical floods; however the models have been calibrated to replicate the flood extents of recent large flood events in 2010 and 2011.

Scope of the Mapping

The limit of flooding shown in this map is not a boundary between flood prone and flood free land. Land outside the flood extent shown on this map could be affected by:
- Flooding from the mapped flood that extends beyond the area that has been mapped;
- Larger storms;
- Flooding from local drainage systems which can occur as a result of localised heavy rainfall or drain blockage;

Areas of very shallow flooding

In areas shown to be affected by flood depths of less than 0.1m (100mm) fences, walls, landscaping and buildings will affect the flow of floodwaters. Resolution to this level of detail is beyond the capabilities of the modelling process and consequently the level of certainty in relation to flood depths in these areas is reduced.

Changes to the catchment

The flood extent shown in the map is based on conditions current at 2013. The location and condition of the levees and embankments around the town is based on pre-2010 conditions. As such, the temporary levees that were constructed in the 2010 and 2011 flood events, and that may or may not still remain as informal embankments, are not included in the mapped conditions. The Quambatook weir conditions are based on the new weir commissioned in 2013.

Further development, earthworks, and other changes to the catchment may affect the actual flood extents.

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Model Extent

Flood Depth (m)
0 - 0.1
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0.5 - 1
Greater than 1m

0 0.5 1 2 Kilometers
1:35,000 at A3

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan

0.5% AEP Depth Map
No Temporary Levees

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design\Quambatook_200y_Depth_Map.mxd

DATE: 2/04/2014	SHEET: 1 of 1	DRAWING NUMBER: 1

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Flooding
A flood occurs when a pipe, channel or river cannot carry the volume of water entering from a catchment. When this occurs, floodwaters travel across the surface of the land potentially damaging property built upon the floodplain and potentially threatening the safety of people in the floodplain. Flooding is a natural event. No two floods behave in exactly the same manner even though they may rise to the same maximum height at a given location. The information given shall be regarded as only representing typical conditions.

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The AEP is the likelihood of occurrence of a flood of a given size or larger in any one year. This is expressed as a ratio, for example 1:100 or 1%. There is a 1% chance that the 1:100 AEP flood will be equalled or exceeded in any one year. Similarly, there is a 5% chance that a 1:20 AEP flood will be exceeded in any one year. Due to the random nature of flood, however, a 1% AEP flood need not occur in every 100 years and conversely, several floods which exceed the 1% AEP year flood could occur within any one period of 100 years.

Impact on Buildings
The flood events shown are a prediction of land affected by flooding when stream flow reaches a certain volume. The map does not necessarily indicate a threat to specific buildings located on that land. Flood assessment for a particular site should consider local ground levels, floor levels of any property and site access.

Basis of Mapping
The data contained on this map is based on survey, hydraulic and hydrological modelling (as at 2013) to an accuracy sufficient for broad scale flood risk management and planning. The modelling reflects current practice, but it must be realised that there are uncertainties and assumptions associated with the data and the process on which the models are based, and the flood extents shown on the map cannot be regarded as exact predictions.
The mapped flood extents are not based on actual historical floods; however the models have been calibrated to replicate the flood extents of recent large flood events in 2010 and 2011.

Scope of the Mapping
The limit of flooding shown in this map is not a boundary between flood prone and flood free land. Land outside the flood extent shown on this map could be affected by:
- Flooding from the mapped flood that extends beyond the area that has been mapped;
- Larger storms;
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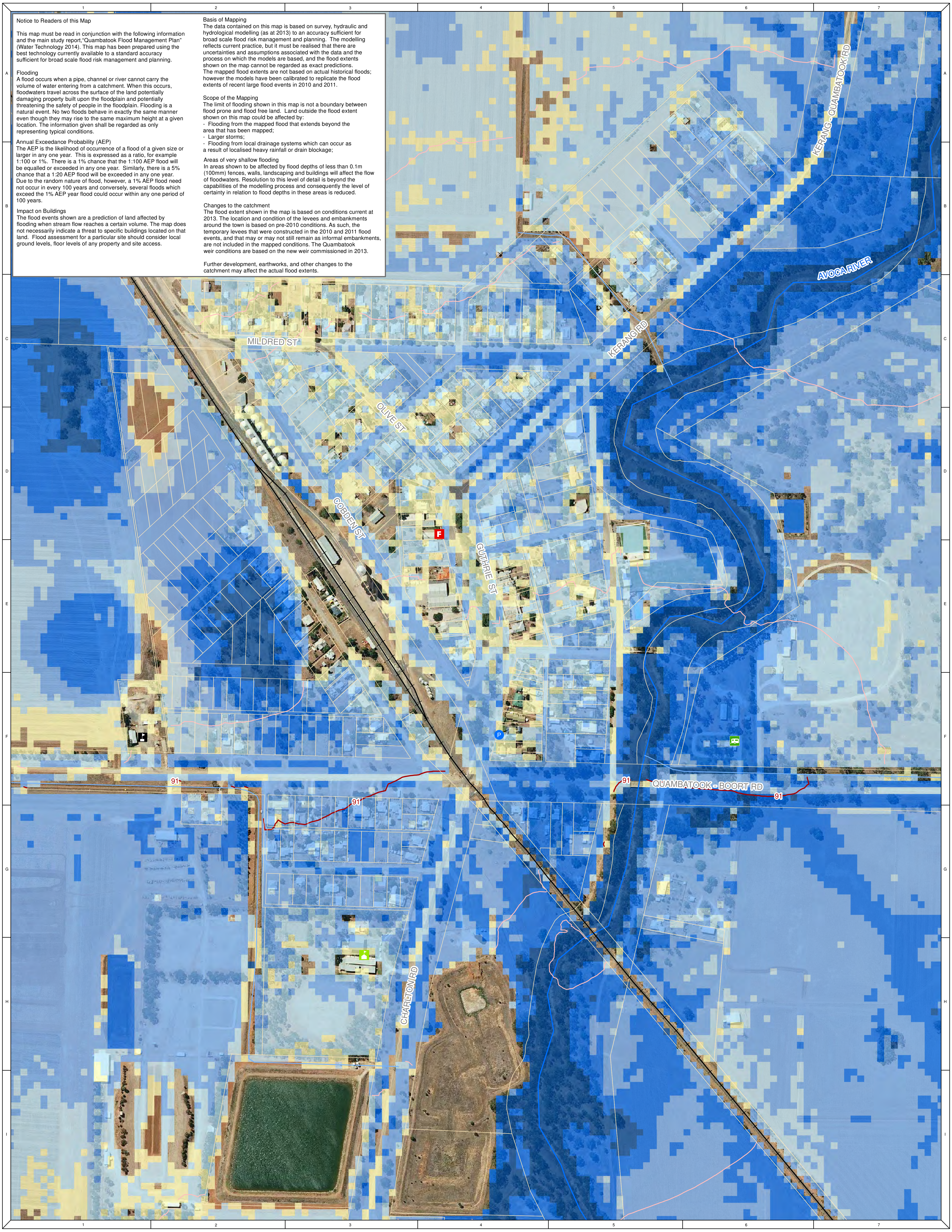
Areas of very shallow flooding
In areas shown to be affected by flood depths of less than 0.1m (100mm) fences, walls, landscaping and buildings will affect the flow of floodwaters. Resolution to this level of detail is beyond the capabilities of the modelling process and consequently the level of certainty in relation to flood depths in these areas is reduced.

Changes to the catchment
The flood extent shown in the map is based on conditions current at 2013. The location and condition of the levees and embankments around the town is based on pre-2010 conditions. As such, the temporary levees that were constructed in the 2010 and 2011 flood events, and that may or may not still remain as informal embankments, are not included in the mapped conditions. The Quambatook weir conditions are based on the new weir commissioned in 2013.

Further development, earthworks, and other changes to the catchment may affect the actual flood extents.



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Flood Depth (m)
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- Greater than 1m

0 75 150 300 Meters

1:5,000 at A3

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

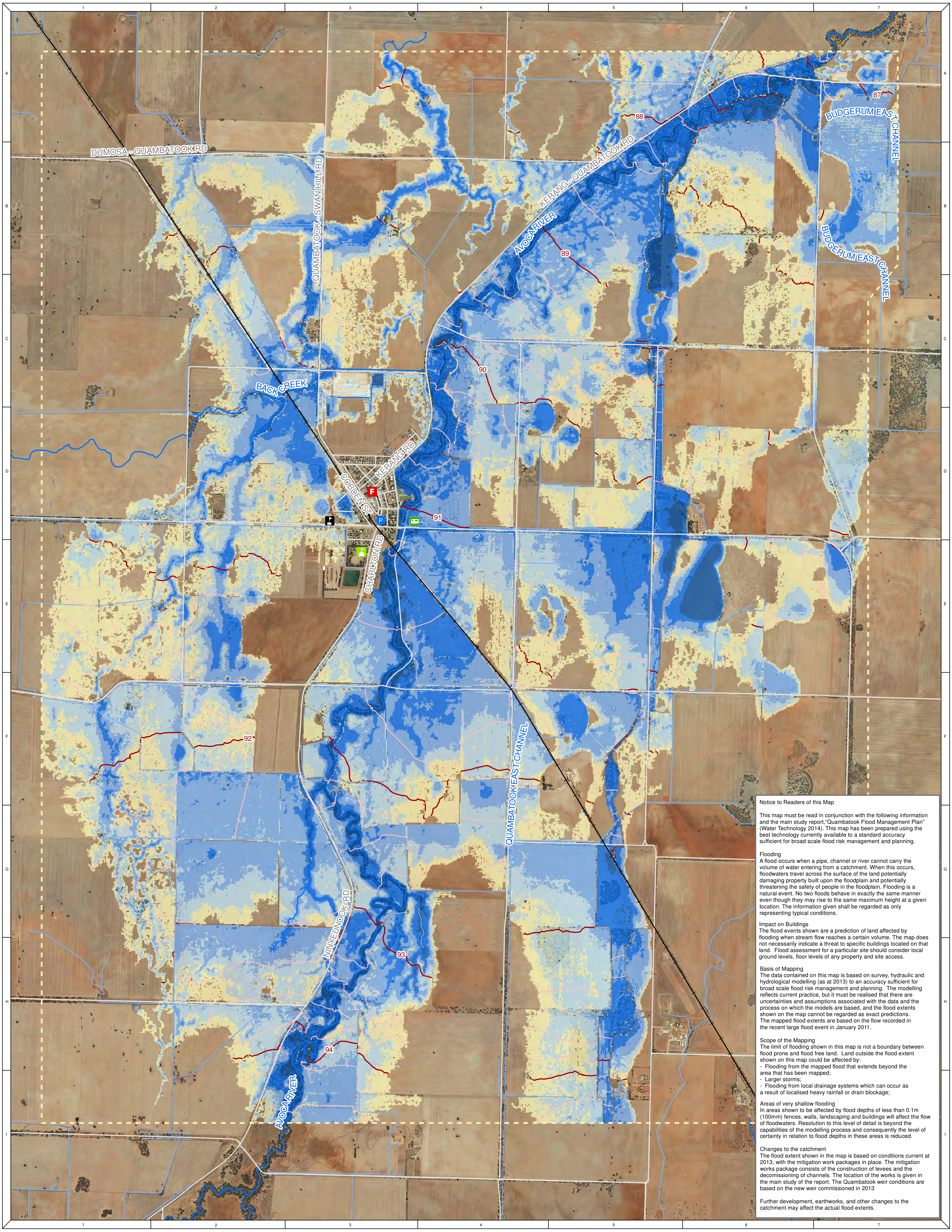
Quambatook Flood Management Plan

0.5% AEP Depth Map - Town Extent
No Temporary Levees

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Design\Quambatook_200y_Depth_Map_Town_Ext.mxd

DATE: 2/04/2013 | SHEET: 1 of 1 | DRAWING NUMBER: 1

APPENDIX C MITIGATION FLOOD MAP



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Flooding
A flood occurs when a pipe, channel or river cannot carry the volume of water entering from a catchment. When this occurs, floodwaters travel across the surface of the land potentially damaging property built upon the floodplain and potentially threatening the safety of people in the floodplain. Flooding is a natural event. No two floods behave in exactly the same manner even though they may rise to the same maximum height at a given location. The information given shall be regarded as only representing typical conditions.

Impact on Buildings
The flood events shown are a prediction of land affected by flooding when stream flow reaches a certain volume. The map does not necessarily indicate a threat to specific buildings located on that land. Flood assessment for a particular site should consider local ground levels, floor levels of any property and site access.

Basis of Mapping
The data contained on this map is based on survey, hydraulic and hydrological modelling (as at 2013) to an accuracy sufficient for broad scale flood risk management and planning. The modelling reflects current practice, but it must be realised that there are uncertainties and assumptions associated with the data and the process on which the models are based, and the flood extents shown on the map cannot be regarded as exact predictions. The mapped flood extents are based on the flow recorded in the recent large flood event in January 2011.

Scope of the Mapping
The limit of flooding shown in this map is not a boundary between flood prone and flood free land. Land outside the flood extent shown on this map could be affected by:
- Flooding from the mapped flood that extends beyond the area that has been mapped;
- Larger storms;
- Flooding from local drainage systems which can occur as a result of localised heavy rainfall or drain blockage;

Areas of very shallow flooding
In areas shown to be affected by flood depths of less than 0.1m (100mm) fences, walls, landscaping and buildings will affect the flow of floodwaters. Resolution to this level of detail is beyond the capabilities of the modelling process and consequently the level of certainty in relation to flood depths in these areas is reduced.

Changes to the catchment
The flood extent shown in the map is based on conditions current at 2013, with the mitigation work packages in place. The mitigation works package consists of the construction of levees and the decomissioning of channels. The location of the works is given in the main study of the report. The Quambatook weir conditions are based on the new weir commissioned in 2013

Further development, earthworks, and other changes to the catchment may affect the actual flood extents.

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Greater than 1m

0 0.5 1 2 Kilometers
1:35,000 at A3

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan

January 2011 Mitigation Map

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Mitigation \Quambatook_Jan2011_Mitigation_Map.mxd

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A flood occurs when a pipe, channel or river cannot carry the volume of water entering from a catchment. When this occurs, floodwaters travel across the surface of the land potentially damaging property built upon the floodplain and potentially threatening the safety of people in the floodplain. Flooding is a natural event. No two floods behave in exactly the same manner even though they may rise to the same maximum height at a given location. The information given shall be regarded as only representing typical conditions.

Impact on Buildings
The flood events shown are a prediction of land affected by flooding when stream flow reaches a certain volume. The map does not necessarily indicate a threat to specific buildings located on that land. Flood assessment for a particular site should consider local ground levels, floor levels of any property and site access.

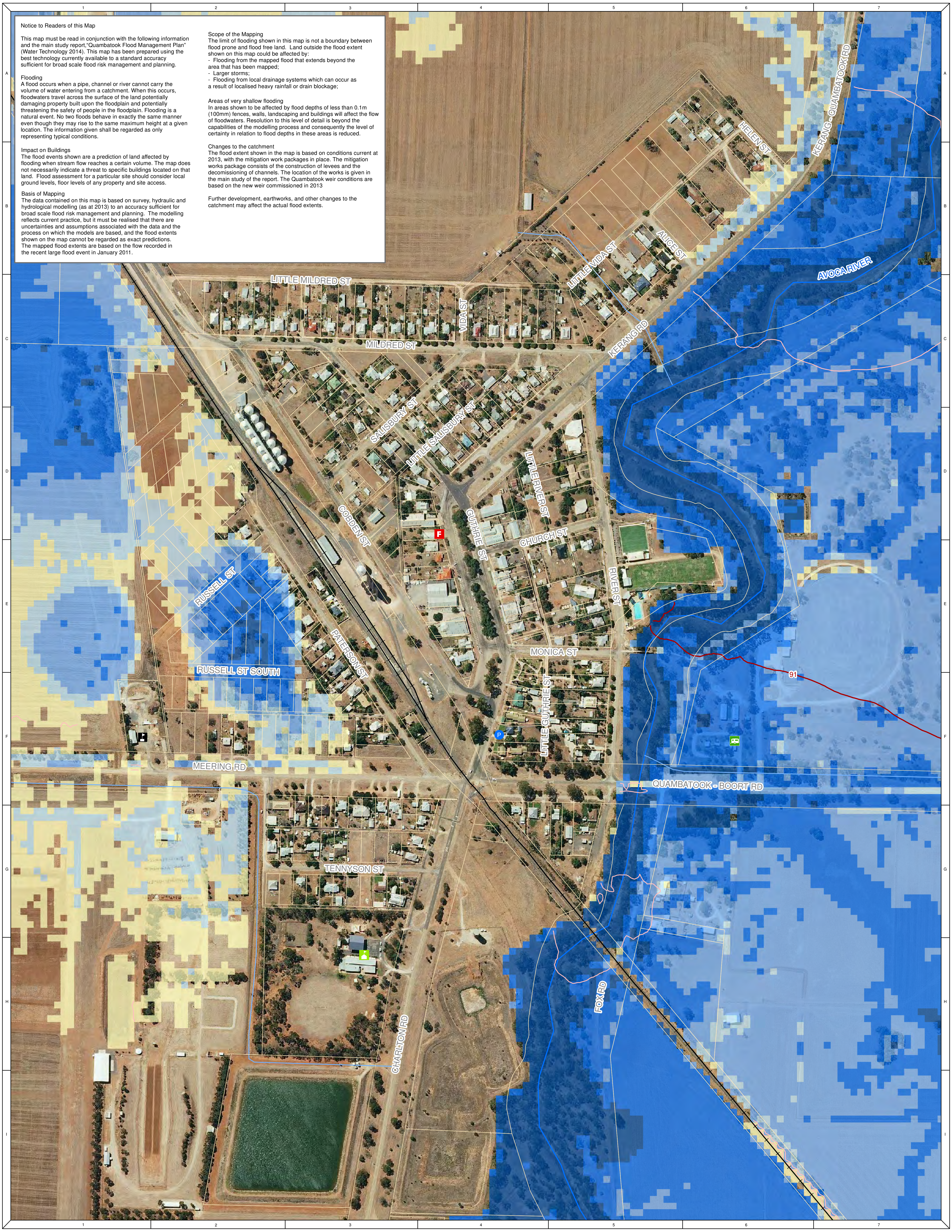
Basis of Mapping
The data contained on this map is based on survey, hydraulic and hydrological modelling (as at 2013) to an accuracy sufficient for broad scale flood risk management and planning. The modelling reflects current practice, but it must be realised that there are uncertainties and assumptions associated with the data and the process on which the models are based, and the flood extents shown on the map cannot be regarded as exact predictions. The mapped flood extents are based on the flow recorded in the recent large flood event in January 2011.

Scope of the Mapping
The limit of flooding shown in this map is not a boundary between flood prone and flood free land. Land outside the flood extent shown on this map could be affected by:
- Flooding from the mapped flood that extends beyond the area that has been mapped;
- Larger storms;
- Flooding from local drainage systems which can occur as a result of localised heavy rainfall or drain blockage;

Areas of very shallow flooding
In areas shown to be affected by flood depths of less than 0.1m (100mm) fences, walls, landscaping and buildings will affect the flow of floodwaters. Resolution to this level of detail is beyond the capabilities of the modelling process and consequently the level of certainty in relation to flood depths in these areas is reduced.

Changes to the catchment
The flood extent shown in the map is based on conditions current at 2013, with the mitigation work packages in place. The mitigation works package consists of the construction of levees and the decomissioning of channels. The location of the works is given in the main study of the report. The Quambatook weir conditions are based on the new weir commissioned in 2013

Further development, earthworks, and other changes to the catchment may affect the actual flood extents.



NOTE
Water Technology Pty. Ltd. has prepared this document in accordance with instruction of Gannawarra Shire Council for their specific use.

DISCLAIMER
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N E S W

Fire Station
Police Station
Depot
School
Caravan Park

Rail Line
River/Creek
Channel/Drain
1m WSE Contours
20cm WSE Contours
Cadastre

Flood Depth (m)
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
Greater than 1m

0 75 150 300 Meters
1:5,000 at A3

WATER TECHNOLOGY
NORTH CENTRAL Catchment Management Authority
Connecting Rivers, Landscapes, People
GANNAWARRA SHIRE COUNCIL

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

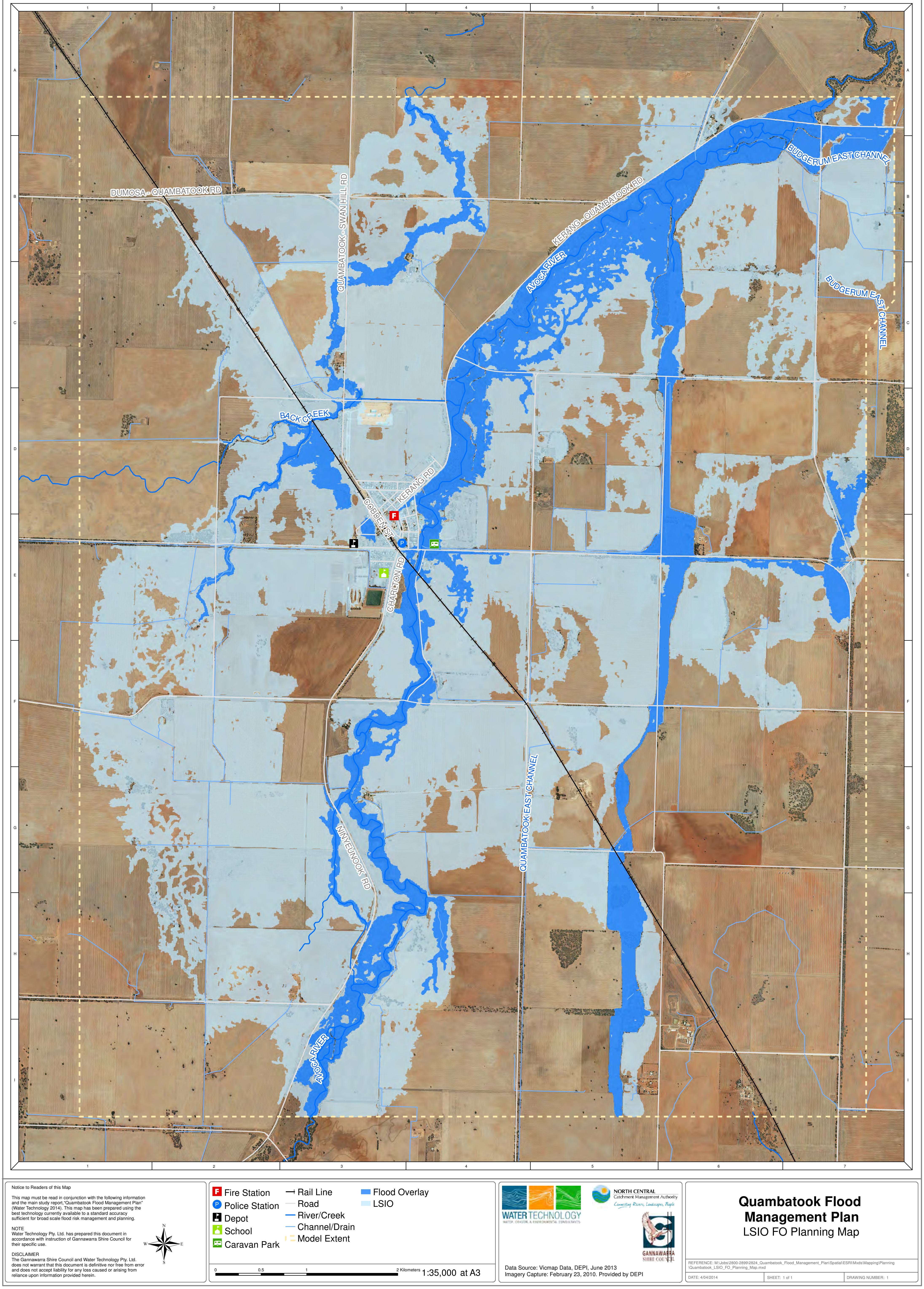
Quambatook Flood Management Plan

January 2011 Mitigation Map - Town Extent

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Mitigation \Quambatook_Jan2011_Mitigation_Map_Town_Ext.mxd

DATE: 2/04/2014	SHEET: 1 of 1	DRAWING NUMBER: 1

APPENDIX D DRAFT PLANNING OVERLAYS



Notice to Readers of this Map

This map must be read in conjunction with the following information and the main study report,"Quambatook Flood Management Plan" (Water Technology 2014). This map has been prepared using the best technology currently available to a standard accuracy sufficient for broad scale flood risk management and planning.

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Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan
LSIO FO Planning Map

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Planning\Quambatook_LSIO_FO_Planning_Map.mxd

DATE: 4/04/2014 | SHEET: 1 of 1 | DRAWING NUMBER: 1

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N
W E
S

- Fire Station
- Police Station
- Depot
- School
- Caravan Park
- Rail Line
- River/Creek
- Channel/Drain
- Cadastre
- Flood Overlay
- LSIO

0 75 150 300 Meters

1:5,000 at A3

Data Source: Vicmap Data, DEPI, June 2013
Imagery Capture: February 23, 2010. Provided by DEPI

Quambatook Flood Management Plan

LSIO FO Planning Map - Town Extent

REFERENCE: M:\Jobs\2800-2899\2824_Quambatook_Flood_Management_Plan\Spatial\ESRI\Mxds\Mapping\Planning \Quambatook_LSIO_FO_Planning_Map_Town_Ext.mxd

DATE: 4/04/2014 | SHEET: 1 of 1 | DRAWING NUMBER: 1