Harrow
Flood Investigation
Summary Report

June 2017

Document Status

Version	Doc type	Reviewed by	Approved by	Distributed to	Date issued
v01	Summary Report	Ben Tate	Ben Tate	Tatjana Bunge	30/06/2017

PROJECT DETAILS

Project Name	Harrow Flood Investigation
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Job Number	4296-01
Report Number	R07
Document Name	4296-01R07v01_SummaryReport.docx

Cover Photo: Flooding in Harrow during January 2011 flood event, captured 10 December 2010, 7:41am (GHCMA)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Overview

Water Technology was commissioned by the Glenelg Hopkins CMA to undertake the Harrow Flood Investigation. The study included detailed hydrological and hydraulic modelling of the Glenelg River and Salt Creek, flood mapping of the Harrow township, and recommendations for flood mitigation works.

The following Summary Report (R07), provides a summary of six previous reporting stages. This report acts as an executive summary of the entire study. A description of each of the staged reports is included below.

R01 - Harrow Flood Investigation – Data Collation and Review (Water Technology 2016)

Review of flood related information for the study area, a review of available topographic and structure data (bridges and culvert information), and verification of topographic data. The report also provided a proposed outline of the hydrologic analysis and hydraulic modelling methodology.

R02 - Harrow Flood Investigation – Hydrology Report (Water Technology 2016)

Hydrologic modelling and analysis report, summarising results of calibration and design RORB modelling, Flood Frequency Analysis and sensitivity testing.

R03 - Harrow Flood Investigation – Hydraulic Calibration Report (Water Technology 2016)

Detailing the hydraulic model calibration and design modelling methodology.

R04 - Harrow Flood Investigation – Modelling Report (Water Technology 2016)

Combining the hydrology and hydraulics calibration and design to produce a report of the modelling completed as part of the Harrow Flood Investigation.

R05 - Harrow Flood Investigation– Flood Intelligence Report (Water Technology 2017)

Containing all information required for appendices A, B, C, D, E and F of the Municipal Flood Emergency Plan. Includes specific information about the Glenelg River and Salt Creek at Harrow, as well as the flood risk to the community of Harrow.

R06 - Harrow Flood Investigation– Final Report (Water Technology 2017)

Combining previous reporting into a comprehensive final report.

R07 - Harrow Flood Investigation – Summary Report (Water Technology 2016e) – this report

Brief summary of all work completed during this project.

These seven reports detail the approaches adopted, the findings and recommendations, of the Harrow Flood Investigation. The reports are supported by several standalone PDF flood maps and digital deliverables.

1.2 Study Area

Harrow is located in south-west Victoria, approximately 75 km north-west of Hamilton and 30 km south-east of Edenhope. The township is located on the Glenelg River, with the Salt Creek tributary flowing into the Glenelg River immediately upstream of Harrow.

The Glenelg River begins in the Grampians National Park where it inflows to the offline Moora Moora Reservoir via a diversion channel, and flows on to Rocklands Reservoir, the largest storage in the system. Rocklands is a significant storage operated by GWMWater and its construction in 1953 has significantly altered the flow regime for the Glenelg River.

Harrow is located approximately 75 km downstream of Rocklands Reservoir. The major waterways are shown in Figure 1-1. The figure shows the Salt Creek catchment to the north flowing into the Glenelg River at Harrow.

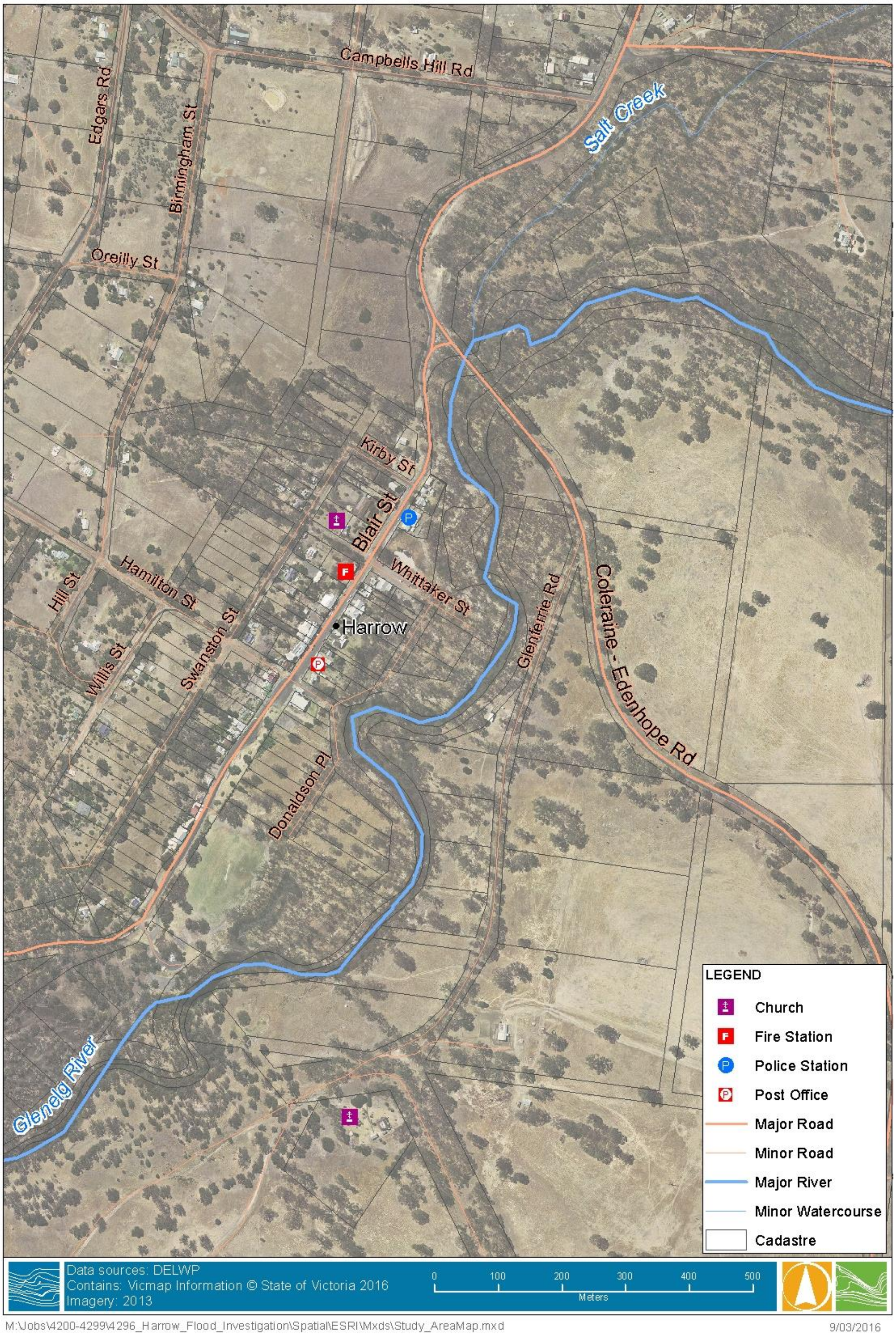

Figure 1-1 Harrow – Major waterways within the township

2. AVAILABLE INFORMATION

2.1 Flood Related Studies

Several previous studies relevant to flooding of the Glenelg River were available, including:

- Glenelg Flood Investigations (Cardno Lawson and Treloar, 2008)
- Casterton Flood Investigation (Cardno, 2011)
- Review of Storage Operation During Floods Grampians Wimmera Mallee Water (Water Technology, 2011)
- Preparation of Glenelg Hopkins CMA Submission to the Review of 2010-11 Flood Warnings and Response (Water Technology, 2012)
- Casterton Flood Intelligence & Warning Improvements (WBM BMT, 2014)
- Glenelg Regional Flood Mapping Project (Water Technology, 2015)
- Glenelg River Technical Flows Study (Water Technology, 2015)

2.2 Available Hydrological Data

2.2.1 Streamflow Data

Currently, there are four operational stream flow gauges upstream of Harrow. An additional gauge at Balmoral was discontinued in 1956. Each of these gauges is shown in Table 2-1, detailing the period of record and maximum flow recorded.

Rocklands Reservoir has a large influence on flows in the Glenelg River. Construction on the reservoir was completed in 1953, therefore events prior to 1953 are not reflective of streamflows that may be observed today, and were omitted from the calibration and design flow determination.

There have been no major spills from Rocklands Reservoir since construction, with the largest 47 m^3/s in 1956. The Fulham Bridge gauge has recorded much larger flows, indicating that the catchment downstream of Rocklands Reservoir can contribute significant flow that generate floods without requiring spills from Rocklands Reservoir. Floods could also be produced by large rainfalls in the upper catchment leading to Rocklands Reservoir filling and spilling in combination with runoff generated in the lower catchment. Given the capacity of Rocklands Reservoir, the current operational rules which mandate the storage must not exceed 80% capacity, and record of spills since 1953, future spills are unlikely to be frequent. For example, in the record wet years of 2010-12, Rocklands Reservoir only filled to around 40% of its operating capacity.

The Fulham Bridge and Harrow streamflow gauges have the highest value to this study. The Fulham Bridge gauge is located approximately 40 km upstream of Harrow while the Harrow gauge is located south of the Harrow township, immediately downstream of the Harrow Recreation Reserve.

2.2.2 Rainfall Data

There are numerous daily rainfall gauges located across the Glenelg River catchment upstream of Harrow. There is also a sub-daily rainfall gauge located at Rocklands.

The daily and sub daily gauges considered relevant to this study are shown below in Table 2-2, detailing each gauge's period of record and maximum daily recording. The gauges within the Harrow catchment area are highlighted in **Bold**.

Table 2-1 Study area streamflow gauge details

Location	Number	Start Date	Start of instantaneous	End Date	Peak Flow (m^3/s)	Peak flow date
Big Cord	238231	24/04/1968	17/05/1979	Current	10.2	Jan 2011
Rocklands	238205	22/03/1941	21/07/1983	Current	77.9* 47.0^	Sep 1942 & Mar 1946 Aug 1956
Balmoral	238201	25/05/1889	-	1/10/1956	365.4	Mar 1946
Fulham Bridge	238224	06/03/1964	8/01/1976	Current	131.3	Dec 2010
Harrow	238210	30/11/2001	30/11/2001	Current	116.7	Dec 2010

* Maximum peak flow occurred prior to the construction of Rocklands Reservoir in 1953
^ Peak flow post the construction of Rocklands Reservoir

Table 2-2 Relevant rainfall gauge details

Gauge Name	Gauge Number	Start of daily record	End of record	Max. Daily Recording (mm)	Year achieved
Clear Lake (Marlbro)	79008	1903	-	117.1	1957
Halls Gap (Post Office)	79074	1958	-	146.6	2011
Harrow (Post Office)	**79021**	**1908**	**-**	**108**	**1946**
Harrow (Pine Hills)	**79022**	**1884**	**2011**	**88.9**	**1952**
Rocklands Reservoir*	**79052**	**1948**	**2010**	**118.1**	**1957**
Telangatuk East (Milingimbi)	**79078**	**1968**	**-**	**95**	**2011**
Balmoral (Post Office)	89003	1884	-	104.1	1952
Mirranatwa (Bowacka)	89019	1901	-	124	1957
Willaura (Yarram Park	89037	1902	-	98	2010
Gatum (Orana)	89043	1953	-	88.4	1957
Coojar (Killara)	**90026**	**1939**	**-**	**90.4**	**1946**
Nareen	90140	1968	2005	68	1987
Wartook Reservoir	79046	1890	-	118.4	1941

* sub daily rainfall gauge

2.3 Storages

There are two major water storages within the Glenelg River catchment upstream of Harrow, Rocklands Reservoir and Moora Moora Reservoir.

Moora Moora Reservoir is a relatively small reservoir upstream of Rocklands Reservoir, constructed in 1934. The reservoir has a Full Supply Volume of 6,300 ML and captures flows from Moora Moora Creek. The Reservoir is offline from the Glenelg River but it diverts a portion of Glenelg River high flows into the storage. Moora Moora Reservoir Outlets to the Moora Channel which passes on to Distribution Heads.

Rocklands was finished construction in 1953, with a capacity of 348,000 ML. It is managed and maintained by GWMWater, and is the largest storage in their system. It was originally designed as a carry-over storage to be managed along with Toolondo Reservoir[1]. Due to its shape, Rocklands has a much higher evaporation than Toolondo and therefore, water was transferred to and stored in Toolondo in preference to Rocklands. Inflow to Rocklands Reservoir averages 101,000 ML/year with much of the flow occurring during the period July to October[2].

The GWMWater O&M Manual for Rocklands Reservoir states that since construction the dam has never passed a major flood. A review of the Rocklands Reservoir Head Gauge levels and discussion with former GWMWater staff[3] indicated reservoir spills have occurred in:

- 1953
- 1955
- 1956
- 1958
- 1960
- 1974
- 1975
- 1988
- 1989
- 1990
- 1992
- 1993
- 1996

Table 2-3 shows the detail of spills occurring from Rocklands Reservoir above 2500 ML/day or 30m^3/s.

Table 2-3 Rocklands Reservoir spill details

Spill Date	*Maximum discharge recorded on the Glenelg River at Rocklands*	
	ML/d	*m^3/s*
August 1956	*4060*	*47.0*
September 1974	*2250*	*26.0*
October 1975	*5300*	*61.3*
July 1983	*2605*	*30.2*
August 1988	*3280*	*38.0*
August 1992	*3540*	*41.0*

[1] Barlow (1987) - Wimmera / Mallee Headworks System Reference Manual

[2] Water Technology (2011) - Review of Storage Operation During Floods Grampians Wimmera Mallee Water

[3] Pers. Comm – John Martin (Former Executive Manager, Sustainable Water and Infrastructure)

2.4 Topographic Data/Survey

2.4.1 LiDAR

High resolution LiDAR was available for the study area, ensuring the topography could be accurately represented in the hydraulic modelling. The Glenelg River Regional Flood Mapping Project[4] used a series of surveyed road crest and survey transects to verify the accuracy of the Index of Stream Conditions (ISC) LiDAR data available for the project. The surveyed transects showed a clear difference between the LiDAR and the surveyed transects, with the ISC LiDAR consistently higher than the survey. This was observed for survey data locations along the Glenelg River across all survey sources. The LiDAR verification process identified that on average the LiDAR was 0.32 m higher than the survey. This was verified by the LiDAR verification undertaken during the Casterton Flood Investigation[5] and Skipton Flood Investigation[6] which also found a uniform difference between the ISC LiDAR data and survey heights of 0.32 m. The ISC LiDAR data was lowered to accommodate for this difference.

2.4.2 Observed peak flood heights and extents

Observed peak flood heights were available within the Harrow township for the following events:

- 1946 (2 observations)
- September 2010 (7 observations)
- December 2010 (9 observations)

Unfortunately, the only formal flood extents available for Harrow are for the 1946 event which was not preferred for calibration due to the construction of Rocklands Reservoir in 1953. However, a significant amount of community anecdotal evidence is available for the more recent events. This information was drawn on during the calibration process.

3. PROJECT CONSULTATION

3.1 Overview

A key element in the development of the Harrow Flood Investigation was the active engagement of residents in the study area. This engagement was developed over the course of the study through community consultation sessions, social media and meetings with a Project Steering Committee including several members of the community. The community consultation sessions were largely managed by Glenelg Hopkins CMA and West Wimmera Shire Council. The aims of the community consultation were as follows:

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

[4] Water Technology (2015), Glenelg Regional Flood Mapping Project, Commissioned by DELWP

[5] Cardno (2011), Casterton Flood Investigation, Commissioned by Glenelg Hopkins CMA

[6] Water Technology (2011), Skipton Flood Investigation, Commissioned by Glenelg Hopkins CMA

3.2 Stakeholder Advisory Group

The Harrow Flood Investigation was led by a Stakeholder Advisory Group consisting of representatives from Glenelg Hopkins CMA, West Wimmera Shire Council, Department of Environment, Land, Water and Planning (DELWP), State Emergency Service (SES), Bureau of Meteorology (BoM) Grampians Wimmera Mallee Water (GWMWater), Water Technology and the Harrow community.

The Steering Committee met on 3 occasions at key points throughout the study, to manage the development of the investigation. The meeting dates and basis for discussion was as follows:

- Thursday 18th February 2016 – Project introduction and overview
- Thursday 2nd June 2016 – Modelling methodology and calibration
- Tuesday 29th November 2016 - Mitigation options, planning scheme overlays, flood intelligence and warning

3.3 Community Consultation

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

- Initial community meeting, Harrow Hermitage Hotel (18th February 2016). The first public meeting was held to outline the objectives of the study to the community, communicate what the community could expect from the study and gather input from the community on observed inundation and potential mitigation solutions.
- Second community meeting, Harrow Hermitage Hotel (2nd June 2016). The second community meeting presented calibration results for the September and December 2010 events and 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 additional flood mitigation options.
- Third community meeting, Harrow Hermitage Hotel (19th December 2016). The final public meeting presented planning scheme layers, mitigation modelling and project outcomes. Community feedback was sought on potential levee design, location and appearance.

In general, the Harrow community was very pleased with the rigour and outcomes of the Harrow Flood Investigation. The community was generally not in favour of any general structural flood mitigation for buildings within the township aside from individual property protection measures which could be investigated by individual property owners.

There was interest in a levee protecting the John Mullagh Memorial Park to prevent repetitive inundation during minor floods. This is discussed in Section 6.2.2.

There was also numerous comments and discussion about environmental flows occurring during flood events, which was perceived to exacerbate flood levels, the impact of environmental flows on peak flood levels during a flood event were shown to be relatively minor.

4. HYDROLOGICAL MODELLING

4.1 Overview and Methodology

The primary aims of the hydrological analysis undertaken for this project included:

- Determine calibration events and flows to be used in the hydraulic model.
- Determine design event peak flow and hydrograph shape for input to the hydraulic model at the model boundaries. Design events included 0.2%, 0.5%, 1%, 2%, 5%, 10% and 20% AEP flood events, Probable Maximum Flood (PMF) and climate change scenarios.
- Test the impact of varying starting levels in Rocklands Reservoir on flows in the Glenelg River downstream of Rocklands.

To achieve these aims, the hydrological assessment was completed using multiple models and approaches. The Glenelg Regional Flood Mapping Project[4] had previously developed a regional scale RORB model and 1D hydraulic model of the Glenelg River. The Fulham Bridge streamflow gauge also provides good streamflow data with Flood Frequency completed for the gauge location. The streamflow gauge and the previous regional scale RORB model was used to develop inflows to the Glenelg River at Fulham Bridge. The RORB model was too coarse to adequately describe the important Salt Creek flows accurately, so a new RORB model for the catchment between the Fulham Bridge gauge and Harrow was developed at a higher level of detail.

The Glenelg River at Fulham Bridge flows and the tributary flows downstream of Fulham bridge were routed through to Harrow using the 1D hydraulic model developed during the Glenelg Regional Flood Mapping Project[4]. This combined rainfall-runoff hydrology and 1D hydraulic routing provided accurate inflows to the Harrow hydraulic model.

A schematic of how the flows were determined for each major catchment area is shown in Figure 4-1.

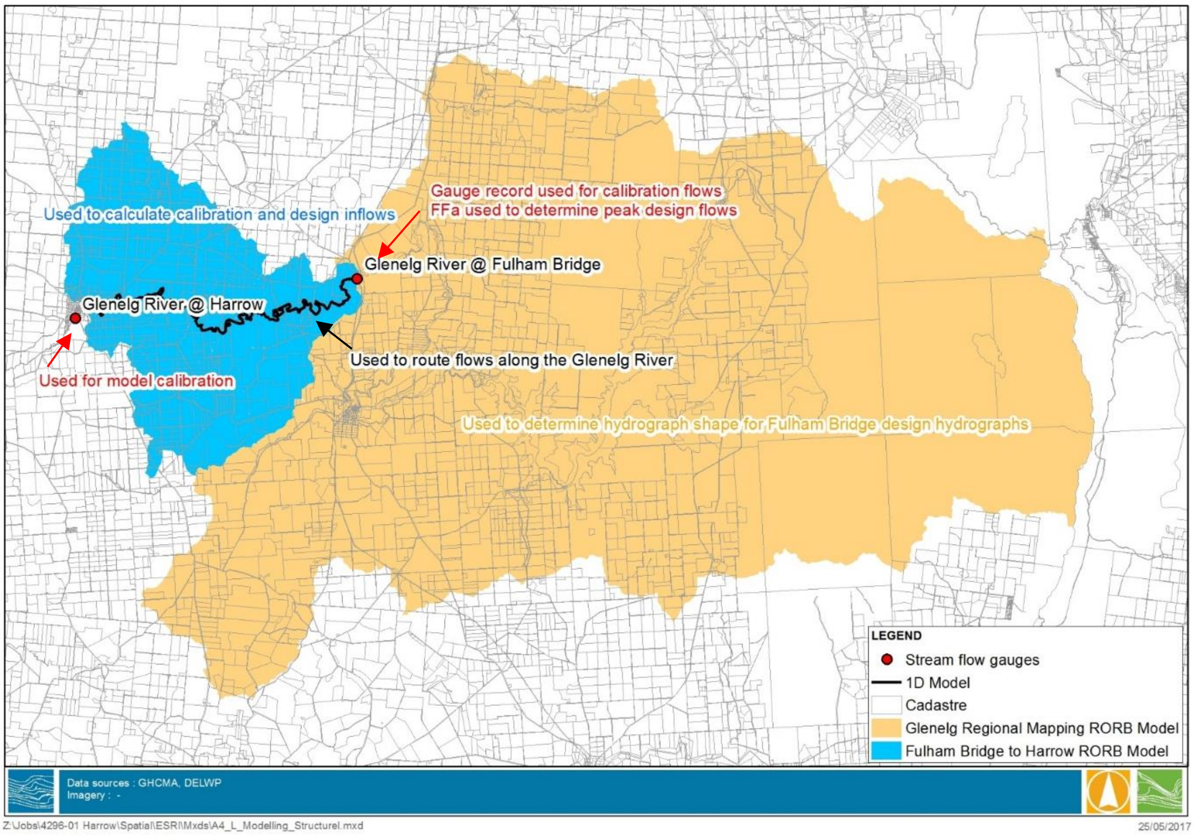

Figure 4-1 Modelling schematisation

4.2 Model Calibration

The RORB model was calibrated using observed events in the Glenelg River focusing on the events available for both Glenelg River gauges at Fulham Bridge and Harrow. During the initial stages of the streamflow data review several large events were highlighted as potential calibration events. Only events post construction of Rocklands Reservoir in 1953 were used. The events used in the calibration of the RORB model were September 2010, December 2010 and January 2011. These events were most recent and therefore represented the most current catchment conditions. There was also the largest amount of calibration information available for these events, with the Harrow streamflow gauge recording all three. Surveyed flood levels were also available for both 2010 events for the hydraulic model calibration. The December and September 2010 events were estimated as 5% and less than 20% AEP respectively.

The RORB model was run using the recorded rainfall information, modelling was initially completed using a 'kc' value of 29, as estimated by the Pearce[7] equation and a preliminary estimate of an initial and continuing loss. The outflow hydrographs were then input into the Glenelg River 1D hydraulic model with the recorded Fulham Bridge hydrograph. The hydraulic model predicted flows at the Harrow streamflow gauge for comparison to the gauged flows.

'kc' and loss values were modelled iteratively varying each individually to test the impact on the modelled hydrograph by comparing to that recorded at the Harrow streamflow gauge. Of the numerous combinations of 'kc', initial loss and continuing loss, a 'kc' of 40, initial loss of 15 mm and continuing loss of 2.5 mm/hr showed the best match between modelled and observed hydrographs for the September 2010 event. The 1D hydraulic model showed the best results with a Manning's 'n' roughness of 0.12, this is representative of very weedy reaches, deep pools, or floodways with heavy stands of timber and underbrush[8]. The September 2010 model results are shown in terms of peak flow and timing in Table 4-1 and graphically in Figure 4-2.

For December 2010, the 1D hydraulic model roughness remained the same as in September 2010. Of the numerous combinations of 'kc', initial loss and continuing loss a 'kc' of 40, initial loss of 50 mm and a continuing loss of 6 mm/hr achieved the best match to historic levels at Harrow. The December 2010 RORB model calibration results are shown in terms of peak flow and timing in Table 4-2 and graphically in Figure 4-3.

For the January 2011 event, the 1D hydraulic model roughness remained the same as the 2010 events. The RORB model was run for the January 2011 event using the recorded rainfall information, modelling was completed using a 'kc' value of 40, as it was shown as the best match during the September and December 2010 calibration modelling. The initial and continuing loss values were iteratively modified until the best match was determined. The initial and continuing loss values that produced the best match to the observed Harrow hydrograph were 50 mm and 10 mm/hr. The January 2011 RORB model calibration results are shown in terms of peak flow and timing in Table 4-3 and hydrograph shape in Figure 4-4.

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

[8] Chow (1959), Open Channel Hydraulics

Table 4-1 September 2010 – Model calibration peak flow and timing

	Observed	Modelled	Difference
Peak flow (first peak)	46.5 m^3/s	48.0 m^3/s	1.5 m^3/s (3.2%)
Timing (first peak)	05/09/1010 7:00 am	04/09/2010 7:00 pm	12 hrs
Peak flow (second peak)	54.1 m^3/s	59.9 m^3/s	5.8 m3/s (10.7%)
Timing (second peak)	07/09/2010 3:45 am	07/09/2010 1:00 am	2 hrs 45 mins

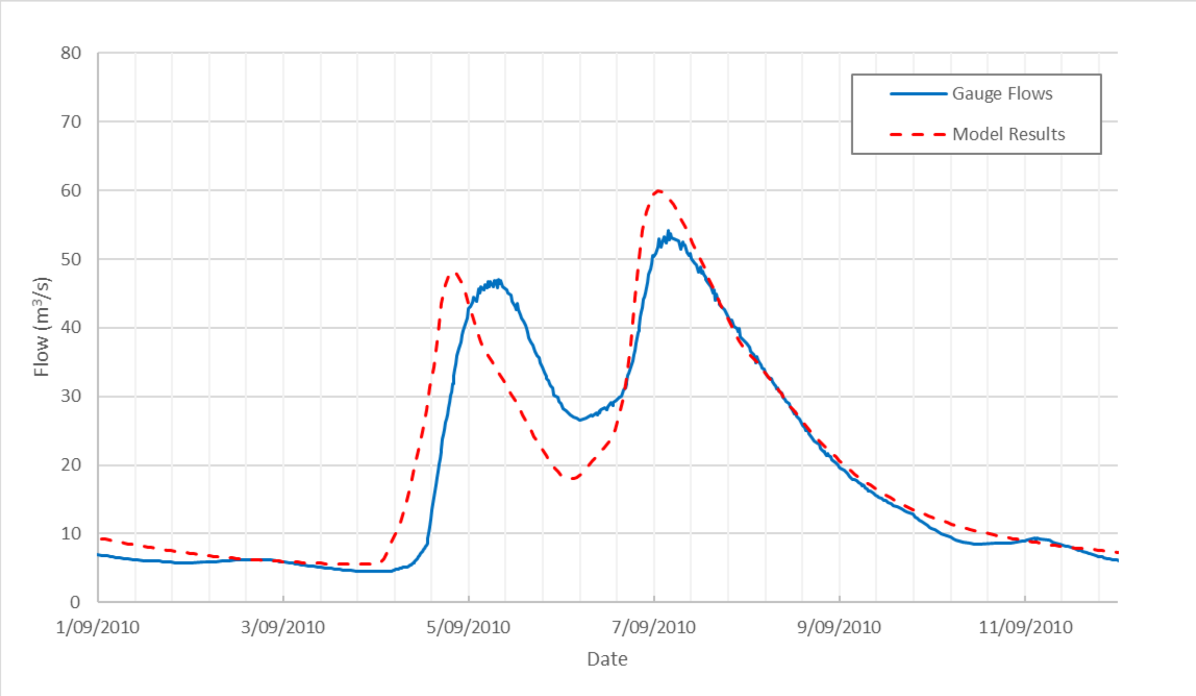

Figure 4-2 September 2010 – Harrow modelled and recorded hydrographs

Table 4-2 December 2010 – Model calibration peak flow and timing

	Observed	Modelled	Difference
Peak flow (first peak)	54.1 m³/s	60.5 m³/s	6.4 m³/s (11.8%)
Timing (first peak)	08/12/2010 4:00 pm	08/12/10 10:00 pm	10 hrs
Peak flow (second peak)	116.7 m³/s	123.0 m³/s	6.3 m³/s (5.4%)
Timing (second peak)	09/12/10 10:00 pm	9/12/2010 10:00pm	-

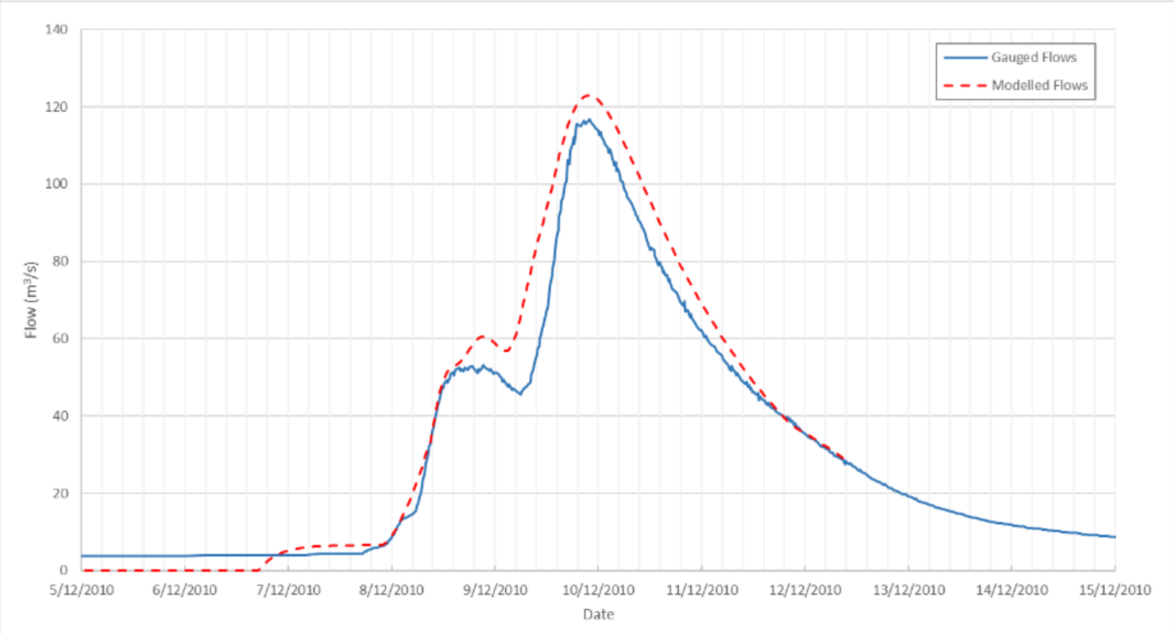

Figure 4-3 December 2010 – Harrow modelled and recorded hydrographs

Table 4-3 January 2011 – Model calibration peak flow and timing

	Observed	Modelled	Difference
Peak flow	79.8 m^3/s	80.4 m^3/s	0.6 m^3/s (0.8%)
Timing	14/01/2011 4:00 am	14/01/2011 2:00 am	2 hrs

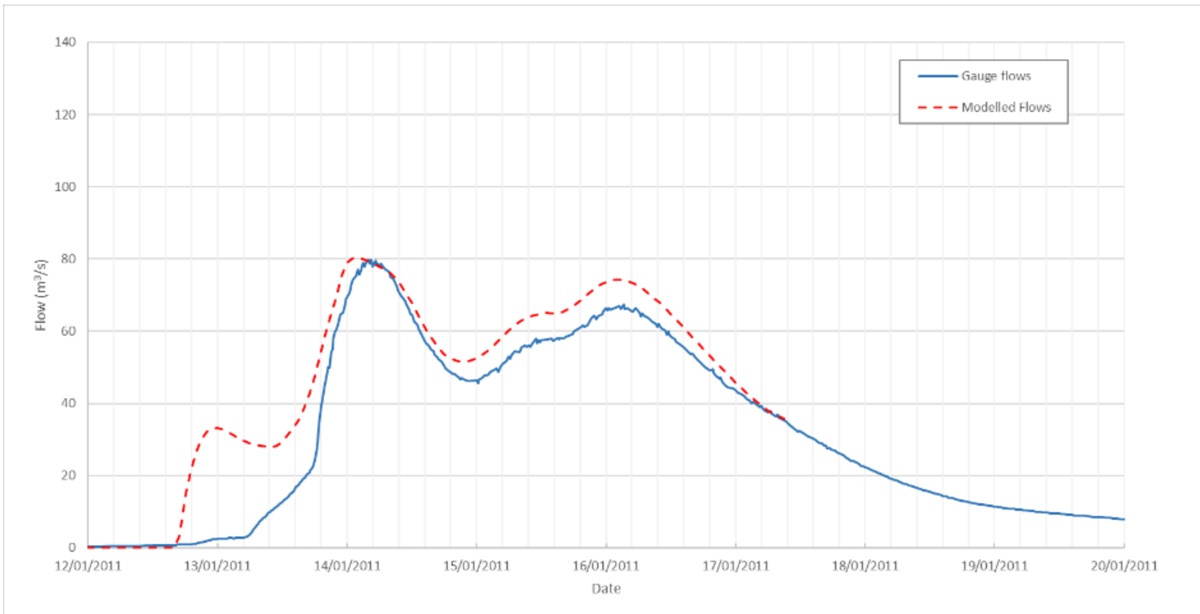

Figure 4-4 January 2011 – Harrow modelled and recorded hydrographs

4.3 Design Modelling

Flows at Fulham Bridge were determined using a Flood frequency Analysis on peak flows and event volume. When fitting the probability distribution in a FFA, small annual peaks with low flows that are not considered floods can skew the analysis and were removed using the Multiple Grubbs Beck Test. Censoring of low flows was especially significant for gauges in the Glenelg River catchment due to the number of low flow years that are present in each gauge annual series. The low flow threshold using the Multiple Grubbs Beck Test was 17.4 m^3/s.

Data for all years of the record, spanning from 1978 to 2015 including 37 annual peaks was used. The annual peak series contained one year with the flow extracted from an extrapolated rating curve recorded in 2010. All annual peaks were considered of sufficient certainty for inclusion into the FFA. With censoring of low flow values, 15 low flows were removed from the analysis.

The FFA for this project was undertaken in Flike[9] and multiple probability distributions were tested and the LP3 distribution was found to be the best match for the dataset when considering the fit by eye produced by Flike.

Design hydrograph shapes were determined from the RORB modelling of the upper Glenelg River completed during the Glenelg Regional Flood Mapping Project[4]. The RORB model shapes were scaled to match the peak flows determined by the FFA in this project.

Downstream of Fulham Bridge a hydrologic model of the Glenelg River catchment was developed to determine the tributary flows between the Fulham Bridge gauge and Harrow. To generate inflows to the 1D hydraulic model between Fulham Bridge and Harrow or directly into 2D hydraulic model of Harrow in the case of Salt Creek. The rainfall-runoff program, RORB, was utilised.

The following methodology was applied for the RORB modelling:

- Glenelg River catchment upstream of Harrow was delineated
- The model catchment areas were divided based on the topography and required hydrograph print (result) locations.
- The RORB model was constructed using appropriately selected reach types, slopes and sub area fraction impervious values.
- Storm files for the chosen calibration events were constructed.
- RORB modelling was calibrated by modifying the RORB 'kc' and loss values with the 'kc' value compared to other regional estimates.
- Design rainfall depths were extracted from the Bureau of Meteorology online IFD tool[10].
- Zone 2 and Zone 6 temporal patterns were compared for a 48 hour duration storm. 48 hrs was approximately representative of the 1975 and December 2010 events, the largest observed events in the Glenelg River catchment. The observed events matched the Zone 2 pattern more closely it was adopted for the design modelling in this project.
- A design spatial pattern was determined u the IFD maps produced by the BoM and included in ARR87[11].

[9] Flike - http://flike.tuflow.com/about/

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

[11] Bureau of Meteorology (1987), Australian Rainfall and Runoff

- Areal reduction factors were used to convert point rainfall to areal estimates and are used to account for the variation of rainfall intensities over a large catchment. Siriwardena and Weinmann (1996)[12]
- An initial loss of 35 mm and a continuing loss of 5 mm as the design loss parameters. The loss parameters were applied across all AEP events and durations. The study team feel the adopted losses are a conservative estimate of rainfall losses in the catchment area. While the adopted losses are higher than those recommended by ARR1987 they are lower than the adopted December and September calibration losses by a reasonable amount

The 1D model was run using the design hydrographs determined for Fulham Bridge (FFA) and the tributaries between Fulham Bridge and Harrow (RORB). Across the three modelled calibration events the Harrow gauge record shows that the localised catchment inflow to the Glenelg River peaked consistently 30-48 hrs before that of the flow routed from Fulham Bridge. A 30 hr spacing was used to separate the RORB generated local catchment flows at Harrow and the Fulham Bridge hydrographs at Harrow. This separation was made by iteratively running the Mike11 model varying the timing of the Fulham Bridge inflow.

The flow routed from Fulham Bridge was larger than that generated by the localised catchment area for between Fulham Bridge and Harrow for each of the modelled design flood events. The localised catchment area contributions modelled in RORB and input into the 1D MIKE11 model provided an initial peak in the Glenelg River prior to the Fulham Bridge routed flows, producing a hydrograph that looks much like those of the three calibration events considered.

The peak flows at Harrow for the modelled flood event are shown in Table 4-4.

Table 4-4 Modelled design event peak flows at Harrow

AEP	Harrow peak flow (m^3/s)	Fulham Bridge peak flow (m^3/s)
20 %	74	74
10 %	105	106
5 %	129	130
2 %	150	152
1 %	162	164
0.5 %	169	172
0.2 %	175	178

It should be noted there is very little attenuation between Harrow and Fulham Bridge due to the addition of flows from the catchment area between Fulham Bridge and Harrow.

[12] Siriwardena and Weinmanm, 1996 - Derivation of Areal Reduction Factors For Design Rainfalls (18 - 120 hours) in Victoria

5. HYDRAULIC MODELLING – DETAILED 1D/2D MODEL

5.1 Overview

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

- One dimensional (1D) hydraulic model of key waterways, drainage lines and hydraulic structures.
- Two dimensional (2D) hydraulic model of the broader floodplain.
- Linked one and two dimensional hydraulic model to accurately model the interaction between in bank flows (1D) and overland floodplain flows (2D).

The hydraulic modelling suite, TUFLOW, was used in this study. TUFLOW is a widely used hydraulic model that is suitable for the analysis of overland flows in urban areas. TUFLOW has four main inputs:

- Topography and drainage infrastructure data
- Inflow data (based on catchment hydrology)
- Roughness
- Downstream boundary condition

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

5.2 Hydraulic Model Schematisation

The TUFLOW model was constructed using MapInfo V11.0 and text editing software. This section details key elements and parameters of the TUFLOW model which adhere to both the AR&R 2D Modelling Guidelines – Project 15 Report as well as the Melbourne Water 2D Modelling Guidelines[13].

The double precision version of the latest TUFLOW release was used for all simulations (TUFLOW Version: 2012-05-AC).

A single-domain approach was utilised to ensure the small areas of interest were modelled at an appropriate scale, while achieving practical model run-times. A relatively fine grid size of 4 m was selected for the Harrow township area to ensure the local tributaries could be accurately represented and mapped.

The 2D model domain is shown below in Figure 5-1.

[13] Melbourne Water (2010), 2D Design Modelling Guidelines

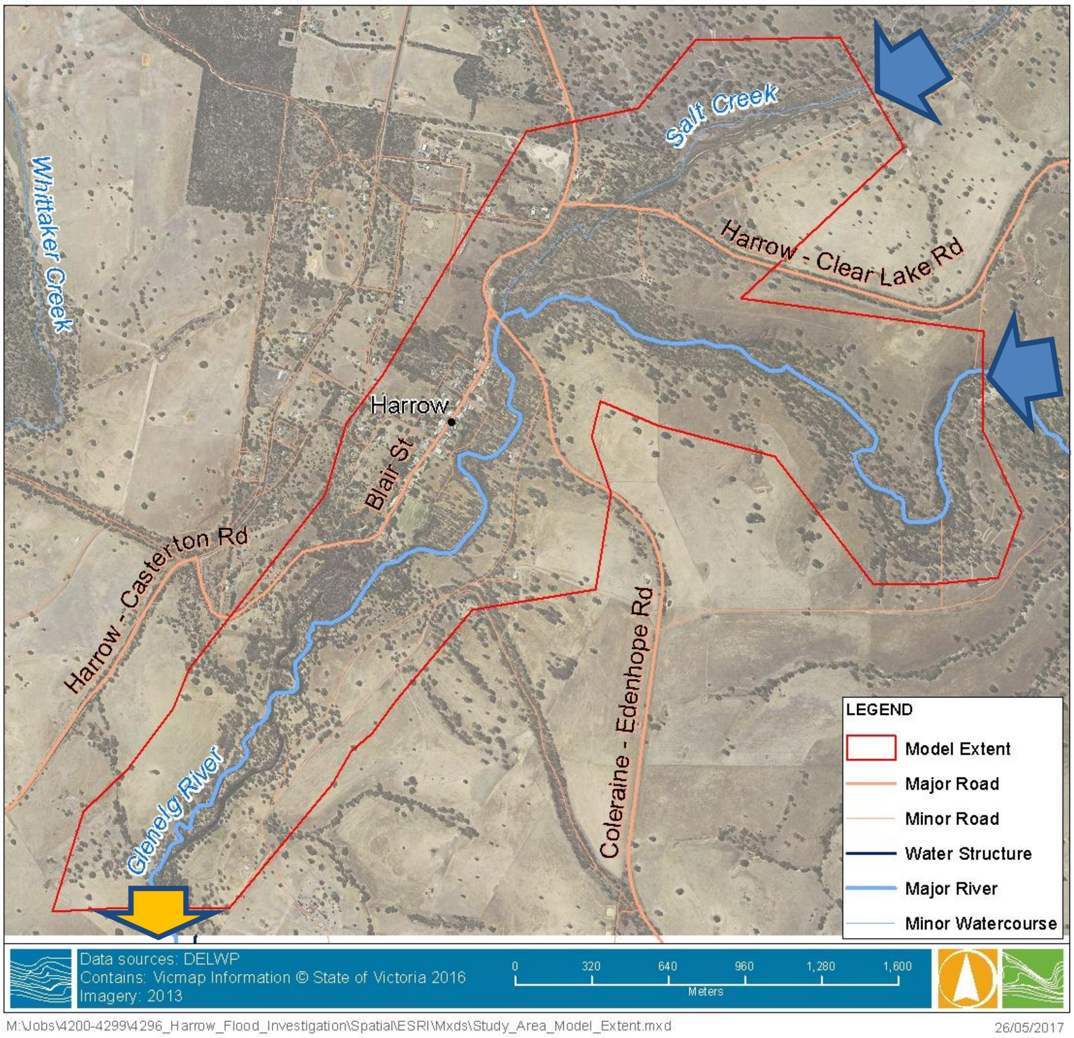

Figure 5-1 Extent of TUFLOW model

The 2D model roughness values were produced based on Land Use Zones, with further refinement through the use of aerial photographs and site visits. The hydraulic model roughness values were also used as a mechanism for model calibration, adjusting the model roughness values to ensure the model results matched the observed flood information. This is discussed further in Section 5.3. The final adopted Manning's 'n' roughness values are listed in Table 5-1 and shown graphically in Figure 5-2.

Table 5-1 Manning's 'n' roughness values

Land Use	Manning's n Roughness Coefficient
Farmland/pasture/ Grassed	0.035
Residential	0.2
Industrial / Commercial zones	0.3
Paved Surface	0.02
Paved roads	0.02
Unpaved roads	0.03
Water bodies	0.03
Rural Residential/Township/Agricultural	0.06
Bushland/dense vegetation	0.1
Vegetated Creek	0.08

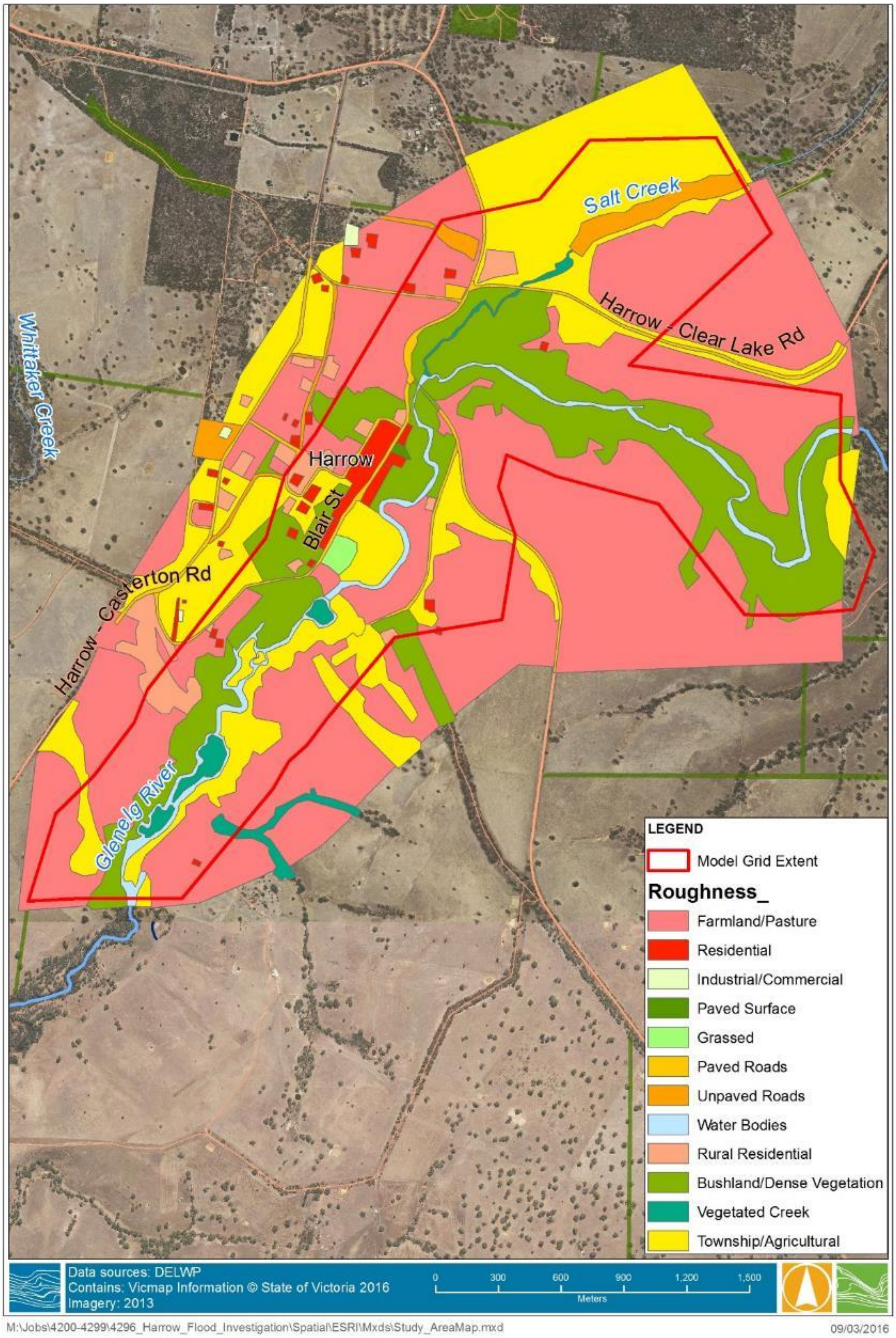

Figure 5-2 Adopted Manning's 'n' roughness values

5.3 Hydraulic model calibration

Hydraulic model calibration was achieved through the comparison of modelled and observed flood heights (provided by Glenelg Hopkins CMA), observed gauge data and anecdotal community comments. December 2010 was used as the primary calibration event with September 2010 used as a secondary event. These events were chosen because of the available peak flood height information, gauge data at Harrow and available anecdotal evidence. Due to both events being within recent memory the community have expressed a good understanding and appreciation for the events.

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

A certain level of judgement is required in the collection of this data by the surveyor and inaccuracies in such data are common. As discussed below, two of the surveyed flood marks were found to be invalid due to obvious errors.

The December 2010 modelled and observed water level hydrograph at Harrow is shown in Figure 5-3, with the modelled comparison to the peak flood height survey shown in Figure 5-4. At seven of the nine points the model was within 100 mm of the surveyed height. The remaining two calibration points indicated the modelled water levels were too high. The landowner at one of the points was contacted by Water Technology and they confirmed flood levels were higher than the survey indicated.

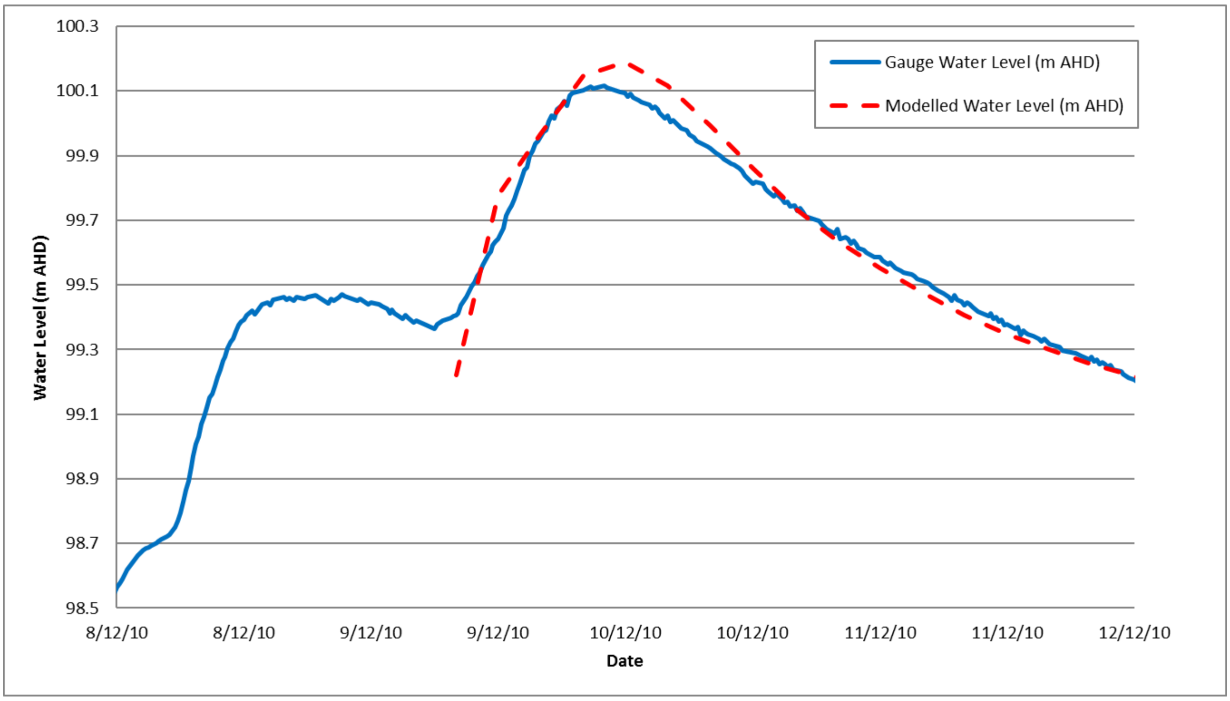

Figure 5-3 Comparison of December 2010 modelled and gauged water levels

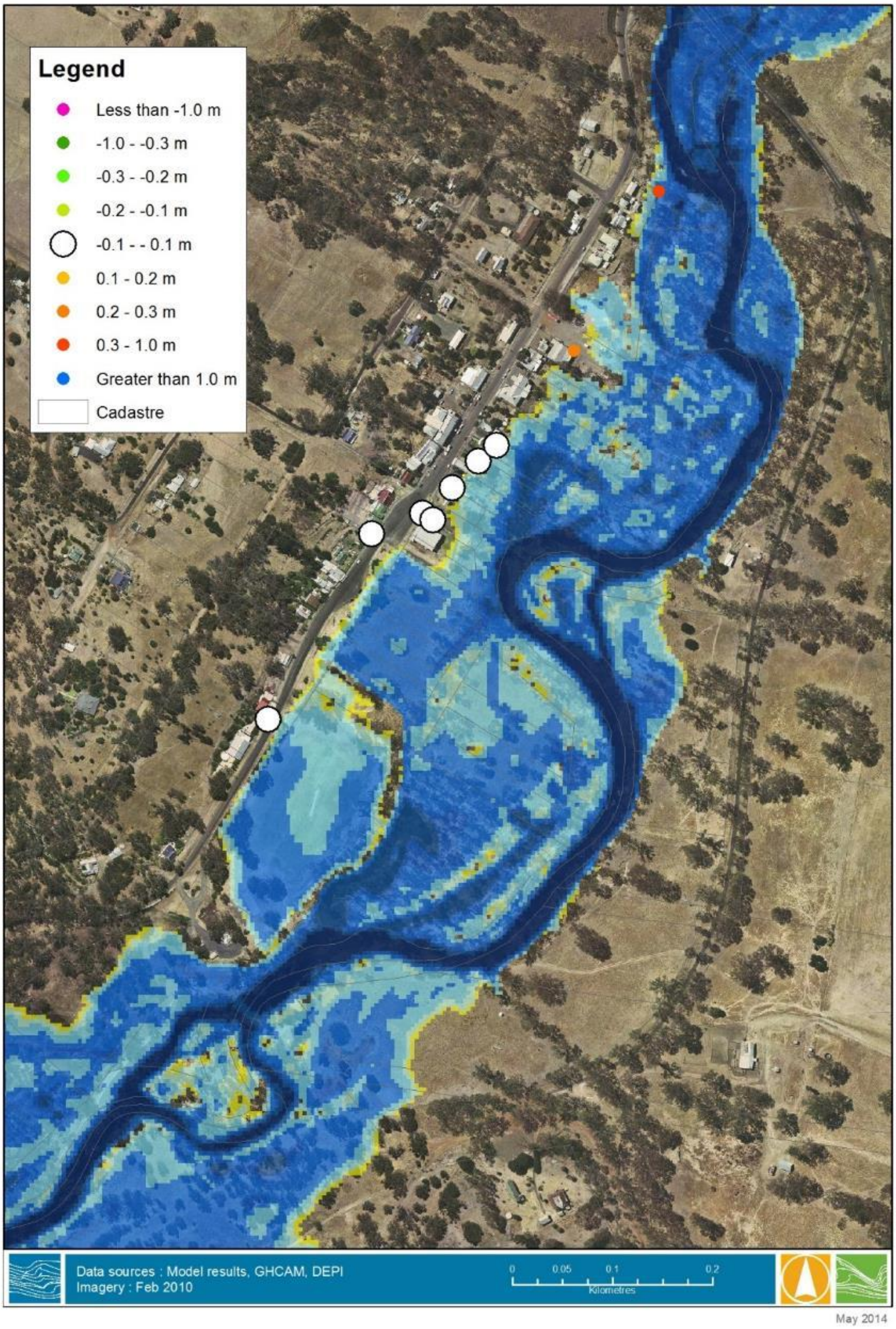

Figure 5-4 Comparison of December 2010 model results against flood survey

The September 2010 modelled and observed water level at the Harrow gauge is shown in Figure 5-5, with the comparison to for the peak flood height survey shown in Figure 5-6. Only 3 of the recorded levels were surveyed to AHD a limited comparison of modelled and surveyed flood levels was available.

Of the 3 reliable surveyed flood marks two showed a difference between modelled and observed levels of less than 0.1 m, indicating a good calibration. The remaining survey marker, located on a power pole immediately upstream of the sporting oval is around 1.6 m higher than the modelled flood levels. Given that the available topographic information shows that the level is significantly higher than the surrounding streets and does not match with observed inundation extents from any historic events, it is likely that this survey point is in error.

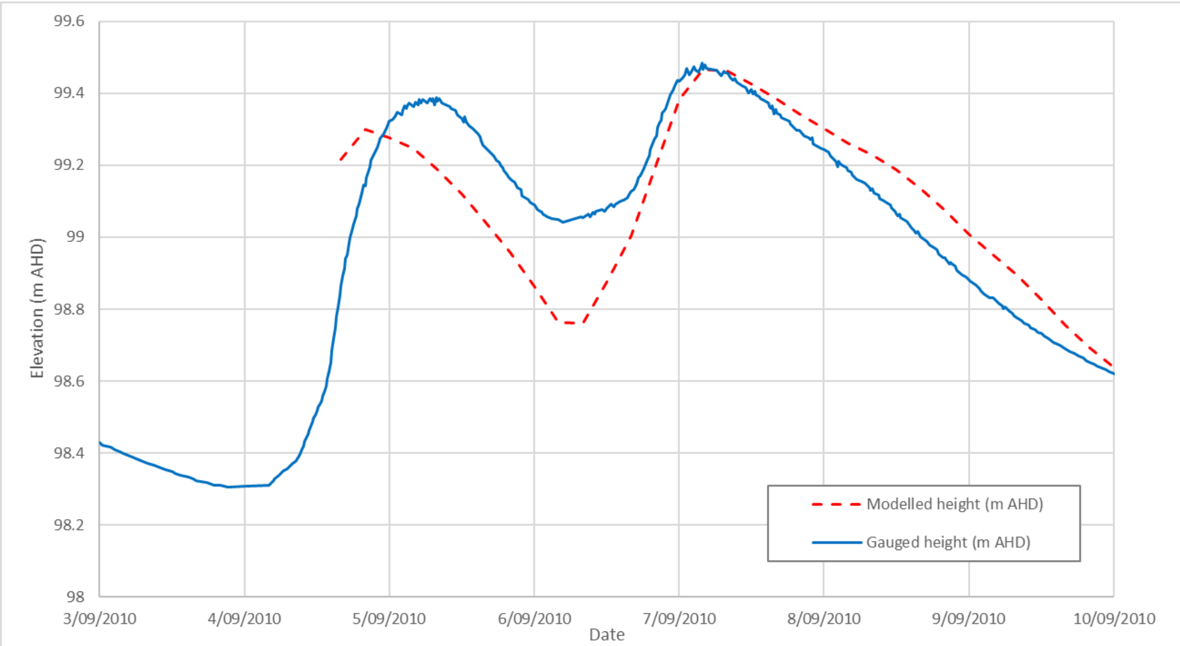

Figure 5-5 Comparison of September 2010 modelled and gauged water levels

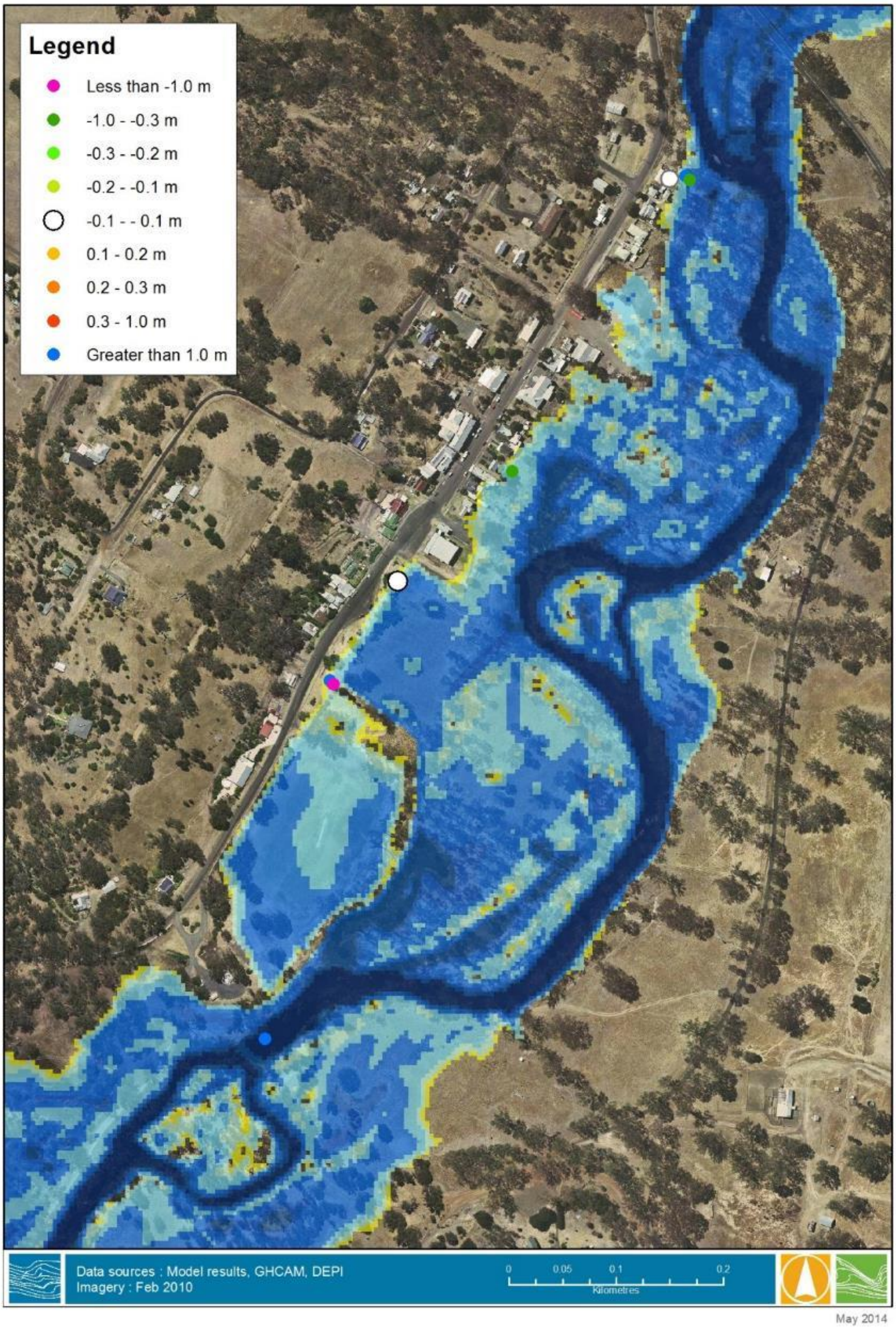

Figure 5-6 Comparison of September 2010 model results against flood survey

5.4 Design Flood Modelling

Design hydraulic modelling was completed, adopting the hydraulic model roughness values determined during the calibration phase, as discussed in Section 5.3. Modelling was completed for the full suite of design events including the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP and PMF events.

These events are overlayed in Figure 5-7, with a closer perspective of the Harrow township shown in Figure 5-8.

The inundation extents in Harrow don't vary much across design events, however the water levels between the 20% AEP and 0.2% AEP events increase by around 0.8 m at the gauge location, from 99.61 m AHD to 100.42 m AHD, the full list of design flood heights and flows at the Harrow gauge is discussed in Section 7.

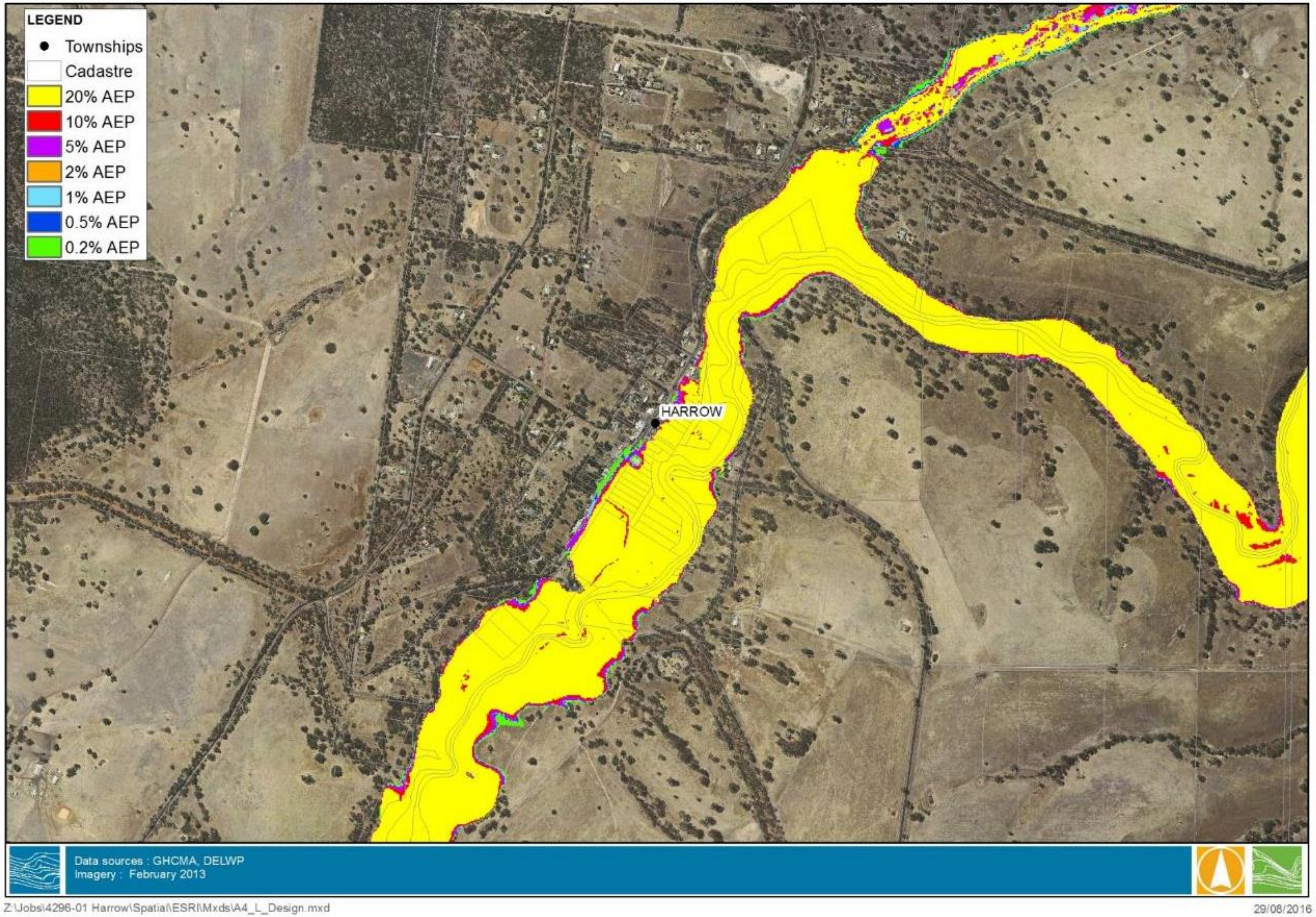

Figure 5-7 Design event flood mapping – All events overlayed

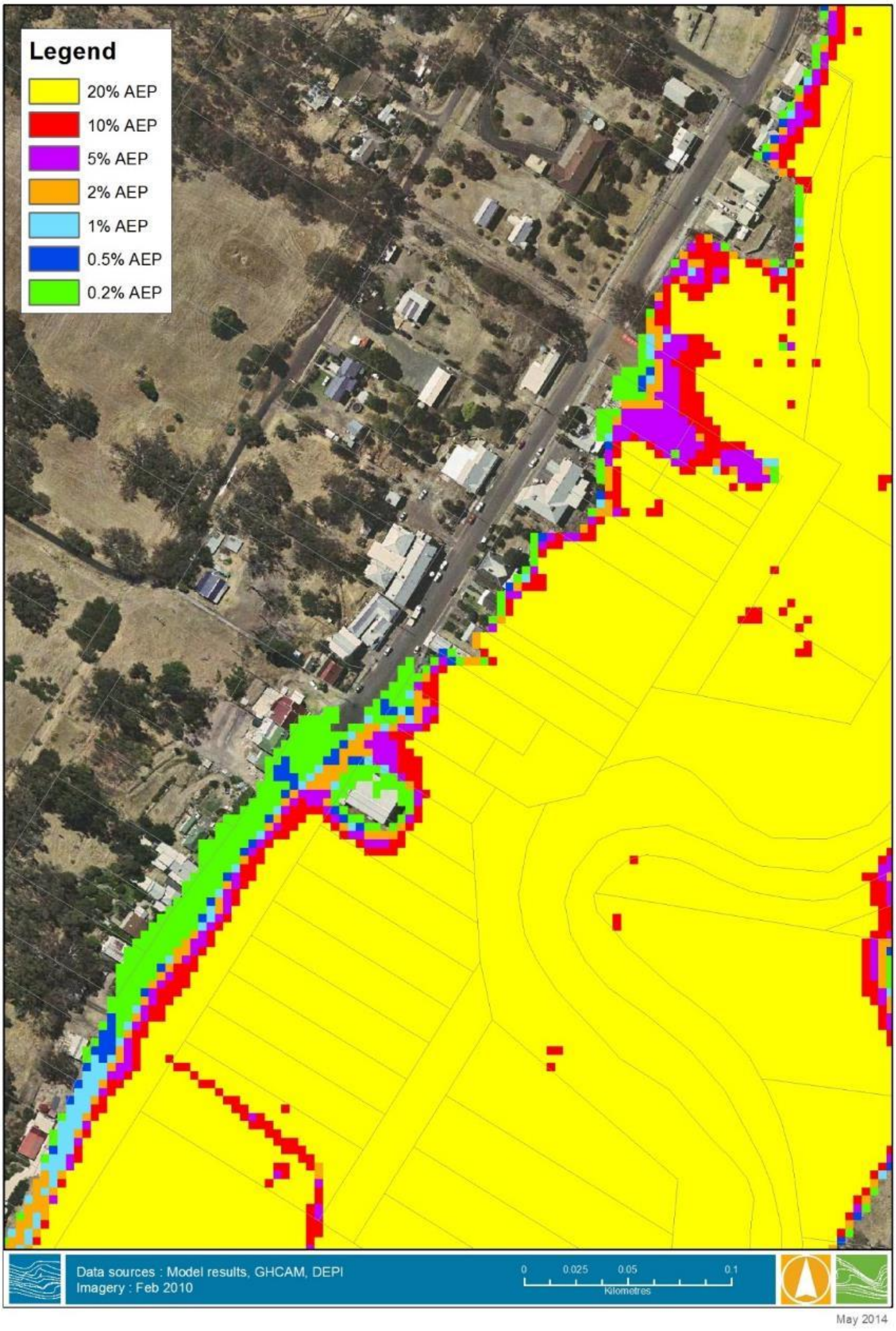

Figure 5-8 Design event flood mapping – All events overlayed (Harrow township)

6. FLOOD RISK MITIGATION

6.1 Overview

Flood risk and flood damages in Harrow can be reduced via both structural and non-structural mitigation measures. Non-structural mitigation measures focus on ensuring that development doesn't occur in high flood risk areas and that the community is aware and prepared for the potential impact of future floods. Structural mitigation options are engineering solutions focused on reducing flood extent, depth and damage.

The 1% AEP flood inundation extent, and properties within Harrow that are flooded above and below are shown in Figure 6-1.

Figure 6-1 1% AEP flood extent and buildings flooded above and below floor in Harrow

6.2 Structural Mitigation Options

6.2.1 Overview

Structural mitigation measures are physical works to reduce the likelihood of flooding in a given location. The full list of potential structural mitigation measures for the Harrow Flood Investigation study area and the source of the suggestion are shown in Table 6-1.

Table 6-1 Suggested mitigation options

Option No.	Detail	Prefeasibility Finding	Source
1	Ensure no environmental flow releases are occurring at the same time as an expected flood event	Modelled as a sensitivity test to demonstrate impact	Community
2	Extract sand “chokes” from the Glenelg River	Unlikely to make a big difference in large floods due to the large proportion of out of bank flows. Sand removal would need to be an ongoing strategy.	Community
3	Remove vegetation (weeds, “phalaris” was specifically mentioned) from the floodplain	Modelled as a sensitivity test.	Community
4	Put an embankment upstream of Harrow controlling the flow to a rate which doesn’t cause damage	Would be very expensive and difficult to maintain and construct. It would also impact on all the downstream Glenelg River.	Community
5	Build/alter the levee around John Mullagh Memorial Park to the same height of the road	Viable option, may cut off flow to a tree of cultural significance.	Steering Committee
6	Build a levee to protect the township along the back of the buildings	Viable way to reduce flood damage, would be expensive and ascetics could be an issue.	Community

7	Remove a choke downstream of Harrow at Deep Creek	The Deep Creek choke is too far downstream to impact on Harrow.	Community
8	Build levees/raised garden beds to protect individual properties	Would require individual landholder communication.	Water Technology

Based on the above list and the results of design modelling two preliminary packages of mitigation options were recommended for initial detailed modelling. Both packages involved testing a number of mitigation measures aimed at reducing local flood risk with the focus on reducing potential loss of life and above floor flooding of buildings. Based on the results of the preliminary modelling a final package of measures was then developed and modelled for the full range of design events. The results of the preliminary mitigation modelling can be found in the main Harrow Flood Investigation Final Report.

6.2.2 Hydraulic Modelling

Hydraulic modelling was completed of the following mitigation options:

- Levee constructed behind the buildings to the south of Blair street.
- Increase the levee height around the John Mullagh Oval

The options were assessed using the calibrated hydraulic model to determine the impact that the options would have on the Harrow community. It is important that a structural mitigation option does not push the problem on to someone else.

The proposed levee alignments are displayed over the 1% AEP flood extent as modelled under existing conditions in Figure 6-2 to illustrate what the option aims to protect against.

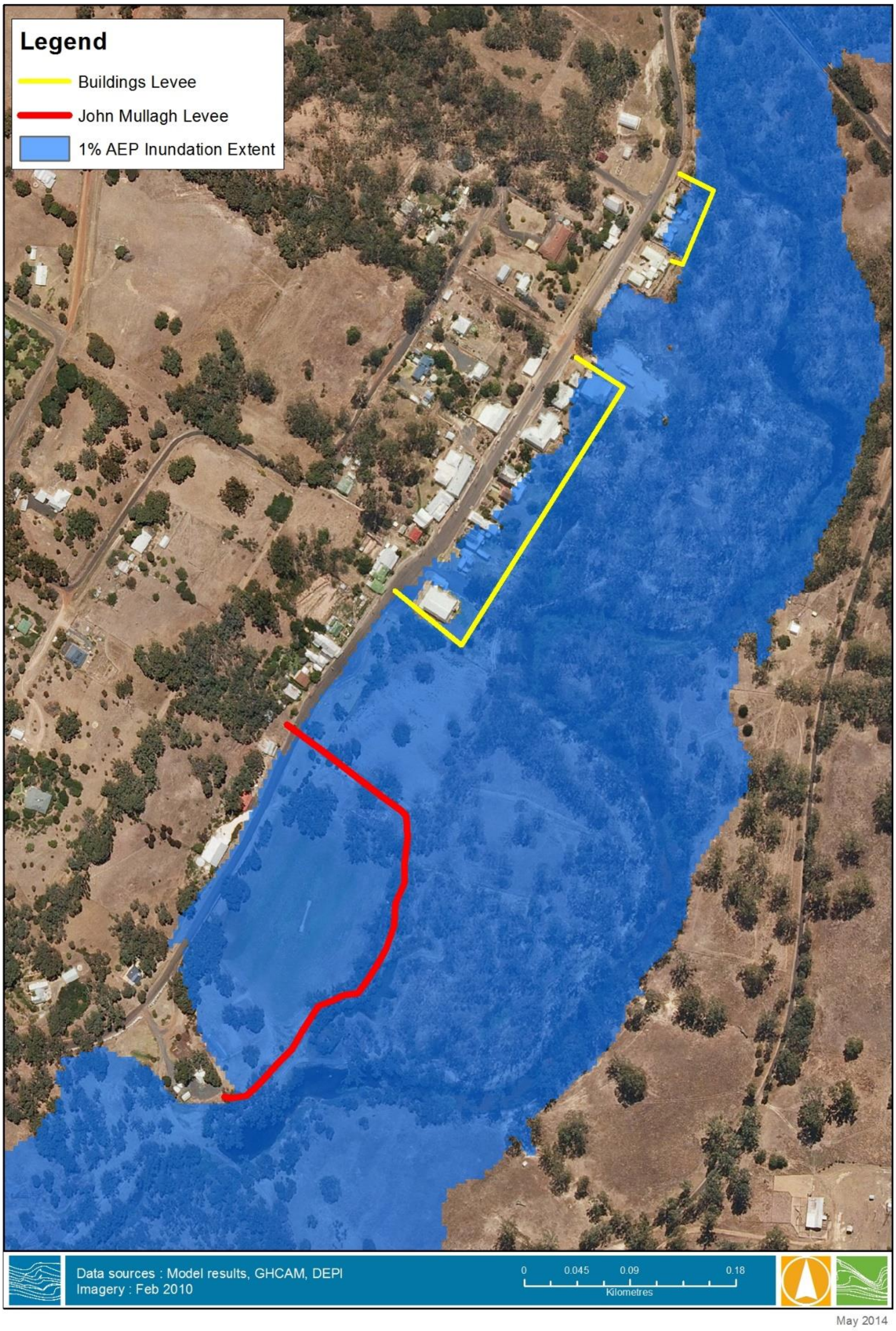

Figure 6-2 Modelled levee alignments in Harrow with 1% AEP existing conditions flooding

Buildings Levees

Two levees were included into the hydraulic model to a height greater than the existing 1% AEP flood levels. The modelling was used to determine the extent of potential adverse water level increases.

The addition of the two levees removed inundation from behind properties along Blair Street. The levee scenario was modelled using the 1% AEP flood event, the modelled extent and depths in proximity to the levee is shown in Figure 6-3. Figure 6-4 and Figure 6-5 show the change in water level as the result of including the north and south buildings levees respectively.

Very little change to water levels upstream and downstream of the levee was observed, with a small increase on the upstream side of each levee. There were no flood level increases on developed blocks. The levee alignment provides complete protection for the houses behind the levee without increasing the risk of inundation for any surrounding properties.

John Mullagh Memorial Park Levee

The existing levee at the John Mullagh oval does not sufficiently protect the oval from inundation during an event equal to or exceeding a 20% AEP. To assess the impact of protecting the oval against flood events the levee was modelled increasing it to above the 1% AEP flood level.

The levee upgrade was modelled for a 1% AEP flood event, with the resulting depth and extent of inundation shown in Figure 6-6, with the change in water levels as a result of the levee' construction shown in Figure 6-7.

Results show the levee caused increased water levels for some distance upstream, impacting on buildings already inundated above and below floor.

To reduce the impact of the levee a lower levee crest height was trialled, reducing the level of protection to a 5% AEP flood event. This was discussed with the community and would ensure that on average the oval would only be inundated once every 20 years, rather than more than once every 5 years in the existing scenario.

The model was re-run for the 1% AEP flood event, allowing the levee to overtop. The modelled depths are shown in Figure **6**-**8** with the change in water levels as a result of the levee shown in Figure 6-9.

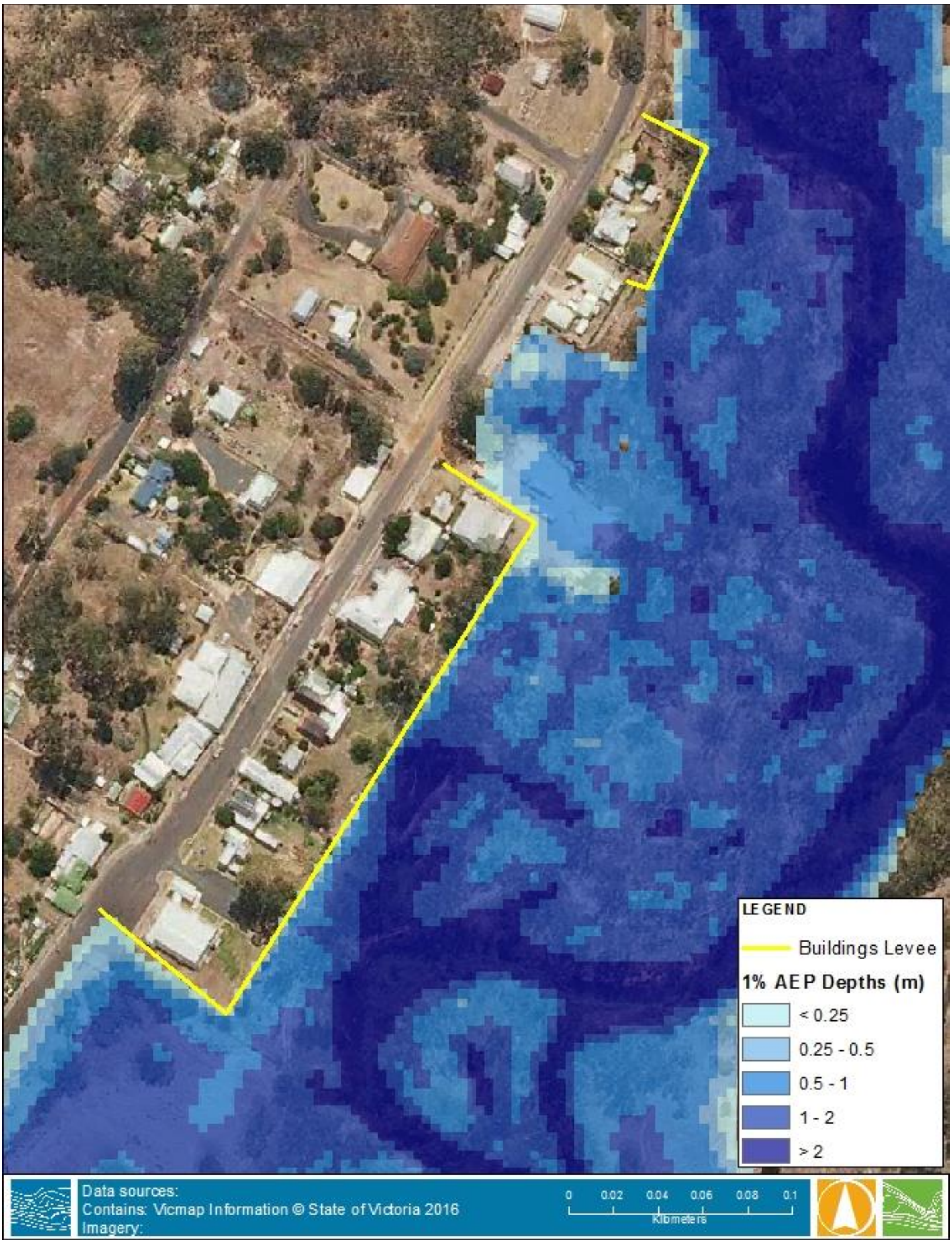

Figure 6-3 Buildings levee alignment 1% AEP flood depths

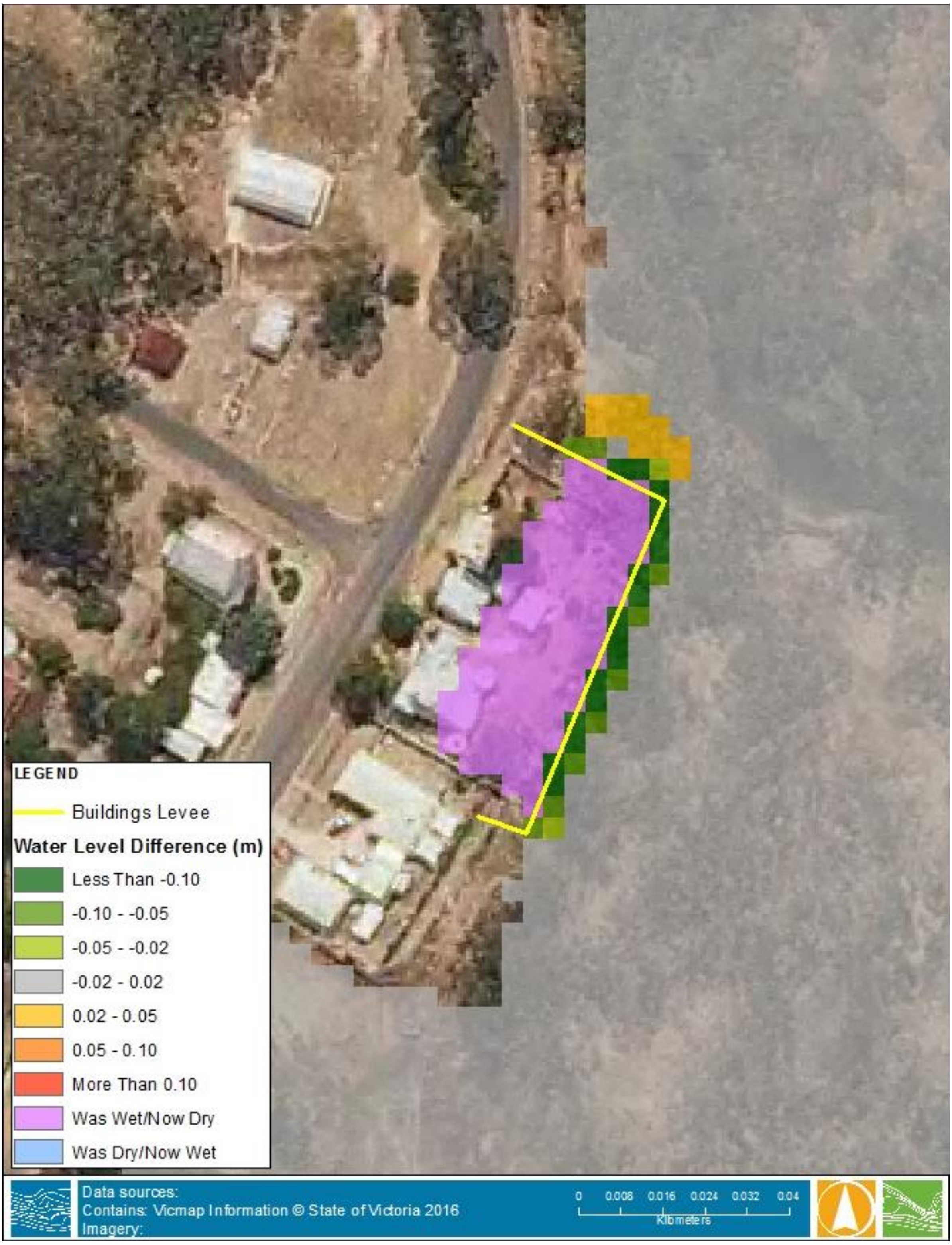

Figure 6-4 North buildings levee alignment 1% AEP water level difference

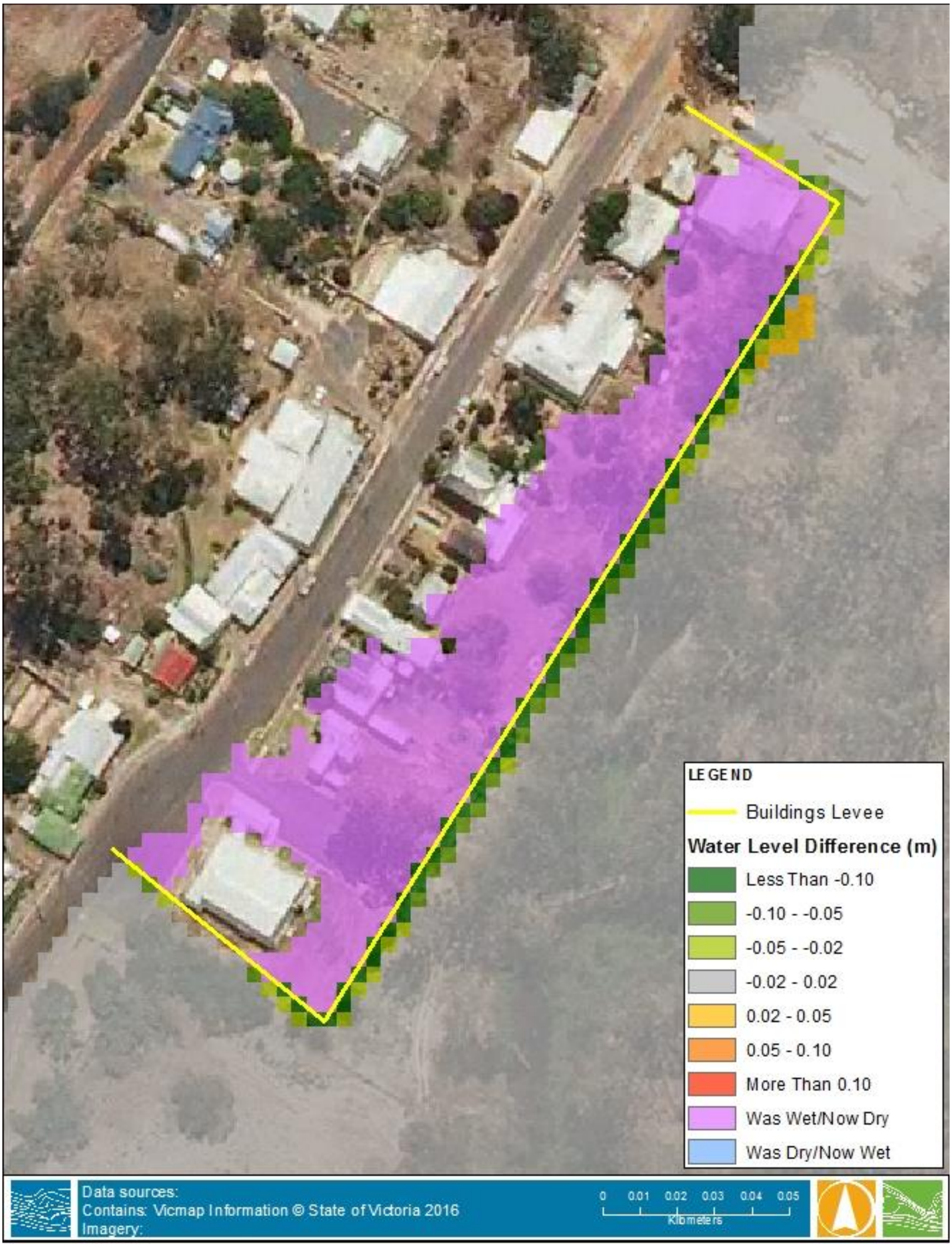

Figure 6-5 South buildings levee alignment 1% AEP water level difference

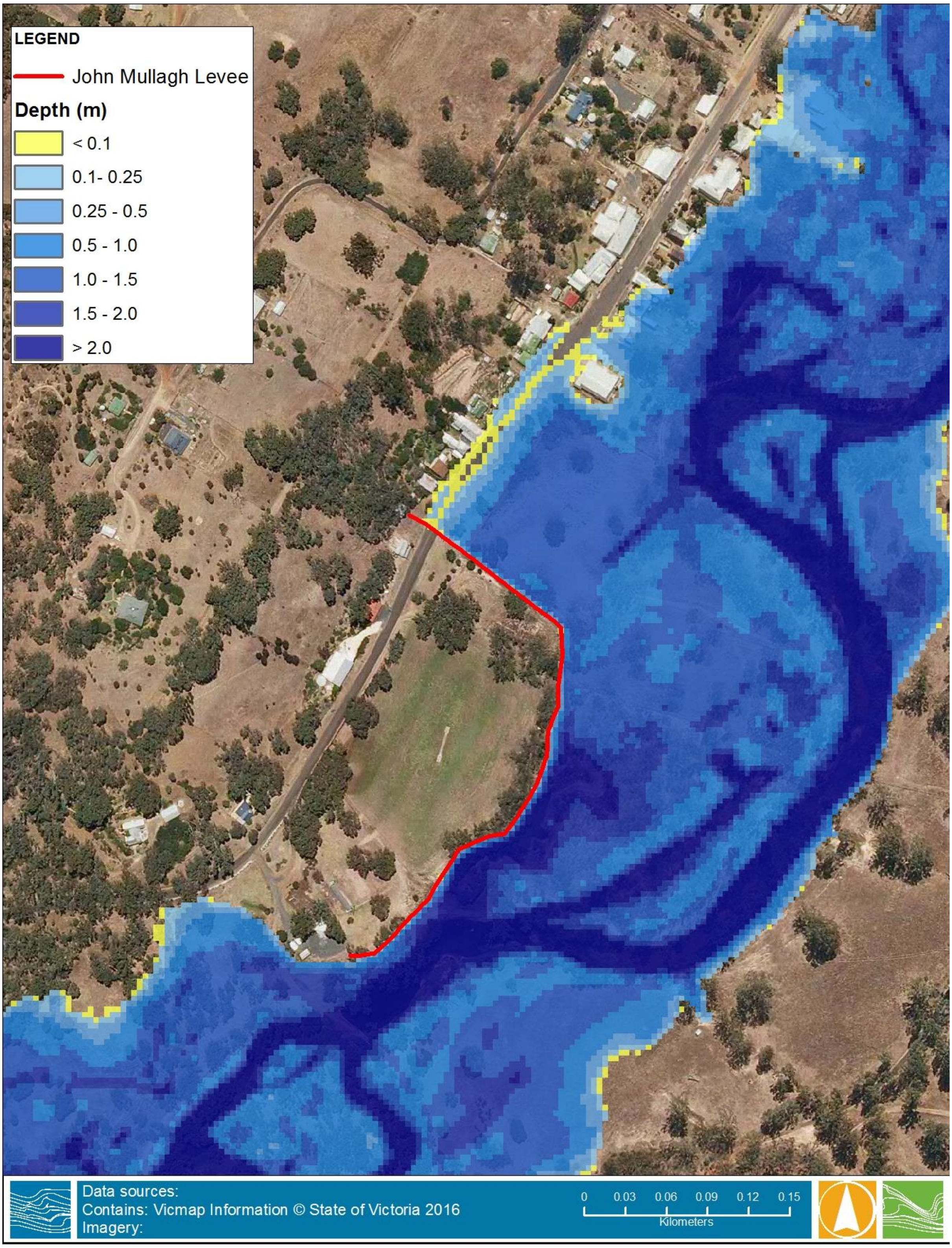

Figure 6-6 John Mullagh oval levee option alignment 1% AEP Depths

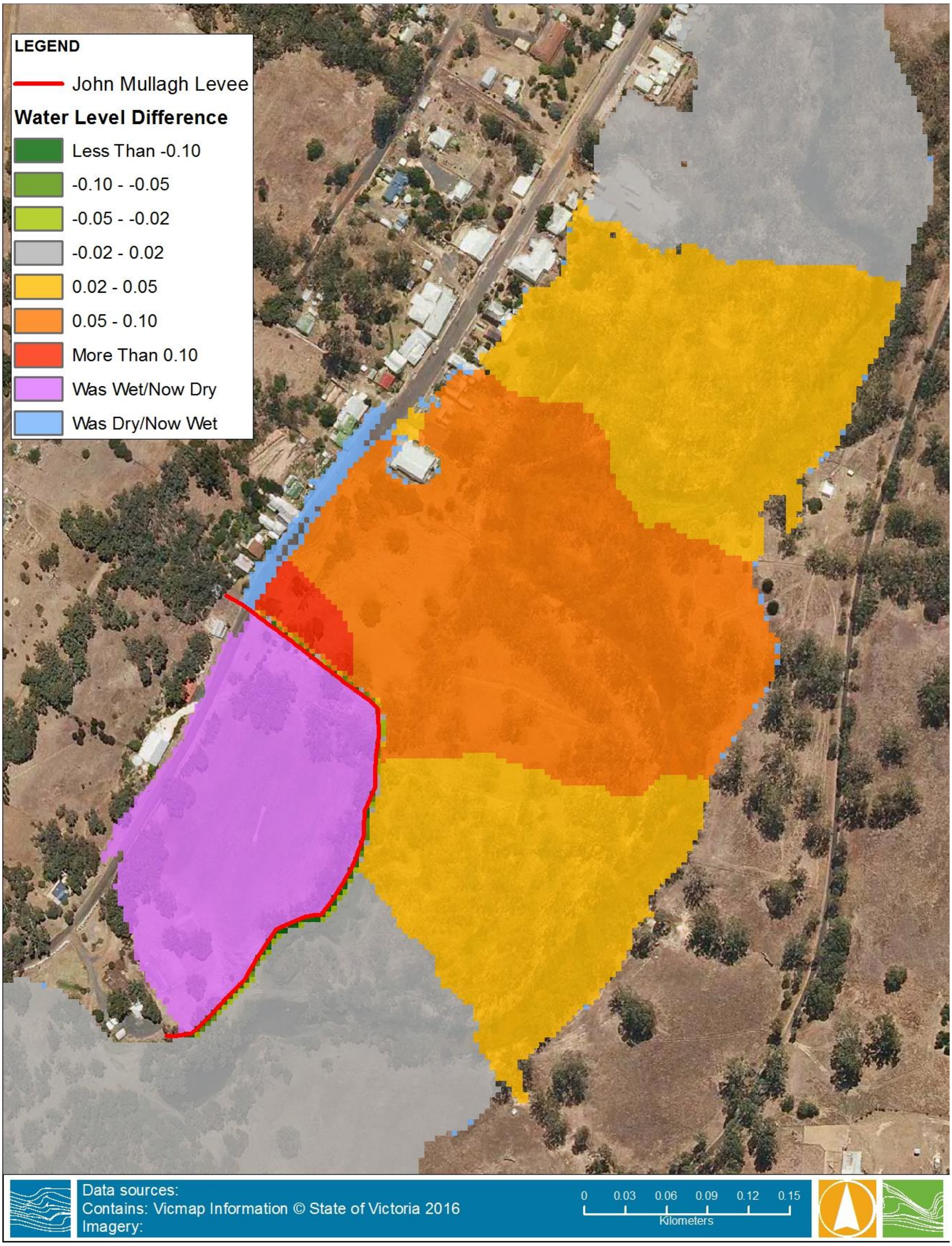

Figure 6-7 John Mullagh oval levee option 1% AEP water level difference

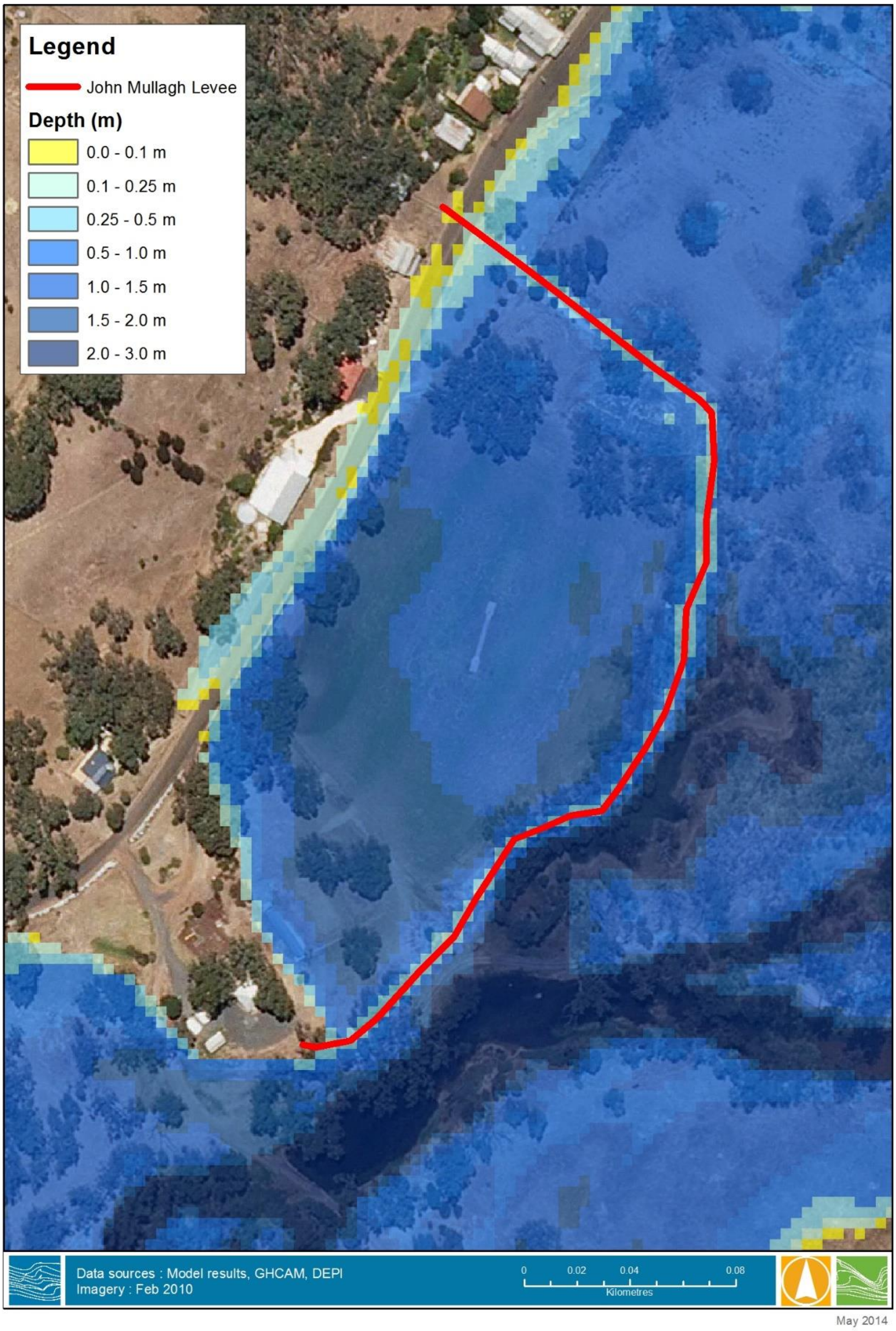

Figure 6-8 John Mullagh oval levee option with 5% AEP protection 1% AEP flood depths

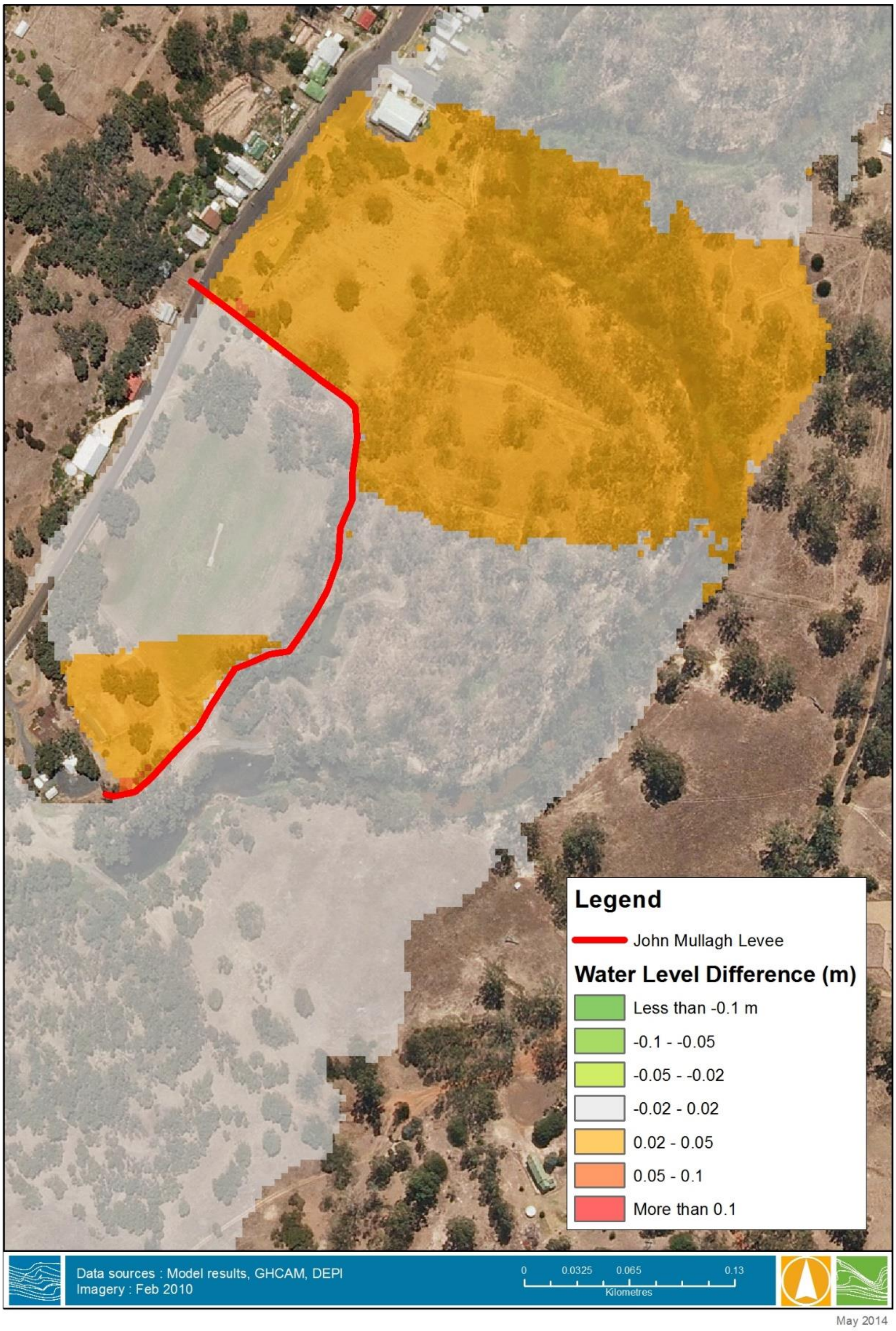

Figure 6-9 John Mullagh oval levee option with 5% AEP protection 1% AEP water level difference

Mitigation Option Cost

Water Technology has undertaken many levee functional designs and costings, we have developed standard spreadsheets based on industry rates from Melbourne Water and Rawlinsons. A 30% contingency cost was included along with engineering and administration costs. It should be noted that these costs are based on estimated rates and should be checked during the detailed design phase.

The Victorian Levee Guidelines has standard recommendations for levee crest width (2 m), batter slopes (3:1 batter on water side, 2:1 on dry side) and clay core with cut-off trench requirements. The levee proposed meets these requirements with a 2 m crest width, 3:1 batter slopes on both sides.

The buildings levee was designed to the 1% AEP level with the inclusion of a 300 mm earthen freeboard.

The John Mullagh levee was increased to the height of 100.04 m AHD, matching the 5% AEP flood event level.

An annual maintenance cost (3% of the total construction cost) was factored in for levee works. The levee was costed with the inclusion of a clay core and cut-off trench based on standard levee construction rates excluding topsoiling and grassing.

The estimated capital cost of the north and south buildings levee was $101,000. The estimated cost of increasing the John Mullagh Memorial Park levee was $60,220. The breakdown of these estimates is shown in Table 6-2 and Table 6-3. These are low capital cost works that could be implemented to protect the township and provide peace of mind to the community of Harrow.

A benefit-cost analysis was undertaken to assess the economic viability of the levee protecting the buildings south of Blair Street. An indicative benefit-cost ratio was based on the construction cost estimates and Average Annual Damages.

The results of the benefit-cost analysis are shown below in Table 9-3. For this analysis, a net present value model was used, applying a 6% discount rate over a 30 year project life. The benefit cost ratio should ideally be equal to or greater than 1, meaning that the long term benefit of flood mitigation equals or exceeds the long term costs. In this analysis, the cost benefit ratio is 0.44, which indicates that the cost of mitigation exceeds the long term benefits. However, it is important to note that this analysis does not include social costs or benefits, some of which may be considered to be of greater value than the economic costs.

Table 6-2 Levee protecting the Harrow township

Levee section	Length (m)	Average height (m)	Volume (m^3)	Estimated Construction Cost	Estimated Annual Maintenance Cost
Northern Levee	120	1.2	758	$32,441	$597
Southern Levee	391	1	1554	$68,738	$1,265
Sub-total 'A'				$62,090	
'A' x Engineering Fee @ 15%				$9,313	
Sub-total 'B'				$71,403	
'B' x Administration Fee @ 9%				$6,426	
Sub-total 'C'				$77,830	
'A' x Contingencies @ 30%				$23,349	
FORECAST EXPENDITURE				$101,179	$1,862

Table 6-3 Levee protecting the John Mullugh Memorial Park

Levee section	Length (m)	Average height (m)	Volume (m^3)	Estimated Construction Cost	Estimated Annual Maintenance Cost
Oval Option B	370	1.1	1334	$60,220	$1,109
Sub-total 'A'				$36,955	
'A' x Engineering Fee @ 15%				$5,543	
Sub-total 'B'				$42,498	
'B' x Administration Fee @ 9%				$3,825	
Sub-total 'C'				$46,323	
'A' x Contingencies @ 30%				$13,897	
FORECAST EXPENDITURE				$60,220	$1,109

Table 6-4 Cost Benefit Analysis

	Existing Conditions	Buildings Levees
Average Annual Damage	$28,229	$22,049
Annual Maintenance Cost	-	$3,035
Annual Cost Savings	-	$3,145
Net Present Value	-	$44,226
Cost of permanent mitigation		$50,358
Capital Cost of Mitigation	-	$101,179
Benefit-Cost Ratio	**-**	0.44

6.3 Non-Structural Mitigation Measures

6.3.1 Overview

There are a range of non-structural mitigation options possible to reduce flood damages, these include:

- Land use planning;
- Flood warning and response; and,
- Flood awareness.

During this project, sub-consultants Planning and Environmental Design and Molino Stewart were engaged to assist with reviewing the current non-structural flood mitigation arrangements for the land use planning and flood warning, response and awareness respectively.

This project produced two separate individual reports as non-structural mitigation measures, if further detail is required, please refer to:

- Planning and Environmental Design (2016), Planning Scheme Amendment Documentation – Harrow Flood Investigation
- Molino Stewart (2016), Harrow Flood Investigation - Flood Warning Assessment and Recommendations Report

6.3.2 Planning Scheme Amendment

Overview

Land use planning controls and building regulations provide mechanisms for ensuring appropriate use of land and building construction, given the flooding risks to a particular area. Land use planning controls are aimed at reducing the growth in flood damages over time. The flood planning overlays balance the likelihood of flooding with the consequences (flood risk).

Flood Related Planning Zone and Overlay Delineation

The Floodway Overlay (FO) and Land Subject to Inundation Overlay (LSIO) extents proposed for the Harrow Flood Investigation study area were based on consideration of the floodway and flood fringe definitions developed by Glenelg Hopkins CMA.

The following specific delineation criteria were applied:

Floodway (FO)

As a minimum, any land where best practice floodplain modelling indicates:

- The 1 % AEP flood depth is likely to reach or exceed 0.5 m; or
- The estimated 1 % AEP flood hazard factor (velocity x depth) can be expected to reach or exceed 0.4 m^2/s.

The land is delineated as floodway for the purpose of land use and development planning. It should be noted that the above criteria are subject to change pending advancements in flood hazard research.

Flood Fringe (LSIO)

Any land that is outside the floodway, but inside the 1 % AEP flood extent is delineated as within the flood fringe by default.

Planning Map Development Principles

The following principles were used to create the draft flood related planning maps:

- The floodway and flood fringe boundaries were defined using the criteria discussed previously.
- The raw flood boundaries were smoothed to create a visually enhanced representation of the floodway and flood fringe boundaries (smoothing from a grid outline to a more continuous boundary).
- Small “holes” less than 100 m^2 were filled in both the land subject to inundation and floodway overlays.

The flood related planning maps were developed in consultation with the West Wimmera Shire Council and Glenelg Hopkins CMA. Through this consultation, due consideration was given to local social, economic and environmental issues.

Planning Scheme Controls

Draft planning scheme controls were developed for the LSIO and FO for the study area, which:

1. Minimise risks to life, health and wellbeing associated with flooding of the township;
2. Maintain to the maximum possible extent, the free passage and temporary storage of floodwaters;
3. Require new development to use materials, design and construction techniques to minimise likely damage by floodwater;
4. Ensure new development will not cause any significant rise in flood level or flow velocity to the detriment of other land holders or property;
5. Ensure flood damage costs are not compounded unduly;
6. Ensure existing development that is affected by flooding is maintained in a manner commensurate with the likely impacts from future flood events.

Figure 6-10 shows the draft FO and LSIO planning layers developed as an output of this study.

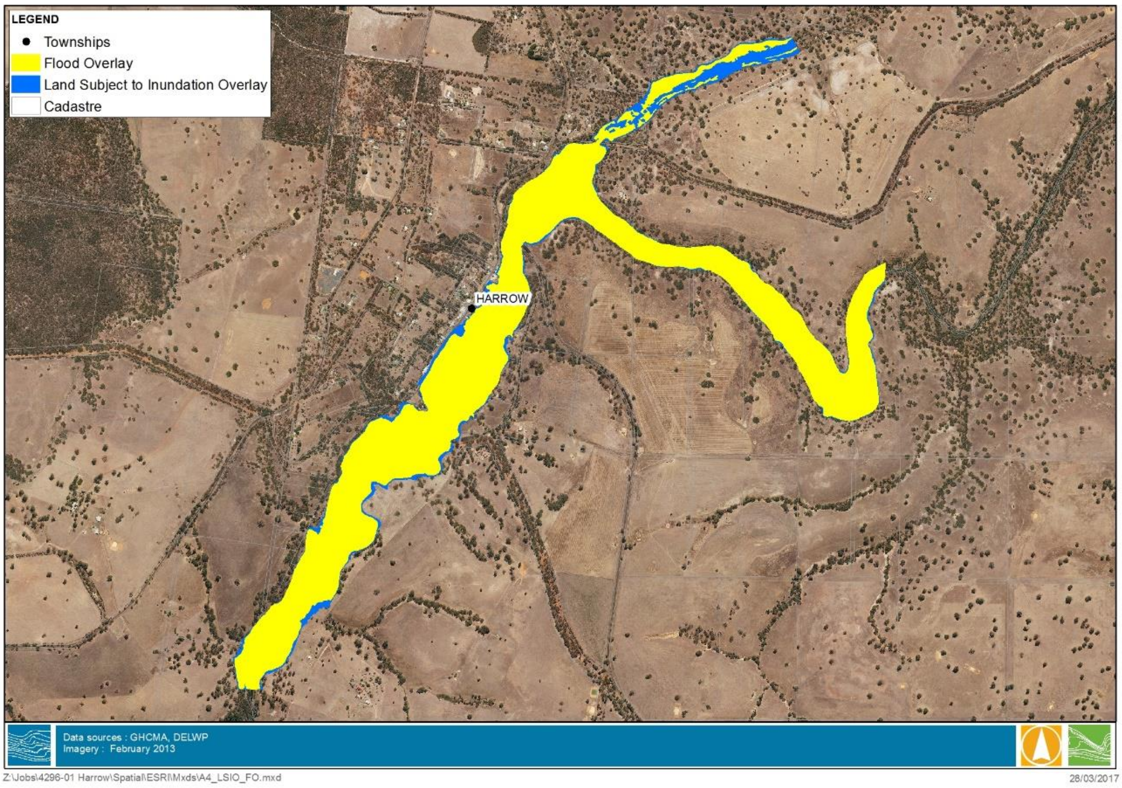

Figure 6-10 Proposed Floodway Overlay and Land Subject to Inundation Overlay maps covering the study area

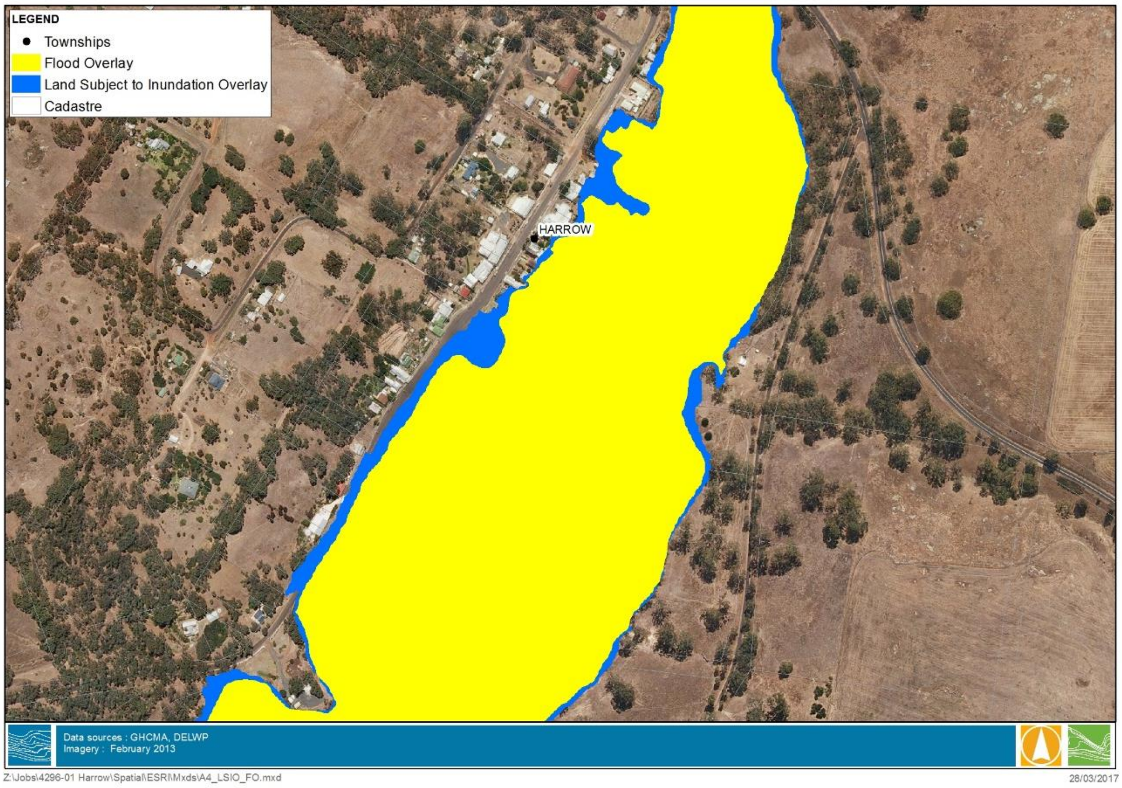

Figure 6-11 Proposed Floodway Overlay and Land Subject to Inundation Overlay maps covering the central Harrow area

6.3.3 Flood Warning and Recommendations

An objective of the Harrow Flood Investigation was to identify options for improved flood warning arrangements. Below is a summary of the full Harrow Flood Investigation – Total Flood Warning Assessment[14]. The review and identification of options for improvement was carried out during the study by:

- Assessing the area's flood warning service needs; and,
- Assessing the potential benefits of a Total Flood Warning System (TFWS) to reduce flood impacts for the community.

Molino Stewart was commissioned by Water Technology to conduct this part of the investigation. Consultation with stakeholders including the Victoria State Emergency Service (VICSES), Glenelg Hopkins Catchment Management Authority and West Wimmera Shire Council was undertaken. Data from the hydrology and hydraulics components of the flood investigation conducted by Water Technology was also used, along with demographic data sources such as the Australian Bureau of Statistics.

The review identified Harrow has a local streamflow gauge (Glenelg River at Harrow) and an upstream streamflow gauge (Glenelg River at Fulham Bridge) that provides ample warning lead time for flooding in the township. Along with the existing flood warning services provided by the BoM and VICSES and the existence of a CFA brigade to support emergency response, the existing configuration allows for the basis of a robust TFWS for Harrow.

However, the review identified some gaps and issues in the current warning provision for Harrow. It recommended the addition of the following components to enable an effective TFWS configuration:

1. The BoM consider enabling the streamflow gauges at Fulham Bridge and Harrow to have flood class levels and that this data is made available online.
2. Crowdsourcing system for Salt Creek involving adjacent landholders requiring the installation of gauge boards as reference points. This would remove the uncertainty surrounding the potential contribution of flows in Salt Creek, this could be as simple as seeking landholder agreement for the SES/CMA for the landholder to provide flood intelligence.
3. The preparation of a Municipal Flood Emergency Plan for Harrow based on the Flood Intelligence Cards produced as part of the flood investigation and detailed in this report.
4. An emergency flood plan for the Harrow RSL club which can experience above-floor flooding.
5. Involvement of the local CFA brigade in community preparedness education for flooding, helping the RSL club with sandbagging and doorknocking to support Harrow residents as a flood progresses.
6. Support for vulnerable people in the community particularly to stock up on food, water and medicines.
7. Community participation in the review and integration of the Harrow TFWS components.

A benefit-cost analysis was conducted for these additional components giving a ratio of 0.84, with the main benefits to people's safety, which were not factored into this analysis.

7. FLOOD INTELLIGENCE

[14] Molino Stewart (2017), Harrow Flood Investigation – Total Flood Warning System Assessment

Flooding in Harrow is driven by two separate catchment areas; up and downstream of Fulham Bridge. The Harrow streamflow gauge has consistently recorded two peak stream heights during historic events representative of the two catchments, an initial peak height due to the rainfall runoff occurring in the catchment downstream of Fulham Bridge (including Salt Creek) and a second peak occurring due to the rainfall runoff in the catchment area upstream of Fulham Bridge. In two of the three historic events modelled in this project the second peak was the largest, however localised rainfall could result in the initial peak being larger.

The Fulham Bridge gauge gives the earliest streamflow indication of potential flooding at Harrow, general indications of flooding can also be determined from rainfall totals within the Glenelg River catchment. Given the proximity between the Harrow and Fulham Bridge gauges there is a consistent timing difference between the timing of peak stream heights. Hydrographs for the September 2010, December 2010 and January 2011 event hydrographs recorded at Fulham Bridge and Harrow are shown in Figure 7-1, Figure 7-2 and Figure 7-3 respectively. Each show a representation of timing of the localised catchment in the Harrow hydrograph, as the first peak, followed by the larger second peak from the broader catchment are upstream of Fulham Bridge.

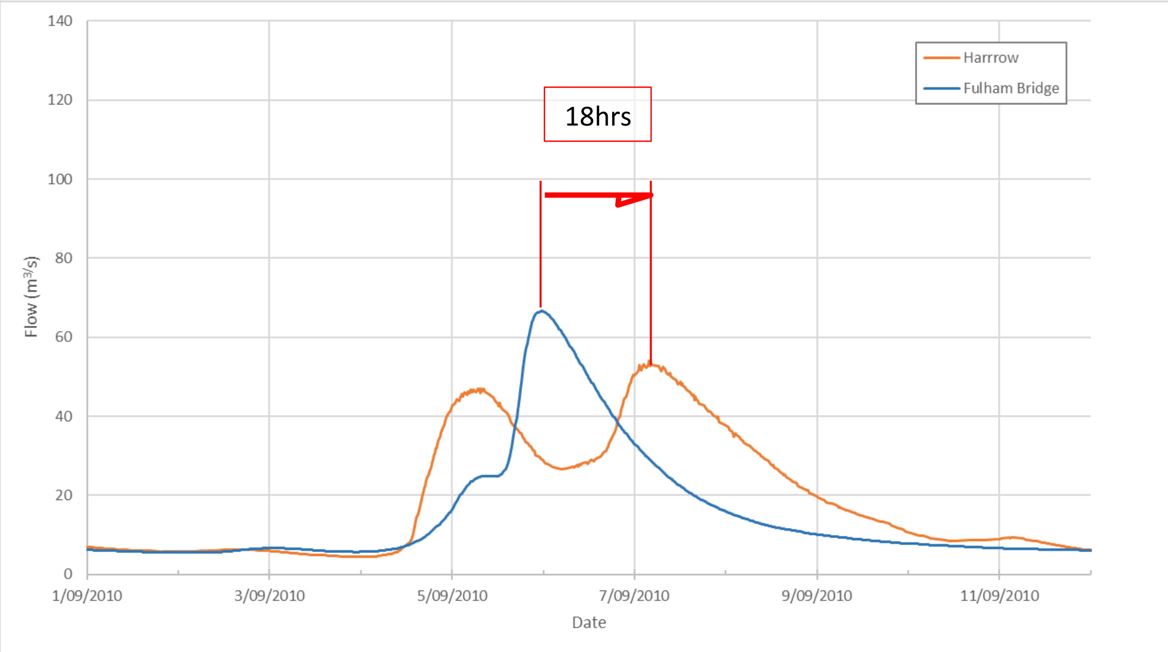

Figure 7-1 September 2010 - Gauged flows at Fulham Bridge and Harrow

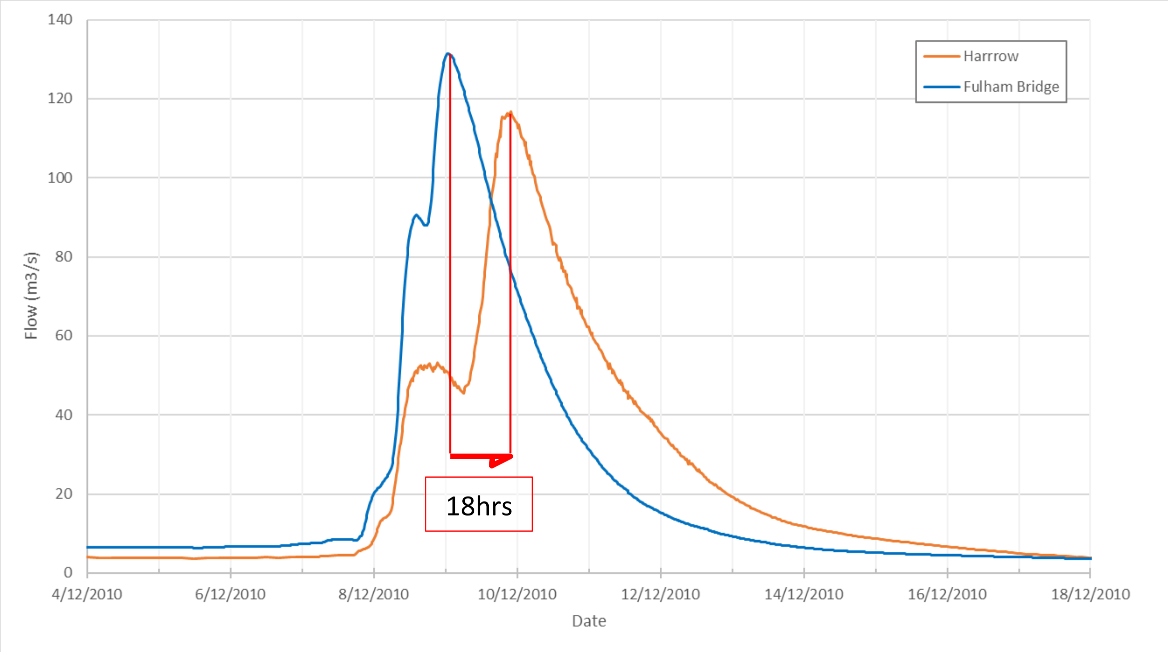

Figure 7-2 December 2010 - Gauged flows at Fulham Bridge and Harrow

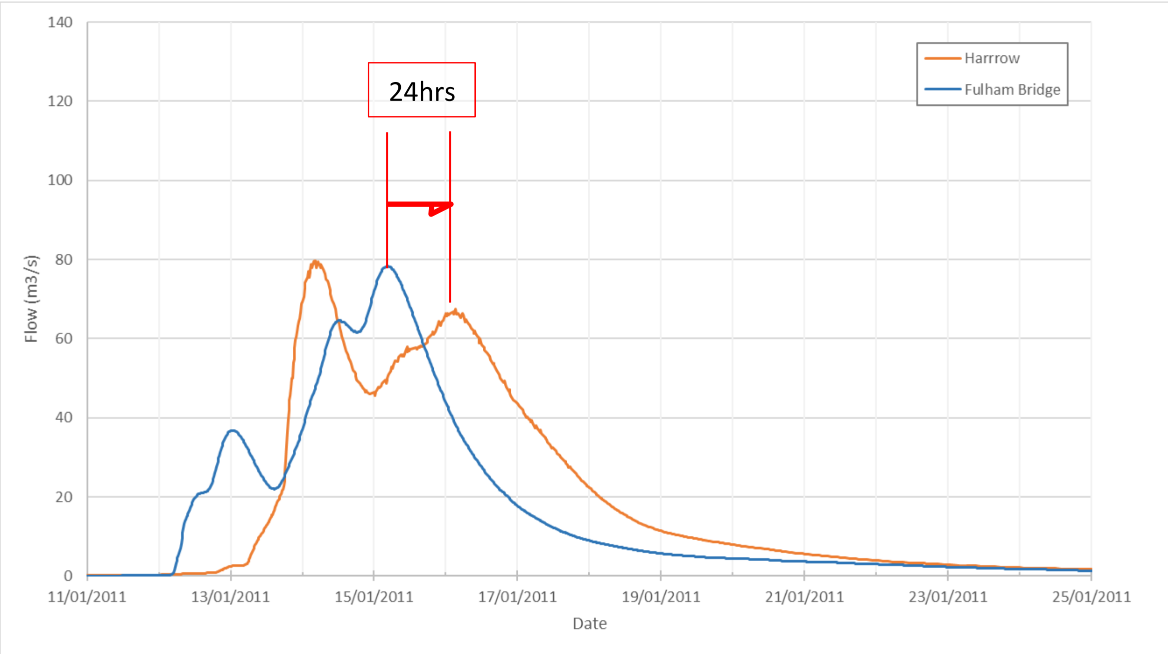

Figure 7-3 January 2011 - Gauged flows at Fulham Bridge and Harrow

Table 7-1 below documents travel times observed during the most recent events on the Glenelg River with time zero the peak timing at Fulham Bridge. Travel times were calculated as the time that the **peak** of the event takes to move from one gauge to the next. Note that the onset of flooding can occur before the peak water level occurs.

Table 7-1 Timing of peak flow on the Glenelg River for historic events – Timing beginning at the Glenelg River at Fulham Bridge streamflow gauge

Reach	September 2011	December 2010	January 2011
Glenelg River at Fulham Bridge	0	0	0
Glenelg River at Harrow	18 hrs	18 hrs	24 hrs

The number of properties impacted for a range of design events is shown below in Table 7-2, the design events are outlined for the Glenelg River at Harrow as this gauge gives the best indication of the predicted flooding within the town.

Properties at risk of flooding in Harrow are primarily on the eastern side of Blair Street. As flood events get larger there is generally only minor increases to depth and extent.

Infrastructure that may be impacted at various AEP's includes:

- Harrow public toilets – First building inundated
- Harrow Library – Access may be limited due to inundation of Donaldson Place
- Harrow Mechanics Institute - Access may be limited due to inundation of Donaldson Place
- Harrow Telephone Exchange – Access may be limited
- Harrow Post Office – Access to building may be limited from the east and south
- Harrow Police Station

A summary of the number of flood impacted properties is shown in Table 7-2.

Table 7-2 Summary of flood affected properties in Harrow

Summary of number of flood affected properties along the Glenelg River in Harrow EXISTING CONDITIONS							
	Design Flood AEP (%)						
	20	10	5	2	1	0.5	0.2
Discharge at Glenelg River Gauge @ Harrow (ML/d)	72	104	130	149	160	168	211
Gauge height at Glenelg River Gauge @ Harrow (m)	2.28	2.50	2.65	2.76	2.82	2.86	3.07
Residential Buildings Flooded Above Floor	0	0	0	1	1	1	1
Commercial Buildings Flooded Above Floor	0	0	0	2	2	2	3
Properties Flooded Below Floor	0	0	1	2	2	3	9
Total Properties Flooded	**0**	**0**	**1**	**5**	**5**	**6**	**13**

8. DATASETS AND MAPPING

8.1 Overview

The flood mapping and datasets developed as part of the Harrow Flood Investigation are described in this section. Details are provided regarding the input data, methodology and outputs for the emergency response inundation and land use planning mapping.

8.2 Flood Inundation Mapping

8.2.1 Overview

Flood inundation maps were provided in pdf format for each flood event at a broad study area scale as well as three local extents focusing on the north, central and southern areas of the study area.

The following map components were generated:

- Flood extent with water level contours for all design events
- Depth shaded for all design events
- Velocity shaded for the 1% AEP design flood event
- Hazard polygons for the 1% AEP design flood event (see Section 8.2.5)

8.2.2 Flood Extent and Flood Depth Zones

The hydraulic analysis provides a regular grid of flood elevations across the hydraulic model study area. The flood extent was developed by converting the 4 m gridded model results into polygons. Shallow depths have not been removed from the results. The extent was smoothed to remove the sharp edges of the grid cells for visual mapping purposes.

Flood depths were classified for mapping using the following classifications:

- 0 m to 0.3 m
- 0.3 m to 0.5 m
- 0.5 m to 1.0 m
- 1.0 m to 2.0 m
- Greater than 2.0 m

8.2.3 Flood Elevation Contours

The flood elevations were contoured at 0.2 m intervals. The automatic contouring procedures can create small disjointed contours, therefore manual refinement of the flood contours was undertaken to improve their interpretability.

8.2.4 Emergency Service Locations

The location of the following emergency services was included on the flood response maps:

- Hospital
- Fire Station
- Police Station
- SES Unit
- Aged Care Facilities

- Schools and Child Care Facilities
- Community Centre

8.2.5 Hazard Mapping

Hazard maps were developed as a significant output of the study. Analysis of flood hazard is used to determine if it is safe for people and vehicles leaving a property during a flood event. Flood hazard was derived for the study area based on Glenelg Hopkins CMA hazard guidelines. The flood hazard extents are based on the following criteria:

High Hazard

- depths greater than or equal to 0.5 metres; *or*
- velocity greater than or equal to 1.5 m/s; *or*
- the product of depth multiplied by velocity greater than or equal to 0.4 m^2/s.

Low Hazard

- depths less than 0.5 metres; *and*
- velocity less than 1.5 m/s; *and*
- the product of depth multiplied by velocity less than 0.4 m^2/s.

Two hazard extents were produced based on the above criteria. The extents can be utilised for both planning and emergency management purposes. The extents were provided as an output of the study in both PDF and digital format.

9. FLOOD DAMAGES ASSESSMENT

A flood damage assessment for the study area was undertaken using the range of design events modelled (20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF design events) for existing conditions. The damage assessment was used to determine the monetary flood damage for the design floods.

The flood damages assessment was also undertaken with the inclusion of the township buildings levees, to determine the potential reduction in damage that could result due to their construction.

Water Technology has developed an industry best practice flood damage assessment methodology that has been utilised for a number of studies in Victoria, combining aspects of the Rapid Appraisal Method, ANUFLOOD and other relevant flood damage literature. The NSW Office of Environment and Heritage stage damage curves are utilised, which represent far superior damage estimates at low depths above floor and below floor than previously used stage damage curves. Water Technology utilises WaterRide to undertake the property inspection and apply the appropriate stage damage curves.

The model results for all mapped flood events were processed to calculate the numbers and locations of properties affected. This included properties with buildings inundated above floor, properties with buildings inundated below floor and properties where the building was not impacted but the grounds of the property were. In addition to the flood affected properties, lengths and damages of flood affected roads for each event were also calculated.

The Average Annual Damage (AAD) was determined as part of the flood damage assessment. The AAD is a measure of the flood damage per year averaged over an extended period. This is effectively a measure of the amount of money that must be put aside each year in readiness for when a flood may happen in the future.

The flood damage assessment for existing conditions is shown below in Table 9-1. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$28,000**.

Two levees protecting the buildings south west of Blair Street were modelled and the reduction in flood damages was calculated. This option was not generally supported by the community but it was determined a better understanding of the potential reduction in flood damage was necessary. The levee around the John Mullagh Memorial Park was not assessed in terms of its reduction to flood damages because of the lack of data available to assess economic damages to the oval and impact on community. Generally, the damage is repaired through volunteer efforts which is largely undocumented.

The flood damage assessment for the levees protecting the properties south of Blair Street is shown below in Table 9-2. The Average Annual Damages (AAD) for existing conditions is estimated at approximately **$22,000.**

9.1 Non-economic Flood Damages

The previous discussion relating to flood damages has concentrated on monetary damages, i.e. damages that are easily quantified. In addition to those damages, it is widely recognised that individuals and communities also suffer significant non-monetary damage, i.e. emotional distress, health issues, etc.

The benefit-cost analysis presented in this report does not factor in this cost. Any decisions made that are based on the above benefit cost ratio need to understand that the true cost of floods in and along the Glenelg River is far higher than the economic damages alone. These intangible costs increase the benefit-cost ratio, improving the argument for approving a mitigation scheme at Harrow.

Table 9-1 Existing conditions damages

ARI (years) / AEP	500y 0.2	200yr 0.5%	100yr 1%	50yr 2%	20yr 5%	10yr 10%	5yr 20%
Residential Buildings Flooded Above Floor	0	0	0	0	0	0	0
Commercial Buildings Flooded Above Floor	3	2	2	2	0	0	0
Properties Flooded Below Floor	35	26	26	26	28	27	26
Total Properties Flooded		**296**	**180**	**81**	**9**	**6**	**4**
Direct Potential External Damage Cost	$306,859	$308,886	$304,114	$299,515	$297,185	$270,523	$230,001
Direct Potential Rural Damage Cost	$15,399	$15,043	$14,943	$14,797	$14,506	$14,100	$13,238
Direct Potential Residential Damage Cost	$0	$0	$0	$0	$0	$0	$0
Direct Potential Commercial Damage Cost	$91,300	$46,396	$36,411	$21,884	$0	$0	$0
Total Direct Potential Damage Cost	**$413,558**	**$370,325**	**$355,468**	**$336,196**	**$311,691**	**$284,623**	**$243,239**
Total Actual Damage Cost *(0.8*Potential)*	**$330,846**	**$296,260**	**$284,375**	**$268,957**	**$249,353**	**$227,698**	**$194,591**
Infrastructure Damage Cost	**$73,337**	**$55,006**	**$49,070**	**$41,184**	**$29,585**	**$26,547**	**$21,892**
Total Cost	**$404,183**	**$351,266**	**$333,445**	**$310,142**	**$278,938**	**$254,246**	**$216,483**
Average Annual Damage (AAD)	**$28,229**						

Table 9-2 Mitigation damages – Option 5

ARI (years) / AEP	500y 0.2	200yr 0.5%	100yr 1%	50yr 2%	20yr 5%	10yr 10%	5yr 20%
Residential Buildings Flooded Above Floor	0	0	0	0	0	0	0
Commercial Buildings Flooded Above Floor	2	0	0	0	0	0	0
Properties Flooded Below Floor	34	23	23	23	23	23	23
Total Properties Flooded	**36**	**23**	**23**	**23**	**23**	**23**	**23**
Direct Potential External Damage Cost	$290,927	$233,263	$231,856	$230,386	$225,937	$214,534	$180,762
Direct Potential Residential Damage Cost	$15,399	$15,043	$14,943	$14,797	$14,506	$14,100	$13,238
Direct Potential Commercial Damage Cost	$5,816	$0	$0	$0	$0	$0	$0
Total Direct Potential Damage Cost	**$312,142**	$0	$0	$0	$0	$0	$0
Total Actual Damage Cost *(0.8*Potential)*	**$249,714**	**$198,645**	**$197,439**	**$196,147**	**$192,354**	**$182,907**	**$155,200**
Infrastructure Damage Cost	**$72,963**	**$54,588**	**$48,158**	**$39,081**	**$27,953**	**$24,807**	**$21,487**
Total Cost	**$322,677**	**$253,233**	**$245,598**	**$235,228**	**$220,307**	**$207,714**	**$176,687**
Average Annual Damage (AAD)	**$22,049**						

9.1.1 Benefit-Cost Analysis

A benefit-cost analysis was undertaken to assess the economic viability of the Combined Mitigation Package. An indicative benefit-cost ratio was based on the construction cost estimates and Average Annual Damages calculated above.

The results of the benefit-cost analysis are shown below in Table 9-3. For this analysis, a net present value model was used, applying a 6% discount rate over a 30 year project life. The benefit cost ratio should ideally be equal to or greater than 1, meaning that the long term benefit of flood mitigation equals or exceeds the long term costs. In this analysis, the cost benefit ratio is 0.44, which indicates that the cost of mitigation exceeds the long term benefits. However, it is important to note that this analysis does not include social costs or benefits, some of which may be considered to be of greater value than the economic costs.

Table 9-3 Cost Benefit Analysis

	Existing Conditions	Buildings Levees
Average Annual Damage	$28,229	$22,049
Annual Maintenance Cost	-	$3,035
Annual Cost Savings	-	$3,145
Net Present Value	-	$44,226
Cost of mitigation		$50,358
Capital Cost of Mitigation	-	$101,179
Benefit-Cost Ratio	**-**	0.44

10. STUDY DELIVERABLES

10.1 Overview

The study deliverables provide a comprehensive set of data that support the study outcomes. The deliverables were supplied on a study USB and consist of background data and outputs as listed below:

- Animations of the 1% AEP flood event
- Digital copies of study reports in PDF format.
- Study survey data (structures, cross-sections and floor levels)
- Other input data including rainfall and flow data
- A property database including flood information
- Digital copies of maps (PDF format)
- GIS datasets for the model results (MapInfo and ArcGIS format)
- The hydrologic and hydraulic model input and result files
- Standalone Flood Visualisation Tool for Harrow

10.2 Mapping Outputs

Details are provided of the study outputs for emergency response, and land use planning mapping including:

- Data sets: grids and shapefiles/tab files
- Planning layers
- Flood response inundation maps
- VFD layer updates

10.2.1 Datasets

The following datasets were provided. All GIS files were provided in ESRI and MapInfo format.

Grids

Gridded datasets of model results were provided for the following:

- PMF – maximum depth, hazard and water surface elevation,
- Climate change sensitivity (10%, 1% and 0.5% AEP flood events) – maximum depth, hazard and water surface elevation,
- Design events (10%, 20%, 5%, 2% 1% & 0.5% AEP flood events) – maximum depth, hazard, velocity and water surface elevation.

Shapefiles/Tab files

ERSI shapefiles and MapInfo Tab files were provided for the following:

- Flood extents
- Floor levels
- Mapping limits
- Water surface elevation (flood level) contours

10.2.2 Maps

Flood inundation maps were provided in pdf format for each flood event. The map base is cadastre as supplied in 2013 and is subject to change.

The following map components were generated:

- Flood extent with water level contours for all design events
- Depth shaded for all design events
- Velocity shaded for the 1% AEP design flood event
- Hazard polygons for the 1% AEP design flood event (see Section 8.2.5)

Each map includes:

- Flood extent,
- Flood level contour at 0.2 m and 1m intervals,
- Depth of inundation,
- Identification of essential services,
- Road/street names,
- Cadastral base,
- Land marks, including all physical man-made features particularly those affecting flood flows and distribution.

Soft copies were provided as PDFs. Related GIS files were provided in ESRI and MapInfo format.

10.2.3 Flood Extent Mapping (VFD Compliant)

All flood mapping data was prepared to the VFD metadata specifications.

10.2.4 Land Use Planning Maps

A draft LSIO/FO map was produced as part of the Planning Scheme Amendment documentation and were provided on the study USB.

11. CONCLUSIONS

11.1 Overview

The Harrow Flood Investigation was successful in providing a much improved understanding of flood behaviour through the study area so that future planning decisions may be soundly based and measures may be put in place to minimise risk to the community. The investigation provides a comprehensive analysis and review of existing and future potential flood risk in the township and surrounding area. The study involved:

- Collection and review of a range of data relevant to the definition of flooding within the study area.
- A survey analysis to develop a detailed description of the study area topography as a basis for analysis and mapping.
- A rigorous hydrologic analysis to develop robust design flood estimates for the study.
- Development of a detailed hydraulic model that is capable of predicting flood impacts in Harrow under a range of conditions.
- Quantification of flood risk in terms of flood damages.
- Thorough sensitivity testing of the hydraulic results under both existing conditions and for climate change scenarios (10%, 20% and 30% increase in rainfall intensity).
- Examination of a range of potential flood mitigation options for different areas within the catchment.
- Review of flood warning and emergency management for the catchment including recommendations for development of a total flood warning system,
- Planning Scheme Amendment documentation for the study area.

11.2 Key Outcomes

The key findings and outcomes of the Harrow Flood Investigation were:

Study Area Hydrology & Hydraulic Characteristics

The study area covers the Harrow township and outlying area, and includes several small tributaries which traverse the township. Flooding within the study area generally occurs through two mechanisms:

1. Flooding in Glenelg River due to widespread and prolonged rainfall; and
2. Flash flooding in Salt Creek due to intense local rainfall.

The tributary catchments have shorter critical storm durations than the main Glenelg River, meaning that they are responsive to short, high intensity storms, whereas the Glenelg River flows are more responsive to sustained long duration rainfall. Historically there has been a 18-24 hour time difference between the peak flow occurring at Fulham Bride and Harrow. It has also been shown that as the size of flood events increase there isn't a substantial increase in depth or flood extent in Harrow, properties along the east of Blair Street are most at risk.

Flood Mitigation – Mitigation of flood risk in the study area was examined with several different measures assessed. A package of mitigation works was recommended which reduces inundation at the Johnny Mullagh Reserve. The recommended package provides the most benefit in terms of reduction in flood impacts without increasing flood levels or extensive levees. Protection of the buildings inundated within Harrow to the south-east of Blair St is possible for a relatively inexpensive cost. However, because the flood damages are relatively minor, the benefit-cost ratio is low.

Planning Controls –The most appropriate flood-related planning controls for study are Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO). Draft overlays were produced along with draft planning documentation to accompany a Planning Scheme Amendment.

11.3 Recommendations

The following recommendations were made from the findings of the Harrow Flood Investigation:

1. The West Wimmera Shire Council Municipal Flood Emergency Plan (MFEP) be updated with the information provided in the Harrow Flood Investigation Flood Intelligence Report.
2. The Land Subject to Inundation Overlay (LSIO) and Flood Overlay (FO) and associated planning scheme amendment documentation produced as part of this study be adopted in the West Wimmera Shire Council Planning Scheme.
3. The Victorian Flood Database (VFD) should be updated using the outputs of the Harrow Flood Investigation which have been formatted into the standard VFD outputs.
4. The Harrow Flood Investigation VFD deliverables should be uploaded to FloodZoom.
5. Bureau of Meteorology Flood Class Levels should be determined for the Glenelg River at Fulham Bridge and the Glenelg River at Harrow streamflow gauges and related to maps in the West Wimmera Shire Council Municipal Flood Emergency Plan.
6. Discuss a community flood observer role with local landholders on Salt Creek, with the aim of capturing local flood information during a flood event.
7. An emergency flood plan for the Harrow RSL club should be created.
8. The local CFA brigade should be actively engaged in community preparedness education for flooding.
9. A levee around the John Mullagh Memorial Park should be considered further with community groups and considered for funding.