Wakool Shire Council

Tooleybuc Flood Study
Final Report

October 2014

Cover photograph: Looking upstream opposite Tooleybuc at the Mallee Highway bridge crossing.

Executive Summary

The Tooleybuc Flood Study was commissioned by the Wakool Shire Council. The study has assessed Murray River flooding conditions at the township of Tooleybuc.

The study has been carried out in accordance with the NSW Government's Floodplain Development Manual (2005). The primary objective of the NSW Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods.

In urban areas, the management of flood-prone land remains the responsibility of local government. The NSW State Government provides funding to assist local councils with the development of floodplain risk management plans and their implementation.

The study has been overseen by Council's Floodplain Risk Management Committee. The Committee met regularly during the study to review progress and provide direction for future activities. The investigations carried out as part of this Flood Study may form the foundations for a future Floodplain Risk Management Study.

Data Review and Community Consultation

Community consultation and data review activities are documented in Sections 3 and 4 respectively of this report.

Community consultation was limited to contact early in the project with those government agencies with an interest in floodplain management at Tooleybuc in order to identify any data held by the respective agencies for potential use during the study. A public notice was placed in local newspapers shortly after the study commenced to make the general public aware of the project.

The data review activities focused on the available streamflow gauging records for the Murray River in the vicinity of Tooleybuc, past reports, past recorded flood levels and the available ground survey and river channel survey data.

A draft version of this report was placed on public exhibition for a four week period in July / August 2014. No submissions were received at the end of the public exhibition period.

Hydrology

The hydrology analysis activities are documented in Section 5 of this report. Hydrology analysis was limited to flood frequency analysis of the gauging station records for the Murray River at the Swan Hill gauge. The discontinued gauging station at Piangil only operated for a 12 year period, not sufficiently long for reliable flood frequency analysis. There are thought to be no major outflows between Swan Hill and Tooleybuc as supported by a comparison of the concurrent period of records at Swan Hill and Piangil.

The adopted 100 year ARI peak design flow derived from the flood frequency analysis is 35,000 ML/day. The design flow range is very compressed due to upstream Murray River flooding influences. Above a flow threshold of about 30,000 ML/day, the majority of the Murray system flow discharges via the Edward / Wakool river system, bypassing the Murray River towns of Tooleybuc, Murray Downs and Barham.

The flood frequency analysis results for the Swan Hill data suggest that the highest recorded event in 1975 was equivalent to an 80 year ARI event. The second highest recorded event in 1993 was equivalent to a 50 year ARI event. The highest recorded event since 2000 occurred in 2011 and was equivalent to a 5 year ARI event.

Hydraulic Modelling - Calibration

The hydraulic modelling calibration activities are documented in Section 6 of the report.

Hydraulic modelling was carried out using the TUFLOW model. All of the study area floodplain was represented using two dimensional modelling techniques based on a 10 metres grid. The terrain data sources used consisted of 2001 LiDAR data of the out of channel floodplain, surveyed cross sections of the river channel obtained in the 1980s by Victorian authorities and surveyed crest heights of the NSW side levee banks obtained in 2013 for this project.

The TUFLOW model was calibrated using recorded flood height data from the November 1975 and the July 1956 floods. The model was calibrated to achieve the optimum level of agreement between the available recorded flood heights and the modelled flood heights. The level of agreement achieved is considered satisfactory after taking into account the accuracy limitations of recorded flood height marks.

Hydraulic Modelling – Design Flood Events

The modelling results for the 5, 10, 20, 50, 100, 200 and extreme event are described in Section 7 of the report.

Flood map outputs associated with the design event modelling are included in Appendix A (design flood extents and heights), Appendix B (provisional flood hazard maps), Appendix C (hydraulic category maps) and Appendix D (flood profile plan).

Notable features of flooding conditions derived from the modelling results are summarized as follows:

- Peak 100 year ARI flood level is 62.00 m AHD at the Mallee Highway bridge. This is well below the bridge soffit level. The bridge deck itself and the Tooleybuc side bridge approach road is not subject to overtopping.
- The Victorian side approach road to the bridge crossing is overtopped by the 100 year ARI flood. The maximum depth of 100 year ARI road overtopping is 0.5 metres approximately 600 metres west of the bridge.
- There are a number of developed properties either within or on the fringe of the 100 year ARI flood extent. Building floor levels are required to confirm whether the buildings on these properties are subject to above floor flooding.
- Areas on the south and north sides of the existing township have been earmarked as potential long term future development areas. Both these areas are protected by rural standard levees which are either outflanked or overtopped in a 100 year ARI event. Possible rezoning of these areas to allow future development is likely to require a major upgrade to the existing levees.

The study has focused on reliably defining flooding conditions on the NSW side of the river, specifically at and adjoining the Tooleybuc township. Less emphasis has been placed on defining flooding conditions on the Victorian side of the river. The flood mapping on the Victorian side of the river is therefore indicative only and not necessarily reliable or representative of actual conditions.

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1. Introduction

The primary objective of the NSW Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods.

The Tooleybuc Flood Study has been undertaken to provide the Wakool Shire Council and other stakeholders with an up to date understanding of Murray River flood risks at Tooleybuc (refer to Figure 1). This will assist Council and other government agencies to make appropriate decisions in relation to future land use planning and also provide the basis from which to proceed with the development of a floodplain risk management study and plan to mitigate flood risks.

This study is the first detailed study undertaken to assess Murray River flooding risks at Tooleybuc (refer to Figure 1). Flooding impacts on the town have been relatively minor in more recent past floods.

This Flood Study represents the first step in the floodplain management process as set out by the NSW Floodplain Development Manual (2005). The four steps are:

- Flood Study – technical assessment to define the nature and extent of flooding under existing conditions;
- Floodplain Risk Management Study - evaluates management options for the floodplain giving consideration to hydraulic, environmental, social and economic issues;
- Floodplain Risk Management Plan – formal plan prepared which outlines the adopted strategies to manage flood risk and flood management issues; and
- Plan Implementation – measures nominated by the plan are put in place.

The Tooleybuc Flood Study was carried out concurrently with studies at Murray Downs and Barham. Separate flood study reports have been prepared for each of the three towns.

The study was undertaken in the following stages:

- **Stage 1 – Data Collection**. This stage encompassed consultation activities relevant to the flood study phase, the review of existing available data, the identification of additional data required to be obtained for the later stages and the confirmation of the approach for the subsequent stages.
- **Stage 2 – Hydrology**. This stage involved flood frequency analysis of historical recorded flows in order to identify appropriate design flows within the study area.
- **Stage 3 – Preliminary Hydraulic Modelling**. This stage encompassed establishment and calibration of the study area hydraulic model and a draft 100 year ARI flood profile.
- **Stage 4 - Final Hydraulic Modelling and Related Tasks**. This stage consisted of hydraulic modelling of the range of required design flood events, the preparation of flood mapping, assessment of climate change potential impacts and location specific flood output data at points of interest.
- **Stage 5 – Draft Flood Study Report**. Draft final report prepared detailing all of the investigations.

- **Stage 6 – Final Flood Study report.** The draft report will be updated as appropriate to take into account any comments received from the Committee.
- **Stage 7 – Project Completion and Handover of Study Materials**. This final stage will involve the handover of project outputs including both electronic and hard copy deliverables.

The Flood Study was overseen by Council's Floodplain Risk Management Committee. The Committee met on five occasions during the project. Progress reports were submitted to the Committee at the completion of Stage 1 and Stage 3. This Flood Study report was submitted to the Committee in draft form in May 2014 before being updated and then placed on public exhibition during July / August 2014.

Two terms are typically used to define the severity of flood events in Australia. The term Average Recurrence Interval (ARI) refers to the long term average number of years between the occurrence of a flood as big as or larger than the selected event. A flood with a discharge as great or greater than the 20-year ARI flood event for example will occur on average once every 20 years. The term ARI is used in this report to describe the size of flood events as it is generally well understood by most.

The alternative term is Annual Exceedance Probability (AEP). This term expresses the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. A 5% AEP event has a 5% chance (i.e. one in twenty) of being equaled or exceeded in any one year.

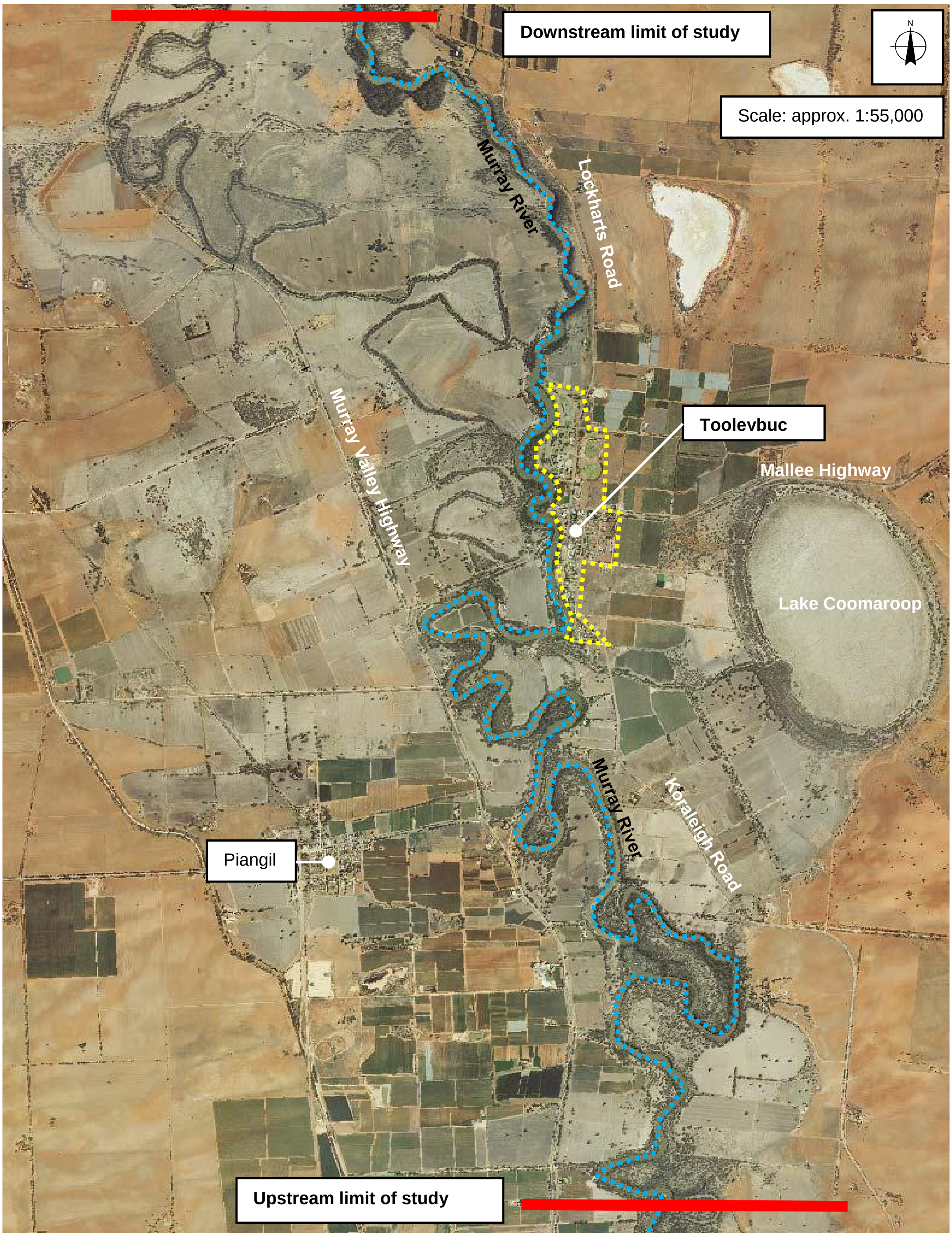

Figure 1 Study Area Plan

2. Study Area Description

2.1 Tooleybuc

Tooleybuc is a small township located on the NSW side of the Murray River, in the western portion of the Wakool Shire (refer to Figure 2). The Post Office at Tooleybuc opened in 1873. The population as recorded by the 2006 Census was 180.

Development is concentrated within the township, with some low density residential lots south of the township along the riverfront. The town includes the Tooleybuc Sporting Club complex, caravan park, motel and a combined primary / secondary school.

The 2009 Land Use Strategy Report (Collie et al, 2009) identifies Tooleybuc as a location suited to 'lifestyle' residential development. Average annual dwelling applications between 1997 and 2007 averaged 0.8.

The nearest township to Tooleybuc is Piangil located 3 km south of Tooleybuc on the Victorian side of the Murray River with a 2006 population of 650. Piangil is located 1 km west of the Murray Valley Highway.

2.2 Catchment Description

The Murray River catchment upstream of Tooleybuc is large, encompassing the catchments of the Upper Murray River, Mitta Mitta River, Kiewa River, Ovens River, Goulburn River, Campaspe River and the Loddon River. The total catchment area is more than 50,000 km^2.

There are major storages located at Dartmouth Dam on the Mitta Mitta River, the Hume Dam on the Murray River upstream of Albury, and the Eildon Dam on the Goulburn River.

Not all flows from the upstream catchment discharge past Tooleybuc. Much of the upstream flow discharges into the Edward and Wakool River system. This anabranch system bypasses to the north of Tooleybuc, only returning to the Murray River 20 km downstream of Tooleybuc.

The following factors influence flooding conditions at Tooleybuc (refer to Figure 3):

- The Barmah choke is a natural floodplain constriction located in the vicinity of Barmah, upstream of Echuca. This natural constriction results in the majority of Murray River flood flows upstream of Barmah being directed northwards into the Edward River system.
- Between Echuca and Swan Hill, in large flood events a significant portion of the Murray River flow discharges northwards into the Wakool River system. This notable occurs at Thule Creek, Barbers Creek, Merran Creek and Waddy Creek.
- There are thought to be no major further outflows from the Murray River between Swan Hill and Tooleybuc. There may be some high level outflows via the Lake Wollare / Lake Goonimur / Lake Poomah system upstream of Nyah, although the limited amount of gauged flow data at Tooleybuc suggests that any outflows are small.

Flooding at Tooleybuc is therefore largely dependent on the rate and timing of flows being discharged by the Loddon River, Campaspe River and Goulburn River tributaries.

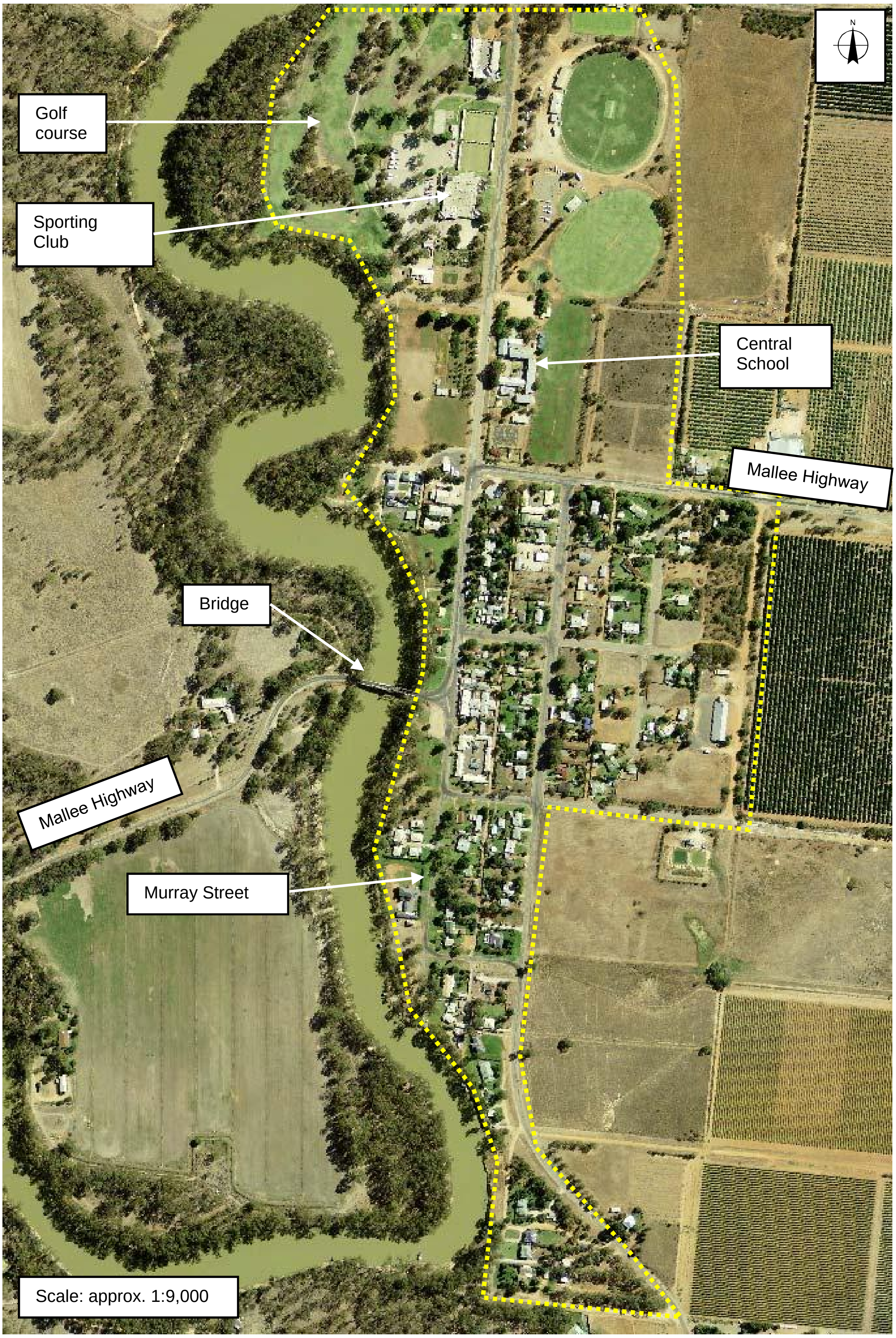

Figure 2 Tooleyuc – Local Features

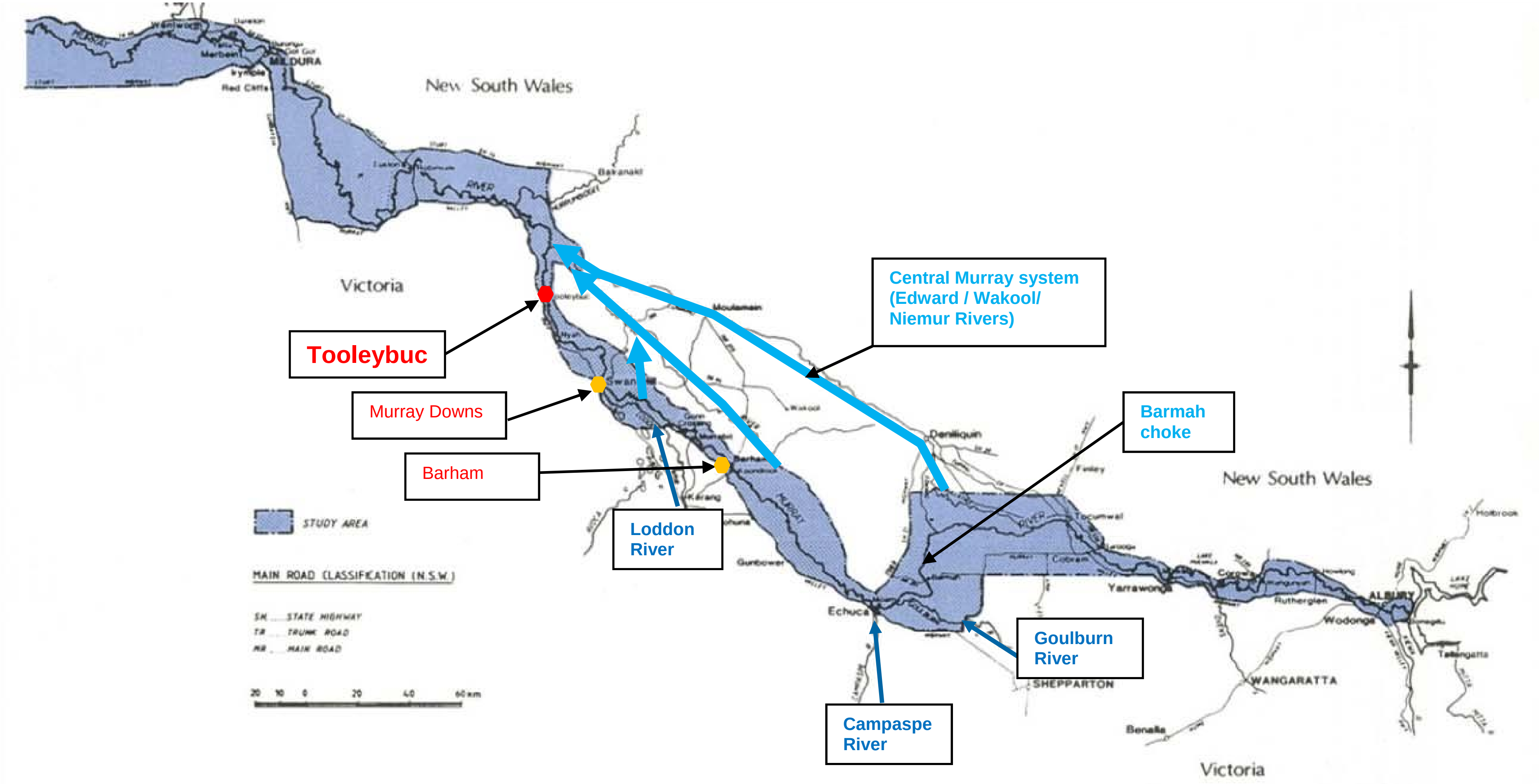

Figure 3 Murray River Floodplain Features

(modified extract from 1986 Murray River Floodplain Management Study)

2.3 Floodplain Description

Local floodplain features at Tooleybuc are shown on Figure 4.

Most of the existing town area at Tooleybuc is located on a sand hill and is elevated above the areas affected by flooding in non-extreme events (i.e. up to and including the 200 year ARI flood). For most of the town, there is therefore little or no risk of river flooding.

Although there are NSW side levees to the north and south of Tooleybuc, the existing town area with the exception of the Golf Course does not rely on levee protection.

The Murray River channel at Tooleybuc is typically approximately 80 metres wide measured from the top of bank and 7 to 8 metres deep. The average floodplain hydraulic gradient based on historical flood event recorded flood levels is 1 in 5,000.

There are rural levee banks present through this reach, notably upstream of Tooleybuc on the NSW side of the river. These levees vary greatly in height and condition. Most have been in place in some form for many decades.

The levee south of Tooleybuc restricts the access of floodwater to Lake Coomaroop. Floodwater can be directed into Lake Coomaroop via a 2 km link channel connecting the Murray River to the lake. A regulator is located at the river end of the link channel. The licensed regulator is operated by the Minnie Bend Flood Prevention Trust.

There is one river bridge crossing at Tooleybuc which forms part of the Mallee Highway route linking the Murray Valley area to the Balranald area. Construction of this bridge was completed in 1925. The historic bridge is the last ‘Allan timber truss and lift span bridge’ constructed in NSW and is listed on the State Heritage Register and also the Victorian Heritage register.

The NSW Roads and Maritime Services Department has recently commenced the planning process for a replacement bridge at Tooleybuc. Route options are yet to be assessed. The existing bridge may or may not remain following the completion of the new bridge crossing.

2.4 Historical Flood Events

The most significant flood events at Tooleybuc based on the flow records at Swan Hill (Station 409204) from 1909 onwards are 1975, 1993, 1981, 1974 and 1973 in order of magnitude. All of these events are post 1970, possibly due to changed flooding conditions at Swan Hill (e.g. closure or partial closure of NSW side effluent flow paths).

Flooding impacts on Tooleybuc, particular for those events since 1970, are thought to have been relatively minor based on anecdotal accounts.

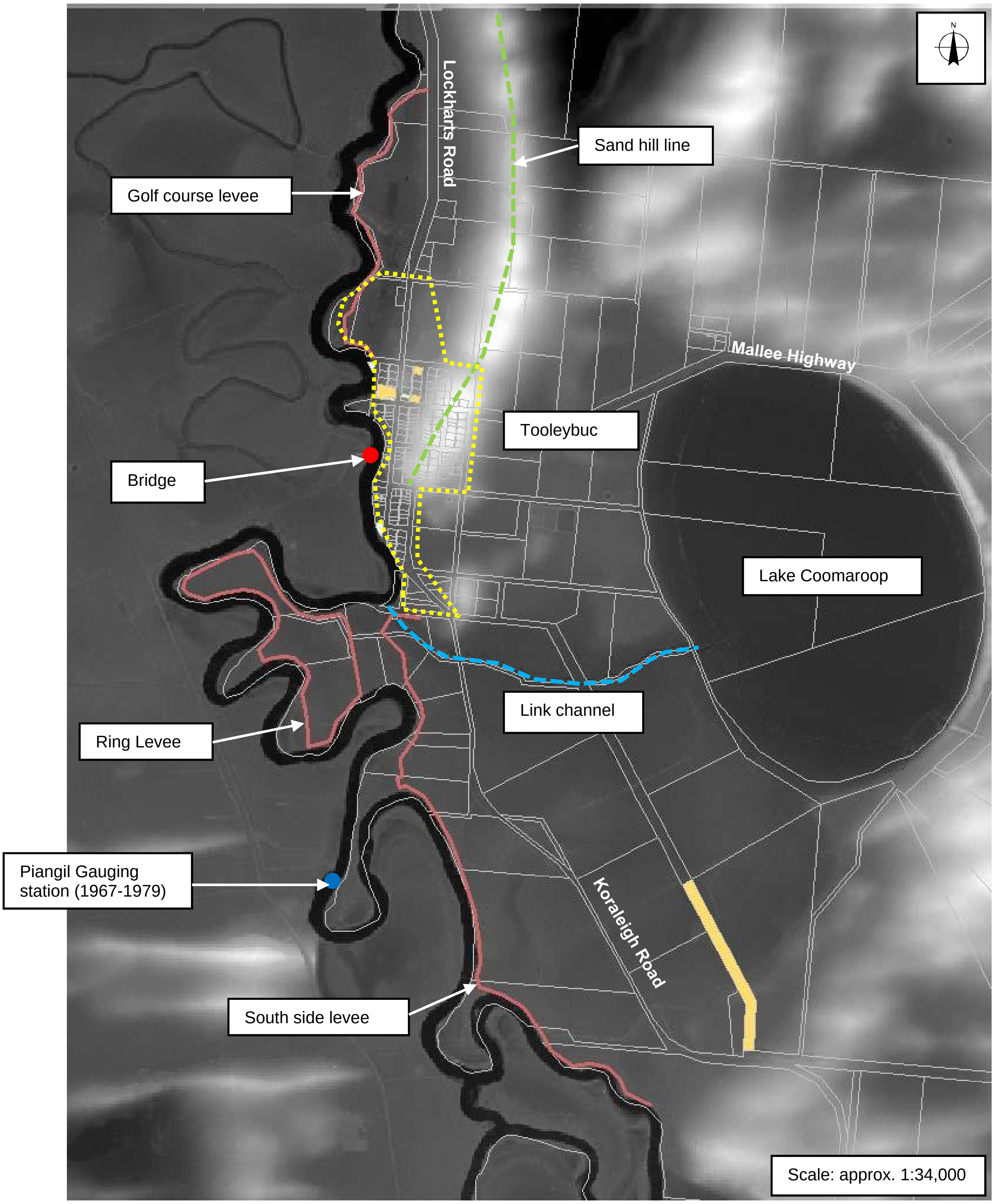

Figure 4 Local Floodplain Features (LiDAR Image)

Photograph 1 Mallee Highway looking south (main street of Tooleybuc)

Photograph 2 Murray Street looking north

Photograph 3 Golf course levee

Photograph 4 South side rural levee

3. Community Consultation

3.1 Overview

The primary objectives in relation to consultation activities during the flood study phase are as follows:

- Informing the relevant government agencies that the study is being undertaken, outlining its objectives and inviting agencies to provide any relevant data they may hold and / or advise of any particular issues of concern;
- Similarly informing relevant local community groups; and
- Similarly informing the general public.

3.2 Floodplain Risk Management Committee

Wakool Shire Council formed a Floodplain Risk Management Committee in 2012.

The Committee consists of representatives from the following organisations:

- Wakool Shire Council, both staff and Councillor representatives
- Office of Environment and Heritage
- NSW Murray Region State Emergency Service
- Local community representatives
- The above Committee met on four occasions during the flood study. Meetings were held in March, May, July and December 2013, and in June 2014.

3.3 Stage 1 Consultation Activities

A public notice was placed in the local newspapers in May 2013 in regards to the flood study. The notice provided basic details in regards to the initiation of the flood study, its objectives and contact details for any community members wishing to either find out further information regarding the project or pass on their thoughts.

Other government agencies with an interest in Murray River floodplain management at Tooleybuc were contacted shortly after the commencement of the study. This included the following organisations:

- Murray Darling Basin Authority (MDBA)
- Mallee Catchment Management Authority
- Goulburn-Murray Water

3.4 Public Exhibition of Draft Flood Study Report

The draft Tooleybuc Flood Study report was submitted to the Floodplain Risk Management Committee in May 2014. The draft report was then updated following a meeting of the Committee in June 2014 to reflect feedback received from the Committee. The draft report was then placed on public exhibition for a four week period in July / August 2014.

No submissions were received at the end of the public exhibition period. The report was subsequently finalised.

4. Data Collection and Review

4.1 Hydrologic Data

A streamflow gauging station operated at Tooleybuc from 1967 to 1979 prior to being closed (Piangil Station 409213 located as shown on Figure 4). The nearest upstream gauging station is located at Swan Hill (Swan Hill Station 409204) for which there are continuous records from 1909 onwards.

Given the absence of any significant inflows or outflows between Swan Hill and Tooleybuc, the Swan Hill recorded flows are suitable for deriving design flow estimates at Tooleybuc based on flood frequency analysis (refer to Section 5).

4.2 Flood Height Data

The primary source for flood height marks at Tooleybuc was the Victoria Flood Data (VFD) database. This database was initially compiled in 2000. It includes a GIS layer for recorded / observed spot elevation flood height marks from past flood events, based on a search of all available data at the time of the original database establishment. Within the study area reach of the Murray River floodplain, there are:

- Three 1975 event recorded flood height marks
- Three 1956 event recorded flood height marks

A local resident advised of a tree located on the upstream side of the bridge crossing with three flood heights marked on the lower trunk area of the tree. The survey of the three marks revealed the highest mark to be approximately 0.4 metres below two nearby recorded 1975 and 1956 flood heights.

The discontinued streamflow gauging station site (Station 409213) is located on the upstream side of the town, opposite the Victorian township of Piangil (refer to Figure 4). The rating curve for the station provides a potential source of flood heights for comparison with the modelled flood heights.

Victorian authorities have defined 100 year ARI flood levels for this section of the Murray River. The levels are 0.25 metres higher than the recorded 1975 height marks.

4.3 Previous Reports

No previous detailed flood studies are known to have been carried out at Tooleybuc and / or Piangil. The 1986 Murray River Flood Plain Management Study report (GHD et al, 1986) makes little or no reference to the Tooleybuc / Piangil reach of the floodplain.

The following reports with links to flooding conditions at Tooleybuc were reviewed during the course of the study:

- Swan Hill Tyntynder Flats Floodplain Management Study (Binnie and Partners, 1992).
- Various reports associated with the Swan Hill Regional Flood Strategy completed during the 1990s.
- Two reports detailing investigations associated with a planning study for a new river bridge crossing at Murray Downs / Swan Hill (Cardno Lawson Treloar, 2009 and 2011).
- Flood Data Transfer Project Flood Mapping Report for the Rural City of Swan Hill (Egis Consulting, 2000).

Flood mapping for the Murray River reach at Tooleybuc was prepared as part of the 1986 Murray River study and the 2000 Flood Data Transfer Project study.

4.4 Terrain Elevation Data

The following terrain data sources informed the study:

- 2001 MDBA LiDAR data. This data was checked against some site survey data provided by Council (unit development site at the corner of River and Lea Streets). The resultant comparison was favourable with elevations within +/- 0.10 metres and no obvious bias.
- Six river channel cross sections from a 1982 Rural Water Commission survey were obtained from Goulburn-Murray Water.
- The NSW RMS provided some plans of the 1925 Murray River bridge crossing at Tooleybuc. The plans were however inadequate for defining the bridge structure. VicRoads were unable to provide any plan data. Basic survey data for the bridge was therefore obtained.

The 2001 LiDAR data at Tooleybuc was compared with a number of alternative survey sources provide by Council and found to be in good agreement with no apparent bias.

4.5 Levees

Existing levee banks are located on the upstream and downstream sides of Tooleybuc. These levee banks appear to be licensed based on advice provided by NSW Office of Water.

The three principal levees in the vicinity of Tooleybuc are described as follows (refer to Figure 4):

- 1.5 km levee on the downstream side of town. Southern most limit of the levee is the south side of the golf course.
- 3 km levee on the upstream side of town. Northern most limit of the levee is the north side of the link channel to Lake Coomaroop.
- Ring levee within a large meander section upstream of the link channel to Lake Coomaroop.

The above levees are private licensed levees and are thought to date back many decades, possibly to around the 1930s. OEH has advised that there are no specific conditions associated with the licenses for these levees, including no height limitations.

A crest height survey of the above three levees was carried out to accurately define the crest elevations. The survey was completed in August 2013. This additional data was used to accurately define these three NSW side levees within the hydraulic model.

On the Victorian side of the river, floodwaters are generally relatively free to discharge across the floodplain between the river channel and the Murray Valley Highway, although there are some local banks present. The Murray Valley Highway is elevated, generally preventing the spread of floodwaters further west, except in very large floods.

5. Hydrology

5.1 Flood Frequency Analysis

The estimation of design flood flows for the study area was undertaken using flood frequency analysis techniques. This approach was suitable given the availability of more than 100 years of continuous streamflow records for the Murray River at Swan Hill (Station 409204).

Flood frequency analysis is the statistical analysis of recorded flows. The resultant statistically derived design flows are therefore a reflection of past floods for the period of available record.

The alternative approach to flood frequency analysis is deterministic rainfall / runoff (hydrologic) modelling. Rainfall / runoff modelling is generally the favoured approach for smaller catchments where concurrent rainfall and streamflow data allows for calibration of models. For larger catchments with complex flow exchanges influenced by hydraulic conditions, deterministic modelling becomes increasingly difficult, if not impossible. Given the size and complexity of the upstream catchment and the availability of the recorded streamflows at Swan Hill, hydrologic modelling was not undertaken.

5.2 Streamflow Data

Streamflow records of interest for Tooleybuc consisted of the following data:

- Murray River at Swan Hill (409204). This station was established in 1909 and is located 1.2 km downstream of the Moulamein Road bridge opposite Swan Hill.
- Murray River at Piangil (409213). This station operated between 1967 and 1979 and was located 300 metres east of the Murray Valley Highway / Mallee Highway intersection close to Tooleybuc (refer to Figure 4)/

There are thought to be no major inflows or outflows to the Murray River between Swan Hill and Tooleybuc. The peak recorded flows at the two gauging station sites for the period when the Piangil gauge was operating are provided in Table 1.

Table 1 Murray River at Piangil – Recorded Flows

Year	Peak Recorded Flow at Piangil (409213) (ML/day)	Peak Recorded Flow at Swan Hill (409204) (ML/day)	Difference (%)
1967	20,800	22,600	-8%
1968	26,100	27,900	-7%
1969	22,600	24,400	-7%
1970	27,600	26,400	+4%
1971	25,100	26,600	-6%
1972	16,600	18,100	-8%
1973	30,200	32,200	-6%
1974	30,000	32,800	-8%
1975	31,300	34,500	-9%
1976	23,800	22,300	+7%
1977	17,200	17,000	+1%
1978	24,100	24,900	-3%
1979	27,700	27,700	0

The three largest flood events during the period 1967 to 1979 when the gauge at Piangil was in operation were 1973, 1974 and 1975. For each of these floods, the gauged peak flow at Piangil is between 91 to 94% of the gauged peak at Swan Hill.

This relatively small reduction in peak flow is likely to be due to outflows into the Lake Woolare / Lake Poonah system on the upstream side of Nyah or possibly simply inaccuracies in the respective rating tables.

Given the small differences between the peak gauged flows at Swan Hill and Piangil, it was decided to base the design flow rates at Tooleybuc on the results of flood frequency analysis for the much longer period of gauged flows at Swan Hill, without further adjustment.

5.3 Flood Frequency Analysis Results

The flood frequency analysis was undertaken using the computer program FLIKE. FLIKE is a program which uses the Bayesian approach and up to five probability models which are commonly used in flood frequency analysis.

The flood frequency analysis results are given in Table 2. The results coincide with fitting the data to an LPIII distribution. The full period of record was used for the analysis. Previous study estimates are given in Table 2 for comparison purposes. The flood frequency analysis derived estimate for the 100 year ARI flow is 35,000 ML/day.

The design flows are compressed within a very narrow range. This is due to upstream Murray River flooding influences (e.g. Barmah Choke, Barbers Creek floodway) which results in the majority of river flows above a threshold of approximately 30,000 ML/day being discharged by the Edward / Wakool system, thereby bypassing Swan Hill and Tooleybuc.

Table 2 Swan Hill – Design Flow Estimates

ARI (years)	Peak Design Flow (ML/day)				
	1992 Study (Note 1)	1995-99 Study (Note 2)	2009 Study (Note 3)	**2014 Study Estimate**	2014 Study 5% & 95% confidence limits
2	25,900	-	-	**25,700**	24,900 – 26,500
5	31,500	-		**29,400**	28,600 – 30,300
10	33,600	-	-	**31,200**	30,300 – 32,200
20	34,800	-	33,800	**32,600**	31,600 – 33,700
50	35,800	-	35,500	**34,000**	32,900 – 35,400
100	36,200	42,100	36,400	**35,000**	33,700 – 36,600
200	-	-	-	**35,700**	34,400 – 37,600

Notes:

1. 1992 Study – Binnie & Partners – Swan Hill / TynTynder Flats Floodplain Management Study.
2. 1995 – 1999 study – Sinclair Knight Merz – Swan Hill Regional Flood Study.
3. 2009 study – Cardno Lawson & Treloar – Detailed Hydrology Study for the Swan Hill Bridge Planning Study.
4. Levels and flows are at the Swan Hill streamflow gauge 409204, located 1.2 km downstream of the Swan Hill bridge.
5. Swan Hill gauge zero is 62.921 m AHD.

The Swan Hill Regional Flood Strategy (Sinclair Knight Merz, 1999) adopts a 100 year ARI flow of 42,100 ML/day at Swan Hill. This is based on an extremely elaborate assessment incorporating hydraulic modelling and various levee failure scenarios. The contributing inflows are nominated by the report as 26,000 ML/day from the Murray River (upstream of Loddon), 31,000 ML/day from the Loddon River and 3,600 ML/day from the Avoca River. The estimated peak is reduced to 42,100 ML/day at Swan Hill after taking into account outflows from Waddy Creek (11,900 ML/day) and floodplain storage attenuation effects.

The gauging station data at the Swan Hill station should reflect all of the various influences on flooding conditions upstream of this location. Given the long period of record (103 years), it would seem overly conservative to discard the flood frequency analysis results and adopt a design flow considerably larger than the 35,000 ML/day outcome.

Based on the peak design flows given in Table 2 (i.e. design flows at Swan Hill), the equivalent ARI of the five highest peak flow events are listed as follows:

- October 1975 (34,500 ML/day) – 80 year ARI
- October 1993 (33,900 ML/day – 50 year ARI
- August 1981 (32,900 ML/day) – 20 year ARI event
- August 1974 (32,800 ML/day) – 20 year ARI event
- September 1973 (32,200 ML/day) – 15 Year ARI event

Since 1993, the highest peak flow at Swan Hill occurred in the first week of February 2011, peaking at 29,600 ML/day. This was equivalent to around a 5 year ARI event based on the current study flood frequency analysis results.

5.4 Design Event Inflow Approach

A review of the gauged flow data for past floods at the Swan Hill gauge confirms that flow rates rise and fall relatively slowly. Examples are described as follows:

- October 1993. This event peaked at 33,900 ML/day on the 9 October. The flow remained above 30,000 ML/day at the Swan Hill gauge from the 2 October to the 25 October.
- November 1975. This event peaked on the 12 November at 34,500 ML/day. The flow remained above 30,000 ML/day from the 23 October through to the 26 November.

Given the slow rates of rise and fall, the use of steady state flow inputs for the hydraulic modelling was adopted.

5.5 Extreme Event

The Murray River system is an extremely complicated system. In an extreme event, it is difficult to predict flooding conditions. Certainly vast areas would be inundated as a result of levees overtopping. This would result in only limited increases in the peak flow rate at Tooleybuc.

For the purpose of modelling an extreme event at Tooleybuc, the approach adopted was a simplistic one involving the adoption of a flow rate equal to three times the 100 year ARI design flow, with flows confined to the limits of the hydraulic model area. This approach is considered likely to result in peak modelled flood levels and extents which are arguably higher than what would actually occur in an extreme event.

6. Hydraulics – Calibration Modelling

6.1 Overview

Hydraulic modelling was carried out consistent with the approach outlined in the NSW Floodplain Development Manual. This approach involves the following steps:

- Assembly of the hydraulic model using the available terrain and waterway structure data.
- Calibration of the model using the available historical flood gauged flow data and recorded flood height data.
- Modelling of a range of design floods using the adopted design flow rates derived from the preceding hydrologic assessment and the calibrated hydraulic model.

The availability of digital elevation model (DEM) data for the study area floodplain allowed the use of a two dimensional hydraulic model, TUFLOW, for the hydraulic modelling. TUFLOW is a computational engine that provides two-dimensional (2D) and one-dimensional (1D) solutions of the free-surface flow equations to simulate flood propagation.

Aspects of the hydraulic model set-ups are described as follows:

- A 10 metres grid spacing was adopted. A finer grid spacing (e.g. 5 metres) would have significantly increased the run time durations.
- The downstream boundary condition was based on an assigned fixed water level consistent with recorded flood heights for historical events.
- The in-channel geometry of the Murray River was defined using surveyed in-channel cross sections obtained by Victorian government agencies during the early 1980s. A DEM of the river channel was generated using the available river channel cross section data and read directly into TUFLOW.
- The overbank floodplain geometry and Victorian side levee crest heights were defined using the 2001 MDBA LiDAR terrain elevation data.
- The NSW side levee banks within the study area were subject to a crest height survey to accurately define their crest height along their routes. The survey was undertaken by Northern Land Solutions during August to September, 2013.
- The bridge opening at Tooleybuc was defined using a combination of plan data and field acquired data.

6.2 Limitations

The TUFLOW hydraulic model was developed to simulate flood flow conditions. Although surveyed river channel cross sections have been used to define the channel geometry, the small number of cross sections available means that the river channel is not sufficiently well defined to be able to predict low flow water surface profiles.

Although the study included the modelling of an extreme flood event, this was performed in quite a simplistic manner. In extreme events, levees on both sides of the river will be overtopped resulting in very large areas being inundated on both the Victorian and NSW sides of the river. It is not practical to assemble models capable of accurately simulating extreme flood conditions given the vast affected areas and the complex upstream hydraulic conditions.

6.3 Hydraulic Model Calibration Approach

Flows for a range of varying size flood events at Toolybuc are compressed within a relatively narrow range due to the upstream floodplain conditions. The Murray River channel and the immediate adjoining floodplain has an upper limiting capacity of approximately 35,000 ML/day at Barham, Murray Downs and Tooleybuc. Flows in excess of this discharge northwards into the Wakool River system upstream of Barham, and between Barham and Murray Downs.

Recorded flood heights at Tooleybuc within the hydraulic model reach were limited to the following:

- Recorded flood heights at the Piangil gauge which operated from 1967 to 1979.
- Three other recorded flood heights for the 1975 flood.
- Three recorded flood heights for the 1956 flood.

The 1975 and 1956 recorded flood heights were therefore the basis for the hydraulic model calibration.

The peak recorded 1975 flow at the Piangil gauge was 31,300 ML/day, 9% lower than the peak recorded flow at the Swan Hill gauge. The Piangil gauge was not operating in 1956. The peak recorded flow at the Swan Hill gauge in 1956 was 31,000 ML/day.

A normal depth derived rating curve was initially trialled as the hydraulic model downstream boundary condition. This was however found to produce a downstream boundary water level which was much lower than the recorded flood heights in the vicinity. Consequently a fixed downstream boundary water level coinciding with the recorded flood heights in the vicinity was adopted.

Mannings roughness values were initially assigned based on a uniform main channel value of 0.06 and a uniform overbank value of 0.05.

Possible changes in levee conditions between 1956, 1975 and 2013 were not factored into the modelling. This was primarily due to any changes being extremely difficult to define. Additionally all of the levees appear to have been present in some shape or form for a long period of time. Possible levee breaches may also have occurred in the 1956 and 1975 floods leading to lower peak flood heights.

Flooding conditions on the Victorian side of the reach modelled are approximated only by the TUFLOW model (e.g. limitation of the 10 metre grid size) and additionally reflect conditions at the time of the 2001 LiDAR survey acquisition. In contrast, the NSW side levees were defined accurately using the crest height survey data obtained for this project in August – September 2013.

6.4 Calibration Modelling Results

The calibration hydraulic modelling results at Tooleybuc are presented in Table 3. The recorded flood height locations are shown on Figure 5.

Comments on the 1975 calibration modelling results are provided as follows:

- Downstream boundary fixed water level of 61.19 m AHD adopted. This coincides with the recorded 1975 flood level at this location (Flood Mark 75-1).
- Flood Mark 75-2 is located 250 metres upstream of the bridge crossing immediately opposite the town. The 1975 modelled height at Flood Mark 75-2 is 0.08 metres lower than the recorded height for a main channel roughness of 0.045.

- Flood Mark 75-3 is located 2.3 km south of the bridge at the Piangil streamflow gauging site which operated from 1967 to 1979. The modelled 1975 flood height is 0.20 metres above the recorded height based on a Mannings roughness of 0.045. If the NSW side levees are lowered, the modelled flood level at the gauge reduces considerably to approaching the recorded height.
- Flood Mark 75-4 is located 4.0 km south of the bridge, well upstream of the existing township limit. The modelled 1975 flood level is 0.13 metres above the recorded height based on a Mannings roughness of 0.045.

Comments on the 1956 modelling results are provided as follows:

- Downstream boundary fixed water level of 61.19 m AHD retained (i.e. minimal flow difference between the 1975 and 1956 events).
- It is not possible to obtain agreement with the recorded level at Flood Mark 56-1 unless the downstream boundary fixed water level is adjusted from that used for the 1975 model set-up.
- The modelled level at Flood Mark 56-2, confirms relatively good agreement between the modelled and recorded heights (0.07 metre difference based on Mannings roughness of 0.045). This is important, given its position directly opposite the town.
- The modelled level at Mark 56-3 is in very close agreement with the recorded height (0.01 m difference with main channel roughness of 0.045).

The following conclusions are therefore drawn from the calibration modelling:

- The model predicted heights are in good agreement directly opposite the town and support the adoption of a main channel Mannings roughness value of 0.045.
- The model predicted heights on the downstream side of Tooleybuc are considered reasonable, based on agreement with the 1975 recorded flood height, all be it through the fixed boundary condition flood level assignment.
- The model predicted flood heights on the upstream side of Tooleybuc are generally higher than the available recorded flood heights, on average by around 0.2 metres. The modelled flood heights are however sensitive to the NSW side levee bank height, which may have been lower or in a breached condition in 1975 and / or 1956. The modelled height at the most upstream mark (56-3) is only 0.01 metres higher than the recorded flood level (assuming roughness 0.045).

Table 3 Tooleybuc – Calibration Modelling Results

Event (peak flow rate ML/day)	Flood height mark number	Recorded flood height (m AHD)	Modelled flood height - m AHD ( ) modelled minus recorded flood level - m			
			Main channel Mannings roughness 0.035	Main channel Mannings roughness 0.045	Main channel Mannings roughness 0.060	NSW side levees removed & roughness 0.060
Nov 1975 (31,300 ML/day)	75-1	61.19	61.19 (+0.02)	61.19 (0.00)	61.20 (+0.01)	61.20 (0.00)
	75-2	62.05	61.87 (-0.18)	61.97 (-0.08)	62.13 (+0.08)	62.08 (+0.03)
	75-3	62.49 (gauge)	62.63 (+0.14)	62.69 (+0.20)	62.81 (+0.32)	62.56 (+0.07)
	75-4	62.90	62.96 (+0.06)	63.03 (+0.13)	63.16 (+0.26)	63.00 (+0.05)
Jul 1956 (31,000 ML/day)	56-1	61.43	61.19 (-0.24)	61.19 (-0.24)	61.20 (-0.23)	61.20 (-0.23)
	56-2	62.08	61.93 (-0.15)	62.01 (-0.07)	62.19 (+0.11)	62.13 (+0.05)
	56-3	62.97	62.90 (-0.07)	62.98 (+0.01)	63.11 (+0.14)	62.92 (-0.05)

Note:

1. Location of the recorded flood heights is shown on Figure 5.

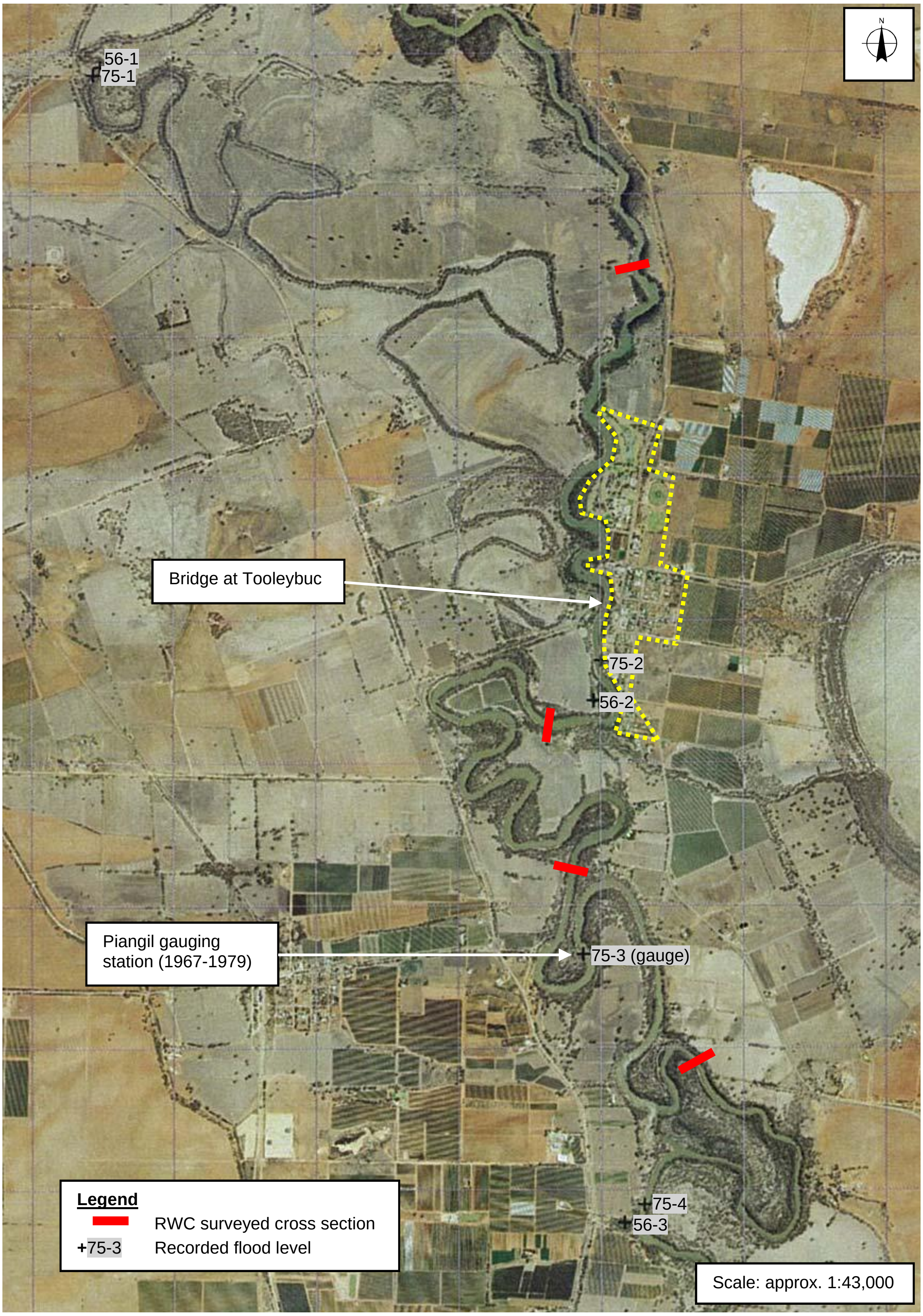

Figure 5 Recorded Flood Heights

6.5 Preliminary 100 Year ARI Design Flood Modelling

The calibrated TUFLOW model was used to produce a preliminary 100 year ARI flood profile and extent.

The following details were adopted for the preliminary 100 year ARI modelling:

- Peak design flow. A peak design flow of 35,000 ML/day was adopted consistent with the 100 year ARI design flow at Swan Hill / Murray Downs. Although the gauged data at Piangil from 1967 to 1979 suggest a small reduction of less than 10% in flow at Tooleybuc compared to Murray Downs, a conservative approach of adopting the higher Murray Downs design flow estimates was adopted. The peak design flow was input as a steady state flow.
- Downstream boundary condition. A fixed downstream boundary water level of 61.3 m AHD was adopted, 0.11 metres higher than the downstream boundary water level for the 1975 calibration modelling. This was considered appropriate given the design flow adopted.
- A main channel Mannings roughness value of 0.045 was adopted given the calibration modelling results.

The 100 year ARI modelling results indicate the following:

- The modelled 100 year ARI flood height at the discontinued Piangil gauge is 62.76 m AHD.
- The modelled flood height at the Moulamein Road bridge is 62.00 m AHD, well below the bridge soffit level of 63.45 m AHD.
- The modelled flood extent is confined to the river side of Murray Street. Grounds flooding of properties with river frontage will affect some properties between the Lake Coomaroop regulated channel offtake and the golf course. Above floor flooding of dwellings is unlikely although this requires confirmation by comparing floor levels with flood levels.
- The Golf Course levee crest heights are above the 100 year ARI flood levels. Flow is however outflanking the southern end of the levee and resulting in the inundation of the area protected by the levee.
- The ring levee on the southern fringe of town is overtopped by the 100 year ARI flood. The levee overtops in multiple locations resulting in inundation of all of the area within the ring levee.
- The south side levee is overtopped by the 100 year ARI flood. Generally the crest height of this levee is elevated above the 100 year ARI flood level, however there are some localised low points in the levee where overtopping occurs, notably adjoining the north side of the link channel to Lake Coomaroop and 600 metres south of the link channel. The overtopping flows inundate a broad area which includes Lake Coomaroop.

As previously indicated, the modelled flood extents on the Victorian side of the river are indicative only. The model results indicate overtopping of the Murray Valley Highway approximately 2 km south of the Mallee Highway junction. These overtopping flows then discharge in a looped shape around Piangil as shown. The model also identifies overtopping of the Murray Valley Highway approximately 3 km north of the turn off to Tooleybuc.

Prior to adopting the above preliminary 100 year ARI event model outputs, further analysis was undertaken to assess the sensitivity of the hydraulic modelling outputs to flow, the adopted Manning roughness, bridge blockage and the downstream boundary model condition. The sensitivity analysis results are provided in the following section.

6.6 Sensitivity Assessment

6.6.1 Flow

The impact of a 20% increase and decrease in the 100 year ARI design flow was assessed using the TUFLOW hydraulic model to identify the sensitivity of the modelled flood levels to the flow rate.

The results are summarised in Table 4. Increasing the design flow by 20% from 35,000 ML/day to 42,100 ML/day will result in an increase in the modelled 100 year ARI flood levels of approximately 0.15 metres. Alternatively reducing the design flow by 20% from 35,000 ML/day to 28,000 ML/day will result in a decrease in the modelled 100 year ARI flow of approximately 0.13 metres.

The flow variations used for the sensitivity analysis are relatively extreme given the narrow range of flow conditions at Tooleybuc. The 100 year ARI adopted design flow at Tooleybuc is only 19% higher than the 5 year ARI design flow. The reasons for this are discussed earlier in the report. They relate primarily to the interaction of flows between the Murray River and its northern Edward / Wakool River anabranch system.

Table 4 Sensitivity of 100 Year ARI Flood Levels to Flow

Location	Predicted change in 100 year ARI flood level (m)	
	20% decrease in 100 year ARI flow	20% increase in 100 year ARI flow
3.3 km downstream of the Tooleybuc bridge	-0.03	+0.03
1.5 km downstream of the Tooleybuc bridge	-0.08	+0.07
Immediately upstream of the Tooleybuc bridge	-0.14	+0.11
400 m south (upstream) of the Tooleybuc bridge	-0.12	0.15
0.7 km south of the Tooleybuc bridge	-0.13	0.15
At the discontinued Piangil gauge site – 2.5 km south of Tooleybuc bridge	-0.10	0.13
4.2 km south of the Tooleybuc bridge	-0.11	0.14

6.6.2 Floodplain Roughness

The sensitivity of the modelled flood levels to the adopted Mannings roughness value was assessed using the hydraulic model. The calibrated Manning roughness values are documented in Section 6.4.

The hydraulic model was used to predict revised 100 year ARI flood levels based on the previously calibrated Mannings values reduced by 25% and increased by 25%. Results are summarised in Table 5.

A 25% increase in the Mannings roughness value results in an average increase in the 100 year ARI flood level of 0.10 metres. The modelled increase varies from a minimum of 0.09 metres to a maximum of 0.11 metres.

A 25% decrease in the Mannings roughness value results in an average decrease in the 100 year ARI flood level of 0.09 metres. The modelled decrease varies from a minimum of 0.08 metres to a maximum of 0.10 metres.

Table 5 Sensitivity of 100 Year ARI Flood Levels to Floodplain Roughness

Location	Predicted change in 100 year ARI flood level (m)	
	25% decrease in Mannings roughness	25% increase in Mannings roughness
3.3 km downstream of the Tooleybuc bridge	-0.03	+0.03
1.5 km downstream of the Tooleybuc bridge	-0.06	+0.06
Immediately upstream of the Tooleybuc bridge	-0.09	+0.08
400 m south (upstream) of the Tooleybuc bridge	-0.09	0.10
0.7 km south of the Tooleybuc bridge	-0.10	0.11
At the old Piangil gauge site – 2.5 km south of Tooleybuc bridge	-0.08	0.09
4.2 km south of the Tooleybuc bridge	-0.09	0.10

6.6.3 Bridge Blockage

The only bridge across the Murray River at Tooleybuc spans the full width of the Murray River channel. Consequently the afflux induced by the bridge is minimal even in large floods.

The sensitivity of the 100 year ARI flood levels to blockage of the bridge opening was assessed by assuming the bridge opening to be 20% blocked.

There was no modelled increase in flood level as a result of the bridge being 20% blocked (i.e. the increase is less than 0.01 metres).

The afflux at the bridge site is small. The 100 year ARI flood level at the bridge is 62.00 m AHD. The waterway area below this level after adjusting for the piers is 470 m^2. The average velocity of flow through the bridge opening is less than 0.9 m/s assuming zero blockage. The velocity through the bridge opening increases to less than 1.1 m/s if 20% blockage of the bridge waterway opening area is assumed. Given these very moderate velocities, negligible afflux would be expected through the bridge openings.

6.6.4 Downstream Boundary Water Level

To test the sensitivity of the upstream modelled flood levels to the assigned downstream boundary fixed water level condition, the downstream boundary water level was raised by 0.3 metre (i.e. from 61.3 to 61.6 m AHD).

The resultant impact upstream was found to:

- Increase in flood height reduces to 0.13 metres, 1.5 km downstream of the Tooleybuc bridge. This is at the downstream limit of the existing town area.
- Increase in flood height reduces to 0.07 metres on the upstream side of the Tooleybuc bridge.

- Increase in flood level reduces to 0.01 metres at the old Piangil gauging station site (i.e. 2.5 km south of the Tooleybuc bridge).
- Zone of influence of the change to the downstream boundary water level is approximately 8 km (i.e. 0.3 metres flood level increase at the downstream boundary progressively dissipates to zero upon reaching 8 km upstream).

6.6.5 Summary of Sensitivity Modelling Results

The sensitive modelling results suggest that the modelled 100 year ARI flood levels are not particularly sensitive to changes in flow, Manning roughness and bridge blockage. This is however partly influenced by the fixed downstream boundary water level influence.

Once overbank flooding occurs at the Tooleybuc reach, large increases in flow are required to generate further increases in flood levels. The flow sensitivity modelling scenarios (+/-20% change in flow) represent extreme limits as highlighted by the range of the various design flows and the associated 5% and 95% confidence limits given in Table 1. The preliminary 100 year ARI design flow is arguably conservative given the apparent slight decrease in the gauged flow between the Swan Hill gauge and the Piangil gauge.

The 100 year ARI flood heights are not particularly sensitive to the Manning roughness parameter values assigned. Again, once overbank flooding occurs, any changes in flood levels appears to require major changes to the flow rate or other influencing parameters such as the roughness.

The bridge waterway area at Tooleybuc is large, spanning the full width of the Murray River channel. The minimal afflux induced by the bridge is not therefore sensitive to blockage of up to 20%. The adjoining west side approach road to the bridge is subject to overtopping to a maximum depth of approximately 0.5 metres approximately 600 metres from the bridge. This also works to limit the afflux induced.

The downstream limit of the TUFLOW model is located 3 km downstream of the likely limit of any future development at Tooleybuc. Any change in the TUFLOW downstream boundary condition will therefore have diminished impact a further 3 km upstream. The sensitivity run involving an increase in the fixed water level of 0.3 metres is an extreme scenario given the relative insensitivity of above overbank flood levels.

6.7 Discussion

6.7.1 Levee Assumptions

The following approach was adopted in regards to the hydraulic model defined levee conditions on the NSW side of the river:

- Levee crest heights defined in the hydraulic model coincide with the 2013 surveyed crest heights. Overtopping can therefore occur at any localised low points in the levee as per the levee height conditions at the time of the survey.
- The levees were not assumed to breach prior to the modelled flood level overtopping the levee crest or to fail (reduce in height) once overtopping occurred.

It could be argued that the above approach results in an outcome which suggests that areas upstream of Tooleybuc are less at risk of flooding than is actually the case. This argument is based on the assertion that the existing rural type levees are of a low standard, and consequently are likely to breach prior to the crest being overtopped and / or fail rapidly following overtopping. This scenario represents a worse scenario than that modelled.

The estimation of flood damages under existing conditions has not formed part of the current study. It is expected that a Floodplain Risk Management Study (FRMS) will follow the completion of this Flood Study and that the FRMS will include the estimation of flood damages.

Careful consideration to the levee assumptions made will need to be given when assessing flood damages under existing conditions, including the NSW government guidelines for 'Modelling Urban Levees for the Estimation of Flood Damages'.

6.7.2 Golf Course Levee

The so-called Golf Course levee (refer to Figure 4) protects the golf course and farmland to the north of the golf course. It is not an urban standard levee.

Close examination of the modelling results confirms that the Golf Course levee is not overtopped by the 100 year ARI flood. It has freeboard of about 200 mm above the 100 year ARI flood levels.

The Golf Couse levee is however marginally outflanked at the southern end of the levee which results in inundation of the area behind the levee. The outflanking could be easily eliminated by erecting a short section of temporary levee if and when the need arises (e.g. with sand bags).

6.7.3 Ring Levee

The ring levee (refer to Figure 4) protects farmland on the south side of Tooleybuc. It is not an urban standard levee and does not protect any parts of the town.

The ring levee is overtopped by the 5 year ARI flood at a small number of localised points. Again it would be relatively easy to top up the levee where overtopping threatens to occur during a flood, given the relatively slow rate of rise.

The 100 year ARI modelled flood level is typically 0.15 metres above the 5 year ARI flood level at this levee. Further raising of the levee during a large flood to protect against overtopping may also be possible.

6.7.4 South Side Levee

The South Side levee (refer to Figure 4) protects farmland and rural homesteads to the south of Tooleybuc. It is not an urban standard levee and does not protect any parts of the town.

The modelling has identified that the levee overtops at one noticeable low point in the levee, 500 metres south of the Lake Coomaroop link channel crossing. A short 15 metres section of the levee at this point is 0.6 metres lower. This allows overtopping in a 5 year ARI event. Minor outflanking at the southern-most end of the levee also occurs in a 5 year ARI event.

The above could easily be prevented by minor works if overtopping or outflanking became a threat. The slow rate of rise of floodwaters would allow time for temporary / top-up works to be done.

The flood mapping has been prepared on the basis of existing levee crest conditions. Widespread inundation behind the South Side levee is therefore shown, including inundation of Lake Coomaroop.

6.7.5 Victorian Side Inundation Extent

The focus of this study is on the Tooleybuc side of the Murray River. As such, considerable effort has been made to accurately define the levee crest heights on this side of the river (i.e. through the levee crest height survey commissioned as part of this study). The levee and road crest heights on the Victorian side of the river have relied upon the 2001 LiDAR data. The flooding conditions modelled on the Victorian side of the river may not therefore entirely reflect existing conditions and / or be affected by the limitations of the accuracy of the LiDAR data.

Comments made in relation to the preliminary 100 year ARI inundation mapping included a query as to the overtopping of the Murray Valley Highway, as predicted by the TUFLOW model. A close examination of the TUFLOW modelled levels and the source 2001 LiDAR ground surface elevations confirm the Murray Valley Highway is being overtopped at a minimum of two locations. The depth of overtopping is generally quite small (less than 0.3 metres). Given the limitations of the data on the Victorian side of the river, the resultant inundation mapping on this side of the river should be viewed as indicative only.

The source of the inundation in the vicinity of the township of Piangil is overtopping of the Murray Valley Highway, 2.3 km south of the junction of the Mallee Valley Highway and the Murray Valley Highway. This could be easily prevented however through some minor earthworks on the west side of the Highway where the LiDAR data shows the break-out flow occurring. Given that this study is for Tooleybuc and the Wakool Shire Council, this issue has not been further investigated.

7. Design Flood Modelling

7.1 Approach

The calibrated Mannings roughness parameter values were retained for the design flood modelling (refer to Sections 6.4 and 6.5).

Design flows were input into the hydraulic model as steady state flows given the slow rate of rise and fall recorded in past floods. The adopted design event flows derived from the flood frequency analysis of the gauged flows at Swan Hill (refer Table 2) are as follows:

- 5 year ARI – 29,400 ML/day
- 10 year ARI – 31,200 ML/day
- 20 year ARI – 32,600 ML/day
- 50 year ARI – 34,000 ML/day
- 100 year ARI – 35,000 ML/day
- 200 year ARI – 35,700 ML/day

Fixed downstream boundary water levels were used for the above design events. The assigned boundary water levels are based on consideration of the calibration modelling results and the variation in stage versus discharge at the discontinued Piangil gauging station. The assigned fixed boundary water levels varied from 61.00 m AHD for the 5 year ARI event to 61.32 m AHD for the 200 year ARI event, consistent with the narrow flood height versus flow range for this reach of the river.

7.2 Flood Map Outputs

A description of flood map outputs produced is provided in the following sections. The map outputs are included in Appendices A to D of this report.

7.2.1 Design Flood Extents and Flood Height Contour Series

Design flood extent and flood height contour mapping for the full range of design floods modelled is included in Appendix A. The flood height contours have been defined at 0.25 metres intervals. Mapping included in Appendix A consists of:

- 100 year ARI event – 0.2 metres interval flood height contours and flood extents:
  - Figure A1 - map covering the whole study area reach modelled (scale 1:50,000 at A3)
  - Figure A2 – map covering the existing and potential future town area only (scale 1:20,000 at A3)
- Further four design events - 0.25 metres interval flood height contours and flood extents covering the existing and potential future town area (scale 1:20,000 at A3)
  - Figure A3 – 5 year ARI
  - Figure A4 – 20 year ARI
  - Figure A5 – 200 year ARI
  - Figure A6 – Extreme event (three times the 100 year ARI event)

Given the pronounced compressed flow range at Tooleybuc, maps for the 10 and 50 year ARI events were not produced.

7.2.2 Hazard Category Map Series

The 2005 FDM provides the following definitions for the two floodplain hazard categories:

- High Hazard
  - '*Possible danger to personal safety, evacuation by trucks difficult, able-bodied adults would have difficulty in wading to safety, potential for significant structural damage to buildings.*'
- Low Hazard
  - '*Should it be necessary, truck could evacuate people and their possessions, able-bodied adults would have little difficulty in wading to safety*.'

The provisional hazard categories have been identified based on hydraulic conditions coinciding with the 100 year ARI flood. This has been determined in accordance with Figure L2 of the 2005 FDM (reproduced in Figure 6 below).

Hazard mapping included in Appendix B is as follows:

- Figure B1 – 100 year ARI event
- Figure B2 – 20 year ARI event

The provisional hazard categories should be reviewed at the time of a Floodplain Risk Management Study taking into account other factors aside from the depth and velocity of floodwaters (e.g. effective warning time, flood readiness, rate of rise of floodwaters, duration of flooding, evacuation problems and flood access considerations).

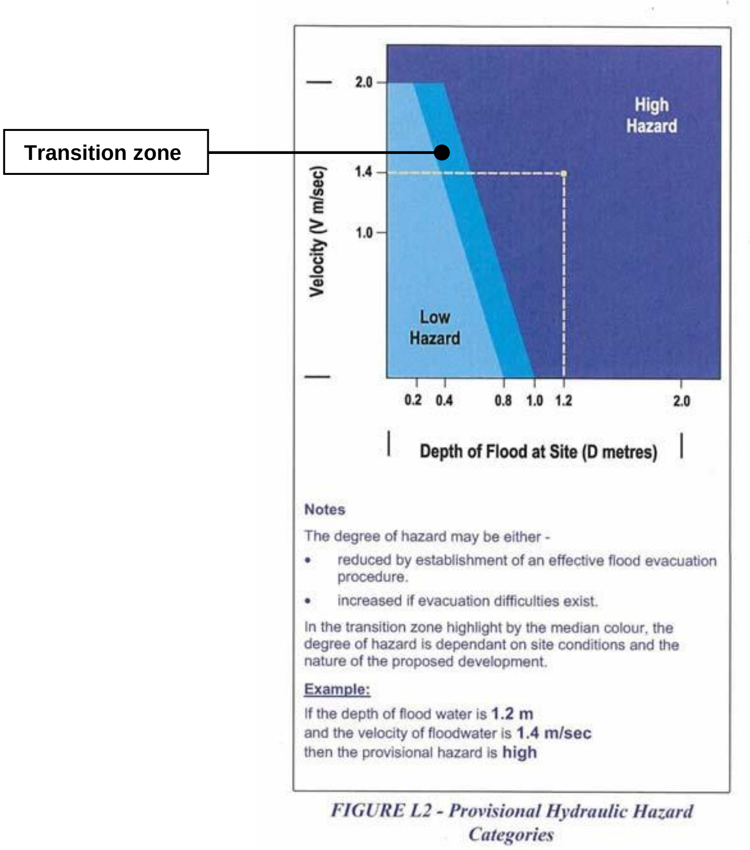

Figure 6 2005 FDM Hazard Categories

(extract from 2005 FDM)

7.2.3 Hydraulic Category Map Series

The 2005 FDM defines three hydraulic categories as follows:

- Floodways
  - '*Those areas where a significant volume of water flows during floods and are often aligned with obvious natural channels. They are areas that, even if only partially blocked, would cause a significant increase in flood levels and / or a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocity occurs*.'
- Flood Storage
  - *'Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.'*
- Flood Fringe
  - *'The remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and / or flood levels.'*

Explicit quantitative criteria for defining the above three hydraulic categories are not provided by the 2005 Manual or the 2007 DECC Guideline for Floodway Definition. The 2005 Manual nominates a guideline which defines flood storage areas as those areas which, if completely filled with solid material, would cause peak flood levels to increase anywhere more than 0.1 m and / or would cause the peak discharge anywhere downstream to increase by more than 10%. The 2007 DECC Guideline nominates that the obstruction of a floodway would lead to either the significant diversion of water away from its existing flow path and / or lead to a significant increase in flood levels.

Recent studies have made use of criteria identified within a technical paper (Howells et al, 2004) as the basis for the hydraulic categorisation. These criteria have been used to produce the hydraulic category mapping at Tooleybux presented in Appendix C. The approach uses the following criteria for the delineation of the floodway:

- Velocity depth product must be greater than 0.25 m^2/s and the velocity must be greater than 0.25 m/s, or
- Velocity is greater than 1.0 m/s

Outside the above defined floodway area, flood storage was defined as those areas where the depth exceeds 0.5 metres. The remaining inundated area was defined as flood fringe.

The hydraulic categorisation mapping provided in Appendix C is as follows:

- Figure C1 – 100 Year ARI event
- Figure C2 – 20 Year ARI event

7.2.4 Design Event Profile Map Series

The flood height contours represent the flood height surface gradient. Flood profiles present the same information plotted on a longitudinal section.

The design flood profile plotted relative to the river route is presented on Figure D1 in Appendix D.

7.2.5 Flood Planning Area

The flood planning area is the area of land below the flood planning level (FPL) which is consequently subject to flood related development controls (e.g. minimum floor level requirements). The FPLs are the combination of flood levels and freeboards selected for floodplain risk management purposes. This typically amounts to the 100 year ARI flood levels plus a freeboard provision. A freeboard of 500 mm is commonly adopted. The FPLs are generally adopted during a floodplain risk management study.

Figure A1 includes an extent line 500 mm above the adopted 100 year ARI flood levels. The area encompassed by the 500 mm extent line would represent the flood planning area assuming that the FPLs are based on the 100 year ARI flood levels plus a freeboard provision of 500 mm.

7.3 Discussion Modelled Flooding Conditions

7.3.1 Existing Development Impacts

Previous discussion in regards to the 100 year ARI modelled flooding conditions are provided in Sections 6.5 and 6.7. Some further detailed descriptions are provided as follows:

- Peak 100 year ARI flood level of 62.00 m AHD is 1.45 metres below the bridge soffit level of 63.45 m AHD). The bridge deck itself or the Tooleybuc side bridge approach road is not subject to overtopping.
- The Victorian side approach road to the bridge crossing is overtopped by the 100 year ARI flood. The road low point of 61.6 m AHD is located approximately 600 metres west of the bridge. The 100 year ARI flood level overtopping the road is 62.1 m AHD. The maximum depth of 100 year ARI overtopping is therefore 0.5 metres.
- Golf Course levee (refer to Figure 4). This rural standard levee is not overtopped by the 100 year ARI modelled flood levels. Floodwater does however marginally outflank the southern end of the levee resulting in inundation of the area on the outside of the levee.
- Ring levee on south side of Tooleybuc (refer to Figure 4). This rural standard levee is broadly overtopped by the 100 year ARI modelled flood levels. The whole of the area inside the ring levee is consequently inundated.
- Second levee south of Tooleybuc (refer to Figure 4). This rural standard levee is locally overtopped at three locations. This results in inundation of a very broad area between the levee and Lake Coomaroop as shown on Figure A1.

The hydraulic modelling and subsequent flood extent mapping assumes that the rural standard levees either side of Tooleybuc do not fail. The crest heights of the levees are based on a levee crest survey undertaken as part of this study in August 2013. It is likely that there has been some subsidence of localised sections of the levees, given that there have been no major floods in this reach of the Murray River since 1993 and hence no cause to top up any sections of levee which may have subsided.

In the event of an impending major flood, the slow rate of rise of floodwaters at Tooleybuc will potentially allow sufficient time for localised raising of low sections of levee which threaten to overtop, and provide sufficient time for extensions of levees where they threaten to be outflanked (e.g. southern end of Golf Course levee).

It is stressed however the existing Tooleybuc township area does not rely on any of the three rural levees modelled.

Developed areas at Tooleybuc within or close to the 100 year ARI extent are (refer to Figure 7):

- Motel located on the west side of Murray Street (Lockhards Road) on northern fringe of town. The motel is located within the 100 year ARI flood extent.
- Development of west side Murray Street opposite Lea Street. This area which includes the River Retreat Villa complex and the Tooleybuc Garage is marginally above the 100 year ARI flood levels.
- Units and a house at 32 to 38 Murray Street. The hydraulic modellings indicates that this area is marginally above the 100 year ARI flood level.
- South end of Murray Street. A large relatively new two storey house is located within the 100 year ARI extent, however the floor level is noticeably raised well above the ground surface level. The house is therefore unlikely to be affected by flooding.
- Residential properties adjacent to the river at the south end of Cadell Street. The hydraulic modellings indicates that this area is marginally above the 100 year ARI flood level.

Floor level elevations for those buildings located on the above properties have not been obtained as part of the current study. A comparison of the floor levels (once obtained) with the flood levels documented in this report will define what, if any, buildings are subject to above floor 100 year ARI flooding.

Flood damages for Tooleybuc have also not been identified as part of this study. Flood damages for the township are expected to be very low given the likelihood that few, if any residential or commercial land use buildings are expected to be subject to above floor flooding.

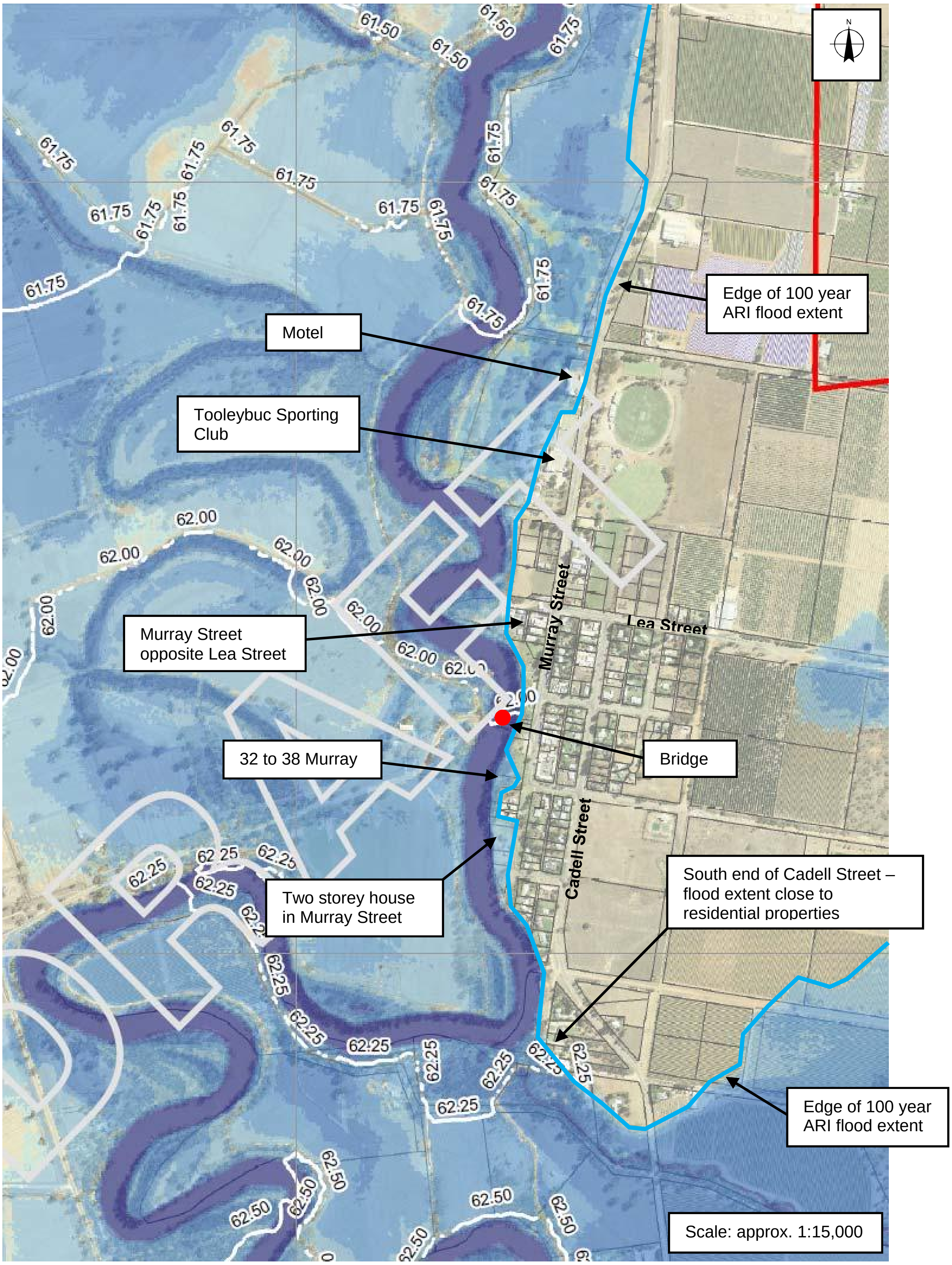

Figure 7 100 Year ARI Flood Extent Map Extract

7.3.2 Future Development – Flooding Issues

An extract from the Land Use Strategy Report (Collie, 2009) presented as Figure 8 shows potential future development areas at Tooleybuc.

There are a large number of existing vacant lots within the existing town area. The quality of these lots (proximity to river, size, adjoining existing development quality) is arguably not attractive to persons seeking to build their dream home.

Of the two earmarked future development areas, the first is located on the north side of the golf course outside the existing town limits. The area is protected against flooding by an existing rural levee (Golf Course levee). The levee is marginally outflanked by the 100 year ARI flood at its southern end resulting in the area protected by the levee being shown as subject to flooding (refer to Figure A2). The levee is also not an urban standard levee (refer to Photograph 3). A major upgrade of the levee to an urban standard is likely to be required to support any future rezoning proposal for the land.

The second area earmarked for future development is shown on the south side of the existing town area. It is also protected from flooding by an existing rural levee (South Side levee). The levee is marginally overtopped in a few locations resulting in the area being shown as subject to flooding (refer to Figure A2). The levee is also not an urban standard levee (refer to Photograph 4). A major upgrade of the levee to an urban standard is therefore likely to be required to support any future rezoning proposal for the land.

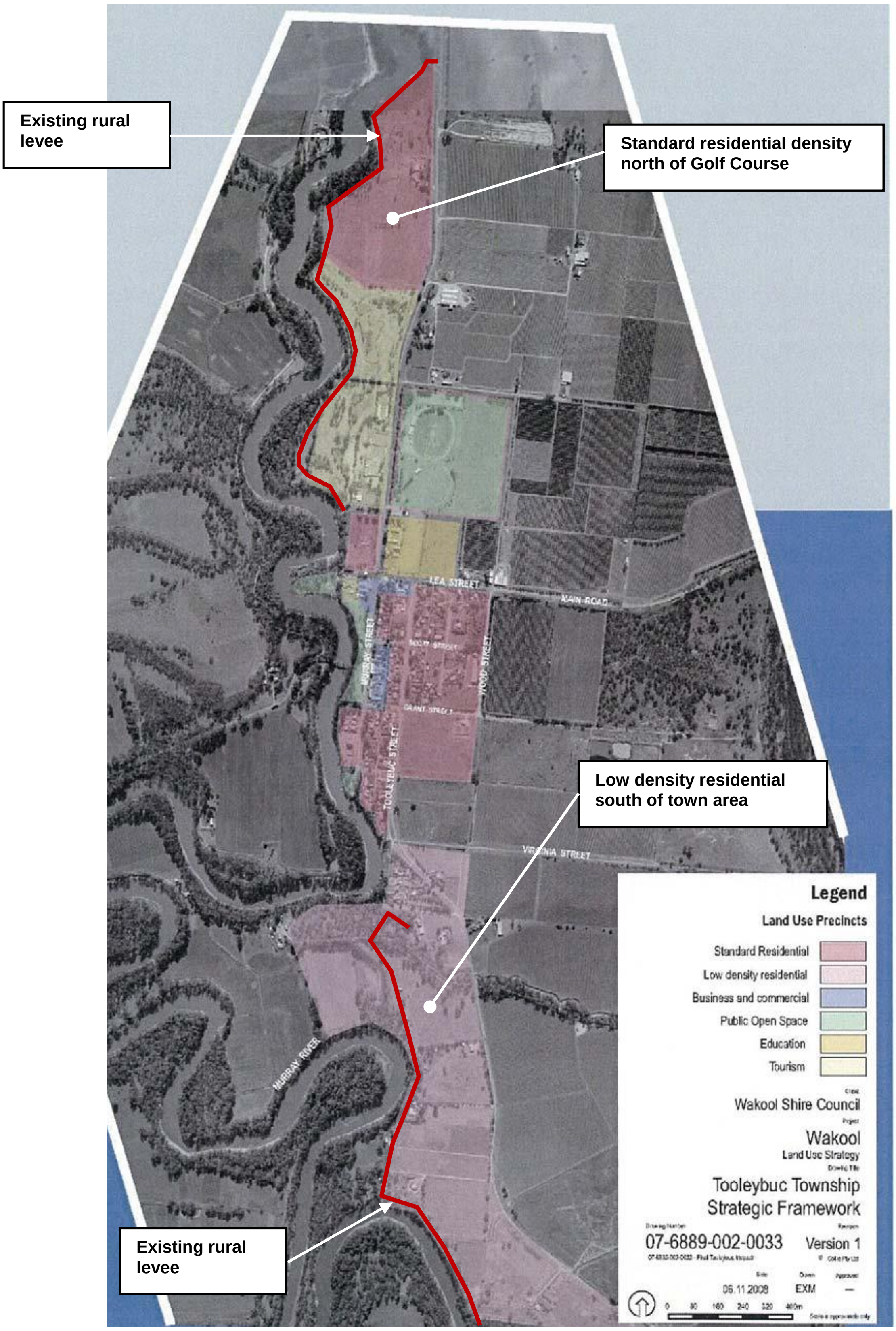

Figure 8 Potential Future Land Use Development Areas at Tooleybuc

(modified extract from 2009 Land Use Strategy Report)

8. Next Steps in Process

This flood study represents the first step in the process set out by the NSW Floodplain Development Manual (2005) leading to the preparation of a Floodplain Management Plan. The second step of the process requires a Floodplain Risk Management Study (FRMS) to be carried out. The FRMS assesses options for managing the flood risk to existing and future development including flood modification works (e.g. levee banks), property modification measures (e.g. land use planning controls) and response modification measures (e.g. better ways to prepare, respond and recover from floods).

In regards to Tooleybuc, the major issues to be addressed by a future FRMS will include:

- Future arrangements associated with any possible extensions, upgrades to and ongoing maintenance of the existing levees adjoining the town.
- An assessment of flood related land use planning and development controls appropriate for Tooleybuc including the adoption of the Flood Planning Area and Flood Planning Levels.
- Refinement of the flood hazard and hydraulic category mapping taking into account factors aside from the depth and velocity of floodwaters (e.g. effective warning time, rate of rise of floodwaters, duration of flooding, evacuation considerations etc).

9. Acknowledgments

GHD has completed the Tooleybuc, Murray Downs and Barham Flood Study project with the assistance of the Wakool Shire Council's Floodplain Risk Management Committee, Council's staff, Office of Environment of Heritage's staff and the other government agency and local residents who have had involvement in the project. The assistance which has been provided is very much appreciated by both GHD and the Wakool Shire Council.

The Wakool Shire Council has prepared this document with financial assistance from the NSW and Commonwealth Governments through the Natural Disaster Resilience Program. This document does not necessarily represent the opinions of the NSW or Commonwealth Governments.

10. Glossary

Annual Exceedance Probability (AEP) - AEP (measured as a percentage) is a term used to describe flood size. AEP is the long-term probability between floods of a certain magnitude. For example, a 1% AEP flood is a flood that occurs on average once every 100 years. It is also referred to as the '100 year flood' or 1 in 100 year flood'.

> 0.5% AEP sometimes referred to as the 1 in 200 year ARI event
>
> 1% AEP sometimes referred to as the 1 in 100 year ARI event
>
> 2% AEP sometimes referred to as the 1 in 50 year ARI event
>
> 5% AEP sometimes referred to as the 1 in 20 year ARI event
>
> 10% AEP sometimes referred to as the 1 in 10 year ARI event
>
> 20% AEP sometimes referred to as the 1 in 5 year ARI event

Afflux - The increase in flood level upstream of a constriction of flood flows. A road culvert, a pipe or a narrowing of the stream channel could cause the constriction.

Australian Height Datum (AHD) - A common national plane of level approximately equivalent to the height above sea level. All flood levels; floor levels and ground levels in this study have been provided in meters AHD.

Average annual damage (AAD) - Average annual damage is the average flood damage per year that would occur in a nominated development situation over a long period of time.

Average recurrence interval (ARI) - ARI (measured in years) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 100-year ARI flood is a flood that occurs or is exceeded on average once every 100 years.

Catchment - The land draining through the main stream, as well as tributary streams.

Critical Duration – The storm duration at which the peak flood flow and/or flood level occurs

Development Control Plan (DCP) - A DCP is a plan prepared in accordance with Section 72 of the *Environmental Planning and Assessment Act, 1979* that provides detailed guidelines for the assessment of development applications.

Design flood level - A flood with a nominated probability or average recurrence interval, for example the 100 year ARI flood is commonly use throughout NSW.

OEH (formerly DECCW, DECC, DNR, DLWC, DIPNR) - Office of Environment and Heritage. Covers a range of conservation and natural resources science and programs, including native vegetation, biodiversity and environmental water recovery to provide an integrated approach to natural resource management. The NSW State Government Office provides funding and support for flood studies.

Discharge - The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m3/s) or megalitres per day (ML/day). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving.

Effective warning time - The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

Extreme flood - An estimate of the probable maximum flood (PMF), which is the largest flood likely to occur.

Flood - A relatively high stream flow that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

Flood awareness - An appreciation of the likely effects of flooding and knowledge of the relevant flood warning, response and evacuation procedures.

Flood Fringe - The remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and / or flood levels.'

Flood hazard - The potential for damage to property or risk to persons during a flood. Flood hazard is a key tool used to determine flood severity and is used for assessing the suitability of future types of land use.

Flood level - The height of the flood described either as a depth of water above a particular location (e.g. 1m above a floor, yard or road) or as a depth of water related to a standard level such as Australian Height Datum (e.g. the flood level was 77.5 m AHD). Terms also used include flood stage and water level.

Flood liable land - Land susceptible to flooding up to the Probable Maximum Flood (PMF). Also called flood prone land. Note that the term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level, as indicated in the superseded Floodplain Development Manual (NSW Government, 2005).

Flood Planning Levels (FPLs) - The combination of flood levels and freeboards selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. The concept of flood planning levels supersedes the designated flood or the flood standard used in earlier studies.

Flood Prone Land - Land susceptible to flooding up to the Probable Maximum Flood (PMF). Also called flood liable land.

Flood stage - see flood level.

Flood Storage - Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.

Flood Study - A study that investigates flood behaviour, including identification of flood extents, flood levels and flood velocities for a range of flood sizes.

Floodplain - The area of land that is subject to inundation by floods up to and including the Probable Maximum Flood event, that is, flood prone land or flood liable land.

Floodplain Risk Management Study – Studies carried out in accordance with the Floodplain Development Manual and assess options for minimising the danger to life and property during floods.

Floodplain Risk Management Plan - The outcome of a Floodplain Management Risk Study.

Floodway - Those areas of the floodplain where a significant discharge of water occurs during floods. Floodways are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

Freeboard - A factor of safety expressed as the height above the design flood level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as "greenhouse" and climate change.

High Flood Hazard - For a particular size flood, there would be a possible danger to personal safety, able-bodied adults would have difficulty wading to safety, evacuation by trucks would be difficult and there would be a potential for significant structural damage to buildings.

Hydraulics Term - given to the study of water flow in waterways, in particular, the evaluation of flow parameters such as water level and velocity.

Hydrology Term - given to the study of the rainfall and runoff process; in particular, the evaluation of peak discharges, flow volumes and the derivation of hydrographs (graphs that show how the discharge or stage/flood level at any particular location varies with time during a flood).

Local catchments - Local catchments are river sub-catchments that feed river tributaries, creeks, and watercourses and channelised or piped drainage systems.

Local Environmental Plan (LEP) – A Local Environmental Plan is a plan prepared in accordance with the *Environmental Planning and Assessment Act*, 1979, that defines zones, permissible uses within those zones and specifies development standards and other special matters for consideration with regard to the use or development of land.

Local overland flooding - Local overland flooding is inundation by local runoff within the local catchment.

Local runoff - local runoff from the local catchment is categorised as either major drainage or local drainage in the NSW Floodplain Development Manual, 2005.

Low flood hazard - For a particular size flood, able-bodied adults would generally have little difficulty wading and trucks could be used to evacuate people and their possessions should it be necessary.

Flows or discharges - It is the rate of flow of water measured in terms of volume per unit time.

Overland flow path - The path that floodwaters can follow if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads. Floodwaters travelling along overland flow paths, often referred to as 'overland flows', may or may not re-enter the main channel from which they left — they may be diverted to another watercourse.

Peak discharge - The maximum flow or discharge during a flood.

Probable Maximum Flood (PMF) - The largest flood likely to ever occur. The PMF defines the extent of flood prone land or flood liable land, that is, the floodplain.

Risk - Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this study, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

Runoff - the amount of rainfall that ends up as flow in a stream, also known as rainfall excess.

SES - State Emergency Service of New South Wales

Stage–damage curve - A relationship between different water depths and the predicted flood damage at that depth.

Velocity - the term used to describe the speed of floodwaters, usually in m/s (metres per second). 10km/h = 2.7m/s.

Water surface profile - A graph showing the height of the flood (flood stage, water level or flood level) at any given location along a watercourse at a particular time.

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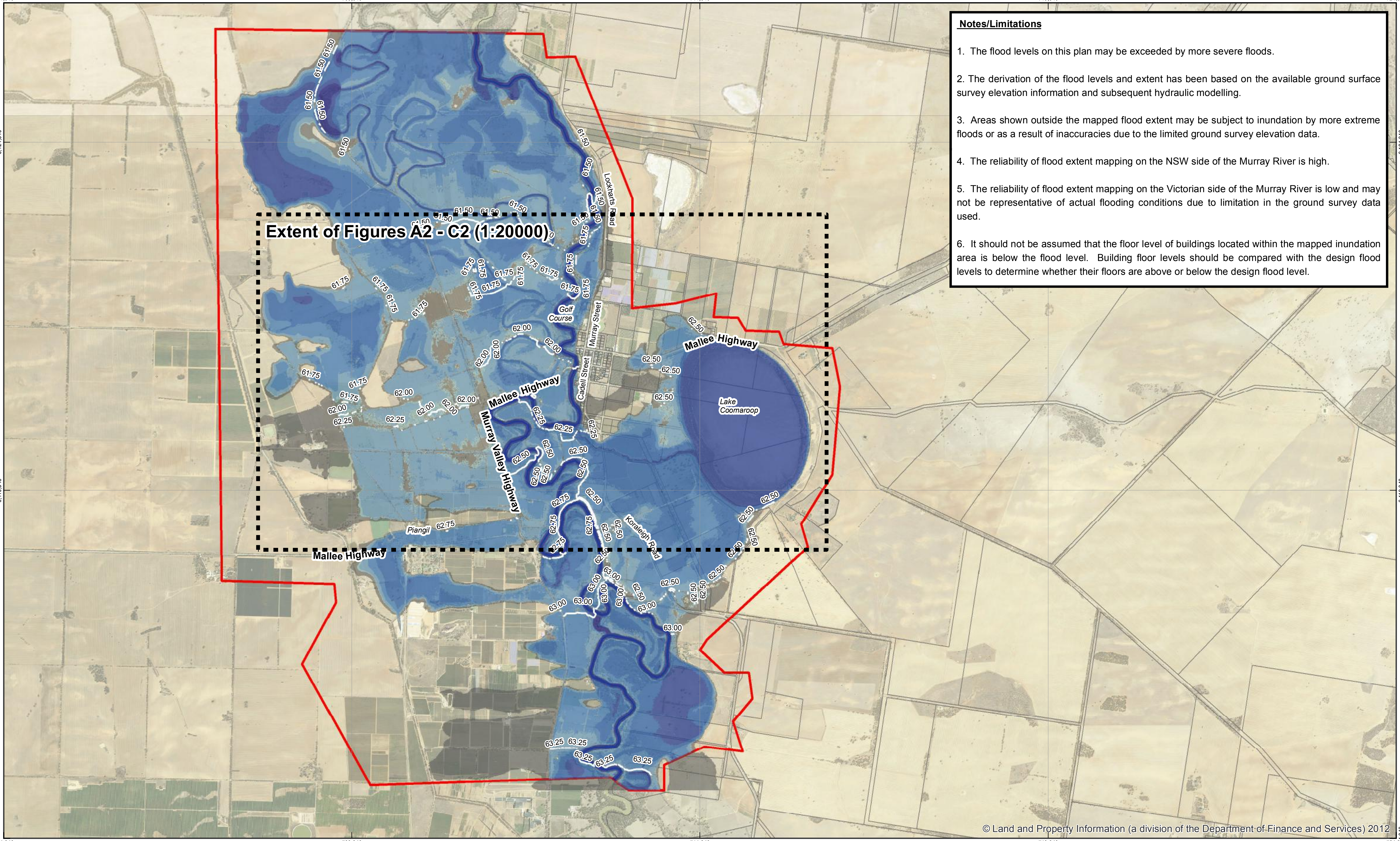
Appendices

Appendix A – Design Flood Maps



Notes/Limitations

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2. The derivation of the flood levels and extent has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.

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4. The reliability of flood extent mapping on the NSW side of the Murray River is high.

5. The reliability of flood extent mapping on the Victorian side of the Murray River is low and may not be representative of actual flooding conditions due to limitation in the ground survey data used.

6. It should not be assumed that the floor level of buildings located within the mapped inundation area is below the flood level. Building floor levels should be compared with the design flood levels to determine whether their floors are above or below the design flood level.

Paper Size A3

0 250 500 1,000 1,500 2,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

Flood Extent and Depth (m)

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00
- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre
- 1% AEP + 0.5m

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Wakool Shire Council
Tooleybuc Flood Study

Job Number	31-30143
Revision	0
Date	07 Oct 2014

100-Year ARI Flood Event
Flood Extent and Depth

Figure A1

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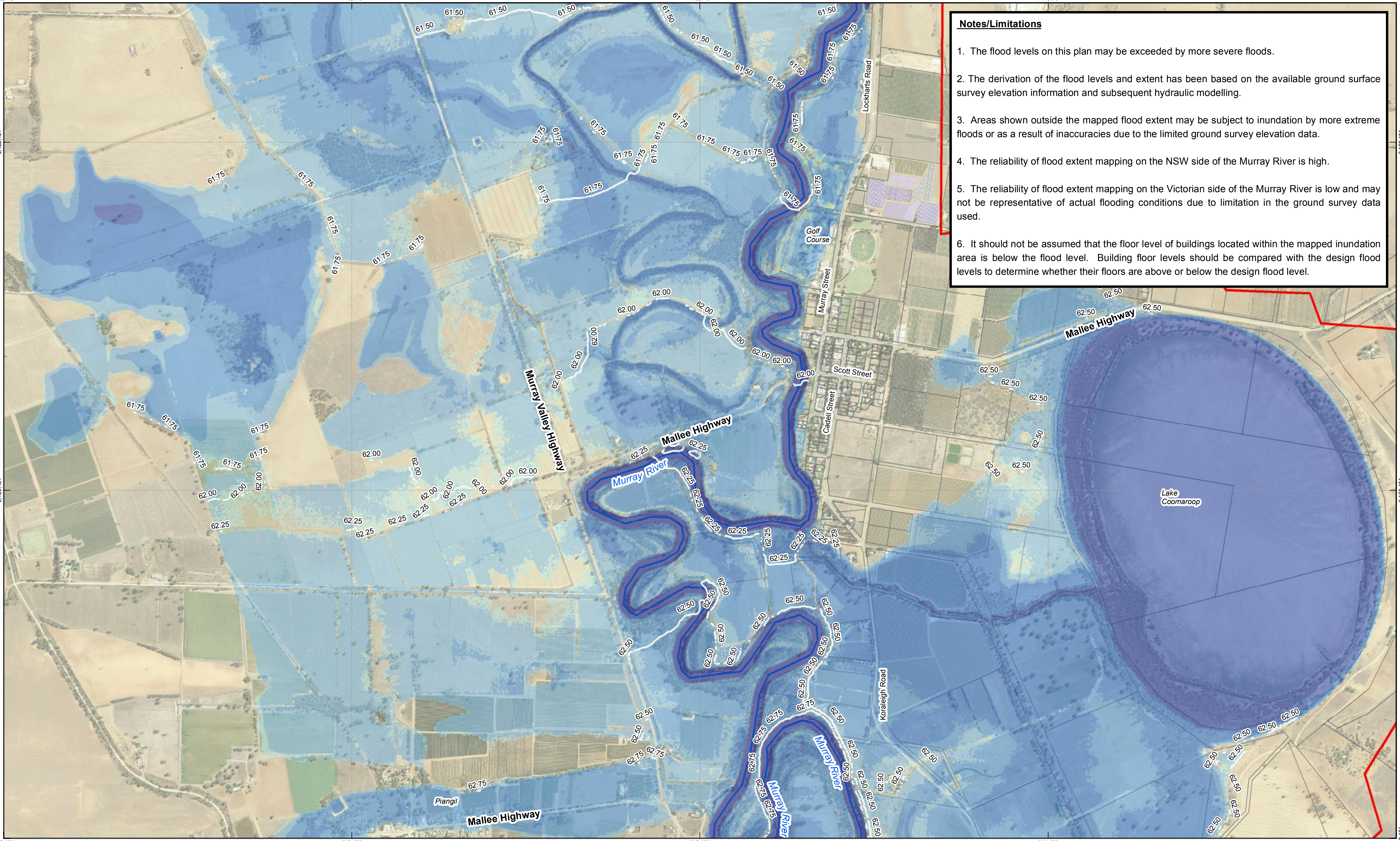
180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas



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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

Flood Extent and Depth (m)

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00

- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

Wakool Shire Council
Tooleybuc Flood Study

Job Number	31-30143
Revision	0
Date	07 Oct 2014

100-Year ARI Flood Event
Flood Extent and Depth

Figure A2

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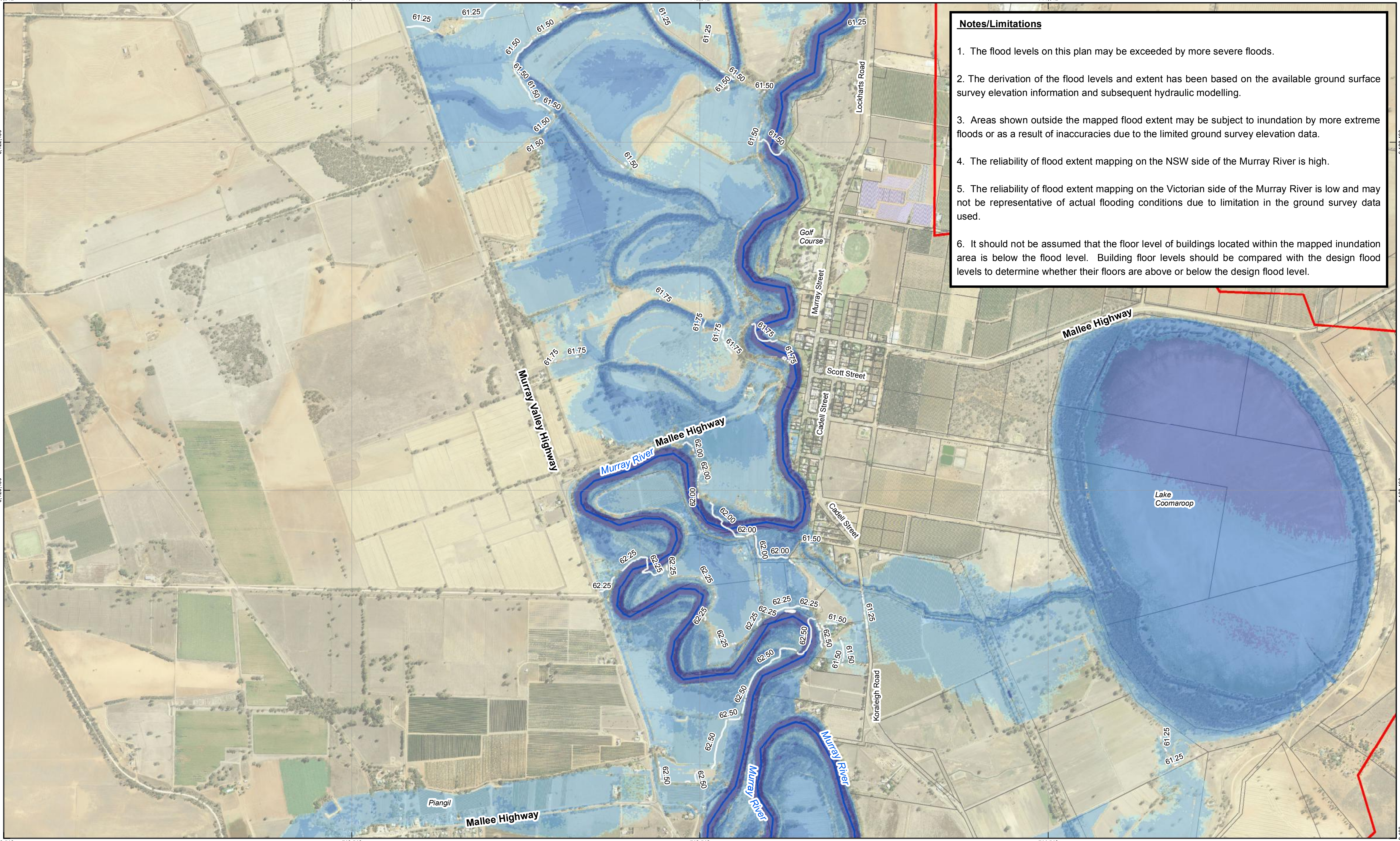
180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas



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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

Flood Extent and Depth (m)

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00

- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

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5-Year ARI Flood Event
Flood Extent and Depth

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Date	07 Oct 2014

Figure A3

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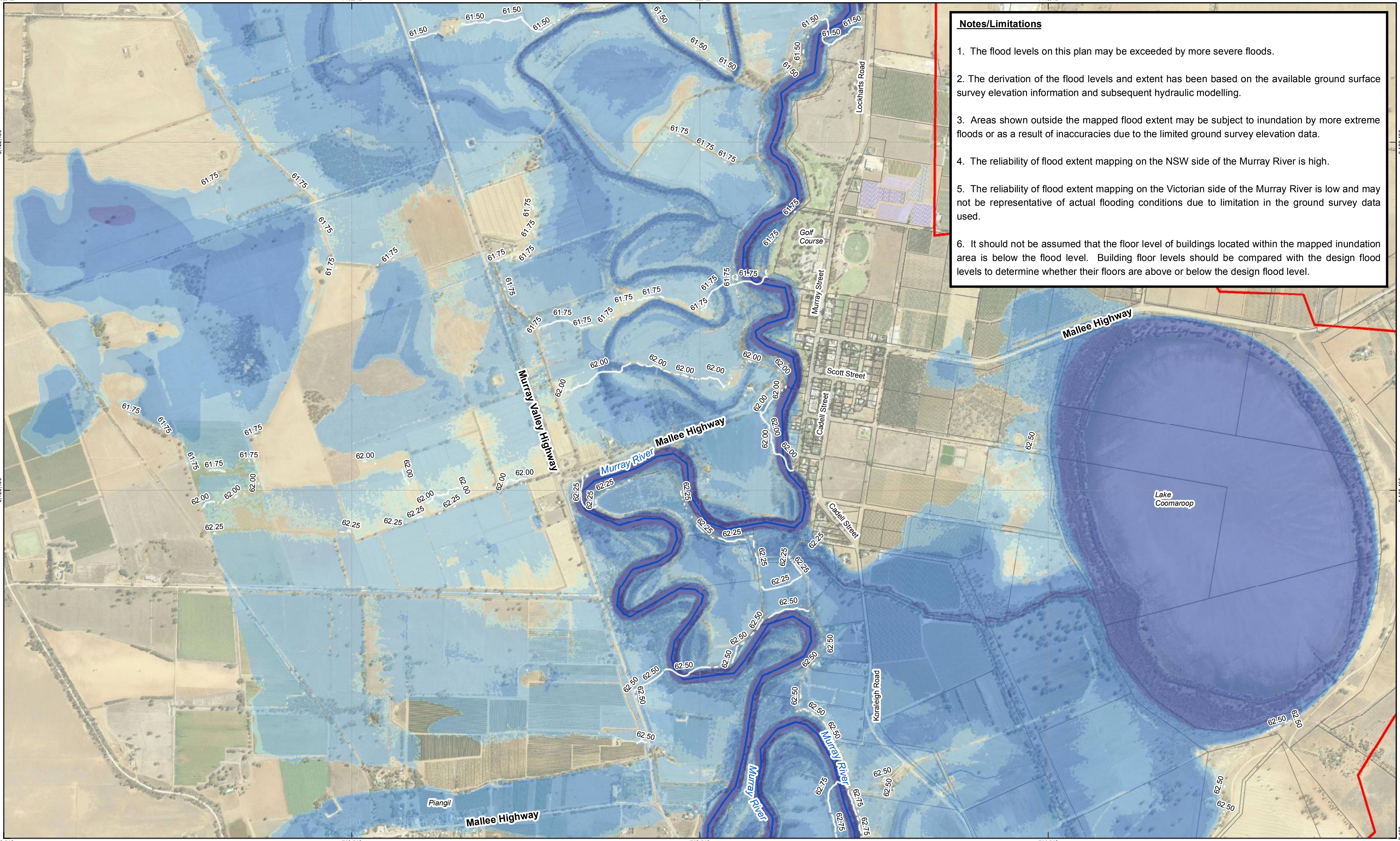
Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas



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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

Flood Extent and Depth (m)

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00
- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

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Job Number	31-30143
Revision	0
Date	07 Oct 2014

20-Year ARI Flood Event Flood Extent and Depth

Figure A4

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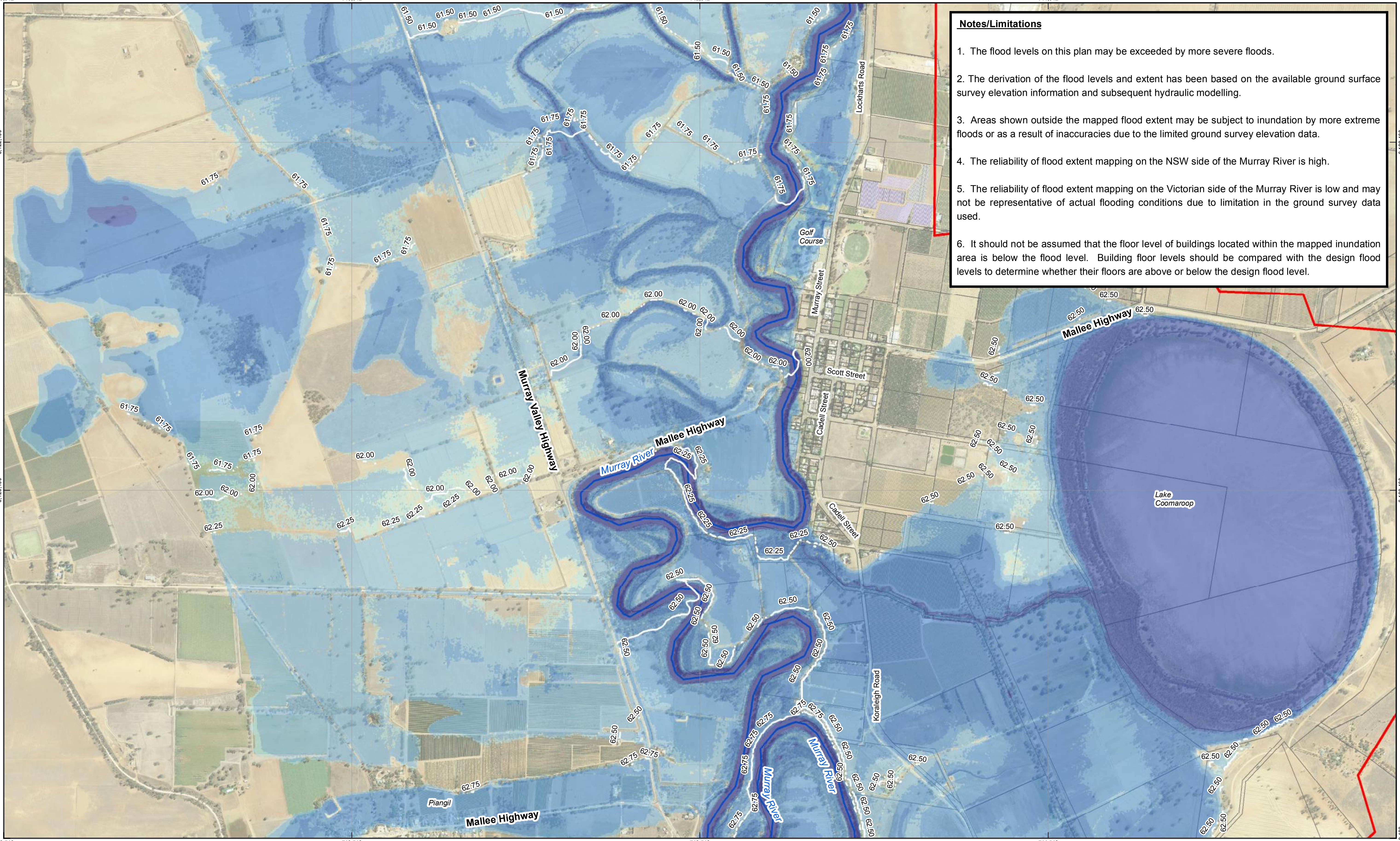
Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas



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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

Flood Extent and Depth (m)

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00
- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

Wakool Shire Council
Tooleybuc Flood Study

Job Number	31-30143
Revision	0
Date	07 Oct 2014

200-Year ARI Flood Event
Flood Extent and Depth

Figure A5

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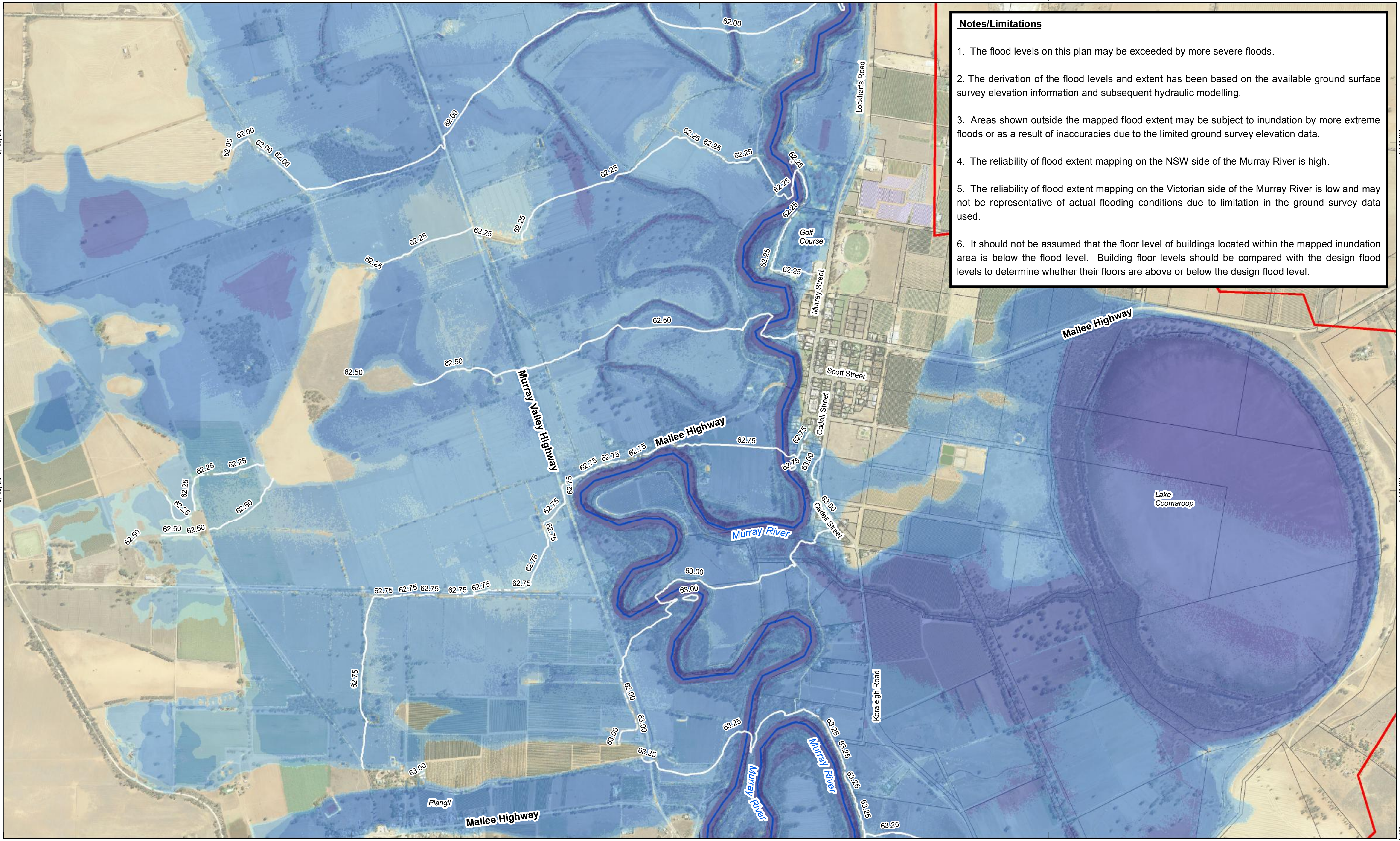
Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas



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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

Flood Extent and Depth (m)

- < 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 4.00
- > 4.00
- Flood Level Contours (mAHD)
- Hydraulic Model Extents
- Cadastre

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Tooleybuc Flood Study

Job Number 31-30143
Revision 0
Date 07 Oct 2014

Extreme Flood Event
Flood Extent and Depth

Figure A6

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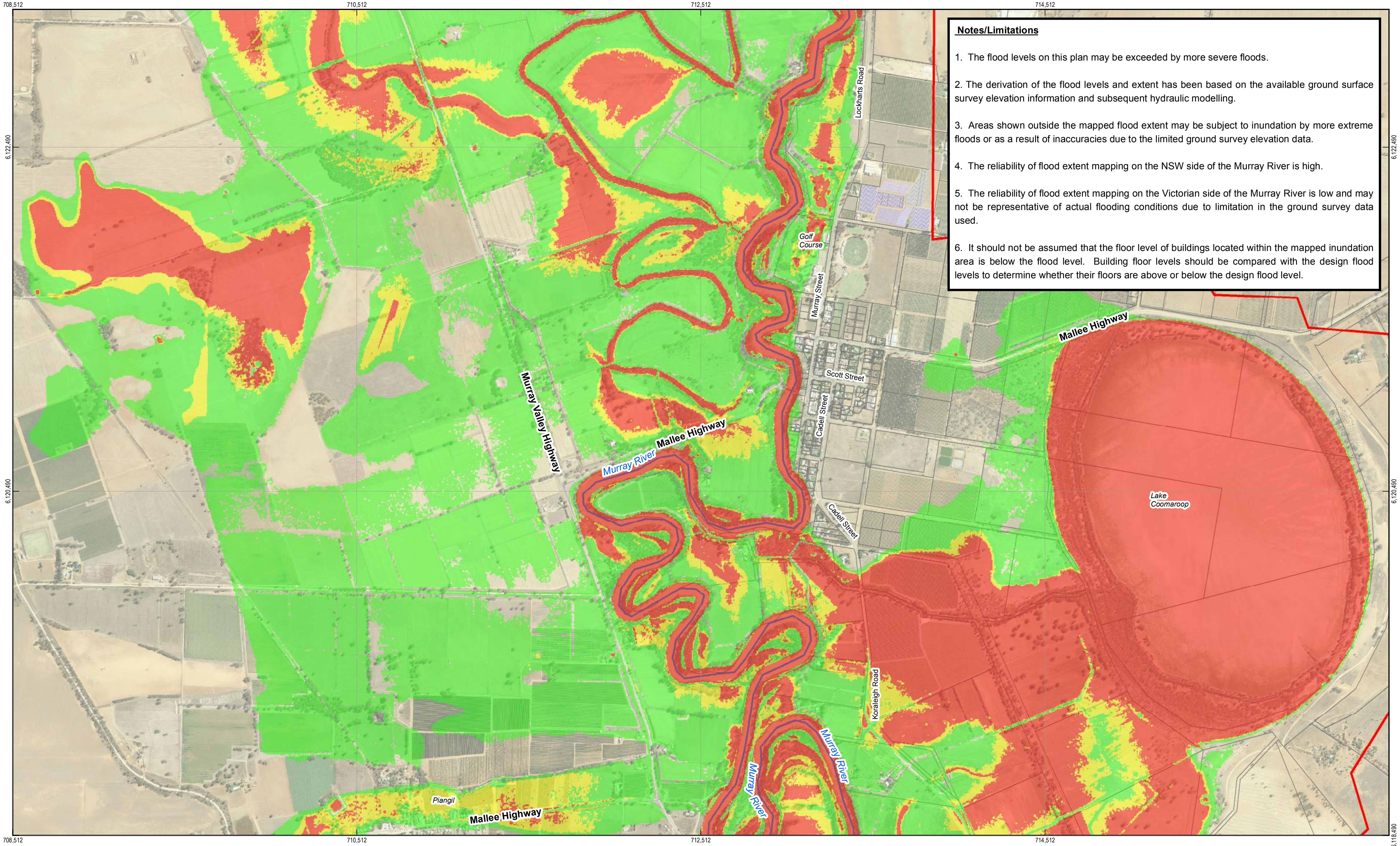
Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

Appendix B – Provisional Hazard Category Maps



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6. It should not be assumed that the floor level of buildings located within the mapped inundation area is below the flood level. Building floor levels should be compared with the design flood levels to determine whether their floors are above or below the design flood level.

Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard
- Hydraulic Model Extents
- Cadastre

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Wakool Shire Council
Tooleybuc Flood Study

Job Number	31-30143
Revision	0
Date	07 Oct 2014

100-Year ARI Flood Event
Provisional Hazard Category **Figure B1**

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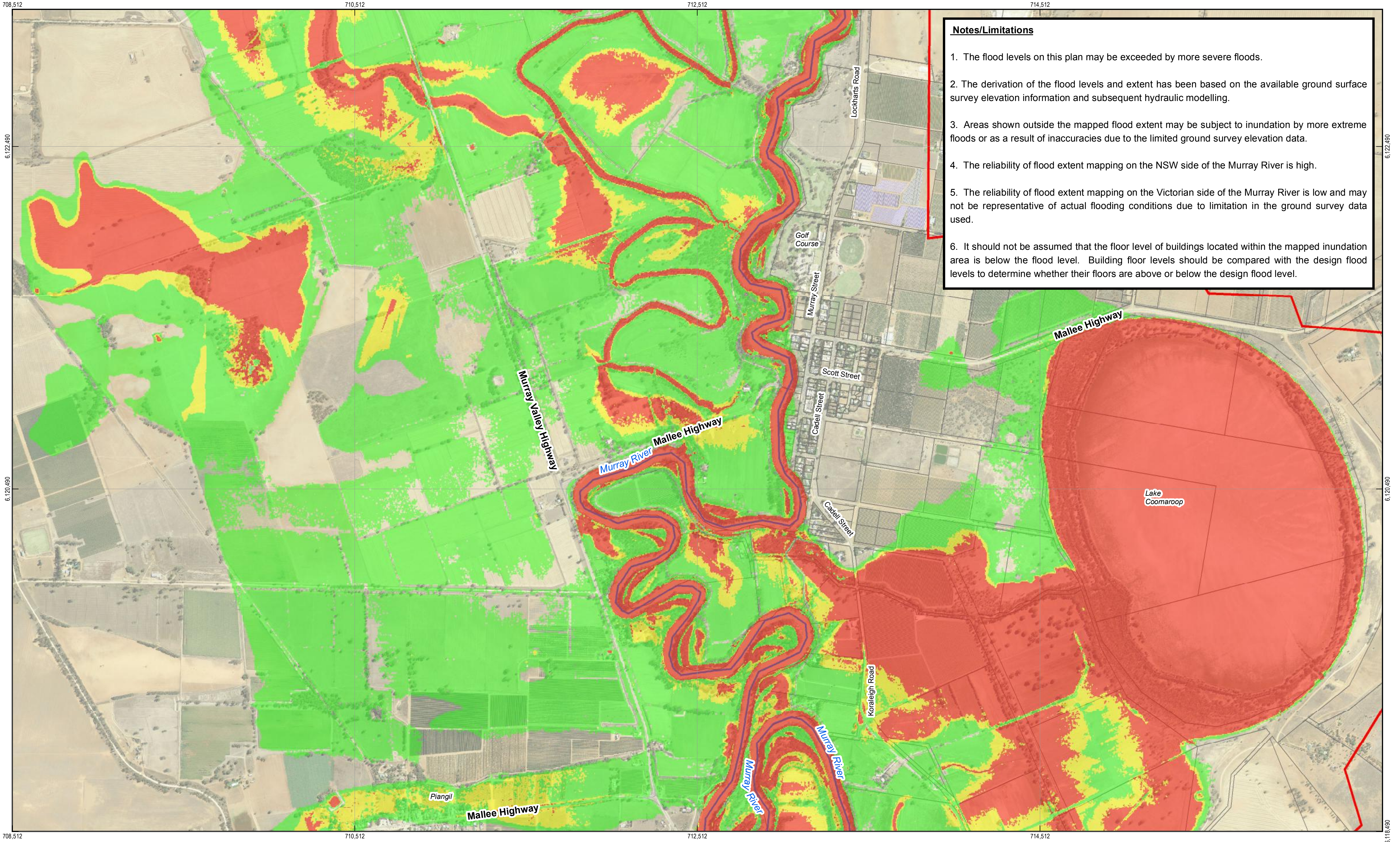
180 Lonsdale Street Melbourne VIC 3000 Australia **T** 61 3 8687 8000 **F** 61 3 8687 8111 **E** melmail@ghd.com **W** www.ghd.com

Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas



Notes/Limitations

1. The flood levels on this plan may be exceeded by more severe floods.

2. The derivation of the flood levels and extent has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.

3. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods or as a result of inaccuracies due to the limited ground survey elevation data.

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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard
- Hydraulic Model Extents
- Cadastre

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Wakool Shire Council
Tooleybuc Flood Study

Job Number	31-30143
Revision	0
Date	07 Oct 2014

20-Year ARI Flood Event
Provisional Hazard Category

Figure B2

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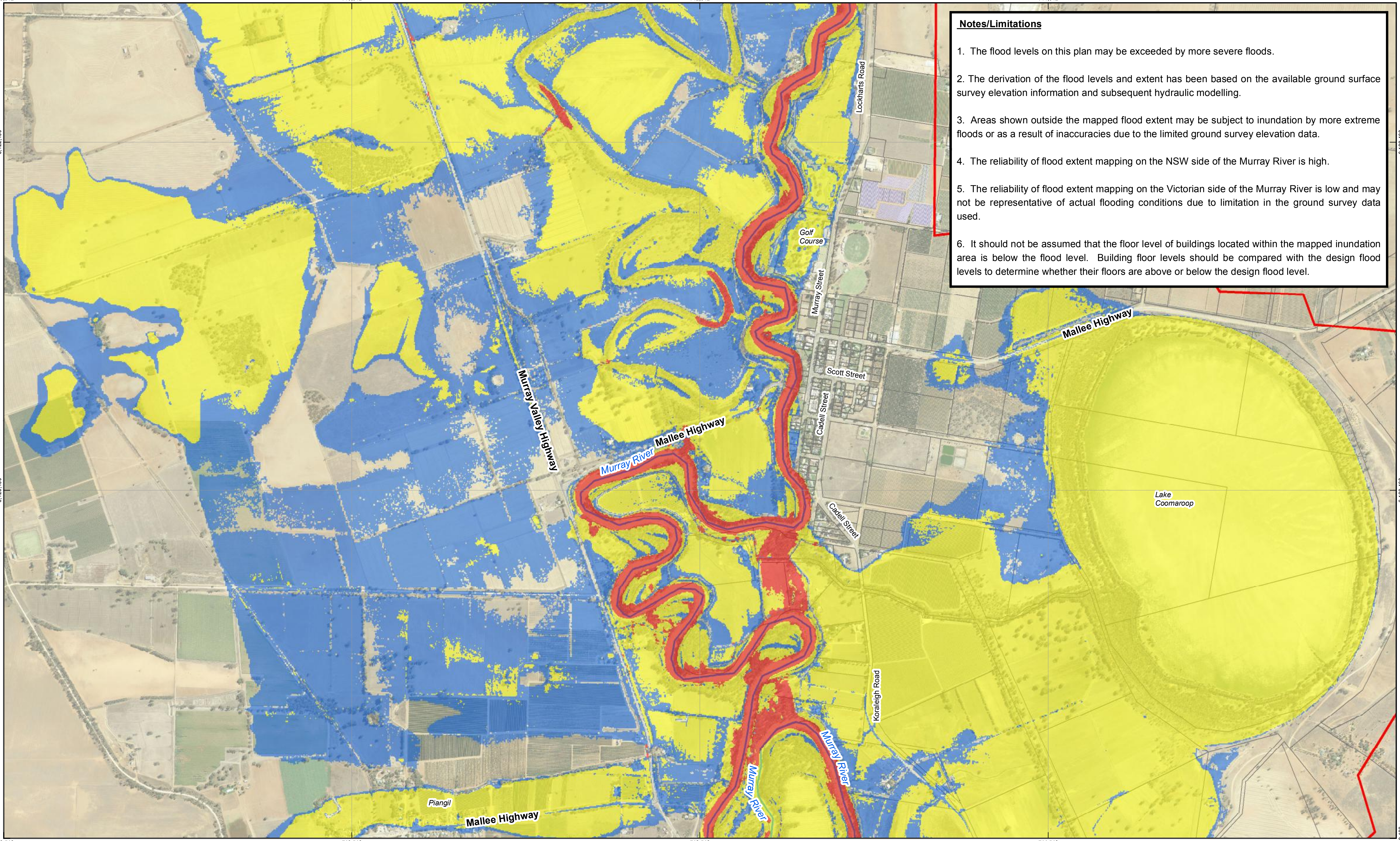
Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

Appendix C – Hydraulic Category Maps



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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

- Flood Fringe
- Flood Storage
- Floodway
- Hydraulic Model Extents
- Cadastre

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Tooleybuc Flood Study

Job Number	31-30143
Revision	0
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100-Year ARI Flood Event Hydraulic Category

Figure C1

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Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

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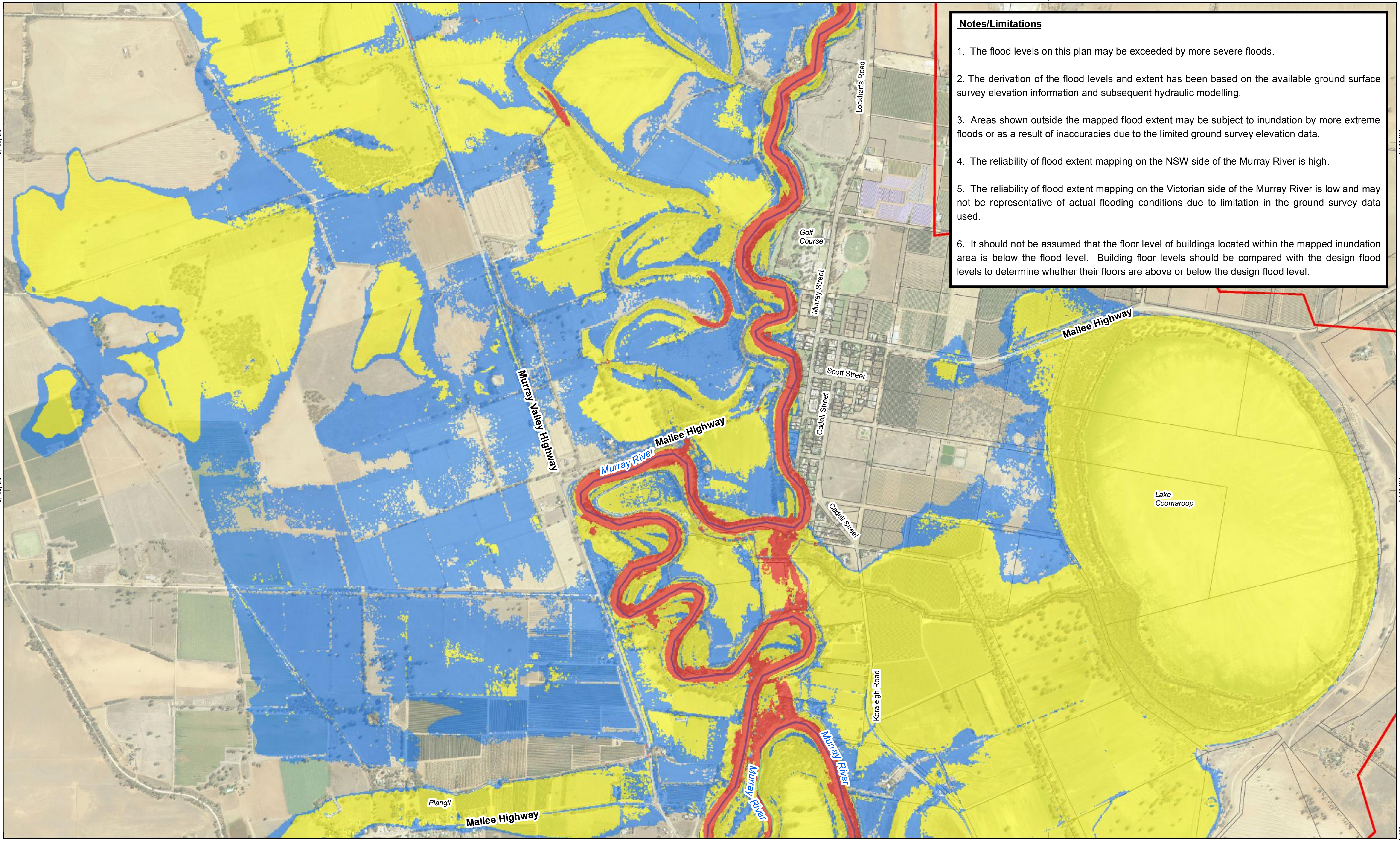

Notes/Limitations

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Paper Size A3

0 125 250 500 750 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 54

N

Legend

- Flood Fringe
- Flood Storage
- Floodway
- Hydraulic Model Extents
- Cadastre

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Wakool Shire Council
Tooleybuc Flood Study

Job Number	31-30143
Revision	0
Date	07 Oct 2014

20-Year ARI Flood Event
Hydraulic Category

Figure C2

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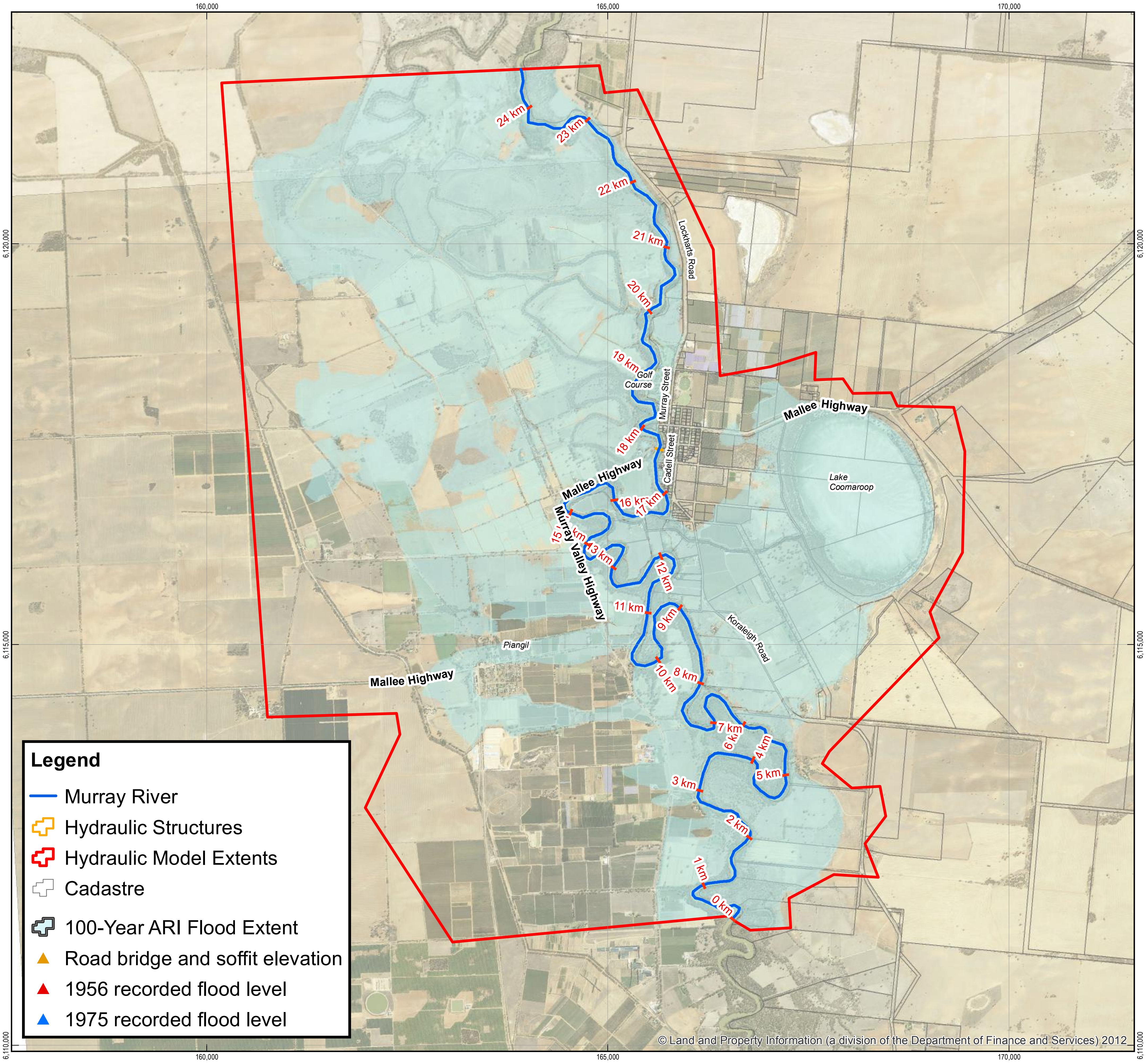
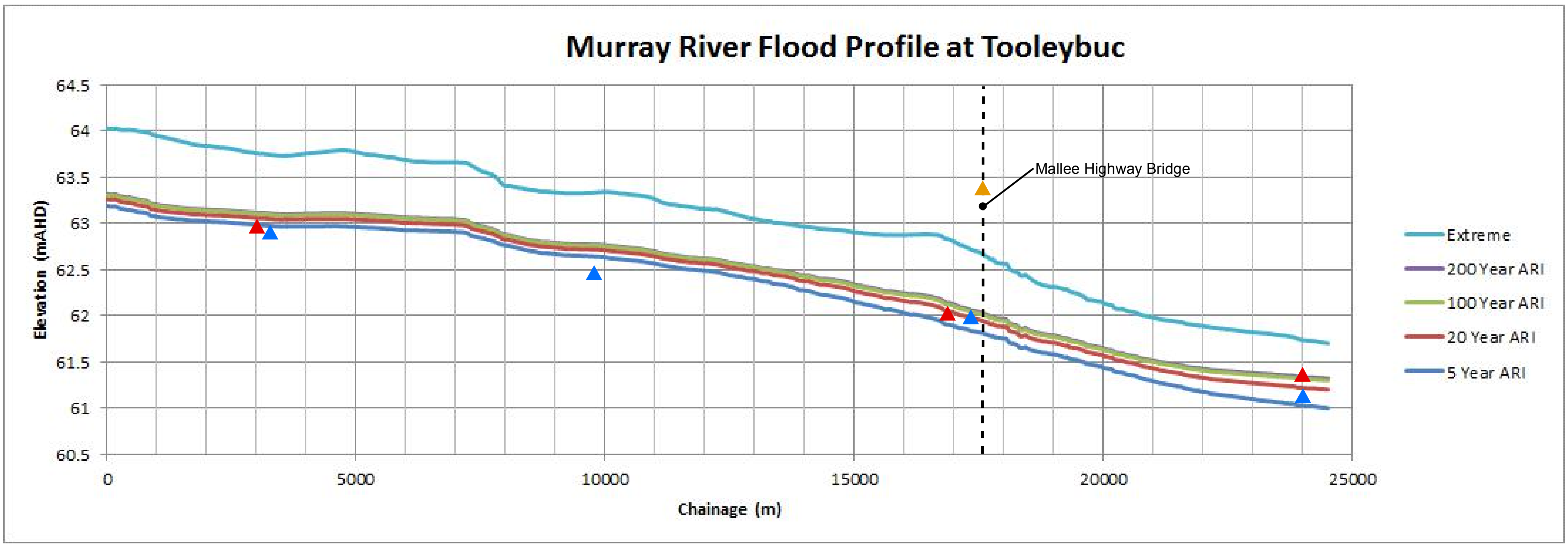
Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

Appendix D – Flood Profile Map

Figure D1 Flood Profile





Paper Size A3

0 250 500 1,000 1,500 2,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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Tooleybuc Flood Study

Murray River Flood Profile

Job Number 31-30143
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Date 07 Oct 2014

Figure D1

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Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

Appendix E – Peak Annual Recorded Gauged Flows

Table E1 Swan Hill – Peak Recorded Flows

Year	Peak Flow (ML/day)	Year	Peak Flow (ML/day)	Year	Peak Flow (ML/day)
1909	**31,000 (rank 7)**	1944	10,200	1979	27,700
1910	28,400	1945	17,400	1980	17,600
1911	27,900	1946	25,800	**1981**	**32,900 (rank 3)**
1912	24,900	1947	26,700	1982	8,000
1913	21,800	1948	23,800	**1983**	**30,600 (rank 9)**
1914	10,800	1949	26,000	1984	23,700
1915	26,300	1950	26,600	1985	22,200
1916	**31,300 (rank 6)**	1951	29,700	1986	24,800
1917	**30,500 (rank 10)**	1952	28,000	1987	24,500
1918	28,500	1953	27,100	1988	24,900
1919	19,100	1954	25,500	1989	28,200
1920	27,600	1955	29,700	1990	24,800
1921	28,500	**1956**	**31,000 (rank 8)**	1991	24,100
1922	22,200	1957	21,500	1992	29,900
1923	29,700	1958	27,500	**1993**	**33,900 (rank 3)**
1924	28,400	1959	15,700	1994	11,800
1925	25,600	1960	29,300	1995	27,400
1926	26,500	1961	19,700	1996	27,900
1927	21,600	1962	20,800	1997	11,700
1928	25,700	1963	23,000	1998	14,100
1929	22,400	1964	29,200	1999	18,800
1930	25,700	1965	24,700	2000	25,100
1931	30,000	1966	24,400	2001	7,600
1932	28,400	1967	22,600	2002	8,700
1933	27,500	1968	27,900	2003	19,100
1934	26,400	1969	24,400	2004	11,900
1935	27,600	1970	26,400	2005	17,900
1936	27,800	1971	26,600	2006	8,400
1937	15,800	1972	18,100	2007	8,700
1938	8,220	**1973**	**32,200 (rank 5)**	2008	8,500
1939	28,200	**1974**	**32,800 (rank 4)**	2009	8,700
1940	10,200	**1975**	**34,500 (rank 1)**	2010	26,600
1941	20,000	1976	22,300	2011	29,600
1942	28,600	1977	17,000	2012	22,300
1943	22,700	1978	24,900		

Notes:

1. Peak flows in the above table are at the Swan Hill streamflow gauge (409204) located 1.2 km downstream of the Moulamein Road bridge.
2. Flows prior to 1986 are based on those documented in the Victorian Water Surface Information to 1987 – Volume 4 (Rural Water Commission of Victoria.
3. Flows from 1987 to 2012 are based on those listed on the Victorian Water Resources Data Warehouse web site.

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Document Status

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		Name	Signature	Name	Signature	Date
A	T Clark	R Berg		R Berg		9/5/2014
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