# Wakool Shire Council

## Murray Downs Flood Study

## Final Report

October 2014

Cover photograph: Looking north (downstream) towards the bridge across the Murray River at Murray Downs/ Swan Hill.

# Executive Summary

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

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 Murray Downs 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 at Swan Hill, 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 adopted 100 year average recurrence interval (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 Barham, Murray Downs and Tooleybuc.

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 October 1993 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).

**Flood Impacts**

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

- Peak 100 year ARI flood level is 67.92 m AHD at the Moulamein Road bridge, well below the bridge soffit level.
- The Moulamein Road is not overtopped in a 100 year ARI flood event. The lowest point in the road (68.20 m AHD) east of the bridge is higher than the 100 year ARI flood level (68.12 m AHD).
- Existing commercial land use properties adjoining the south side of the Moulamein Road are protected from 100 year ARI flooding by a rural standard levee.
- Existing residential development adjoining Murray Downs Drive (e.g. Kidman Reid Drive estate, golf course estate, golf course resort) is expected to be limited to grounds flooding of the lowest parts of some lots in a 100 year ARI event.
- Overall flooding impacts on existing development at Murray Downs are expected to be low. The most potential for flood damage lies with a breach of the levee resulting in flooding of the commercial properties on the south side of the Moulamein Road.
- A breach of the existing levee on the north side of the Moulamein Road could result in flooding impacts on the commercial land use properties to the east of the levee.
- Of the currently undeveloped areas zoned to allow future residential development, these areas with the exception of some fringe areas, are elevated above the 100 year ARI flood levels without relying on levee protection.

The study has focused on reliably defining flooding conditions on the NSW side of the river, specifically for the area at and adjoining Murray Downs. Less emphasis has been placed on defining flooding conditions on the Victorian side of the river which includes the Pental Island area. The flood mapping on the Victorian side of the river is therefore indicative only and not necessarily reliable or representative of actual conditions.

# Table of Contents


1. Introduction ..... 1
2. Study Area Description ..... 4
   - 2.1 Murray Downs ..... 4
   - 2.2 Catchment Description ..... 4
   - 2.3 Floodplain Description ..... 7
   - 2.4 Historical Flood Events ..... 7
3. Community Consultation ..... 12
   - 3.1 Overview ..... 12
   - 3.2 Floodplain Risk Management Committee ..... 12
   - 3.3 Stage 1 Consultation Activities ..... 12
   - 3.4 Public Exhibition of Draft Flood Study Report ..... 12
4. Data Collection and Review ..... 13
   - 4.1 Hydrologic Data ..... 13
   - 4.2 Flood Height Data ..... 13
   - 4.3 Previous Reports ..... 13
   - 4.4 Terrain Elevation Data ..... 14
   - 4.5 Levees ..... 14
5. Hydrology ..... 15
   - 5.1 Approach ..... 15
   - 5.2 Streamflow Data ..... 15
   - 5.3 Flood Frequency Analysis Results ..... 16
   - 5.4 Design Event Inflow Approach ..... 17
   - 5.5 Extreme Event ..... 17
6. Hydraulics – Calibration Modelling ..... 18
   - 6.1 Overview of Conditions ..... 18
   - 6.2 Limitations ..... 18
   - 6.3 Hydraulic Model Calibration Approach ..... 19
   - 6.4 Calibration Modelling Results ..... 20
   - 6.5 100 Year ARI Design Flood Preliminary Modelling ..... 23
   - 6.6 Sensitivity Assessment ..... 24
   - 6.7 Discussion ..... 26
7. Design Flood Modelling ..... 28
   - 7.1 Approach ..... 28
   - 7.2 Flood Map Outputs ..... 28
   - 7.3 Discussion – Flood Impacts / Issues ..... 31
   - 7.4 Points of Interest ..... 33
8. Next Steps in Process ..... 34

9. Acknowledgments ...... 35
10. Glossary ...... 36
11. References ...... 39

# Table Index

Table 1 Five Highest Recorded Flood Flows at Murray Downs since 1909 ...... 7
Table 2 Design Flow Estimates at Swan Hill / Murray Downs ...... 16
Table 3 Murray Downs – Calibration Modelling Results ...... 21
Table 4 Sensitivity of 100 Year ARI Flood Levels to Flow ...... 24
Table 5 Sensitivity of 100 Year ARI Flood Levels to Floodplain Roughness ...... 25
Table 6 Flood Data – Points of Interest ...... 33

# Figure Index

Figure 1 Study Area Plan ...... 3
Figure 2 Murray Downs Local Feautures ...... 5
Figure 3 Murray River Floodplain System Features ...... 6
Figure 4 Floodplain Features ...... 9
Figure 5 Recorded Flood Heights ...... 22
Figure 6 2005 FDM Hazard Categories ...... 29
Figure 7 Potential Future Land Use Development Areas at Murray Downs ...... 32

# Appendices

Appendix A – Design Flood Maps
Appendix B – Provisional Hazard Category Maps
Appendix C – Hydraulic Category Maps
Appendix D – Flood Profile Map
Appendix E – Peak Annual Recorded Gauged Flows

# 1. Introduction

The NSW Government's Flood Prone Land Policy is aimed at providing solutions to existing flooding problems as well as ensuring that new development within flood prone areas is compatible with the prevailing flood risk and does not create additional problems.

The Murray Downs 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 Murray Downs (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.

Previous flood studies have been completed for the Swan Hill reach of the Murray River. These have tended to focus on issues other than flooding on the Murray Downs side of the floodplain, including the adjoining much larger Swan Hill township on the Victorian side of the river.

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 Murray Downs Flood Study was carried out concurrently with studies at Barham and Tooleybuc. 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.

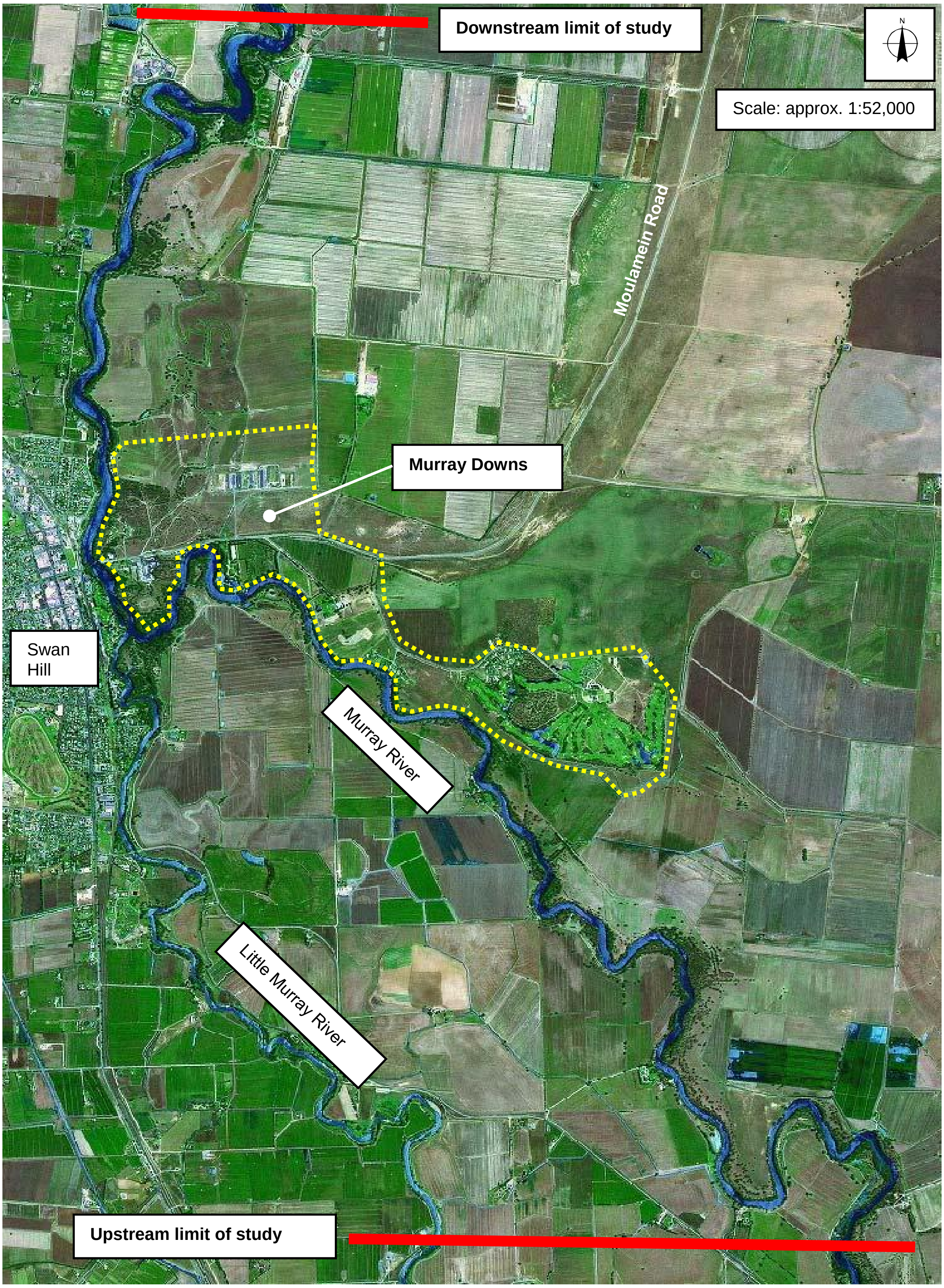



Figure 1 Study Area Plan

# 2. Study Area Description

## 2.1 Murray Downs

Murray Downs is a small township located on the NSW side of the Murray River, opposite the larger Victorian township of Swan Hill (refer to Figure 2). The population as recorded by the 2006 Census is 200.

There are a number of commercial land use properties on the Moulamein Road including a hotel, transport company and some marine activities. A second cluster of commercial / industrial properties is located 400 metres north of the Moulamein Road.

The main attraction for visitors to Murray Downs is the Golf and Country Club. A residential estate adjoins the north western corner of the golf course.

There is a second residential estate located midway by the golf course estate and the Murray Downs homestead at Kidman Reid Drive. Development is currently proceeding at this estate.

The 2009 Land Use Strategy Report identifies Murray Downs as a location suited to further residential development, in particular in proximity to the golf course and river area. The report notes however that there are extensive areas subject to flooding which will form a barrier to development in these areas. Average annual dwelling applications between 1997 and 2007 averaged 3.8.

## 2.2 Catchment Description

The Murray River catchment upstream of Murray Downs 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 Murray Downs. Much of the upstream flow discharges into the Edward and Wakool River system. This large complex anabranch system bypasses to the north of Murray Downs, returning to the Murray River 20 km downstream of Tooleybuc.

The following factors influence flooding conditions at Murray Downs (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.

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

Severe flooding at Murray Downs / Swan Hill requires major flows in both the upstream Murray River and Loddon River. The Loddon River flood of January 2011 peaked at the highest level on record at Kerang (gauged flow 14,400 ML/day). The subsequent peak Murray River gauged flow at Swan Hill was however only 29,400 ML/day, marginally lower than the official moderate flood level of 4.6 metres at the Swan Hill gauge.

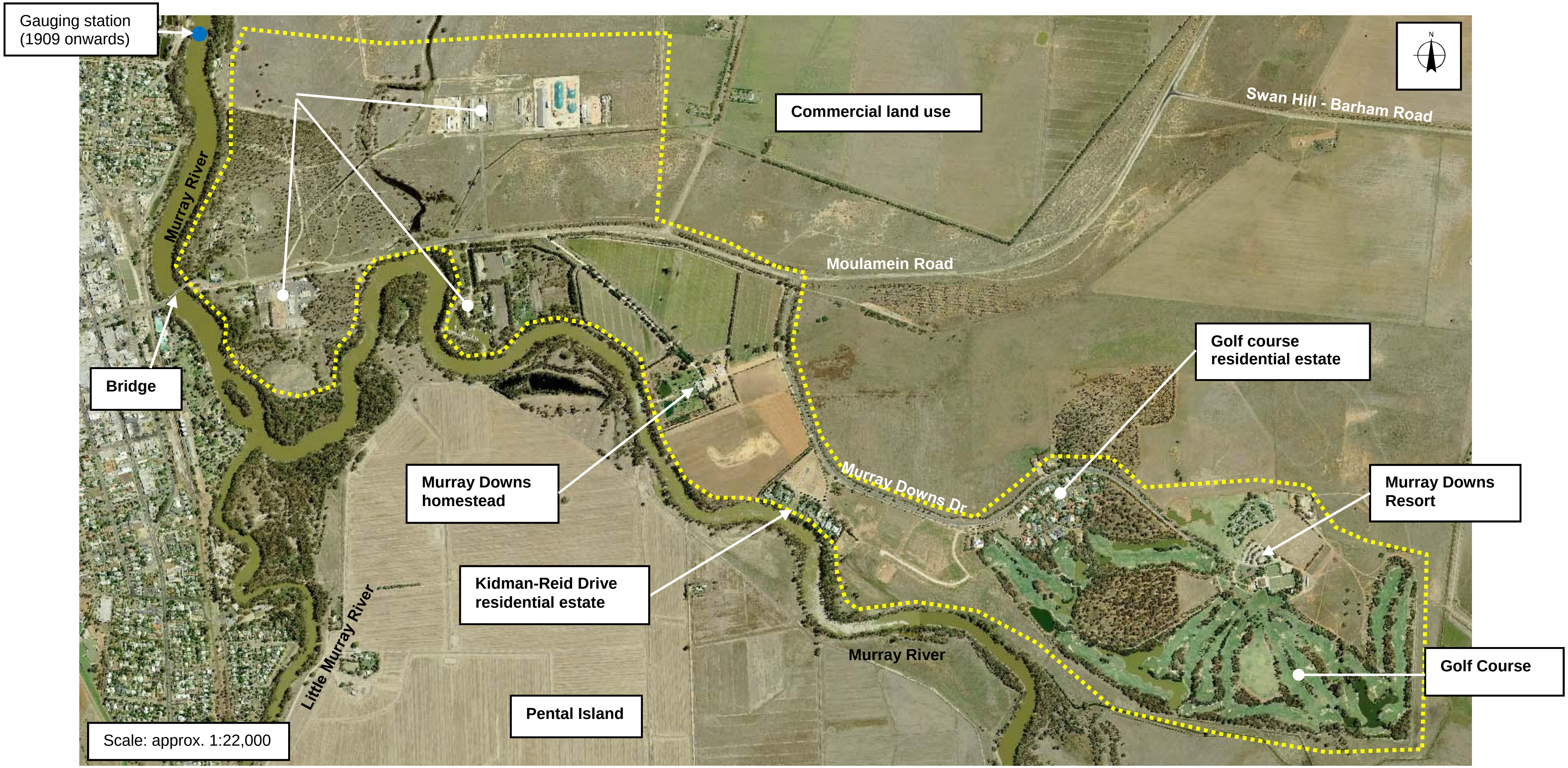
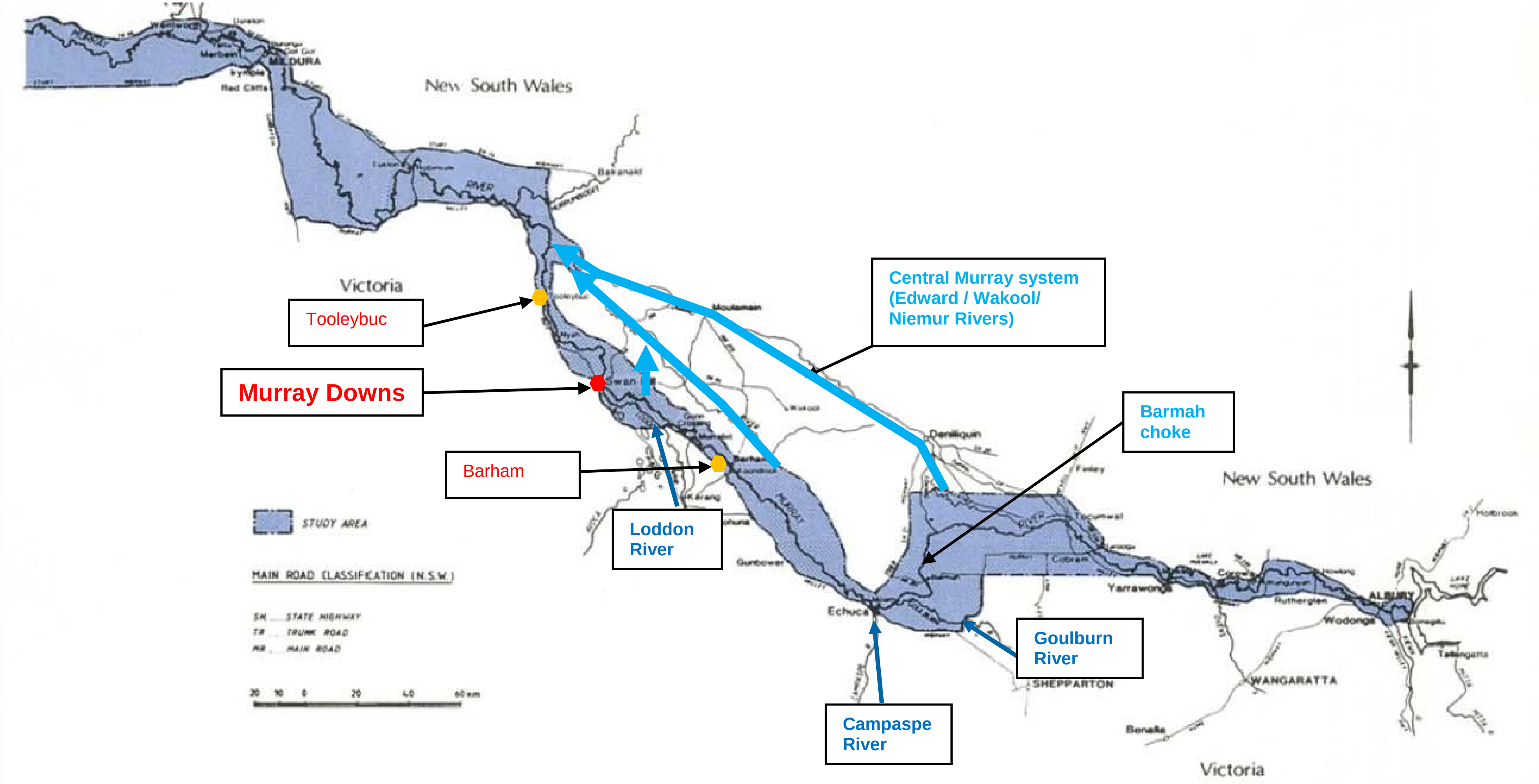



Figure 2 Murray Downs Local Feautures




## Figure 3 Murray River Floodplain System Features

(modified extract from 1986 Murray River Floodplain Management Study)

## 2.3 Floodplain Description

Flooding conditions for the Swan Hill / Murray Downs reach are extremely complex.

The Murray Downs reach of the Murray River is extensively leveed on both the NSW and Victorian sides of the river. These levees date back to the late 1800s and have evolved since then. The levees range markedly in height and condition. The levee banks on the NSW side of the river at Murray Downs are typically of a standard which is more compatible with rural levees.

Past reports (Gutteridge, Haskins & Davey, 1986) indicate that Swan Hill itself has not experienced significant flooding since the 1916 / 1917 floods due to the town levee protection system. The report indicates the levee banks were raised after 1973 achieving a freeboard of 400 mm above the 100 year ARI flood level. If the levee system was to fail, flooding impacts at Swan Hill would be severe.

A natural high level bypass floodway (Murray Downs Creek) is located 500 metres east of the Moulamein Road Murray River bridge (refer to Figure 4). The last remaining waterway structures allowing flow into this floodway have been closed since prior to 1990.

The area enclosed by the Murray River and Little Murray River channels (i.e. within Victoria) is referred to as Pental Island. This area is protected by ring levee banks.

There is the one bridge crossing over the Murray River at Murray Downs. Construction of this bridge was completed in 1897. The historic bridge has an uplift span which allows large marine craft to pass through the raised opening.

The Golf Course complex is located on distinct high ground. This ridge of high ground parallels the Moulamein Road preventing any risk of floodwaters threatening Murray Downs from areas located north of the golf course.

## 2.4 Historical Flood Events

The most significant flood events at Murray Downs based on the flow records at Swan Hill (Station 409204) from 1909 onwards are 1975, 1993, 1981, 1974 and 1973 in order of magnitude (refer to Table 1). All of these events are post 1970 possibly due to changed flooding conditions (e.g. closure or partial closure of NSW side effluent flow paths) which may have resulted in higher flows past Swan Hill / Murray Downs. The 1956 event peaked at 67.56 m AHD, 0.14 metres below the 1975 event peak.

Table 1 Five Highest Recorded Flood Flows at Murray Downs since 1909

| Event Rank | Year | Peak Flood Height metres (m AHD) | Peak Flow (ML/day) |
|---|---|---|---|
| 1 | 1975 | 4.78 (67.70) | 34,500 |
| 2 | 1993 | 4.72 (67.64) | 33,900 |
| 3 | 1981 | 4.73 (67.65) | 32,900 |
| 4 | 1974 | - | 32,800 |
| 5 | 1973 | - | 32,200 |

Notes:

1. Levels and flows are at the Swan Hill streamflow gauge 409204, located 1.2 km downstream of the Swan Hill bridge (refer to Figure 4).

2. Gauge zero is at 62.921 m AHD.

A recorded flood level for the 1870 flood is given in the 1992 Swan Hill / Tyntynder Flats Floodplain Management Study report (Binnie& Partners 1992).  The basis and location of the reported 1870 flood level of 67.81 m AHD is not defined in the report.  The 1870 flood is however generally acknowledged as the largest Murray River flood to have occurred since at least 1850.  Floodplain conditions were quite different in 1870 with many of the influences that have been present since the early 1900s not in place in 1870.

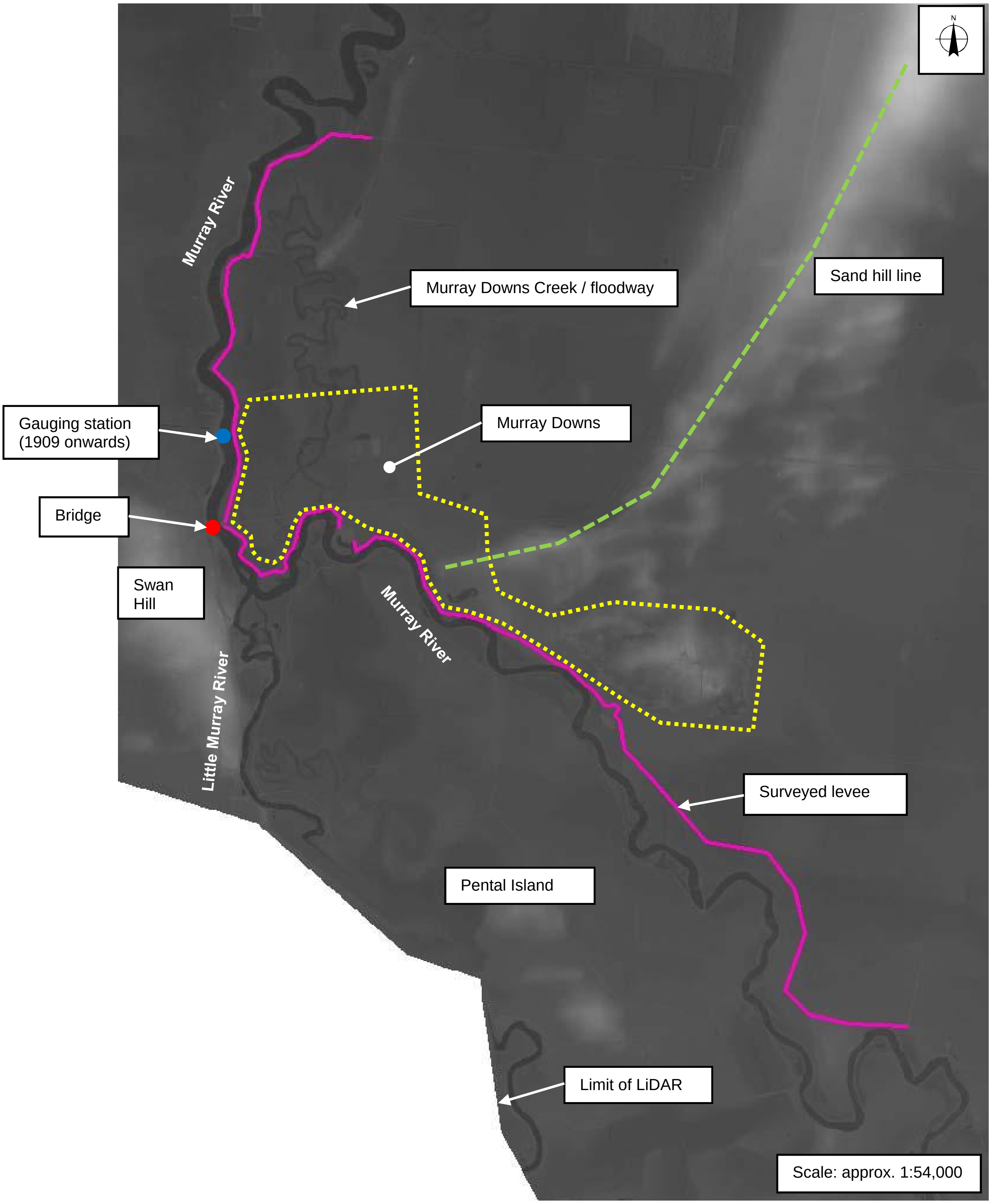



Figure 4 Floodplain Features

(base imagery is 2001 LiDAR image)

**Photograph 1 Gauging station site (from Victorian side)**

**Photograph 2 Levee bank adjacent to river– view north from Moulamein Road**

**Photograph 3 Kidman Reid Drive estate – view south**

**Photograph 4 Levee bank opposite golf course – view east**

# 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.
- 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 five 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 Murray Downs were contacted shortly after the commencement of the study. This included the following organisations:

- Murray Darling Basin Authority.
- North Central Catchment Management Authority.
- Goulburn-Murray Water.

## 3.4 Public Exhibition of Draft Flood Study Report

The draft Murray Downs 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 has operated at Swan Hill since 1909 (Swan Hill Station 409204). The station is located 1.2 km downstream of the Moulamein Road bridge (refer to Figure 2).

Data from the above station was utilised for flood frequency analysis undertaken for this study.

## 4.2 Flood Height Data

The primary source for flood height marks at Murray Downs 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:

- Eighteen 1906 recorded flood height marks.
- Nine 1993 recorded flood height marks.
- Eight 1956 recorded flood height marks.
- Seven 1975 recorded flood height marks.
- Small number of other event 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 flood height marks.

## 4.3 Previous Reports

Previous detailed flood studies at Murray Downs have been focused either on flooding impacts risks to Swan Hill, or influences on flooding conditions upstream and downstream of Swan Hill (i.e. NSW and Victorian side levee banks).

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

- Murray River Floodplain Management Study (Gutteridge Haskins & Davey, 1986).
- 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 (Lawson & Treloar, 1995, Lawson & Treloar, 1998 and Sinclair Knight Merz, 1999).
- 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).

## 4.4 Terrain Elevation Data

The following terrain data sources informed the study:

- 2001 MDBA LiDAR data.
- Six river channel cross sections from a 1980/81 State Rivers and Water Supply Commission survey were obtained from Goulburn-Murray Water.
- The NSW RMS provided some plans of the Murray River bridge crossing at Murray Downs.

When checked against other reliable data sources supplied by the Wakool Shire Council, the 2001 LiDAR data at Murray Downs was found to be consistently around 0.2 metres higher than the comparison data. To limit study costs and avoid the need for a new survey, the 2001 LiDAR DEM data was lowered uniformly by 0.20 metres. The adjusted 2001 DEM data was used for defining the out of channel floodplain geometry.

## 4.5 Levees

The Murray Downs floodway (refer Figure 4) has effectively been isolated from floodwaters for some considerable time. All Moulamein Road waterway structures are understood to have been closed since 1990 (Binnie and Partners, 1992).

A complex network of licensed levees is present on the north side of the Moulamein Road. These levees effectively confine flows to the river corridor. Some of these levees are effectively redundant given the existing status of the Moulamein Road.

Upstream of the Moulamein Road, almost the entire route parallel to the Murray River channel is occupied by a licensed levee to upstream of the golf course. In some locations, sections of the levee are in very poor condition (e.g. immediate section upstream of the bridge).

A levee crest height survey was undertaken for the NSW side levees within the study area. The survey data was obtained in August 2013. The surveyed crest heights were used to define the NSW side levees within the hydraulic model.

Within Victoria, both the Murray River and the Little Murray River anabranch are lined with levees. These levees have been in place for many decades. The township of Swan Hill is protected from flooding by an urban standard levee. The Victorian side rural levees outside Swan Hill are generally of a lesser standard.

The North Central CMA provided surveyed levee crest height data for the Victorian side levees. This survey data was collected as part of a 2012/13 rural levees assessment project.

# 5. Hydrology

## 5.1 Approach

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

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 utilised for Murray Downs consisted of the following station 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 (refer to Figure 2).

The station at Swan Hill has operated continuously since 1909. The highest gauged flow was in 1975 at a time when the flood height was at 4.77 m (67.69 m AHD) only 0.01 m below the peak for this event and the highest ever recorded flood level at the gauge. The rating table is therefore likely to be reliable over the full range of flood events up to at least this height.

Some previous studies (e.g. Binnie & Partners, 1992) have limited the period subject to flood frequency analysis to post 1971. The reason given for this is that the flows past Swan Hill have been influenced by changes to levee conditions on the NSW side of the river which has reduced the flows able to be discharged into the NSW effluent streams.

Levee bank construction on the NSW side of the Murray River upstream and downstream of the Moulamein Road may also have affected the stage discharge characteristics at the gauging station.

The estimated peak discharge of the 1975 flood is 34,500 ML/day. This is the largest estimated peak discharge on record (i.e. since 1909). The gauged peak of the 1916 flood by comparison is 31,300 ML/day. As indicated above, it is possible that the actual 1916 peak flow at Swan Hill after accounting for Murray Downs floodway flows may have been higher than the 1975 event flow.

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 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.

## 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.

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.

The current study flood frequency analysis derived estimate for the 100 year ARI flow is 35,000 ML/day. The flood frequency analysis results were subsequently adopted for input into the hydraulic modelling. The recorded streamflows since 1909 do not support the adoption of a model derived estimate which is much higher and depends on various levee failure scenarios. Adopting the 42,100 ML/day figure would only seem logical in the absence of lengthy or reliable streamflow records.

Table 2 Design Flow Estimates at Swan Hill / Murray Downs

| ARI (years) | Peak Design Flow (ML/day) | | | | |
|---|---|---|---|---|---|
| | 1992 Study | 1995-99 Study | 2009 Study | **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 – 99 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. Gauge zero is at 62.921 m AHD.

Based on the adopted design flows given in Table 2, the equivalent ARI of the five highest peak flow events at Swan Hill 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 recorded at the Swan Hill gauge 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 Murray Downs (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.
- October 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 will be adequate.

## 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 Murray Downs.

For the purpose of modelling an extreme event at Murray Downs, 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 of Conditions

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 floodplains 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 fee-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 (i.e. by the State River and Water Supply Commission / Rural Water Commission of Victoria). 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 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 will include the modelling of an extreme flood profile, this was performed in quite a simplistic manner. In extreme events, levees on both sides of the Murray 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 Murray Downs are compressed within a relatively narrow range due to the upstream floodplain conditions. The Murray River channel and the immediate adjoining floodplain have an upper limiting capacity of approximately 35,000 ML/day at Barham and Murray Downs. Flows in excess of this discharge northwards into the Wakool River system both upstream of Barham, and between Barham and Murray Downs.

The following recorded flood heights within the hydraulic model reach at Murray Downs are available:

- Eighteen 1906 recorded flood height marks.
- Nine 1993 recorded flood height marks.
- Eight 1956 recorded flood height marks.
- Seven 1975 recorded flood height marks.
- Small number of other event heights.

The 1975 and 1993 event recorded flood height marks were used for the model calibration. Floodplain conditions for these more recent events will have been more similar to the current floodplain conditions, compared to 1906 or 1956. The changes to the Moulamein Road for example have altered flooding conditions to that which existed before.

Assumptions made in regards to the hydraulic modelling are listed as follows:

- Steady state flow inputs were used as discussed in Section 5.3.
- Gauged flows: 1975 peak flow – 34,500 ML/day, 1993 peak flow - 33,900 ML/day.
- A normal depth derived rating curve was initially trialled as the 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 height in the vicinity was adopted.
- Possible changes in levee conditions between 1975, 1993 and 2013 were not factored into the modelling. This was primarily due to any changes being extremely difficult to define. Additionally most of the levees appear to have been present in some shape or form for a long period of time. Levee breaches may have occurred in the 1975 and 1993 floods leading to lower peak flood heights.
- The NSW side levees were defined using the crest height survey data obtained for this project. A crest height survey of the NSW side levee banks within the study area was completed in August – September 2013.
- Victorian side levee crest heights were defined using data supplied by the North Central Catchment Management Authority based on a recent levee crest survey.

## 6.4 Calibration Modelling Results

The calibration / validation hydraulic modelling results at Murray Downs are presented in Table 3. The location of the recorded flood heights is shown on Figure 5.

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

- Fixed downstream boundary water level of 67.20 m AHD adopted.
- It was necessary to lower the river channel Mannings roughness values down to 0.035 to achieve a reasonable match between the available modelled and recorded flood heights.
- The difference in the modelled flood level downstream of the Moulamein Road when using a main channel Manning roughness of 0.035 compared to 0.045 is about 0.2 metre.
- The resultant modelled 1975 flood levels at Marks 75-2, 75-3, 75-4 and 75-5 are all within +/- 0.1 metre. This represents very good agreement.
- The accuracy of the recorded flood height at Mark 75-1 is queried. The recorded height is within 0.01 metre of the recorded height at the gauge, located 2 km upstream. Given the average flood gradient for this floodplain reach is 1 in 8,000, it is inevitable that the modelled flood is approximately 0.2 metres lower than the suspect recorded flood level at Mark 75-1.
- Upstream of the Moulamein Road, the modelled flood heights are almost 0.3 metres higher than the two recorded 1975 flood heights. This is thought to be due to the influence of the levees present. The removal of the internal levees around Pental Island reduces the modelled flood levels by up to 0.2 metres (refer to results in Table 3).

Comments on the 1993 modelling results are provided as follows:

- Fixed downstream boundary water level of 67.20 m AHD retained (flow difference between the 1956 and 1975 events is small).
- The modelled 1993 flood level at the gauge (Mark 93-1) is 0.02 metres higher than the recorded level. This is the only 1993 recorded flood height downstream of the Moulamein Road.
- At the two closed 1993 recorded flood levels on the upstream side of the Moulamein Road, the modelled flood level is within 0.1 metre of the recorded level. Both modelled heights are higher than the recorded heights.
- Further upstream, the modelled flood levels are between 0.15 and 0.37 metres higher than the recorded levels. This is again though to be due to the influence of the existing levee banks. Removing the internal Pental Island levees reduces the modelled flood levels by up to 0.2 metre. Furthermore the outer levees at the upstream end of the TUFLOW model are assumed to confine flows, which is not the case on the NSW side.

In summary, the modelled TUFLOW flood levels are considered to be in good agreement with the recorded flood levels after taking into account various factors including the assumptions regarding the levees upstream of the Moulamein Road, the suspect nature of a few of the recorded heights and other uncertainties (e.g. changes in floodplain conditions between 1975, 1993 and 2013).

The modelled flood height at the Swan Hill gauging station site based on a flow of 29,500 ML/day (5 year ARI event) and using a main channel Mannings roughness of 0.035 is 67.57 m AHD. This is 0.09 metres higher than the flood level derived from the rating curve. This further supports the adoption of a river channel Mannings roughness of 0.035 or lower.

It is important to note that the modelled flood heights are based on some conservative assumptions. The internal Pental Island levees do not overtop until the modelled flood height exceeds their crest height. Flows are also confined to within the NSW side levee towards the upstream end of the TUFLOW model.

The following conclusions are drawn from the modelling:

- The model predicted flood heights in the vicinity of the Moulamein Road and further downstream are in good agreement with the recorded flood heights.
- The model predicted flood heights on the upstream side of Murray Downs are considered to represent upper bound flood height estimates of what will occur given similar flow rate conditions due to conservative assumptions in regards to the levees present.
- The model results support the adoption of a main channel Mannings roughness value of 0.035 for the design flood modelling.
- A fixed downstream boundary water level approach is appropriate for the design flood modelling given the calibration modelling outcomes.

Table 3 Murray Downs – Calibration Modelling Results

| Flood event (peak flow rate – ML/day) | Mark number | Recorded flood height (m AHD) | Modelled flood level - m AHD ( ) – modelled minus recorded – m | | |
|---|---|---|---|---|---|
| | | | Main channel Mannings roughness 0.035 | Main channel Mannings roughness 0.045 | 0.035 with Pental Island levees removed |
| Nov 1975 (34,500 ML/day) | 75-1 | 67.69 | 67.48 (-0.21) | 67.67 (-0.02) | 67.50 (-0.19) |
| | **75-2 (gauge)** | **67.70** | 67.67 (-0.03) | 67.90 (+0.20) | 67.70 (0.00) |
| | 75-3 | 67.74 | 67.77 (+0.03) | 68.04 (+0.10) | 67.81 (+0.07) |
| | 75-4 | 68.05 | 68.14 (+0.09) | 68.37 (+0.32) | 68.16 (+0.11) |
| | 75-5 | 68.65 | 68.68 (+0.03) | 68.94 (+0.29) | 68.65 (0.00) |
| | 75-6 | 68.51 | 68.79 (+0.28) | 68.87 (+0.36) | 68.66 (+0.15) |
| | 75-7 | 68.80 | 69.06 (+0.26) | 69.21 (+0.41) | 68.86 (+0.06) |
| | | | | | |
| Oct 1993 (33,900 ML/day) | **93-1 (gauge)** | **67.64** | 67.66 (+0.02) | 67.89 (+0.25) | 67.69 (+0.05) |
| | 93-2 | 68.02 | 68.05 (+0.03) | 68.33 (+0.31) | 68.07 (+0.05) |
| | 93-3 | 67.82 | 67.91 (+0.09) | 68.20 (+0.38) | 67.96 (+0.14) |
| | 93-4 | 68.09 | 68.27 (+0.18) | 68.58 (+0.49) | 68.21 (+0.12) |
| | 93-5 | 68.28 | 68.59 (+0.31) | 68.79 (+0.51) | 68.37 (+0.09) |
| | 93-6 | 67.99 | 68.14 (+0.15) | 68.38 (+0.39) | 68.17 (+0.18) |
| | 93-7 | 68.44 | 68.81 (+0.37) | 68.95 (+0.51) | 68.56 (+0.12) |
| | 93-8 | 68.93 | 69.28 (+0.35) | 69.46 (+0.53) | 69.11 (+0.18) |
| | 93-9 | 68.67 | 69.06 (+0.39) | 69.22 (+0.55) | 68.86 (+0.19) |

Note:

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

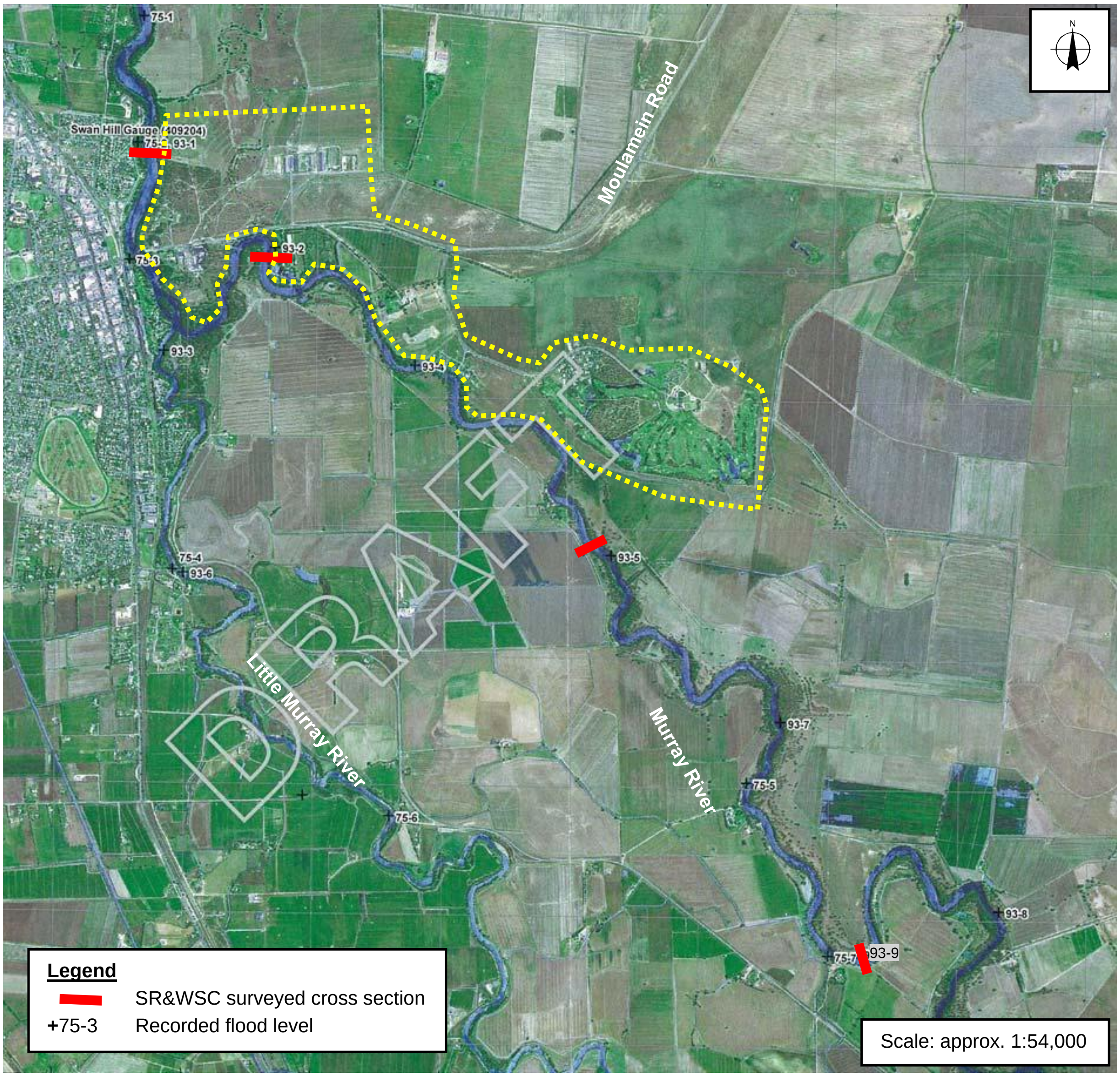



Figure 5 Recorded Flood Heights

## 6.5 100 Year ARI Design Flood Preliminary 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 based on the flood frequency analysis results. The peak design flow was input as a steady state flow given the extremely slow rates of rise and fall in this reach of the river.
- Downstream boundary condition. A fixed downstream boundary water level of 67.25 m AHD was adopted. This was considered appropriate given the water level adopted for the calibration events.
- A Manning roughness main channel uniform value of 0.035 was adopted given the calibration modelling results.

The 100 year ARI modelling results indicate the following:

- The modelled flood height at the Swan Hill gauge is 67.71 m AHD.
- The modelled flood height at the Moulamein Road bridge is 67.92 m AHD, well below the bridge soffit level of 69.57 m AHD.
- The modelled flood height on the upstream side of the Moulamain Road, opposite the Murray Downs Floodway is 68.12 m AHD. This is lower than the road low point of 68.20 m AHD.
- The modelled flood height opposite the Kidman Reid Drive estate is 68.35 m AHD. This is lower than the estate ground surface levels.
- Some minor localised levee overtopping occurs at the NSW side levee, 550 metres north of the Moulamein Road.
- Elsewhere floodwaters are confined by the NSW side levee bank from the downstream end of the model to the Kidman Reid Drive estate. The surveyed levee crest heights in some locations are only marginally above the modelled 100 year ARI flood levels. This includes the developed area adjoining the south side of the Moulamein Road.
- The area between the Golf Course and the Murray River channel is subject to flooding, as are low lying parts of the Golf Course.
- The area east of the Golf Course is also subject to flooding. This area has not been modelled given the difficulties in simulating flooding for this area without a major expansion of the hydraulic model. It is not an area where future development is being considered.

The focus of this study is on the Murray Downs 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 and some other more recent survey 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.

## 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 0.2 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 0.3 metres.

The flow variations used for the sensitivity analysis are relatively extreme given the narrow range of flow conditions at Murray Downs / Swan Hill. The 100 year ARI adopted design flow at Murray Downs 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 km downstream of the Swan Hill / Murray Downs bridge | -0.04 | +0.04 |
| 1 km downstream of bridge (i.e. at the gauging station) | -0.14 | +0.13 |
| Immediately upstream of the Swan Hill / Murray Downs bridge | -0.19 | +0.17 |
| 0.9 km upstream of the Swan Hill / Murray Downs bridge | -0.23 | +0.21 |
| Just downstream of the Murray Downs homestead | -0.27 | +0.23 |
| Opposite the Kidman Reid Drive estate | -0.30 | +0.23 |
| Opposite the golf course estate | -0.30 | +0.19 |
| Upstream of the golf course | -0.28 | +0.13 |
| Upstream limit of hydraulic model | -0.31 | +0.16 |

### 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 0.17 metres. The modelled increase varies from a minimum of 0.13 metres to a maximum of 0.21 metres.

A 25% decrease in the Mannings roughness value results in an average decrease in the 100 year ARI flood level of 0.20 metres. The modelled decrease varies from a minimum of 0.12 metres to a maximum of 0.25 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 |
| 1 km downstream of bridge (i.e. at the gauging station) | -0.12 | +0.13 |
| Immediately upstream of the Swan Hill / Murray Downs bridge | -0.16 | +0.17 |
| 0.9 km upstream of the Swan Hill / Murray Downs bridge | -0.18 | +0.19 |
| Just downstream of the Murray Downs homestead | -0.21 | +0.21 |
| Opposite the Kidman Reid Drive estate | -0.24 | +0.20 |
| Opposite the golf course estate | -0.24 | +0.17 |
| Upstream of the golf course | -0.22 | +0.11 |
| Upstream limit of hydraulic model | -0.25 | +0.15 |

### 6.6.3 Bridge Blockage

The only bridge across the Murray River at Murray Downs / Swan Hill 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 67.71 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 67.25 to 67.55 m AHD).

The resultant impact upstream was found to:

- Increase in flood height reduces to 0.20 metres at the gauging station located 1 km downstream of the Swan Hill – Murray Downs bridge.
- Increase in flood height reduces to 0.18 metres at the Swan Hill - Murray Downs bridge.
- Increase in flood level reduces to 0.0.05 metres on the upstream side of the golf course.

### 6.6.5 Summary of Sensitivity Modelling Resuults

The high end 100 year ARI flow estimate of 42,100 ML/day documented in a major study undertaken in the 1990s (SKM, 1999) results in modelled flood levels which are typically 0.2 metres higher than the flood levels coinciding with the adopted design flow of 35,000 ML/day. Flood level increases are limited as overtopping of the NSW side levee system occurs for the higher flow conditions. The Moulamein Road will also be overtopped at the higher flow.

The modelled flood levels with the 20% lower flow (i.e. 28,000 ML/day) are typically 0.3 metres lower than with the adopted design flow of 35,000 ML/day. This is approximately the difference in water level expected based on the rating table at the gauging station. The modelled water level at the gauging station is only 0.14 metres lower, however this is influenced by the fixed downstream boundary water level.

The 100 year ARI flood heights are not particularly sensitive to the Manning roughness parameter values assigned. Main channel velocities are typically relatively low (e.g. 1.0 m/s) which limits the influence of the stream roughness.

The bridge waterway area at Murray Downs 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 downstream limit of the TUFLOW model is located 2.5 km downstream of the likely limit of any future development at Murray Downs. Any change in the TUFLOW downstream boundary condition will therefore have diminished influence a further 2.5 km upstream. Notwithstanding this, the downstream boundary water level can influence flood levels to opposite the golf course.

## 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 at Murray Downs:

- 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 parts of Murray Downs 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 North of Moulamein Road

The existing levee paralleling the NSW side river bank north of the Moulamein Road confines up to the 100 year ARI event, with the exception of some very marginal localised overtopping 0.55 km north of the road. The typical freeboard varies from zero to 0.2 metres. The levee is unlikely to meet the standards required of modern urban levees.

The Moulamein Road provides protection to those areas on its north side. The 100 year ARI flood level on the upstream side of the road is 0.08 metres below the road surface level. Floodwater is consequently excluded from the Murray Downs ‘floodway’.

### 6.7.3 South Side of Moulamein Road

The existing levee paralleling the NSW side river bank south of the Moulamein Road is not overtopped in a 100 year ARI event. The freeboard varies from close to zero to 0.5 metre. The rural standard levee is in a relatively poor condition.

The existing levee provides protection to commercial land use properties fronting onto the south side of the Moulamein Road.

### 6.7.4 Kidman Reid Drive / Golf Course Reach

Further upstream, floodwaters remain confined in a 100 year ARI event opposite the Murray Downs homestead. The 100 year ARI flood level opposite the homestead is 68.25 m AHD. The levee bank crest height is 68.6 m AHD. The homestead itself is located on naturally high ground (71 m AHD).

There is no levee bank present opposite the Kidman Reid Drive estate (i.e. the estate area is naturally high). The 100 year ARI flood level opposite the estate is 68.4 m AHD. Ground levels over the estate vary from 68.6 to 69.2 m AHD.

There is no formal levee bank opposite the golf course. A continuous low level bank is present from east of the Kidman Reid Drive estate. The bank forms part of irrigation infrastructure. The modelling indicates that the bank does not prevent flooding of the low lying parts of the golf course in a 100 year ARI event. Flooding extends across the golf course to the edge of the residential estate.

### 6.7.5 Area East of Golf Course

The area on the east side of the golf course is subject to flooding. This area has effectively been excluded from the TUFLOW model given the difficulties experienced in incorporating the breakaway flow path leading northwards away from the immediate Murray River floodplain. The Murray River levee was artificially raised to prevent overflows upstream of the golf course.

The area east of the golf course is not earmarked for future development.

# 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 Swan Hill gauging station. The assigned fixed boundary water levels varied from 66.95 m AHD for the 5 year ARI event to 67.27 m AHD for the 200 year ARI event, consistent with the narrow flood height versus flow range at the gauging station.

## 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 B to F 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 – 0.25 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 Murray Downs, 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).

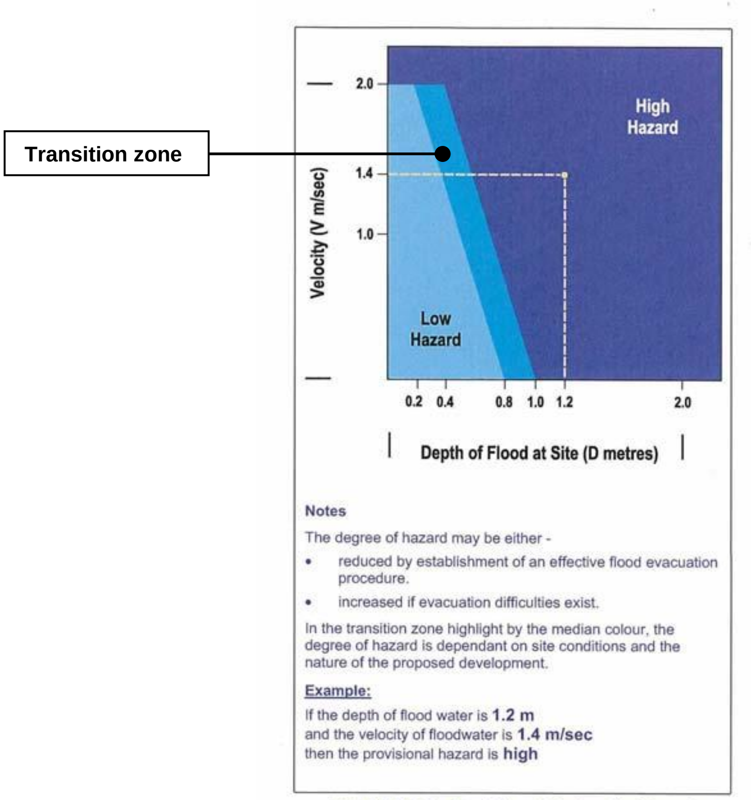



*FIGURE L2 - Provisional Hydraulic Hazard Categories*

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 Murray Downs 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 – Flood Impacts / Issues

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

### 7.3.1 Existing Development Impacts

The flood modelling results indicate that the impacts on existing development at Murray Downs up and including a 100 year ARI event are likely to be minor. This outcomes assume however that the existing rural standard levee protecting commercial development adjoining the south side of the Moulamein Road does not breach. If the levee does breach, floodwaters will then impact on the properties in this area. The extent of these impacts will depend on what, if any buildings are subject to above floor flooding.

The existing residential and commercial land use development on Murray Downs Drive (i.e. Kidman Reid Drive estate, golf course estate, Resort at the golf course) is not expected to be affected by flooding up to the 100 year ARI event. The grounds of the southern most properties within the existing golf course residential estate appear to be subject to flooding. The floor levels of the houses on these properties are likely to be elevated above the 100 year ARI flood level.

Floor level elevations for buildings at Murray Downs potentially affected by flooding 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 Murray Downs have also not been identified as part of this study. Flood damages for the township are expected to be low given the likelihood that few, if any residential or commercial land use buildings are expected to be subject to above floor flooding in a 100 year ARI event.

### 7.3.2 Future Development – Flooding Issues

An extract from the Land Use Strategy Report (Collie, 2009) presented as Figure 7 shows potential future development areas at Murray Downs.

Current residential development is proceeding at the Kidman Reid Drive estate. This estate is not subject to 100 year ARI flooding, nor does it rely on levee protection (refer to Figure A2).

Between the Kidman Reid Drive estate and the Murray Downs homestead property, the residential zoned land is not affected by 100 year ARI flooding.

On the east side of the Kidman Reid Drive estate, the adjoining residential zoned land is not affected by 100 year ARI flooding. Further west, the intervening area between the golf course and the Murray River is subject to 100 year ARI flooding. Any potential future rezoning of land adjoining the south side of the golf course would need to adequately flooding issues.

The future development area located wholly within the golf course (i.e. south of the existing golf course estate) is located on high ground elevated above the 100 year ARI flood level.

The area on the north side of Murray Downs Drive adjoining the existing golf course estate is on high ground elevated above the 100 year ARI flood level.

The existing commercial land use area on the south aside of the Moulamein Road is protected from flooding by a rural land use standard levee. Any future development or redevelopment within this area should be subject to appropriate flood related development controls (e.g. minimum floor level requirements)

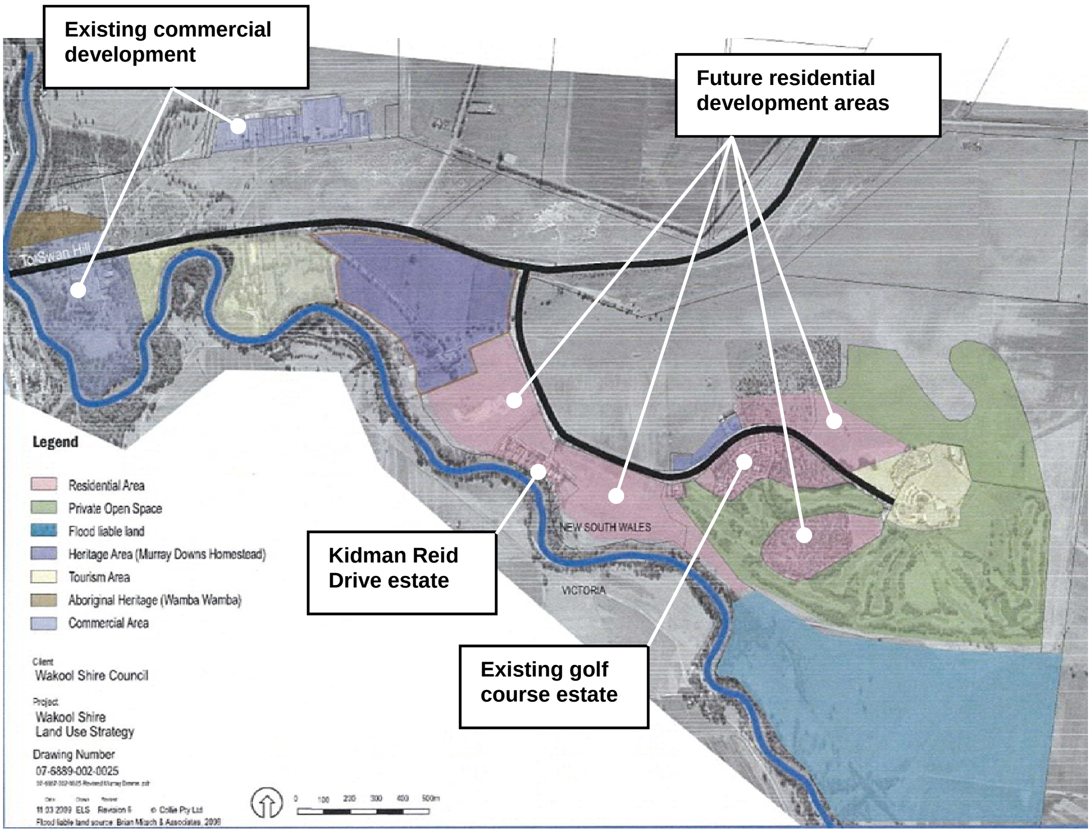



Figure 7 Potential Future Land Use Development Areas at Murray Downs

(modified extract from 2009 Land Use Strategy Report

## 7.4 Points of Interest

Detailed hydraulic model output is provided in Table 6 at particular points of interest within the study area floodplain. This data is provided to assist with flood response plans. The data is generally based on modelled predictions as distinct from actual recorded observations in past flood events. There may therefore be some differences between actual flood conditions encountered in future floods and the modelled data given in Table 6.

Table 6 Flood Data – Points of Interest

| Location | Overtopping Threshold | | | 100 Year ARI Depth Overtopping (m) | Indicative Duration Overtopping |
|---|---|---|---|---|---|
| | Flow (ML/day) | ARI (years) | Swan Hill gauge height (m) | | |
| Moulamein Road – low point 500 metres west of river bridge | > 36,000 | > 200 | > 4.83 | 0.0 | na |
| Levee north of Moulamein Road | 35,500 | 100 | 4.79 | < 0.02 | 1 to 7 days |
| Levee south of Moulamein Road - bridge to 1 km east of bridge | > 36,000 | > 200 | > 4.83 | 0.0 | na |
| Levee - Murray Downs homestead to Moulamein Rd | > 36,000 | > 200 | > 4.83 | 0.0 | na |
| Levee opposite the Golf Course | 33,000 | 25 | 4.73 | 0.1 | 1 to 7 days |

Note:

1. Gauge zero datum at the Swan Hill gauging station site is 62.92 m AHD.

# 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 Murray Downs, the major issues to be addressed by a future FRMS will include:

- Future arrangements associated with any possible upgrades to and ongoing maintenance of the levee system at Murray Downs.
- An assessment of flood related land use planning and development controls appropriate for Murray Downs 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 Murray Downs, Tooleybuc 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.

# 11. References


Binnie & Partners (July 1992). *Swan Hill / Tyntynder Flats Floodplain Management Study*. Prepared for the Shire of Swan Hill.

Cardno (May 2011). *Swan Hill Bridge Flood Study Detailed Hydraulic Study Addendum Report*. Prepared for VicRoads.

Cardno Lawson Treloar March 2009). *Detailed Hydrology Study for the Swan Hill Bridge Planning Study*. Prepared for VicRoads.

Collie, Ivey, Geolyse and Groupwork (April 2009). Wakool Shire LEP review – Land Use Strategy Report. Prepared for Wakool Shire Council.

Department of Environment Climate Change and Water (January 2011). *Floodplain Management Plan – Wakool River Stage 2 – Moama-Moulamein Railway to Gee Gee Bridge*.

Department of Land and Water Conservation Specialist Coastal and Flood Serrvices Branch (July 2000). *Edward and Wakool Rivers Floodplain Management Strategy – Noorong Road to Wakool Murray Junction*. Prepared for NSW Department of Land and Water Conservation.

Egis Consulting (May 2000). *Flood Data Transfer Project – River Basin Report – Murray River Basin*. Prepared for the Department of Natural Resources and Environment.

Egis Consulting (May 2000). *Flood Data Transfer Project – Rural City of Swan Hill Report*. Prepared for the Department of Natural Resources and Environment.

Gutteridge Haskins & Davey, Cameron McNamara, and Lawrie Montgomerie & Pettit (December 1998). Murray River Flood Plain Management Study. Both a 'Summary Report', a 'Detailed Report', and a 'Flood Plain Atlas' prepared for the Rural Water Commission of Victoria and the Water Resources Commission of NSW.

Lawson & Treloar (April 1995). *Swan Hill Regional Flood Strategy – Hydraulic Evaluation of Strategies*.

Lawson & Treloar (April 1998). *Swan Hill Regional Flood Strategy – Hydraulic Assessment*.

Rural Water Commission of Victoria (1990). *Victorian Water Surface Information to 1987 – Volume 4.*

Sinclair Knight Merz (September 1999). *Swan Hill Regional Flood Strategy Completion Phase – Report to Community*.

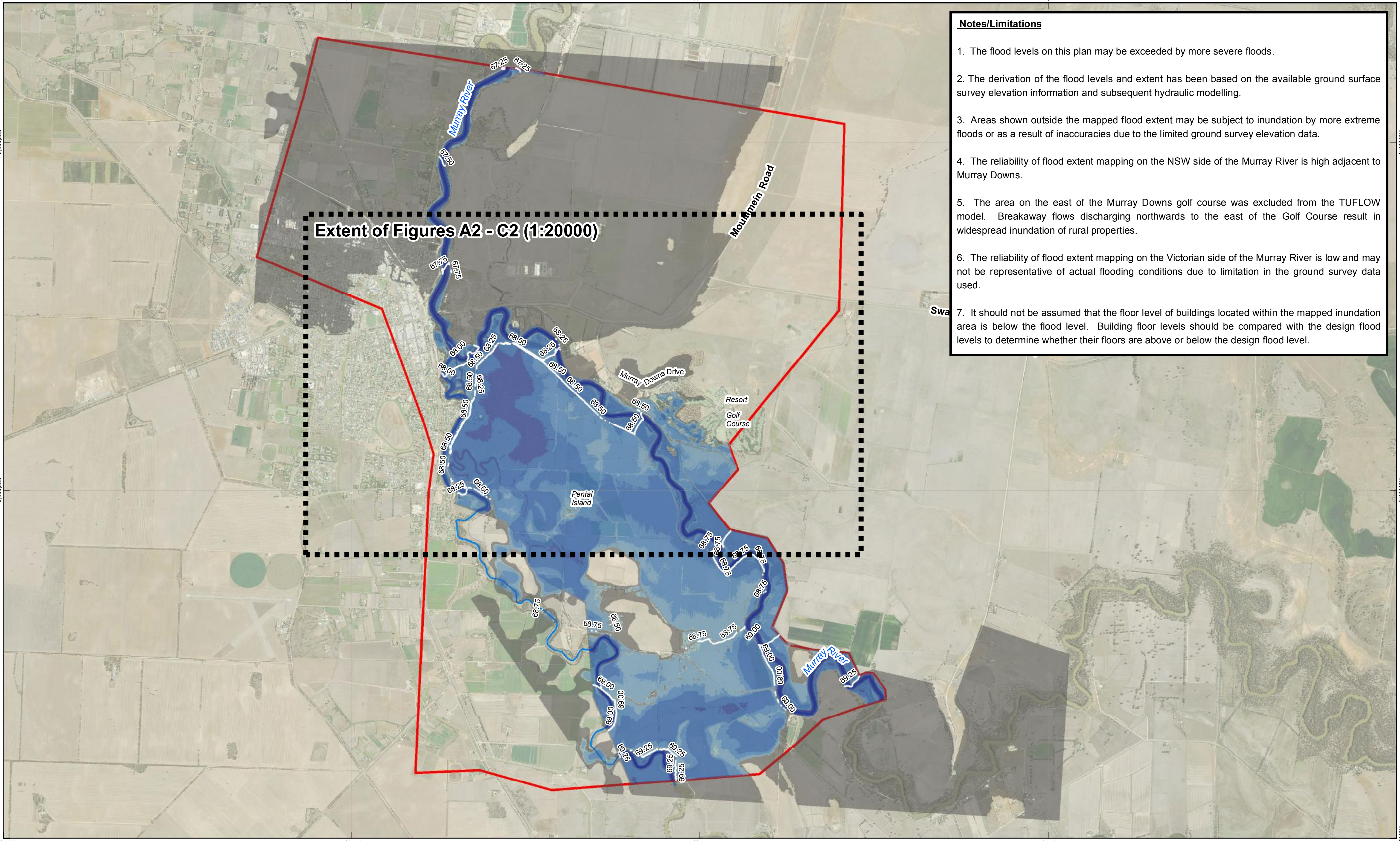
Wakool Shire Council (1997). Local Disaster Plan (Displan)

Wakool Shire Council (December 2007). *Shire of Wakool Local Flood Plan.* A sub-plan of the Wakool Shire Local Disaster Plan.

# Appendices

# Appendix A – Design Flood Maps


| | |
|---|---|
| Figure A1 | 100 Year ARI Event – Flood Extent and depth – Sheet 1 |
| Figure A2 | 100 Year ARI Event – Flood Extent and Depth – Sheet 2 |
| Figure A3 | 5 Year ARI Event – Flood Extent and Depth |
| Figure A4 | 20 Year ARI Event – Flood Extent and Depth |
| Figure A5 | 200 Year ARI Event – Flood Extent and Depth |
| Figure A6 | Extreme Event – Flood Extent and Depth |




**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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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
- 100 Year ARI + 0.5m

GHD | WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

100-Year ARI Flood Event
Flood Extent and Depth

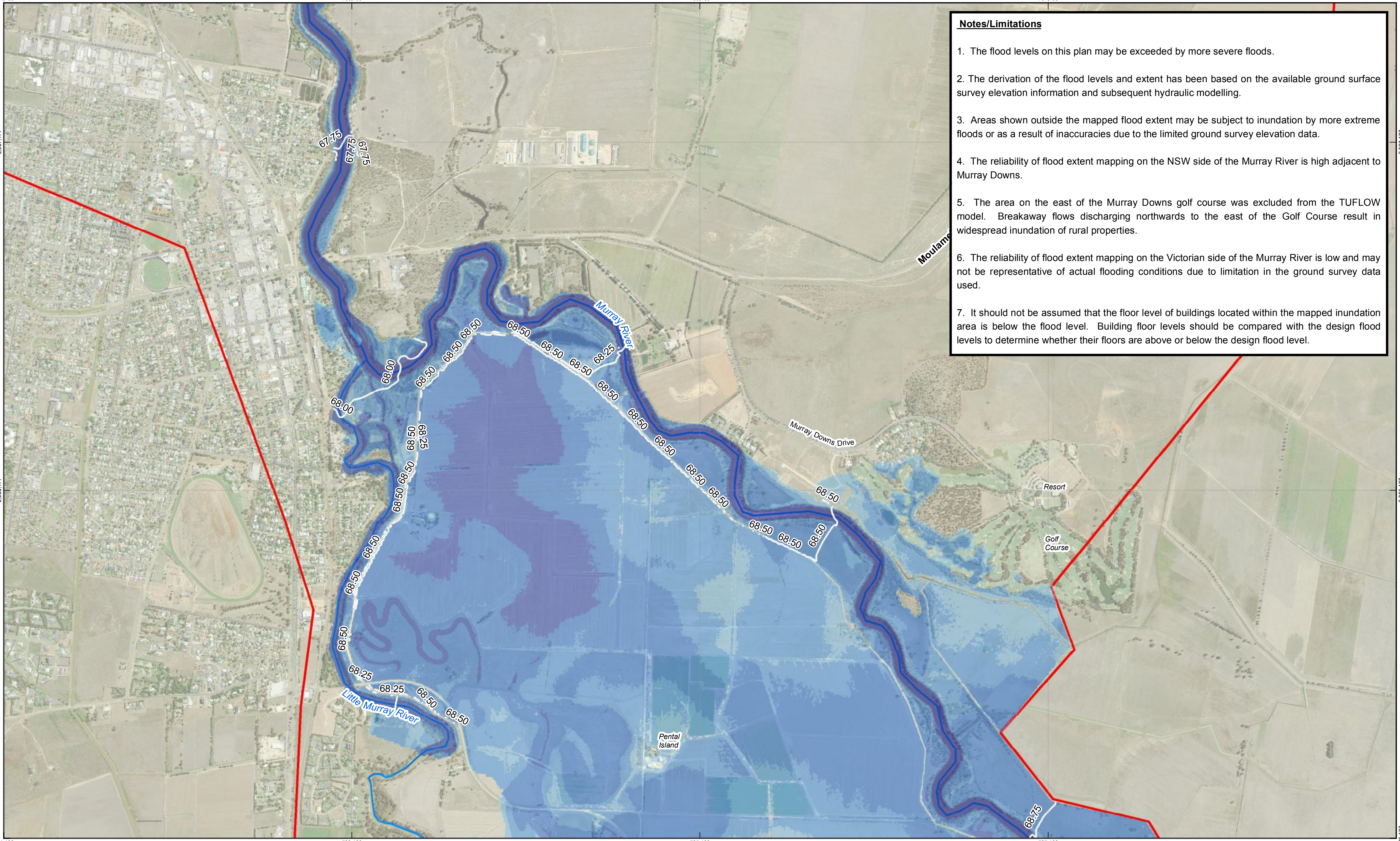
Figure A1

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_A1_Rev_0.mxd

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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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**

**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

GHD | WSC WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

# 100-Year ARI Flood Event
# Flood Extent and Depth

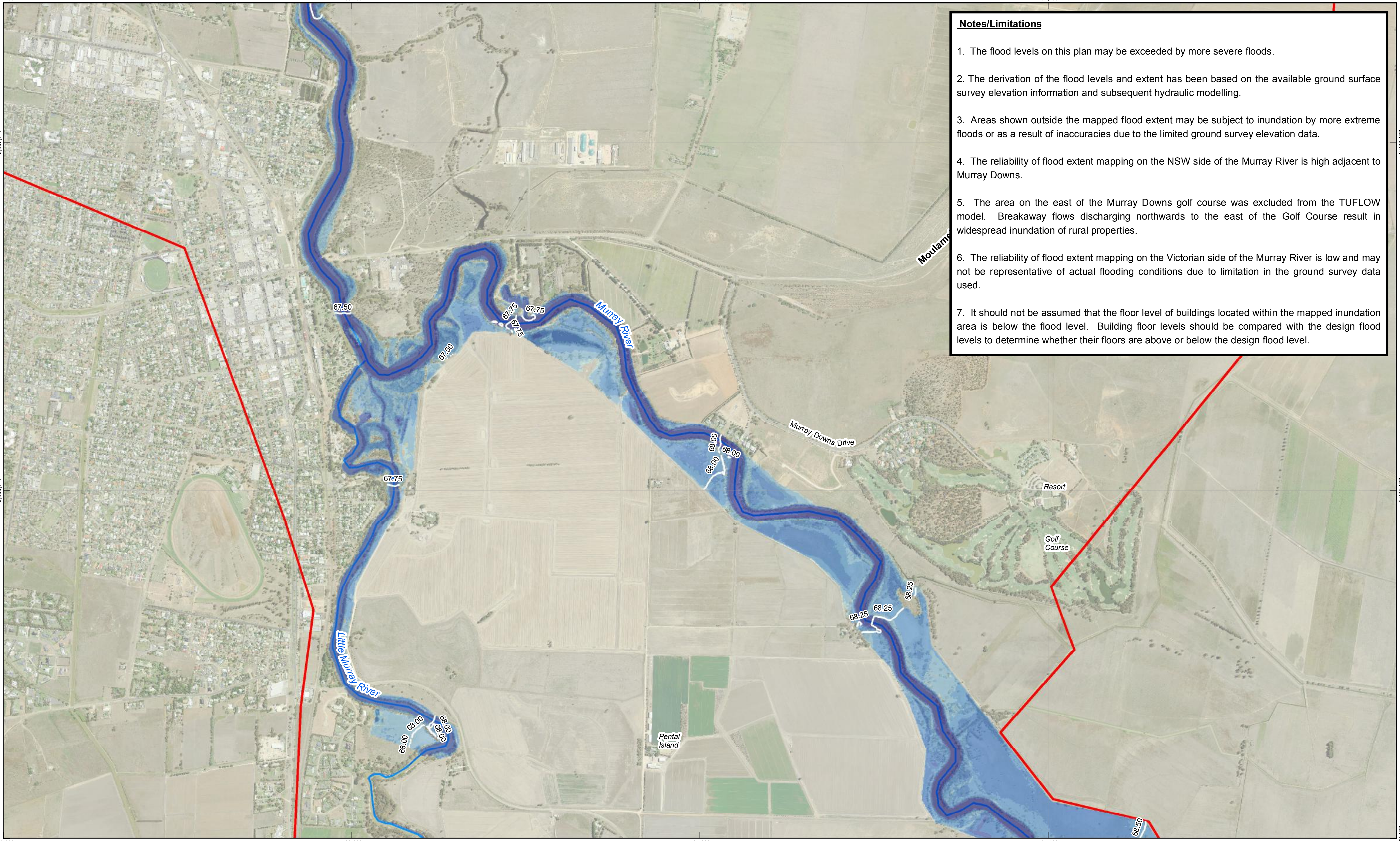
Figure A2

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_A2_Rev_0.mxd


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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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**

**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

GHD | WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

# 5-Year ARI Flood Event
# Flood Extent and Depth

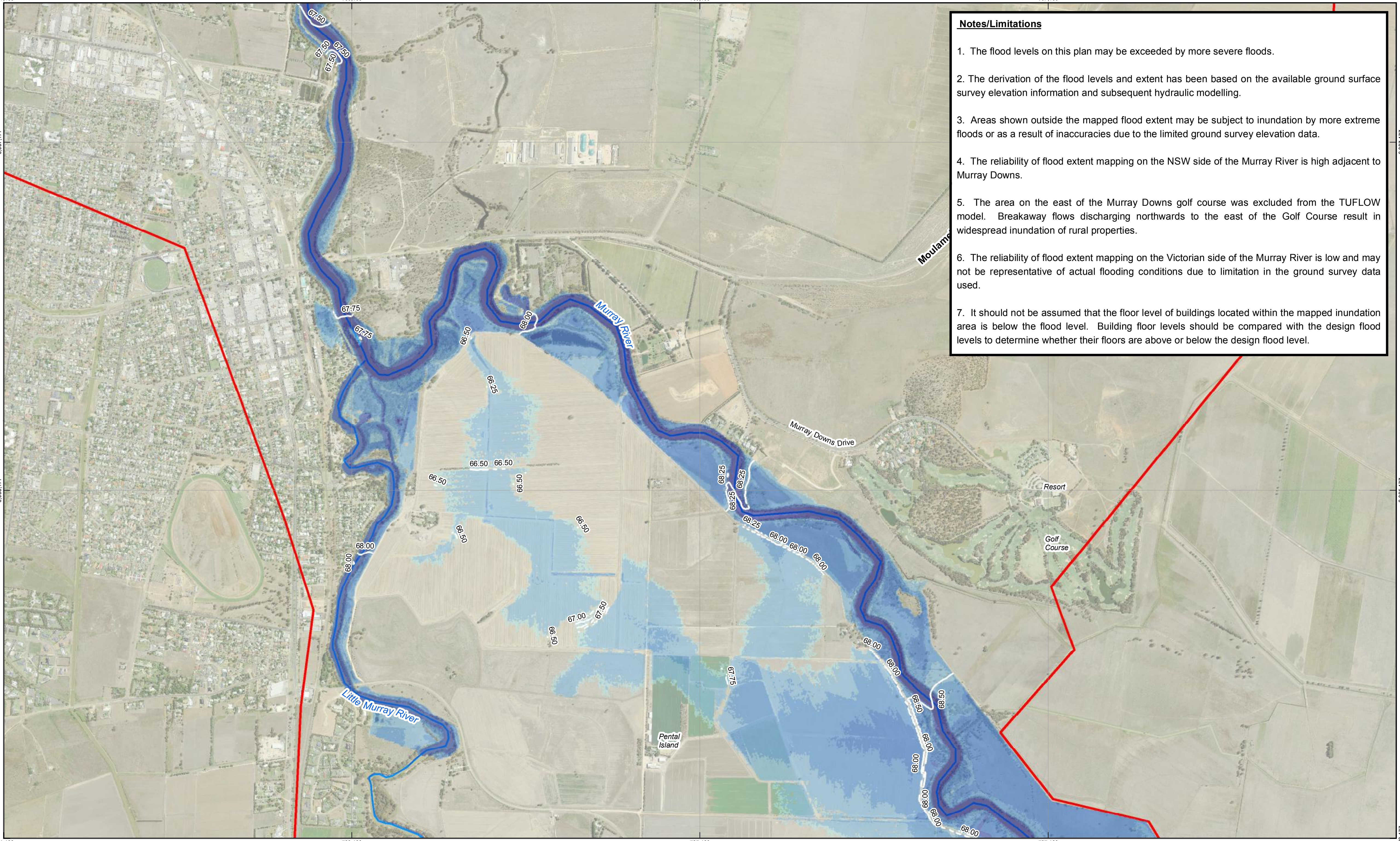
Figure A3

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_A3_Rev_0.mxd

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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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**

**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

GHD | WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

## 20-Year ARI Flood Event
## Flood Extent and Depth

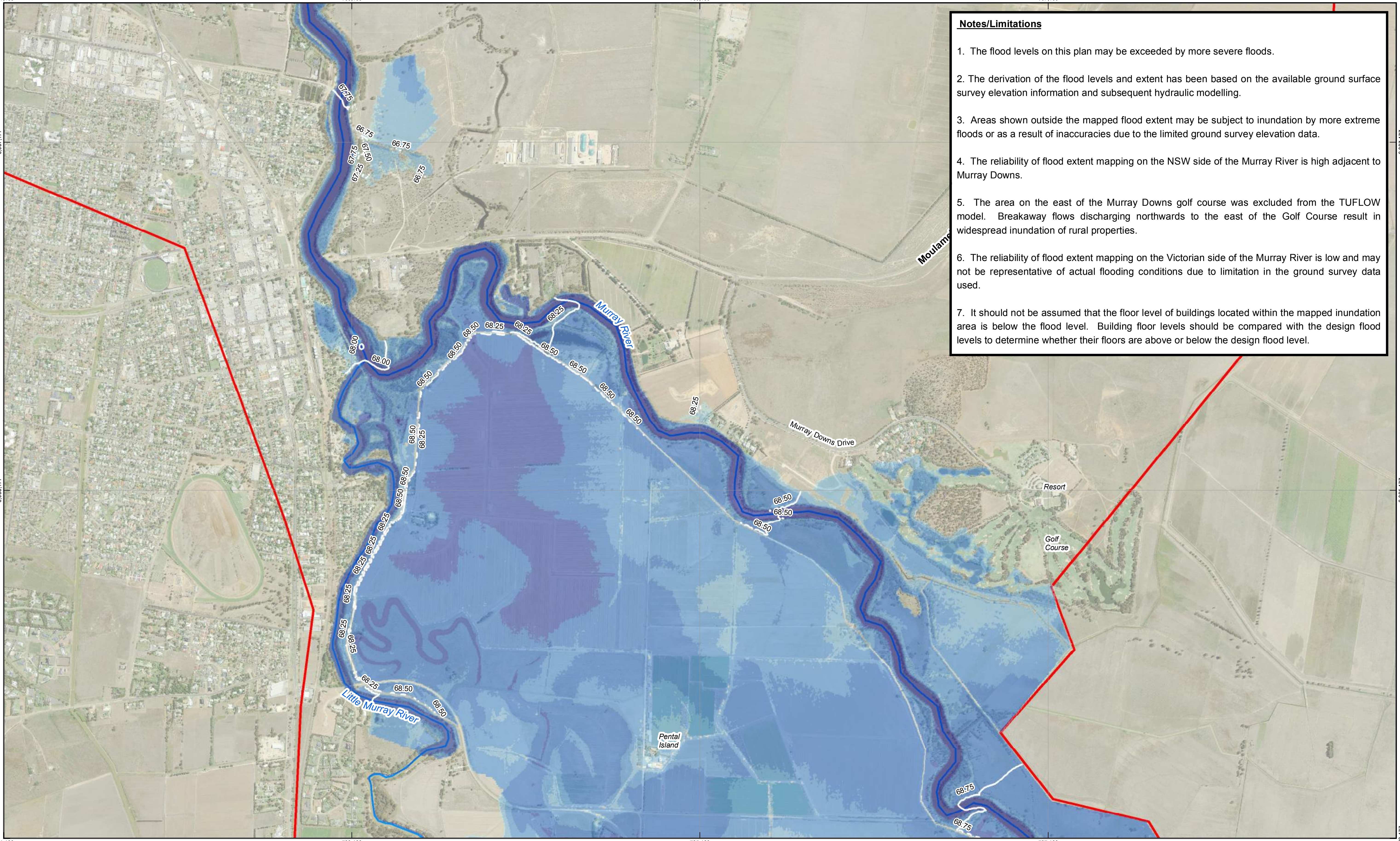
Figure A4

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_A4_Rev_0.mxd

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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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**

**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

GHD | WSC WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

# 200-Year ARI Flood Event Flood Extent and Depth

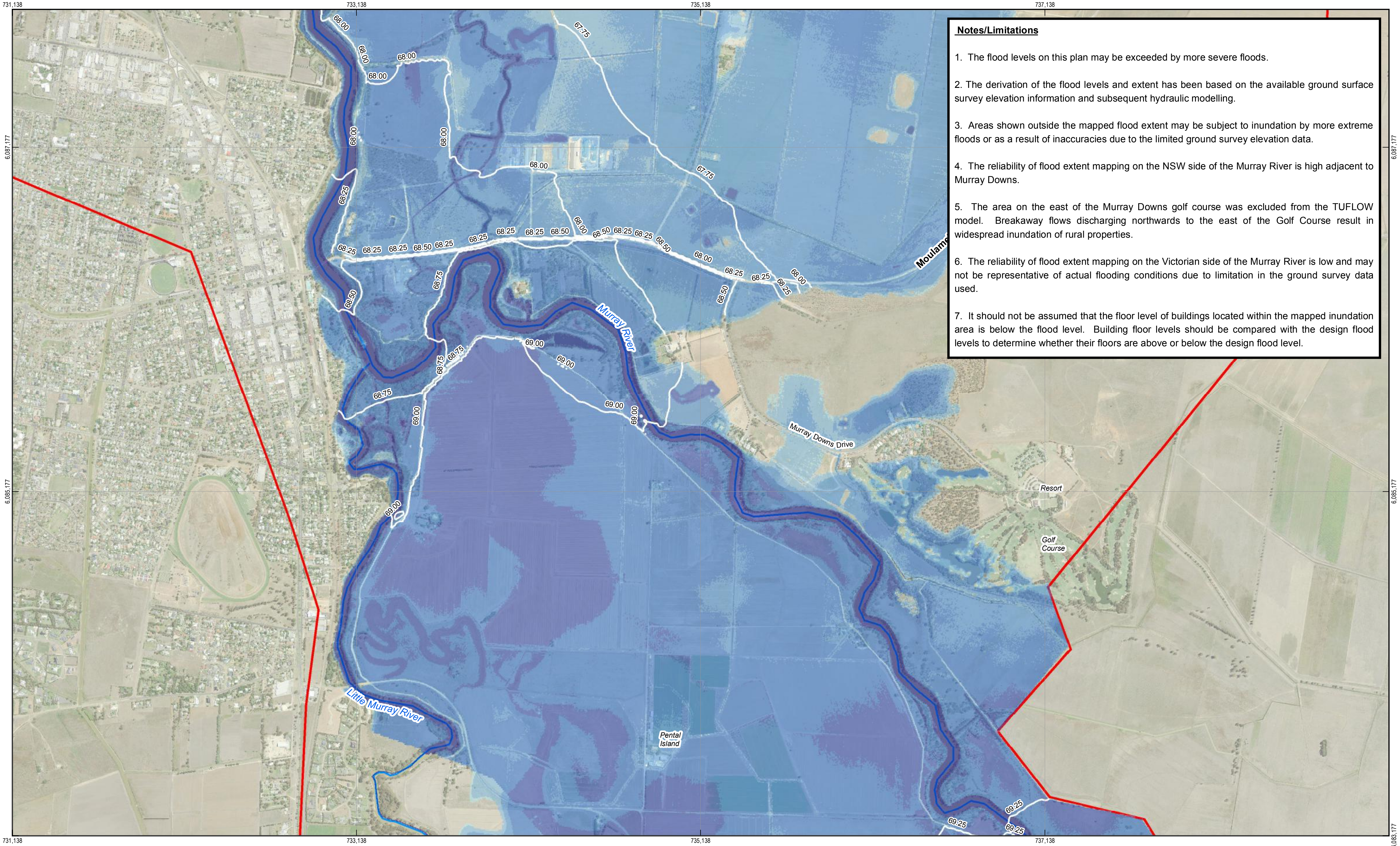
Figure A5

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_A5_Rev_0.mxd

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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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**

**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

GHD | WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

# Extreme Flood Event Flood Extent and Depth

Figure A6

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_A6_Rev_0.mxd

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

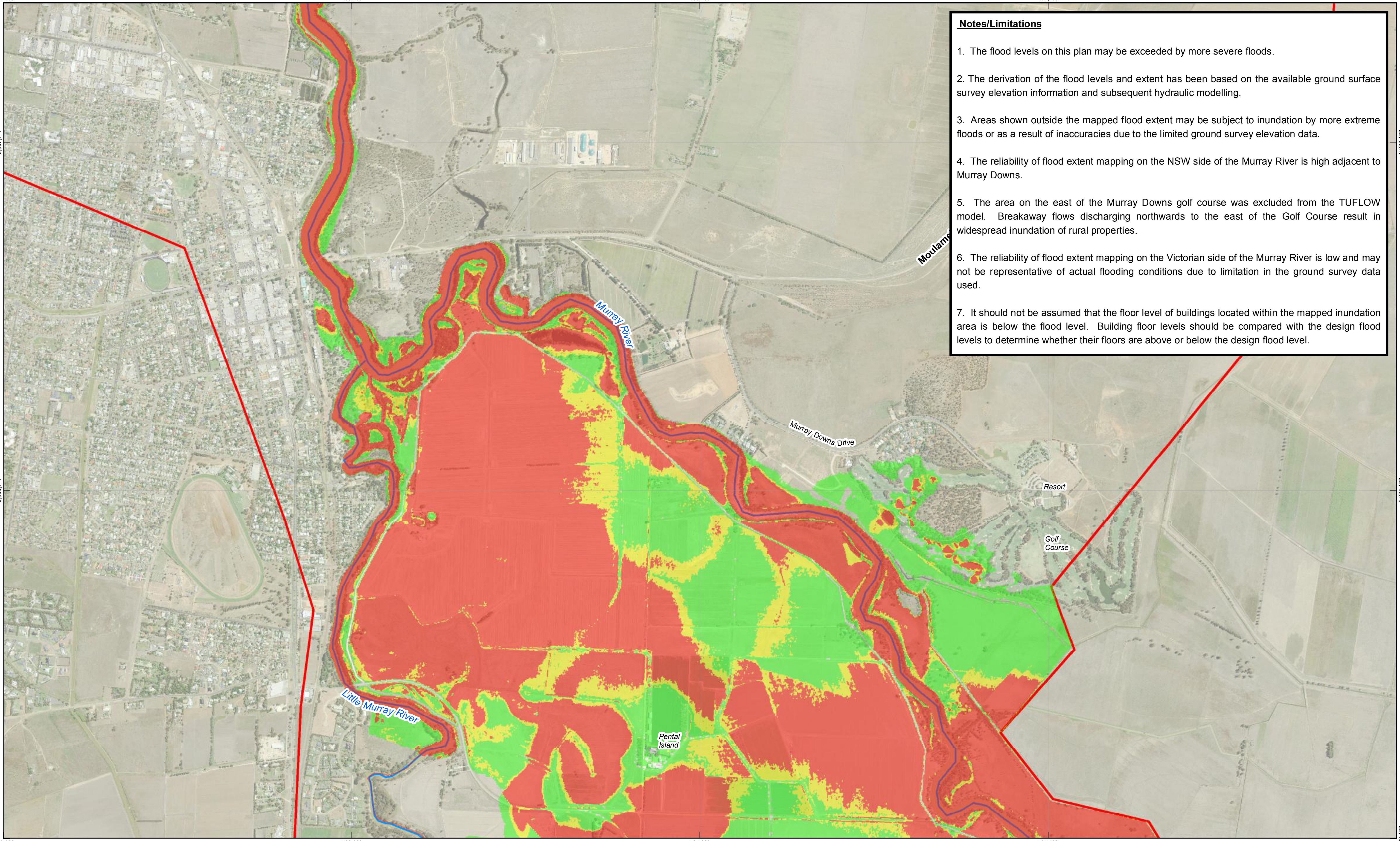


Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

# Appendix B – Provisional Hazard Category Maps

Figure B1 Provisional Hazard Category – 100 Year ARI Event

Figure B2 Provisional Hydraulic Category – 20 Year ARI Event




**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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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

GHD

WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

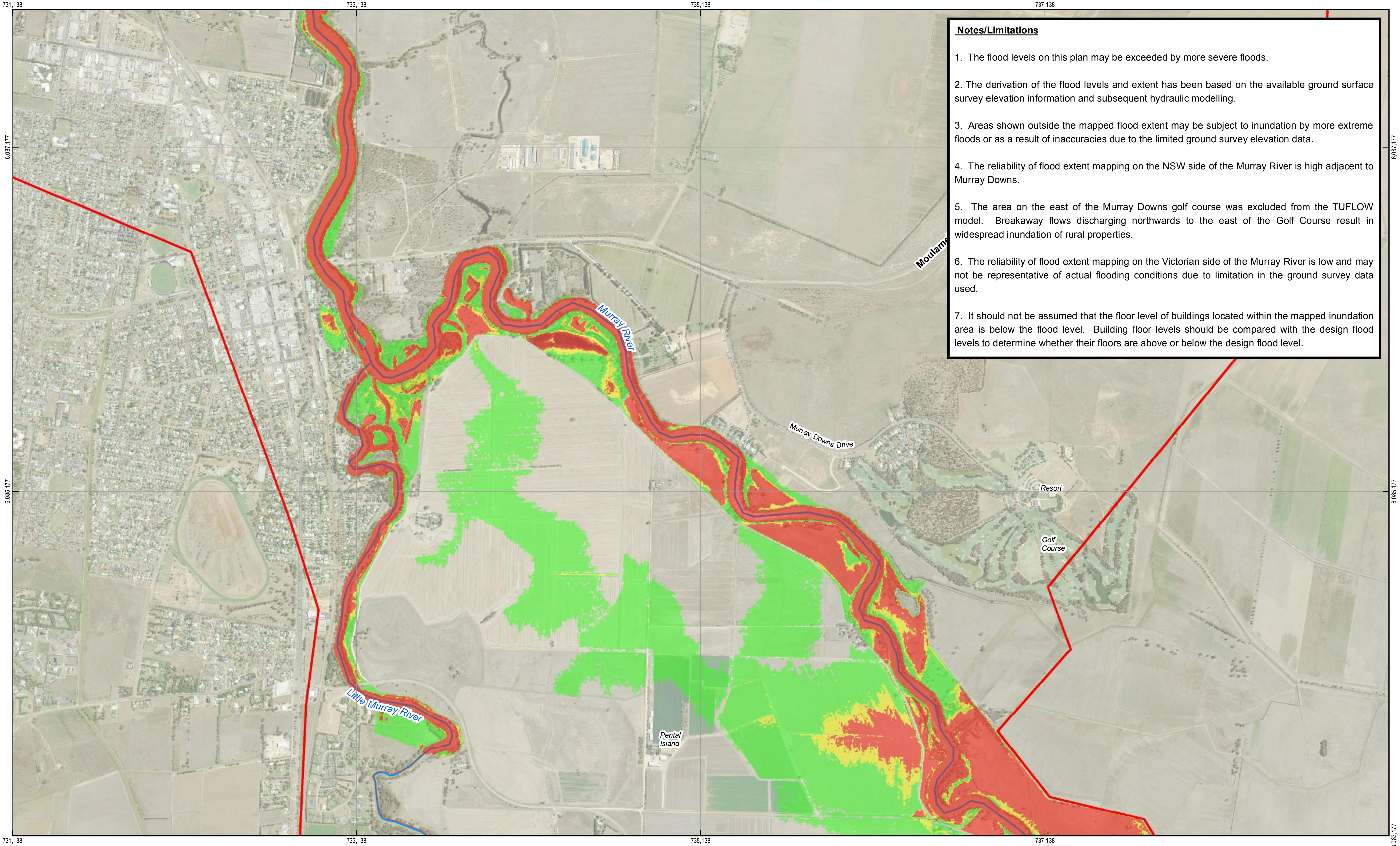
## 100- Year ARI Flood Event
## Provisional Hazard Category Figure B1

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_B1_Rev_0.mxd

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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

## 20- Year ARI Flood Event Provisional Hazard Category

## Figure B2

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_B2_Rev_0.mxd

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

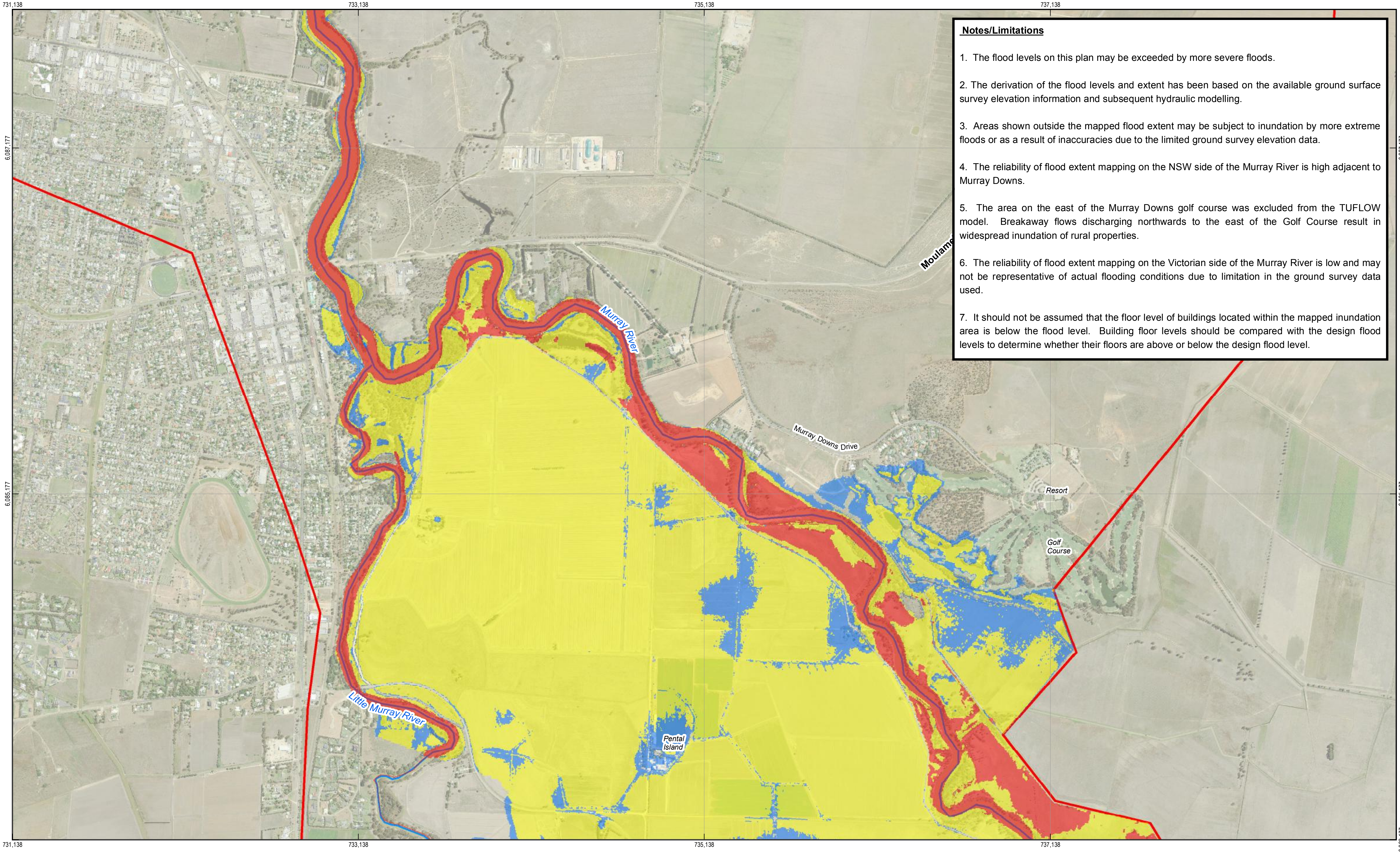


Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

# Appendix C – Hydraulic Category Maps

Figure C1 100 Year ARI Flood Event - Hydraulic Category

Figure C2 20 Year ARI Flood Event - Hydraulic Category




**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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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 elevation data used.

7. 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**

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

GHD

WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

100- Year ARI Flood Event
Hydraulic Category

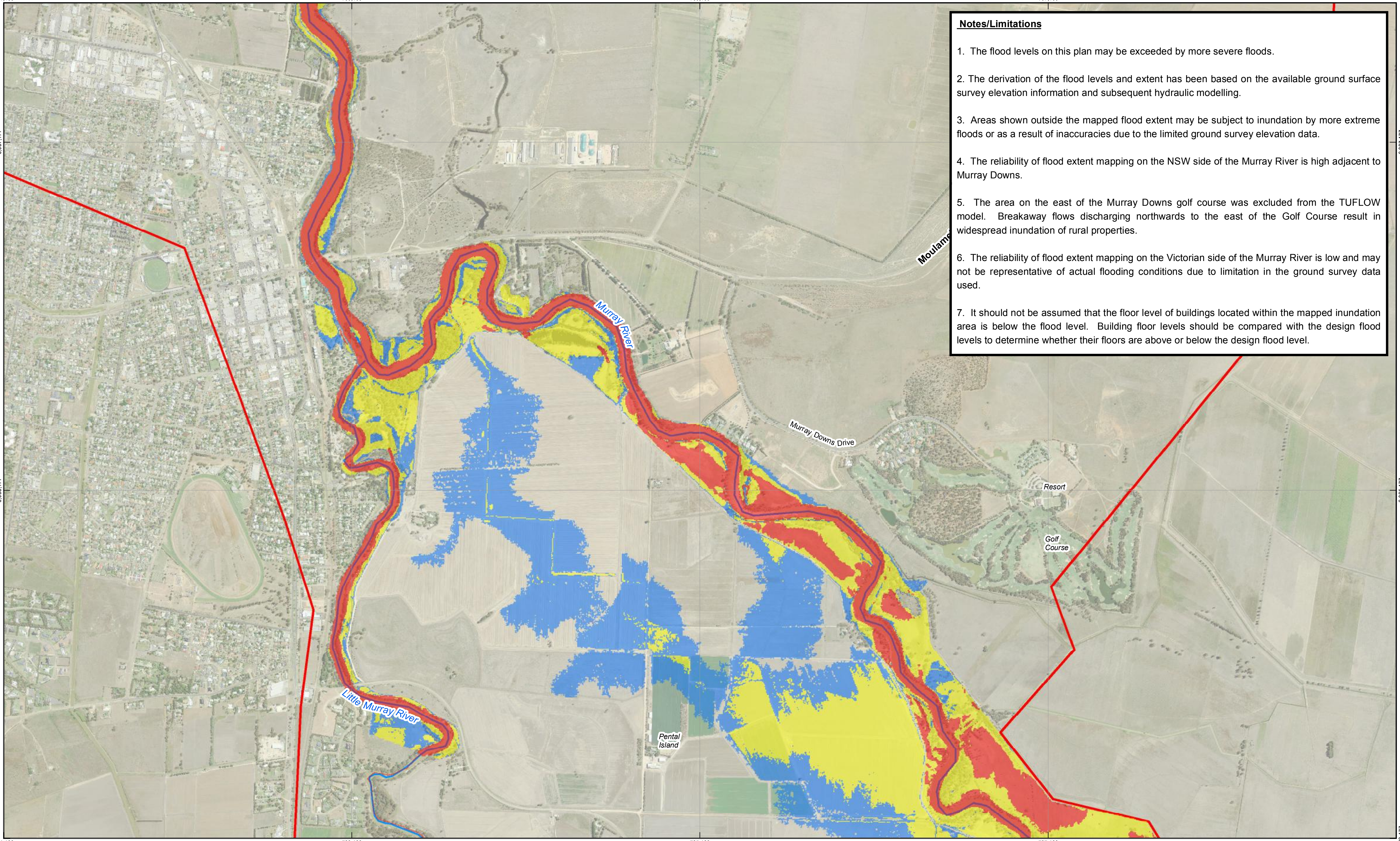
Figure C1

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_C1_Rev_0.mxd

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.

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

5. The area on the east of the Murray Downs golf course was excluded from the TUFLOW model. Breakaway flows discharging northwards to the east of the Golf Course result in widespread inundation of rural properties.

6. 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.

7. 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**

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

GHD | WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

| | |
|---|---|
| Job Number | 31-30143 |
| Revision | 0 |
| Date | 07 Oct 2014 |

20- Year ARI Flood Event
Hydraulic Category

Figure C2

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_C2_Rev_0.mxd

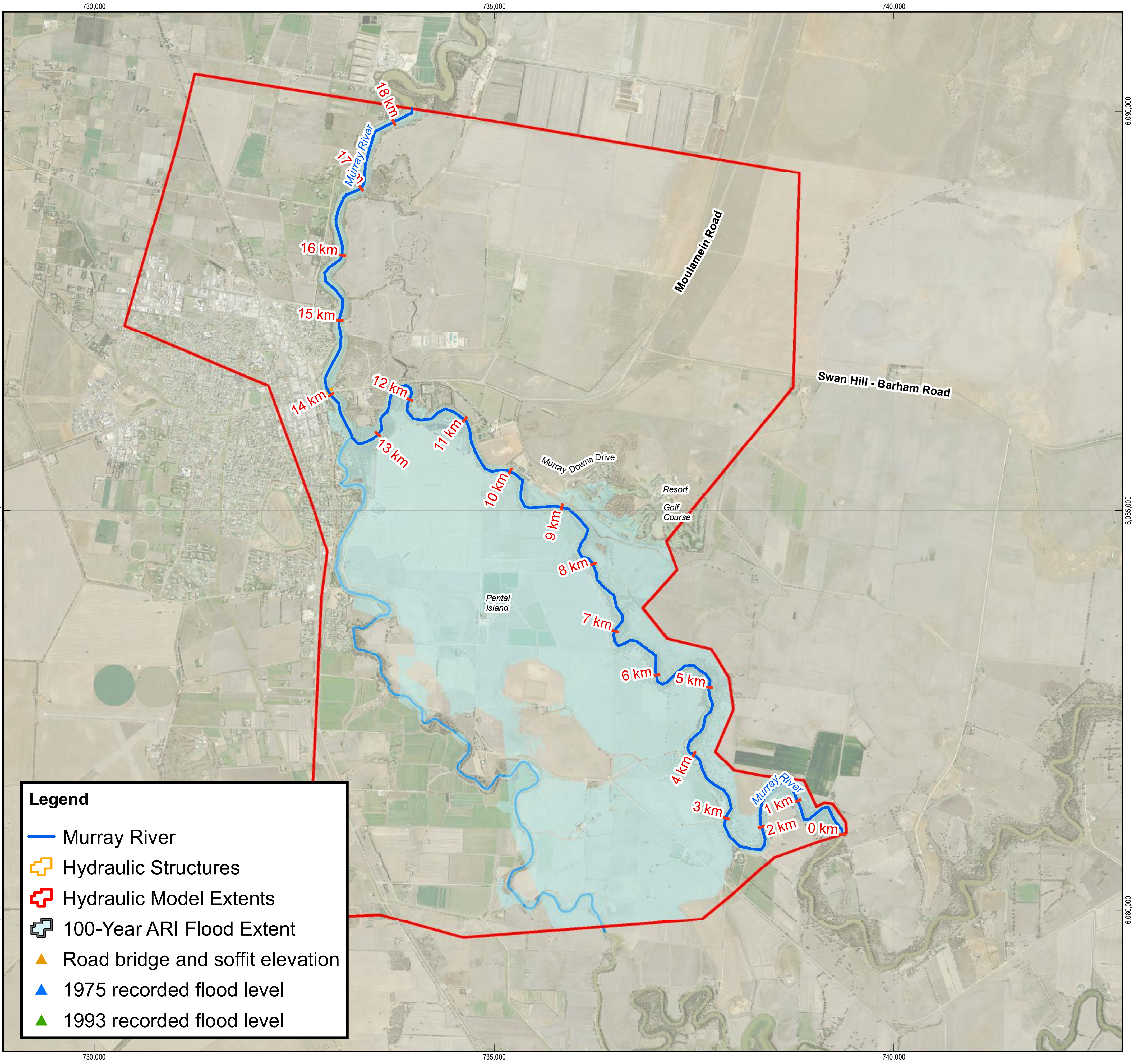
180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

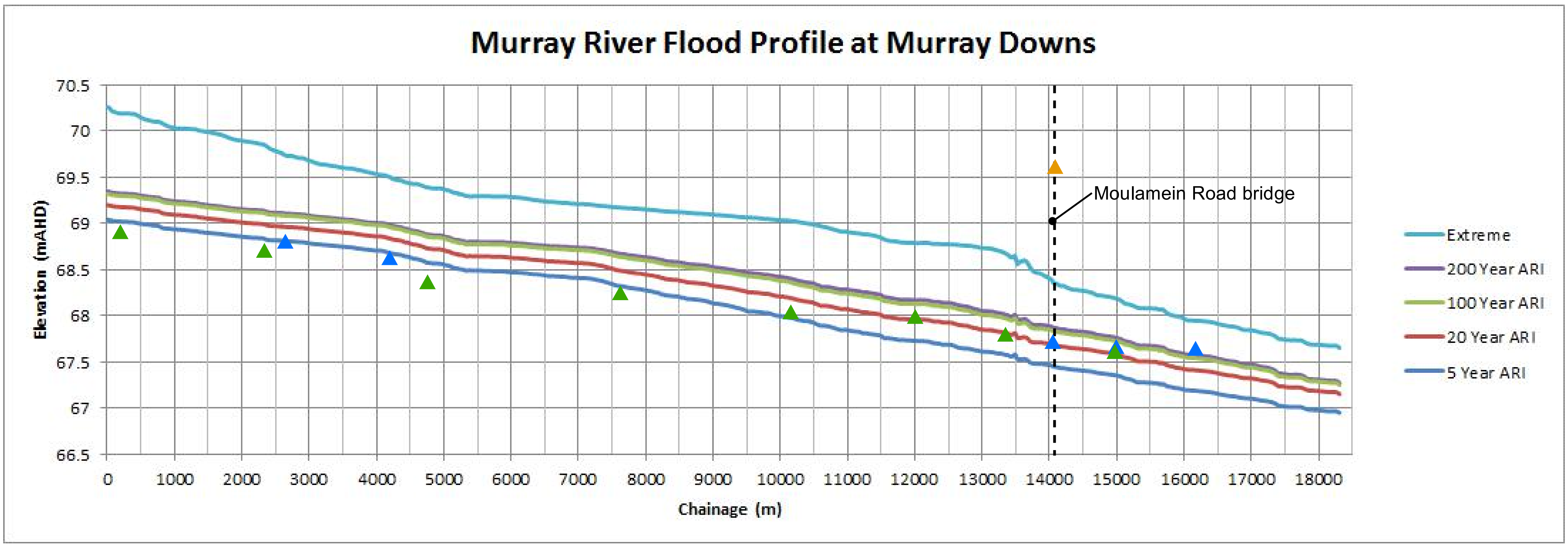


Data source: All flood data supplied by GHD, all Aerial background imagery supplied by Wakool Shire Council. Created by:sldouglas

# 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 54

N

GHD

WAKOOL SHIRE COUNCIL

Wakool Shire Council
Murray Downs Flood Study

Murray River
Flood Profile

Job Number 31-30143
Revision 0
Date 07 Oct 2014

Figure D1

G:\31\30143\GIS\Maps\Deliverables\Murray Downs\31_30143_WSC_Murray_Downs_FS_Figure_D1_Rev_0.mxd

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

# 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.

GHD

105 Hume Street
Wodonga VIC 3690 Australia PO Box 992
T: 61 2 6043 8700   F: 61 2 6043 8711   E: abxmail@ghd.com



G:\31\30143\WP\6932.docx

Document Status

| Rev No. | Author | Reviewer | | Approved for Issue | | |
|---|---|---|---|---|---|---|
| | | Name | Signature | Name | Signature | Date |
| A | T Clark | R Berg | | R Berg | | 9/5/2014 |
| B | T Clark | R Berg | | R Berg | | 17/6/2014 |
| 0 | T Clark | R Berg | | R Berg | | 7/10/2014 |

www.ghd.com