Greater Hume Shire Council

Walla Walla Flood Study, Floodplain Risk Management Study and Plan

Flood Study

Final Report

February 2017

Cover photograph: View east into town along the Walla West Road (Queen Street) during the October 2010 flood.

Executive Summary

The Walla Walla Flood Study, Floodplain Risk Management Study and Plan was commissioned by the Greater Hume Shire Council. Council is currently in the process of having floodplain risk management plans prepared for all of the larger towns within the Shire.

Walla Walla experiences flooding from a number of waterways and drains. Notable flooding occurred most recently in parts of Walla Walla in October 2010 and March 2012.

This report documents the Flood Study phase of the project. The next phase of the project (Floodplain Risk Management Study) will involve an assessment of flood mitigation options to reduce the future impacts of flooding. A Floodplain Risk Management Plan will then be prepared which presents the adopted measures.

The project is being 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 Walla Walla Floodplain Risk Management Committee. The Committee is meeting regularly during the project to review progress and provide direction for future activities.

Data Review and Community Consultation

The data review and community consultation activities are documented in Sections 3 and 4 of this report. There is no pluviometer data within the study area catchments or streamflow data for the study area waterways.

Flood data available includes some observed 2010 and 2012 flood levels and photographs of past flooding. There is very limited recorded data available for earlier floods. Anecdotal accounts however indicate that a flood in January 1974 was more severe than the more recent significant floods in 2010 and 2012.

A project community engagement guide and questionnaire was distributed to all residents of Walla Walla in March 2016 shortly after the commencement of the study providing an overview of the project, identifying the local community representatives on the Committee and requesting residents to contact Council if they are aware of any data or issues of relevance to the study.

A Community Flood Forum was held in April 2016 to provide residents with an opportunity to discuss the project with members of the Committee, Council officers and the consultant's project manager.

Flood Modelling - Hydrology and Hydraulics

The hydrology analysis activities are documented in Section 5 of this report. Peak design flow estimates were derived using a number of methods. The adopted peak design flows take into account the respective estimates, design flows adopted for recent nearby flood studies and the available observed flood levels.

The hydraulic modelling activities are documented in Sections 6 and 7 of the report.

Hydraulic modelling was carried out using the two dimensional TUFLOW model. The study area floodplain was represented using a 4 metre grid with key features better defined using breaklines. The terrain data source used was a 2013 LIDAR aerial survey obtained specifically for this study.

Design Flood Outputs

The modelling results for the 5, 10, 20, 50, 100, 200, 500 year ARI and the Probable Maximum Flood (PMF) are described in Section 7 of the report. Flood map outputs associated with the design flood 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 plans).

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

- There is a small amount of flow transferred from the Walla West Waterway to Petries Creek upstream of Walla Walla. Petries Creek does not influence flooding within Walla Walla.
- Flooding from the Walla West Waterway does not generally extend into developed areas at Walla Walla with the exception of the area immediately upstream of the railway line. Floodwaters are elevated on the south side of the railway due to the limited capacity of the existing bridge structure resulting in inundation of properties in this area.
- Most of the serious flooding problems at Walla Walla are due to flooding from the Queen Street Waterway. Floodwaters affect much of the intervening area between the Queen Street Drain and the railway line. The discharge capacity of the Queen Street Drain is equivalent to approximately a 5 year ARI event.
- Depths of flooding outside the waterways and drains at Walla Walla are generally less than 0.3 metre up to and including the 100 year ARI event. Consequently flooding conditions outside the waterway corridors are generally characteristic of Low Hazard (refer to Figures B1 and B2) and Flood Fringe (refer to Figures C1 and C2).
- All of the main roadways into and out of Walla Walla are subject to inundation (Lookout Road, Walla West Road, Walla Walla Road and the Jindera-Walla Walla Road). Most of the roadway flooding will be to depths of less than 0.5 metre in a 100 year ARI event and for durations not expected to exceed 3 hours.

Flood Damages

The flood damages assessment results are documented in Section 8 of this report. Flood damages at Walla Walla were estimated using the outputs from the hydraulic modelling. The damages estimates are based on a comparison of the modelled flood levels with building floor levels and flood damage data which accounts for direct property damages (e.g. contents damages, external damages and structural damages).

The principle outputs from the flood damage analysis are summarised as follows:

- There are 23 properties subject to above floor flooding in a 100 year ARI event. Twelve of these properties are residential, with the remaining eleven commercial or industrial. The average height of 100 year ARI above floor flooding for these 23 properties is 0.16 metre.
- In a PMF event, an estimated 65 properties are subject to above flood flooding.
- The average annual damage (AAD) for Walla Walla is $250,000 per annum.
- The estimated damage in a 100 year ARI event is $2.37 million.

Issues for Floodplain Risk Management Study

Issues to be assessed during the next stage of the project (Floodplain Risk Management Study) are described in Section 9 of this report. They include:

- The adequacy of the railway bridge structure at the Walla West Waterway on the north side of Queen Street.
- Flooding of the area on the south side of the railway affecting properties in Queen Street, Railway Street, Commercial Street and Market Street.
- Flooding of the roads providing access into and out of Walla Walla (Lookout Road, Walla West Road, Walla Walla Road, Jindera-Walla Walla Road).

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1. Introduction

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

The Walla Walla Flood Study, Floodplain Risk Management Study and Plan project is being undertaken to provide the Greater Hume Shire Council and other stakeholders with an up to date understanding of flooding conditions at Walla Walla. This will assist Council and other government agencies to make appropriate decisions in relation to future land use planning.

This Flood Study report 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 project is being undertaken in the following stages:

- Stage 1 – Data collection/assessment and initial community consultation. This stage encompassed the identification, acquisition and review of data available for the project, confirmation of any additional ground or waterway structure survey data to be obtained, and the initial community consultation activities.
- Stage 2A – Completion of modelling and flood damages assessment Part 1. This stage encompassed the hydrology assessment, the hydraulic model assembly, calibration and preliminary 100 year average recurrence interval ARI design flood modelling.
- Stage 2B - Completion of modelling and flood damages assessment Part 2. This stage consisted of the final hydraulic modelling of the range of required design events, the preparation of flood mapping and location specific flood output data at points of interest, and flood damage analysis.
- Stage 3 – draft Flood Study report, public exhibition of draft report and final Flood Study report. The draft report will document all of the Stage 1 and 2 investigations. The draft report will be placed on public exhibition. Any public submission received will then be taken into account as part of the Flood Study report finalisation process.
- Stage 4 – Floodplain risk management options assessment and community consultation. Options to reduce the impact of future floods will be assessed. This will take into account feedback from the community obtained during Stage 1 and any further feedback obtained during Stage 4.
- Stage 5 – Draft FRMS and FRMP reports. Draft reports will be prepared. The FRMS draft report will document all of the investigations and activities undertaken during Stage 4. It will provide the supporting information for the justification of the recommended mitigation options. The draft FRMP report will document the proposed floodplain risk management measures.

- Stage 6 – Public exhibition of the draft FRMS and FRMP reports. The draft documents will be placed on public exhibition. Submissions received by the end of the public exhibition period will be taken into account when finalising the FRMP.

The project is being overseen by Council's Floodplain Risk Management Committee. The Committee met on four occasions prior to the completion of Stage 3 (Flood Study).

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.

2. Study Area Description

2.1 Walla Walla

Walla Walla is located 30 km north of Albury (refer to Figure 1). The town was first established in 1869 when settlers of German extraction moved to the town site. The town was initially named Ebenezer and later changed to Walla Walla.

The 2011 census records Walla Walla to have a population of 544. The town area is elongated in shape in the north-south direction, with residential, commercial and industrial land use dispersed along Commercial Street.

The major industries in Walla include silo manufacturing, shed manufacturing, a winery and grain depot.

Waterways and indicative catchment boundaries are shown on Figure 2. The catchments are predominantly cleared agricultural land, the only exceptions being some woodland areas on the higher slopes.

Other notable local features include:

- Corowa-Culcairn Railway. The railway was opened in 1892 and operated for almost 100 years before being decommissioned in 1991. The railway line remains intact including the waterway structures (bridges) at Petries Creek and the unnamed waterway, although some of these structures are not in good condition.
- Gum Swamp. The waterways at Walla Walla all discharge to this 400 hectare wetland located on the north side of Walla Walla.

2.2 Catchment and Waterway Description

2.2.1 Petries Creek

Petries Creek has a catchment area of 40 km^2 at the Corow-Culcairn Railway. The creek has an incised channel, typically 1.5 to 2 metres deep. The headwaters of the Petries Creek catchment are located 10 km south of Walla Walla as shown on Figure 2.

Waterway structures are located at the Railway, Walla West Road and Lookout Road.

Petries Creek discharges into Gum Swamp at Lookout Road on the north side of Walla Walla. The catchment area at Lookout Road is 47 km^2. Outflows from Gum Swamp discharge westwards to Billabong Creek.

2.2.2 Walla West Waterway

The Walla West Waterway has a catchment area of 18 km^2 at Lookout Road. The waterway generally has limited channel incision and is more characteristic of a depression. The headwaters of this catchment are located 6 km south east of Walla Walla as shown on Figure 2.

Waterway structures are located at the Walla-Jindera Road, Railway, Cemetery Road, Lookout Road and Cummings Road.

The Walla West Waterway discharges into Gum Swamp at Cummings Road on the north side of Walla Walla. The catchment area at Cummings Road is 27 km^2.

The Walla West Waterway and Petries Creek are quite close at one point on the south side of Walla Walla (refer to Figure 2). This study defines what flow exchange occurs between the two waterways at this site.

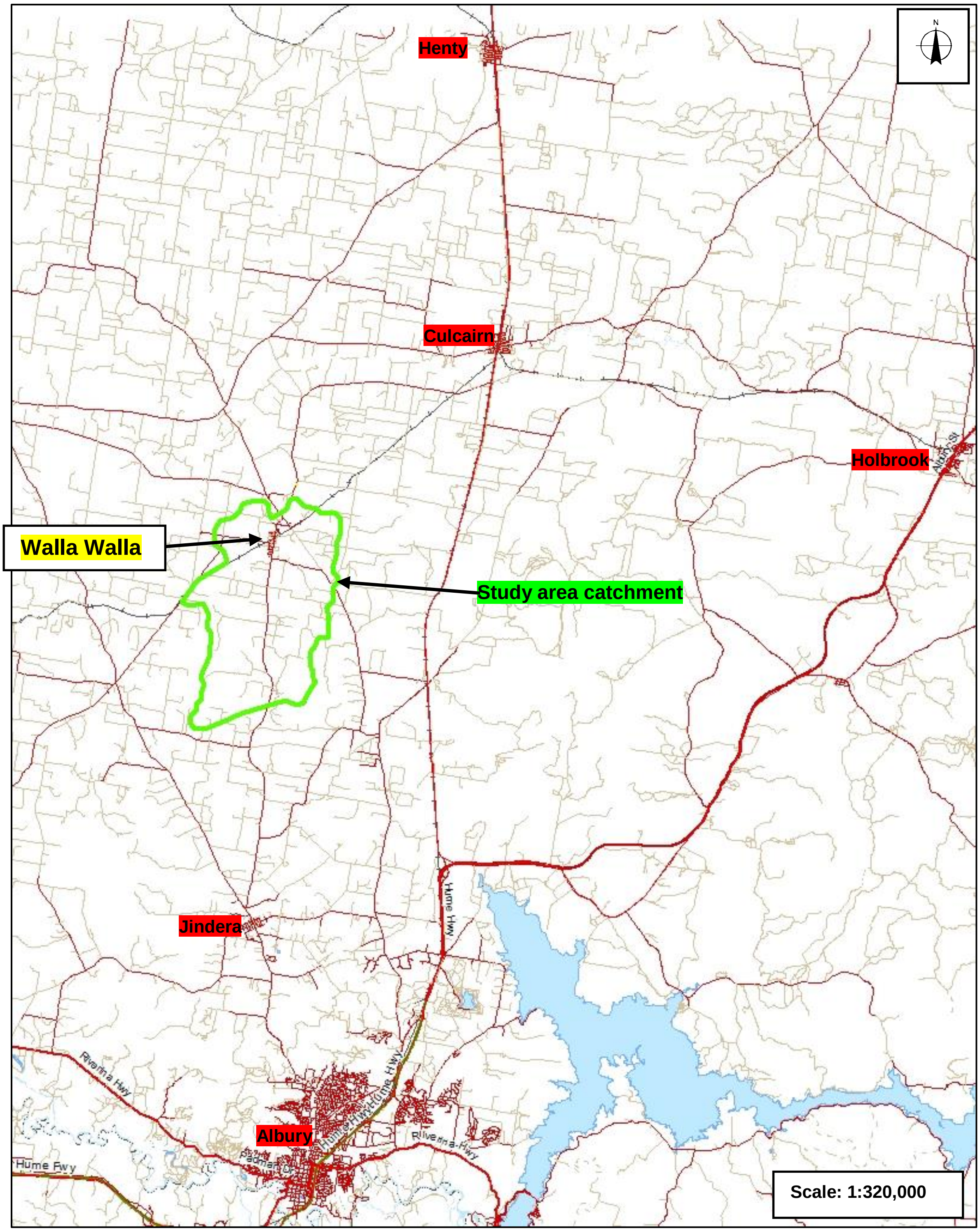

Figure 1 Walla Walla Locality Plan

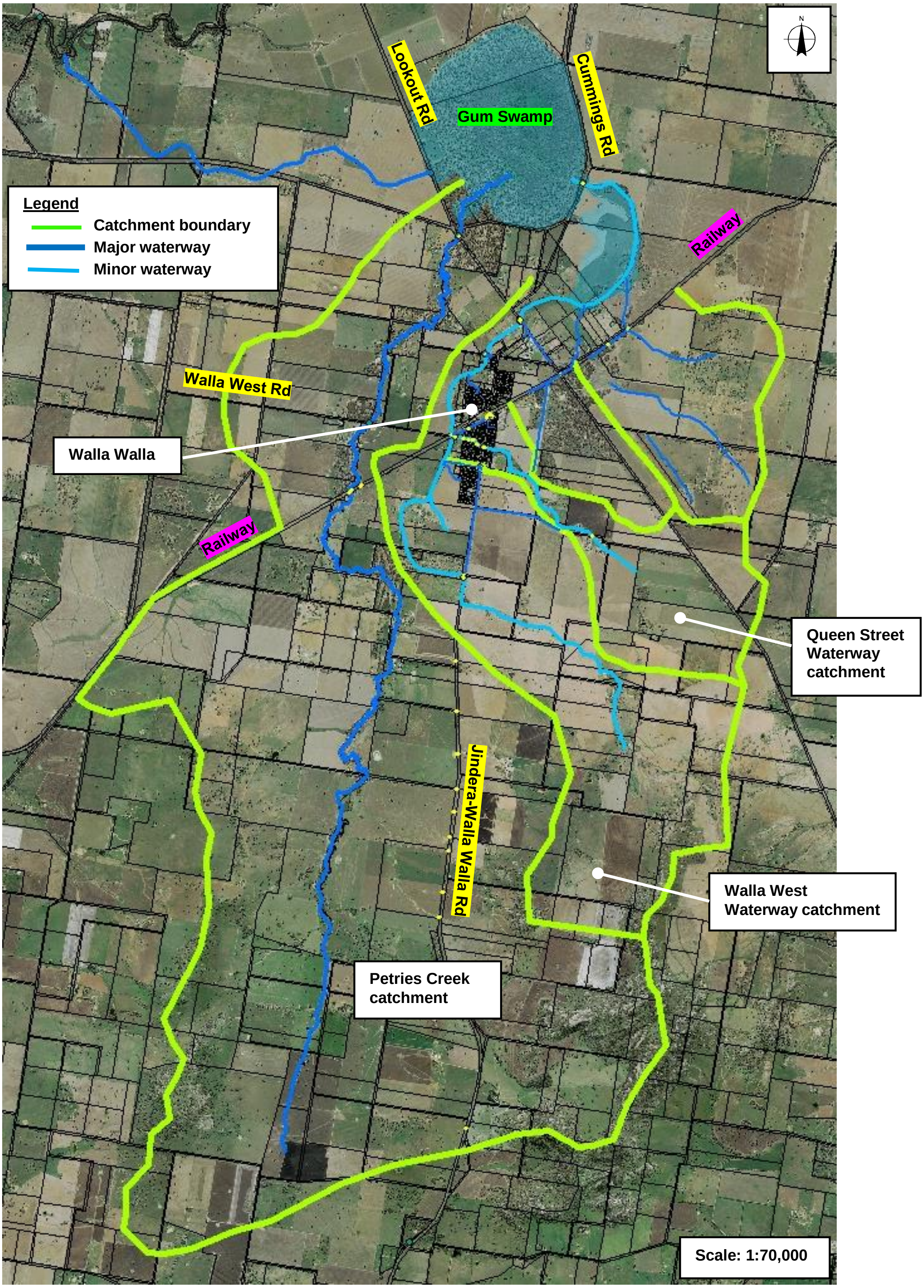

Figure 2 Catchment Plan

2.2.3 Queen Street Drain

The Queen Street Waterway has a catchment area of 4 km^2 on the eastern fringe of Walla Walla (refer to Figures 2 and 3). The waterway is a natural depression with limited channel incision.

A drain has been constructed along the indicative waterway route through Walla Walla. This drain is referred to as the Queen Street Drain by this report. There is no incised waterway at the upstream limit of the town drain.

There are seven culvert structures located along the Queen Street Drain route within the town. The drain on the upstream side of Commercial Street is concrete lined. Downstream of Commercial Street, the drain is unlined.

2.2.4 Other Local Drains

Other notable local drains are the (refer to Figure 3):

- Edward Street Drain. This drain discharges to the Walla West Waterway. Inflows to the drain are from the roadside drains discharging northwards down the Commercial Street to the Edward Street intersection. There are three culvert structures present along the drain route.
- Air Strip Drain. Runoff east of the air strip discharges to culvert crossings under the Morgans Road, Railway and Chinatown Lane. This drain has no incision, with flows confined by the adjoining railway embankment. There are three culvert structures present along the drain route.
- Railway Drain. This drain is located on the south side of the Railway line between Commercial Street and the Walla West Waterway. This drain is an excavated drain which receives inflows from a pipe drain at the Commercial Street end of the drain. There is one access crossing culvert structure present along the drain route.

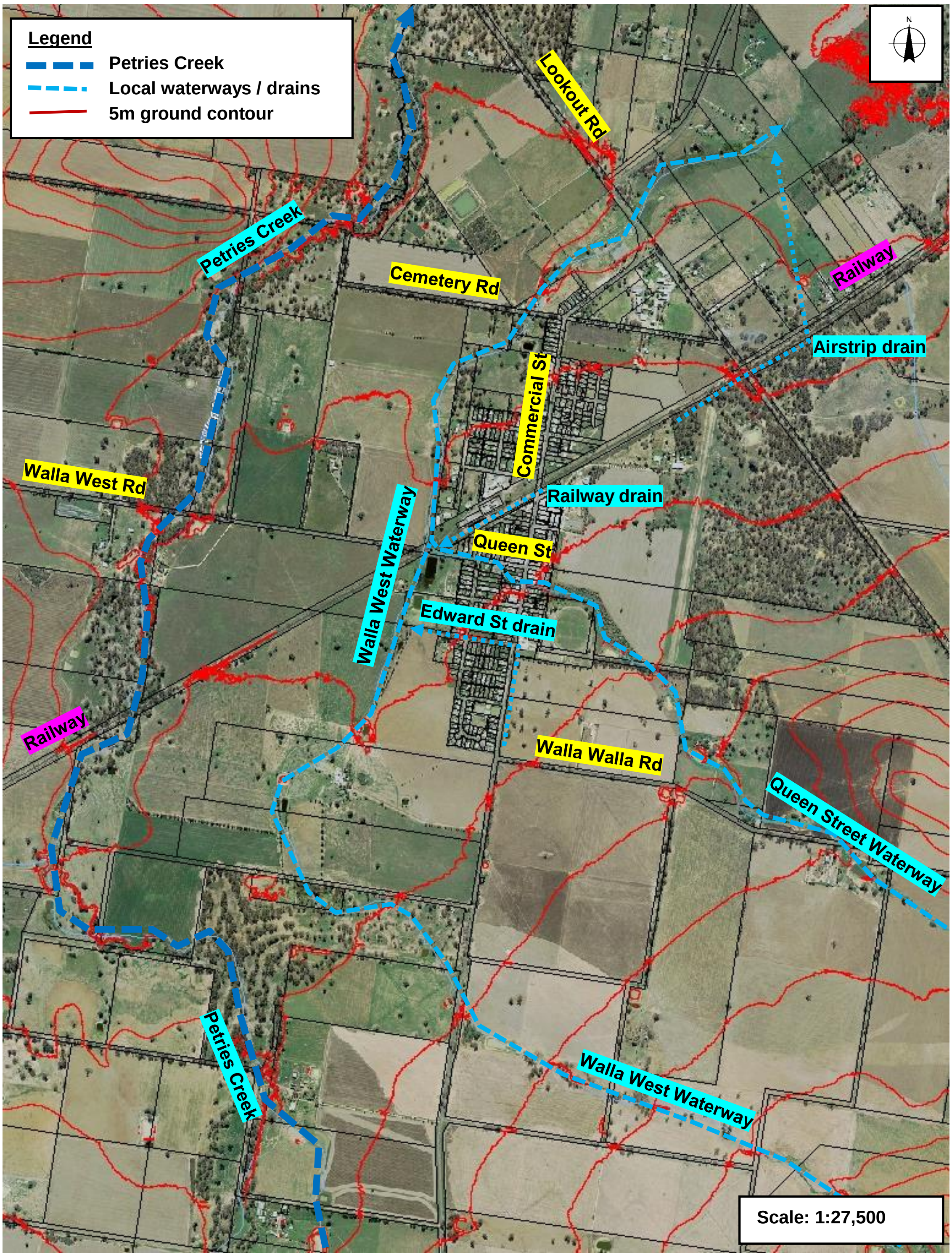

Figure 3 Local Waterways Plan

3. Community Consultation

3.1 Floodplain Risk Management Committee

Council has established a Floodplain Risk Management Committee (FRMC) to oversee the Walla Walla project. The ten person Committee consists of the following members:

- Three local community members.
- Two Council staff representatives.
- One Councillor.
- Single representatives from OEH, SES, Department of Planning and Infrastructure and the BOM.

The inception Committee meeting took place in February 2016. The Committee has since met during May and August 2016.

At the inception Committee meeting, it was decided that a Flyer (Community Engagement Guide (CEG)) and Questionnaire would be distributed to all residents of Walla Walla and a Flood Forum open to the public would be held.

3.2 Community Engagement Guide and Questionnaire

The CEG was prepared following the inception Committee meeting. The CEG was distributed to all residents of Walla Walla in March 2016.

The CEG provided residents with project information concerning:

- The reasons why the Flood Study, Floodplain Risk Management Study and Plan is being undertaken for Walla Walla.
- The role of the Committee and the local community members on the Committee.
- The names of the Councillors and the community representative on the Committee.
- A request that residents complete and return the Questionnaire attached to the Newsletter.
- Contacts details for both Council and GHD.
- Details in regards to the then upcoming Community Forum held on the 5 April 2016.

The questionnaire sought to obtain some basic flood data information and obtain resident views on what they see as worthwhile in terms of mitigation measures. The questions posed included:

- Resident details (contact details, duration at address).
- Personal observations and impacts in past floods experienced.
- Views on potential flood mitigation options.

A copy of the CEG and Questionnaire is included in Appendix E.

3.3 Questionnaire Responses

Nine completed questionnaire responses were received.

Data supplied and issues raised by the questionnaire responses are summarised as follows:

- Flood photographs supplied by multiple respondents with their completed questionnaire.
- Instances of past above floor flooding at two locations.
- Roadway access into and out of Walla Walla is affected by flooding (i.e. Walla Walla Road, Lookout Road, Walla West Road and Jindera-Walla Walla Road).
- The most common flood mitigation action was for 'improved waterways and waterway structures' (eight of the nine responses) followed by improved development controls (three of the nine responses).

3.4 Community Forum

A Community Forum was held at Walla Walla on the 5 April 2016. Residents had been notified in regards to the Forum within the CEG distributed on the 24 March 2016.

The Forum provided an opportunity for residents to meet with Council's project officer, GHD's project manager and the community representatives on the FRMC to either pass on any data held, discuss aspects of the project, or to convey any specific concerns in relation to flooding impacts.

Three community members attended the Forum (Rupert Paech, Herb Simpfendorfer and Elwyn Kotzur). They passed on their observations during recent flood events, how these floods had impacted on their properties and any other knowledge held relevant to the project. Notable issues raised by the attendees included:

- Council considered a diversion of high flows from the Queen Street Waterway to the Walla West Waterway on the south side of the town in the 1970s. The diversion followed flooding of the Queen Street area during large floods in 1973 / 1974. Ultimately the diversion did not proceed due to a range of factors (e.g. cost).
- Photographs supplied of flooding at Walla Walla in the 1931 flood. This flood is known to have been the largest upper Billabong Creek flood on record.

3.5 Resident Interviews

Interviews with a number of residents were held in the weeks after the Community Forum. Residents selected for informal interviews were as a result of referrals by others or follow-ups in response to questionnaires received.

Notable issues raised during discussions with residents include:

- Waterway corridor adjoining to the sportsground has been revegetated which may have resulted in altered flow conditions in recent floods (e.g. March 2012) possibly leading to more flows discharging northwards to the Railway Street area.
- Significant flooding occurred in 1973 / 1974. Floodwater from the Queen Street waterway affects the area in the vicinity of the Queen Street / Commercial Street intersection.
- Properties on the north side of Queen Street either side of Market Street experienced significant flooding in October 2010. Residents have indicated flooding was exacerbated by blockage of the Queen Street Drain due to the fence across the drain on the south side Queen Street road reserve boundary.

- In flood events, a significant amount of floodwater discharges northwards down the roadside drains in Commercial Street, north of the Walla Walla Road. Significant overflows occur westwards down Scholz Street, Herman Street and laneways. No past instances of above floor flooding have been identified for this area.
- Floodwater inundates a large area on the upstream (south) side of Cemetery Road. No past instances of above floor flooding have been identified for this area.
- Inundation occurs in Klemke Avenue during rainfall events. Impacts on adjoining properties are thought to be more aligned with nuisance level flooding.
- Floodwaters have caused temporary road closures at Lookout Road (Walla West Waterway), Walla West Road (Walla West Waterway and Queen Street Drain), Walla Walla Road (Queen Street Waterway) and the Jindera-Walla Walla Road (Walla West Waterway).

3.6 Public Exhibition of the Draft Flood Study Report

Council adopted the draft Walla Walla Flood Study report at the November 2016 Council meeting for the purpose of placing the draft report on public exhibition.

The draft Flood Study report was subsequently placed on public exhibition for a four week period which finished on the 23 December 2016. A Community Forum was held at Walla Walla on the 13 December 2016 in support of the public exhibition process.

One public submission was received by Council. A copy of this submission is included in Appendix F. In response to the submission received, some additional explanatory content was added to the relevant sections of the report (Sections 4.3.4 and 6.6.7).

4. Data Review

4.1 Previous Reports

No previous detailed flood studies have been undertaken for Walla Walla.

The following reports have documented flooding conditions and impacts at Walla Walla in the recent October 2010 and March 2012 floods:

- Flood Intelligence Collection and Review for Towns and Villages in the Murray and Murrumbidgee Regions following the October 2010 Flood (Bewsher Consulting, 2012).
- Flood Intelligence Collection and Review for 24 Towns and Villages in the Murray and Murrumbidgee Regions following the March 2012 Flood (Bewsher Consulting, 2013).

4.2 Hydrologic Data

4.2.1 Streamflow Data

There is no streamflow data for the waterways in the vicinity of Walla Walla. There are no current or discontinued gauging stations located on Petries Creek.

4.2.2 Recorded Rainfall Data

The nearest rainfall pluvio station to Walla Walla is located at the Bowna Creek streamflow gauging station at Yambla, located 18 km south east of the township and 9 km outside the Petries Creek catchment. The Yambla station is not therefore a reliable indicator of rainfall conditions within the relatively small catchment draining to Walla Walla.

An official BOM daily rainfall station is located at the Walla Walla Post Office (Station Number 074117). This station commenced operation in 1925. The highest monthly 24 hour totals recorded at the Walla Walla Post Office site are given in Table 1. There may however have been higher 24 hour totals given that the gauge is occasionally not read every 24 hours, in which instances a total over the lapsing period is recorded.

4.2.3 Design Rainfall Intensity-Frequency-Duration Data

Design rainfall intensity-frequency-duration (IFD) data for Walla Walla is given in Table 2. The data is derived from the 1987 edition of Australian Rainfall and Runoff.

The design rainfall data and temporal pattern for the probable maximum precipitation (PMP) used to determine the probable maximum flood (PMF) used for this study is based on the Generalised Short Duration Method (GSDM) for Australia (BOM, 2003).

Table 1 Highest Daily Recorded Rainfalls

Month	Highest 24 Hour Rainfall Recorded period 1925 to 2015	
	Year Recorded	Total (mm)
January	1925	91.4
February	1939	99.8
March	2010	83.0
April	1992	108.0
May	1942	101.6
June	1936	53.3
July	2003	43.2
August	1983	60.8
September	1963	49.0
October	1935	114.6
November	2012	127.0
December	1961	78.2

Note:

1. Above figures excludes possible higher daily totals where the gauge was not read every 24 hours which occurs from time to time.

Table 2 Design Rainfall Data

Storm Duration (hours)	Design Rainfall (mm)			
	1 year ARI	5 year ARI	20 year ARI	100 year ARI
0.5	9	17	23	33
1.0	11	20	28	39
2.0	15	26	36	50
3.0	19	33	45	62
6.0	21	37	50	68
12.0	27	45	60	80
24.0	33	55	72	96
48.0	42	68	88	116
72.0	51	82	106	137

Note:

1. The above design rainfall figures are based on the 1987 edition of Australian Rainfall and Runoff, with no areal reductions applied.

4.3 Past Floods at Walla Walla

4.3.1 Available Records

There are no streamflow data records for the waterways at Walla Walla which would allow for a ranking of past floods.

Two relatively recent floods occurred in October 2010 and March 2012 which anecdotal accounts suggest are the most severe Petries Creek floods to have occurred since 1973 / 1974.

4.3.2 October 2010 Flood

The October 2010 event consisted of two distinct rainfall bursts. Recorded totals at the Walla Walla Post Office site are as follows (to 9 am on the days quoted):

- 13 October 2010 – 36 mm
- 14 October 2010 – 26 mm
- 15 October 2010 – 32 mm
- 16 October 2010 – 43 mm

A description of flooding conditions is provided in the SES Flood Intelligence report (Bewsher Consulting, 2012). Notable details in regards to the October 2010 flood event are:

- Resident accounts indicate that flood levels rose quickly, peaking at 1.30 to 2.30 pm on Friday 15 October.
- Flooding was evident in the vicinity of the drain on the south side of Queen Street.
- Flooding in the Queen Street area is thought to have been exacerbated by blockages across the drain route (e.g. where the drain crosses the boundary security fence on the north side of the Queen Street road reserve at a car yard – refer to Figure 4).
- No houses able to be identified as having been subject to above floor flooding, notwithstanding that the Border Mail reported that 15 homes in the town were affected by flooding.

4.3.3 March 2012 Flood

The March 2012 flood was a complex event, with three distinct rainfall bursts within the week long event. Recorded rainfalls at the Walla Walla Post Office and Culcairn Bowling Club sites are as follows (to 9 am on the days quoted):

- Seven day total to 4 March 2012 – 190 mm
- Four day total to 4 March 2012 – 107 mm
- One day total to 4 March 2012 – 79 mm

The flood inducing rainfall occurred on the afternoon and evening of Saturday 3 March 2012. This rainfall fell on what would have been a semi saturated catchment as a result of the preceding rainfall.

October 2010 flood – Queen Street drain

Queen Street drain at same location as the above photograph

Figure 4 Queen Street Drain

A description of flooding conditions at Walla Walla during the March 2012 flood is provided in the SES Flood Intelligence report (Bewsher Consulting, 2013). Notable details in regards to the March 2012 flood event are:

- Peak flood levels were slightly lower than those recorded in October 2010.
- Similar to October 2010, flooding was notable in the Queen Street area as a result of rural runoff from the catchment draining to the north side of the Sportsground.
- Sand bags requested by 121 Commercial Street at 8.40 am on Sunday 4 March 2012 in response to stormwater being observed to be seeping through bricks in the front room.
- No houses confirmed as subject to above floor flooding.
- Floodwater confirmed to be across the Walla West Road at the Petries Creek crossing.

4.3.4 Other Historical Floods

Flooding at Walla Walla is reported to have occurred in the following years:

- June / July 1931. Photographs of 1931 flooding in the vicinity of the Queen Street / Commercial Street intersection were provided by a local resident (refer to Figure 5). The 1931 flood is the largest flood on record for Billabong Creek at Walbundrie, however this does not necessarily apply to the much smaller catchment waterways at Walla Walla.
- 1973 / 1974. A major flood was recorded for Bowna Creek in January 1974. The Bowna Creek catchment adjoins the Petries Creek catchment. The Bowna Creek flood peak occurred on the evening of 10 January 1974. This followed a significant runoff event seven days earlier. A total of 67 mm was recorded at the Walla Walla Post Office site for the 24 hours to 9 am on the 11 January 1974. Anecdotal accounts suggest that flood levels in the January 1974 flood at Walla Walla were higher than flood levels in the more recent 2010 and 2012 flood events. Specific locations nominated where flood levels are reported to have been higher in 1974 are 56-60 Commercial Street (Kotzur silo factory site) and 64 Commercial Street (Landmark building). Few recorded details are however available in relation to flooding conditions in 1973 / 1974 at Walla Walla.
- July 1990. Greater Hume Shire Council supplied photographs showing minor flooding at Walla Walla on the 18 July 1990. The photographs show drains running full or close to full across town. A total of 26 mm of rainfall was recorded on this date.
- July 1995. Greater Hume Shire Council supplied a number of photographs of flooding at Walla Walla on the 17 July 1995. The photographs show Walla West Waterway road overflows at Lookout Road and Queen Street, the Edward Street Drain running full, Petries Creek overflows at Walla West Road and the Commercial Street east side drain running full on the south side approach to town. A total of 38 mm of rainfall was recorded on this date.
- September 2005. A total of 48 mm of rainfall was recorded at the Walla Walla Post Office site for the 24 hours to 9 am on the 29 September 2005. This event also caused moderate flooding at Jindera.
- February 2011. A total of 33 mm of rainfall was recorded at the Walla Walla Post Office site for the 24 hours to 9 am on the 12 February 2011. This followed quite large rainfall totals approximately one week earlier. This event also caused moderate flooding at Jindera.

Figure 5 1931 Flood Photographs

4.4 Flood Photographs

Flood photographs at Walla Walla were sourced as follows:

- 1931 Flood – supplied by Rupert Paech (Flood Forum).
- July 1990 flood – supplied by Greater Hume Shire Council.
- July 1995 flood – supplied by Greater Hume Shire Council.
- October 2010 Flood –supplied by Phillip Nadebaum with his questionnaire response.
- January 2011 and November 2012 Floods – supplied by Andrew Kotzur with his questionnaire response.

4.5 Observed Flood Levels

Peak flood levels have not been accurately recorded in past floods at Walla Walla.

A number of different sources provided approximate observed flood levels. These flood levels are for the recent 2010 or 2012 floods. The sources consisted of the two SES Flood Intelligence reports for the 2010 and 2012 floods and interviews with local residents.

The observed flood levels are listed in Table 3.

Table 3 Observed Flood Levels

Mark No.	Flood Event	Location	Level (m AHD)	Source	Description
1	Oct 2010	30m downstream of Cemetery Road	205.8	GHD interview with resident	Walla West Waterway - next to shed doorway entrance – reliability moderate
2	Oct 2010	20m downstream of Cemetery Road	205.8	GHD interview with resident	Walla West Waterway – next to circular yard post – reliability moderate
3	Oct 2010	20m downstream of Cemetery Road	205.7	GHD interview with resident	Walla West Waterway – next to power pole – reliability moderate
4	Oct 2010	80 m upstream of Cemetery Road	206.5	GHD interview with resident	Walla West Waterway – approx. ground extent – reliability moderate
5	Oct 2010	Western end of Wenke Street	208.9	GHD interview with resident	Walla West Waterway – approx. ground extent – reliability low
6	Oct 2010	21 Stitt Street	210.0	GHD interview with resident	Walla West Waterway – approx. ground extent – reliability moderate
7	Oct 2010	6 Queen St	212.4	GHD interview with resident	Walla West Waterway - 0.01 m below house floor level – moderate reliability
8	Oct 2010	8 Queen St	212.45	SES Flood Intelligence report (Bewsher, 2012)	0.08 m below house floor level - moderate reliability
9	Oct 2010	14 Queen St	213.0	GHD interview with resident	0.02 m below house floor level – low reliability
10	2010 or 2012	80 Commercial St	214.45	GHD interview with shop occupant	At base of step into shop – moderate reliability
11	2012	Corner Commercial & Railway Streets	213.8	GHD interview with shop occupant and separate questionnaire response	0.1 m above the Landmark building floor level at entry point – low reliability
12	Oct 2010	119 Commercial St	218.4	SES Flood Intelligence report (Bewsher, 2012).	0.3 m above ground surface - low reliability
13	2010 or 2012	123/125 Commercial St	218.85	Photographs supply by resident	0.1 m above ground surface – low reliability

Note:

1. Mark locations are shown on Figure 11.

4.6 Ground Survey Data

A LiDAR survey of the Walla Walla township area and the surroundings was completed in July 2013 by NSW Land and Property Information.

The aerial survey was undertaken specifically to provide a reliable digital elevation model of the ground surface for this flood study project. The vertical accuracy of the data is 0.3 metres at two sigma (95% confidence).

The extent of the LiDAR survey data relative to the area selected for hydraulic modelling and the catchment boundary is shown on Figure 6.

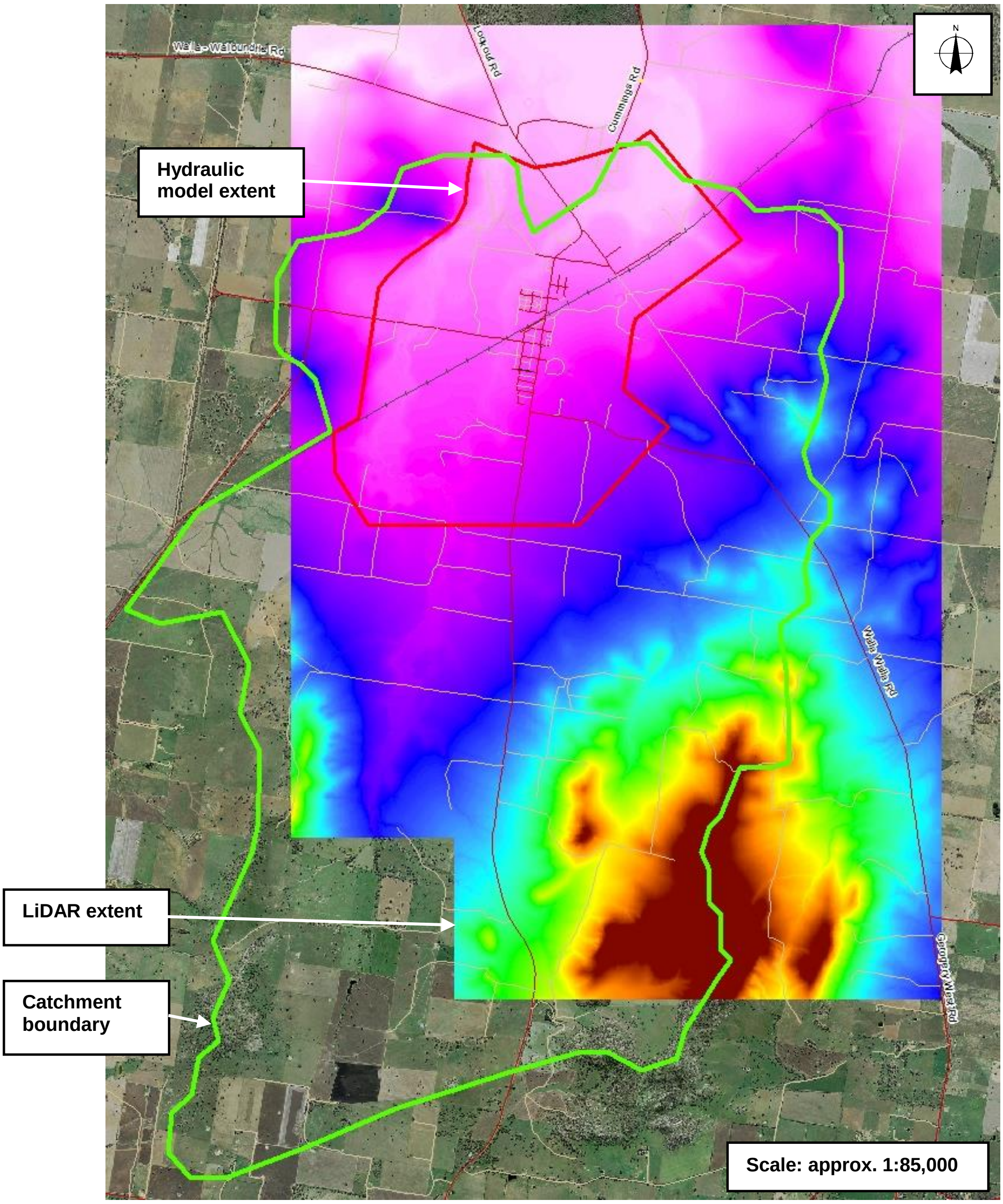

Figure 6 Extent of LiDAR Data Coverage

4.7 Waterway Structures

The waterway structures located within the hydraulic model area are listed in Table 4 and shown on Figure 7.

All of the culvert structures were inspected and measured up in the field (i.e. size, length, estimated height from obvert to road crown / overflow).

The invert level of the culvert structures defined within the hydraulic model is based on the LiDAR derived road crown surface level at the culverts (from the 1 metre DEM) and the field assessed height from the culvert invert level to the road crown level.

Waterway structures are described as follows:

- **Petries Creek.** There are three Petries Creek waterway structures in the vicinity of the study area. The two Petries Creek railway structures are large bridges. The Walla West Road culvert structure has sufficient capacity to discharge minor flood flows only. Large flood flows are discharged over a 300 metres causeway section of the road.
- **Walla West Waterway.** There are five waterway structures along the Walla West Waterway route. These are all road culvert crossings with the exception of a bridge structure at the Railway. There are two culvert structures located in close proximity under the Jindera-Walla Walla Road. These culverts discharge into an excavated drain which conveys runoff westwards to a large farm dam.
- **Queen Street Waterway / Drain.** The Queen Street Waterway which enters the town on the north side of the sportsground has seven culvert structures along its route including five road crossings (Commercial Street, Queen Street, Market Street and two laneways) and two driveways.
- **Other drains.** All of the waterway structures along the Edward Street Drain and Air Strip Drain are culverts.

Table 4 Waterway Structures

No.	Road / Rail	Waterway	Structure Details	Waterway area (m^2)
P1	Corowa Culcairn Railway	Petries Creek	Main bridge - 59 m overall span	77
P2	Corowa Culcairn Railway	Petries Creek	Overbank bridge - 30 m overall span	35
P3	Walla West Road	Petries Creek	1 No. 2.5 x 1.5 m BC	3.8
U1	Walla Walla Jindera Road	Unnamed creek	Northern most culvert – 4 No. 1.2 x 0.9 m BC	4.3
U2	Walla Walla Jindera Road	Unnamed creek	Southern most culvert – 1 No. 2.4 x 0.6 m BC	1.4
U3	Corowa Culcairn Railway	Unnamed creek	Bridge – 10 m overall span	13
U4	Walla Cemetery Rd	Unnamed creek	3 No. 2.4 x 1.2 m BC	12
U5	Lookout Road	Unnamed creek	4 No. 0.9 x 0.45 m BC	1.6
Q1	Commercial Street – footbridge	Queen St Drain	1 No. 3.6 x 0.75 m opening	2.7
Q2	Commercial Street – road culvert	Queen St Drain	1 No. 3.6 x 0.75 m opening	2.7
Q3	Unnamed laneway 1	Queen St Drain	2 No. 1.5 x 0.75 m BC	2.3
Q4	Queen St - Driveway 1	Queen St Drain	2 No. 1.5 x 0.65 m BC	2.0
Q5	Queen St – Driveway 2	Queen St Drain	2 No. 1.5 x 0.8 m BC	2.4
Q6	Queens St at Market St crossing	Queen St Drain	2 No. 1.5 x 0.8 m BC	2.4
Q7	Queen St – Driveway 3	Queen St Drain	2 No. 1.2 x 0.6 m BC	1.4
Q8	Queen St	Queen St Drain	1 No. 0.9 x 0.3 m BC	0.3
E1	Commercial St - Driveway	Edward St Drain	1 No. 2.1 x 0.6 m BC	1.3
E2	Commercial St	Edward St Drain	2 No. 1.2 x 0.45 m BC	1.1
E3	Unnamed Laneway	Edward St Drain	2 No. 1.2 x 0.45 m BC	1.1
E4	Market Street	Edward St Drain	2 No. 1.2 x 0.45 m BC	1.1
A1	Morgans Road	Air Strip Drain	2 No. 0.45 m dia.	0.3
A2	Corowa Culcairn Railway	Air Strip Drain	4 No. 1.2 x 0.8 m BC	3.8
A3	Chinatown Lane	Air Strip Drain	2 No. 0.375 m dia.	0.2
T1	Corowa Culcairn Railway	Unnamed depression	Bridge – 23 m overall span	47

Note: The above structures are shown on Figure 7.

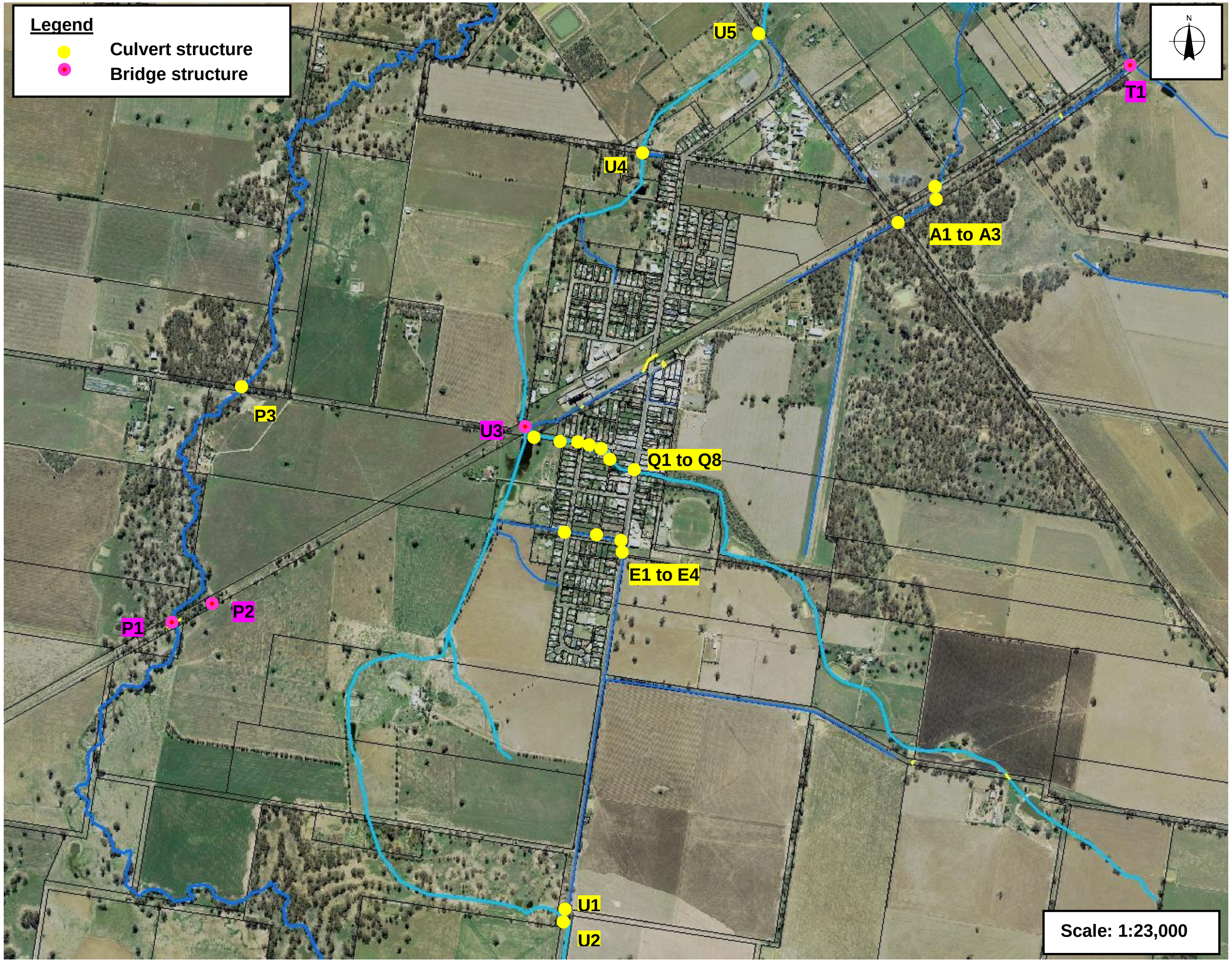

Figure 7 Waterway Structure Locations

5. Hydrology

5.1 Approach

The catchments draining to Walla Walla are relatively small (refer to Figures 1 and 2). The largest catchment is that of Petries Creek which has a catchment area of 40 km^2 at the Corowa-Culcairn Railway. The Walla West Waterway has a catchment area of 18 km^2 at Lookout Road.

There are no streamflow gauges or rainfall pluviometers located within the study area catchments. Under these circumstances:

- Flood frequency analysis as a method of estimating design flows is not possible.
- Calibration of a rainfall runoff model using recorded rainfall and streamflow data is not possible.

Observed flood level data is limited to the recent October 2010 and March 2012 floods. A landholder on Petries Creek just outside Walla Walla has indicated that the 2010 and 2012 floods peaked at around the same level and are the highest Petries Creek flood levels experienced since he first occupied the property in 1979.

Given the limited available data, a three stage approach was used for the hydrologic / hydraulic joint 'calibration' process. The first stage involved the identification of the peak 100 year ARI design flows. This was done as follows:

- Estimates derived using the Regional Flood Frequency Estimation (RFFE) method.
- Estimates derived using the Probabilistic Rational method.
- Estimates derived using a catchment area dependent formula based on analysis of estimated 100 year ARI peak flows for catchments within the Great Dividing Range.
- Adoption of peak 100 year ARI design flows taking into account the above estimates and a comparison with estimates adopted recently at Jindera and Henty.

The second stage of the process involved generating design event hydrographs for export into the hydraulic model. The XP-RAFTS model was used for this purpose. The XP-RAFTS model was calibrated to match the adopted peak 100 year ARI design flows.

The third stage of the process involved hydraulic (TUFLOW) modelling using the exported XP-RAFTS hydrographs. This involved some minor adjustments to the hydrologic model such that the TUFLOW modelled peak 100 year ARI flows best matched the adopted 100 year ARI design flows. The modelled 5 and 100 year ARI flood levels were also compared with the available 2010 and 2012 observed flood levels in order to confirm the modelled flood levels are of the approximate expected height.

5.2 Peak Design Flow Estimates

The first stage of the joint hydrologic / hydraulic modelling process involved the estimation of peak 100 year ARI flows for the study area waterways at Walla Walla.

Peak design flows were estimated using the:

- The (RFFE) method. This method was developed as part of Australian Rainfall and Runoff Project 5 (IEAust, 2015). The method was developed using regression analysis undertaken for all available gauged streamflow data.

- Probabilistic Rational method. This method is detailed in Australian Rainfall and Runoff (IEAust, 2001). The application of the Rational method within the area north of Albury is expected to provide a lower bound estimate for the 100 year ARI peak flow.
- Catchment area based formula which was derived from the estimated peak 100 year ARI flows for 70 catchments located within and around the Great Dividing Range (GDR) in Victoria (4.67 x Area $^{0.763}$).

The above three estimation methods were used to identify the peak 100 year ARI design flows for Petries Creek, the Walla West Waterway and the Queen Street Waterway. The results are given in Table 5. The estimates peak flows have the following characteristics:

- RFFE estimates are between 57 to 75% higher than the Rational method lower bound estimates.
- RFFE estimates are up to 15% lower than the Victorian GDR formula estimates.

The RFFE estimates are similar to the estimates adopted for Jindera and Henty as part of recently completed flood studies at these towns.

The Jindera study (GHD, 2015) adopts a peak 100 year ARI flow of 80 m^3/s for Four Mile Creek (catchment area 50 km^2). The corresponding RFFE estimate is 81 m^3/s.

The Henty study (WMAwater, 2013) adopts a peak 100 year ARI flow of 138 m^3/s for Buckargingah Creek (catchment area 85 km^2). The corresponding RFFE estimate is 135 m^3/s.

Given the above, the RFFE estimates were adopted as the preliminary peak 100 year ARI design flows for the waterways at Walla Walla, subject to the outcome of the preliminary hydraulic modelling assessment.

Table 5 Peak Design Flows

Waterway and location	Catchment area (km^2)	Peak 5 and 100 year ARI flow estimate (m^3/s)				
		RFFE method		Rational method		Victorian GDR method
		5 yr	100 yr	5 yr	100 yr	100 yr
Petries Creek at old golf course site	34.2	19	61	11	36	69
Petries Creek upstream of Lookout Rd	46.7	24	75	14	46	88
Walla West Waterway upstream Jindera Rd	8.3	7	22	4	14	23
Walla West Waterway at Railway	16.5	11	36	6	21	40
Walla West Waterway at TUFLOW boundary	27.0	16	51	9	31	58
Queen Street Waterway at sportsground	4.3	4	14	2	8	14

5.3 XP-RAFTS Model

The second stage of the joint hydrologic / hydraulic modelling process involved the estimation of 5 and 100 year ARI design event hydrographs for input into the hydraulic model. The use of hydrographs rather than steady state peak flows is necessary to allow for floodplain storage attenuation effects to be taken into account, relative timing differences between flows in the waterways to be taken into account and flooding duration characteristics to be assessed.

XP-RAFTS is a hydrologic model which has been widely used on Australian catchments since the late 1980s. Similar to most hydrologic models, the total catchment area is split into multiple subcatchments based on watershed boundaries. Data required for each subcatchment includes the catchment area, slope, percentage of impervious surfaces, rainfall loss rates and a surface roughness factor. The hydrographs generated from each subcatchment are then routed or lagged through the waterway network to the total catchment outlet.

The XP-RAFTS model was developed as follows:

The delineation of subcatchment boundaries and properties. Subcatchment boundaries were determined using the LiDAR ground surface elevation data within the LiDAR data coverage (refer to Figure 6) and using the state map series topographic data GIS layers outside the LiDAR coverage. The subcatchment layout is shown on Figure 8. Subcatchment properties (percentage of impervious surfaces, slopes and roughness) were determined using aerial photography and the LiDAR elevation data. The percentage of impervious surfaces present was assigned as follows:

  - Rural land use catchment – 5%
  - Town area urban catchments – varies from 10% to 60% depending on the density and type of land use

- Design rainfall intensity frequency duration (IFD) data used was consistent with Australian Rainfall and Runoff (IEAust, 1987).
- Rainfall losses. Design rainfall losses were assigned based on loss rates recommended for the local region (IEAust, 1987). Rainfall losses adopted were as follows:
  - Initial loss 15 mm
  - Continuing loss rate 2.5 mm/hr
- The subcatchment hydrographs outside the hydraulic model area were lagged using directly specified time lags based on waterway lengths and nominal assigned velocities.

The XP-RAFTS model was subsequently adjusted such that the modelled peak design flows best matched the preliminary peak 100 year ARI design flows for the three main waterways at Walla Walla (i.e. as per the RFFE estimates in Table 5). This involved adjusting the Bx parameter value for the respective waterway subcatchments. The effect of this was to alter the hydrograph shape including the peak flow. Although somewhat unconventional, this process was considered preferable to varying the rainfall loss parameter values in order to retain rainfall loss rates consistent with those nominated for the local region.

5.4 TUFLOW Hydrualic Model Input

The 100 year ARI design storm hydrographs for design storm durations ranging from 1 hour to 12 hours were generated using the XP-RAFTS model.

Hydrographs for those catchments outside the TUFLOW modelled area were input into the model as a total area hydrograph at the upstream boundary of the model. Hydrographs for subcatchments within the TUFLOW modelled area were input as local area hydrographs.

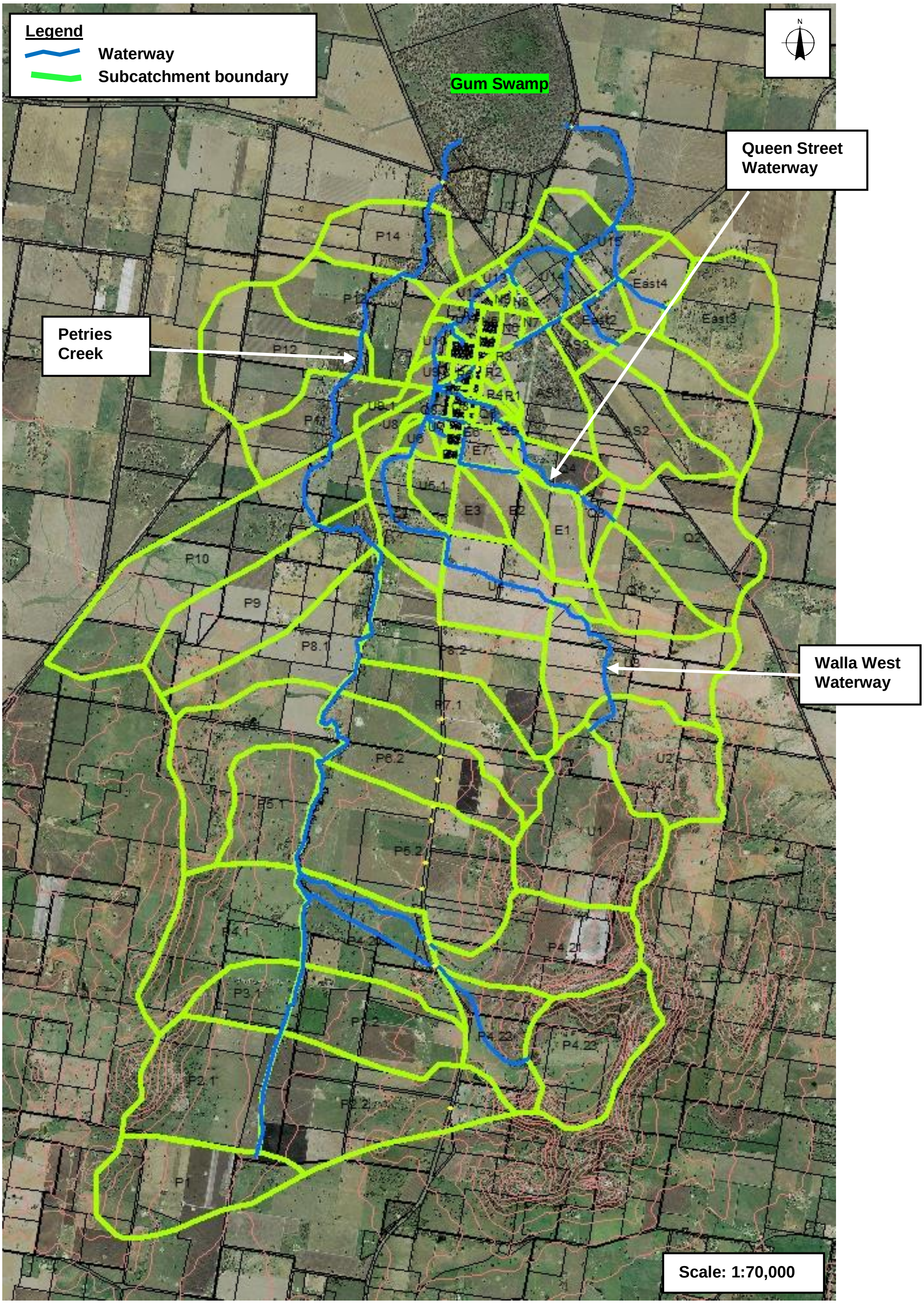

Figure 8 Subcatchment Layout for XP-RAFTS Model

The TUFLOW model was subsequently run for different design storm durations (i.e. 1 hour, 2 hour, 3 hour, 4.5 hour, 6 hour, 9 hour and 12 hour). The peak critical duration modelled flow for the three waterways was compared to the RFFE estimates. Some adjustments were made to the XP-RAFTS model until a good match between the RFFE estimates in Table 5 and the TUFLOW critical duration modelled peak flows was achieved.

The final step in the process involved a comparison of the modelled 5 and 100 year ARI flood levels with the available observed 2010 and 2012 flood levels. This part of the process is documented in Section 6.5.

5.5 PMF

The determination of the PMF hydrographs was undertaken using the Generalised Short-Duration Method (GSDM). This method is appropriate for catchments smaller than 1,000 km^2 (BOM, 2003).

The resultant PMP design intensities and GSDM temporal pattern were applied to the XP-RAFTS model according to the GSDM spatial distribution approach. Modelling details are summarised in Table 2.

The resultant XP-RAFTS critical duration peak PMF design flows were generally in the vicinity of 12 times the 100 year ARI peak design flows.

Table 6 PMF - GSDM

Parameter	Value Used
Elevation adjustment factor	1.00
Moisture adjustment factor	0.61
Terrain category	90% smooth
Adjusted average PMP depth – 1 hour duration	240 mm
Adjusted average PMP depth – 2 hour duration	310 mm
Adjusted average PMP depth – 3 hour duration	360 mm
Initial rainfall loss	0 mm
Continuing rainfall loss	0 mm/hr

6. Hydraulic Modelling

6.1 Approach

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 data.
- Modelling of a range of design floods using the adopted design flow rates derived from the joint hydrologic and hydraulic assessment.

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 ling are described as follows.

- Grid size. The grid spacing was selected taking into account the need to keep practical run time durations. A grid size of 4 m was subsequently adopted.
- Where necessary, finer landscape features influencing flooding conditions were defined using breaklines. This involved specifying crest elevations in the case of road and rail crowns and invert levels in the case of drains. The specified elevations were defined based on interrogation of the 1 m grid DEM LiDAR data.
- Bridge and culvert structures have been defined using a combination of the collected field data and the LiDAR data.

The extent of the TUFLOW hydraulic model is shown on Figure 9. The extent has been selected to encompass all of the existing and future development areas at Walla Walla based on the 2013 LEP land use zonings. It also encompasses Petries Creek west of Walla Walla to allow for the modelling of any flow exchanges between Petries Creek and the unnamed waterway (Walla West Waterway).

The three main natural waterways modelled are (refer to Figure 9):

- Petries Creek -catchment area 40 km^2 at Railway
- Walla West Waterway -catchment area 18 km^2 at Lookout Road
- Queen Street Waterway – 4 km^2 on north side of sportsground

The following main stormwater drains are represented within the hydraulic model (refer to Figure 9):

- Queen Street Drain - catchment area 4.3 km^2 at Walla West Waterway
- Edward Street Drain - catchment area 1.8 km^2 at Market Street
- Railway Drain - catchment area 0.3 km^2
- Airstrip Drain - catchment area 2.9 km^2 at railway culvert

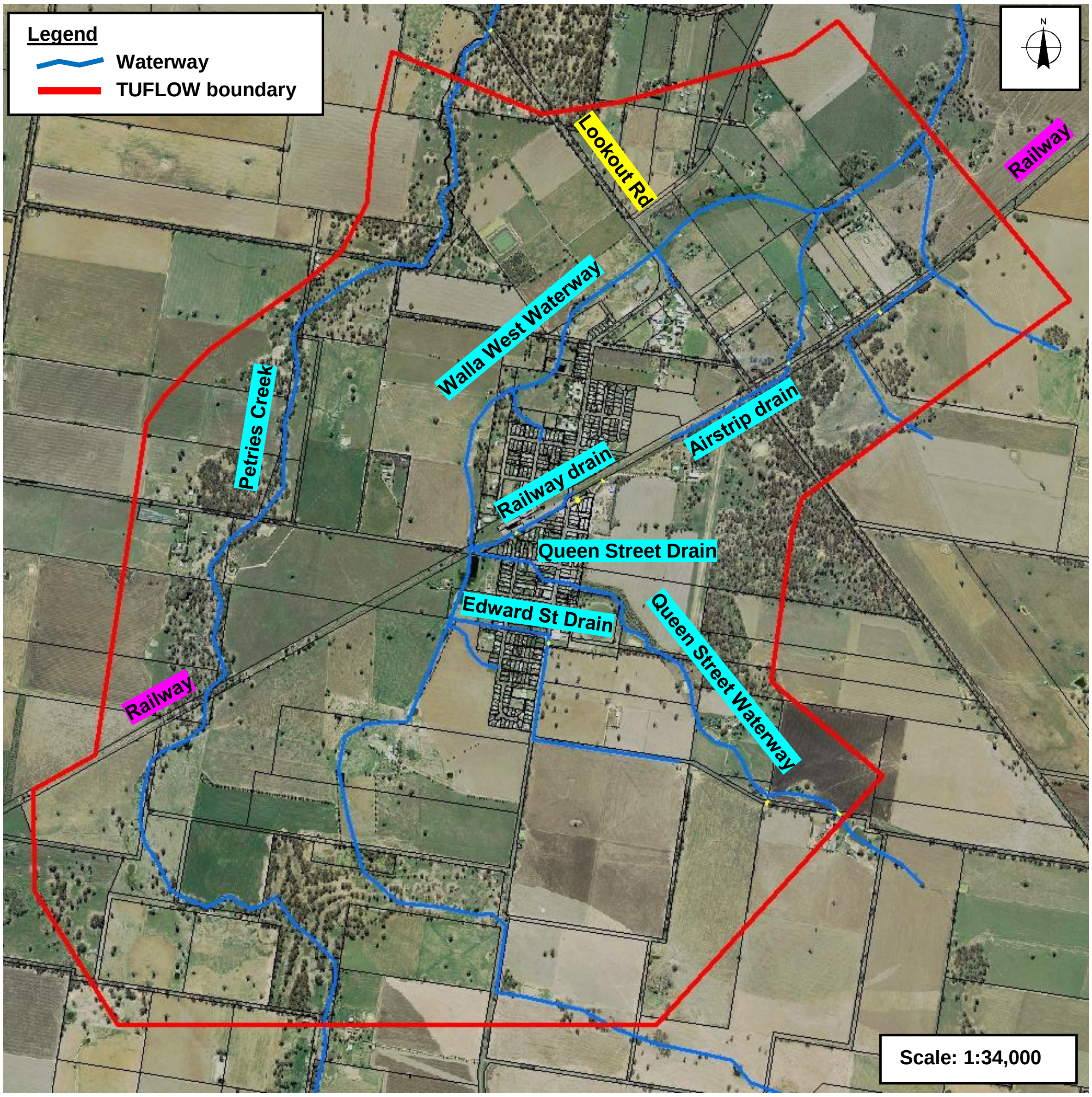

Figure 9 TUFLOW Hydraulic Model Extent

6.2 Downstream Boundary Conditions

6.2.1 Walla West Waterway

The downstream boundary of the hydraulic model at the Walla West Waterway is located 1,400 metres downstream of Lookout Road (refer to Figure 9).

The Walla West Waterway consists of a 600 m wide broad flat depression at the proposed TUFLOW model downstream boundary. The ground surface in the depression is approximately 199.8 m AHD at the TUFLOW boundary. The base of Gum Swamp is at approximately 199.0 m AHD. The lower reaches of the Walla West Waterway will be subject to backwater inundation from Gum Swamp in large floods.

A stage discharge rating curve was developed at the Walla West Waterway downstream boundary.

The rating curve data is given in Table 7. The rating curve is based on:

- Indicative XP-RAFTS modelling of flood flows through Gum Swamp.
- Hydraulic analysis of culvert and road overflows at the Cummings Road waterway structure.
- HEC-RAS modelling between Cummings Road and the TUFLOW downstream boundary.

The subsequent identified 100 year ARI flood level at the TUFLOW boundary is 200.94 m AHD. The ground surface level of the waterway bed on the downstream side of Lookout Road is 202.5 m AHD. Flooding conditions within the town are not therefore influenced by flooding conditions downstream of the TUFLOW boundary.

Table 7 Walla West Waterway – Rating Curve at TUFLOW Boundary

ARI (years)	Gum Swamp flood level (m AHD	Walla West Waterway design flow (m^3/s)	Walla West Waterway flood level upstream of Cummings Road (m AHD)	Flood level at TUFLOW boundary (m AHD)
5	199.8	13	200.30	200.33
100	200.4	53	200.90	200.94
500	200.5	87	201.00	201.07
PMF	201.7	720	201.7	202.2

6.2.2 Petries Creek

The downstream boundary of the hydraulic model at Petries Creek is located 300 metres upstream of Lookout Road (refer to Figure 9).

A stage discharge rating curve was developed for Petries Creek at the TUFLOW model downstream boundary.

The rating curve data is given in Table 8. The rating curve is based on:

- Indicative XP-RAFTS modelling of flood flows through Gum Swamp.
- Hydraulic analysis of culvert and road overflows at the Lookout Road waterway structure.
- HEC-RAS modelling between Lookout Road and the TUFLOW downstream boundary.

Table 8 Petries Creek – Rating Curve at TUFLOW Boundary

ARI (years)	Gum Swamp flood level (m AHD	Petries Creek design flow (m^3/s)	Petries Creek flood level upstream of Lookout Road (m AHD)	Petries Creek flood level at TUFLOW boundary (m AHD)
5	199.8	21	200.9	202.2
100	200.4	80	202.3	202.5
500	200.5	126	202.5	202.7
PMF	201.7	810	203.0	203.8

The Petries Creek downstream boundary condition assigned will have no influence on flooding conditions within Walla Walla including any potential exchange of flows with the Walla West Waterway with the possible exception of the PMF event.

6.3 Waterway Structures and Blockage Assumptions

The following waterway structures are represented within the hydraulic model (refer to Figure 6):

- Bridges
  - Two Petries Creek railway bridges
  - Walla West Waterway railway bridge
  - Railway bridge at the eastern end of Chinatown Lane (local waterway only).
- Culverts
  - Queen Street Drain – seven culvert structures along route between Queen Street and Commercial Street, culvert at the Walla Walla Road
  - Edward Street Drain – three culvert structures
  - Petries Creek – one culvert structure at Walla West Road
  - Walla West Waterway – three culverts (Jindera-Walla Walla Road, Cemetery Road and Lookout Road)
  - Railway line – two culverts (just south of Walla West Road and 200 m east of Morgans Lane)
  - Commercial Street culvert on south side of the Railway line
  - Walla Walla Road at the Jindera-Walla Walla Road intersection

Bridge soffit levels were determined by subtracting the field assessed height difference between the soffit and the railway embankment crest from the LiDAR defined embankment crest level. Bridge opening dimensions and pier arrangements were measured in the field.

Culvert invert levels were determined by subtracting the field assessed height difference between the invert and the LiDAR defined road crown level. Culvert sizes were measured in the field.

The two Petries Creek rail bridges and the rail bridge on the east side of town are large span structures. The Petries Creek bridges do not influence flooding conditions within Walla Walla.

The railway bridge located at the downstream end of the Queen Street Drain (refer to Figure 10) does significantly influence upstream flooding conditions due to its limited size. This bridge is also vulnerable to blockage given the relatively small span openings. The overall abutment to abutment span is 10 metres. There are five piers within the waterway opening. A medium size exotic tree has also grown up through the dilapidated bridge deck structure. This bridge was modelled as 25% blocked for all modelling runs.

All culverts were modelled as 25% blocked for all modelling runs. This blockage figure is in line with the AR&R guidelines (AR&R, 2015). Blockage was assigned uniformly across the waterway structure opening.

Figure 10 Railway Bridge at Walla West Waterway

6.4 Terrain Features – Z Lines

Breaklines (Z lines) were used to define the following features within the hydraulic model:

- Queen Street Drain
- Edward Street Drain
- Drain between Commercial Street and Walla West Waterway on south side of Railway
- Railway line crest
- Levee crests adjoining the Walla West Waterway upstream of Lookout Road
- Road crown at waterway crossings on Walla West Road, Cemetery Road, Lookout Road, Commercial Street, Jindera Road

Drain inverts and road crown elevations for the Z lines were extracted from the 1 m LiDAR DEM data.

6.5 Hydraulic Model Calibration

True hydraulic model calibration cannot be undertaken given the absence of:

- Pluviometer data within the study area catchment.
- Streamflow data for any of the study area local waterways.

The approach to the quasi hydrologic / hydraulic model calibration has therefore been to:

- Estimate peak design flows and hydrographs as per the approach outlined in the preceding Section 5.
- Mannings roughness values assigned based on field assessed conditions and past experience.
- Firstly adjustment of the modelled inflow hydrographs until the TUFLOW modelled peak flow at selected locations on Petries Creek, Walla West Waterway and the Queen Street Waterway closely matches the adopted 100 year ARI peak design flows (refer to Section 5.3).
- Secondly comparison of the resultant modelled peak flood levels for the 5 and 100 year events with the available observed flood levels with subsequent adjustments to the hydraulic model where required.

The XP-RAFTS runoff hydrographs were input into the hydraulic model at the TUFLOW boundary waterway upstream limits and at subcatchment outlet locations within the TUFLOW modelled area. A range of design storm durations (1 hour to 12 hours) were modelled to enable the highest peak flow and flood level for each ARI event to be identified.

The available observed modelled flood levels are listed in Table 3 and shown on Figure 11. The source of the levels is either GHD interviews with residents during the current study or the SES data intelligence report for the October 2010 flood (refer to Table 3 for further details).

All of the resident interview identified observed flood levels relate to either the October 2010 or the March 2012 floods. These two floods were similar in size and are thought to be the two highest creek flood events at Walla Walla (i.e. Petries Creek and Walla West Waterway) since the 1970s. The October 2010 event may have been marginally higher than March 2012, although the data is not conclusive. Both events consisted of multiple rainfall bursts over a period of four days in the case of 2010 and six days in the case of 2012.

The definitive equivalent ARI of the 2010 and 2012 floods cannot be established given the absence of gauged streamflow data. The anecdotal data would however strongly suggest that flow conditions in Petries Creek and the Walla West Waterway were most likely considerably in excess of a 5 year ARI event.

The TUFLOW critical duration peak modelled flows were able to closely match the adopted peak 100 year ARI flow estimates without needing to make any significant adjustments to the XP-RAFTS inflow hydrographs.

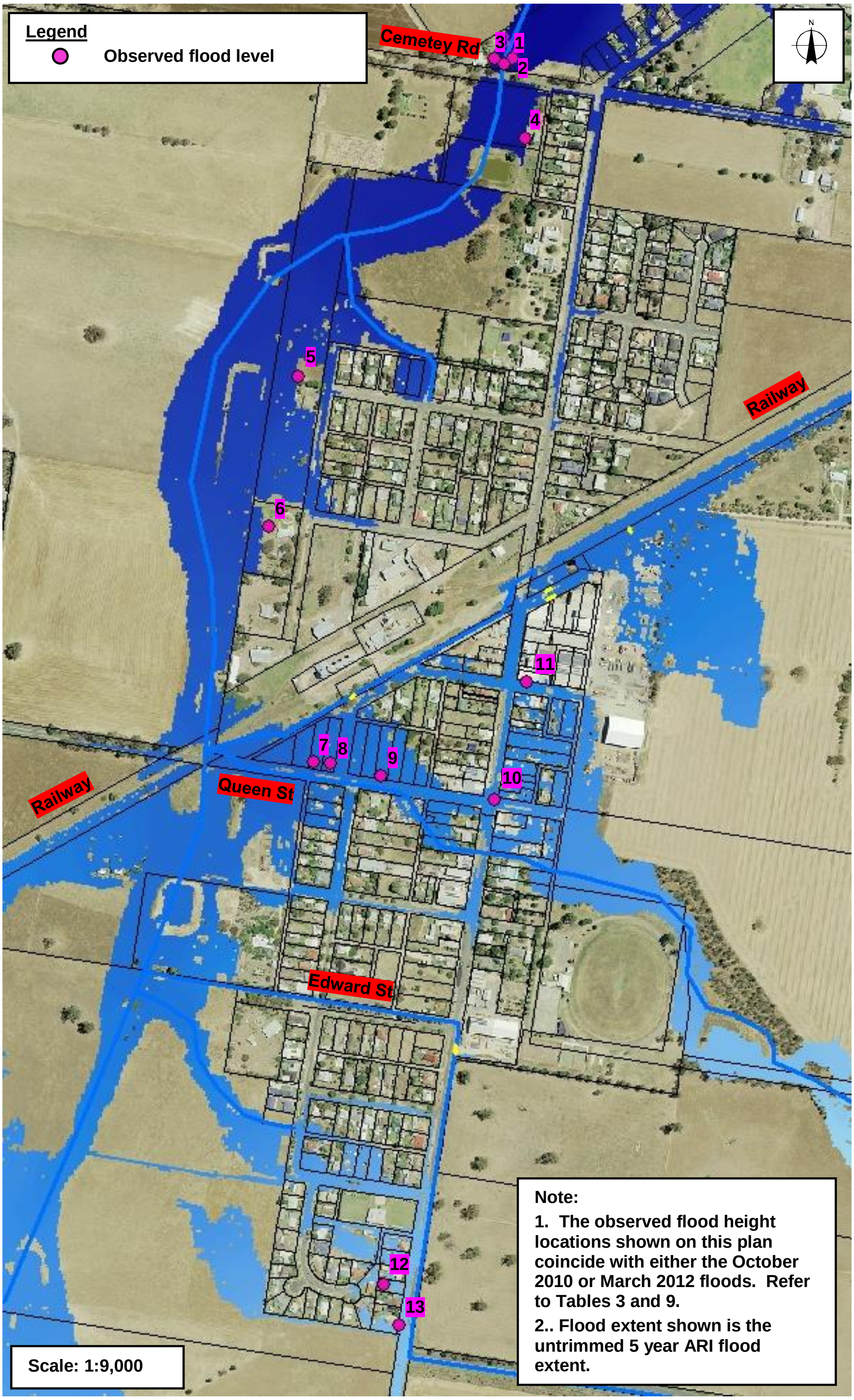

Figure 11 Observed Flood Height Mark Locations

Table 9 Observed and Modelled Flood Levels

Mark No.	Location	Waterway	Observed level (m AHD)	Modelled 5 year ARI flood level (m AHD) (5 year level minus observed level)	Modelled 100 year ARI flood level (m AHD) (100 year level minus observed level)	Indicative equivalent ARI based on comparison of heights (years)
1	30 m downstream Cemetery Rd	Walla West waterway	205.8	205.66 (-0.14)	205.95 (0.15)	20
2	20 m downstream Cemetery Rd	Walla West waterway	205.8	205.74 (-0.06)	206.05 (0.25)	10
3	20 m downstream Cemetery Rd	Walla West waterway	205.7	205.75 (+0.05)	206.07 (0.37)	4
4	80 m upstream Cemetery Rd	Walla West waterway	206.5	206.30 (-0.20)	207.29 (0.81)	10
5	West end Wenke St	Walla West Waterway	208.9	Dry	208.92 (0.02)	50
6	21 Stitt Street	Walla West Waterway	210.0	209.85 (-0.15)	210.09 (+0.09)	35
7	6 Queen Street	Walla West Waterway	212.4	212.20 (-0.20)	212.90 (+0.50)	20
8	8 Queen Street	Walla West Waterway	212.45	212.40 (-0.05)	212.90 (+0.45)	10
9	14 Queen Street	Overland flow	213.0	213.07 (+0.07)	213.23 (+0.23)	4
10	East side Queen / Commercial St	Overland flow	214.45	214.42 (-0.03)	214.55 (+0.10)	10
11	Railway St – Landmark building	Overland flow	213.8	213.78 (-0.02)	213.90 (+0.10)	10
12	119 Commercial Street	Overland flow	218.4	218.25	218.30	> 100 – mark suspect
13	123/125 Commercial St	Overland flow	218.85	218.85	218.9	5

Note:

1. Mark locations are shown on Figure 11.

The modelled 5 and 100 year ARI flood levels are listed in Table 5 for comparison with the observed levels. The modelled levels have been derived using the following Mannings roughness values:

- Petries Creek waterway corridor – 0.06
- Medium to dense Woodland / forest areas – 0.08
- Rural pasture and light density trees – 0.04
- Development within town – 0.10
- Queen Street concrete lined drain – 0.02
- Queen Street unlined drain – 0.03

The very large Kotzur Silo factory building footprint was made impervious to flow.

6.5.1 Walla West Waterway

Observed flood marks 1 to 8 in Table 9 are controlled by flooding within the Walla West Waterway. Seven of the eight modelled 5 year ARI flood levels are lower than the observed flood levels indicating that the 2010 and 2012 events were more severe than a 5 year ARI flood event. The one observed flood height (Mark 3) above the modelled 5 year ARI flood level is considered quite suspect given it conflicts with the adjoining Marks 1 and 2.

The preliminary modelled 100 year ARI flood levels for the Walla West Waterway vary from 0.02 to 0.81 metre above the observed levels. This large spread is due to:

- Low reliability of some marks (e.g. Mark 5 – the resident was not particularly confident in their recollection).
- The high spread in the level differential between the 5 and 100 year ARI flood levels. Within the Cemetery Road and Railway afflux zones, the differential is up to 1 metre. For areas not influenced by afflux, the differential is typically 0.3 metre.

6.5.2 Local Overland Flow Flooding

Observed flood heights 9 to 13 are controlled by local overland flooding. For these shallow sheet like flow conditions, it is more difficult for the 4 m grid TUFLOW hydraulic model to reliably predict the absolute height of flooding given the various local influences which are not represented within a 4 m grid model. The use of Z lines to represents road and rail crowns, and drain inverts to some extent overcomes this limitation.

None of the observed marks could be described as highly reliable. The following comments are made in relation to the observed marks 9 to 13:

- Mark 9 is at a house on the north side of Queen Street. The depth of flooding is very shallow at this point. The modelled 5 year ARI flood level is marginally higher than the observed 2010 flood level.
- Mark 10 is the approximate observed height on the east side of Commercial Street at the Queen Street intersection. The modelled 5 year ARI flood level is marginally lower than the observed 2010 / 2012 level.
- Mark 11 is at the Landmark building in Railway Street. The modelled 5 year ARI flood level is close to the observed height. This building is known to have been subject to above floor flooding. The entry floor level off Railway Street appears to be equal in height to the adjoining road crown level and as such is very vulnerable to flooding.

- Marks 12 and 13 are in areas where there is very shallow sheet flow. The marks are not considered to be of low reliability and are likely to be influenced by local features not represented within the hydraulic model (e.g. semi impervious fences).

6.6 100 Year ARI Flooding Conditions

6.6.1 Petries Creek

The brief for this project indicated that modelling of Petries Creek would most likely not be required given its location 1 km to the west of the town's western fringe. Petries Creek has however been included within the hydraulic model due to the potential for flow exchange between Petries Creek and the Walla West Waterway closer to town.

The preliminary hydraulic modelling has identified that flow exchanges between the two waterways are limited to the area in the vicinity of the old golf course near the upstream limit of the hydraulic model (refer to Figure 12). The modelling has found that a portion of the flow within the Walla West Waterway discharges into Petries Creek as follows:

- 5 year ARI event – 1.5 m^3/s equivalent to 20% of the upstream Walla West Waterway total flow.
- 100 year ARI event – 3.0 m^3/s equivalent to 14% of the upstream Walla West Waterway total flow.

The above assumes that there are same size floods in ARI terms in both creeks. Assuming a 5 year ARI flood in Petries Creek and a 100 year ARI flood in the Walla West Waterway, this results in 3.2 m3/s of flow being transferred from the Walla West Waterway into Petries Creek (i.e. very little change compared to 100 year ARI flooding in both creeks).

The above modelling confirms that Petries Creek has very little influence on flooding conditions at Walla Walla with the possible exception of extreme events (e.g. PMF).

A rural landholder interviewed by GHD on the south side of the old golf course site confirmed that the flow exchange between the two creek involves overflows passing from the Walla West Waterway to Petries Creek.

Other factors of note in relation to Petries Creek are as follows:

- Railway line embankment is not overtopped in a 100 year ARI flood. The two very large bridges are able to pass the 100 year ARI flow with minimal afflux.
- Walla West Road is overtopped in a 5 year ARI event at the Petries Creek crossing.

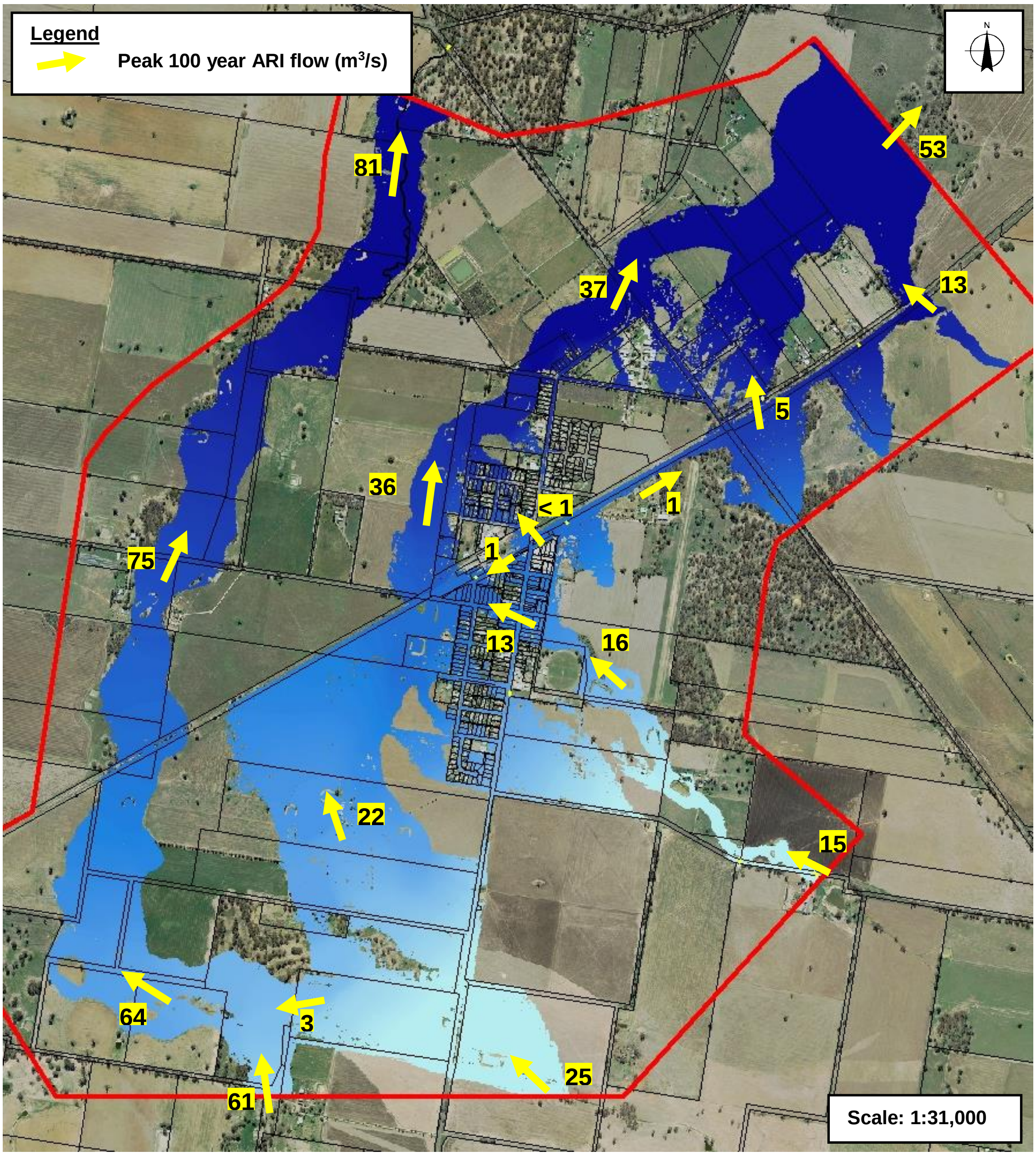

Figure 12 100 Year ARI Peak Design Flows

6.6.2 Walla West Waterway

The Walla West Waterway is characteristic of a broad depression at Walla with minimal incised channel definition. A number of observed flood levels were available for this waterway coinciding with the 2010 and 2012 floods (refer to Table 3 and Figure 11).

Flood levels in both floods appear to have been similar, although if anything the 2010 flood may have peaked slightly higher, although there are no reliable observed flood levels at the same location for both events to confirm this.

The 100 year ARI flood extent for the Walla West Waterway is shown on Figure A2 in Appendix A. The 100 year ARI inundation extent associated with flows in the Walla West Waterway does not encroach into existing developed areas with the exception of the area adjoining the south side of the railway line. The afflux zone on the upstream side of the railway results in inundation of properties at the western end of Queen Street.

Although Cemetery Road also causes significant afflux, this does not lead to 100 year ARI inundation of upstream residential properties.

The Jindera Road and Lookout Road are both overtopped in a 5 year ARI flood by the Walla West Waterway.

Levees are located within the Walla West Waterway route upstream of Lookout Road. The two low level levees have very little influence on flooding conditions and are outflanked in a 5 year ARI event.

6.6.3 Local Over Flooding – Queen Street Waterway Catchment

The waterway adjoining the sportsground is the largest source of local overland flooding. This waterway (Queen Street Waterway) loses all incised channel definition on the eastern fringe of Walla.

Flooding conditions are described as follows:

- 100 year ARI flood – approximately 30% of the flow is conveyed by the Queen Street Drain. The balance discharges as shallow sheet flow through much of the town area between the drain and the Railway line.
- Flooding conditions are generally characteristic of shallow sheet flow. This notably affects properties in Queen Street, Railway Street and the large Kotzur Silo factory site on the east side of Commercial Street.
- 100 year ARI overflows at the railway line on the west side of Commercial Street (only 0.1 m^3/s).

6.6.4 Local Overland Flooding – Edward Street Drain Catchment

Overland flow drains to the Edward Street Drain via the roadside drain down the east side of Commercial Street. This roadside drain varies in size but in places has a capacity of 0.5 m^3/s (based on 2013 LiDAR survey). The capacity of the Edward Street Drain itself is approximately 2 m^3/s.

The hydraulic modelling shows broad shallow inundation through much of the area south of the Edward Street Drain. Typically 100 year ARI flow depths are less than 0.1 metres. Flow will tend to concentrate in Scholz Street, Herman Street and the laneways.

The shallow depth of flooding means that above floor flooding is unlikely unless floor levels are close to ground levels.

6.6.5 Other Local Overland Flow – South Side of Railway

The natural high point on the south side of the Railway line is approximately 300 metres east of Commercial Street. This high point is not pronounced however, with very little fall between this point and Commercial Street.

In a 100 year ARI flood, floodwater on the north side of the Kotzur Silo factory discharge eastwards as shown on Figure 12 (1 m^3/s). These flows with additional incoming local overland flow discharges eastwards across Morgans Road.

East of Morgans Road, there are two large Railway waterway crossings which discharge flow northwards to the Walla West Waterway.

There is some local runoff draining from the area adjoining the west side of the Kotzur Silo factory. Runoff from this small area of approximately 20 hectares is not of any particular consequence. The overflows from the 430 hectare catchment Queen Street Waterway are the main cause of flooding problems for this area.

6.6.6 Other Local Overland Flow – North Side of railway

Development at Walla Walla on the north side of the Railway is not expected to be subject to anything other than shallow inundation from local overland flow due to the small size of the catchments. Flooding impacts are therefore expected to be confined to nuisance level flooding (e.g. shallow inundation of roadways once table drains overflow, shallow grounds flooding of properties).

In a 100 year ARI event, a small amount of flow overtops the Railway line on the west side of Commercial Street and then discharge north westwards to the Walla West waterway. The amount of flow (0.1 m^3/s) is too small to cause any serious flooding impacts.

6.6.7 Other Issues

The modelling assumes that the railway line ballast is impervious to flow. There have been some anecdotal reports that seepage through the ballast may have occurred in the 2012 flood, notably on the east side of Commercial Street.

Significant seepage through the railway ballast is thought to be unlikely. A house located in the area where the anecdotal seepage is reported to have occurred was inspected by GHD. The floor level of the house in question is raised only marginally above ground level and would be particularly vulnerable to very shallow flow which could be induced by local runoff.

Some seepage through the railway line ballast will occur. The amount of flow seeping through the railway ballast will however be limited by the:

- Relatively short duration of flooding at Walla Walla.
- Limited water pressure given the depth of floodwater banking up against the south side of the railway embankment (ballast) is 0.2 to 0.4 metre on the east side of Commercial Street.
- Limited porosity of the ballast.

Floodplain storage effects are negligible at Walla Walla. The peak flow for example within the Walla West Waterway is not attenuated as a result of the storage available on the upstream side of the railway. The reason for this is the available storage is small compared to the 100 year ARI design flood runoff volume.

6.7 Sensitivity Assessment

6.7.1 Downstream Boundary Conditions

Section 6.2 describes the approach to defining downstream boundary conditions within the hydraulic model.

The Petries Creek downstream boundary only influences flooding conditions for a few hundred metres upstream of the boundary. It has no impact on the flow exchange between the Walla West Waterway and Petries Creek, 4 km to the south.

The Walla West Waterway downstream fixed 100 year ARI water level is 200.9 m AHD. The floodplain is a flat bottomed 700 metres wide depression at the boundary. The modelled 100 year ARI flood level on the downstream side of Lookout Road, located 1.4 km upstream of the hydraulic model boundary, is approximately 203.5 m AHD. Flooding conditions at Lookout Road are not therefore sensitive to the assigned boundary flood level.

The assigned downstream boundary conditions do not therefore influence 100 year ARI flooding conditions within the town.

6.7.2 Bridge and Culvert Blockage

Section 3.3 describes the assumption made in relation to the extent of bridge and culvert blockage.

For the purpose of a waterway structure blockage sensitivity assessment, the following approach was used:

- Bridge openings – 50% blockage of all four railway bridges assumed (compares to 25% for Walla West Waterway railway bridge and 0% blockage for the three other railway bridges).
- Culverts – 50% blockage for all culvert structures assumed (compares to 25% for all culverts).

The modelling results are summarised in Table 10.

The modelled increases in the upstream 100 year ARI flood level due to the increased blockage are small (not more than 0.05 metre). The reason for this is that all of the waterway structures with the exception of the Petries Creek railway bridges are overtopped regardless of what blockage is assumed. Increases in road or rail overflows therefore translates into a small increase in flood level due to the flat terrain conditions present.

Table 10 Sensitivity of 100 Year ARI Flood Levels to Structure Blockage

Crossing / waterway structure	Predicted change in 100 year ARI flood level with 50% Culvert and Bridge Blockage (m)
Walla West Waterway – Jindera Rd culvert	0.04
Walla West Waterway - railway bridge	0.02
Walla West Waterway - Cemetery Road	0.05
Walla West Waterway - Lookout Road	0.01
Edward Street Drain - Market Street	0.02
Queen Street Drain – Commercial Street	0.01
Queen Street Drain – Market Street	0.01
Overland flow – Railway Street	0.01
Overland flow – Commercial Street / railway line	0.00

6.7.3 Floodplain Roughness

For the purpose of assessing the sensitivity of the modelled 100 year ARI flood levels to the assigned Mannings roughness values, the roughness values were increased by 25%.

The modelling results are summarised in Table 11.

The 100 year ARI flood levels increase by up to 0.06 metres as a result of the high roughness values. This level of change is relatively small.

Table 11 Sensitivity of 100 Year ARI Flood Levels to Mannings Roughness

Location	Predicted change in 100 year ARI flood level coinciding with a 25% increase in the Mannings roughness value (m)
Walla West Waterway – Edward St Drain	+0.06
Walla West Waterway – upstream railway	0.00
Walla West Waterway – opposite Stitt St	+0.04
Walla West waterway – upstream Cemetery Rd	+0.01
Walla West Waterway – downstream Cemetery Rd	+0.06
Walla West Waterway – at Lookout Rd	+0.02
Commercial Rd / Scholz St intersection	+0.01
Market Street low point between Scholz & Herman	+0.01
Edward Street Drain upstream Market Street	0.00
East of entry point to Queen Street Drain	+0.03
Queen St Drain on upstream side of Commercial St	+0.02
Queen Street Drain upstream Market Street	+0.03
Queen Street Drain downstream of Market Street	+0.01
Railway Street outside Landmark entry point	+0.03
East side of Commercial St on south side of railway	+0.01

6.7.4 Flow Estimates / Climate Change

The level of sensitivity of the modelled 100 year ARI flood levels to flow is illustrated by the results in Table 12 which consist of the:

- Peak design flows for the 5, 100 and 500 year ARI events. The flows listed are the critical duration hydraulic model derived peak flows.
- Corresponding peak 5, 100 and 500 year ARI flood levels.

The 500 year ARI flows are generally 40 to 60% % higher than the 100 year ARI peak flows. The 500 year ARI flood levels vary from 0.03 to 0.16 metre higher than the 100 year ARI flows. There are very few locations at Walla Walla where flows are confined which prevent significant increases in flood level with increasing flow, particularly for floods exceeding the 100 year ARI flood.

The Floodplain Risk Management Guideline (FRMG) '*Practical Considerations of Climate Change*' (DECC, 2007) provides details on the possible implication of climate change as they relate to flood studies in NSW. This includes the following predicted rainfall intensities for the 40 year ARI, 24 hour duration design rainfall intensity for the Murray catchment:

- Indicative range of -3% to + 25% by the year 2030
- Indicative range of -7% to + 29% by the year 2070

A 25% increase in design intensity would reduce the equivalent ARI of the existing 100 year ARI 24 hour duration design intensity to approximately 25 years ARI. Similarly, the equivalent ARI of the existing 500 year ARI design intensity would reduce to approximately 125 years ARI.

The 25% increase is however at the upper end of the nominated range. The lower end of the nominated range results in a small reduction in the future rainfall intensities.

The above rainfall intensity increases are for a 24 hour duration event. The Walla Walla study area catchments are relatively small with shorter duration rainfall events (e.g. 1 to 6 hours) critical.

The 500 year ARI flood levels could therefore be viewed as the upper bound climate change induced 100 year ARI flood levels. At Walla Walla, this would generally involve increases in the 100 year ARI flood level of not more than 0.2 metre.

The 5 year ARI flood levels in Table 12 vary from 0.1 to 1.0 metre below the 100 year ARI flood levels. The largest differential occurs within afflux influenced zones (e.g. Walla West Waterway upstream of Cemetery Road and the railway line). At these afflux influenced locations, flood levels rise considerable with increasing flow until the road or rail embankments are overtopped.

Table 12 Sensitivity of Flood Levels to Flow

Location	5 year ARI		100 year ARI		500 year ARI	
	Peak Flow (m^3/s)	Flood Level (m AHD)	Peak Flow (m^3/s)	Flood Level (m AHD)	Peak Flow (m^3/s)	Flood Level (m AHD)
Walla West Waterway - at Edward St Drain junction	6	212.72	22	213.10	36	213.26
Walla West Waterway – upstream railway	8	212.04	34	212.88	55	212.96
Walla West Waterway – opposite Stitt St	8	209.77	36	210.10	58	210.19
Walla West waterway – upstream Cemetery Rd	8	206.28	36	207.28	58	207.42
Walla West Waterway – downstream Cemetery Rd	8	205.33	37	205.57	58	205.72
Walla West Waterway – at Lookout Road	8	203.64	37	203.88	59	204.00
Commercial Rd / Scholz St intersection	-	217.87	-	217.93	-	217.96
Market Street low point between Scholz & Herman St	0.3	215.49	1.2	215.62	2.1	215.66
Edward Street Drain upstream Market Street	1.0	215.21	2.2	215.43	2.9	215.45
East of entry point to Queen Street Drain	4.6	215.52	16	215.68	23	215.76
Queen St Drain on upstream side of Commercial St	4.2	214.40	13	214.51	18	214.57
Queen Street Drain upstream Market Street	4.2	213.28	13	213.44	18	213.51
Queen Street Drain downstream of Market Street	-	212.32	-	212.89	-	212.99
Railway Street outside Landmark building entry point	0.2	213.80	1.5	213.90	2.4	213.98
East side of Commercial St on south side of railway	-	212.90	-	212.99	-	213.04

Note:

1. The flows listed are the critical duration hydraulic model derived flows.

7. Design Flood Mapping

7.1 Approach

The process leading to the adoption of the 100 year ARI design flood outputs is described in the preceding Section 6. Following the adoption of the 100 year ARI design outputs, the remaining design events consisting of the 5, 10, 20, 50, 200 and 500 year ARI events and the PMF event were modelled.

The modelled hydrographs for various design storm durations were generated by XP-RAFTS and input into TUFLOW. The TUFLOW modelled maximum flood level, depth, velocity, extent and depth times velocity were then derived based on processing the various design storm duration modelling outputs and identifying the highest flows and flood levels induced.

7.2 Flood Map Outputs

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

7.2.1 Design Flood Extents and Flood Height Contour Map Series

Design flood extent and flood height contour mapping for the full range of design floods modelled is included in Appendix A.

Flood extent and height mapping included in Appendix A consists of:

- Figure A1 – 100 year ARI covering the whole of the hydraulic model area (scale 1:25,000 at A3)
- Figure A2 – 100 year ARI for the township and surrounding area (scale 1:15,000 at A3)
- Figure A3 – 5 year ARI
- Figure A4 – 10 year ARI
- Figure A5 – 20 year ARI
- Figure A6 – 50 year ARI
- Figure A7 – 200 year ARI
- Figure A8 – 500 year ARI
- Figure A9 – PMF

The following comments are made in relation to the design event flood maps in Appendix A:

- Although flood height contours are shown on Figures A2 to A9 at 1 metre intervals, contours can be produced at 100 mm intervals or even less using the modelled design flood surfaces.
- Flood depths less than 100 mm have been trimmed from Figures A1 to A9. There are extensive areas at Walla Walla which are subject to shallow inundation to a depth of less than 100 mm in a 100 year ARI flood.
- Although there may be buildings located within the mapped inundation areas, it should not be assumed that the floor level of any individual building is below the flood level. Building floor level elevations should be compared with the design event flood heights to determine whether their floors are above or below the design flood height as has been done as part of the flood damages assessment (refer to Section 8).

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 solely on hydraulic conditions determined in accordance with Figure L2 of the 2005 FDM as reproduced in Figure 13. The hazard maps are included in Appendix B as follows:

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

The provisional hazard categories will be reviewed as part of the 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).

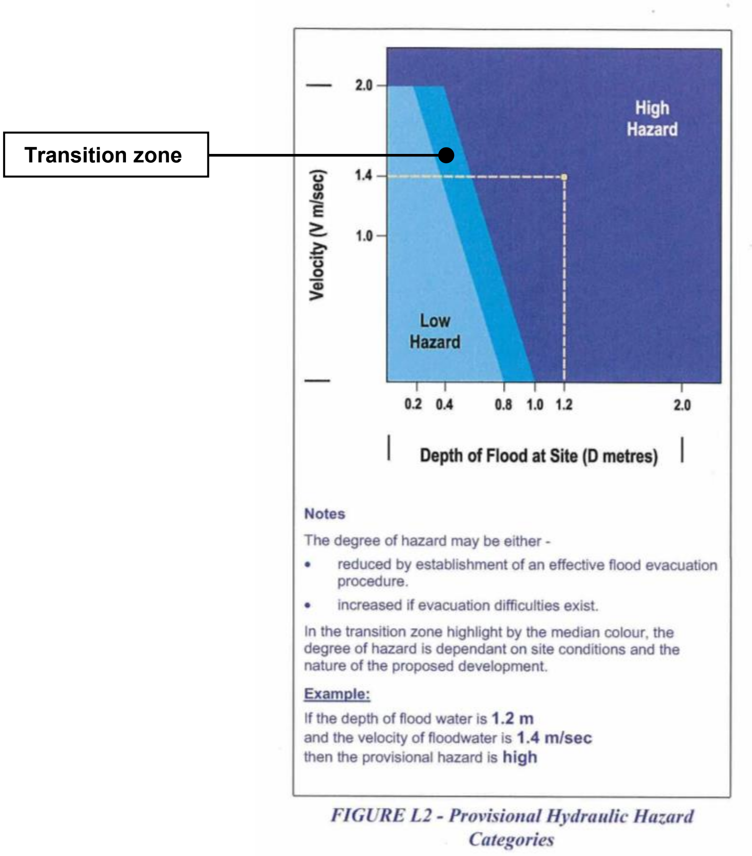

Figure 13 2005 FDM Hazard Categories

(extract from 2005 FDM)

The extent of the provisional 100 year ARI high hazard defined areas is quite limited as shown on Figure B1. High hazard areas are generally limited to the incised waterway channels. The only notable provisional high hazard area within which existing development is located is on the upstream side of the Railway at the Walla West Waterway where flood depths are high due to the high afflux associated with the railway.

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. This criteria has been used to produce the hydraulic category mapping at Walla Walla 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

As an exception to the above, those areas where the depth of flooding is 1.0 metre or more but do not meet either of the above two criteria were defined as floodway.

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 is provided in Appendix C for the following events:

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

The extent of the 100 year ARI floodway defined areas is generally limited to the incised waterway corridors. Other notable 100 year ARI floodway defined areas are:

- The area bounded by the Railway, Queen Street and Market Street is part floodway and part flood storage due to the relatively high depth of flooding.
- The Queen Street Drain corridor and Queen Street itself west of Commercial Street are classified as floodway areas.
- The Walla West Waterway at the downstream end of the hydraulic model is classified as floodway due to the high depth of flooding (greater than 1 metre based on the indicative Gum Swamp downstream boundary flood level).

7.2.4 Design Event Profile Map Series

The flood height contours represent the flood height water surface gradient. Flood profiles present the same information plotted on a longitudinal section following the centreline of the waterway.

Design flood profiles are presented in Appendix D for the following waterways:

- Figure D1 - Walla West Waterway from the Jindera-Walla Walla Road to the downstream boundary of the hydraulic model. The Walla West Waterway longitudinal gradient is generally in the vicinity of 0.5% upstream of Lookout Road.
- Figure D2 - Queen Street Waterway from Walla Walla Road to the junction with the Walla West Waterway. The Queen Street Drain longitudinal gradient is generally in the vicinity of 0.7% within the town.

7.3 Other Features of Interest

Detailed hydraulic model output is provided in Table 13 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 13.

Overtopping of roadways will occur at most of the waterway crossings. Road culvert capacities generally coincide with minor flood events (i.e. less than the 5 year ARI design flow).

Local road culvert crossings are notably located at:

- Jindera-Walla Walla Road – indicative capacity 5 year ARI.
- Walla Walla Road – indicative capacity of culvert 2 year ARI.
- Lookout Road - indicative capacity of culvert 1 year ARI.
- Walla West Road - indicative capacity of culvert less than 1 year ARI at the Walla West Waterway.

The duration of road overtopping will vary from flood to flood depending on the rainfall characteristics of each event. The duration of flooding is typically not expected to exceed 3 to 6 hours given the relatively small contributing catchment areas and the associated short time of concentrations (travel time for runoff from the most remote catchment point to reach the point of interest).

Table 13 Road and Rail Waterway Crossings

Creek	Location	Waterway structure	Discharge capacity (m^3/s)	100 year ARI afflux (m)	Overtopped (Threshold – years)	Depth 100 year ARI overtopping (m)
Petries Creek	Railway	59 m & 30 m span bridges	> 100	0.2	No - > 500	Na
	Walla West Rd	2.5 x 1.2 m BC	< 10	0.1	Yes - < 5	0.6
Walla West Waterway	Jindera-Walla Walla Rd	4 x 1.2 x 0.9 m BC 1 x 2.4 x 0.6 m BC	< 10	0.2	Yes - 5	0.3
	Railway	10 m span bridge	20	0.9	Yes – 25 to 50	0.10
	Cemetery Rd	3 x 2.4 x 1.2 m BC	20	0.9	Yes – 25 to 50	0.25
	Lookout Rd	4 x 0.9 x 0.45 m BC	3	< 0.1	Yes - < 5	0.4
Queen Street waterway	Walla Walla Road	4 x 1.2 m x 0.3 m BCs	3	< 0.1	Yes - < 5	0.2
	Commercial St at Queen St	1 x 3.6 x 0.75 m BC	5	0.2	Yes - 10	0.2
	Laneway 1	2 x 1.5 x 0.75 m BC	3.5	< 0.1	Yes – 5 to 10	0.3
	Driveway 1	2 x 1.5 x 0.65 m BC	3.0	< 0.1	Yes – 5 to 10	0.3
	Driveway 2	2 x 1.5 x 0.8 m BC	4.0	< 0.1	Yes – 5 to 10	0.3
	Market Street	2 x 1.5 x 0.8 m BC	4.0	< 0.1	Yes – 5 to 10	0.2
	Laneway 2	2 x 1.2 x 0.6 m BC	2.5	< 0.1	Yes – 5	0.5
	Queen Street	1 x 0.9 x 0.3 m BC	0.5	< 0.1	Yes - < 5	1.3
Local drain	Morgans Lane	2 x 0.45 m diam.	0.5	< 0.1	Yes - < 5	0.1

Notes

1. BC – box culvert (i.e. 4 x 1.2 x 0.9 m BC is a four cell box culvert structure, each cell 1.2 m (high) x 0.9 m (wide)).

2. Overtopping depths are the water depths above the road crown.

8. Damages

8.1 Overview

Flood damages are estimated as part of flood studies to quantify the impact of flooding within the study area. Flood damages are typically estimated for a range of varying size flood events (e.g. 5 year ARI to the PMF). The average annual damage (AAD) is also calculated which represents the expected average annual flood damage which is likely to occur as measured over a long period of time.

The flood damage estimation process involves comparing building floor levels with the modelled flood levels for the full range of floods modelled. Those individual buildings which are subject to above floor flooding are identified by this process. The subsequent floodplain risk management study tends to focus on flood mitigation measures which can alleviate the severity of flooding for those habitable buildings which are subject to above floor flooding, particularly those flooded in events less severe than the 100 year ARI event.

The flood damages database is also typically used during the subsequent FRMS to assess the benefits of the various flood mitigation options under consideration. The flood damage is re-estimated for post mitigation conditions. The reduction in flood damages can then be compared with the cost of the mitigation measure under consideration to assess its cost effectiveness.

Flood damages are categorised as follows:

- Tangible damages. These are financial in nature and can be measured in monetary terms. Tangible damages are further subcategorised into:
  - Direct damages. These are caused by floodwaters wetting goods and possessions, thereby reducing their value.
  - Indirect damages. These are the additional financial losses caused by a flood and include accommodation and food costs for evacuees, loss of wages due to disruption to employment, loss of business sales.
- Intangible damages. These include the stress and illness caused to those during and after a flood. By definition, they cannot be quantified in monetary terms and are therefore excluded from the damage estimates.

8.2 Floor Level Survey

The estimation of flood damages requires floor level elevations for those buildings which are included in the damages database.

The following approach was used for assigning floor levels to properties at Walla Walla:

- The floor level elevations of 66 buildings located within the 100 year ARI flood extent were obtained by a survey firm (i.e. accuracy within +/- 0.03 metres).
- The floor level elevations of a further 252 buildings located outside the 100 year ARI flood extent but within the PMF extent (refer to Figure A9) were assigned a floor level based on adding 300 mm to the average ground surface elevation. The ground surface levels were obtained from the LiDAR 1 m grid terrain data.

Of the 66 buildings which are within or partly within the 100 year ARI flood extent and were subject to an actual floor level survey:

- 44 are residential buildings (detached houses, townhouses, units).
- 22 are non residential (mixture of commercial and industrial).

The property damages includes the main building on each property. The data base excludes secondary buildings such as sheds, carports and garages which typically may have lower floor levels compared to the main building. The damages calculations include an allowance for external damages which occur prior to above floor flooding which accounts for flood damage to the secondary buildings and their contents.

In the case of the large Kotzur Silo building at 56-60 Commercial Street, floor levels were surveyed at 5 entry points into the building, with each entry point represented as a stand alone building within the property database.

8.3 Approach

The following approach has been used for the estimation of flood damages at Walla Walla:

- Threshold design flood at which flood damage commences was assumed to coincide with the 3 year ARI event (5 year ARI event is the smallest design flood modelled).
- Flood damages were computed for the 5, 10, 20, 50, 100, 200, 500 year ARI and the PMF event.
- The flood damage assessment as it applies to residential development was undertaken in accordance with the current OEH guidelines. Australian Bureau of Statistics data for Walla was used to configure the OEH residential damages spreadsheet.
- Flood damages were estimated based on the resultant OEH height damage curve and the depth of water above the floor. The flood heights for the respective design flood events at each building location were obtained from the TUFLOW hydraulic modelling results.
- Damages for non residential properties were estimated consistent with the approach used on other recent studies within the region including studies at Lockhart, The Rock and Ardlethan.

8.4 Damage Estimate Results

8.4.1 Above Floor Flooding

The above floor flooding results are summarised in Table 14. Notable outcomes are as follows:

- There are four properties where the main building is subject to above floor flooding in a 5 year ARI event.
- 23 properties are subject to above floor flooding in a 100 year ARI event. The average height of above floor flooding for these 23 properties is 0.16 metres.
- In a PMF event, 65 properties are subject to above floor flooding.

Of the above 23 properties flooded to above floor level in a 100 year ARI event, 12 are residential properties and 11 are non residential (commercial or industrial) properties. For the 23 properties subject to above floor 100 year ARI flooding, the average height of the floor above ground is 0.16 metres.

8.4.2 Flood Damages

The flood damage estimation results are summarised in Table 15. Notable outcomes are as follows:

- Average annual damage (AAD) for the Walla Walla study area is $250,000/annum.
- Floods up to a 5 year ARI event account for 13% of the AAD. Most of this damage is due to external flood damage (i.e. damage to contents stored outside the main building below floor level).
- Floods more severe than a 100 year ARI event account for 14% of the AAD.
- The estimated damage in a 100 year ARI event is $2.37 million.

Table 14 Above Floor Flooding Assessment Summary Results

Flood ARI (years)	Number of buildings subject to above floor flooding (excludes secondary buildings – sheds, carports, garages etc)		
	Residential	Non residential	Total
5	3	1	4
10	5	3	8
20	9	5	14
50	12	8	20
100	12	11	23
200	15	12	27
500	17	14	31
PMF	65		

Note:

1. Above relates to the main building on each property.

Table 15 Flood Damage Assessment Summary Results

Flood ARI (years)	Estimated Flood Damage ($)			Event Contribution to AAD (%)
	Residential	Non residential	Total	
5	300,000	190,000	490,000	13
10	450,000	310,000	760,000	25
20	730,000	640,000	1,370,000	21
50	1,010,000	820,000	1,830,000	19
100	1,200,000	1,170,000	2,370,000	8
200	1,420,000	1,370,000	2,790,000	5
500	1,720,000	1,560,000	3,280,000	4
PMF	5,740,000	2,510,000	8,250,000	5
Average Annual Damage (AAD)	140,000	110,000	250,000	-
Net present value (NPV) over 20 years at a discount rate of 7 %	2,650,000			
NPV over 20 years @ 4%	3,400,000			
NPV over 20 years @11%	1,990,000			

9. Issues for FRMS

9.1 Existing Development

The next stage of this project, the floodplain risk management study, will assess options for mitigating flooding impacts on existing development. This will naturally focus on those areas where the impacts are most severe.

This Flood Study has assessed flooding impacts associated with the waterways and main drains within the study area. Flooding conditions at Walla Walla are generally characteristic of local overland flow flooding. These conditions include:

- Short flooding durations, unlikely to exceed 3 hours.
- Shallow sheet flooding, with minimal increases in flood depth with increasing flood ARI. The flood hazard conditions in a 100 year ARI event are therefore mostly low (refer to Figures B1 and B2).

The flood damage analysis has identified that 23 properties are subject to above floor flooding (12 residential and 11 non residential (commercial or industrial). The average depth of above floor flooding for these 23 properties is 0.16 metre in a 100 year ARI event.

The depth of 100 year ARI above floor flooding only exceeds 0.30 metre at two properties (0.51 and 0.57 metre depth above floor at the two properties in question).

9.1.1 Walla West Waterway upstream of Railway

Flood levels on the upstream side of the Railway at the Walla West Road (Queen Street) are elevated due to the afflux induced by the existing Walla West Waterway bridge structure. The 100 year ARI afflux is 0.9 metres.

The elevated upstream 100 year ARI flood levels cause problems to properties located on the south side of the Railway. Properties in this area were close to being flooded to above floor level in the recent 2010 and 2012 floods.

The potential replacement of the existing Railway bridge structure with a larger waterway structure is expected to be assessed during the FRMS.

9.1.2 Queen Street Waterway / Drain

Much of the flooding problems at Walla Walla stem from flows conveyed into town by the Queen Street Waterway.

The waterway approaching the upstream limit of the Queen Street Drain has very little incised definition. Floodwater consequently spreads out and flows northwards towards the Railway and westwards through the town. This affects many properties within the intervening area between the Queen Street Drain and the Railway.

Even if floodwater could be funnelled to the Queen Street Drain entry point, the drain has no more than 5 year ARI capacity. Overflows will therefore occur in larger floods.

There are a number of potential mitigation approaches which could be assessed to address flooding from the Queen Street Waterway. Options include an upgrade of the capacity of the Queen Street Drain and diversion options to divert or partly divert floodwater to a course which bypasses the current Queen Street Drain route.

9.1.3 Roadway Flooding

All of the roadways leading into and out of Walla Walla are subject to flooding. The threshold for roadway flooding is particularly low for the Walla West Road and Lookout Road (1 year ARI indicative overtopping threshold). The Walla Walla Road (2 year ARI threshold) and the Jindera-Walla Walla Road (5 year ARI threshold) are also subject to flooding.

There will therefore be periods when Walla Walla is semi isolated, although heavier vehicles should be able to continue to use the Jindera-Walla Walla Road in particular.

The FRMS is expected to further assess the issue of roadway access into and out of Walla Walla during flooding.

9.1.4 Other Areas

Flooding elsewhere in Walla Walla is characteristic of shallow sheet flow conditions. The roadside drains discharging northwards down either side of Commercial Street overflow in large flood events leading to shallow flooding for much of the area between Commercial Street and the Walla West Waterway. This is not expected to lead to any above floor flooding however and as such is not a serious problem.

North of the Railway, flooding conditions are also shallow with 100 year ARI flood levels generally not expected to exceed 0.1 metre. The only properties at threat in these circumstances are where floor levels are at or only marginally above ground levels.

9.2 Proposed Development

The floodplain risk management study will assess appropriate land use planning and development controls for new development at Walla Walla.

Shallow overland flow covers some of the areas which are either already zoned for development or are ear marked for rezoning for future development. Appropriate flood based planning controls will be important for these areas.

10. Acknowledgements

The Greater Hume Shire Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

GHD has completed the Walla Walla Flood Study project with the assistance of Council's Floodplain Risk Management Committee including the local residents on this Committee, Council's staff, Office of Environment of Heritage's staff, NSW SES 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 the Council.

11. Abbreviations and Glossary

11.1 Abbreviations

AAD	Average annual damage
AEP	Annual exceedance probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
DEM	Digital elevation model
LEP	Local Environmental Plan
FDM	Floodplain Development Manual (2005)
FPA	Flood planning area
FPL	Flood planning level
FRMS	Floodplain Risk Management Study
FRMP	Floodplain Risk Management Plan
LiDAR	Light Detection and Ranging (also known as ALS)
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
SES	State Emergency Service

11.2 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.

12. References

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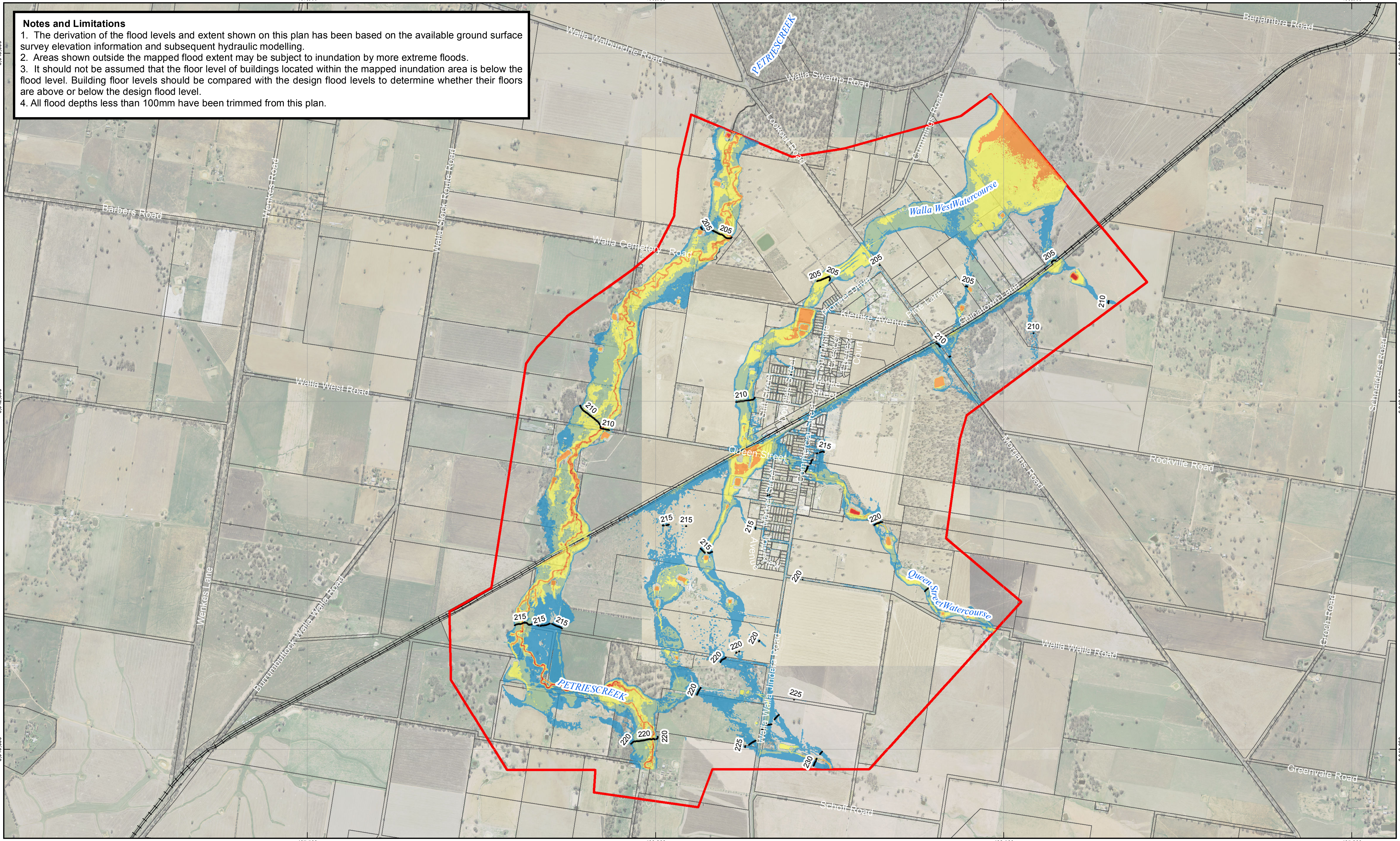
Appendices

Appendix A – Design Flood Maps

Notes and Limitations

1. The derivation of the flood levels and extent shown on this plan has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.
2. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods.
3. 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.
4. All flood depths less than 100mm have been trimmed from this plan.



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Grid: GDA 1994 MGA Zone 55

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- 1.00 - 2.00
- > 2.00
- Cadastre
- Hydraulic Modelling Extent
- Flood Contours (mAHD)
- Railway

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Walla Walla Flood Study

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100 Year ARI Flood Event
Flood Extent and Depth

Figure A1

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

Data source: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

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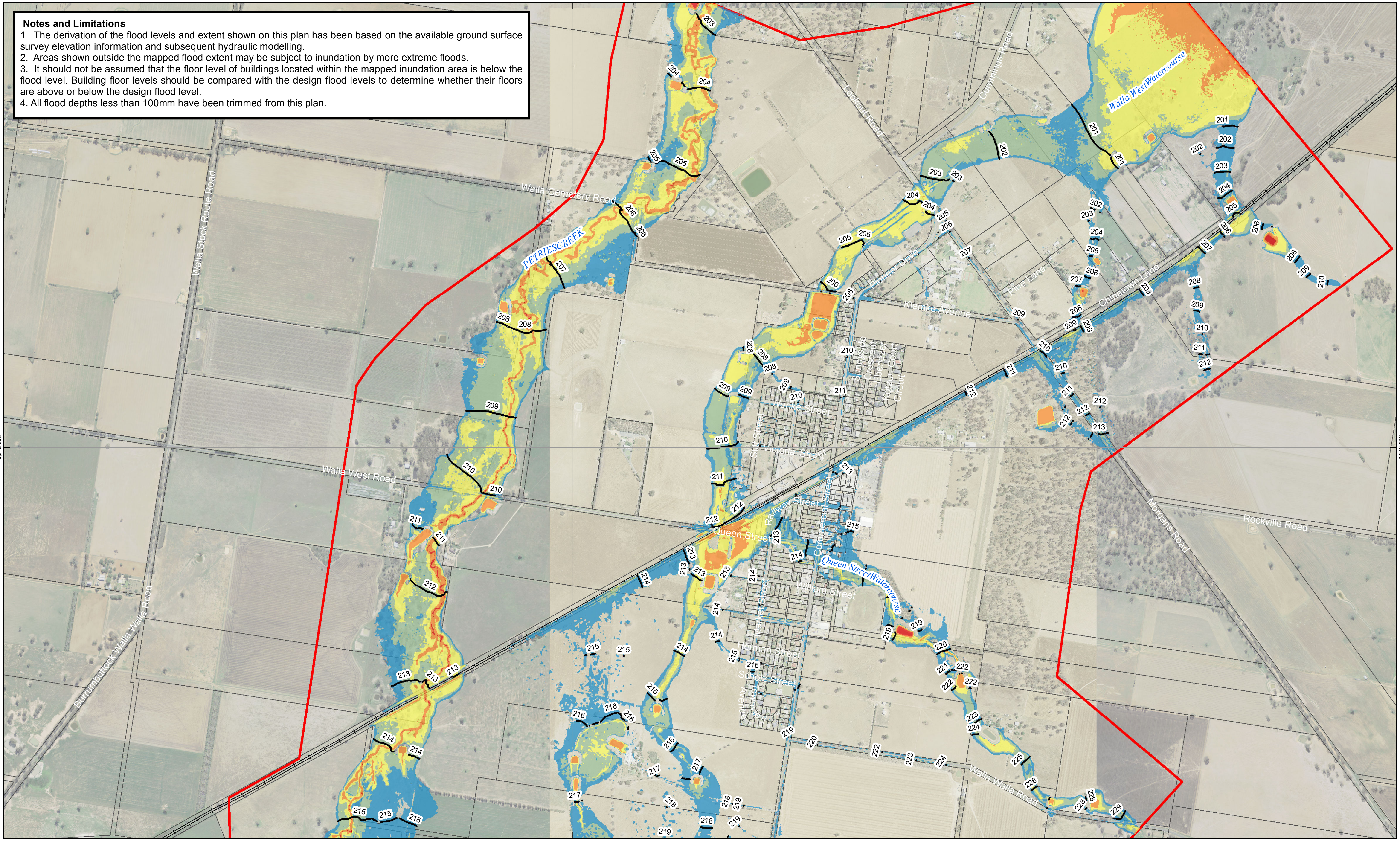

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- > 2.00
- Cadastre
- Hydraulic Modelling Extent
- Flood Contours (mAHD)
- Railway

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Date	8 Feb 2017

100 Year ARI Flood Event
Flood Extent and Depth

Figure A2

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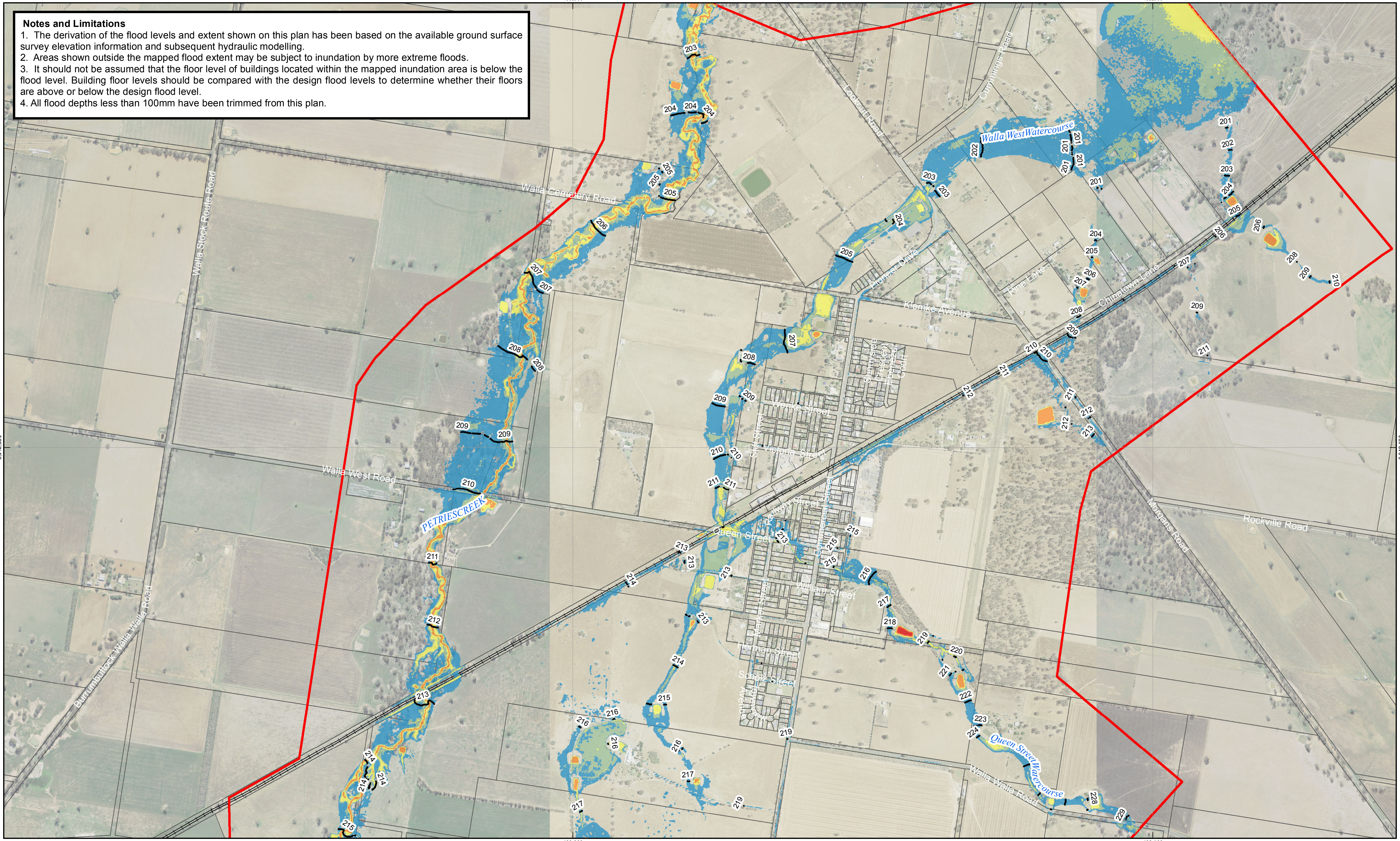

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Cadastre
Hydraulic Modelling Extent
Flood Contours (mAHD)
Railway

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Date	8 Feb 2017

5 Year ARI Flood Event
Flood Extent and Depth

Figure A3

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Data source: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

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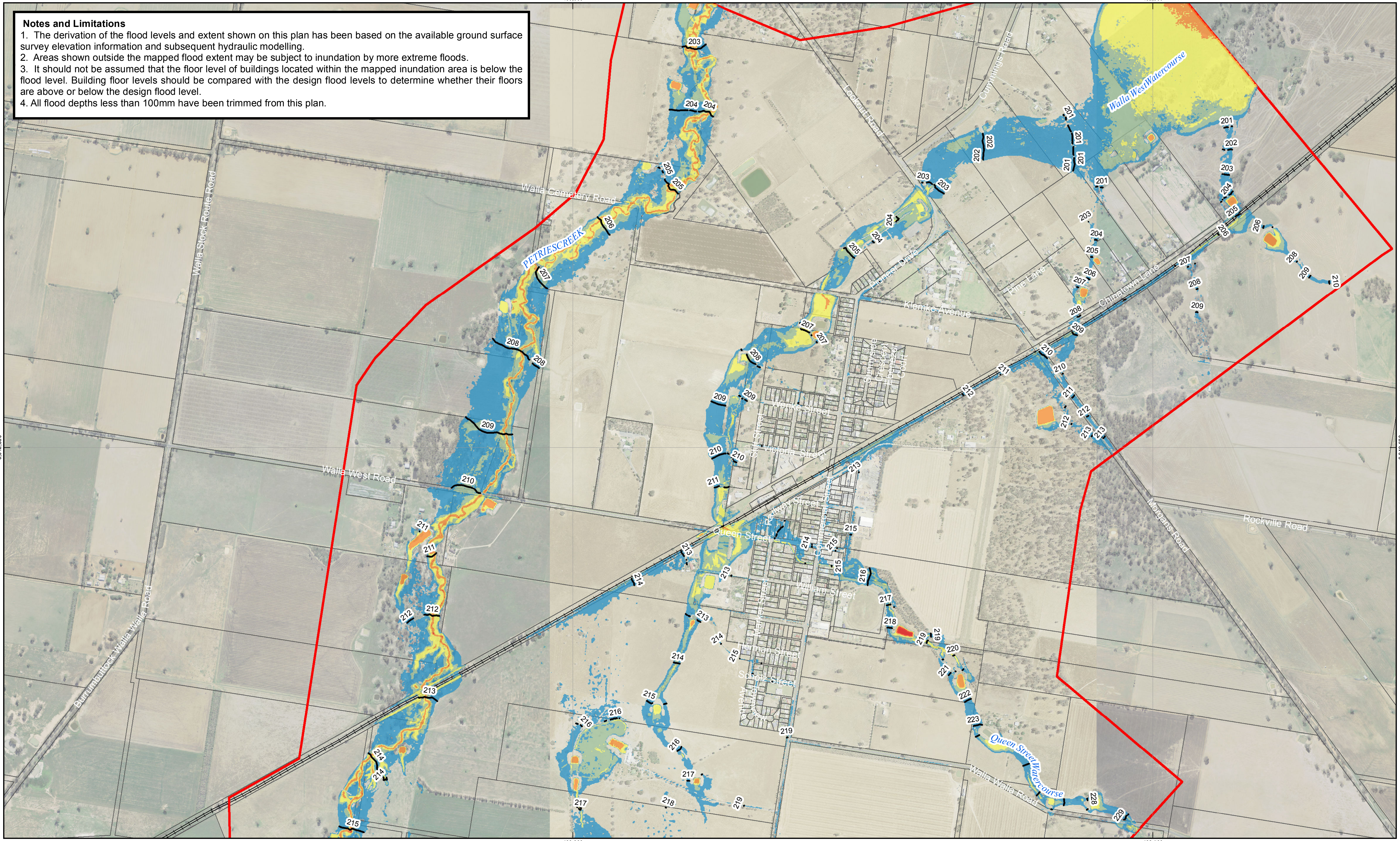

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Cadastre
Hydraulic Modelling Extent
Flood Contours (mAHD)
Railway

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Date	8 Feb 2017

10 Year ARI Flood Event
Flood Extent and Depth

Figure A4

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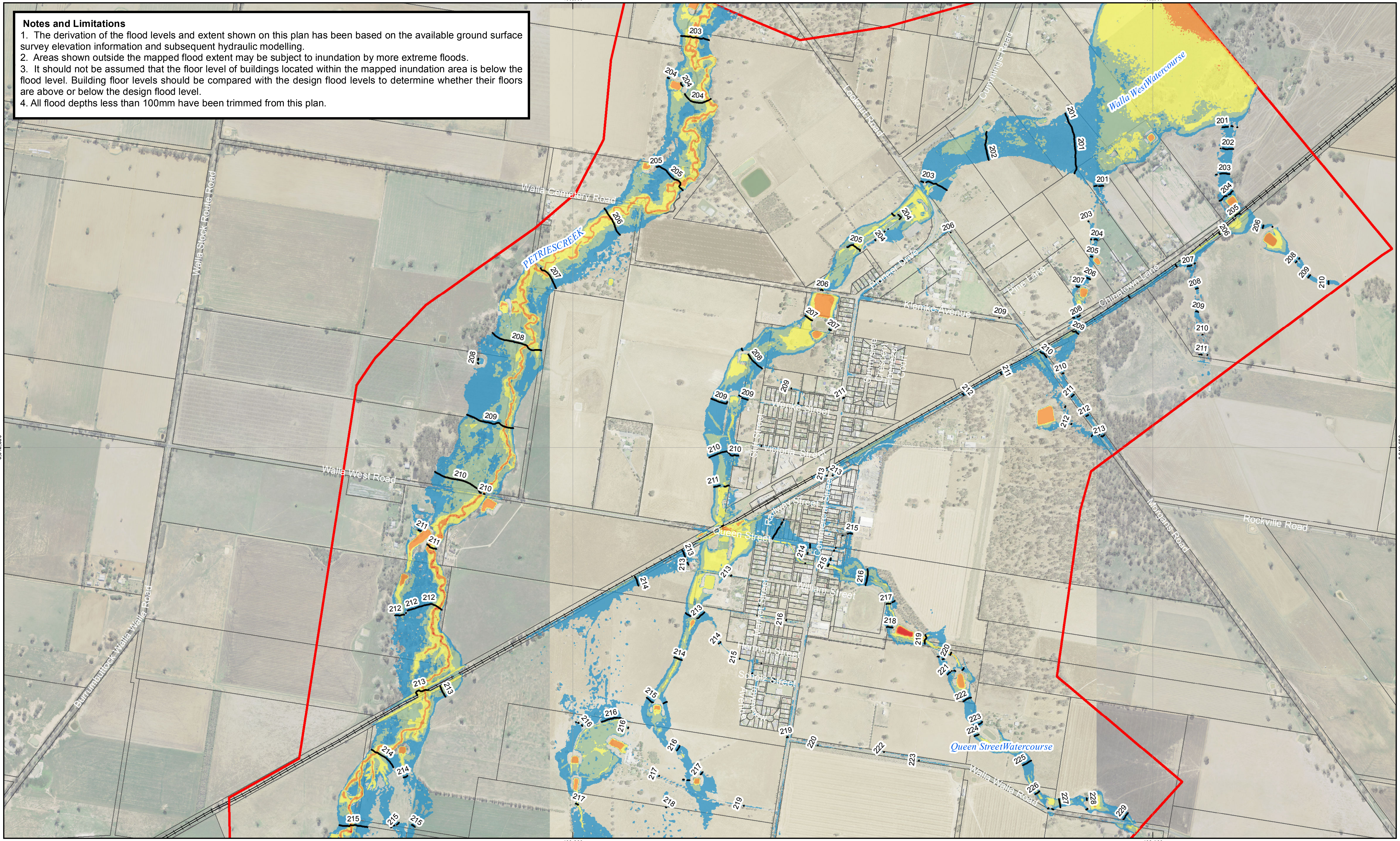

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Cadastre
Hydraulic Modelling Extent
Flood Contours (mAHD)
Railway

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Date	8 Feb 2017

20 Year ARI Flood Event
Flood Extent and Depth

Figure A5

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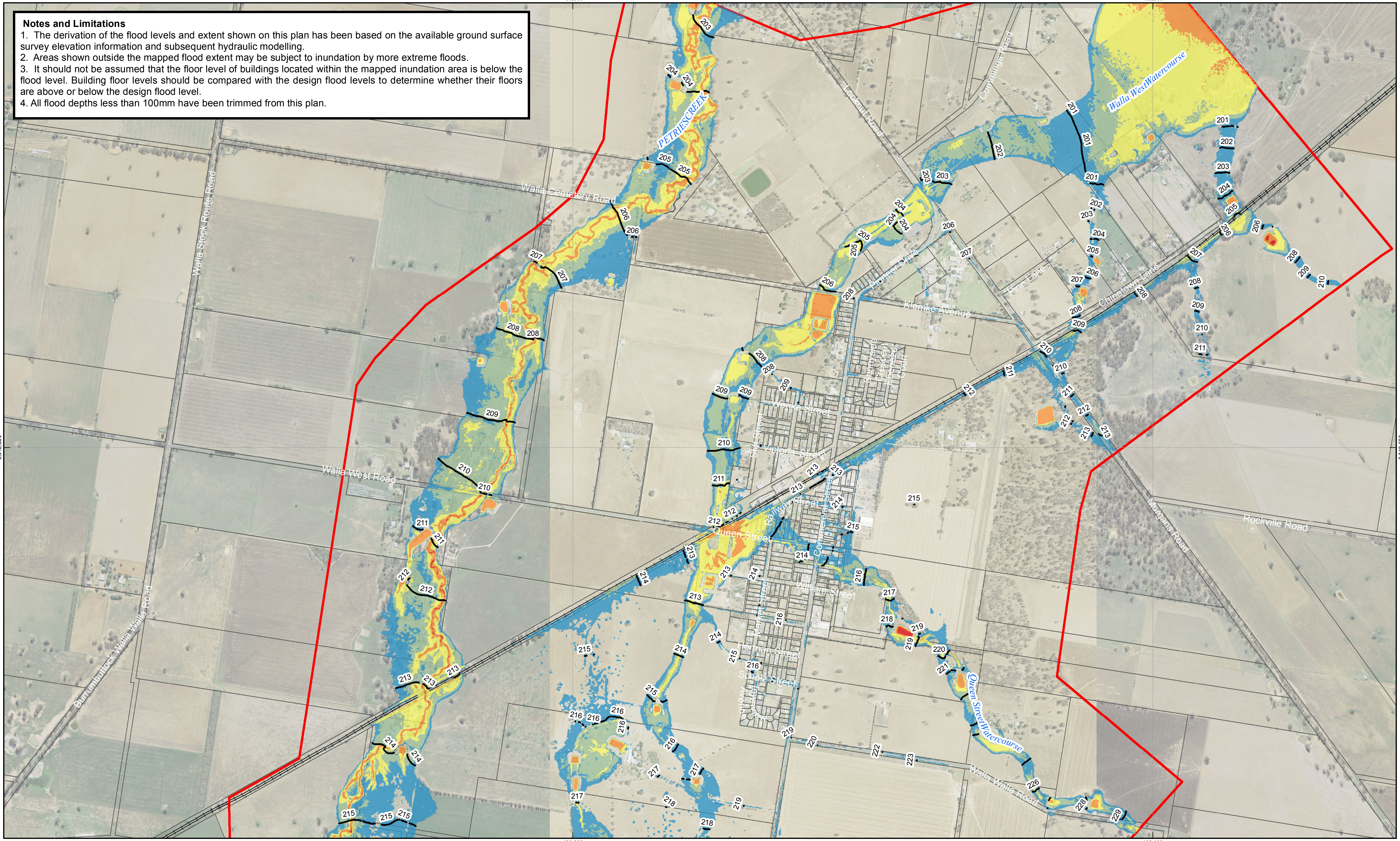

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Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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LEGEND

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- 0.50 - 1.00
- 1.00 - 2.00
- > 2.00
- Cadastre
- Hydraulic Modelling Extent
- Flood Contours (mAHD)
- Railway

Greater Hume Shire Council
Walla Walla Flood Study

Job Number	31-33591
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Date	8 Feb 2017

50 Year ARI Flood Event
Flood Extent and Depth

Figure A6

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Data source: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

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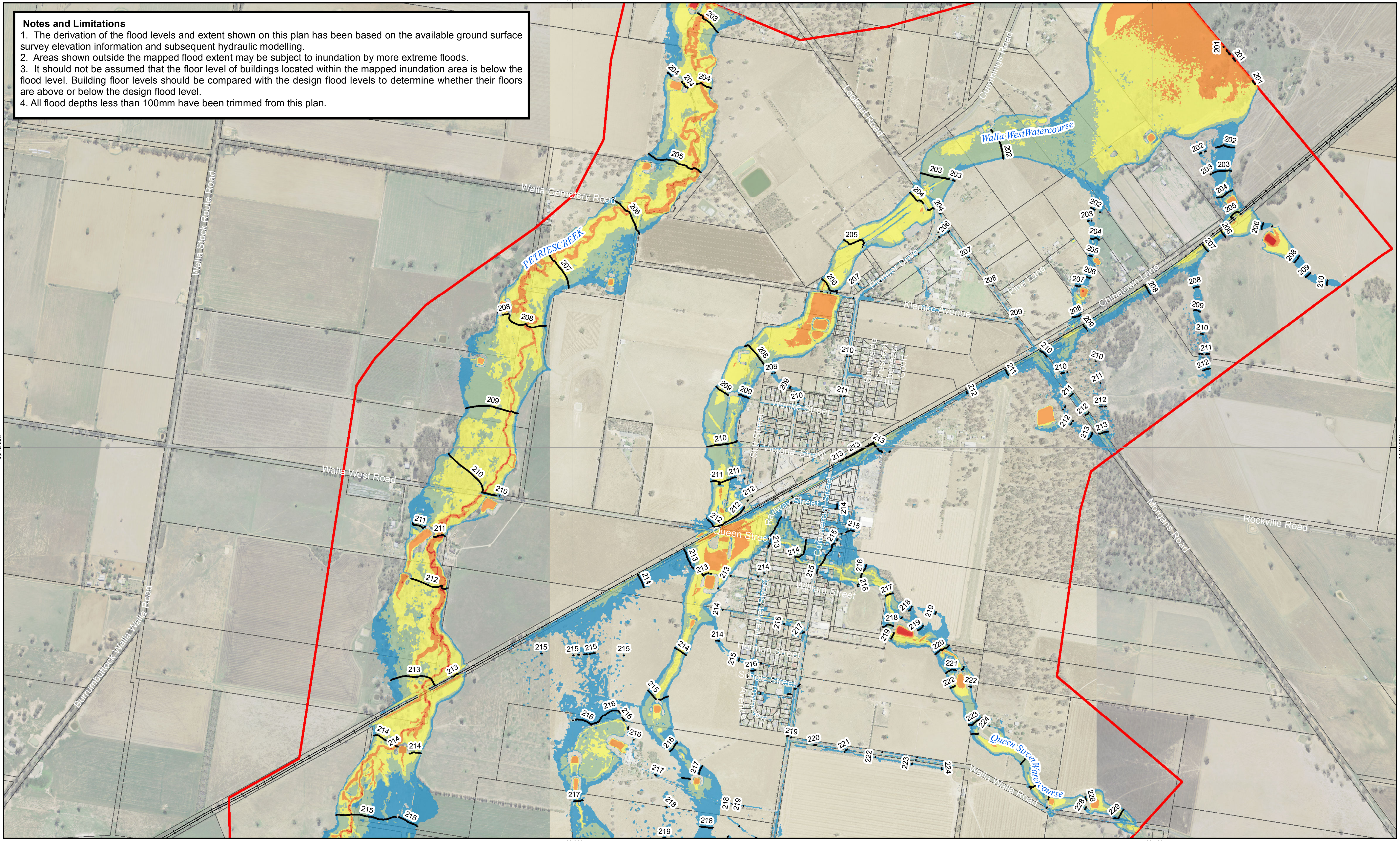

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Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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- 0.30 - 0.50
- 0.50 - 1.00
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- > 2.00
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- Hydraulic Modelling Extent
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- Railway

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Walla Walla Flood Study

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Date	8 Feb 2017

200 Year ARI Flood Event
Flood Extent and Depth

Figure A7

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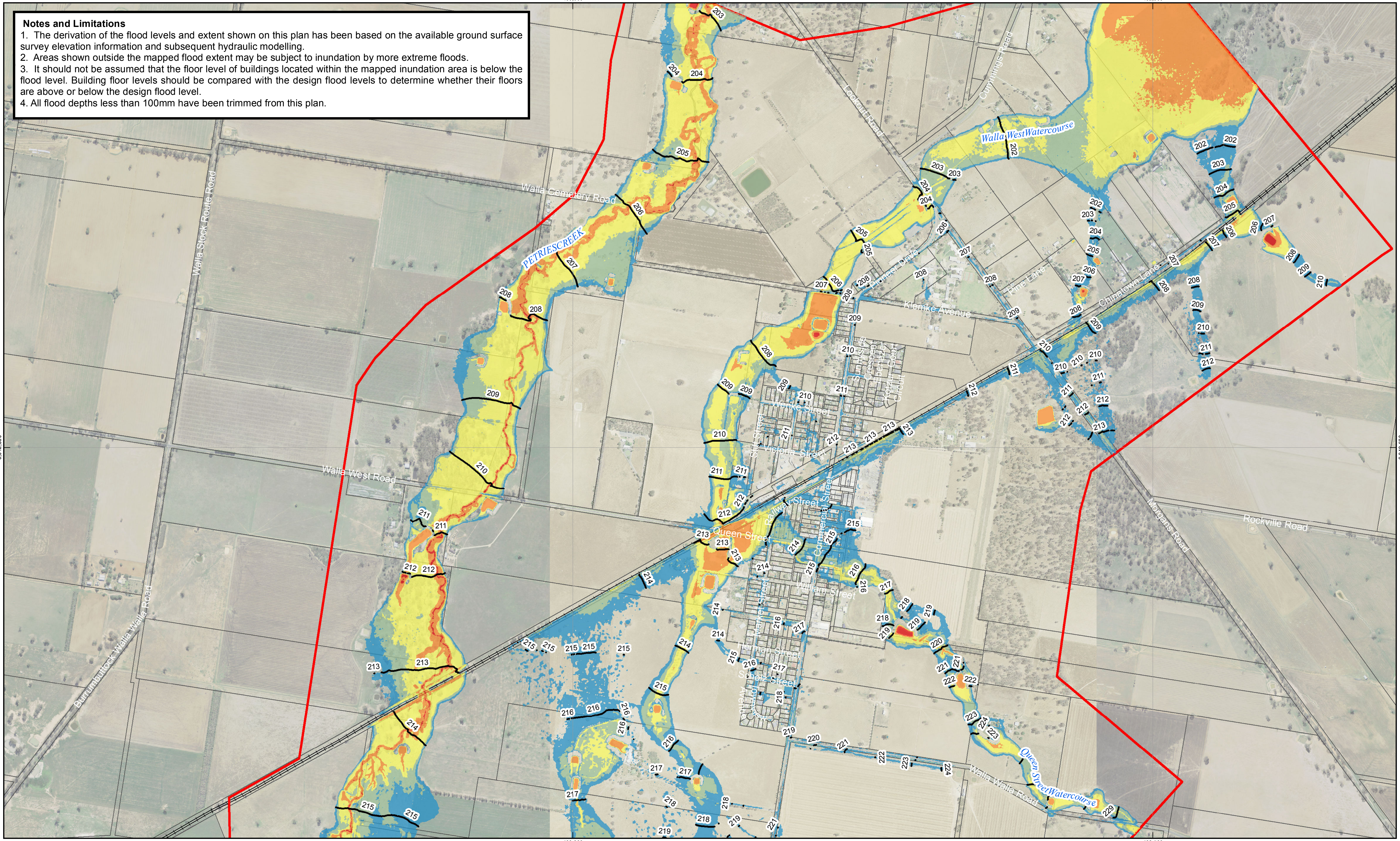
180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

Data source: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

Notes and Limitations

1. The derivation of the flood levels and extent shown on this plan has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.
2. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods.
3. 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.
4. All flood depths less than 100mm have been trimmed from this plan.



Paper Size A3

0 125 250 500

Metres

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

N

LEGEND

- Cadastre
- Hydraulic Modelling Extent
- Railway
- 0.10 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- \> 2.00
- Flood Contours (mAHD)

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Walla Walla Flood Study

Job Number	31-33591
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500 Year ARI Flood Event
Flood Extent and Depth

Figure A8

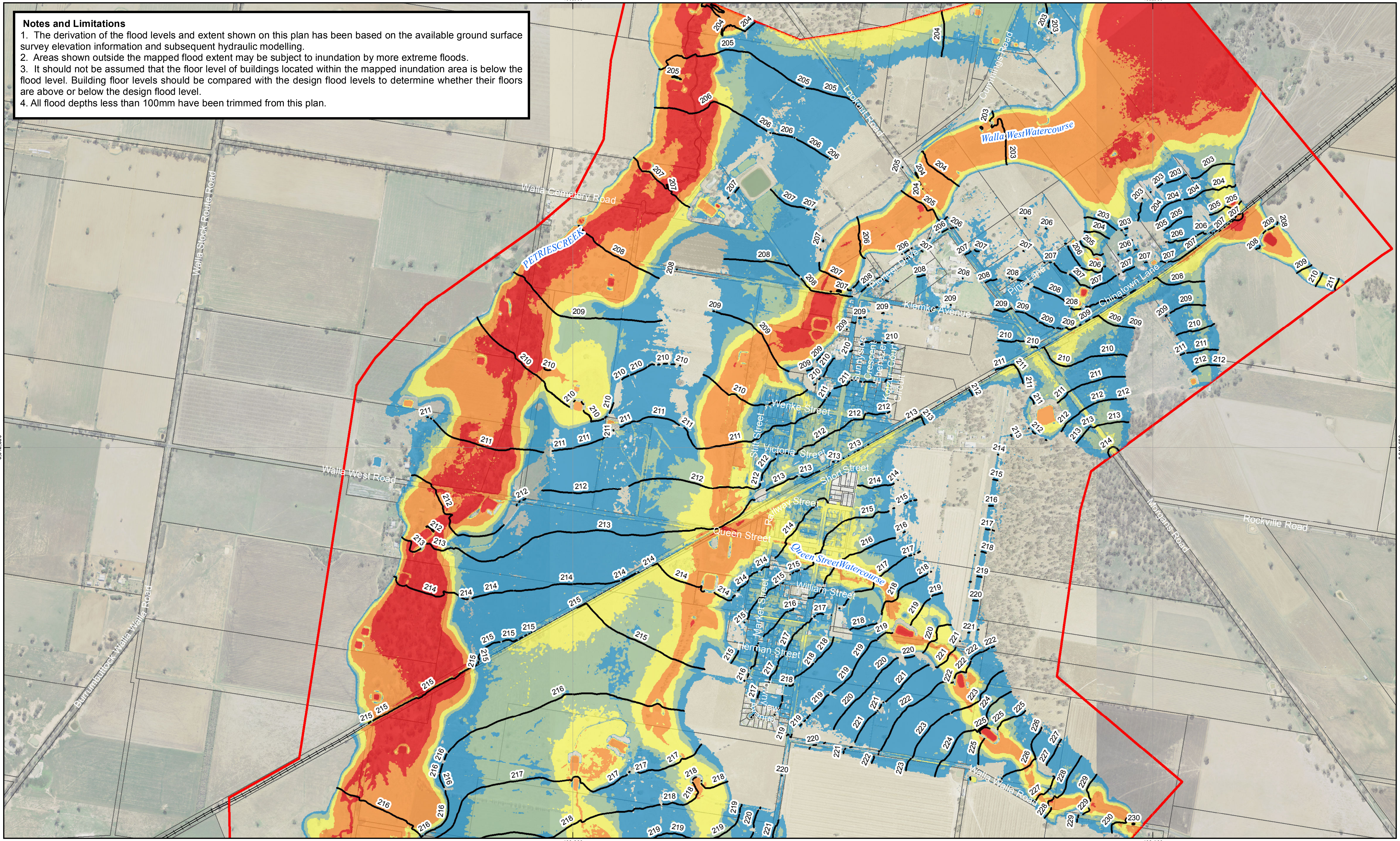
G:\31\33591\GIS\Maps\Deliverables\31_33591_Walla_FS_Fig_A9_500yr_Flood_Extent_and_Depth_Rev_A.mxd

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: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

Notes and Limitations

1. The derivation of the flood levels and extent shown on this plan has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.
2. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods.
3. 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.
4. All flood depths less than 100mm have been trimmed from this plan.



Paper Size A3

0 125 250 500

Metres

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

N

LEGEND

- 0.10 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- > 2.00
- Cadastre
- Hydraulic Modelling Extent
- Flood Contours (mAHD)
- Railway

Greater Hume Shire Council
Walla Walla Flood Study

Job Number	31-33591
Revision	B
Date	8 Feb 2017

PMF Flood Event
Flood Extent and Depth

Figure A9

G:\31\33591\GIS\Maps\Deliverables\31_33591_Walla_FS_Fig_A10_PMF_Flood_Extent_and_Depth_Rev_A.mxd

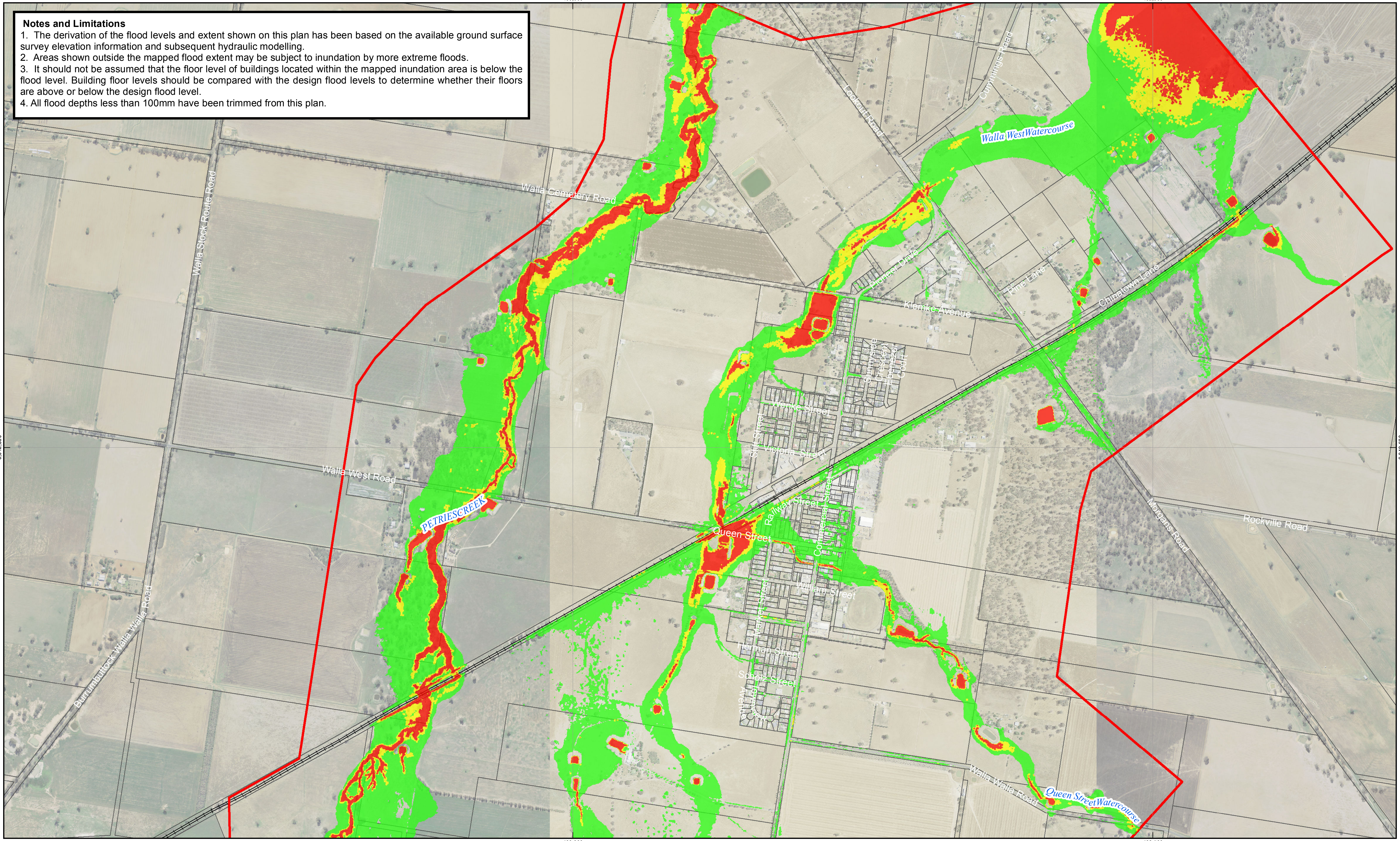
180 Lonsdale Street Melbourne VIC 3000 Australia **T** 61 3 8687 8000 **F** 61 3 8687 8111 **E** melmail@ghd.com **W** www.ghd.com

Data source: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

Appendix B – Provisional Hazard Category Maps

Notes and Limitations

1. The derivation of the flood levels and extent shown on this plan has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.
2. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods.
3. 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.
4. All flood depths less than 100mm have been trimmed from this plan.



Paper Size A3

0 125 250 500

Metres

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

N

LEGEND

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard
- Cadastre
- Hydraulic Modelling Extent
- Railway

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Walla Walla Flood Study

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100 Year ARI Flood Event
Provisional Flood Hazard

Figure B1

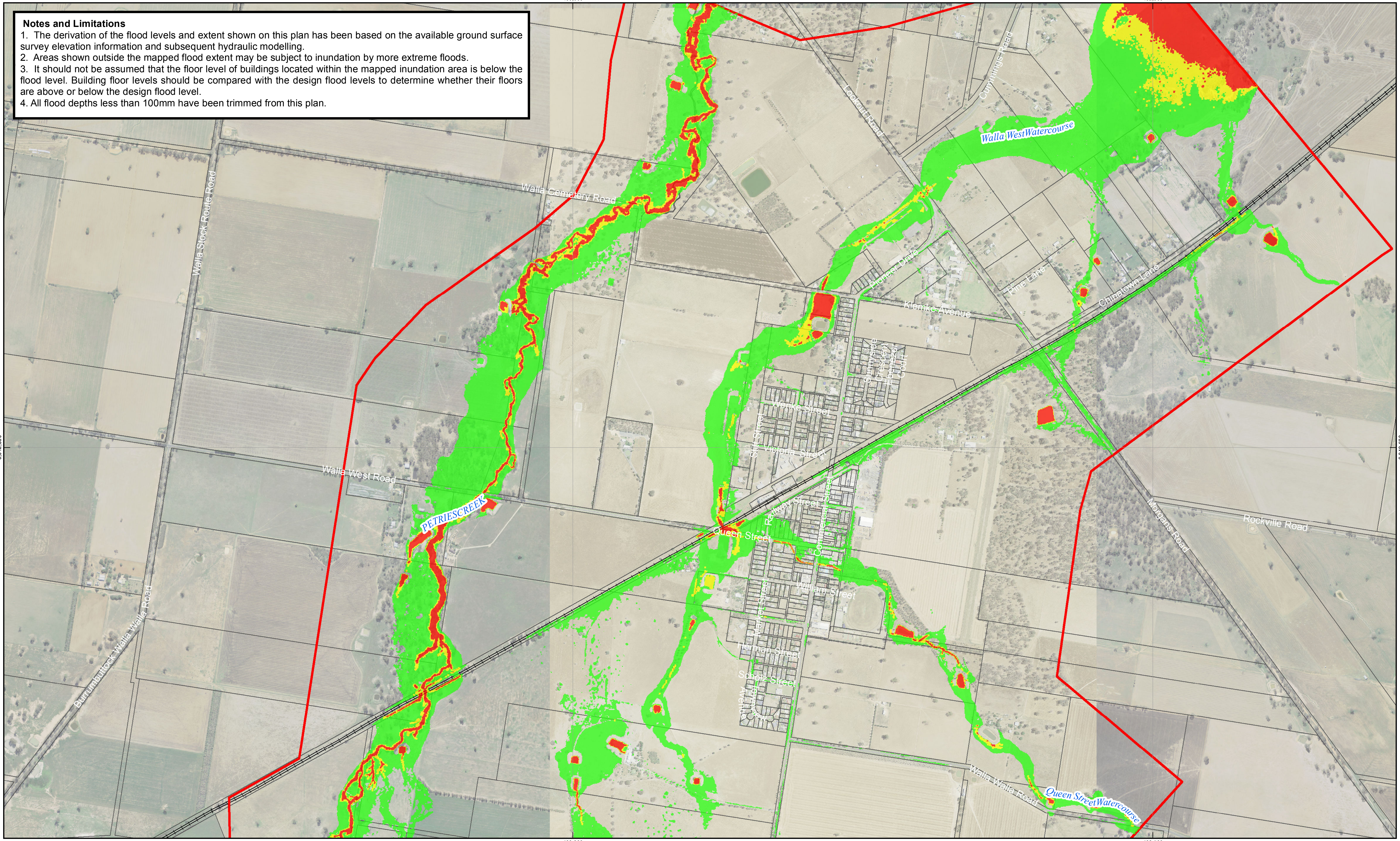
G:\31\33591\GIS\Maps\Deliverables\31_33591_Walla_FS_Fig_B1_100yr_Flood_Hazard_Rev_A.mxd

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: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

Notes and Limitations

1. The derivation of the flood levels and extent shown on this plan has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.
2. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods.
3. 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.
4. All flood depths less than 100mm have been trimmed from this plan.



Paper Size A3

0 125 250 500

Metres

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

N

LEGEND

- 1 - Low Hazard
- 2 - Intermediate Hazard
- 3 - High Hazard
- Cadastre
- Hydraulic Modelling Extent
- Railway

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Walla Walla Flood Study

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20 Year ARI Flood Event
Provisional Flood Hazard

Figure B2

G:\31\33591\GIS\Maps\Deliverables\31_33591_Walla_FS_Fig_B2_020yr_Flood_Hazard_Rev_A.mxd

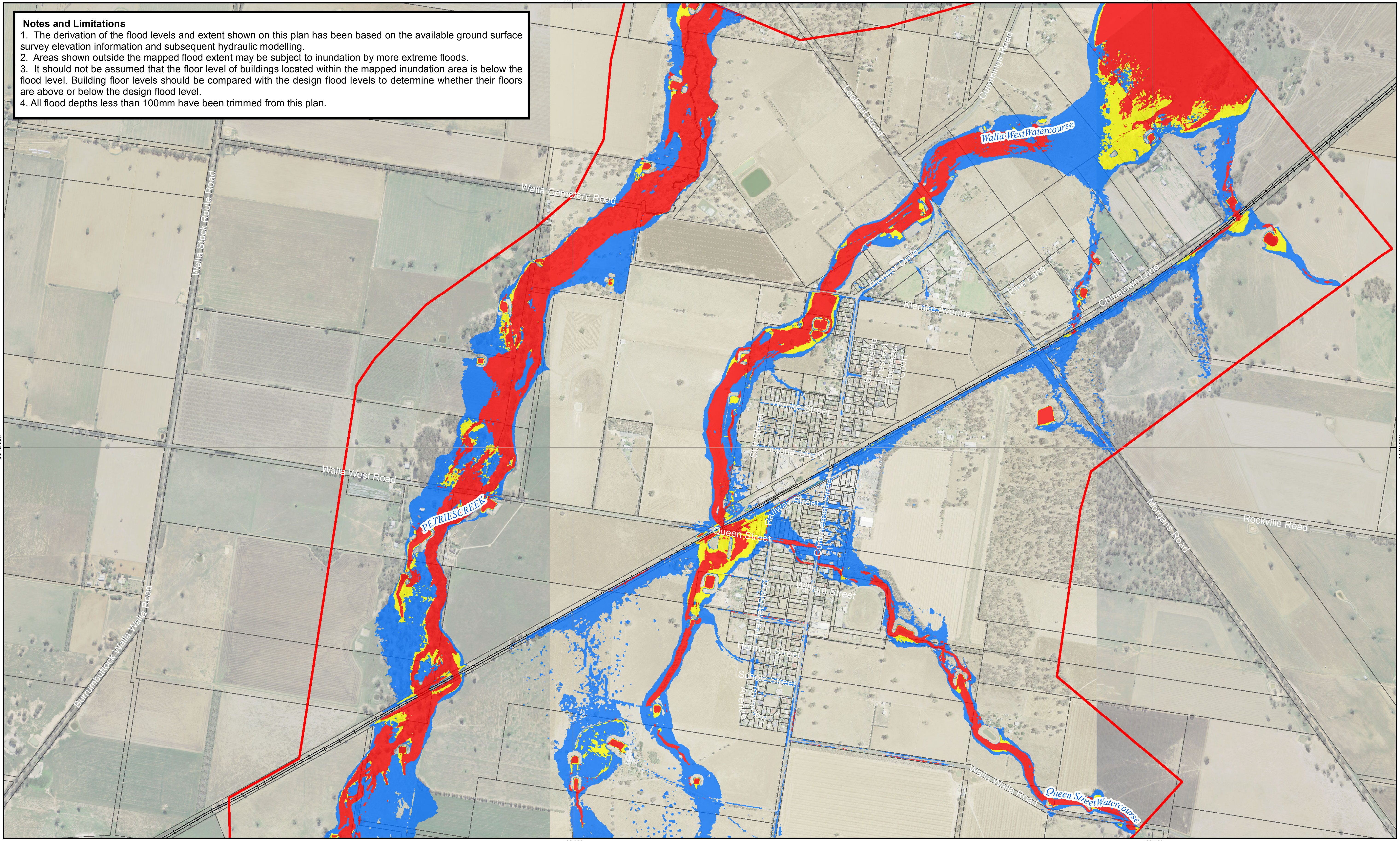
180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

Data source: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

Appendix C – Hydraulic Category Maps

Notes and Limitations

1. The derivation of the flood levels and extent shown on this plan has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.
2. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods.
3. 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.
4. All flood depths less than 100mm have been trimmed from this plan.



Paper Size A3

0 125 250 500

Metres

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

N

LEGEND

- Flood Fringe
- Flood Storage
- Floodway
- Cadastre
- Hydraulic Modelling Extent
- Railway

Greater Hume Shire Council
Walla Walla Flood Study

Job Number	31-33591
Revision	B
Date	8 Feb 2017

100 Year ARI Flood Event Hydraulic Category

Figure C1

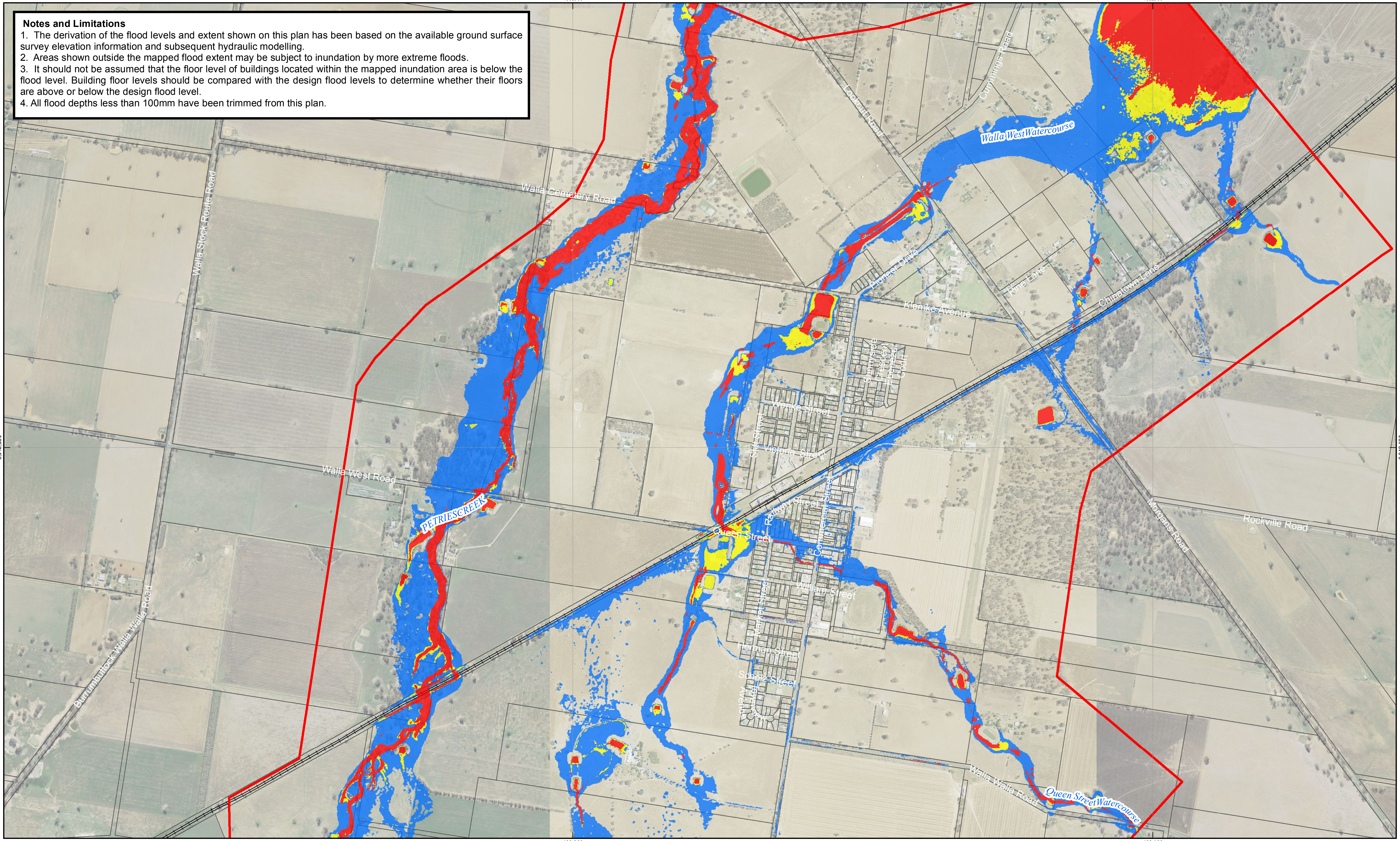
G:\31\33591\GIS\Maps\Deliverables\31_33591_Walla_FS_Fig_C1_100yr_Flood_Category_Rev_A.mxd

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: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

Notes and Limitations

1. The derivation of the flood levels and extent shown on this plan has been based on the available ground surface survey elevation information and subsequent hydraulic modelling.
2. Areas shown outside the mapped flood extent may be subject to inundation by more extreme floods.
3. 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.
4. All flood depths less than 100mm have been trimmed from this plan.



Paper Size A3

0 125 250 500

Metres

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

N

LEGEND

- Flood Fringe
- Flood Storage
- Floodway
- Cadastre
- Hydraulic Modelling Extent
- Railway

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Walla Walla Flood Study

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Date	8 Feb 2017

20 Year ARI Flood Event
Hydraulic Category

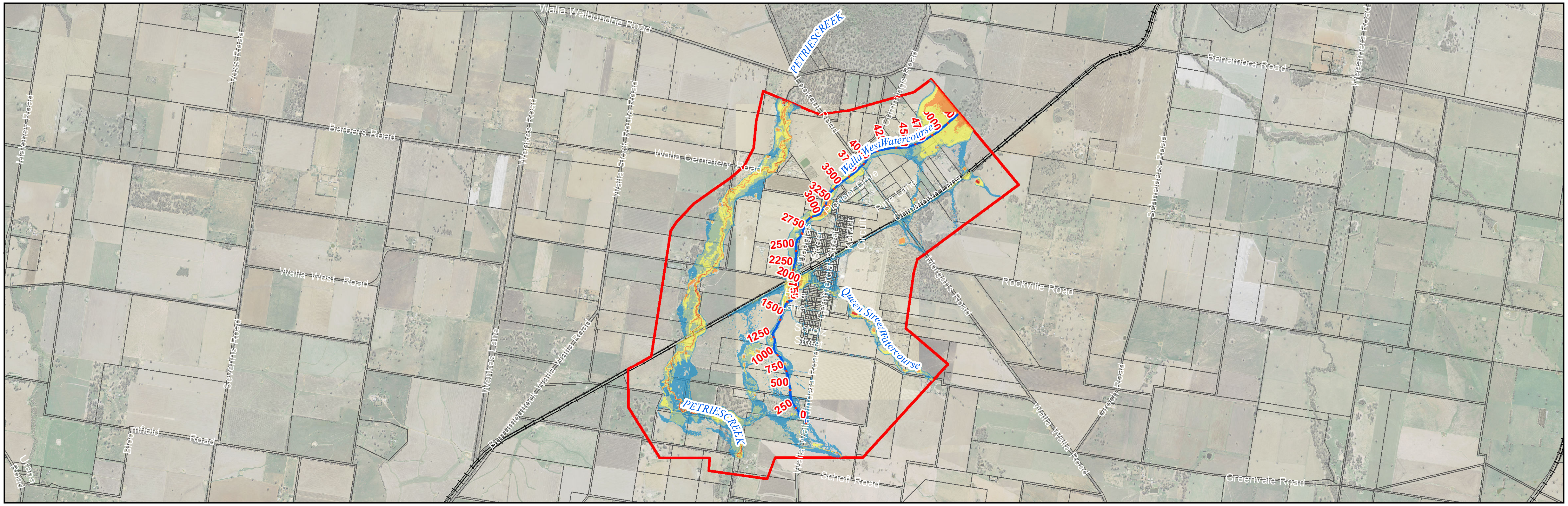
Figure C2

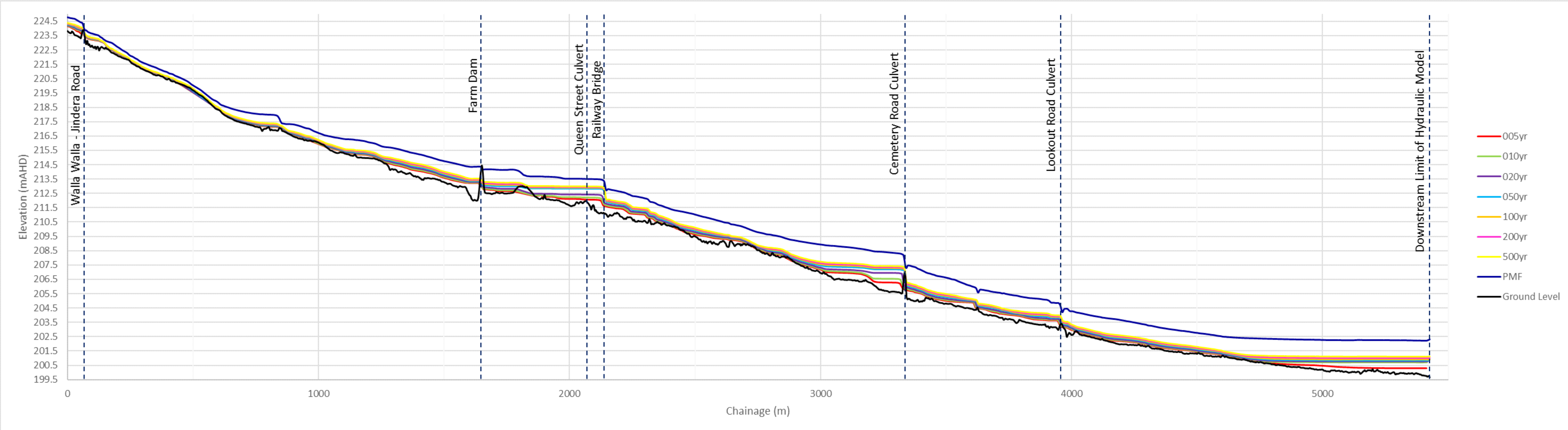
G:\31\33591\GIS\Maps\Deliverables\31_33591_Walla_FS_Fig_C2_020yr_Flood_Category_Rev_A.mxd

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: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

Appendix D – Flood Profile Maps





Paper Size A3

0 412.5 825 1,650

Metres

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

N

LEGEND

- 0.10 - 0.30
- 0.30 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- > 2.00
- Cadastre
- Hydraulic Modelling Extent
- Walla West Watercourse
- Railway

Greater Hume Shire Council
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Date	8 Feb 2017

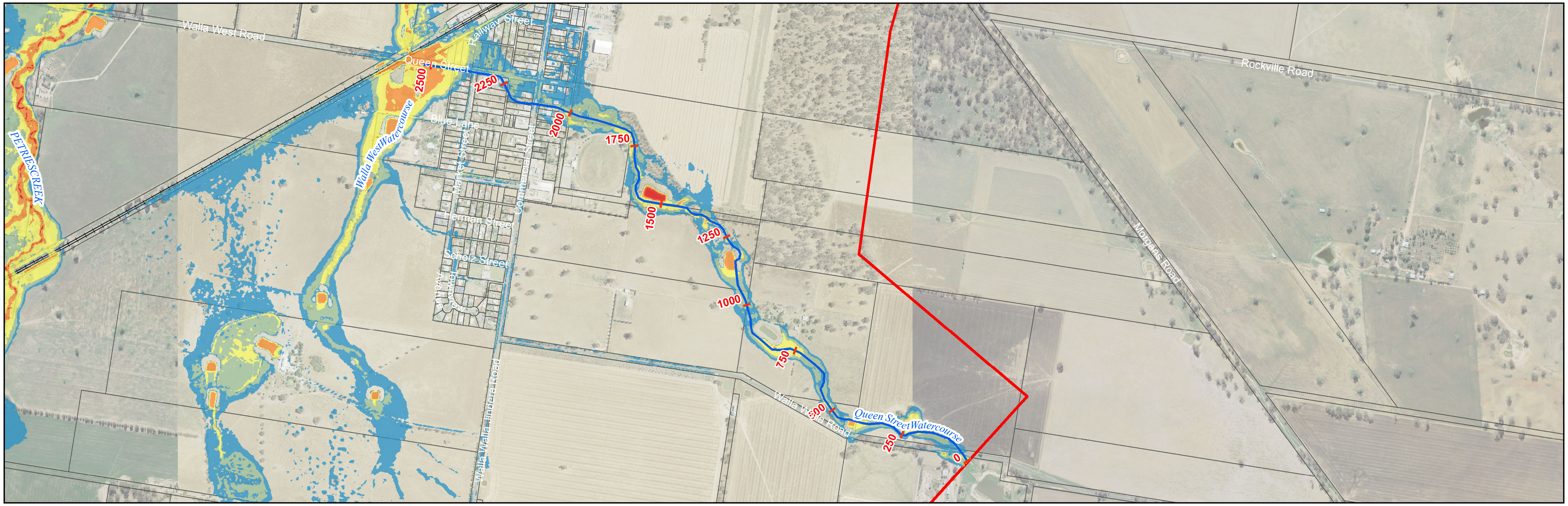
Walla West Waterway Flood Profile

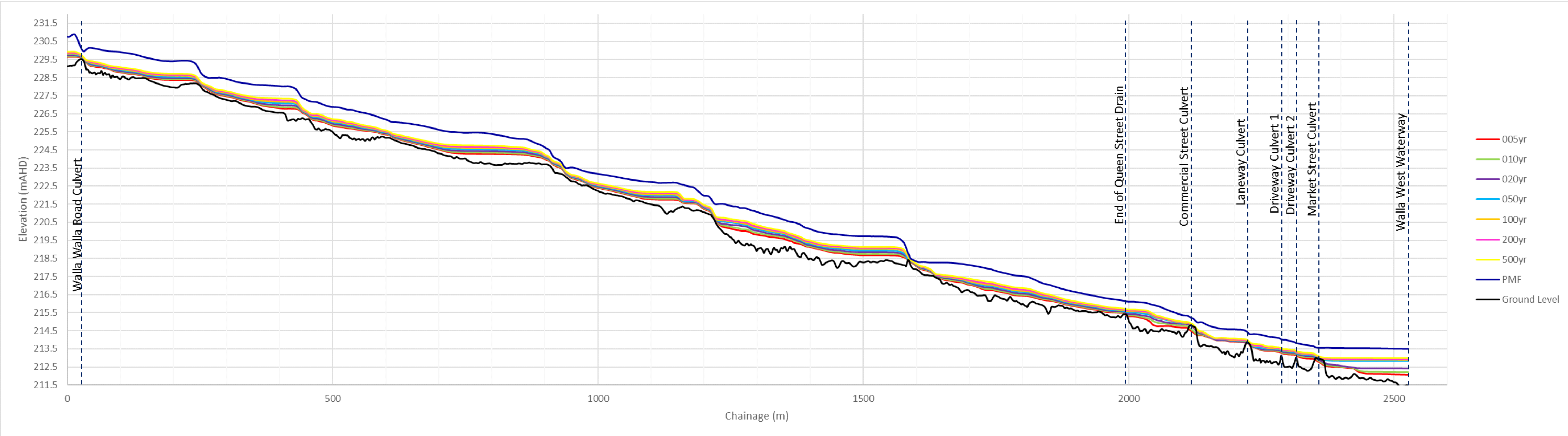
Figure D1

G:\31\33591\GIS\Maps\Deliverables\31_33591_Walla_FS_Fig_D1_Walla_West_Longsection_Rev_A.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: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas





Paper Size A3

0 105 210 420

Metres

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

N

LEGEND

0.10 - 0.30
0.30 - 0.50
0.50 - 1.00
1.00 - 2.00
> 2.00
Cadastre
Hydraulic Modelling Extent
Queen Street Watercourse
Railway

Greater Hume Shire Council
Walla Walla Flood Study

Job Number	31-33591
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Date	8 Feb 2017

Queen Street Waterway & Drain Flood Profile

Figure D2

G:\31\33591\GIS\Maps\Deliverables\31_33591_Walla_FS_Fig_D2_Queen_Street_Longsection_Rev_A.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: Flood modelling data, GHD 2014, Imagery, Greater Hume Shire council, 2010. Created by:sldouglas

Appendix E – CEG and Questionnaire

Community Engagement Guide

Questionnaire

Walla Walla Flood Study, Floodplain Risk Management Study & Plan

Community Engagement Guide No 1

Overview

To help mitigate the effects of future floods at Walla Walla, Greater Hume Shire Council has contracted GHD to prepare a Floodplain Risk Management Plan for the town.

The study will produce detailed flood mapping which will assist in confirming those areas suitable for future development and for the setting of minimum floor level heights.

Parts of Walla Walla are affected by flooding from high intensity rainfall storm events. Significant flooding at Walla Walla has recently occurred in September 2005, October 2010, February 2011 and March 2012.

Greater Hume Shire Council is also preparing Floodplain Risk Management Plans for all larger towns within the shire, including Holbrook, Culcairn, Henty and Jindera.

Flooding at Walla Walla can be due to flooding from the waterway aligned down the western side of the town, or due to flooding from local runoff generated from the catchment areas on the east side of town which then discharges westwards through the town. This includes the drain in the vicinity of Queen Street.

Council and GHD are committed to listening to the concerns and issues of the community and stakeholders. Throughout the study there will be opportunities for the local community and stakeholders to provide feedback during the project.

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The project is being funded by Greater Hume Shire Council and Office of Environment and Heritage.

Estimated budget for the project is $120,000.

Floodplain Risk Management Committee

Council has formed the Walla Walla Floodplain Risk Management Committee (WWFRMC) to oversee the preparation of the Floodplain Risk Management Plan. Members of this Committee include Councillor Karen Schoff, and local community representatives Kim Lieschke, Anthony Brinkmann and Shane Trimble.

The WWFRMC provides a link between the flood study team and the community throughout the various stages of the project. The WWFRMC will meet throughout the course of the project.

Questionnaire

The project team is keen to learn from local residents when and where past flooding has occurred at Walla Walla. We are interested in how you and your property have been affected, particularly if your house or workplace at Walla Walla has been subject to above floor flooding.

We are also interested in getting an understanding of your thoughts towards particular flood management options.

Attached is a survey questionnaire that all members of the community are being encouraged to fill out. You can email

your completed questionnaire to **mail@greaterhume.nsw.gov.au or you can drop it off at Lieschke Motors at the corner of Commercial and Queen Streets.** Your completed questionnaire will be used by Council and its consultant.

You may, for example, have noted the peak flood height as a mark on a tree, fence post, shed wall, house wall or some other object. If you have yourself accurately recorded such flood height marks or are aware of others recording marks, it would be appreciated if you could provide these details in your questionnaire response.

Community Forum

A community forum provides residents with the opportunity to speak to the consultant's project manager and members of the WWFRMC regarding any aspects of the project. The forum details are as follows:

When: **Tuesday, 5 April 2016 4pm to 7pm**
Where: **Walla Walla Hall**

You can call in at the hall at any time during the session and have an individual discussion with someone from the WWFRMC or the consultant. If you have any photographs of flooding for example, bring these along with you.

YOUR input is important

Submissions, completed survey quesionnaires, photographs or other information will be received until 30 April 2016.

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Contact Information

Contact details are provided below if you have any questions about the questionnaire or any other general questions regarding the project.

You can also contact members of the WWFRMC to discuss any issues or concerns you may have relevant to the project.

For more information contact:

GHD Project Manager - Trevor Clark
PO Box 992, Wodonga, Vic, 3689
Phone – 02 6043 8735
Email – trevor.clark@ghd.com

Council Project Supervisor – Michael Oliver
PO Box 99, Holbrook, NSW, 2644
Phone – 02 6029 8588
Email – moliver@greaterhume.nsw.gov.au

Community Representative

- Karen Schoff 0428 860 833
- Kim Lieschke 0412 691 312
- Anthony Brinkmann 0459 292 296
- Shane Trimble 0428 300 069

Walla Walla Flood Plan, Floodplain Risk Management Study & Plan

Survey Questionnaire

Name: ______________________________

Address: ______________________________

Telephone: ______________ Mobile: ______________

1. How long have you lived at Walla Walla? __________ Years__________ Months
2. Have you ever seen/experienced flooding at Walla Walla? Yes No (*Please circle*)
3. If yes, in what year and month did the floods take place?

____

____

4. What effects did the previous floods have on you and your property (e.g. was your house flooded to above floor level, garage / carport / shed flooding, or grounds only flooding)?

____

____

5. How do you prepare for a flood?

____

____

____

6. To reduce the effects of flooding, do you believe Council should focus its efforts on:

	Tick if YES
• improved waterways and waterway structures (bridges/culverts/drainage)	☐
• educating people about how to prepare for a flood	☐
• improved flood warning and communication	☐
• encouraging residents to make property modifications (e.g. house raising)	☐
• voluntary purchase of properties in high risk areas	☐
• improved development controls	☐
• all of the above	☐

Walla Walla Flood Plan, Floodplain Risk Management Study & Plan

Survey Questionnaire

7. Are there any other issues you would like the project team to take into consideration?

Please attach any further information that you would like to provide to the questionnaire. Thank you for taking the time to complete this survey. Please return any completed questionnaires and any other information (e.g. copies of flood photographs) to Walla Walla RTC - WAW Credit Union, Commercial Street, Walla Walla or alternatively scan and email to **mail@greaterhume.nsw.gov.au**

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Appendix F – Copy of Public Submission and Response

Copy of the only public submission received on the November 2016 draft Walla Walla Flood Study report

Copy of GHD response to the public submission

From: Andrew C. Kotzur [redacted]
Sent: Tuesday, 29 November 2016 7:45 AM
To: Steven Pinnuck; Margaret Killalea
Subject: Submission - Walla Flood Study

Hi Steve/Marg

Wasn't sure who or how to send this.

I have read the GHD flood study and generally agree with it. However I would make two comments;

Railway Line
The report says that "there is some anecdotal evidence" to suggest that the railway line is not impervious and that the modelling assumes it is impervious. I have seen significant amounts of water flowing through the ballast in the 2010 and 2012 events. Inspection of the railway line construction will indicate that the ballast is porous. Were the results of the study change significantly when the railway ballast is considered to be porous, then this should be seen as a major flaw in this report.

1973-1975 Events
Whilst I understand the difficulties of not having concrete evidence, I believe that the 1973-1974 events are very much understated. In addition to the flooding noted;

- The property at 64 Commercial st (currently Landmark) experienced higher levels of flooding then than in the 2010 and 2012 events.
- The property at 56-60 Commercial st (Kotzur) experienced flooding right through the building (including major electrical reconstruction due to damage). The flooding in 2010/2012, by comparison, was minor and managed with a few sand bags.
- The property on the Sth/east corner of the Commercial St level crossing (was the railway Station Master's residence) had in excess of 300mm of water running through it. All buildings there at the time, except the house which was elevated by 600-900mm) were inundated.

Regards

Andrew Kotzur

KOTZUR

60 Commercial St, Walla Walla, NSW 2659
T + 61 (0) 2 6029 4700 **F** + 61 (0) 2 6029 2307
E[redacted] **W** www.kotzur.com

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From: Trevor Clark
Sent: Monday, 6 February 2017 10:21 AM
To: [redacted]
Cc: Michael Oliver (InTouch)
Subject: Walla Flood Study
Attachments: AndrewKotzurSubmission.pdf; DiversionPlan_opt.pdf

CompleteRepository: 3133591
Description: Walla Walla Flood Study
JobNo: 33591
OperatingCentre: 31
RepoEmail: 3133591@ghd.com
RepoType: Job

Hi Andrew,

Thanks for your thoughts on the Walla Flood Study report – have attached your email submission. The Flood Study report will be finalised shortly. In response to your submission I have made some changes to the relevant sections of the report. Changes described below.

Railway line seepage issue

The section of the report which deals with the seepage issue (6.6.7) will be expanded as follows:

> The modelling assumes that the railway line ballast is impervious to flow. There have been some anecdotal reports that seepage through the ballast may have occurred in the 2012 flood, notably on the east side of Commercial Street.
>
> Significant seepage through the railway ballast is thought to be unlikely. A house located in the area where the anecdotal seepage is reported to have occurred was inspected by GHD. The floor level of the house in question is raised only marginally above ground level and would be particularly vulnerable to very shallow flow which could be induced by local runoff.
>
> Some seepage through the railway line ballast will occur. The amount of flow seeping through the railway ballast will however be limited by the:
>
> - Relatively short duration of flooding at Walla Walla.
> - Limited water pressure given the depth of floodwater banking up against the south side of the railway embankment (ballast) is 0.2 to 0.4 metre on the east side of Commercial Street.
> - Limited porosity of the ballast.

1973/75 Flood Events Issue

Section 4.3.4 of the report (second dot point) will be expanded as follows:

- 1973 / 1974. A major flood was recorded for Bowna Creek in January 1974. The Bowna Creek catchment adjoins the Petries Creek catchment. The Bowna Creek flood peak occurred on the evening of 10 January 1974. This followed a significant runoff event seven days earlier. A total of 67 mm was recorded at the Walla Walla Post Office site for the 24 hours to 9 am on the 11 January 1974. Anecdotal accounts suggest that flood levels in 1974 were higher than flood levels in the more recent 2010 and 2012 flood events. Specific locations nominated where flood levels are reported to have been higher in 1974 are 56-60 Commercial Street (Kotzur silo factory site) and 64 Commercial Street (Landmark building). Few recorded details are however available in relation to flooding conditions in 1973 / 1974 at Walla Walla.

I have also added a few sentences to the Executive Summary indicating that anecdotal accounts suggest that the January 1974 flood was more severe than the 2010 and 2012 floods.

The next stage of the project is the Floodplain Risk Management Study which assesses options to reduce flooding impacts on the town. It would be good to get your thoughts on options to address flooding from the waterway which is referred to as the Queen Street Waterway in the report (aligned around the east and north sides of the sportsground). One fairly radical option would be to divert flows away from the town – see the attached plan. The yellow route was considered by Council back in the 1970's. The red route diverts flow to the downstream side of town (to a large bridge under the railway line at the eastern end of Chinatown Lane). You may have some ideas of your own.

There is a Walla Flood Committee meeting tomorrow evening (7 February). Happy to meet with you later in the week to discuss further if this happened to suit.

Regards

Trevor Clark
Senior Water Resources Engineer

GHD
T: 02 6043 8700 | V: 317735 | M: 0427 211 853 |trevor.clark@ghd.com
Suite 5, 105 Hume Street, Wodonga, VIC, 3690, Australia | http://www.ghd.com/
Water | Energy & Resources | Environment | Property & Buildings | Transportation

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A	T Clark	M Medwell-Squier		R Berg		7/10/2016
B	T Clark	R Berg		R Berg		8/11/2016
0	T Clark	R Berg		R Berg		9/5/2017

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