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GOULBURN FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

FINAL REPORT

July 2022

Goulburn Floodplain Risk Management Study and Plan

Final Report

Project:	Goulburn Floodplain Risk Management Study and Plan
Project Number:	180068
Client:	Goulburn Mulwaree Council
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Date	Version	Description
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21-October-2021	5	DRAFT REPORT – FOR EXHIBITION
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03-March-2020	3	Milestone 5 Report – Flood Risk Assessment
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Cover image: 2012 Flood Event, Wollondilly and Mulwaree River confluence, Supplied

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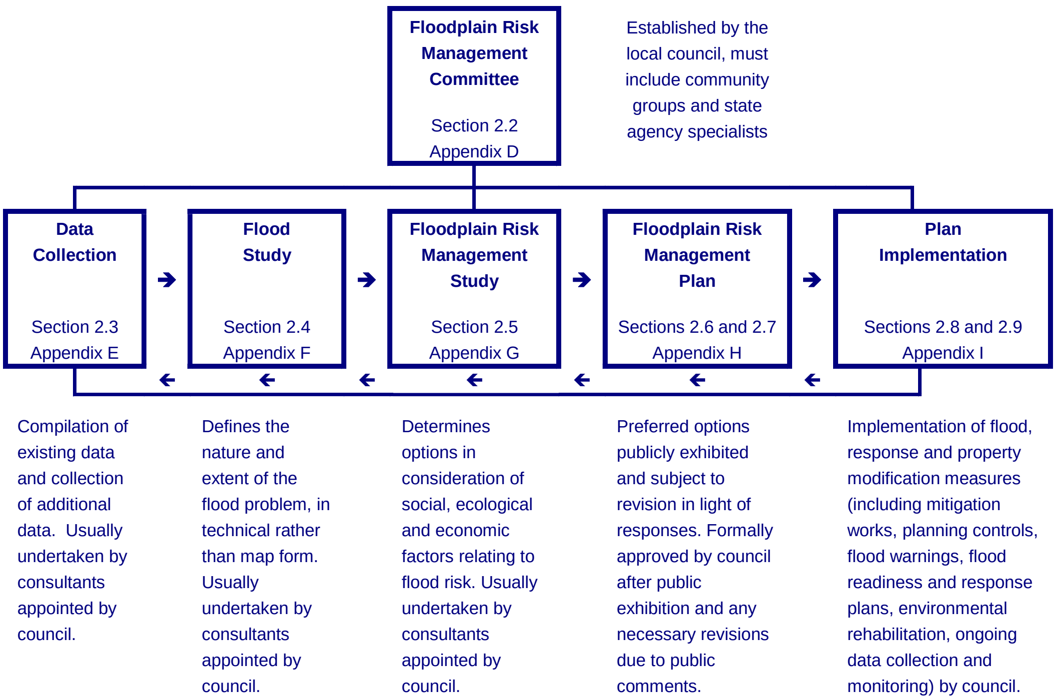
FOREWORD

The New South Wales (NSW) Government's Flood Prone Land Policy aims 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.

Through the NSW Department of Planning, Industry and Environment (formerly NSW Office of Environment and Heritage (OEH)) and the NSW State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding, flood risk management, flood emergency management and land-use planning matters.

The Floodplain Development Manual (NSW Government 2005) assists councils to meet their obligations through a five-stage process resulting in the preparation and implementation of floodplain risk management plans. Image 1 presents the process for plan preparation and implementation.



*In*Source: NSW Government (2005)*nanagement process in New South Wales (FDM, 2005)*

EXECUTIVE SUMMARY

Introduction

Goulburn Mulwaree Council (Council) has received financial support from the State Floodplain Management program managed by the NSW Department of Planning, Industry and Environment to undertake a floodplain management investigation for the Wollondilly and Mulwaree Rivers at Goulburn. GRC Hydro Pty Ltd (GRC Hydro) have been engaged by Council to undertake a floodplain risk management study and develop a draft floodplain risk management plan.

This study comprises a flood study revision, Floodplain Risk Management Study (FRMS) and Floodplain Risk Management Plan (FRMP) which are consistent with the NSW Government's Floodplain Development Manual (FDM, 2005).

The objective of this study is to improve the understanding of Wollondilly and Mulwaree Rivers flood behaviour and flood impacts on the existing and future local community. The study has undertaken testing and investigation of practical, feasible and economic management measures to treat existing, future and residual risk. The FRMS provides a basis for informing the development of a FRMP which will document and convey the decisions on the management of flood risk into the future.

Flood Study Revision

A Flood Study was completed by WMAwater on behalf of Council in 2016. The Flood Study was revised to implement the most recent version of Australian Rainfall and Runoff Guidelines (ARR2019), along with various catchment changes that have occurred since completion of the Flood Study.

The Flood Study calibrated model parameters have been applied without modification to the current study models. Model updates undertaken as part of the current study have been validated to Flood Frequency Analysis (FFA) to substantiate the revised design flow estimates associated with the application of ARR2019. Validation of the hydraulic model and comparison to previous studies has also been undertaken.

Details of the Flood Study revision are presented in Appendix A.

Analysis of Model Results

The computer model results from the revised flood study were used to develop important information to better understand flood risk and inform floodplain management. These outputs include definition of flood hazard, flood function, emergency response categories and flood planning levels.

Community Risk Assessment

An assessment of Goulburn's riverine flood behaviour and community profile was carried out to determine specific areas of flood risk across a range of metrics, including; property flood liability, flood hazard, hydraulic categories, the economic impact of flooding and available flood warning.

Flood consequences for the following were assessed:

- Identification of key flood risk areas / flooding hotpots (Section 8.2);
- Information on flooded roads (Section 8.3);
- Analysis of property flood liability (Section 8.4);
- Assessment of the economic impact of riverine flooding in Goulburn (Section 8.5);
- Review of critical infrastructure and sensitive land uses (Section 8.6); and
- Assessment of available flood warning (Section 8.7).

The identified flooding hotspots are summarised in Table ES 1.

Table ES 1: Flood Hazard – Vulnerability Thresholds

Hotspot #	Location	Risk Factors
1	Avoca Street	Property flooding and evacuation issues
2	Fitzroy Street downstream of Marsden Bridge	Property flooding and evacuation issues
3	East Grove	Property flooding, road flooding, isolation issues
4	Braidwood Road	Property flooding and evacuation issues
5	Towrang Road Bridge	Road flooding and isolation issues

A summary of the mainstream flood liability of individual lots and buildings affected by Wollondilly and Mulwaree River flooding at Goulburn is presented in Table ES 2.

Table ES 2: Property Flood Affection

	Residential		Non-residential	
Design Event (AEP)	Number of Properties affected	Number of Properties affected above Floor Level	Number of Properties affected	Number of Properties affected above Floor Level
20%	1	0	1	1
10%	1	1	1	1
5%	8	6	6	4
2%	55	41	11	10
1%	106	70	19	18
0.5%	153	125	26	24
0.2%	207	194	44	40
PMF	2069	2041	476	470

Net flood damage estimates that combine residential and non-residential flood damages are presented in Table 22 and amount to an average annual cost for flooding of ~$2.1 million per annum.

Table ES 3: Goulburn Mainstream Flood Damages

Design Event (AEP)	Flood Damages Total	Flood Damage per property
20%	$729,500	$729,500
10%	$1,614,100	$861,900
5%	$3,564,700	$568,500
2%	$9,644,400	$506,000
1%	$16,565,600	$499,900
0.5%	$26,276,200	$525,700
0.2%	$44,739,700	$604,500
PMF	$943,851,200	$1,426,200
Average Annual Damages (AAD)		$2,100,000

The flood liability of various sensitive and critical developments and infrastructure was examined including for medical facilities, evacuation centres, emergency services, sewage treatment, water and electrical infrastructure, childcare, schools, and aged care.

Flood Risk Management Measures

Flood risk management measures which aim to reduce, or otherwise, manage flood risk in Goulburn were assessed. These measures ranged from large-scale civil works, such as the construction of levees, to non-works interventions, such as planning controls for new developments. Feasible measures, found to effectively reduce flood risk, have been ranked for implementation in the Floodplain Risk Management Plan (see Section 10).

Floodplain Risk Management measures are categorised in the NSW Floodplain Development Manual (Reference 11) as follows:

- Property Modification Measures (Section 9.1) are those which involve modifying existing properties to manage their flood risk. This includes planning-related measures such as minimum floor levels and zoning based on the locality's flood risk. They also include house raising, and in cases of high flood risk, voluntary purchase schemes.
- Response Modification Measures (Section 9.2) are those that improve the ability of people to plan for and react to flood events. They often involve emergency services and can be targeted at different phases of a flood, e.g., preparation, response and recovery.
- Flood Modification Measures (Section 9.3) are those that change the behaviour of the flood itself through works or other measures. These measures often work to exclude flow from an area (for example a levee bank) or to reduce the peak flow (for example a detention basin).

Assessment of each of the modification measures for various options has been undertaken.

Draft Floodplain Risk Management Plan

A Floodplain Risk Management Plan was developed which aims to manage existing and future flood risk for riverine flooding at Goulburn in accordance with the NSW Floodplain Development Manual (2005). The Plan aims to achieve the following overarching objectives:

- Reduce the flood hazard and risk to people and property, now and in the future;

- Protect, maintain and where possible enhance the floodplain environment; and
- Ensure floodplain risk management decisions integrate social, economic and environmental considerations.

The flood management measures recommended for implementation are presented in Table ES 4. The measures have been prioritised with high, medium and low classifications along with who is responsible for implementation and cost estimates presented.

Table ES 4: DRAFT Floodplain Risk Management Plan

Flood Management Measure	Section	Priority	Cost	Responsibility
Property Modification Measure				
Updated Section 10.7 Planning Certificates	9.1.2.3	High	Council cost estimate	Council
Update Council's LEP to include Clause '5.22 Special Flood Considerations'	9.1.2.4	Medium	Council cost estimate	Council
Revise Council's Development Control Plan Flood Policy	9.1.2.5	Medium	Council cost estimate	Council
Undertake Overland Flow Flood and Flood Risk Management Studies for Goulburn	9.1.2.6	Medium	$100,000	Council
Undertake a Voluntary Purchase Feasibility Assessment	9.1.3.1	High / Low	Feasibility assessment - $30,000 / VP implementation - ~$9.1 million	Council
Response Modification Measures				
Update Goulburn Flood Intelligence	9.2.3.2	High	SES cost estimate	NSW SES
Install flood warning signage at hazardous road crossings	9.2.3.3	High	$140,000	Council
Install automatic boom gates at key flooded crossings	9.2.3.4	Medium	$100,000 / gate	Council
Develop a community flood education program	9.2.3.5	Medium	Council cost estimate	Council / NSW SES
Install a historic flood marker	9.2.3.6	Medium	$8,000	Council
Scoping study for a Total Flood Warning System	9.2.4.3	High	$60,000	Council / NSW SES
Flood Modification Measures				
Develop/implement a vegetation management plan	9.3.3.5	Low	$1 million + ongoing costs	Council
Towrang Bridge upgrade	9.3.3.8	Low	$10 million	Council / RMS
Improve flood access to Eastgrove	9.3.3.9	Low	$2 million	Council / RMS

1. INTRODUCTION

1.1 The Floodplain Risk Management Program

Goulburn Mulwaree Council (Council) has received financial support from the State Floodplain Management program managed by the NSW Department of Planning, Industry and Environment (formerly OEH) to undertake a floodplain management investigation for the Wollondilly and Mulwaree Rivers at Goulburn. To meet this objective GRC Hydro Pty Ltd (GRC Hydro) have been engaged by Council to undertake a floodplain risk management study.

This study composes stages 3 and 4, as well as revision of stage 2, of the five-stage process, as outlined in the NSW Government's Floodplain Development Manual (FDM, 2005). These works include:

- **Flood Study** – a flood study (WMAwater) completed in 2016 has been revised using Australian Rainfall and Runoff 2019 techniques;
- **Floodplain Risk Management Study (FRMS)** – which assesses the impacts of floods on the existing and future community and allows the identification of management measures to manage flood risk; and a
- **Floodplain Risk Management Plan (FRMP)** – that outlines a range of measures, for future implementation, to manage existing, future and residual flood risk effectively and efficiently.

Following the completion of the FRMP, the final stage of the FDM (2005) floodplain management process will involve implementing the findings of the FRMP. Further details of each of these FDM (2005) stages are outlined below.

Data Collection (completed as part of the 2016 Flood Study)

The collection and collation of data necessary for the completion of the flood and floodplain risk management studies is a fundamental part of the floodplain management process. It is typically begun at the outset of the study, but generally continues throughout the period of the project as data becomes available. The quality and quantity of available data is key to the success of a flood study and FRMS.

Flood Study (completed as part of the 2016 Flood Study)

A flood study is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan. It aims to provide an understanding of flood behaviour and consequences for a range for flood events. Information obtained in the data collection phase is used to assist in the development of hydrologic and hydraulic models which are calibrated and verified to improve confidence in model results.

Floodplain Risk Management Study (included in the current study)

A floodplain risk management study increases understanding of the impacts of floods on the existing and future community. It also allows testing and investigating practical, feasible and economic management measures to treat existing, future and residual risk. The floodplain risk management study will provide a basis for informing the development of a floodplain risk management plan.

Floodplain Risk Management Plan (included in the current study)

The floodplain risk management plan documents decisions on the management of flood risk into the future. The FRMP uses the findings of a floodplain risk management study, to outline a range of measures to manage existing, future and residual flood risk effectively and efficiently. This includes an itemised list of measures and prioritised implementation strategy.

1.2 Objectives

The objective of this study is to improve the understanding of Wollondilly and Mulwaree Rivers flood behaviour and flood impacts on the existing and future local community. The study allows for the testing and investigation of practical, feasible and economic management measures to treat existing, future and residual risk. The FRMS will provide a basis for informing the development of a FRMP which will document and convey the decisions on the management of flood risk into the future.

Prior to commencement of the FRMS, the Flood Study, which was completed in 2016, was revised using Australian Rainfall and Runoff 2019 (ARR2019) methodologies. ARR2019 is considered best practise and the results of this analysis have been used as a basis for the current study.

The overall project provides an understanding of, and information on, flood behaviour and associated risk to inform:

- relevant government information systems;
- government and strategic decision makers on flood risk the community;
- flood risk management planning for existing and future development;
- emergency management planning for existing and future development, and strategic and development scale land-use planning to manage growth in flood risk;
- other key stakeholders (including utility providers and the insurance industry) on flood risk;
- providing a better understanding of the:
  - variation in flood behaviour, flood function, flood hazard and flood risk in the study area;
  - impacts and costs for a range of flood events or risks on the existing and future community;
  - impacts of changes in development and climate on flood risk;
  - emergency response situation and limitations;
  - effectiveness of current management measures;
- facilitating information sharing on flood risk across government and with the community.

The study outputs can also inform decision making for investing in the floodplain; managing flood risk through prevention, preparedness, response and recovery activities; pricing insurance, and informing and educating the community on flood risk and response to floods. Each of these areas has different user groups with varied needs.

A key objective of this study is to meet the requirements of the identified end user groups (see Section 1.3), which have been tailored to the context of the current study.

1.3 Project End Users

The study outputs are suitable to inform decision making for investing in the floodplain; managing flood risk through prevention, preparedness, response and recovery activities; pricing insurance, and informing and educating the community on flood risk and response to floods. Each of these areas has different user groups, whose needs vary. The key end-user groups that this study aims to support are identified in Table 1.

Table 1: Project End Users

Potential end user group
High-level strategic decision makers
Community
Flood risk management professionals
Engineers involved in designing, constructing and maintaining mitigation works
Emergency management planners
Land-use planners (strategic planning and planning controls)
Hydrologists and meteorologists involved in flood prediction and forecasting
Insurers
Emergency Services (SES, NSW Police, RFS, NSW Fire and Rescue)

2. BACKGROUND

2.1 Study Area

The city of Goulburn is located in the Southern Tablelands of NSW, 220 km south-west of Sydney, at the confluence of the Wollondilly and Mulwaree Rivers. The study area covers these rivers within the city of Goulburn and extends from upstream of Rossiville Weir on the Wollondilly River and upstream of the Hume Highway on the Mulwaree River, to downstream of Murrays Flat.

The Wollondilly River rises in the Great Dividing Range east of Crookwell and drains the south-western section of the Hawkesbury River Basin. The catchment is situated in hilly country with steep overbank slopes and has an area of 708 km² upstream of Goulburn. The floodplain is typically well defined and relatively narrow through Goulburn.

Mulwaree River is one of the largest and southernmost tributaries of the Wollondilly. It rises in the Great Dividing Range just south of Tarago and flows northwards to Goulburn. Its catchment covers an area of 770 km². To the west, it is bounded by steep slopes, and to the east, by undulating country.

The Wollondilly River and Mulwaree River join to the north-east of the city with a combined catchment area of 1,478 km². Floods may occur independently in either river, although floods in the Wollondilly River tend to back up into the Mulwaree River.

Historically, numerous major flood events have had led to significant impacts for the community of Goulburn. The earliest recorded flood was in 1870, with flood events also occurring in 1900, 1925, 1942, 1950, 1952, 1959, 1961, 1974, 1990, 2007, 2010 and 2012. On Wollondilly River, the December 2010 event is thought to be the largest flood event to affect Goulburn since settlement of the city, with an estimated probability of 1% AEP. On the Mulwaree River, the October 1959 event is estimated to be the largest event on record with an estimated probability ranging from 1% to 0.5% AEP.

Goulburn has a population of 22,890 (2016 census), with a median age of 40 years old (slightly older than the national average). The median household weekly income is $1,164, approximately 80% of the national average. Over 95% of dwellings are free-standing or semi-detached residences with less than 5% described as flats/apartments. English is by far the most commonly spoken language in the home (~94%).

2.2 Goulburn Flood Mechanisms

Flooding is often associated with inundation from large rivers however there are other flood mechanism that can cause inundation. Goulburn is affected by two key flood mechanisms: mainstream flooding and overland flow flooding. These two types of flooding are presented schematically in Image 2.

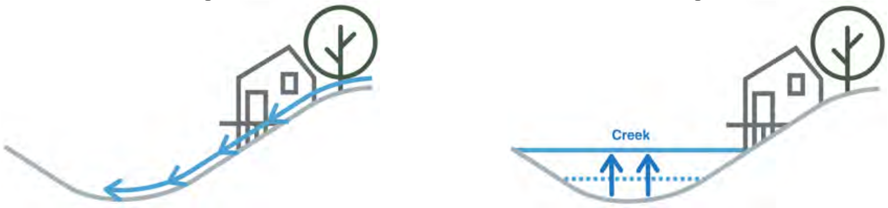
Mainstream flooding occurs from rising water on a defined water course causing the watercourse to beak its banks and inundate area that are usually dry. This mechanism typically occurs over a long period of time and can result in deep flood waters. Mainstream flooding occurs in Goulburn from the Wollondilly and Mulwaree Rivers and is the focus of the current floodplain risk management study as well as the Wollondilly and Mulwaree River Flood Study (Reference 6). Mainstream flooding can also occur in Goulburn from smaller tributaries flowing toward these rivers, however this flood mechanism has not been considered as part of the current study.

Overland flow flooding occurs when excess rainfall runoff is generated from impervious surfaces and flows toward a watercourse. This type of flooding is often referred to as “stormwater” flooding or “flash flooding” due to short warning times. Typically, this type of flooding rises and recedes over a short period of time and the floodwaters are usually relatively shallow and fast moving. Overland flow flooding occurs within Goulburn as runoff from rainfall events flows downhill toward the Mulwaree and Wollondilly Rivers. It must be noted, however, that overland flow flooding is not considered in the current study.

Image 2: Flood Mechanisms affecting Goulburn

Oveland Flow Flooding

Mainstream Flooding



2.3 Social Demographics

Goulburn’s social demographics can provide a valuable insight into the community flood awareness and identify factors that may impede residents from acting and reacting to a flood. Data from the 2016 Census (Australian Bureau of Statistics) has been obtained and assessed below.

The Goulburn urban centre has a population of 22,900 residents living in 10,100 private dwellings. 19% of the population is aged 65 or older which is slightly above the NSW average of 16%.

Approximately 7% of respondents to the 2016 Census indicated that they had moved into the Goulburn area within the last 12 months and 19% of respondents had relocated to Goulburn in the last 5 years. This information provides insight into the general flood awareness of the community, particularly as a noteworthy portion of the population moved to the area after the major flood events in 2010, 2012 and 2013. This highlights that a community flood risk education program could be an effective means to manage flood risk in Goulburn. Notwithstanding, the majority of the Goulburn population are likely to have a good awareness of the flood risk from the Mulwaree and Wollondilly rivers having lived in the area during these events.

Community engagement and provision of flood information is a key part of the Floodplain Risk Management Process. As such, the 2016 Census data provides useful information pertaining to the languages spoken by Goulburn residents. Based on this data, approximately 87% of Census respondents reported that English was the primary language spoken at home.

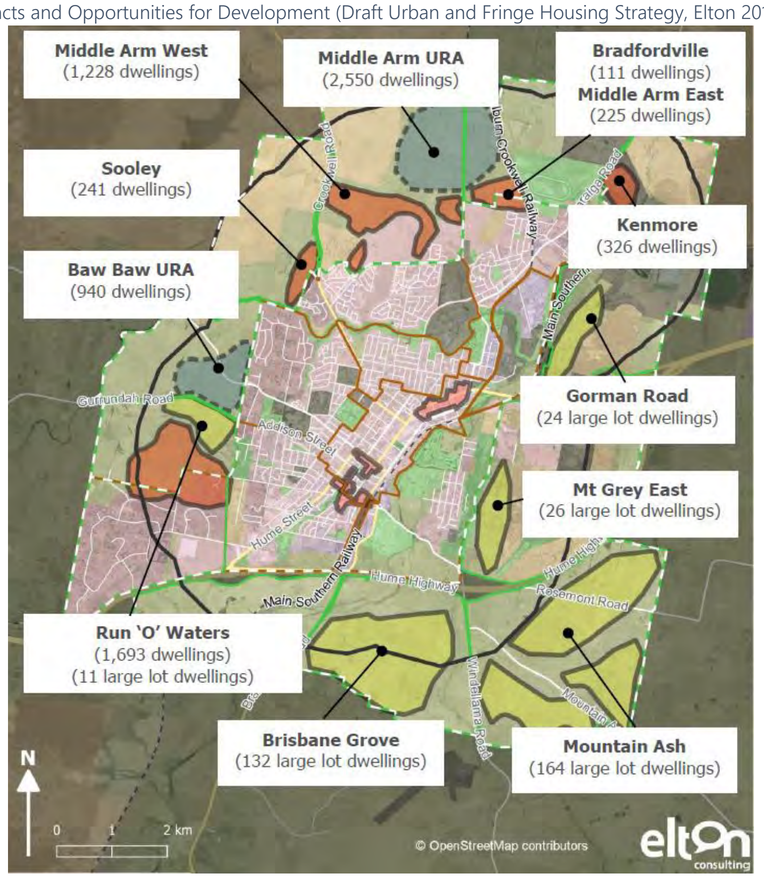
Evacuation during flood events is primarily undertaken by residents in private vehicles however consideration needs to be taken for those dwellings that do not possess a motor vehicle and as such, alternative means of evacuation will need to be provided. The 2016 Census data indicates that 9% of households in Goulburn do not possess a motor vehicle with an additional 5% not providing a response. Given this proportion, alternative means of evacuation may be important for emergency management and flood planning.

2.4 Future Development Areas

Council is in the process of reviewing potential areas of future development to meet demands from expected population growth. A range of possible future growth areas are being considered, including:

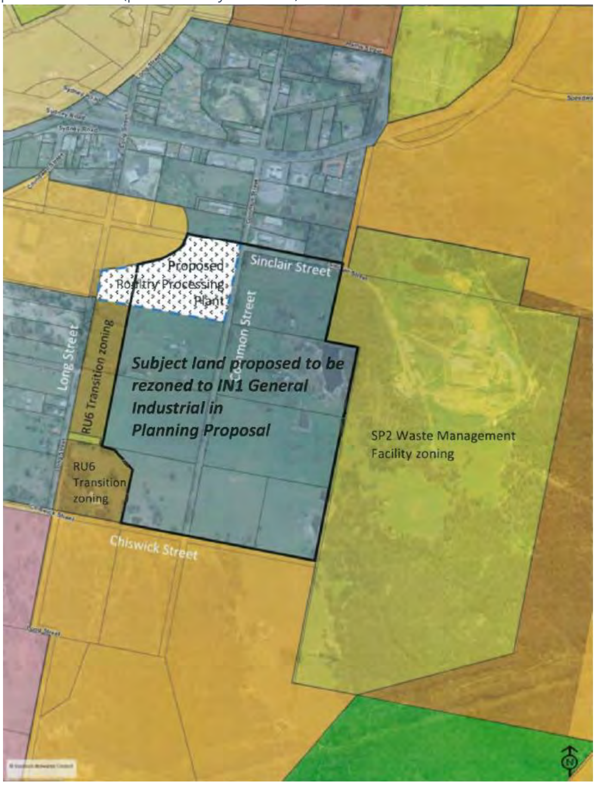
- Urban and Fringe Housing Strategy for Goulburn and Marulan - new urban release areas and intensification of existing areas. This includes six Serviced Residential areas and five Large Lot Residential areas in the short to medium term (1 to 10 years) with combined area of ~1,460 ha, as well as two long term Urban Release Areas (beyond 2036) with an area of 870 ha. The potential growth areas are presented in Image 3;

Image 3: Precincts and Opportunities for Development (Draft Urban and Fringe Housing Strategy, Elton 2019)



- Northeast Enterprise Corridor- this land is currently subject to be rezoned from B6 Enterprise Corridor to IN1 General Industrial. The location is presented in Image 4.

Image 4: Northeast Enterprise Corridor (provided by Council)



- Dossie Street Planning Proposal- this land is currently subject to a planning proposal to rezone land from predominantly undeveloped RU2 Rural Landscape to the zones indicated in Image 5.

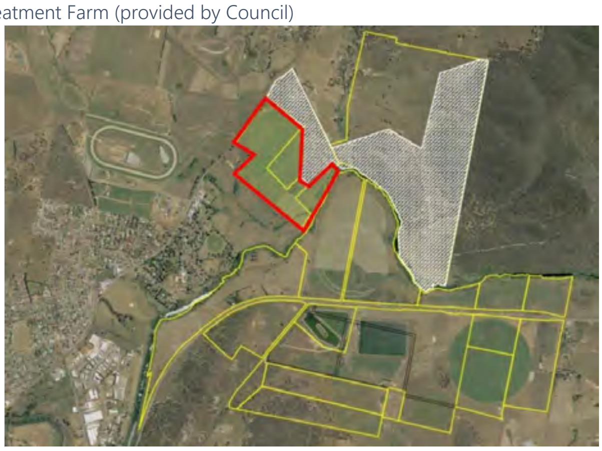
Image 5: Dossie Street Planning Proposal (provided by Council)

- Goulburn Health Hub on Ross Street- this land was previously subject to a planning proposal to rezone it from IN1 General Industrial to SP2 Health Infrastructure to support a hospital, aged care facility etc. This planning proposal has been abandoned due to the site being situated within the PMF extent. The site is now subject to an alternate planning proposal to rezone the land presented in Image 6.

Image 6: Goulburn Health Hub on Ross Street (provided by Council)

- Wastewater Treatment Farm - Council is currently considering the possibility of rezoning part of the wastewater farm to R5 large lot residential as indicated in Image 7 by the red polygon.

Image 7: Wastewater Treatment Farm (provided by Council)



3. DATA COLLECTION AND REVIEW

3.1 Previous Studies

Several studies related to flooding from the Wollondilly and Mulwaree rivers at Goulburn have been undertaken. The most relevant to the current study are the Wollondilly and Mulwaree River Flood Study (WMAwater, 2016) and the Wollondilly River and Mulwaree Chain of Ponds Floodplain Risk Management Study and Plan (SMEC, 2003). A third study, Monitoring Network for Goulburn Flood Warning System (Southeast Engineering and Environmental, 2012), is also relevant. These studies are summarised below.

3.1.1 Wollondilly and Mulwaree River Flood Study (WMAwater, 2016)

The Wollondilly and Mulwaree Rivers Flood Study (the Flood Study) comprised the first and second stages of the Floodplain Management Program. The key outputs of the Flood Study were:

- Calibrated/validated hydrologic and hydraulic models for the Wollondilly and Mulwaree Rivers through the Goulburn township and surrounding area. These models, which used the WBNM software for the hydrologic assessment, and TUFLOW for the hydraulic model, have been updated as part of the current study, however calibrated model parameters remain unchanged; and
- Design flood information for a range of flood events, including basic information (peak flood depth, level and velocity) and processed outputs (provisional hydraulic hazard and hydraulic classification). This information has been revised as part of the current study using Australian Rainfall and Runoff 2019 (ARR2019) methods and techniques.

Table 2 summarises the approach and results of the Flood Study.

Prior to commencement of the FRMS, the Flood Study was revised using Australian Rainfall and Runoff 2019 (ARR2019) methodologies. ARR2019 is considered best practise and the results of this analysis have been used as a basis for the current study.

Table 2: Summary of 2016 Flood Study

Feature	Description	Relevance to FRMS&P (current study)
Data collection	The following data was collected for the Flood Study: • ALS ground surface elevation data, flown in 2011. • River bathymetry survey of approximately 200 cross-sections along the Wollondilly and Mulwaree rivers. • 90 m SRTM Data for upper subcatchments delineation • Council GIS data including aerial photos, LEP layers, cadastral and road data. • Hydraulic structure plans from Council, RMS and Australian Rail and survey of structures where plans were not available. • Bureau of Meteorology (BOM) design rainfall data, and rainfall data from 7 pluviometers and 64 daily read stations. • Various catchment studies along the rivers.	The data collected in the Flood Study has been utilised and added to in the current study. Several hydraulic structures have been built/proposed for upgraded since the Flood Study. These have been implemented in the current hydraulic model (see Appendix A, Section A3.2.2).

	• Historic rainfall and stream gauge data • Questionnaire responses and peak flood level marks throughout Goulburn.	
Hydrologic Model	A WBNM model was established for the study area, with 97 subcatchments with an average area of 23km^2 with imperviousness based on aerial imagery. The subcatchments were routed and the total hydrographs generated for each event were read into the hydraulic model at the upstream boundary. Rating curves at various gauges were analysed and extrapolated in a hydraulic model to provide a stage/discharge relationship used for model calibration. The hydrologic model was calibrated to three historic flood events: December 2010, March 2012 and June 2013. Further design flows were verified to Flood Frequency Analysis.	The Flood Study hydrologic models have been used in the current study and updated for ARR2019 (see Appendix A, Section A2.3).
Hydraulic Model	A 2D TUFLOW hydraulic model was established to model the design flood behaviour in the Goulburn area along the Wollondilly and Mulwaree rivers. Inflows were derived from the hydrologic model and the downstream boundary is a fixed water level boundary that was found to have no impact on flood behaviour. Hydraulic features such as bridges crossing the rivers, road crest levels and river bathymetry were included in the TUFLOW model. The hydraulic model was calibrated for historic events using flows from the calibrated hydrologic model, stream gauge data and peak flood level information obtained from the Community Consultation.	The overall hydraulic modelling approach has been adopted for use in the current study, updated for ARR2019 and incorporated new hydraulic structures. (see Appendix A, Section A3.2.2)
Design Flood Information	The following results were produced by the study: • Peak flood levels and depths the 5-year ARI, 10%, 5%, 2% 1%, 0.5% AEP and PMF events. • Provisional hydraulic hazard and hydraulic classification for the 20%, 5% and 1% AEP, and PMF. • Preliminary Flood Emergency Response Classification of Communities. • Sensitivity of 1% AEP flood losses, the lag parameter, Manning's roughness values and climate change scenarios. • Detailed description of flood behaviour for four flooding hotspots.	The current study has updated the modelling approach using ARR2019 and produced new design flood information, which supersede that produced by the Flood Study. The study will also produce final hydraulic hazard and hydraulic classification.
Community Consultation	The study involved distribution of a newsletter and questionnaire to residents and business owners, with 300 properties receiving the material and 46 responding to the questionnaire. There was also a community workshop held for the general public.	The current study is undertaking a similar consultation process.

3.1.2 Wollondilly River and Mulwaree Chain of Ponds Floodplain Risk Management Study and Plan (SMEC, 2003)

In 2003, SMEC undertook the Wollondilly River and Mulwaree Chain of Ponds Floodplain Risk Management Study and Plan building on the results of the 1986 Goulburn Flood Study (Water Resources Commission of NSW). This study updated the HEC-2 model to a HEC-RAS model and updated the FFA. The RFFA was also updated to include additional gauges in the surrounding area, resulting in an increase in the 1% AEP event flow. The 2003 SMEC Study 1% AEP flood levels are noted to be significantly higher that the revised flood levels of the current study (see Appendix A, Section A2.6).

A floodplain risk management study was undertaken for which various management options were assessed. A summary of pertinent management options is listed below:

- Floodplain Environmental Enhancement - invasive species management was recommended action of the Plan;
- Eastgrove Levee – two alignments were considered, however were not recommended due to social, environmental and economic impacts;
- Victoria Street Levee - two alignments were considered, however were not recommended due to adverse impacts on flood levels;
- Advice on Land Use Management – recommendations for modification of council's LEP, DCP and land use zonings were made and have subsequently been implemented. A discussion of Council's planning policy is presented in Section 4.2.2;
- Voluntary Purchase and House Raising – were considered as viable floodplain management measures for 48 identified properties and a scheme was recommended;
- Improvement of flood warnings – recommendations for additional rainfall and stream gauges was made on both rivers;
- Update of SES Flood Intelligence – review and update based on flood information published in the SMEC (2003) study. This has been implemented by requires revision using the current study findings;
- Community Awareness program – educate the community so that they are fully aware that floods are likely to interfere with normal activities in the floodplain; and
- Update Emergency Plans - to provide a basis for planning, preparation, response and recovery activities by SES and other emergency service providers during flood event.

3.1.3 Monitoring Network for Goulburn Flood Warning System (Southeast Engineering and Environmental, 2012)

The study was prepared for Goulburn Mulwaree Council in 2012. It developed recommendations for a flood monitoring system for the Wollondilly and Mulwaree catchments, including use of a hydrologic model and review of flood warning tools. It recommends a system of gauges for both catchments, as follows:

- For Mulwaree - three rain gauges at upstream of Pejar Dam, at 'Pomeroy' close to existing solar array, and upstream of Sooley Dam on Bumana Creek, plus a dam level gauge on

Pejar Dam, and a new river gauge at Marsden Weir – all with radio transmitter compatibility.
- For Wollondilly - two rain gauges at Lake Bathurst and at Bullamalita on the Gundary Creek catchment, and two new river gauges Inverlochy Bridge and Landsdowne Bridge – all with radio transmitter compatibility.

It recommends that Council own, operate and maintain the gauging system, and that BOM will collect data to assist with warning development and feed information to an ALERT base station at Goulburn SES office.

DPE have provided further information regarding the status of the recommendations. At the time of writing, the Marsden Weir and Inveralochy gauges have been installed but are not currently being utilized.

3.2 Site Visit

A site visit was undertaken with attendees from Council, DPE, NSW SES and GRC Hydro visiting various flood hotspots identified in the Flood Study (2016). Proposed infrastructure on the floodplain was also examined, including the Landsdowne Bridge, Gibson Street footbridge and May Street bridge.

Additional site visits have been undertaken by GRC Hydro to familiarise engineers with the study area and obtain floor level estimates that were able to be determined via Google StreetView (see Section 3.3).

3.3 Property Floor Level Data

Property floor level estimation was completed for 249 properties within the Flood Planning Area (see Section 7.4). This process was undertaken by estimating the height between the ground level and the lowest habitable floor level. The ground level for each property was determined using LiDAR data. The floor level was determined by adding the LiDAR ground level to the estimated height from ground to floor level.

The height from ground level and to the lowest habitable floor level was estimated, where possible, via Google StreetView for each property within the 1% AEP flood extent. Nearby physical features were used to aid the estimation of the ground to floor height, such as the number of bricks to the floor level or the height of a nearby garbage bin. During this process, additional information pertaining to each property was recorded such as the type of house construction and the number of storeys.

For the 2324 properties outside of the FPA but within the PMF extent, the floor height relative to ground was set at 300 mm above ground level.

4. POLICIES, LEGISLATION AND GUIDANCE

4.1 Implemented Guidelines and References

Table 3 presents the guidelines, manuals and technical reference documents used for this study. These documents detail best practice in regard to management of flood risk. They cover both best practice about the technical assessment of flood behaviour and flood risk, and, more generally, who has responsibility for managing flood risk and how this management is best achieved in the area.

Table 3: Guidelines and reference documents

Reference	Topic
Australian Emergency Management (AEM) Handbook Series, Managing the floodplain: A guide to best practice in flood risk management in Australia – AEM Handbook 7	Best practice
AEM Handbook 7, Technical flood risk management guideline – Flood Hazard	Flood hazard
AEM Handbook 7, Technical flood risk management guideline – Flood Emergency Response Classification	Emergency response
AEM Handbook 7, Technical flood risk management guideline – Flood risk information to support land-use planning	Land use
AEM Handbook 7, Technical flood risk management guideline – Assessing options and service levels for treating existing risk	Mitigation options and service levels
AEM Handbook 6, National Strategy for Disaster Resilience – community engagement framework	Community engagement
Australian National Committee on Large Dams (ANCOLD) Guidelines	Dam safety
Australian Rainfall & Runoff 2019	Best practice
Section 733 of the Local Government Act, 1993	Liability & indemnity for compliance with the principles in the manual
NSW Government's Floodplain Development Manual (2005)	Flood prone land policy and industry practice
SES requirements from floodplain risk management process	SES requirements
Practical consideration of climate change	Climate change

4.2 Relevant Legislation

Management of flood risk is governed by local controls in Council's Local Environment Plan (LEP, 2008) and Development Control Plan (DCP, 2009). However, there are also various state and national plans and policies relevant to flooding that overarch the local government legislation. Information on each is presented in the following section.

4.2.1 State and National Plans and Policies

State and national plans and policies related to floodplain management are listed below, including their relevance to the current study:

- Australian Rainfall and Runoff 2019 – sets out hydrological data and procedures to be used for hydrological and hydraulic modelling of flooding in Australia and have been implemented in the current study.
- Building Code of Australia - provides a standard for the design and construction of new buildings in Flood Hazard Areas (FHA) with the aim of reducing risk to building occupants.
- NSW Environmental Planning and Assessment Act 1979 – Is the overarching state legislation for local legislation. The Act provides the framework for regulating and protecting the environment and controlling development. Pursuant to Section 9.1 of the EP&A Act, councils have the responsibility to facilitate the implementation of the NSW Government's Flood Prone Land Policy.
- NSW Flood Prone Land Policy - aims to reduce the impact of flooding and flood liability on individual landowners and occupiers of flood prone property and to reduce private and public losses resulting from floods via economically positive methods where possible. The NSW Floodplain Development Manual supports the policy.
- NSW Government's Floodplain Development Manual (2005) – Defines the assessment of flood risk in NSW, including flood hazard, hydraulic categories and other variables. More broadly it sets out the objectives for floodplain development in the state, including description of types of management measures.
- State Environmental Planning Policy (Exempt and Complying Development Codes) (2008) - are environmental planning tools used to address planning issues within NSW. In a flooding context, the SEPP for Exempt and Complying Development Codes 2008 is key for defining:
    - Exempt developments, where development can occur without the need for development consent; and
    - Complying development, where development must be carried out in accordance with a complying development certificate.

  The policy provides further information on where and development of flood-prone land should occur.
- NSW DPE guidelines relating to flooding - various guidelines have been published by DPE for specific aspects of flood risk assessment in NSW. Some specifically related to the study are:
    - Floodway Definition (2007)
    - Practical Consideration of Climate Change (2007)
    - Incorporating 2016 Australian Rainfall and Runoff in studies (2019)
    - Residential Flood Damages (2007)
    - Drainage Behind and Through Levees (2007)
    - SES Requirements from the FRM Process (2007)

4.2.2 Local Policies

It is the responsibility of local governments within NSW to manage flood risk within their respective LGA's. Two key planning documents are used for the management of this risk and their purpose is outlined below:

- The Local Environment Plan (LEP): The LEP is a key planning tool for local governments whereby it sets out zoning and high-level development controls in the LGA.

- The Development Control Plan (DCP): The DCP provides detailed planning and design guidelines to support the LEP.

The following sections provide an overview of the current flood related development controls in Goulburn's LEP and DCP and the technical standards and guidelines that pertain to the current study.

4.2.2.1 Local Environmental Plan

Clause 7.1 of the Goulburn Local Environmental Plan (LEP, 2009) contains provisions that control the development of flood prone land. The 'Flood Planning' clause is presented below:

7.1 Flood Planning

(1) The objectives of this clause are as follows:
- *(a) to maintain the existing flood regime and flow conveyance capacity,*
- *(b) to enable safe occupation and evacuation of land subject to flooding,*
- *(c) to avoid significant adverse impacts on flood behaviour,*
- *(d) to avoid significant effects on the environment that would cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses,*
- *(e) to limit uses to those compatible with flow conveyance function and flood hazard.*

(2) This clause applies to land identified as "Flood Planning Area" on the Flood Planning Map.

(3) Development consent is required for any development on land to which this clause applies.

(4) Development consent must not be granted for development on land to which this clause applies unless the consent authority is satisfied that the development will not:
- *(a) adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, or*
- *(b) significantly alter flow distributions and velocities to the detriment of other properties or the environment of the floodplain, or*
- *(c) affect the safe occupation or evacuation of the land, or*
- *(d) significantly detrimentally affect the floodplain environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, or*
- *(e) be likely to result in unsustainable social and economic costs to the community as a consequence of flooding, or*
- *(f) if located in a floodway:*
  - *(i) be incompatible with the flow conveyance function of the floodway, or*
  - *(ii) cause or increase a flood hazard in the floodway.*

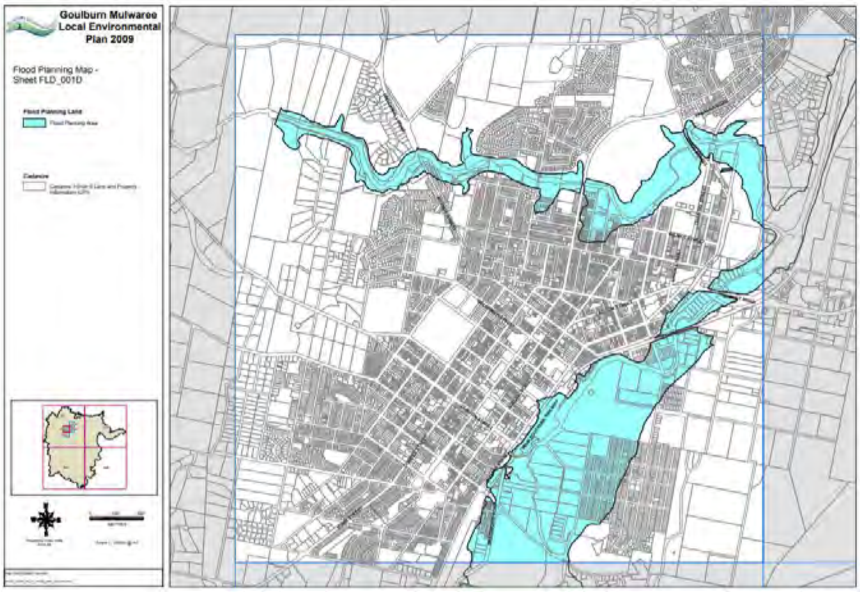
Image 8 presents the Flood Planning Area map to which the LEP (2009) refers.

Review of the LEP (2008) indicate the following issues that need to be addressed:

- Clause (2) refers only to the 'Flood Planning Area map' which means that controls only apply to areas within the blue extent on Image 8. This means that flood controls only apply for Wollondilly and Mulwaree River flooding in the vicinity of Goulburn, and no controls apply for creeks tributaries of these rivers, overland flows or even other areas in the LGA (outside of the blue extent) affected by these rivers;

- Inclusion of a 'Flood Planning Area map' within an LEP is typically not recommended due to difficulties associated with updating an LEP if the map requires revision. By removing the map from the LEP, updating the map (which can be in the DCP or individual FRMS instead) is relatively simple. Having the clause refer to a map in the LEP means that the map cannot be updated (as is required if results change or a levee is upgraded, for example) without a Planning Proposal;
- There is no consideration of the potential impacts of climate change;
- Flood planning controls for sensitivity uses are not considered for areas outside of the Flood Planning Area.

Image 8: Goulburn LEP Flood Planning Area



Modifications to the LEP (2009) will be recommended as part of the Milestone 6 report.

4.2.2.2 Development Control Plan

'Chapter 3.7: Flood Affected Lands', of the Goulburn Development Control Plan (DCP, 2009) contains provisions that control the development of flood prone land. The 'Flood Affected Lands' clause is summarised below. Suggestions for amendment of the DCP will be discussed as part of the Milestone 6 report.

S3.7.1.1 Definitions

The 'definitions' section states that the 'flood planning area' is land that is at or below the flood planning level. This definition is not supported by the LEP which states that the flood planning area is as indicated in the Flood Planning Area map (see Image 8).

S3.7.1.2 Controls for development at or below the flood planning level

A summary of the various controls is provided below:

- *applicants must have regard to the provisions of clause 7.1 LEP 2009*
- *construction – pier and beam construction or suspended slabs must be used to minimise the requirement for cut and fill and allow floodwaters to flow under the building*
- *cut and fill – cut and fill should be minimised for all development within the floodplain.*
- *flood storage – no development is permissible in areas designated as flood storage, unless it can be demonstrated that there will be no decrease in net flood storage available on the site.*
- *building materials and construction methods – flood compatible materials at or below the flood planning level.*
- *structural soundness – all proposed structure must withstand the force of floodwater.*
- *fencing – solid fences that impede the flow of floodwaters are not permissible.*
- *residential floor levels – all habitable rooms within residential development must be at or above the flood planning level*

Commercial and Industrial Development:

- *flood evacuation and management – all development applications for industrial and commercial development must be supported by a flood emergency plan. Appropriate warning and advisory signage must be prominently visible at entry/exit points.*
- *parking – no excavated underground car parking is permitted on land at or below the flood planning level.*

Non-habitable buildings:

- *Class 10 buildings and structures in association with a permissible / existing use are permitted in a flood-affected area other than a floodway hazard category.*
- *Engineering details for the effect of flooding are not required for non-habitable buildings and structures.*

The Wollondilly River and Mulwaree Chain of Ponds Floodplain Risk Management Study and Plan (SMEC, 2003) provides a flood function/hazard matrix that recommends permissible and prohibited uses for various land uses and flood function/hazard. Generally, the matrix recommends that, open type land uses are suitable for all flood function/hazard categories, with the following recommendations for different zoning types:

- Residential Uses - only suitable in low hazard flood fringe and storage areas. This is consistent with best practise;
- Industrial Uses - are allowed in high hazard areas. This is not recommended due to potential increases in risk to life; and
- Commercial Uses - are not accepted in any flood affected area. This places overly onerous restrictions on commercial development.

S3.7.1.3 Mapping

This section refers to the Flood Planning Area map presented in the LEP(2009). Various reference material is noted to be 'highly recommended for development within the Flood Planning Area. The reference material is produced by the Hawkesbury – Nepean Floodplain Management Steering Committee (2006) which is now superseded by documents discussed in Section 4.1.

4.3 Goulburn Mulwaree Local Flood Plan

The Goulburn Mulwaree Local Flood Plan (LFP) was published in October 2012 and covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures from flooding within the LGA. The document provides clear and concise details for all agencies responding to all levels of flooding within the LGA.

Flood preparedness strategies are largely focused on the maintenance of the LFP, flood risk management in the LGA and incorporation of data such as flood intelligence and flood warning systems. Furthermore, the plan details preparedness in the form of community education and training and maintenance of SES personnel and equipment.

'The flood threat' is discussed in Annex A of the LFP. A summary of pertinent details is presented below:

- Specific mention of flood risk due to failure of Pejar and Sooley Dams is discussed in Section A1 of the LFP. Failure of the dams are expected to impact on dwellings in Goulburn and it is noted in Section A5 that 'water from the dam to begin to arrive at Marsden Bridge about approximately 10 minutes after the commencement of failure and reach a peak approximately 1 hour after the breach'. Council have installed warning systems on both dams to monitor and provide alerts on dam water levels.
- Section A3 notes that 'flooding of both rivers in the Goulburn area that warning times are generally short – in the order of hours following heavy rainfall in the catchments. For the Mulwaree River, the time from onset of heavy rainfall in the catchment to flooding in the town is about thirteen hours, whereas for the Wollondilly River it is approximately 7 hours;
- Section A3 states that there are no gauges to indicate river heights for either river and the BoM does not have any classification of flood levels for Goulburn. Consequently, flood levels would be broadly classified as per the descriptions for minor, moderate and major flooding.
- Section A3 makes reference to flood maps produced during the SMEC 2003 Floodplain Risk Management Study which can be updated to consider the current study.
- Section A4 discusses the flood history at Goulburn. Information on historic flood events can be gleaned from the Flood Study (2016). It should be noted that the 2010 and 1959 events were the floods of record on the Wollondilly and Mulwaree Rivers respectively. However, the 2010 Wollondilly River event is noted have cause flooding to 10 properties and be classified as moderate flooding. The number of affected properties can be review in conjunction with the NSW SES as should the selected 'moderate' flood category.
- Section A6 discusses Extreme Flooding and incorrectly notes that the 1961 event is the flood of record on the Wollondilly as well as uses the 1% AEP flood level from the SMEC (2003) study. The LFP can be updated to consider the current study results.
- Section A6 should aim to further highlight the extreme nature of the PMF at Goulburn, including the number of affected properties and typical flood hazards experienced.

'Effects on the Community' is discussed in Annex B of the LFP. A summary of pertinent details is presented below:

- Section B2 states that there are no schools, childcare centres or aged care facilities that are flooded. This can be updated as per the information presented in Section 8.6 of this report. Some information in relation to flooding of utilities and infrastructure is provided, however it is recommended to be updated with the information presented in Section 8.6.1.4. No discussion of the flood liability of Goulburn Correctional Centre is provided.
- Section B6 notes that the floodplain is predominantly classified as 'rising road access', however this requires update based on the current study as higher risk areas (Isolated Submerged) are present during extreme events.
- The number of affected properties can be updated based on the current study.
- Section B6 notes that 'rural areas of Towrang and Big Hill become isolated when the Wollondilly River floods the low-level bridges on Towrang Road, just north of the Hume Highway and Brayton Road about 10 km Northwest of Marulan. There are approximately 200 residences and about 400 persons identified as showing this area as their place of residence'.

5. COMMUNITY CONSULTATION

The community consultation program was undertaken in late 2019. This consultation aimed to inform the community of the study and to collect information relating to potential flood mitigation measures, community engagement and development on flood prone land. A newsletter and questionnaire were distributed to residents in areas affected by mainstream flood affectation and also advertised in the local newspaper and Council's Facebook page.

The newsletter and questionnaire are presented in Appendix G.

5.1 Newsletter and Questionnaire

A newsletter and questionnaire were developed for the Goulburn Mulwaree community in collaboration with Council. The newsletter introduced the study and its objectives and requested feedback via the questionnaire. Preliminary 1% AEP event results were used to identify key locations where the targeted newsletter and questionnaire were sent (approximately 200 properties). Community members who did not receive a questionnaire were still able to participate in the questionnaire via Council's website.

Newsletters and questionnaires were distributed by Council and 56 responses were received from the community. Approximately 41% of respondents indicated that they had experienced flooding in their yard or garage, while 14% of respondents had experienced over floor flooding. These results highlight that there is a general awareness of flooding in Goulburn and the potential for flooding to impact on properties.

Community members were asked about their preferred method of notification if their property is identified as subject to flood risk. Approximately 66% of respondents indicated that they would like to be notified by mail in this instance and 54% of respondents identified that this information should be publicly available on Council's website. This information will be of use during the latter parts of the current study once properties are identified within the final Flood Planning Area.

The questionnaire asked the community about the management of flood related development controls within the floodplain and the varying degrees of restrictions that can be applied. Approximately 66% of respondents selected that property owners should be informed of the potential flood risks and flood related development controls on their property and allow for development provided that these controls are adhered to. These results will inform the implementation of flood related development controls for properties within the final Flood Planning Area.

The questionnaire provided a range of mitigation measures to manage flood risk and asked community members to select their preferred measures. Approximately 61% of respondents selected modifying creeks and channels to increase their capacity and 54% of respondents selected construct, repair and/or increase the size of existing levee banks. Other popular measures included imposing greater flood related development controls and increase strategic flood planning (52%) and upgrading flood warning, evacuation planning and emergency response measures (52%). Consideration of these community preferences has been taken into account when deriving and assessing potential flood management measures which will be presented as part of the Milestone 6 report.

5.2 Public Exhibition

The draft study and plan were placed on Public Exhibition from 1 April 2022 – 2 May, 2022. The purpose of the exhibition period was to inform the community and other stakeholders about the findings of the study and to invite feedback before the study and plan are adopted by Council.

Council organised the public exhibition and promoted awareness of the report and public exhibition period through a range of channels, including:

- Letter sent to all landowners in the PMF (approximately 3,500 letters).
- A notice in the Goulburn Post.
- Notice on Council's website and Facebook page.
- Email notification to Council's stakeholder list which include a variety of consultants, builders, conveyancers, real estate agents and other professionals in the development industry (approximately 475 in total).

Interested residents were provided with hard copies of the report at Council offices in Goulburn, and at the library. Alternatively, the report and related materials were provided for download from Council's website. The website contained two videos, one of Council staff explaining key concepts related to flooding in town, and a recorded PowerPoint presentation by GRC Hydro covering the main findings of the study.

Residents were generally interested in the study and there were a small number of submissions received. The website recorded 98 unique visitors with an average visit of seven minutes, indicating a good level of engagement. The website videos were also posted to Facebook and reached 5,206 people there, and 982 engagements (comments, likes, shares or clicks). 29 people directly contacted Council staff (via phone, email or in person) and the library experienced a constant turnover of people viewing hard copies of the exhibition material.

Six submissions were received from the public as well as one from Water NSW and one from the SES. These are presented in Appendix K and have been incorporated into this final version of the report, where applicable.

6. FLOOD STUDY REVISION

The Flood Study (Reference 6) developed a hydrologic/hydraulic modelling system that has been adopted and updated in the current study. An explanation of these types of models is described below:

- Hydrologic model – which is a computer software tool that simulates catchment processes which affect how rainfall is converted into runoff; and a
- Hydraulic model – which is a computer software tool that simulates the flow characteristics of a river, creek, channel or overland flow path in terms of flood extent, depths, levels and velocities.

The system was used to firstly convert rainfall into flow via the hydrologic model, and then the hydrologic model flows were applied to the hydraulic model to define flood behaviour.

With the update to the Australian Rainfall and Runoff Guidelines (ARR2019), along with various catchment changes that have occurred since the Flood Study was completed in 2016, a revision and update of the hydrologic/hydraulic modelling system was undertaken in the current study.

The Flood Study calibrated model parameters have been applied without modification to the current study models. Model updates undertaken as part of the current study have been validated to Flood Frequency Analysis (FFA) to substantiate the revised design flow estimates associated with the application of ARR2019. Validation of the hydraulic model and comparison to previous studies has also been undertaken.

Details of the Flood Study revision are presented in Appendix A.

7. ANALYSIS OF FLOOD MODEL RESULTS

The computer model results from the revised flood study have been further processed to develop important information that can be used to better understand flood risk (flood hazard, flood function, emergency response categories) as well to inform floodplain management (flood planning area).

7.1 Flood Hazard

Flood hazard is defined as a source of potential harm or a situation with the potential to result in loss (ARR2019). The current study has calculated the flood hazard in accordance with the Australian Emergency Management Handbook 7 Guideline and ARR2019. The method considers the threat to people of various ages (children, adults) and to the community interacting with floodwaters (pedestrians, vehicles and those within buildings). Image 9 and Table 4 present the relationship between the velocity and depth of floodwaters and the corresponding classification.

Image 9: Flood Hazard Curves (Australian Emergency Management Handbook 7)

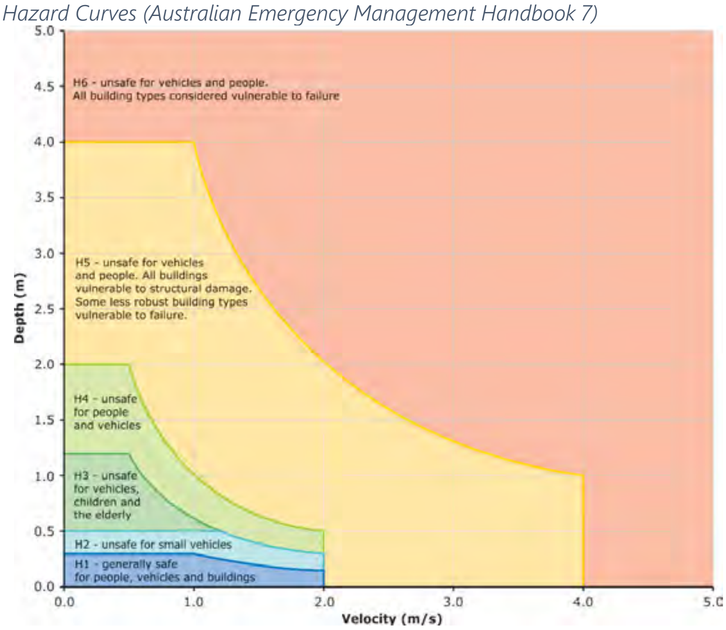


Table 4: Flood Hazard – Vulnerability Thresholds

Hazard Classification	Description
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

Flood hazard classifications are presented in the following figures:

- Figure *2*: Flood Hazard – 5% AEP Design Event;
- Figure *3*: Flood Hazard – 1% AEP Design Event; and
- Figure *4*: Flood Hazard – PMF Design Event.

The following areas of hazard are noted:

- In the 5% AEP event a number of dwellings in the Eastgrove area experienced H1-H3 hazard, with one property experiencing H4 hazard. Other flood liable areas such as Avoca Street and Fitzroy Street, have properties that are flood affected, however hazardous flow is not close to homes;
- During the 1% AEP event, properties near Avoca Street are subject to H1 to H4 hazard flows, a number of properties at Eastgrove experience H5 hazard flooding and properties along Braidwood Road experience H3 hazard flooding;
- During the PMF event large areas of Goulburn are subject to high flood hazard flooding with a H5 and H6 hazard classification.

Due to the number of properties that experience high hazard flooding, particularly during extreme events, implementation of a flood warning system is recommended (this will be examined as part of the Milestone 6 report).

7.2 Flood Function

Flood Function (also known as Hydraulic Categories) refers to the classification of floodwaters into three categories: floodway (also known as the flow conveyance), flood storage and flood fringe. These categories help to describe the nature of flooding across the floodplain and aid planning when assessing developable areas. According to the Australian Emergency Management Handbook 7, these three categories can be defined as:

- Floodway– the areas where a significant proportion of the floodwaters flow and typically align with defined channels. If these areas are blocked or developed, there will be significant redistribution of flow and increased flood levels across the floodplain. Generally, the floodway are areas of deep and/or fast-moving floodwaters;
- Flood Storage – areas where, during a flood, a significant proportion of floodwaters extend into, water is stored and then recedes after a flood. Filling or development in these areas may increase flood levels nearby.
- Flood Fringe – areas that make up the remainder of the flood extent. Development in these areas is unlikely to alter flood behaviour in the surrounding area.

There is no prescribed methodology for deriving each category and as such categorisation is typically determined based on experience and knowledge of the study area. A detailed explanation of this methodology is provided in Appendix E.

Based on the methodology outlined in Appendix E, the Flood Function categories were derived for the 5% AEP, 1% AEP and PMF events with the results presented in figures:

- Figure *5*: Flood Function – 5% AEP Design Event;
- Figure *6*: Flood Function – 1% AEP Design Event; and
- Figure *7*: Flood Function – PMF Design Event.

7.3 Emergency Response Classifications

Flood Emergency Response pertains to a set of classifications that advise how a community is affected by flooding and informs the decision-making process during a flood event. These classifications consider the full range of flood behaviour up to the PMF event. Factors such as isolation, evacuation routes, effective warning times, the rate of rise of floodwaters and the duration of isolation are considered when determining the classification.

In the current study, Flood Emergency Response classifications have been undertaken in accordance with the Australian Emergency Management Handbook 7 and are detailed in Table 5.

Table 5: Flood Emergency Response Classifications (AIEM Handbook 7)

Primary Classification	Secondary Classification	Tertiary Classification
Flooded (F) The area is flooded in the PMF	Isolated (I) Isolated from community evacuation facilities by floodwater and/or impossible terrain as waters rise during events up to the PMF. Likely to lose services during a flood.	Submerged (FIS) Where all land in isolated area will be fully submerged in PMF after becoming isolated.
		Elevated (FIE) Where there is a substantial amount of land in isolated areas elevated above the PMF.
	Exit Route (E) Areas that are not isolated in the PMF and have an exit route to community evacuation facilities.	Overland Escape (FEO) Evacuation from the area relies upon overland escape routes that rise out of the floodplain
		Rising Road (FER) Evacuation routes from the area follow roads that rise out of the floodplain.
Not Flooded	Indirect Consequence (NIC) Areas that are not flooded but may lose services.	
	Flood Free Areas that are not flood affected or indirectly affected by flooding.	

Emergency response classifications for the 5%, 1% AEP and PMF events are presented in the figures outlined below:

- Figure *9*: Flood Emergency Response – 5% AEP Design Event;
- Figure *10*: Flood Emergency Response – 1% AEP Design Event; and
- Figure *11*: Flood Emergency Response – PMF Design Event.

During a flood event, if event magnitude is unknown, analysis of the PMF event is the key output for emergency response. In the PMF event, large areas of the study area are classified as indirect consequence (see Figure 11) whereby residents' properties are not flooded, however, factors such as services or commuting are affected by a PMF flood.

Large areas of the study area, including Fitzroy Street on the Wollondilly River, are classified as rising road access, indicating that as their properties become inundated, residents will have road access to evacuate during a PMF event. Similarly, the Eastgrove area is classified as an area with rising road access, whereby residents are able to access flood free land in the Eastgrove area however they will be unable to access services on the other side of the Mulwaree River until floodwaters recede.

7.4 Flood Planning Area

The Flood Planning Area (FPA) defines properties that are subject to flood related development controls. The FPA is a key planning tool for managing and mitigating flood risk in an LGA. The current study has defined the FPA for areas subject to mainstream flooding from the Wollondilly and Mulwaree rivers.

The process of deriving the FPA varies greatly depending on the dominant flood mechanism in a study area. The Floodplain Development Manual (2005) recommends the generation of the FPA using the 1% AEP flood level plus a freeboard. This methodology is suitable for mainstream flooding and has been adopted in the current study.

A detailed assessment has been undertaken to determine what freeboard is selected to derive the FPA. The current study has considered a range of factors which influence the level of freeboard and utilised the joint probability framework outlined in the NSW Public Works study (2010, Reference 12) to determine an appropriate level of freeboard for the FPA.

Freeboard is used as a factor of safety and is incorporated into the FPA and resulting Flood Planning Level (FPL). This ensures that the selected level of protection for a structure is reasonably achieved and uncertainties in the design are accounted for. In a flooding context, a freeboard is used to account for design variables such as:

- Uncertainties in design flood level estimates;
- Increased water levels due to wind and wave action;
- Localised hydraulic effects (local water surge, hydraulic jumps etc.);
- Design flood level increases due to climate change; and
- Post construction settlement and defects.

A joint probability analysis has been undertaken to determine an appropriate freeboard on the variables described above and their respective probability of occurrence. This analysis is presented in Appendix F.

Based on the results of the freeboard assessment, a freeboard of 0.8 m has been adopted for the entire study area. This freeboard was applied to the 1% AEP event and used to derive the Flood Planning Area presented in Figure 8.

8. COMMUNITY FLOOD RISK ASSESSMENT

8.1 Overview

An assessment of Goulburn's flood behaviour and community profile has been carried out to determine specific areas of flood risk across a range of metrics, including; property flood liability, flood hazard, hydraulic categories, the economic impact of flooding and available flood warning.

The following sections utilise the revised flood study results (Appendix A) and analysis presented in Section 7, to examine areas of risk associated with Wollondilly and Mulwaree River flooding at Goulburn. The following sections describes the consequences of flooding at Goulburn and include:

- Identification of key flood risk areas and the development of flooding hotpots (Section 8.2);
- Information on flood roads (Section 8.3);
- Analysis of property flood liability (Section 8.4);
- Assessment of the economic impact of riverine flooding in Goulburn (Section 8.5);
- Review of critical infrastructure and sensitive land uses (Section 8.6); and
- Assessment of available flood warning (Section 8.7).

The findings from this analysis will be used to focus flood risk management measures efforts on high flood risk areas in the upcoming Milestone 6 report.

8.2 Flooding Hotspots

Flooding hotspots refer to areas that are particularly flood affected and/or affected by hazardous flooding. Five hotspot areas have been identified with a summary presented in Table 6, and further details presented in ensuing sections. The location of the various hotspots is presented in Figure 1.

Table 6: Flood Hazard – Vulnerability Thresholds

Hotspot #	Location	Risk Factors
1	Avoca Street	Property flooding and evacuation issues
2	Fitzroy Street downstream of Marsden Bridge	Property flooding and evacuation issues
3	East Grove	Property flooding, road flooding, isolation issues
4	Braidwood Road	Property flooding and evacuation issues
5	Towrang Road Bridge	Road flooding and isolation issues

8.2.1 Hotspot 1: Avoca Street

Hotspot 1 represents the Avoca Street area which is bounded by Victoria, Kinghorne and Kenmore Streets. Flooding in this area occurs when backwater from the Wollondilly River overtop its banks, inundating properties in the vicinity. This area is first inundated in flood events greater than the 5% AEP. Table 7 presents the flood levels at the corner of Derwent Street and Bellevue Street (levels are indicative for the area and are not expected to vary significantly based on location) for the full range of design flood events. In events greater than and including the 2% AEP event, flood affectation is significant with flood depths presenting a risk to life and property in the hotspot area.

Table 7: Hotspot 1 - design flood levels

Design Event (% AEP)	Level (m AHD)
Ground Level	629.5
20% AEP	N/A*
10% AEP	N/A*
5% AEP	629.8
2% AEP	630.6
1% AEP	631.3
0.5% AEP	632.0
0.2% AEP	632.8
PMF	640.3

* Note: Not flood affected in these events.

Table 8 describes the area's flood behaviour and flood risk.

Table 8: Avoca Street Hotspot – Flood Risk Summary

Flood Risk Characteristics	Description
Depth of flooding	• Flooding first beings in the 5% AEP on Bellevue Street near the corner of Derwent Street, with flood depths of up to 0.6m, however property flooding does not occur until the 2% AEP event. • In 1% AEP, flood depths at low points on Bellevue and Avoca Streets approach 2.0m and the flood extent reaches approximately 130m north of Kinghorne Street. • Flood depths of 3.6m are expected at the above-mentioned low points in the 0.2% AEP event with flood depths exceeding 1m covering the majority of the area and the flood extent reaching 60m from Kinghorne Street. • During the PMF event, flood depths of up to 11m affect properties, with all properties in the area experiencing flood depths of at least 6m. The hotspot flood characteristics change from a flood storage area to a floodway area as flows breakout from the Wollondilly River and flow towards the Mulwaree River.
Flood hazard	• In the 1% AEP event approximately 9 properties are affected by H4 hazard flooding and a further 14 properties are affected by H3 hazard. All roads within the flood extent experience H2 hazard or above. • In 0.2% AEP event approximately 27 properties are affected by H5 hazard flooding and a further 40 properties are affected by H3 hazard. • In the PMF event, the entire region is subject to H6 hazard flood conditions.
Properties flooded	• 10 in 2% AEP • 31 in 1% AEP • 46 in 0.5% AEP • 60 in 0.2% AEP • 134 in PMF
Properties flood above floor	• 7 in 2% AEP • 14 in 1% AEP • 38 in 0.5% AEP

	• 56 in 0.2% AEP • 134 in PMF
Evacuation	There are various evacuation difficulties that must be considered. Sags on both Avoca and Bellevue Streets can lead to localised isolation of properties. Individual properties may also become isolated when surrounded by significant flood depths forming potential Isolated Submerged risk areas during rare flood events.
Duration	Depending on the event magnitude and duration, flooding likely to last several hours to a day.
Additional Risk Factors	High hazard flow affecting numerous residential properties. Limited warning time is currently available.
Gauge Levels	Flooding of the low point on Bellevue Street near the corner of Derwent Street is expected when the historic Marsden Weir gauge reaches 2.5 m (632.96 mAHD). First over floor flooding of properties is expected when the gauge reaches 2.9 m (633.36 mAHD).

8.2.2 Hotspot 2: Fitzroy Street downstream of Marsden Bridge

Hotspot 2 is located at properties on the downstream (eastern) side of Fitzroy Street on the southern side of Marsden Bridge. During intermediate to rare events, the Wollondilly River encroaches on the rear boundary line of these properties. In very rare and extreme events, the Wollondilly River overtops Fitzroy Street to the south of Marsden Bridge and flows though properties, resulting in high velocity/H5 hazard flows and significant evacuation constraints for a number of dwellings.

Table 9 presents the Wollondilly River flood levels at the property boundary to the rear of these properties.

Table 9: Hotspot 2 - design flood levels

Design Event (% AEP)	Level (m AHD)
Ground Level	631.1
20% AEP	N/A*
10% AEP	631.6
5% AEP	632.4
2% AEP	633.3
1% AEP	633.9
0.5% AEP	634.5
0.2% AEP	635.3
PMF	643.6

* Note: Not flood affected in these events.

Table 10 describes the area's flood behaviour and flood risk.

Table 10: Fitzroy Street Hotspot – Flood Risk Summary

Flood Risk Characteristics	Description
Depth of flooding	• Flooding of the rear of the several lots in the area first occurs in events larger than the 10% AEP, however property flooding does not occur until the 2% AEP event. • Flood depths increase significantly with event magnitude with 0.5m depths in the 5% AEP increasing to 2m in the 1% AEP

	event. • In the 0.5% AEP event, flow overtops Fitzroy Street with depths of ~0.1m over the road and flood depth near a number of dwellings is in the order of 0.6m. • Flow depths over Fitzroy Street increase up to 1.0 m during the 0.2% AEP event resulting in high hazard flow conditions with significant risk to life potential for residents attempting to evacuate. • During the PMF event, flood depths of up to 12m affect properties in the area.
Flood hazard	• During the 5% AEP event a number of properties are affected by high hazard flooding (H3+) to the rear of the lot, however flooding does not impact on the dwellings. • In the 1% AEP event three (3) properties are affected by H3 to H4 flooding which could lead to evacuation issues. • In 0.2% AEP event five (5) properties are affected by H4 hazard flooding, with two (2) also subject to H5 flooding. • In the PMF event, the entire region is subject to H6 hazard flood conditions.
Properties flooded	• 1 in 10% AEP • 3 in 5% AEP • 4 in 2% AEP • 7 in 1% AEP • 8 in 0.5% AEP • 10 in 0.2% AEP • 15 in PMF
Properties flood above floor	• 2 in 0.5% AEP • 4 in 0.2% AEP • 12 in PMF
Evacuation	Three (3) properties are surrounded by H3 to H4 hazard flooding during the 1% AEP event which could hamper evacuation attempts. In the 0.2% AEP event, five (5) properties are subject to high hazard flow (H4 – H5) conditions which would make evacuation attempts extreme challenging. Due to high velocity flows overtopping Fitzroy Street in this area, it is unlikely that NSW SES would be able to assist in evacuating these properties.
Duration	Depending on the event magnitude and duration, flooding likely to last several hours to a day. Flows overtopping Fitzroy Street would be expected to only occur for a few hours at most.
Additional Risk Factors	Significant evacuation issues during very rare to extreme flood events.
Gauge Levels	Overtopping of Fitzroy Street is expected when the historic Marsden Weir gauge reaches 4.9 m (635.36 mAHD). First over floor flooding of properties is expected when the gauge reaches 4.4 m (632.86 mAHD).

8.2.3 Hotspot 3: Eastgrove Area

Hotspot 3 represents the Eastgrove area on the eastern side of the Mulwaree River. Properties at Eastgrove are affected by flooding in events as frequent as the 20% AEP. Table 11 presents the design flood levels at the intersection of Park Road and Forbes Street.

Table 11: Hotspot 3 - design flood levels

Design Event (% AEP)	Level (m AHD)
Ground Level	627.9
20% AEP	628.0
10% AEP	628.2
5% AEP	628.8
2% AEP	629.8
1% AEP	630.5
0.5% AEP	631.1
0.2% AEP	632.1
PMF	640.3

* Flood levels for the area will vary when moving upstream or downstream of the Park Road and Forbes Street intersection.

Table 12 describes the area's flood behaviour and flood risk.

Table 12: Eastgrove Area Hotspot – Flood Risk Summary

Flood Risk Characteristics	Description
Depth of flooding	• Shallow flooding to the rear of the several lots in the area first occurs in the 20% AEP event. • Flood depths increase significantly with event magnitude with a number of properties in low laying areas affected by flood depths of 0.5m in the 5% AEP, which increases to 2.5m in the 1% AEP event. • During the PMF event, flood depths of up to 12m affect properties in the area.
Flood hazard	• During the 5% AEP event 11 properties are affected by H3 hazard flooding, with one (1) affected by H4 hazard. The majority of roads within the flood extent are subject to H2 or greater flood hazard, restricting vehicle access. • In the 1% AEP event ~16 properties are affected by H5 flooding, and a further 22 properties flooded by H3-H4 hazard. • In 0.2% AEP event seven (7) properties are affected by H6 hazard, 35 are affected by H5 hazard flooding, with 14 flooded by H3-H4 hazard. • In the PMF event, the entire region is subject to H6 hazard flood conditions.
Properties flooded	• 1 in 20% AEP • 1 in 10% AEP • 7 in 5% AEP • 32 in 2% AEP • 47 in 1% AEP • 53 in 0.5% AEP • 66 in 0.2% AEP • 128 in PMF
Properties flood above floor	• 0 in 20% AEP • 1 in 10% AEP • 5 in 5% AEP • 26 in 2% AEP • 37 in 1% AEP • 48 in 0.5% AEP • 61 in 0.2% AEP • 127 in PMF
Evacuation	Most properties have rising road access, however properties at the northern end of Emma Street and southern end of Hercules Street will have reduced access due to road flooding. There properties have potential overland escape routes available, however neighbouring properties would need to be accessed.

Duration	Depending on the event magnitude and duration, flooding likely to last several hours to a day.
Additional Risk Factors	Access to Eastgrove from Goulburn is typically via Bungonia and Park Roads and Sterne Street. These roads are frequently flood affected (see Section 8.3) reducing access to the area. During major flooding, access to Goulburn CBD may be available via Hetherington Street, however this road may be affected by overland flow flooding and/or road damage due to localised runoff.
Gauge Levels	Information for the Lansdowne Bridge gauge was not available at the time of writing. Gauge information will be included in the Milestone 6 report.

8.2.4 Hotspot 4: Braidwood Road

Hotspot 4 is located between Braidwood Road and the railway and is situated on the western side of the Mulwaree River. Table 13 presents the design flood levels at the intersection of Braidwood Road and Ottiwell Street.

Table 13: Hotspot 4 - design flood levels

Design Event (% AEP)	Level (m AHD)
Ground Level	629.8
20% AEP	N/A*
10% AEP	N/A*
5% AEP	N/A*
2% AEP	630.0
1% AEP	630.6
0.5% AEP	631.2
0.2% AEP	632.2
PMF	640.3

* Note: Not flood affected in these events.

Table 14 describes the area's flood behaviour and flood risk.

Table 14: Braidwood Road Hotspot – Flood Risk Summary

Flood Risk Characteristics	Description
Depth of flooding	• The area is not flood affected until events approaching the 2% AEP event. In this event, flood depths of up to 0.3 m are expected. • In the 1% AEP event, flood depths increase by ~0.7m with flood depths of up to 1.0m expected. • In the 0.2% AEP event, the flood extent in the region is greatly increased and flood depths of up to 2.5m are noted. • During the PMF event, flood depths of up to 11m affect all properties in the area.
Flood hazard	• In the 1% AEP event ~16 properties are affected by H3 hazard flooding, as is access via Braidwood Road to the region. • In 0.2% AEP event 17 properties are affected by H5 hazard and 23 are affected by H3-H4 hazard. • In the PMF event, the entire region is subject to H6 hazard flood conditions.

Properties flooded	• 14 in 2% AEP • 24 in 2% AEP • 34 in 0.5% AEP • 38 in 0.2% AEP • 41 in PMF
Properties flood above floor	• 6 in 2% AEP • 14 in 2% AEP • 24 in 0.5% AEP • 35 in 0.2% AEP • 41 in PMF
Evacuation	By the time properties are threatened by flooding, road access to the area will have been removed by the flooding of Braidwood Road. During extreme events, the only overland escape routes are via the rail corridor which is heavily fenced. Evacuation during very rare to extreme events is likely to required assisted evacuation via boat.
Duration	Depending on the event magnitude and duration, flooding likely to last several hours to a day.
Additional Risk Factors	Poor access/egress once Braidwood Road is flooded.
Gauge Levels	Information for the Lansdowne Bridge gauge was not available at the time of writing. Gauge information will be included in the Milestone 6 report.

8.2.5 Hotspot 5: Towrang Road Bridge

Hotspot 5 is the Towrang Road bridge which crosses the Wollondilly River downstream of Goulburn. The bridge is situated outside of the current study model extent, however, has been identified as an area of flood risk during consultation with Council and the NSW SES.

The frequency at which the bridge is inundated is not known, however reports from Council and the SES indicated that it was flooded during the 2010 flood event, and there are reports of flooding occurring in 2011, 2016, 2020 and 2021, indicating the bridge is flooded relatively frequently. Flooding of the bridge poses a significant risk to vehicles that attempt to traverse the bridge during times of flood. Frequently flooded crossings increase the chance that vehicles will enter flood waters which can pose a significant risk to life.

The bridge may be closed for several days during major flood events which results in the isolation of properties along Towrang Road. The SES LFP states (see Section 4.3) that there are approximately 200 residences and about 400 persons living in the area. Isolation can have implications for emergency vehicle access such as ambulances which increases the risk to life if there is a medical emergency during a flood event.

At the time of writing there are plans to upgrade the bridge, with the replacement to be approximately 4.5 m than what currently exists. Completion of the bridge project is expected for 2021. This will significantly reduce the flood risk at the hotspot.

8.3 Road Inundation

Hazardous flooding of roads occurs when there is enough flow to knock over pedestrians or transport cars off the road due to buoyancy and frictional instability. In Australia, vehicles attempting to cross flooded roads is the largest causes of injury and fatality during a flood. The ability of flow to move or completely float a car is often underestimated, with as little as 0.3 m (30 cm) depth enough to move a small car, even at low flow speeds (this corresponds to H2 hazard). Given these figures, an analysis of structures crossing the Wollondilly and Mulwaree River floodplains and key evacuation routes has been undertaken.

Table 15 presents the flood probability which is responsible for first inundating various roads. This table also includes information from Council on the typical frequency, depth and duration of flooding, as well as several roads that are outside the study area.

Table 15: Inundation of roads on the floodplain

River	Structure	First Flooded	Council Comment
Wollondilly River	Rossi Bridge (Range Road)	>0.5% AEP	
	Marsden Bridge (Crookwell Road)	>0.2% AEP	
	Gibson Street footbridge	**<20% AEP**	
	Victoria Street Bridge	>0.2% AEP	
	Kenmore Bridge (Tarlo Street)	>0.2% AEP	
	Railway Bridge (230 m downstream of Tarlo Street)	>0.2% AEP	
	Sewer Aqueduct (240 m upstream of confluence)	>0.2% AEP	
	Carrick Road (low level causeway, outside Study Area)		Frequency – Once per year Duration – 5 days Depth of flooding – 0.3-1.0 m
	Mills Road (as above)		Frequency – 5 times per year Duration – 3 weeks Depth of flooding – 0.3-1.0 m
	Bulls Pit Road (as above)		Frequency – 5 times per year Duration – 3 weeks Depth of flooding – 0.3-1.0 m
	Brayton Road (as above)		Frequency – 2 times per year Duration – 3 days Depth of flooding – 0.3-1.0 m
	Murrays Flat Road		Frequency – Three times per year Duration – 2 weeks Depth of flooding – 0.3-1.0 m
Mulwaree River	Bridge along Braidwood Road	>0.2% AEP	
	Hume Highway Bypass Bridges	>0.2% AEP	
	Lansdowne Bridge (inclusive of upgrade)	>0.5% AEP	
	Park Road Culverts	<20% AEP	
	Golf Avenue	<20% AEP	
	Golf Course crossing adjacent to Alfred Street	<20% AEP	
	May Street Bridge (inclusive of upgrade)	<20% AEP	Frequency – Once per year Duration – 3 days Depth of flooding – 0.3-1.0 m
	Railway Viaduct (480 m downstream of May St)	>0.2% AEP	
	Sydney Road Bridge	>0.2% AEP	

	Brisbane Grove Road		Frequency – 3 times per year Duration – 3 days Depth of flooding – 0.3-0.5 m

Analysis of the Flood Emergency Response classifications (see Section 7.3) indicated key locations in the study area that are isolated in various flood magnitudes. These areas are primarily along the eastern side of the Mulwaree River, areas along Braidwood Road and parts of Goulburn near the river confluence during extreme events. Analysis of the evacuation routes for these areas has been undertaken and is presented in Table 16.

Table 16: Mainstream inundation of Key Roadways used for evacuation

River	Key Roadway	First Flooded	Council Comment
Wollondilly River	Isolated Submerged and Isolated Elevated area in Goulburn Township Key access via Auburn Street and Lagoon Street prior to inundation	>0.2% AEP	
Mulwaree River	Bungonia Road – near Goulburn Brewery	<20% AEP	Frequency – Once per year Duration – 2 days Depth – 0.3-1.0 m
	Braidwood Road at Cooma Avenue	>5% AEP	
	Braidwood Road – north of Bungonia Road	>5% AEP	
	Park Road	<20% AEP	Frequency – Once per year Duration – 3 days Depth of flooding – 0.3-0.5 m
	Blackshaw Road – adjacent to Mulwaree River	<20% AEP	
	Lower Sterne Street	<20% AEP	
	Forbes Street	<20% AEP	
	Heatherington Street	>0.2% AEP	

The flood liability of the roadways presented in Table 16 pertain to the mainstream flood affectation only. It is important to note that these evacuation routes may be inundated by overland flow flooding. As such, these roadways may be first flooded in more frequent events than those noted in Table 16, if coincidence flooding occurs (mainstream and overland flow flooding). A key example of this is Heatherington Street, which is utilised as an important evacuation route for Eastgrove residents. A number of overland flow paths cross this roadway and may cause the street to be inundated in more frequent overland flow flood events.

8.4 Property Flood Liability

The mainstream flood liability of individual lots and buildings affected by Wollondilly and Mulwaree River flooding at Goulburn has been assessed. Flood affectation on a per property level was assessed by comparison of each lot's ground level (proximate to the building) and habitable floor level to design flood levels at the property. The comparison is made at a point location on each lot, usually at the visible entry (i.e., front door). The floor level at each lot was estimate based on the methods outlined in Section 3.3. This analysis only pertains to mainstream flooding and does not consider overland flow flood liability.

Figure 12 presents the event which is responsible for first inundating each property above floor level. The analysis presents both residential and non-residential development types. A summary of Goulburn's mainstream property flood liability is presented Table 17 and Table 18 for residential and non-residential properties respectively.

Table 17: Residential Property Flood Affection

Design Event (AEP)	Number of Properties affected	Number of Properties affected above Floor Level
20%	1	0
10%	1	1
5%	8	6
2%	55	41
1%	106	70
0.5%	153	125
0.2%	207	194
PMF	2069	2041

Table 18: Non-residential Property Flood Affection

Design Event (AEP)	Number of Properties affected	Number of Properties affected above Floor Level
20%	1	1
10%	1	1
5%	6	4
2%	11	10
1%	19	18
0.5%	26	24
0.2%	44	40
PMF	476	470

8.5 Flood Damages Assessment

8.5.1 Overview

A flood damages assessment is used to quantitively assess the impacts of flooding on the community. Generally, a flood damages assessment aggregates the following:

- Direct costs to individual properties such as structural damages or damage to contents;
- Indirect costs to individual properties such as clean-up, disposal or loss of income; and
- Cost of damage to infrastructure.

The flood damages assessment described herein has been completed for 2,573 properties within the PMF flood extent. The assessment is based on the property flood liability analysis presented in

Section 8.4. Based on the flood liability of each development, a monetary value is applied to each property based on the level of property damage over a range of design flood events.

The analysis has been undertaken using two different methods for residential and non-residential properties, with further details provided in the Sections 8.5.2 and 8.5.3 respectively.

8.5.2 Residential Properties

Residential flood damages have been estimated in accordance with 'Floodplain Risk Management Guideline – Residential Flood Damages' (DECC, 2007 - Reference 3). Applied parameters used in this analysis are presented in Table 19.

Table 19: Residential flood damages inputs

	Input Value
Post late 2001 adjustments	1.83
Post Flood Inflation factor	1.20
Building damage repair limitation factor	1.00 (long duration)
Typical House Size	219 m^2 (average of 2570 digitised buildings in LGA)
Total Building Adjustment factor	2.00
Average Contents Relevant to Site	$54,750*
Contents Damage Repair Limitation factor	0.90 (long duration)
Level of Flood Awareness	Low
Effective warning time	3 hours (indicative only)
Typical table bench height	0.9
External Damage	$6,700*
Clean Up Costs	$4,000*
Likely time in alternative accommodation	3 weeks
Additional accommodation costs/loss of rent	$200*/week

*Note these are 2001 values which are adjusted using the post late 2001 adjustment factor

Residential Flood Damage estimates provide a monetary value of flood damages for each property for a range of design flood events. A key outcome of this assessment is the Average Annual Damage (AAD). The AAD is equal to the total damage caused by all floods over a long period of time divided by the number of years in that period (Reference 11). The AAD is primarily used during a Floodplain Risk Management Study and Plan (FRMS&P) to compare the relative economic merits of various proposed flood mitigation measures.

A residential AAD of $653,500 was calculated for the riverine flooding in Goulburn. Table 20 presents the AAD and the total Residential Flood Damages per design event.

Table 20: Residential Flood Damages

Design Event (AEP)	Flood Damages Total	Flood Damage per property
20%	$12,300	$12,300
10%	$109,700	$109,700
5%	$613,000	$76,600
2%	$4,524,900	$79,400
1%	$8,609,500	$81,200
0.5%	$14,671,500	$95,900
0.2%	$23,661,400	$114,300
PMF	$344,119,700	$166,300
Average Annual Damages (AAD)		$653,500

8.5.3 Non-Residential Properties

The calculation of tangible non-residential flood damages on a large scale can be highly varied. Non-residential flood damages are dependent on factors such as:

- The nature of business undertaken at the property. For example, a business which has a quick turnaround of produce (or limited stock), such as a florist, is likely to suffer a smaller economic loss due to flooding than a business with highly valuable stock and a slower turnaround time, such as an electronics store.
- The floor space of a non-residential property can be related to the amount of stock stored on site and therefore the amount of stock vulnerable to flooding.
- The duration of inundation of a non-residential property and extent of damages can directly affect the length of time that the business may be closed.
- The level of flood awareness/preparedness such as the amount of flood warning and ability to move vulnerable stock can affect the level of flood damage experienced.

To further complicate the calculation of non-residential flood damages, a change of occupancy of a non-residential property can greatly change the economic flood damage experienced due to the potential change in the nature of business at the property.

There is no prescribed methodology for calculating non-residential flood damages provided by DPE in Reference 3.

The Flood and Coastal Erosion Risk Management – A Manual for Economic Appraisal (Reference 4) produced by the Flood Hazard Research Centre at Middlesex University in the United Kingdom developed non-residential flood damages curves based on observed flood damages from the early 2000's. The current study has adopted a typical non-residential flood damage relationship between depth of inundation and damage per square metre of floor space from this Manual and applied it for non-residential properties in Goulburn. This flood damages curve was adjusted to account for the exchange rate from pounds sterling to Australian dollars and inflation from 2013 to present. The floor space of each non-residential property in Goulburn was individually calculated and the flood damages curve was adjusted accordingly.

The described methodology provides an indicative estimate of non-residential damages. This estimate is considered fit for purpose in the comparative assessment of flood mitigation measures that are discussed in Section 9.

Non-residential Flood Damage estimates provide a monetary value of flood damages for each property for a range of design flood events. A key outcome of this assessment is the Average Annual Damage (AAD). The AAD is equal to the total damage caused by all floods over a long period of time divided by the number of years in that period (Reference 11). The AAD is primarily used during a Floodplain Risk Management Study and Plan (FRMS&P) to compare the relative economic merits of various proposed flood mitigation measures.

A non-residential AAD of $1,411,400 was calculated for the riverine flooding in Goulburn. Table 21 presents the AAD and the total Non-residential Flood Damages per design event.

Table 21: Non-residential Flood Damages

Design Event (AEP)	Flood Damages Total	Flood Damage per property
20%	$717,200	$717,200
10%	$1,504,400	$752,200
5%	$2,951,700	$491,900
2%	$5,119,500	$426,600
1%	$7,956,100	$418,700
0.5%	$11,604,700	$429,800
0.2%	$21,078,300	$490,200
PMF	$599,731,500	$1,259,900
Average Annual Damages (AAD)		$1,411,400

8.5.4 Goulburn Mainstream Flood Damages

Net flood damage estimates that combine residential and non-residential flood damages are presented in Table 22.

Table 22: Goulburn Mainstream Flood Damages

Design Event (AEP)	Flood Damages Total	Flood Damage per property
20%	$729,500	$729,500
10%	$1,614,100	$861,900
5%	$3,564,700	$568,500
2%	$9,644,400	$506,000
1%	$16,565,600	$499,900
0.5%	$26,276,200	$525,700
0.2%	$44,739,700	$604,500
PMF	$943,851,200	$1,426,200
Average Annual Damages (AAD)		$2,064,900

8.6 Risk to Sensitive Land Uses and Critical Infrastructure

Critical infrastructure is located throughout the area and if inundated during a flood, may significantly impact the functioning of the town. The following section describes the flood liability of various critical infrastructure. The section also describes the exposure of facilities particularly sensitive to inundation, including childcare, schools and aged care.

An overview figure (Figure 13) shows the location of the facilities presented in the following section, overlaid on the 1% AEP and PMF flood extent. It should be noted that the categorisation of each facility's flood affectation in the following section is only based on riverine flooding and some sites may also have flood liability from overland flow.

8.6.1.1 Hospitals and Ambulance

Hospitals often house vulnerable persons who may require additional resources, warning time and assistance, if evacuation is required. An assessment of the flood affectation of medical facilities found that both hospitals in Goulburn are located outside of the PMF flood extent (see Table 23).

Table 23: Flood affectation at Goulburn medical facilities

Medical Facility	Location	First Flooded
Goulburn Base Hospital	Goldsmith Street	*Not Flooded*
Goldsmith Street Surgery	Goldsmith Street	*Not Flooded*

Goulburn Ambulance Station (located in the Southern Sector of the NSW Ambulance Goulburn Area) is located on Clifford Street, near Sloane Street. The ambulance station services Goulburn and surrounding areas. The station is significantly flood affected during the PMF event by flood depths of up to 5m (however the site is ~3m above the 0.2% AEP event). Further, flooding of roads in the region (see Section 8.3) may lead to difficulties reaching the Ambulance Station due to roads being cut.

8.6.1.2 Aged and Vulnerable Care

Aged and special care facilities often house vulnerable persons who may require additional resources, warning time and assistance, if evacuation is required. The unplanned/abrupt evacuation of aged care facilities is associated with increased mortality rates in vulnerable people.

Goulburn has a number of aged care facilities which are all outside of the 0.2% AEP flood extent however some are flooded in the PMF event. It is important that these facilities have effective flood plans for extreme flood events. Extreme refers to floods of 1 in 2000 and above (equivalent to 0.0005% AEP). Table 24 presents the flood affection of these aged care facilities.

Table 24: Flood affectation at Goulburn aged care facilities

Aged Care Facility	Location	First Flooded
Warrigal	7 St Aubyn Road	*Not Flooded*
Gill Waminda Aged Care Centre	4 Mary Street	*Not Flooded*
Southern Cross Care Tenison Residential Aged Care	19 Upper Sterne Street	Extreme Events
RFBI Goulburn Masonic Village	10 Long Street	Extreme Events
BaptistCare Home Services	179 Clinton Street	*Not flooded*
Wollondilly Gardens Retirement Village	10 Mary Martin Drive	Extreme Events
Ingenia Gardens Goulburn	52 Chatsbury Street	Extreme Events

8.6.1.3 Schools and Childcare Centres

Table 25 and Table 26 present the flood affectation of early learning facilities and educational facilities in Goulburn. Typically, these locations are not flooded or only experience flooding during extreme events. A notable exception is the PCYC OSHC Goulburn which is first flooded in the 5% AEP event and as such, a flood evacuation plan is recommended to be considered for this location.

Table 25: Flood affectation at Goulburn early learning facilities

Early Learning Facility	Location	First Flooded
Eastgrove Child Care Centre	5 Chiswick Street	Not Flooded, isolated in PMF
Goulburn Family Day Care	126 Cowper Street	*Not flooded*
River Heights Child Care Centre	58 Fitzroy Street	Extreme Events
Kindy Patch Goulburn	117 Gibson Street	*Not Flooded*
Scaliiwags Children's Centre	9 James Place	Not Flooded (likely flooded by overland flow)
Orana Pre-School	128 Cowper Street	*Not Flooded*
SDN Goulburn Children's Education and Care Centre	2-4 McKell Place	Not flooded, access issues in PMF
Goulburn TAFE Children's Centre	Verner Street	*Not Flooded*
UnitingCare Goulburn West Outside School Hours Care	Goulburn West Primary School	*Not flooded*
St Saviour's Long Day Care	132 Cowper Street	*Not Flooded*
Cool Kids OSHC	204 Bourke Street	*Not Flooded*
Goodstart Early Learning	207 Faithfull Street	*Not Flooded*
Lilac Early Learning	30 Barry Crescent	*Not Flooded*
The Learning Tree Child Care Centre	101 Lagoon Street	Extreme Events
Goulburn Pre School	15 Mount Street	*Not Flooded*
New Horizons Pre School	26 Long Street	*Not Flooded*
PCYC OSHC Goulburn	Avoca Street	**Flooded in 5% AEP**
Romp & Stomp	7 O'Sullivan Street	Extreme Events, isolation issues
St Saviours Vacation Care	130 Cowper Street	*Not Flooded*

Table 26: Flood affectation at Goulburn educational facilities

Education Facility	Location	Flood affectation
Goulburn High School	132 Goldsmith Street	*Not flooded*
Bradfordville Public School	30 Hamden Street	*Not flooded*
The Crescent School	Fitzroy Street	*Not flooded*
East Goulburn Primary School	Eleanor Street	Extreme Events, isolation issues in smaller events
Goulburn Public School	204 Bourke Street	*Not flooded*
Goulburn West Primary School	Combermere Street	*Not flooded*
Goulburn Junior College	120 Taralga Road	*Not flooded*
Mulwaree High School	40 McDermott Drive	*Not flooded*
Goulburn North Public School	1 Union Street	Extreme Events
Goulburn South Public School	2 Addison Street	Extreme Events
St Josephs Primary School	101 Lagoon Street	Extreme Events
St Peters and St Pauls Primary School	10 Knox Street	*Not flooded*
Wollondilly Public School	Newton Street	*Not flooded*
Trinity Catholic College	Clinton Street	*Not flooded*
Tambelin Independent School	20 Fenwick Crescent	Extreme Events

8.6.1.4 Risk to Critical Infrastructure

Flood damage to public infrastructure can have a significant contribution to the total cost of a flood event as well as disturbing the day-to-day operations of the Goulburn community. Table 27 presents the flood affectation of key infrastructure in Goulburn.

Table 27: Flood affectation to critical public infrastructure

Infrastructure	Location	First Flooded
Flood Evacuation Centres		
Goulburn Soldiers Club	Market Street	Extreme Events
Goulburn Works Club	McKell Place	Extreme Events
Goulburn SES	Lanigan Lane	Extreme Events
Sewage Works	Ross Street	Extreme Events
Water Filtration Plant	Wheeo Road	*Not flooded*
Electrical Substations		
Essential Energy Depot	Memorial Road	*Not flooded*
Allstate Power Pty Ltd	33 Pursehouse Place	*Not flooded*
Goulburn Correctional Centre	Maud Street	Extreme Events

Of note are the flood evacuation centres, Goulburn SES, sewage plant and Goulburn correctional centre are all subject to inundation during extreme flood events. Alternative evacuation centres for extreme flood events are recommended to be nominated in the Goulburn Local Flood Plan.

8.7 Available Flood Warning

The amount of warning available for an impending flood can significantly impact on the risk to life and the degree of flood damage. Both the Wollondilly and Mulwaree Rivers have relatively short response times which increases the flood risk. However, response times are not so short that development of a flood warning system is not possible.

The Local Flood Plan (2012) states that 'flooding of both rivers in the Goulburn area, that warning times are generally short – in the order of hours following heavy rainfall in the catchments. The LFP notes that the time from the onset of heavy rainfall to flooding in the town is about 13 hours for the Mulwaree River and seven (7) hours for the Wollondilly River. A more appropriate way of determining available warning is to consider the amount of time between the end of a rainfall burst (rather than the 'onset') and the flood peak. Design rainfall applied for the 5%, 1% AEP and PMF events has been analysed with the results presented in Table 29.

Table 28: Approximate time from end of a rainfall burst to flood peak at Goulburn

Catchment	5% AEP Travel Time	1% AEP Travel Time	PMF Travel Time
Wollondilly	7.0 h	6.1 h	4.1 h
Mulwaree	8.7 h	5.5 h	2.5 h

* Note that only one storm event was examined for each AEP. Available flood warning may vary significantly dependant on event magnitude, duration, temporal pattern and other factors.

Table 29 presents flood travel times from existing gauges to Goulburn, along with the percentage of the area of the catchment relative to the catchment at Goulburn. Gauges that service catchments that are a small percent of the total catchment area are less useful for flood warning. The results show that both The Towers and Cardross gauges provide limited available warning time with only 30 minutes available in the PMF event. The Pomeroy gauge provides a longer available warning time, however only gauges 42% of the total catchment area to Goulburn and as such would have reduced capacity to provide reliable flood predictions.

Table 29: Hydrologic Model Available Warning Time

Gauge Name	ID#	Catchment	% of Total Catchment Area	5% AEP Travel Time	1% AEP Travel Time	PMF Travel Time
Pomeroy	212006	Wollondilly	42%	4 h	3.6 h	1.6 h
Cardross	212047	Wollondilly	75%	1.6 h	1.4 h	0.6 h
The Towers	2122725	Mulwaree	80%	0.7 h	0.5 h	0.5 h

* Note that only one storm event was examined for each AEP. Available flood warning may vary significantly dependant on event magnitude, duration, temporal pattern and other factors.

9. FLOOD RISK MANAGEMENT MEASURES

Assessment flood risk management measures is a key objective of the current study which aim to reduce, or otherwise, manage the flood risk in Goulburn. These measures can vary from large-scale civil works, such as the construction of levee, to non-works interventions, such as planning controls for new developments. The current study has undertaken a detailed assessment of management measures and their relative cost/benefit. Feasible measures, found to effectively reduce flood risk, have been ranked for implementation in the Floodplain Risk Management Plan (see Section 10).

Floodplain Risk Management measures are categorised in the NSW Floodplain Development Manual (Reference 11) as follows:

- Property Modification Measures (Section 9.1) are those which involve modifying existing properties to manage their flood risk. This includes planning-related measures such as minimum floor levels and zoning based on the locality's flood risk. They also include house raising, and in cases of high flood risk, voluntary purchase schemes.
- Response Modification Measures (Section 9.2) are those that improve the ability of people to plan for and react to flood events. They often involved emergency services and can be targeted at different phases of a flood, e.g., preparation, response and recovery.
- Flood Modification Measures (Section 9.3) are those that change the behaviour of the flood itself through works or other measures. These measures often work to exclude flow from an area (for example a levee bank) or to reduce the peak flow (for example a detention basin).

Table 30 briefly describes typical mitigation measures in each of these categories.

Table 30: Description of Modification Measures (according to (Reference 11))

	Measure	Description
Property Modification Measures	Land Use Planning	Strategic assessment of flood risk to guide consent authorities to manage and reduce exposure to flood risk for future development areas.
	Zoning	Application of land use controls for flood prone areas of future development without also unjustifiably restricting development in these areas.
	Development Controls	Where development is acceptable, development controls are used to manage flood risk.
	Voluntary Purchase	In residential areas of high hazard on the floodplain posing a risk to life, the purchase of properties can their removal/demolition can be undertaken.
	Voluntary House Raising	In residential areas, exposed to frequent over floor flooding from low hazard and localised flow, this can be avoided by voluntary house raising.
	Flood Proofing of Buildings	Flood proofing pertains to the design and construction of buildings using materials that are flood compatible as to minimise flood damage to the building and its contents.
	Flood Access	In areas where isolation occurs during a flood event for long periods of time, planning measures need to be considered for access during these times.

Response Modification Measures	Flood Education, Flood Information Leaflets & Community Readiness	Flood education pertains to informing the community of the flood risk to ensure general community awareness and flood readiness.
	Flood Prediction and Warning	Flood prediction and warning can be implemented on catchments with large times of concentration to allow time to ready to the community.
	Local Flood Plans	Local flood plans can be used to identify significantly flood affected areas and outline various measures to be undertaken before, during and after a flood.
	Recovery Planning	Plans for recovery planning can be developed to ensure that Council and other authorities have addressed the community's needs and provided the needed services.
Flood Modification Measures	Flood Mitigation Dams	Flood mitigation dams can be used to reduce downstream discharges. This relies on the dam having capacity to store flood waters prior to a flood.
	Retarding Basins	Retarding basins pertain to small dams to provide flood storage on overland flowpaths or small tributaries.
	Levees	Levees and embankments can be used to protect existing developed areas by excluding flood waters.
	Bypass Floodways	Bypass floodways can be used to redirect floodwaters away from flood existing developed areas to reduce flood levels along a channel.
	Channel Modifications	Channel modifications refer to modifying a channel either by widening, deepening, realigning or clearing the waterway to allow for more efficient channel flow.
	Floodgates	Floodgates can be used to control and exclude flow along a small creeks or waterways.

The following sections provide detailed assessment of these measures and their relative cost/benefit.

9.1 Property Modification Measures

9.1.1 Background

The current study has assessed property modification measures and planning advice for the management of existing and future flood risk. While such measures do not change the flood behaviour itself, over time they can remove dwellings and other buildings from hazardous flood areas and ensure the remaining flood-prone areas are well-equipped to deal with flooding. Such measures are particularly suited to areas where flood modification measures (works) are either not feasible or prohibitively expensive. In most cases property modification measures are implemented via Council policies, which can be used to stipulate where and how development can occur within the floodplain.

The measures outlined in the following sections are proposed to be included in the Floodplain Risk Management Plan.

9.1.2 Flood Planning and Future Development

9.1.2.1 Overview

It is the responsibility of local governments within NSW to manage flood risk within their respective LGA's. Two key planning documents are used for the management of this risk and their purpose is outlined below:

- The Local Environment Plan (LEP): The LEP is a key planning tool for local governments whereby it sets out zoning and high-level development controls in the LGA.
- The Development Control Plan (DCP): The DCP provides detailed planning and design guidelines to support the LEP.

Section 4.2.2 reviews Council's current flood policies and outlines various issues that need to be addressed.

The following sections provide recommendations to be implemented in Council's planning policy, as well as review existing land zonings and proposed future development areas.

9.1.2.2 Adoption of a Flood Planning Level and Flood Planning Area (Option PM01)

Flood Planning Level Overview

Councils are responsible for determining an appropriate Flood Planning Levels (FPL) within their local government area. Land below the FPL is defined as the Flood Planning Area (FPA) and is subject to the flood related development controls outlined in Council's Local Environmental Plan. Proposed amendments to Council's LEP are discussed further in Section 9.1.2.4.

FPLs are a combination of a defined flood event (DFE) flood level and a freeboard. Freeboard is used as a factor of safety to ensure that the selected level of protection is reasonably achieved, and uncertainties in flood level estimates are accounted for. The Floodplain Development Manual (FDM) states that a DFE of the 1% AEP plus a freeboard (typically 0.5 m) should generally be used as the minimum recommended level for setting residential FPLs.

In some circumstances it may be appropriate to use a DFE other than the 1% AEP event, however this requires application for Exceptional Circumstances as per Planning Circular PS07-003[1]. This is not recommended as part of the current study, however a non-standard freeboard is recommended.

A freeboard assessment was undertaken, and a freeboard of 0.8 m has been adopted for riverine flooding in the study area. Further details of the freeboard assessment are presented in Section 7.4.

[1] NSW Department of Planning and Environment (DPE) have recently released the Flood Prone Land Package, part of which proposes revised flood clauses for LEPs which may remove the need to apply for Exceptional Circumstances for use of a DFE other than the 1% AEP flood. This is discussed further in Section 9.1.2.4.

Flood Planning Area Overview

The Flood Planning Area (FPA) is land below the FPL and often represents the spatial extent to which flood related development controls as outlined in LEP Clause, 5.21 Flood Planning' (Section 9.1.2.4) apply. Recommended changes to Council's flood planning policy, as detailed in Sections 9.1.2.4 and 9.1.2.5 aim to move away from this approach through the application of Flood Planning Constraint Categories for flood planning. With implementation of these changes the FPA will no longer delineate the extent to which flood development controls will apply, and instead will form the combined extent of FPCC1, FPCC2 and FPCC3 (see Section 9.1.2.5).

Council's current LEP (2009) presents a FPA map which defines the extent to which planning controls apply. Inclusion of the 'Flood Planning Area map' within the LEP is not recommended, however, inclusion of a FPA map in the Development Control Plan (DCP) or individual FRMS, provides guidance without requiring a Planning Proposal to update.

Summary and Recommendations

A Flood Planning Level set at the 1% AEP flood level plus 0.8 m is recommended to be implemented by Council for residential development affected by riverine flooding. Reduced freeboards may be suitable for other development types, or for overland flow flooding.

Implementation of the FPL can be undertaken through the draft Flood Policy (see Appendix H) and the Development Control Plan. Adjustment of Council's LEP with the FPA/FPL is not recommended as the LEP now uses the standard flood clause released in 2021.

The FPA will form the extent of the Flood Planning Constraint Category #3 (see Section 9.1.2.5) for riverine flood planning controls. The areas of FPCC1 and FPCC2 inside FPCC3 are also included in the FPA.

Recommendation: Council is recommended to define a Flood Planning Level set at the 1% AEP flood level plus 0.8 m for residential development affected by riverine flooding. This can be included as part of the draft Flood Policy and DCP update. The FPA will delineate the extent of FPCC3 as detailed in Section 9.1.2.5.

9.1.2.3 Updated Section 10.7 Planning Certificates (Option PM02)

Option Overview

Council are currently responsible for providing information on flooding at a per-property level. This is provided via Section 10.7 certificate. This information promotes flood awareness for current and prospective owners of a property, in communicating the different sized floods that can occur and the source or sources of flooding. The certificates also assist owners in applying the correct flood planning controls at the property, which will then tend to reduce flood risk for the study area in the long term.

It is understood that at the time of writing Council provide flooding information with reference to the 2003 and 2016 studies. It is recommended to update the information provided following adoption of the current study, to the latest design flood behaviour. Secondly, information such as the lots' Flood Planning Constraint Category (FPCC) as described in the draft flood policy should be provided once that policy is adopted.

There are multiple ways that Council can extract the information at each property depending on what software is used at Council. Some councils have automated the extraction of data although it's noted this typically still requires some manual inputs and oversight, especially for larger lots where there is significant variation of flooding behaviour across the lot. Some councils have also established an online mapping platform that shows flood mapping outputs overlaid with a cadastral layer and other spatial information.

Recommendation: Council is recommended to continue to provide flooding information on a per property basis via the Section 10.7 certificate, and that information should be updated following the adoption of this study as well as following any policy revisions (LEP and DCP including Flood Policy).

9.1.2.4 Local Environmental Plan Amendments (Option PM03)

Option Overview

It is the responsibility of local governments within NSW to manage flood risk within their respective LGA's. Flood clauses in Local Environmental Plans (LEP) provide statutory planning controls to regulate development and manage flood risk. The LEP is a key planning tool for local governments which sets out zoning and high-level development controls.

NSW Department of Planning and Environment (DPE) have recently released the Flood Prone Land Package, part of which incorporated revised flood clauses for LEPs. The Flood Prone Land Package has been considered herein.

Flood Planning Clause

Revised standard flood clauses for LEPs were released for NSW in July 2021 by the NSW Department of Planning and Environment (DPE). The clause is now included in the Goulburn Mulwaree Local Environmental Plan 2009 as '5.21 Flood Planning' and has replaced the repealed clause '7.1 Flood Planning'. '5.21 Flood Planning' applies to land 'within the flood planning area' and sets objectives and conditions to manage flood risk associated with development in these areas.

Clause '5.21 Flood Planning' addresses the concerns detailed in Section 4.2.2.1 about Council's previous LEP and amendments to this clause are not recommended.

Special Flood Considerations Clause

The Flood Prone Land Package also includes a 'Special Flood Considerations' clause which applies flood related development controls for sensitive and hazardous development to land between the flood planning area and the probable maximum flood. This clause aims to manage residual flood risk during extreme events. The text of this clause is available here:

https://legislation.nsw.gov.au/view/pdf/asmade/epi-2021-226

Implementation of the Special Considerations Clause is required for effective application of the draft flood policy discussed in Section 9.1.2.5.

Summary and Recommendations

The Goulburn Local Environmental Plan (2009) has recently been updated with the standard clause '5.21 Flood Planning'. This improves controls for the management of flood risk and is supported by this study. It is recommended clause '5.22 Special Flood Considerations' is also adopted so that effective implementation of the flood policy discussed in Section 9.1.2.5 can be applied.

Recommendation: It is recommended that Council adopt and implement clause '5.22 Special Flood Considerations' in the Goulburn Mulwaree Local Environmental Plan (2009).

9.1.2.5 Revision of Goulburn Development Control Plan (2009) (Option PM04)

Option Overview

A Development Control Plan (DCP) provides detailed planning and design guidelines to support the LEP. Review of the Goulburn Development Control Plan (GDCP, 2009) (see Section 4.2.2.2) found significant modification of the document is required to match current 'best practise' advice.

The 'Australian Disaster Resilience Guideline 7-5, Flood Information to Support Land-use Planning' (ADR 7-5) presents a methodology for the management of flood risk through flood planning which considers variations in flood behaviour and risk across the floodplain. The methodology consolidates outputs from a flood or floodplain risk management study to group flood-related constraints into simplified Flood Planning Constraint Categories (FPCC). The FPCC approach to flood planning is considered 'best practice' and is recommended to be implemented by Council when revising the GDCP (2009).

Flood Planning Constraint Categories

The information presented in the current study provides a detailed description of the flood behaviour and other considerations across the floodplain, including:

(i) Flood extents, depths and levels for a range of flood events (Appendix A1);

(ii) Flood function (Section 7.2);

(iii) Flood hazard (Section 7.1);

(iv) Constraints on emergency management (Section 7.3); and

(v) Flood Planning Area definition (Section 7.4).

Considering the above-described flood characteristics during land-use planning, can provide greatly improved planning outcomes and community resilience to flood risk. FPCC combines these elements of flood behaviour to produce a succinct set of information that breaks the floodplain down into areas with similar degrees of constraint which can be treated similarly in land-use planning activities.

The methodology outlines four FPCCs which separate areas of the floodplain from the most constrained (and therefore least suitable for intensification of land use or development—FPCC1), to the least constrained (and therefore more suitable for intensification of land use or development—FPCC4). Where considered necessary, FPCC subcategory mapping can provide a further breakdown of FPCC1 and FPCC2 (ADR 7-5) as well as specific controls catered to these constraints.

The methodology requires consideration of regionally specific flood characteristics and constraints and as such there is no one-size-fits-all template that can be directly applied. For example, at Goulburn loss of flood storage (assuming an impact assessment shows no adverse impacts affecting surrounding properties) is unlikely to significantly influence flood behaviour. However, on densely populated rivers such as the Georges River in Sydney, loss of flood storage creates a cumulative impact that needs to be mitigated, and as such should be considered in categorisation. Similarly, due to significant event scaling at Goulburn, flood hazard in events rarer than the DFE should be considered in development of categories to manage risk to life during very rare to extreme events. These types of considerations, specific to riverine flooding at Goulburn, are examined in Table 31 and have been used in development of the FPCCs.

FPCC are relatively complex due to the large amount of flood and development information being considered. Flood planning controls will vary depending on the:

- Proposed development category;
- Design factors that are being considered; and the
- Flood Planning Constraint Category in which the development is located.

The result is that there are many variables that need to be considered to determine what controls apply. As such, a matrix approach has been adopted to simplify consideration of the variables. Appendix H presents the FPCC matrix that has been used for incorporation of robust planning controls into a future DCP.

<u>Summary and Recommendations</u>

The Goulburn Development Control Plan (2009) requires amendment. Consideration of the Flood Planning Constraint Category approach (outlined in ADR 7-5) in development of DCP controls is recommended to provide robust flood planning controls for riverine flooding. The revised FPL and FPA (Option PM01) is also recommended to be included in the DCP. Note that an FPA is implicitly included within the FPCC approach.

A Draft Flood Policy that implements the FPCC approach to flood planning is presented in Appendix H.

Recommendation: Council are recommended to prepare a revised DCP using the FPCC approach to flood planning and Draft Flood Policy presented in Appendix H.

Table 31: Flood Planning Constraint Categories (ADR 7-5) and Goulburn Riverine Flooding Considerations

FPCC	Constraint	Implications	Key considerations	Subcategory	Goulburn Riverine Flooding Considerations
1	Floodway and storage areas in the DFE	Development or changes to topography within flow conveyance areas and flood storages areas affect flood behaviour, which will alter flow depth or velocity in other areas of the floodplain. Changes can negatively affect the existing community and other property	The majority of developments and uses have adverse impacts on flood behaviour. Consider limiting uses and development to those compatible with maintaining flood function	a	Figure 6 presents the DFE (1% AEP) flood function. The Wollondilly River floodplain is predominately classified as Flood Conveyance due to the steep rising topography surrounding the channel. Areas of flood storage are noted along the Mulwaree River floodplain, however, are limited in their extent, generally located from the Hume Highway to Sydney Road. The encroachment analysis discussed in Appendix F found that total blockage of the Flood Storage and Flood Fringe areas resulted in typically less than 0.1 m of afflux during the DFE. A such, Council should consider allowing filling and development in Flood Storage areas if it can be shown that flood impacts do not affect surrounding properties.
	H6 hazard in the DFE	Hazardous conditions considered unsafe for vehicles and people. All building types are considered vulnerable to structural failure	The majority of developments and uses are vulnerable to failure in this flood hazard category. Consider limiting developments and uses to those that are compatible with flood hazard H6	b	Figure 2 presents the DFE flood hazard. H6 hazard is predominantly located within the Wollondilly and Mulwaree River channels. These areas are unsuitable for development of most types.
2	Floodway in events larger than the DFE	Floodway areas may develop during an event larger than the DFE. For example, 0.2% AEP if 1% AEP is the DFE. People and buildings in these areas may be affected by flowing and dangerous floodwaters	Consider compatibility of developments and users with rare flood flows in this area	a	The flood function for the 5%, 1% and PMF events are presented in Figure 5 to Figure 7. Due to the magnitude and rarity (approximate probability is 1 in 1,000,000) of PMF, use of this event for various aspects of flood planning can results in overly onerous planning controls and sterilisation of the floodplain which is contradictory to the objectives of the FDM (2005). As such, the flood function mapping for the 0.05% AEP event was produced for use in FPCC development. This is consistent with recommendations in ADR 7-5 which states *'Particular care should be taken where the difference in flood levels, between the defined flood event and the probable maximum flood, or an equivalent extreme event, is significant. Where this is the case, additional care is needed when examining emergency management considerations'*. The average difference between the 1% AEP and PMF events flood level due to riverine flooding at Goulburn is 10 m.
	Flood hazard H5 in the DFE	Hazardous conditions are considered unsafe for vehicles and people, and all buildings are vulnerable to structural damage	Many uses and developments will be vulnerable to flood hazard. Consider limiting new uses to those compatible with flood hazard H5. Consider treatments such as filling (where this will not affect flood behaviour) to reduce the hazard to a level that allows standard development conditions to be applied. Alternatively, consider a requirement for special development conditions	b	Figure 2 presents the DFE flood hazard. Majority of development types are unsuitable in these areas. Development is potentially viable if flood hazard can be reduced (through fill or otherwise) and flood evacuation/egress issues can be effectively managed without impacting on NSW SES services.
	Emergency response—isolated and submerged areas	Area becomes isolated by floodwater or impassable terrain, with loss of evacuation route to the community evacuation location. The area will become fully submerged with no flood-free land in an extreme event, with ramifications for those who have not evacuated and are unable to be rescued	Consequences of isolation and inundation can be severe. Consider the consequences of: • evacuation difficulty or inundation of the area on the development and its users, which may include limitations on land use, or on land use that has occupants who are more vulnerable to disruption and loss • the development on emergency management planning for the existing community, including the need for additional treatments • the development on community flood recovery • disruption or loss of the development on the users and wider community	c	Figure 9 to Figure 11 present Flood Emergency Response Classifications (FERC) for the 5%, 1% and PMF events respectively. Due to the extreme magnitude of the PMF, large areas of Goulburn are classified as Isolated Submerged. As such, strict controls applied to existing residential development is likely to be considered overly onerous and the DFE has been used. However, sensitive / critical uses or density intensification should consider the FERC.
	Emergency response—isolated but elevated areas	Area becomes isolated by floodwater or impassable terrain, with loss of an evacuation route to a community evacuation location. The area has some land elevated above the extreme flood level. Those not evacuated may be isolated with limited or no services, and will need rescue or resupply until floods recede and roads are passable	Some developments and their users may be vulnerable to disruption or loss. Consider: • the consequences of disruption or loss of the development on the users and the wider community • limiting land use, or land use that has occupants who are more vulnerable to disruption and loss • additional emergency management treatment requirements • issues associated with the level of support required during a flood, particularly for long-duration flood events	d	As per (2c). FPCC2d has been defined by all areas identified as Isolated Elevated in the 1% AEP Flood Emergency Response Classification.
	Flood hazard H6 in floods larger than the DFE	Hazardous conditions may develop in an event rarer than the DFE, which may have implications for the development and its occupants	Consider the need for additional development conditions to reduce the effect of flooding on the development and its occupants	e	The flood hazard for the 5%, 1% and PMF events are presented in Figure 2 to Figure 4. As discussed in (2a) above, the 0.05% AEP event was analysed and flood hazard mapping produced and used for development of the FPCC2 extent.

FPCC	Constraint	Implications	Key considerations	Subcategory	Goulburn Riverine Flooding Considerations
3	Outside FPCC2—generally below the DFE and the FPL	Hazardous conditions may exist creating issues for vehicles and people. Structural damage to buildings that meet building standards unlikely because of flooding	Standard land-use and development controls aimed at reducing damage and the exposure of the development to flooding in the DFE are likely to be suitable. Consider the need for additional conditions for emergency response facilities, key community infrastructure and vulnerable users	-	Standard controls to be applied, consistent with the objectives of the revised LEP discussed in Section 9.1.2.4. The extent of FPCC3 is defined as the extent of the FPA discussed in Section 9.1.2.2, including also all areas of FPCC1 and FPCC2.
4	Outside FPCC3, but within the probable maximum flood (or similar extreme event)	Emergency response may rely on key community facilities such as emergency hospitals, emergency management headquarters and evacuation centres operating during an event. Recovery may rely on key utility services being able to be readily re-established after an event	Consider the need for conditions for emergency response facilities, key community infrastructure and land uses with vulnerable users	-	Controls to be applied for sensitive and critical land uses as per the objectives of the revised LEP 'Floodplain Risk Management' clause discussed in Section 9.1.2.4. This is defined as land outside of FPCC3 but below the PMF flood level.

9.1.2.6 Advice on Land-use Planning Considering Overland Flooding (Option PM05)

Option Overview

Overland flow flood behaviour differs significantly compared to mainstream flooding. Flood depths are generally much shallower, however high velocities can be expected as well as short catchment response times. As such, traditional flood planning controls are often unsuitable for the management of flood risk to overland flow flooding.

The limitations of the LEP (2009) discussed previously, remove Council's ability to apply planning controls to areas affected by overland flows. However, recommendations made to amend Council's LEP presented in Section 9.1.2.4 will ameliorate this issue.

Council's DCP is recommended to contain controls tailored for overland flow. In this case, the FPCC approach outlined in Section 9.1.2.5 is recommended, however modification of the matrix and applied controls is required to consider the overland flow flood risk.

So that overland flow flood risk can be understood for Goulburn an overland flow flood and floodplain risk management study is recommended to be undertaken with the findings of this study used to determine appropriate flood planning controls to address overland flow flood risk.

Cost

The estimated cost to undertake a flood study and floodplain risk management study for Goulburn is $100,000. Additional Council cost would be incurred to implement an overland flow draft flood policy into Council's DCP.

Summary and Recommendations

Recommendations made in Section 9.1.2.4 will apply LEP controls relating to flooding to areas affected by overland flow. However, support from robust DCP controls should also be implemented. It is recommended that a FPCC DCP matrix specific to overland flow be developed and implemented into Council's DCP. This will require Council to undertake an overland flow flood and floodplain risk management study for Goulburn.

Recommendation: Council are recommended to undertake an overland flow flood and floodplain risk management study. The findings from this analysis can be used to prepare a revised DCP using the FPCC approach to flood planning. The approach should consider overland flow flooding with controls to be tailored for overland flow flood behaviour.

9.1.2.7 Advice on Land-use Zoning Considering Flooding (Option PM06)

Overview

The Floodplain Development Manual (2005) states that '*Land use planning limits and controls are an essential element in managing flood risk and the most effective way of ensuring future flood risk is managed appropriately*'. Council are recommended to give due consideration to selecting appropriate zones and related provisions when flood prone land is being rezoned as an effective and long term means of limiting danger to personal safety and flood damage to future developments. Zoning of flood prone land should be based on an objective assessment of land suitability and capability, flood risk, environmental and other factors and should not unjustifiably restrict development simply because land is flood prone (FDM, 2005).

A review of land use zones that considers local flood characteristics has been undertaken for the Wollondilly and Mulwaree River floodplains. The Australian Disaster Resilience Handbook Collection (Handbook 7) states that risk management can be achieved by informing land zonings through consideration of flood function, flood hazard, emergency response limitations, and vulnerability of different development types. Consideration of these characteristics has been undertaken to identify potential appropriate adjustments to land use zonings.

To reduce future flood risk potential due to development pressures, undeveloped lots situated in high hazard (H3 or greater), floodway areas and areas with significant evacuation constraints, are considered hazardous and may be considered for downzoning to a land use type that does not permit residential, business or industrial land uses.

Council has already downzoned land in the Eastgrove area and is recommended to continue this process in conjunction with the Voluntary Purchase discussed in Section 9.1.3.1. In addition, downzoning may be considered in the Avoca Street and Braidwood Road areas, however again this is dependent on potential Voluntary Purchase of existing properties.

Summary and Recommendations

Land zones should be considered in conjunction with flood characteristics. Downzoning of land can be considered for areas of high hazard to remove the risk of future development.

9.1.2.8 Review of Future Development Areas (Option PM07)

Overview

As discussed in Section 2.4, Council is in the process of reviewing potential areas of future development to meet demands from expected population growth. These development areas are considered in conjunction with the FPCC discussed in Section 9.1.2.5. Note that this assessment considered riverine flooding and only high-level consideration of potential tributary flooding or overland flows is provided.

Table 32: Preliminary Assessment of Future Development Areas

Growth Area	Type*	Estimated Riverine FPCC	Likelihood of tributary/overland flow constraints	Estimated Suitability of proposal
UFHS* (Middle Arm West)	R1	Above PMF	Low	Suitable
UFHS (Middle Arm URA)	R1	Above PMF	Low	Suitable
UFHS (Bradfordville)	R1	Above PMF	Low	Suitable
UFHS (Middle Arm East)	R1	Above PMF	Low	Suitable
UFHS (Kenmore)	R1	FPCC 4	Low	Suitable
UFHS (Gorman Road)	R5	Above PMF	Low	Suitable
UFHS (Mt Grey East)	R5	Above PMF	Low	Suitable
UFHS (Mountain Ash)	R5	Outside Study Area	High	Not known. Areas potentially unsuitable

Growth Area	Type*	Estimated Riverine FPCC	Likelihood of tributary/overland flow constraints	Estimated Suitability of proposal
UFHS (Brisbane Grove)	R5	FPCC 1, 2, 3, 4 and Above PMF, Outside Study Area	Low	Fair
UFHS (Run 'O' Waters)	R5	Above PMF	Low	Suitable
UFHS (Baw Baw URA)	R5	FPCC 4, Above PMF	Low	Suitable
UFHS (Sooley)	R5	FPCC 4, Above PMF	Low	Suitable
Northeast Enterprise Corridor	IN1	Above PMF	Moderate	Fair
Dossie Street Planning Proposal	R5, IN1, E1, RE1	Above PMF	Low	Suitable
Goulburn Health Hub on Ross Street	R1, B6, RE1	FPCC 4	Moderate	Suitable
Wastewater Treatment Farm	R5	FPCC 1, 2 ,3, 4 and Above PMF	High	Areas potentially unsuitable

* Draft Urban and Fringe Housing Strategy (UFHS) – land zones not provided. As such, development types specified as 'Serviced Residential' assumed R1 zoning, and Large Lot Residential assumed R5 zoning.

Summary and Recommendations

The riverine flood risk to Proposed Future Development Areas should be considered in conjunction with flood characteristics. Further analysis in regard to overland flow and tributary flooding should also be undertaken to assess potential constraints.

9.1.3 Property Modification Measures

9.1.3.1 Voluntary Purchase (Option PM08)

Option Overview

Voluntary Purchase (VP) removes residential properties subject to high hazard flood conditions from the floodplain. VP is an effective floodplain risk management measure for exiting development for which it is impractical or uneconomic to mitigate flood risk by other means. Properties must satisfy the criteria outlined in the 'Floodplain Management Program - Guidelines for voluntary purchase schemes' to be eligible. The document states that '*VP is a recognised and effective floodplain risk management measure for existing properties in areas where:*

- *there are highly hazardous flood conditions from riverine or overland flooding and the principal objective is to remove people living in these properties and reduce the risk to life of residents and potential rescuers*
- *a property is located within a floodway and the removal of a building may be part of a floodway clearance program that aims to reduce significant impacts on flood behaviour elsewhere in the floodplain by enabling the floodway to more effectively perform its flow conveyance function*

- *purchase of a property enables other flood mitigation works (such as channel improvements or levee construction) to be implemented because the property will impede construction or may be adversely affected by the works with impacts not able to be offset'*

Eligible properties are purchased by Council with funding potentially available as part of the Floodplain Management Program. The process is entirely voluntary and often takes many years to implement due to budget limitations.

<u>SMEC (2003) VP Scheme Review</u>

The SMEC (2003) study recommended the implementation of a VP scheme for 48 properties. Council has provided a list of properties that were recommended for VP which has been reviewed based on the criteria listed the VP Guidelines.

A number of properties in hazardous areas have been demolished under the scheme, reducing flood risk in these areas. However, it was found that most remaining properties did not satisfy the required criteria based on the flood characteristics identified by the current study. This is likely due, in part, to a significant reduction in 1% AEP flow estimates, resulting in the current study 1% AEP flood levels to be 1 to 1.5 m lower than the SMEC (2003) study flood levels. This is discussed in Section A3.5. Further, the SMEC (2003) study criteria for determining eligibility was based on the flood depth above floor level. This ignores the fact that properties with raised floor levels may be situated in areas of significant flood hazard, posing a risk to the structural integrity of the building, people trying to evacuate or emergency service personnel performing a rescue. This criteria resulted in properties situated close to the flood fringe being selected for VP (due to low floor levels), whilst nearby properties in areas of higher hazard not being selected.

Due to the above findings, properties identified as eligible for VP by the SMEC (2003) study are no longer recommended. Instead, GRC Hydro have undertaken analysis below to determine properties subject to significant flood risk, that satisfy the criteria outlined in the VP Guidelines.

<u>Properties Recommended for VP Feasibility Assessment</u>

An assessment of property flood risk was undertaken by considering the following:

- The event AEP responsible for first flooding a property above floor level. Only properties flooded in the 1% AEP event or more frequent events were selected, unless subject to H5/H6 hazard classification which could affect the structural stability of the building;
- The maximum flood hazard at the property in the 1% AEP event;
- The maximum flood hazard at the property in the 0.2% AEP event;
- Flood access hazard in the 1% AEP event. Only properties with flood access of H4 hazard or higher were selected as resident evacuation/emergency personal access would be hazardous under these conditions.

26 properties were identified that satisfy the above criteria. They are recommended for assessment as part of a VP feasibility Assessment.

<u>Impact on Flood Liability</u>

As a VP scheme removes properties from the floodplain, the overall flood risk is significantly reduced with 26 properties no longer flooded during any event. However, VP schemes can take many decades to fully implement and the flood risk to properties remains high until the VP scheme is complete.

The number of properties no longer flooded above floor for various events is presented in Table 33, along with the expected reduction in damages per event. A reduction in Average Annual Damages of $158,000 is expected as well as a decrease in risk to life.

Table 33: Voluntary Purchase, Reduction in Damages and Above-floor Flooding

Event	Number of Properties No Longer Flooded Over Floor	Number of Newly Flooded Over Floor Properties	Reduction in Event Damages1
20% AEP	0	0	$ 12,000
10% AEP	0	0	$ 110,000
5% AEP	4	0	$ 492,000
2% AEP	18	0	$ 2,797,000
1% AEP	20	0	$ 4,385,000
0.5% AEP	22	0	$ 5,740,000
0.2% AEP	22	0	$ 3,238,000
PMF	22	0	$ 5,102,000
Average Annual Damage reduction			$ 158,000

<u>Cost Estimate</u>

Under a VP scheme, property values are determined by the Valuer General and a 'flood unencumbered' value is determined for each property. The median sold property price in Goulburn is $390,000 for a three-bedroom home, however, property prices in identified areas were noted to be less than the Goulburn median on average. An estimated median value for the properties recommended for VP feasibility is $340,000 per property, and a total cost of $9.1 million for all properties. The median value is based on records of property sales and does not include the cost of demolition.

It should be noted that adoption by Council of Voluntary Purchase scheme does not require the immediate expenditure of this amount and the scheme can be implemented over as many years as is required.

<u>Benefit / Cost Ratio Analysis</u>

The option's reduction in Average Annual Damages, the Net Present Value (NPV) of this reduction (assuming 50 year design life and 7% discount rate) and the benefit-cost ratio are as follows:

- Average Annual Damage reduction: $158,000
- NPV of reduction: $2,327,000
- Cost estimate of option: $9,100,000
- Benefit-cost ratio: 0.3

The benefit-cost ratio is 0.3, which means the cost of the option is three times its benefit, and so cannot be justified on economic grounds alone. However, removal of these properties from high hazard areas significantly reduces risk to life for a full range of flood events which provides a significant intangible benefit.

Community Acceptance

34% of respondents were interested in Voluntary Purchase or Voluntary House Raising as a potential mitigation measure indicating community acceptance of the proposed option is low. However, the scheme is entirely voluntary with residents able to make their own choice in relation to involvement in the scheme if eligible.

Summary and Recommendations

A detailed Voluntary Purchase feasibility study is recommended to be considered by Council with focus on the 26 properties listed in this report. The estimated cost to undertake a feasibility assessment is $30,000. Detailed investigation is suggested following the requirements of the 'Floodplain Management Program Guidelines for voluntary purchase schemes. The analysis is likely to include (but not be limited to):

- One on one meetings/site visit for each the property;
- Detailed examination of the build type/likelihood of failure;
- Determination of the build year (properties constructed post 1986 are not eligible);
- An estimate of the property value;
- Further review of the hydraulic characteristics/risk pertinent to the VP Guidelines;
- Review of access, evacuation potential and isolation issues. This will include consultation with the SES including their view of where to risk to life exists;
- Economic, social and environmental costs and benefits;
- The support of the affected community for VP as determined through consultation with affected owners;
- Viability of the scope and scale of the scheme and how the scheme will be prioritised generally on the basis of degree of flood hazard exposure; and
- An implementation plan for the scheme.

Recommendation: Council are recommended to prepare a Voluntary Purchase feasibility assessment in accordance with requirements outlined in 'Floodplain Management Program Guidelines for voluntary purchase schemes'.

9.1.3.2 Voluntary House Raising (Option PM09)

Option Overview

Voluntary House Raising (VHR) raises the finished floor level of eligible residential properties to reduce the frequency of flooding. VHR can be an effective strategy for existing properties in low flood hazard areas where mitigation works to reduce flood risk to properties are impractical or uneconomic. Properties must satisfy the criteria outlined in the 'Floodplain Management Program - Guidelines for voluntary house raising schemes' to be eligible. The document states that 'VHR is recognised as an effective floodplain risk management measure for both riverine and overland flood conditions. It is generally undertaken to:

- *reduce the frequency of exposure to flood damage of the house and its contents – Reducing the frequency of household disruption, associated trauma and anxiety, and clean up after floods may also have social benefits.*
- *as a compensatory measure where flood mitigation works adversely affect a house which is generally considered part of the mitigation work rather than a separate VHR scheme.'*

Key to the eligibility for VHR is requirement for the property to be situated in a 'low flood hazard' area, whilst also being frequently flooded. These criteria are often in conflict for riverine flooding in non-coastal NSW. For example, a property that is situated on the edge of the 1% AEP flood extent is unlikely to be flooded by events more frequent than the 1% AEP event (and thus the benefit of house raising is likely to be low), whilst potentially being situated in hazardous areas in events rarer than the 1% AEP. For example, the 0.2% AEP and PMF events on the Wollondilly and Mulwaree River in Goulburn are on average 1.5 m and 10 m higher respectively than the 1% AEP flood level. This means that even if a property is raised above the 1% AEP flood level, the flood hazard in a very rare or extreme event could greatly exacerbate flood risk. This is potentially compounded by a false sense of security that can be instilled in residents that have elevated floor levels, resulting in delayed or non-evacuation when required.

Summary and Recommendations

Voluntary House Raising is not considered as suitable means of flood risk management for areas affected by riverine flooding at Goulburn. Properties that are frequently flooded due to Wollondilly and Mulwaree River flooding are situated in high hazard areas that are unsuitable for VHR.

9.1.3.3 Flood Proofing (Option PM10)

Option Overview

Flood proofing aims to reduce the impact of flooding on flood affected buildings by using water resistant materials. It is achieved by a combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.

Flood proofing buildings during construction can be readily achieved through selection of appropriate materials a considerations of the site's flood liability. Flood proofing new development where floor levels are constructed lower than the FPL level is recommended and can be included as a flood planning control in Council's DCP. This is examined in Section 9.1.2.5.

Retrofitting permanent flood proofing measures to existing development is difficult to implement and not recommended as a flood mitigation measure. However, temporary flood proofing measures such as flood barriers and sandbags can provide some flood protection if adequate warning time is available.

Summary and Recommendations

Retrofitting flood proofing to existing development is not supported as a flood mitigation measure, however, should not be discouraged by Council if private property owners want to implement these measures at their own expense.

Incorporating flood proofing measures into new development should be a requirement of Council's flood planning policy for development below the FPL.

Recommendation: Council are recommended to define flood planning controls which require flood proofing measures be incorporated into new development below the FPL.

9.2 Response Modification Measures

9.2.1 Introduction

The following sections present the assessed response modification measures for management of existing and future flood risk. While such measures do not change the flood behaviour itself, they can reduce risk to life through improved flood preparedness, warning and response. Such measures are particularly suited to areas where flood modification measures (works) are either not feasible or prohibitively expensive, as well as to address residual flood risk for very rare to extreme floods.

9.2.2 Relevant Documents

The assessment of response modification measures is based on the Australian Institute for Disaster Resilience (AIDR) manuals (2009):

- Manual 20 - Flood Preparedness
- Manual 21 - Flood Warning
- Manual 22 - Flood Response

9.2.3 Flood Preparedness

9.2.3.1 Overview

Manual 20 states 'The *'manageability' of flooding is enhanced by effective preparation for floods' and that 'this preparation should be undertaken for all areas in which there is an interaction between flooding and human activities. It should involve purposeful planning for floods and the engagement and education of the members of flood-liable communities about flood risks and their management'.*

The current study has identified areas of flood risk and the measures discussed in the ensuring sections aim to manage this risk through planning and preparation for future flood events.

9.2.3.2 Review and Update of Goulburn Intelligence

9.2.3.2.1 Goulburn Mulwaree Local Flood Plan (Option RM01)

Option Overview

The Goulburn Mulwaree Local Flood Plan (LFP) is a Sub-Plan of the Goulburn Local Emergency Management Plan and was published in October 2012. The Plan covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures from flooding within the LGA. The NSW SES are responsible for the development and maintenance of the LFP.

As the key flood emergency management document, the LFP should be updated when additional information becomes available. Specifically, findings from the current study and recommendations presented herein provide the most up to date flood risk profile for Goulburn, and are recommended to be incorporated to assist in the management of flood risk through emergency response.

Recommended Amendments

It is recommended that the LFP be updated to incorporate the findings of the current study. Specific recommendations are presented below:

- Section A3 states that there are no gauges to indicate river heights for either river and the BoM does not have any classification of flood levels for Goulburn. As per the recommendation in Section 9.2.3.2, review and update of Goulburn flood intelligence is required to include the findings from this FRMS.
- Section A3 makes reference to flood maps produced during the SMEC 2003 Floodplain Risk Management Study. These are recommended to be updated to consider the findings of the current study.
- Section A4 discusses the flood history at Goulburn. Information on historic flood events should be gleaned from the Flood Study (2016). It should be noted that the 2010 and 1959 events were the floods of record on the Wollondilly and Mulwaree Rivers, respectively. However, the 2010 Wollondilly River event is noted to have caused flooding to 10 properties and be classified as moderate flooding. The number of affected properties may be reviewed in conjunction with the NSW SES as should the selected 'moderate' flood category.
- Section A6 discusses Extreme Flooding and incorrectly notes that the 1961 event is the flood of record on the Wollondilly as well as uses the 1% AEP flood level from the SMEC (2003) study. It is recommended that the LFP be updated to consider the information presented in the current study.
- Section A6 should further highlight the extreme nature of the PMF at Goulburn, including the number of affected properties and typical flood hazards experienced.
- Section B2 states that there are no schools, childcare centres or aged care facilities that are flooded. This can be updated as per the information presented in Section 8.6. Some

information in relation to flooding of utilities and infrastructure is provided, however this can be updated with the information presented in Section 8.6.1.4. Discussion of the flood liability of Goulburn Correctional Centre can also be provided.

- Section B6 notes that the floodplain is predominantly classified as 'rising road access', however this requires update based on the current study as higher risk areas (Isolated Submerged) are present during extreme events.
- The number of affected properties can be updated based on the current study. The information presented in Section 8.4 outlines this information on a per property basis.

Summary and Recommendations

The Goulburn Mulwaree Local Flood Plan (LFP) provides important flood intelligence, and it is recommended that it be updated to include the findings of the current study. The NSW SES are responsible for maintaining LFPs.

Recommendation: The NSW SES are recommended to update the Goulburn Mulwaree Local Flood Plan to include the findings of the current study and recommendations presented herein.

9.2.3.2.2 Develop Flood Intelligence Cards (Option RM02)

Option Overview

Flood Intelligence Cards (FICs) provide concise flood intelligence that correspond to a local stream gauge level, which is used to inform emergency response during a flood. The NSW SES are responsible for the development and maintenance of FICs.

As discussed previously, Section A3 of the LFP states that there are no local gauges that provide river levels for Goulburn and accordingly, there is no FIC for Goulburn. However, it is recommended that FICs be developed for the Marsden Wier, Inveralochy Bridge and Lansdowne Bridge gauges using the information presented in the current study. Additional flood modelling may also be beneficial in the development of the FICs in lieu of historic flood information recorded at these gauges. Some gauge information has been provided in the hotspots section of this report (see Section 8.2).

Summary and Recommendations

The development of FICs for the Mulwaree and Wollondilly Rivers is recommended. The NSW SES are responsible for development of FICs.

Recommendation: It is recommended that the NSW SES develop FIC for the Lansdowne Bridge gauge and Marsden Weir gauge. Pertinent information can be obtained from the current study and improved with additional modelling where required.

9.2.3.2.3 Evacuation Centre Review (RM03)

Option Overview

There are two flood evacuation centres in Goulburn, located at the Goulburn Soldiers and Works Clubs. Both locations are flooded during the PMF, and it is recommended that alternative evacuation centres be nominated in the LFP.

The evacuation centre locations can be chosen in consultation between Council, the NSW SES and proposed location owners. Potential locations could include the various educational facilities presented in Table 26 with a 'not flooded' classification, or private facilities outside of the PMF extent.

Recommendations

Recommendation: NSW SES to nominate alternate flood evacuation centres outside of the PMF extent, in consultation with Council.

9.2.3.3 Warning Signage at Hazardous Road Crossings (Option RM04)

Option Overview

In Australia, the most common cause of fatality during a flood is drowning from attempting to cross a flooded bridge or road. As described in Section 8.3, there are numerous roads that experience hazardous flood conditions during relatively frequent floods (H2 and above is hazardous for vehicles).

This option consists of installing warning signage at roads in each town to reduce the incidence of motorists attempting to cross hazardous flood flow. Signage at flood-prone roads typically includes a warning sign (e.g., 'Road Subject to Flooding, Indicators Show Depth') and depth markers on both approaches. These can be cost-effective in managing flood risk, especially for areas where a bridge/culvert upgrade is not feasible. Recent research has found that static signage tends to be ignored by drivers and that dynamic signage is more effective at warning against crossing hazardous flooding.

Locations Recommended for Flood Warning Signage

The locations presented in Table 34 experience hazardous flow and would benefit from depth markers and warning signage.

Table 34: Recommended Flood Signage for Flooded Roads and Crossings

River	Location	First Flooded	Sign Type	Comment
Wollondilly	Gibson Street Footbridge	< 20% AEP	Flood warning	Warning sign recommended for pedestrians
	Towrang Bridge (Hotspot 5)	~ 50% AEP	Dynamic flood warning	High hazard flow conditions. Upgrade of the existing crossing to a bridge structure is a recommended flood modification option (R07) and is

River	Location	First Flooded	Sign Type	Comment
				currently planned for completion by 2022. If the bridge is upgraded, warning signage is not required, however depending on timing may be considered as an interim measure.
Mulwaree	Park Road culvert crossing	< 20% AEP	Flood depth marker, flood warning	Frequently flooded crossing.
	Blackshaw Road underpass	< 20% AEP	Dynamic flood warning, flood depth marker	Frequently flooded road.
	Golf Avenue	< 20% AEP	Flood depth marker, flood warning	Frequently flooded crossing.
	May Street Bridge	< 20% AEP	Dynamic flood warning, flood depth marker	High hazard flow conditions. Flood warning signage is recommended even with proposed upgrade of this crossing.
	Bungonia Road near Goulburn Brewery	<20% AEP	Flood depth markers	Frequently flooded crossing.
	Bungonia Road at western Landsdowne Bridge approach	< 20% AEP	Dynamic flood warning, Flood depth markers	Frequently flooded road with drop from elevated bridge. Warning for vehicles travelling to the west.
	Forbes Street between Bungonia and Glenelg Streets	< 20% AEP	Flood depth markers	Frequently flooded road.

Depth markers are already present at some of the flood prone crossing, however, should be checked to ensure that they are suitably reflective and effective for notifying night time drivers of potential flood risk.

Cost Estimate

Standard flood depth markers and warnings signs that comply with Austroads requirements (inclusive of posts/brackets and freight) cost approximately $2,000 per crossing (quote obtained from Artcraft on 17/9/20).

Dynamic signage adds an electronic sign above the standard warning sign, that lights up to indicate when the road is flooded. A recent project using flashing signs that are automatically triggered has had early success in Queensland, and cost approximately $25,000 per crossing.

The estimated cost of purchase for all signs is ~$110,000 not including the cost of installation. It is estimated that the cost of installation and management is ~$25,000.

Summary and Recommendations

Flood warning signs and depth markers are recommended for flooded roads and crossing. Dynamic warning signs are recommended for particularly hazardous crossings.

Recommendation: Council are recommended to install flood warning signage to minimise the risk of motorists and pedestrians entering flood waters.

9.2.3.4 Automatic Boom Gates for Key Flooded Roads (Options RM05)

Overview

Automatic boom gates can be considered for frequently used low level crossing that are subject to considerable flood hazard. Currently Council has an automatic boom gate at the Blackshaw Street underpass, however it was noted to be unreliable by Council staff and the NSW SES. Other low-lying roads such as Bungonia Road and Towrang Bridge, currently rely on Council staff to manually close the road once the crossing becomes inundated. This can result in a period when the road crossing is hazardous for vehicles, but not yet closed by Council.

There are various types of automatic boom gates, for example some may close due to a trigger level being reached at an upstream gauge (pre-existing gauges could be used), whilst others trigger due to the water level at the location of the road crossing. However, the objective remains the same, with the pressure and responsibility of rapid road closures reduced for Council staff.

It is worth noting that frequently flooded low-level crossings that experience high traffic volumes are typically also suitable for road raising works to reduce flood liability. Road raising is the preferred method of mitigating risk to high hazard low level crossing, however, may not be financially feasible. In circumstances where road raising is not feasible, or unlikely to occur for many years, automatic booms gates may be considered.

Locations Recommended for Automatic Boom Gates

Due to the expense of installing automatic boom gates, this management measure is only recommended for roads that experience significant traffic volumes and are subject to high flood hazard. Two locations are recommended:

- Blackshaw Street underpass - as mentioned, Council has an automatic boom gate at this location which is noted to malfunction resulting in the road often not being closed during times of flood. It is strongly recommended that Council either fix or replace the existing boom gate with a more reliable model.
- Towrang Bridge – as described in Hotspot 5 (Section 8.2.5), Towrang Bridge is frequently flooded by high hazard flow conditions. The bridge is also situated some distance from town which can make it difficult for Council staff to close the bridge in a timely fashion. An automatic boom gate could be installed at this location and triggered by the Murrays Flat gauge upstream. Section 9.3.3.8 recommends raising of Towrang Road crossing as a risk management measure (Option R07), however Council is recommended to consider the timing of this project and determine if installation of an automatic boom gate as an interim management measure is warranted. Current planning is to have the new bridge constructed by 2022.

Installing dynamic warning signs (see Section 9.2.3.3) at the location of proposed boom gate locations are to be considered.

Cost

The estimated cost of installation of an automatic boom gate with associated trigger gauge (using telemetry technology) is estimated to be ~$100,000 per crossing.

Summary and Recommendations

Automatic boom gates are suitable for closing hazardous road crossings that experience high traffic volumes. Implementation of this risk management strategy reduces the responsibility for Council to close flooded roads in a timely fashion. Replacement of the existing boom gate at the Blackshaw Street underpass is recommended, and Council may consider an automatic boom gate for the Towrang Bridge crossing as an interim risk management measure, pending potential future upgrade of the crossing.

Recommendation: Council to consider implementing automatic boom gates at roads subject to high hazard flood conditions and high traffic volumes.

9.2.3.5 Community Flood Education (Option RM06)

Option Overview

The level of awareness of flooding in a community is an important indicator of how well the community can prepare for, respond to and then recover from a flood event. Beyond general awareness that flood risk exists in a particular town, flood education is most effective when it facilitates resilience to flooding in a community. This encompasses understanding of the types of flood risk, the available warning systems, measures that can be taken in preparation for a flood event, personal safety and protection of assets during a flood, and recovery from a severe flood event. In each of the four towns, the level of engagement and awareness will vary significantly between those with high flood risk and those who are only indirectly affected by flooding.

It is recommended that flood education be tailored to each area and carried out across a range of methods. Materials used in education could consist of:

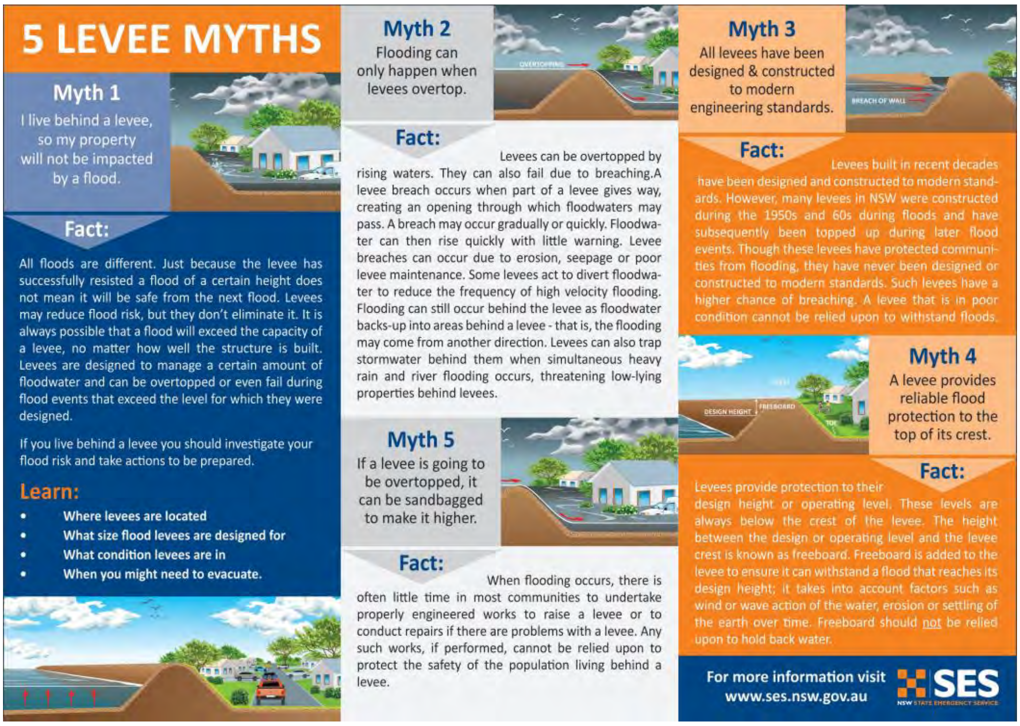
- information on previous floods including photos
- design flood information as described in the flood risk sections of this report
- SES information on preparing for a flood, common hazards during a flood, and the recovery phase (see Image 10 below as an example)

The range of communication methods adopted is recommended to cover different demographics and groups within the community. Available methods include:

- SES and Council stall at local events, with fact sheets, maps and SES staff available to talk to interested residents.
- Flood depth markers showing the height reached by historical floods. This is discussed further in Section 9.2.3.6.

- Periodic articles in press and social media, which describe the history of flooding and useful information on the current flood risk, and available resources.
- Council website with various information on flooding available in one location
- Education packages for primary schools and secondary schools. See https://www.ses.nsw.gov.au/for-schools/ for examples.

Image 10: Example of a flood education fact sheet (source: NSW SES)



Recommendations

Council and the NSW SES are recommended to develop a community flood education program.

Recommendation: Implement a community flood education program.

9.2.3.6 Historic Flood Marker (Option RM07)

Option Overview

Understanding flood risk and the magnitude of potential flooding can be difficult to communicate to residents of flood affected areas, particularly if flood risk is associated with rare flood events which have not be experienced by the population at risk. Providing information that can help the community visualise the magnitude of potential flooding can improve community awareness which will often lead to better emergency response.

An effective means of communicating flood risk is through showing historic flood levels via a gauge or board in a publicly accessible location. An example of this is the historic event flood marker found at Gundagai, NSW which is shown in Image 11.

Image 11: Gundagai Historic Flood Marker

Source: Wikimedia Commons, Author: Conquimbo

<u>Cost Estimate</u>

Based on the quote obtained from Artcraft for signage discussed in Section 9.2.3.3, the estimated cost for a historic event depth marker is $8,000.

<u>Summary and Recommendations</u>

It is recommended that historic flood marks be installed by Council in locations subject to flood risk which are frequented by the community. The flood marker may also include design flood levels obtained from the current study. The first four flooding hotspots listed in this report may be suitable locations, depending on what records Council have of flooding at each location.

Recommendation: Council to install historic event depth markers in flood prone areas frequented by the community.

9.2.4 Flood Warning

9.2.4.1 Overview

Effective flood warning provides information to a population at risk of flooding so that flood response measures can be implemented. A flood warning system is made up of various complementary factors which together allow for the understanding of an impending flood, as well as the ability to take action to mitigate its effects. '*Manual 21 – Flood Warning*' of the Australian Disaster Resilience Handbook Collection outlines the following components of a flood warning system:

- Monitoring of rainfall and flow data;
- Prediction of flood magnitude and timing;
- Understanding of the consequence of an impending flood;
- Development of messaging to describe consequence and what response should be undertaken;
- Dissemination of warning messages;
- Effective response strategies; and
- Review of the warning system after flood events.

The objective of an effective flood warning system is that the amount of flood warning available should exceed the amount of time required to respond.

9.2.4.2 Existing Flood Warning System Review

Liaison with NSW SES and BoM indicates that no official flood warning system is currently in use for Wollondilly or Mulwaree River flooding at Goulburn. The NSW SES currently rely on stream gauge levels for gauge information at Goulburn, as well as visual inspection of the rivers, to determine river levels and what emergency response actions are required. The current arrangement does not allow for predictive or advanced warnings of an impending flood which may limit the SES ability to effectively respond, particularly for very rare to extreme events or when flooding occurs in both rivers/multiple locations simultaneously.

The SMEC (2003) study made recommendations for the installation of additional pluviometer rain gauges and stream gauges in both the Wollondilly and Mulwaree River catchments. It was suggested that these gauges be linked with BoM systems to allow real-time flood predictions for Goulburn.

More recently the *Monitoring Network for Goulburn Flood Warning System* (Southeast, 2012) study was prepared on behalf of Council. The study scope was to 'undertake a review of flood studies undertaken within the city of Goulburn, to develop a flood monitoring system for the Wollondilly and Mulwaree catchments, construct a hydrology model and create flood warning tools'. As part of the study a meeting was held between Council, NSW SES and BoM. The outcomes from the meeting in relation to the Flood Warning System were:

1. *The SES would host an ALERT base station in their office,*
2. *The BoM would provide assistance in the selection and location of gauge stations and provide indicative costs,*
3. *Council would set up, own and operate the gauge stations which would be compatible and communicate with the BoM's Flood Warning Centre; and*
4. *The BoM would collect and interpret data from the gauges using ALERT at the Flood Warning Centre, the same data would be provided to the ALERT base station in the SES office in Goulburn.*

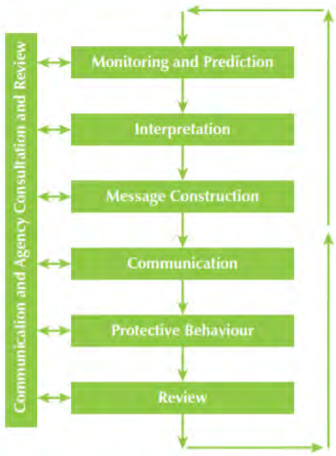
Due to significant flood risk experienced at Goulburn, development of a robust total flood warning system to complement the existing procedures is recommended to manage risk to life.

9.2.4.3 Scoping Study for Total Flood Warning System (Option RM08)

Option Overview

Manual 21 describes the '*goal of flood warning is to help flood management agencies and the members of flood-prone communities to understand the nature of developing floods so that they can take action to mitigate their effects.*' A Total Flood Warning System (TFWS) integrates various components and coordination between agencies as presented in Image 12.

Image 12: The Components of the Total Flood Warning System (AIDR, 2009)



As part of a scoping study, available rainfall and stream gauge data should be reviewed and used to develop a robust flood prediction model. The model would be developed to provide river level estimates for both the Wollondilly and Mulwaree Rivers that relate to the FICs discussed in Option RM02 (Section 9.2.3.2). Messaging and communication are recommended to be developed in consultation with the community, NSW SES and Council and can be undertaken in conjunction with the recommendations discussed in Option RM06 (Section 9.2.3.5).

The scoping study will include fit for purpose measures under a TFWS and then recommend the most suitable options. This will likely include a template of a Flood Warning System Owners Manual and recommended inclusions for the NSW SES Local Flood Plan.

Cost

The estimated cost for a Total Flood Warning System scoping study is $60,000.

Summary and Recommendations

Goulburn experiences significant flood risk, particularly during rare to extreme events. There is currently no total flood warning system in place in Goulburn, with a significant population at risk during a range of flood events. It is recommended that a Total Flood Warning System (TFWS) be developed for the Wollondilly and Mulwaree Rivers at Goulburn.

Recommendation: Develop a Total Flood Warning System for the Wollondilly and Mulwaree Rivers at Goulburn.

9.3 Flood Modification Measures

9.3.1 Background

The following sections present the findings from the detailed assessment of agreed flood modification measures. A 'Longlist' of flood modification measures was developed with Council and in consideration of community input obtained from questionnaire responses (Section 9.3.2). These measures are discussed in the following section. The 'Longlist' of options was then refined to produce a 'Shortlist' of options based on discussions between Council, the Floodplain Management Committee, DPE, NSW SES and GRC Hydro (Section 9.3.3).

9.3.2 Flood Modification Measures – Longlist

A staged process was used to select measures that warranted detailed assessment. This involved developing a longlist of measures, and then further assessing those that were most likely to be effective, with input from Council and the Floodplain Management Committee.

The longlist of measures has been summarised in Table 35, with the location of each option presented in Appendix I, Figure I *1*, along with information that was provided to the Committee and Committee preferred options.

Table 35: Flood Modification Measures Longlist

Code	Description	Preliminary Assessment Outcome
L01	Levee behind properties on Fitzroy Street downstream of Marsden Bridge	Not selected for further assessment – rated as moderate feasibility with poor B/C ratio. Large embankment required, limited property benefits, will likely cause flood impacts.
L02	Marsden Weir Park Levee - road raising/embankment to prevent inundation of properties on Fitzroy Street (Hotspot 2)	Selected for assessment.

Code	Description	Preliminary Assessment Outcome
L03	Levee behind properties on Buffalo Crescent North	Not selected for further assessment – rated as moderate feasibility with poor B/C ratio. A levee would likely cause flood impacts with limited property benefits.
L04	League Park Levee - from Victoria Street to Derwent Street to prevent inundation of Avoca Street area (Hotspot 1)	Selected for assessment
L05	Eastgrove Levee - from Forbes Street and Hercules Street (Hotspot 3)	Selected for assessment
L06	Braidwood Road Levee - along eastern side of Braidwood Road (Hotspot 4)	Selected for assessment
L07	Minor levee on May Street	Not selected for further assessment – rated as moderate feasibility with poor B/C ratio. A levee would likely cause flood impacts with limited property benefits.
L08	Minor levee on Lower Sterne Street	Not selected for further assessment – rated as moderate feasibility with poor B/C ratio. A levee would likely cause flood impacts with limited property benefits.
VM01	Vegetation Management Plan	Selected for assessment
C01	Clearing debris and excess vegetation from Wollondilly River	Not selected for further assessment – rated as low feasibility with poor B/C ratio. Limited feasibility due to significant environmental impacts with limited benefits. A comparable option which assessed vegetation management combined with channel dredging was assessed in Option G01 (Section 9.3.3.7).
C02	Clearing debris and excess vegetation from Mulwaree River	Not selected for further assessment – rated as low feasibility with poor B/C ratio. Limited feasibility due to significant environmental impacts. Targeted vegetation management was assessed for Fitzroy Flats (Option C03) presented in Section 9.3.3.6.
C03	Fitzroy Flats Vegetation Management	Selected for assessment
C04	Vegetation Management Plan	Selected for assessment
G01	Wollondilly River Dredging - between Victoria Street and Mulwaree confluence	Selected for assessment
R01	Raise Bungonia Road between Lansdowne Bridge and Braidwood Road	Not selected for further assessment – rated as low feasibility. Other routes can more effectively and economically provide flood access to Eastgrove. Flood impacts are likely.
R02	Raise Braidwood Road near Cooma Avenue to prevent backwatering from Mulwaree River	Not selected for further assessment – rated as low feasibility with poor B/C ratio. Option L06 provides similar outcome and is expected to be more economical.
R03	Raise Park Road and Blackshaw Road between Railway and Hercules Street	Not selected for further assessment – rated as low feasibility. The required height of the roadway for flood immunity in rare events would be infeasible, however, a moderate height increase could provide immunity for the frequent flood events. Would also likely cause impacts upstream.
R05	Raise Lower Sterne Street and May	Not selected for further assessment – Option R08 has been

Code	Description	Preliminary Assessment Outcome
	Street	examined in preference as discussed at the Floodplain Management Committee Meeting (6th February 2020)
R06	Raise May Street between East Street and Chiswick Street	Not selected for further assessment – Option R08 has been examined in preference as discussed at the Floodplain Management Committee Meeting (6th February 2020)
R07	Towrang River Crossing Upgrade	Selected for assessment
R08	Formalising access from Eastgrove to Sydney Road via Heatherington Road	Selected for assessment

9.3.3 Flood Modification Measures – Shortlist

Options identified for further consideration and analysis are presented in the following sections.

9.3.3.1 Marsden Weir Park – road raising/embankment (Option L03)

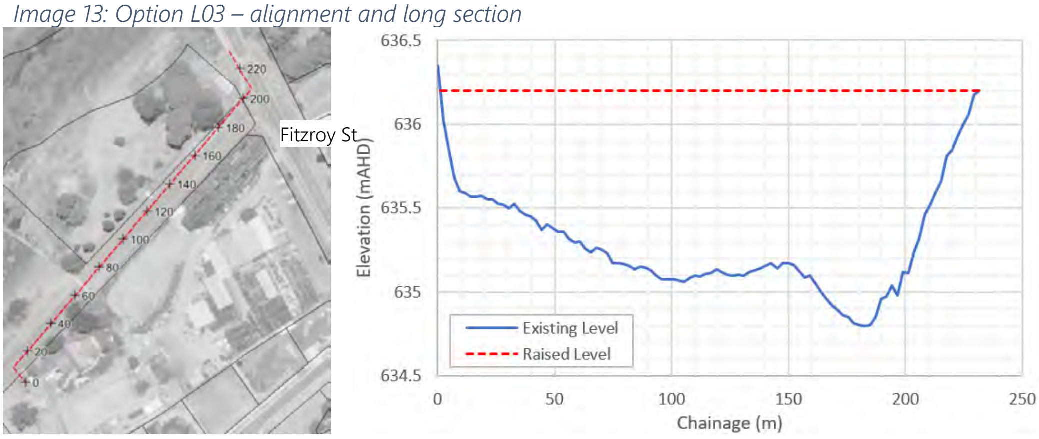
Option Overview

Option L03 aims to reduce the risk to properties on the downstream (eastern) side of Fitzroy Street on the southern side of Marsden Bridge, as described in Hotspot 2 (Section 8.2.2).

The mitigation measure involves raising ~230m of the carpark access road along the southern edge of Marsden Weir Park (see Image 13) by 1.1 m on average. Raising of the road reduces the risk of flood waters overtopping Fitzroy Street, as well as the flood hazard once the road is overtopped. A similar outcome could be achieved by construction of a levee bordering the road.

It should be noted that if raising the road by 1.1 m is not found to be viable, any raising of the road (or an embankment) in this area would reduce the risk of water overtopping Fitzroy Street and thus the risk to properties downstream.

Image 13: Option L03 – alignment and long section



Impact on Flood Liability

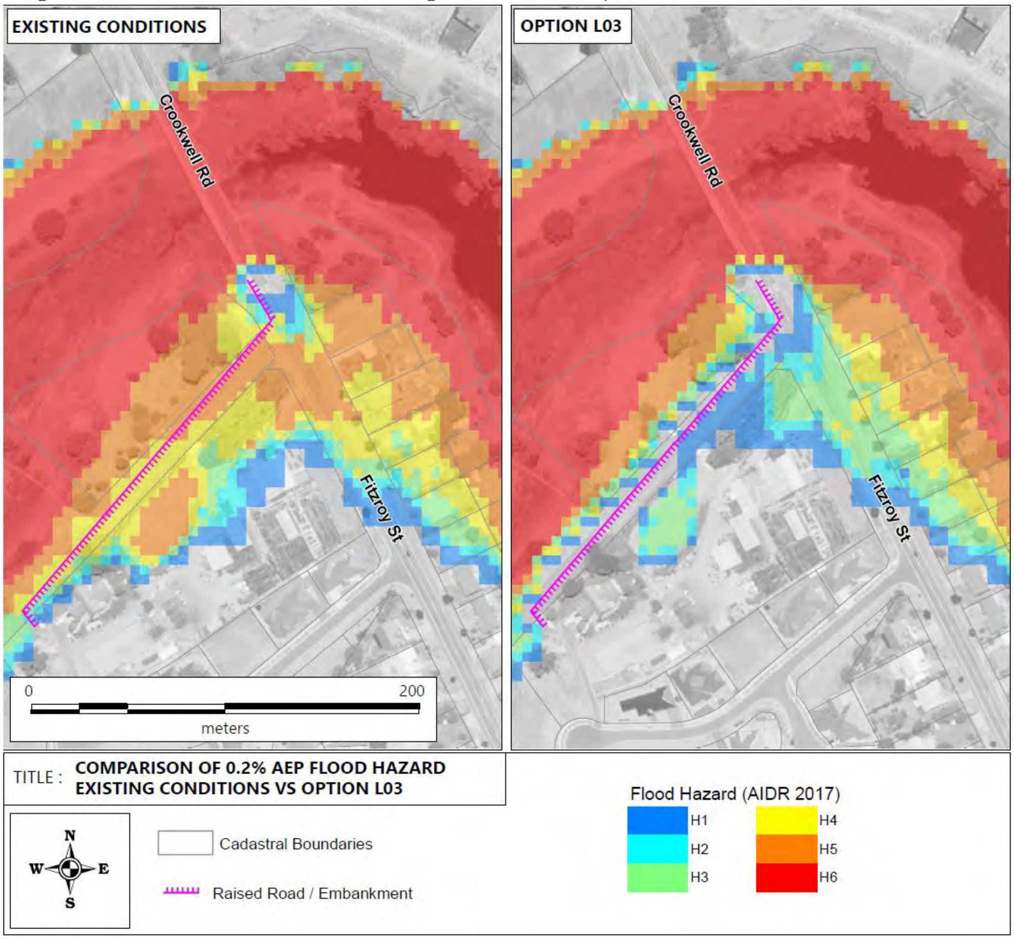
Option L03 does not significantly change the flood liability of properties on Fitzroy Street as these properties can also be flooded due to elevated Wollondilly River levels downstream of Marsden

Bridge. However, the frequency at which Fitzroy Street is overtopped is reduced, and for events that do overtop the road, the flow velocity is reduced which results in lower flood hazard.

The reduction in flood hazard for the 0.2% AEP event is presented in Image 14. Under existing conditions, properties described in Hotspot 2 are affected by H5 hazard flooding which could compromise the structural integrity of dwellings and remove evacuation potential. The flood hazard conditions are such that it is unlikely that rescue efforts could be attempted by emergency personnel. With implementation of Option L03, the flood hazard between each of the properties and Fitzroy Street are reduced to typically H3 which would allow unassisted egress for able body adults. Areas of H4 hazard are noted, however velocities are reduced which would improve the chance of assisted rescue.

For events rarer than 0.2% AEP, flood hazard would progressively approach the existing conditions flood hazard as event magnitude increases.

Image 14: 0.2% AEP Flood Hazard – Existing Conditions vs Option L03



Cost Estimate

The cost to implement the works will vary dependant on the applied approach. Three options, ranked according to the estimated cost, are presented below:

- Road raising – the most expensive due to the requirement of providing a suitable road surface (both in material and design grades etc.). Likely to provide the least obtrusive urban design for Marsden Weir Park amenity;
- Embankment – Cheaper than raising the road (cost mainly associated with cost of an earthen embankment). Likely to impact on park amenity and aesthetics.
- Progressive road raising as part of ongoing maintenance – minimal additional cost to existing road maintenance requirements. Will result in delayed implementation.

Benefit / Cost Ratio Analysis

As previously discussed, Option L03 reduces risk to life, however, provides a negligible reduction is property flood liability. As such, a tangible benefit / cost ratio has not been assessed.

Social and Environmental Impacts

The proposed works are not expected to have any adverse social impacts. The reduction in risk to life provides intangible benefits including reduced disruption, social stresses, trauma and impacts on emergency personal and health care facilities.

Road raising will reduce the impact on approximately a dozen mature trees (predominately poplar and conifer), however could impact on the park aesthetics. Appropriate urban design could reduce the visual impacts. Construction of a levee would more likely require the removal of existing trees, as well as create visual impacts, which would have a negative environmental impact.

Constraints and Considerations

It is recommended that the following be considered should Options L03 be implemented:

- The maximum height of the raised road / embankment is controlled by the Marsden Bridge crest level. Raising Option L03 above this level will not stop flow passing down Fitzroy Street once the bridge is overtopped, however may still reduce flood hazard to existing properties.
- Due to the above, a freeboard cannot be incorporated into the design to provide additional confidence if the performance of the option.
- Fitzroy Street may need to be regraded/raised to tie-in to the raised carpark road which could result in difficulties connecting to existing driveways (which are already steep) and potentially drainage issues for local catchments to the west.

Community Acceptance

55% of respondents were interested in assessing mitigation measures that included the construction of levee embankments. This would indicate that community acceptance of the proposed option is moderate. The wider community is likely to be accepting if economic impacts are minimised and the reduction in risk to life is communicated.

Summary and Recommendations

Implementation of Option L03 will reduce risk to life for events above the 1% AEP to ~0.2% AEP event. For flood events more frequent than 1% AEP or rarer than 0.2% AEP, the impact of Option L03 will be negligible. Notwithstanding, Option L03 is recommended as a flood risk management measure.

Recommendation: Measure does not warrant inclusion in the Floodplain Risk Management Plan. Council can investigate how to implement Option L03 whilst minimising the economic impact.

9.3.3.2 League Park Levee (Option L04)

Option Overview

The mitigation measure consists of construction of a new levee to protect the residential area surrounding League Park from Wollondilly River flooding, as described in Hotspot 1 (Section 8.2.1). This concept levee design has been developed to mitigate Wollondilly River flooding in the areas for event up to the 1% AEP flood.

The mitigation measure involves the construction of a levee ~640m in length with typical heights ranging between 1 to 3 m above existing ground (inclusive of a freeboard of 0.6 m, see freeboard assessment in Appendix F). The levee alignment and long section (approximate crest level inclusive of freeboard) are presented in Image 15 and Image 16. The levee is predominately composed of an earthen embankment, however a portion of the levee at the eastern end of Derwent Street (~chainage 520 to 600) is required to be retaining wall construct to minimise flow obstruction. For the purposes of this assessment is has been assumed that the earthen embankment has a 2 m wide crest with 1 in 2 grade batter slopes.

Impact on Flood Liability

Option L04 reduces the flood liability of properties due to Wollondilly River flooding in the area defined as Hotspot 1. The design height of the levee provides protection for the 1% AEP event.

The option was simulated for a range of flood events with the results are presented in Table 36 below. The table shows that the option has significant benefit in rare floods in the 2% - 1% AEP range, with around $1.7 million reduction in damages and 15 properties no longer flooded above floor. 28 properties are no longer flooded above floor level in the 0.5% AEP event assuming the levee freeboard does not fail. The distribution of impacted properties is presented in Image 17.

There is a negligible effect in events smaller than the 2% AEP due to the limited existing flood liability of the region in frequent events. As such, the Annual Average Damages (AAD) reduction is modest ($20,000/year).

The levee results in an increase in flood level for areas outside of the levee, which leads to one additional property to become flooded over floor and several properties to be adversely affected in the yard. The impact on peak flood level for the 1% AEP event is presented in Image 17.

Image 15: Option L04 – levee alignment

Image 16: Option L04 – long section

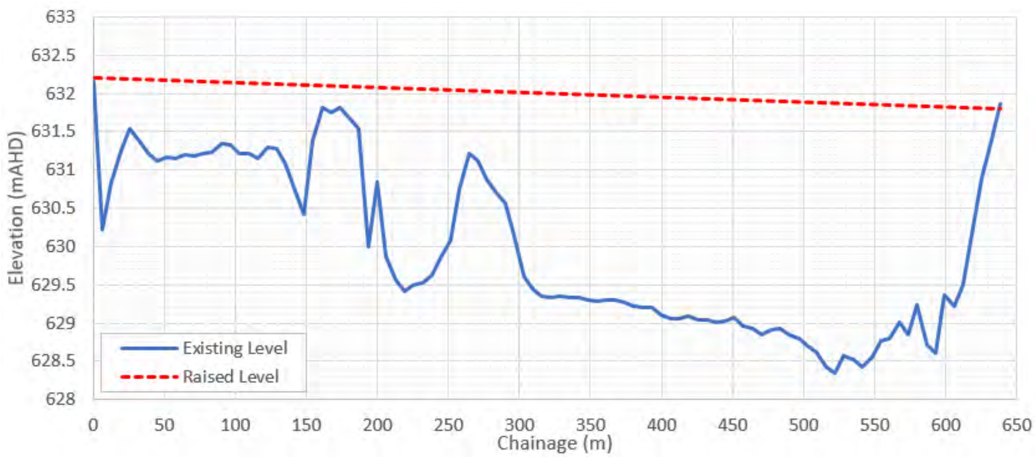
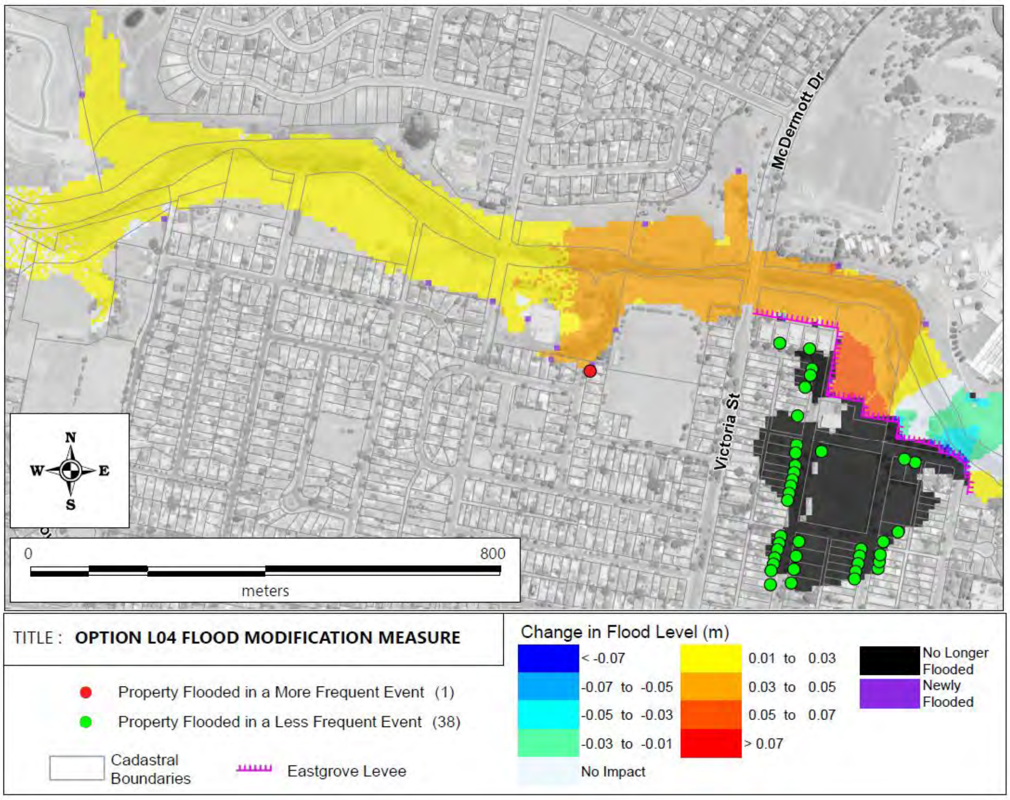


Table 36: Option L04, Reduction in Damages and Above-floor Flooding

Event	Number of Properties No Longer Flooded Over Floor	Number of Newly Flooded Over Floor Properties	Reduction in Event Damages[1]
20% AEP	0	0	$0
10% AEP	0	0	-$50,700
5% AEP	0	0	$0
2% AEP	6	0	$531,600
1% AEP	15	0	$1,769,400
0.5% AEP	28	1	$0
0.2% AEP	0	1	$0
PMF	0	0	$0
Average Annual Damage reduction			$20,100

1. The levee has been modelled with freeboard, which should not be relied upon in events larger than the design event. Events larger than the design event (1% AEP) have been adjusted to have no change in flood damages, despite there being change in property affectation due to beneficial/adverse impacts, as shown in the other columns. The details of how the flood damages have been calculated are presented in Section 8.5, and include damages associated with flooding of the lot or yard.

Image 17: Option L04 – 1% AEP flood level impact and change in property flood liability



Cost Estimate

A preliminary cost estimate for the option is presented in Table 37 with further details presented in Appendix J. The cost estimate is indicative only and should not be relied on for reasons other than the purposes of this preliminary feasibility assessment.

Table 37 Option L04 Cost Estimate

Item	Cost Estimate
Pre-construction Costs	$140,000
Site Preparation	$13,000
Earthworks	$480,000
Civil Construction	$180,000
Total (incl. contingency and GST)	$1,100,000

Benefit / Cost Ratio Analysis

The option's reduction in Average Annual Damages, the Net Present Value (NPV) of this reduction (assuming 50 year design life and 7% discount rate) and the benefit-cost ratio are as follows:

- Average Annual Damage reduction: $20,000
- NPV of reduction: $300,000
- Cost estimate of option: $1,100,000
- Benefit-cost ratio: 0.3

The benefit-cost ratio is 0.3, which means the cost of the option is around three times its benefit, and so cannot be justified on economic grounds alone.

Social and Environmental Impacts

Option L04 is expected to impact of the visual amenity of the area due to the large embankment size. This is particularly the case for the western end of Derwent Street where a retaining wall type levee will need to be implemented due to spatial constraints.

The impact on visual amenity is estimated to be significant and may be a major constraint in building the levee. As described, the new levee would be approximately:

- 0.95 m high between Victoria Street and Avoca Street
- 2.3 m high between Avoca Street and Derwent Street
- 3.4 m high between Derwent Street and Kenmore Street
- 1.4 m high at Kenmore Street

The levee would obstruct or completely remove the view that many properties have towards the river, as well as dividing the park area. Feedback on the option will be sought from residents during public exhibition of this study.

Image 18: Visualisation of Option L04 near Derwent Street

Approximately a dozen mature oak trees may need to be removed along Derwent Street and several trees near Victoria Road, which would be considered a significant environmental impact.

As previously described, there are also flood impacts affecting areas outside of the levee. Whilst these impacts can generally be considered minor, they do have an adverse impact on a number of properties increasing the flood liability of the lots as well as one additional property flooded above floor in events rarer than 1% AEP. This situation creates 'winners and losers' which can be contentious from a social harmony perspective.

<u>Constraints and Considerations</u>

It is recommended that the following be considered should Options L04 be implemented:

- The eastern end of Derwent Street is constrained and will require construction of a retaining wall type levee. The wall will be ~3.5 m high which will result in considerable hydrostatic force, with the potential for dynamic forces due to floating debris, that should be accounted for in the design.
- Design of a suitable spillway to minimise the chance of catastrophic failure is likely to be problematic. Ideally the spillway would allow areas behind the levee to fill before the levee crest is overtopped. This will be difficult to achieve due to the fast rate of rise of the Wollondilly River.
- Internal stormwater systems will need to be developed to discharge through the levee and will require the use of flap gates at the outlets to these systems.
- Fitzroy Street may need to be regraded/raised to tie-in to the raised carpark road which could result in difficulties connecting to existing driveways (which are already steep) and potentially drainage issues for local catchments to the west.

Community Acceptance

55% of respondents were interested in assessing mitigation measures that included the construction of levee embankments. This would indicate that community acceptance of the proposed option is moderate. Community members living close to the levee may be less accepting once the significant visual impact of the levee is understood. The wider community may also have issue with the economic impacts.

SMEC (2003) Study Findings

Section 9.2.3 of the SMEC (2003) study investigates two levee alignments similar to Option L04. The studies Flood Working Group (similar to the current study Flood Management Committee) decided not to adopt either option 'due to adverse impacts on flood levels upstream'.

Summary and Recommendations

Implementation of Option L04 will provides substantial benefit to the residential area around the park for rare flood events with an AEP ranging between ~2% - 1%. However, it has significant impacts on visual amenity and results in adverse impacts affecting several properties outside of the levee. The economic benefit of this levee cannot justify the cost of construction.

Recommendation: Council to investigate how to implement Option L03 whilst minimising the economic impact.

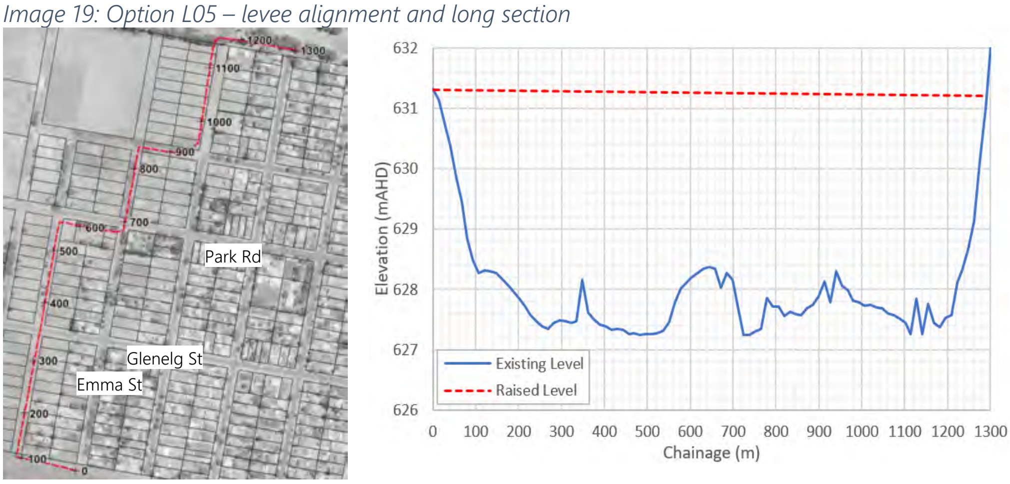
9.3.3.3 Eastgrove Levee (Option L05)

Option Overview

Option L05 consists of construction of a new levee to protect the Eastgrove residential area from Mulwaree River flooding, as described in Hotspot 3 (Section 8.2.3). This concept levee design has been developed to mitigate Mulwaree River flooding in the area for event up to the 1% AEP flood.

The mitigation measure involves the construction of a levee ~1,300 m in length with a typical height of 3 to 4 m above existing ground (inclusive of a freeboard of 0.8 m, see freeboard assessment in Appendix F). The levee alignment and long section (approximate crest level inclusive of freeboard) are presented in Image 19. The levee is predominately composed of an earthen embankment and requires two road crossings at Park Road and Glenelg Street. For the purposes of this assessment is has been assumed that the levee embankment has a 2 m wide crest with 1 in 2 grade batter slopes. Road gradients would need to be developed considering Austroads guidelines.

Image 19: Option L05 – levee alignment and long section



Impact on Flood Liability

Option L05 reduces the flood liability of properties due to Mulwaree River flooding in the area defined as Hotspot 3 (see Section 8.2.3). The design height of the levee provides protection for the 1% AEP event.

The option was simulated for a range of flood events with the results presented in Table 36 below. The table shows that the option has significant benefit in rare floods, but limited benefit in common and very rare or extreme floods (e.g., 0.2% AEP and PMF). There are 36 properties that no longer experience above-floor flooding for the 1% AEP event, and there is a corresponding reduction of around $4 million in flood damages expected during this event. A reduction in AAD of $104,000 is expected with implementation of this option. The distribution of impacted properties is presented in Table 38.

The levee results in an increase in flood level for areas outside of the levee, which results in one additional property to become flooded over floor in the 2% AEP event and numerous properties to be adversely affected in the yard. The impact on peak flood level for the 1% AEP event is presented in Table 38.

Table 38: Option L05, Reduction in Damages and Above-floor Flooding

Event	Number of Properties No Longer Flooded Over Floor	Number of Newly Flooded Over Floor Properties	Reduction in Event Damages[1]
20% AEP	0	0	$12,000
10% AEP	1	0	$59,000
5% AEP	5	0	$516,000
2% AEP	26	1	$2,764,000
1% AEP	36	0	$4,317,000
0.5% AEP	48	0	$0[2]
0.2% AEP	2	0	$0
PMF	0	0	$0
Average Annual Damage reduction			$104,000

1. This includes properties both beneficially and adversely impacted by the levee. As an example, in the 1% AEP no properties are newly flooded above floor level due to the levee, but five properties experienced an increase in flooding, with an average damage increase of $3,800 in that event.
2. The levee has been modelled with freeboard, which may or may not protect against events larger than the design event. Events larger than the design event (1% AEP) have been adjusted to have no change in flood damages, despite there being change in property affectation due to beneficial/adverse impacts, as shown in the other columns.

Cost Estimate

A preliminary cost estimate for the option is presented in Table 39 with further details presented in Appendix J. The cost estimate is indicative only and should not be relied on for reasons other than the purposes of this preliminary feasibility assessment.

Table 39: Option L05 Cost Estimate

Item	Cost Estimate
Pre-construction Costs	$460,000
Site Preparation	$20,000
Earthworks	$1,930,000
Civil Construction	$370,000
Total (incl. contingency and GST)	$3,550,000

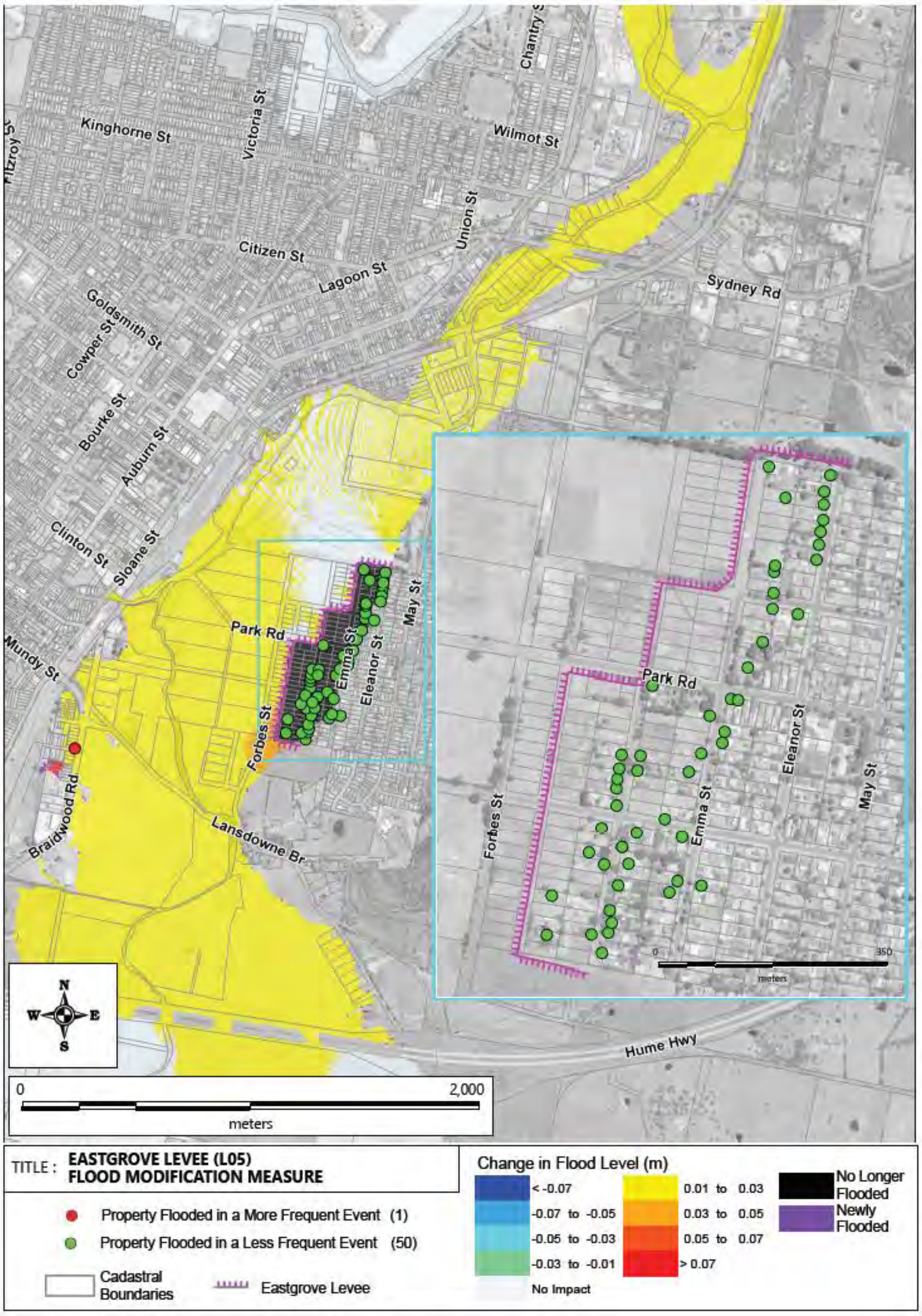
Benefit / Cost Ratio Analysis

The option's reduction in Average Annual Damages, the Net Present Value (NPV) of this reduction (assuming 50 year design life and 7% discount rate) and the benefit-cost ratio are as follows:

- Average Annual Damage reduction: $104,000
- NPV of reduction: $2,050,000
- Cost estimate of option: $3,550,000
- Benefit-cost ratio: 0.6

The benefit-cost ratio is 0.6, which means the cost of the option is two times its benefit, and so cannot be justified on economic grounds alone.

Image 20: Option L05 – 1% AEP flood level impact and change in property flood liability



Social and Environmental Impacts

Option L05 is expected to impact of the visual amenity of the area due to the large embankment size with levee heights above existing ground of 3-4 m. The levee would obstruct or completely remove the view that many properties have towards the river and park areas. As described, the new levee would be approximately:

- 3.3 m high between Forbes Street, Glenelg Street and Park Road
- 3.6 m high between Park Road and Emma Street
- 2.9 m high at Goulburn Golf Club

Image 21: Visualisation of Option L05 near Emma Street

As previously described, there are also flood impacts affecting areas outside of the levee. Whilst these impacts can generally be considered minor, they do have an adverse impact on a number of properties increasing the flood liability of the lots as well as one additional property flooded above floor. This situation creates 'winners and losers' which can be contentious from a social harmony perspective.

Similarly, land acquisition may be required for some portions of the levee, and people whose views are obstructed or land is acquired may not be in favour of the option.

Approximately a dozen mature gumtrees would need to be removed along Park Road and the historic road easement east of Forbes Street, which would be considered a significant environmental impact.

There is a significant catchment inside of the levee and overland flows and drainage would need to be managed appropriately which could be challenging from a drainage/hydraulics perspective.

Constraints and Considerations

It is recommended that the following be considered should Options L05 be implemented:

- Levee road crossings at Park Road and Glenelg Street would be required and would be large structures to elevate the road above the top of the levee crest (3-4 m high). These raised roads could result in difficulties connecting to existing driveways
- Design of a suitable spillway to minimise the chance of catastrophic failure is required. Ideally the spillway would allow areas behind the levee to fill before the levee crest is overtopped.
- Internal stormwater systems will need to be developed to discharge through the levee and will require the use of flap gates at the outlets to these systems. The catchment inside of the levee is significant and major stormwater drainage works are likely required. The levee design should ensure that the drainage channel to the south of golf course is constructed outside of the levee, which could be difficult to achieve due to spatial constraints.
- The levee alignment aims to use Council owned land where possible, however, acquisition of land may be required.

Community Acceptance

55% of respondents were interested in assessing mitigation measures that included the construction of levee embankments. This would indicate that community acceptance of the proposed option is moderate. Community members living close to the levee may be less accepting once the significant visual impact of the levee is understood. The wider community may also have issue with the significant economic impacts.

SMEC (2003) Study Findings

Section 9.2.2 of the SMEC (2003) study investigates two levee alignments similar to Option L05. The studies Flood Working Group (similar to the current study Flood Management Committee) decided not to adopt the option 'due to social, environmental and economic impacts'.

Summary and Recommendations

Implementation of Option L05 will provides substantial benefit to the residential area in Eastgrove, for rare flood events with an AEP ranging between ~10% to 1%. However, the economic benefit of this levee cannot justify the cost of construction and the option has significant impacts on visual amenity and results in adverse impacts affecting several properties outside of the levee.

Recommendation: Eastgrove Levee (Option L05) is not recommended as part of the Floodplain Risk Management Plan

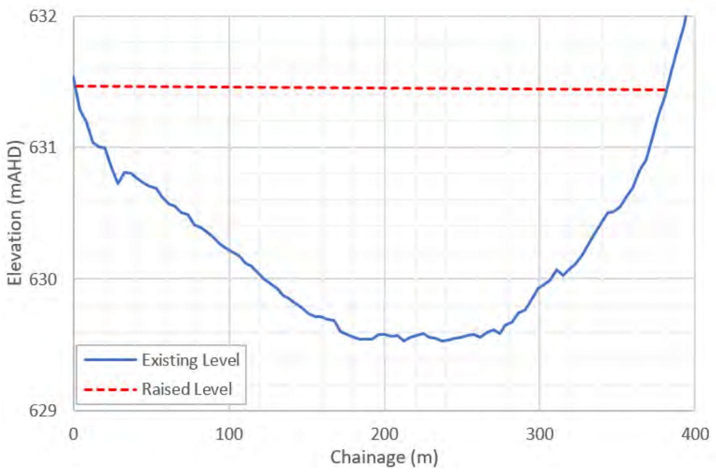
9.3.3.4 Braidwood Road Levee (Option L06)

Option Overview

Option L06 consists of construction of a new levee to protect the Braidwood Road residential area from Mulwaree River flooding, as described in Hotspot 4 (see Section 8.2.4). This concept levee design has been developed to mitigate Mulwaree River flooding in the area for event up to the 1% AEP flood.

The mitigation measure involves the construction of a levee ~380 m in length with a typical height of 1 to 1.5 m above existing ground (inclusive of a freeboard of 0.8 m, see freeboard assessment (see Appendix F)). The levee alignment and long section (approximate crest level inclusive of freeboard) are presented in Image 22. The levee is predominately composed of an earthen embankment and requires a road crossing at Bungonia Road and raising of access roads at Ottiwell Street and Cooma Avenue. For the purposes of this assessment is has been assumed that the levee embankment has a 2 m wide crest with 1 in 2 grade batter slopes. Road gradients would need to be developed considering Austroads guidelines.

Image 22: Option L06 – levee alignment and long section



Impact on Flood Liability

Option L06 reduces the flood liability of properties due to Mulwaree River flooding in the area defined as Hotspot 4 (see Section 8.2.4). The design height of the levee provides protection for the 1% AEP event.

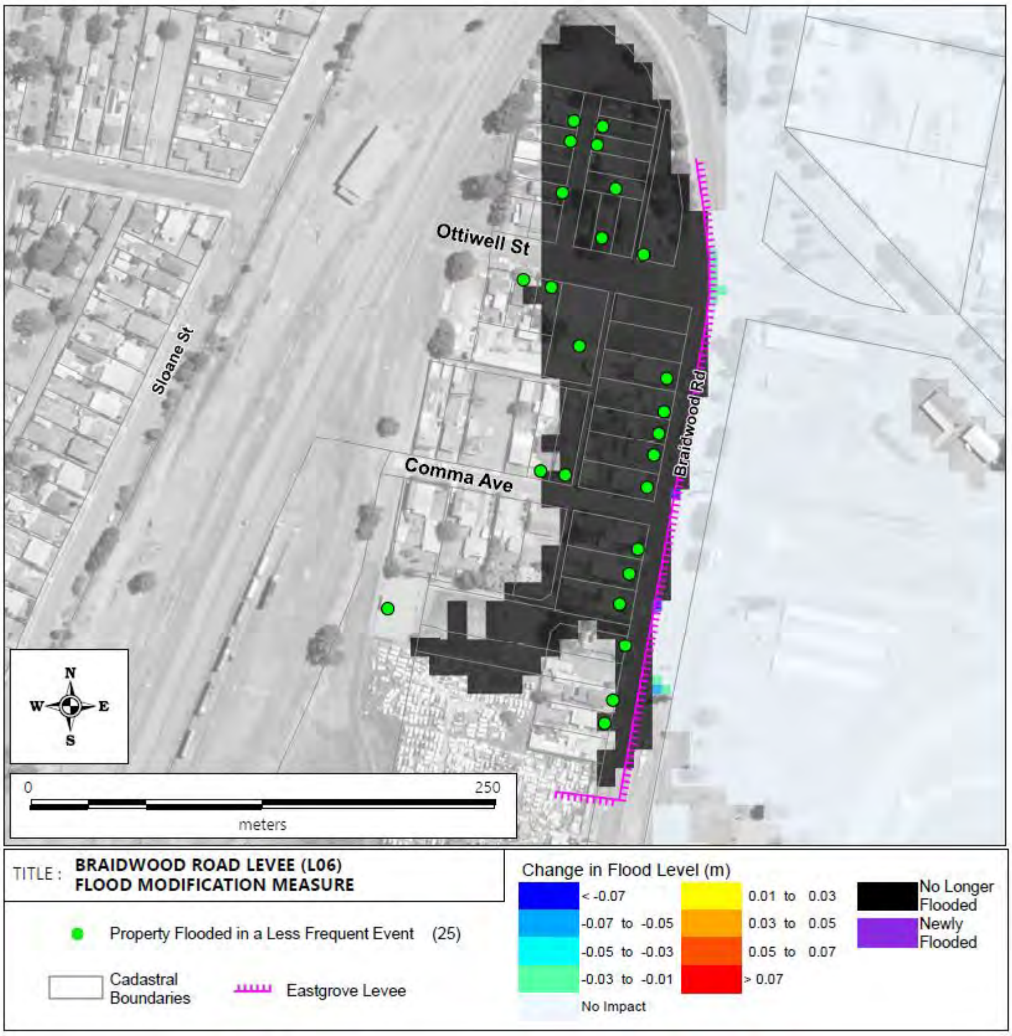
The option was simulated for a range of flood events with the results are presented in Table 40 below. The table shows that the option has significant benefit in rare floods (2 to 1% AEP), but limited benefit in common events as the area is not flooded under existing conditions. During very rare or extreme floods (e.g. 0.2% AEP and PMF) the levee is overtopped and does not provide protection. There are 14 properties that no longer experience above-floor flooding for the 1% AEP event with implementation of Option L06, and there is a corresponding reduction of around $1.6 million in flood damages expected during this event. A reduction in AAD of $18,000 is expected with implementation of this option. The distribution of impacted properties is presented in Image 23.

Table 40: Option L06, Reduction in Damages and Above-floor Flooding

Event	Number of Properties No Longer Flooded Over Floor	Number of Newly Flooded Over Floor Properties	Reduction in Event Damages[1]
20% AEP	0	0	$0
10% AEP	0	0	$0
5% AEP	0	0	$0
2% AEP	6	0	$490,000
1% AEP	14	0	$1,641,500
0.5% AEP	25	0	$0[1]
0.2% AEP	0	0	$0
PMF	0	0	$0
Average Annual Damage reduction			$18,000

1. This includes properties both beneficially and adversely impacted by the levee

Image 23: Option L06 – 1% AEP flood level impact and change in property flood liability



Cost Estimate

A preliminary cost estimate for the option is presented in Table 41 with further details presented in *Appendix J. The cost* estimate is indicative only and should not be relied on for reasons other than the purposes of this preliminary feasibility assessment.

Table 41: Option L06 Cost Estimate

Item	Cost Estimate
Pre-construction Costs	$ 70,000
Site Preparation	$ 20,000
Earthworks	$ 260,000
Civil Construction	$ 160,000
Total (incl. contingency and GST)	$ 700,000

Benefit / Cost Ratio Analysis

The option's reduction in Average Annual Damages, the Net Present Value (NPV) of this reduction (assuming 50 year design life and 7% discount rate) and the benefit-cost ratio are as follows:

- Average Annual Damage reduction: $18,000
- NPV of reduction: $330,000
- Cost estimate of option: $700,000
- Benefit-cost ratio: 0.5

The benefit-cost ratio is 0.5, which means the cost of the option is twice the value of its expected benefit, and it cannot be justified on economic grounds alone.

Social and Environmental Impacts

Option L06 is expected to impact of the visual amenity of the area due to the large embankment size. As described, the new levee would be approximately:

- 1.4 - 1.9 m high along the east side of Braidwood Road, with lower heights at either end
- 0.6 m high from Braidwood Rd into Goulburn Auto Wreckers

Approximately a dozen mature conifers may need to be removed along Braidwood Road, which would be considered an environmental impact.

Constraints and Considerations

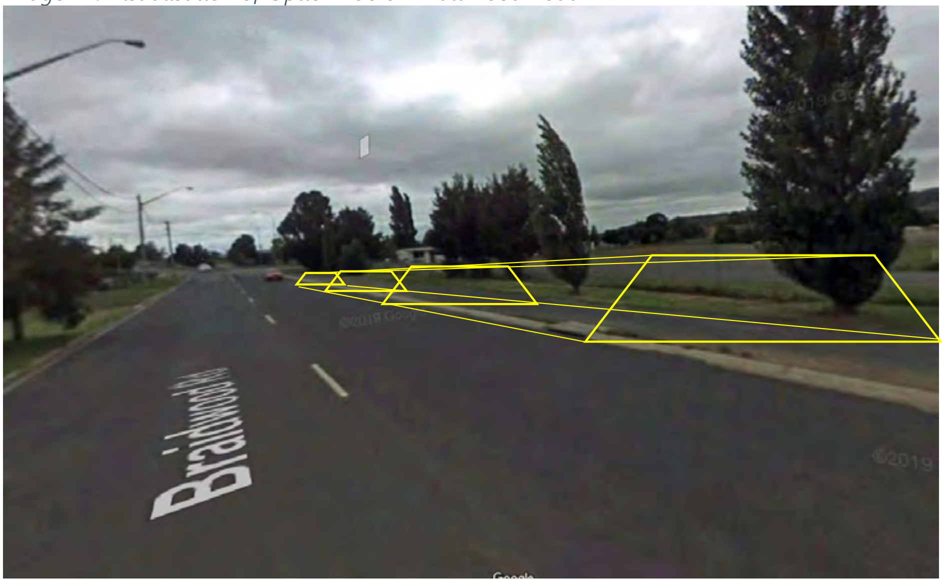
The following should be considered should Options L06 be implemented:

- Levee road crossings at Bungonia Road would be required and would require large structures to elevate the road above the top of the levee crest (1.5 m high).
- Internal stormwater systems will need to be developed to discharge through the levee and will require the use of flap gates at the outlets to these systems.

Community Acceptance

55% of respondents were interested in assessing mitigation measures that included the construction of levee embankments. This would indicate that community acceptance of the proposed option is moderate.

Image 24: Visualisation of Option L06 on Braidwood Road



<u>Summary and Recommendations</u>

Implementation of Option L06 will provides substantial benefit to the residential area along Braidwood Road for rare flood events with an AEP ranging between 2% to 1%. However, the economic benefit of this levee cannot justify the cost of construction.

Recommendation: Braidwood Road Levee (Option L06) is not recommended as part of the Floodplain Risk Management Plan

9.3.3.5 Vegetation Management Plan (Option VM01)

Vegetation management may provide limited localised benefits for flood affectation. Widespread removal of vegetation is not feasible or cost effective, and will result in significant detrimental impacts to the riparian corridor. However, selective removal of invasive species such as willows, blackberry and box elders can enhance channel conveyance and should be considered. Removal of vegetation should be undertaken in conjunction with replanting of native vegetation that is suitable for riparian regeneration. Replanting of native vegetation should aim to not increase the density of vegetation in sensitive areas of the rivers or those that are adjacent to urban areas. Selection of appropriate vegetation types will minimise the risk of channel erosion and provide various environmental benefits, whilst not significantly impacting on flood characteristics. A vegetation management program can be implemented to enhance channel conveyance characteristics and reduce erosion potential.

> **Recommendation**: Council is recommended to consult with NSW Waterwatch, Goulburn/Mulwaree Landcare and Local Land Services to develop a vegetation management program that aims to remove invasive plant species that impact on channel conveyance and replace with native vegetation that supports riparian health.

As mentioned, whilst widespread vegetation clearing is not feasible, targeted vegetation management or clearing may be effective for sensitive areas. Two key locations have been identified for analysis as presented in Section 9.3.3.6 and 9.3.3.7.

9.3.3.6 Fitzroy Flats Vegetation Management Plan (Option C03)

Option Overview

Option C03 aims to reduce flood levels on the Mulwaree River. The option potentially benefits Eastgrove and the Braidwood Road area as described in Hotspot 3 and 4 (see Sections 8.2.3 and 8.2.4).

The mitigation measure involves targeted vegetation management in the Fitzroy Flats area. The intention of the works is to improve the conveyance of the floodplain and river channel, to reduce flood levels upstream. The approximate extent of proposed works is presented in Image 25 along with photographs of vegetation type. Vegetation management would need to focus on the removal of invasive species which are prominent in the area.

Council have advised that there are plans to investigate construction of a park in the area. Vegetation management could be incorporated into the park design with the objective being to minimise the density of the understory. Selection of appropriate species and continuing vegetation management can result in reductions in flood levels upstream.

Image 25: Extent of Option C03 vegetation management zone (pink polygon)

Impact on Flood Liability

The assessment of how effective implementation of a vegetation management plan in the Fitzroy Flat area would be is contingent on the amount of understory vegetation that can be removed.

This assessment assumed dense vegetation (Mannings of ~0.1) is reduced to light vegetation types (Mannings of ~0.06) which may not be feasible for all locations, and is likely to be at the upper end of what is feasible in terms of vegetation clearing from an environmental perspective. However, if vegetation management is incorporated into the future park design, a significant reduction may be able to be achieved.

The option was simulated for a range of flood events with the results presented in Table 42 below and flood level impacts for the 1% AEP event shown in Image 26. This shows that the option provides reductions in yard and lot flood liability due to widespread, albeit minor, reductions in flood level for a range of events.

Table 42: Option C03, Reduction in Damages and Above-floor Flooding

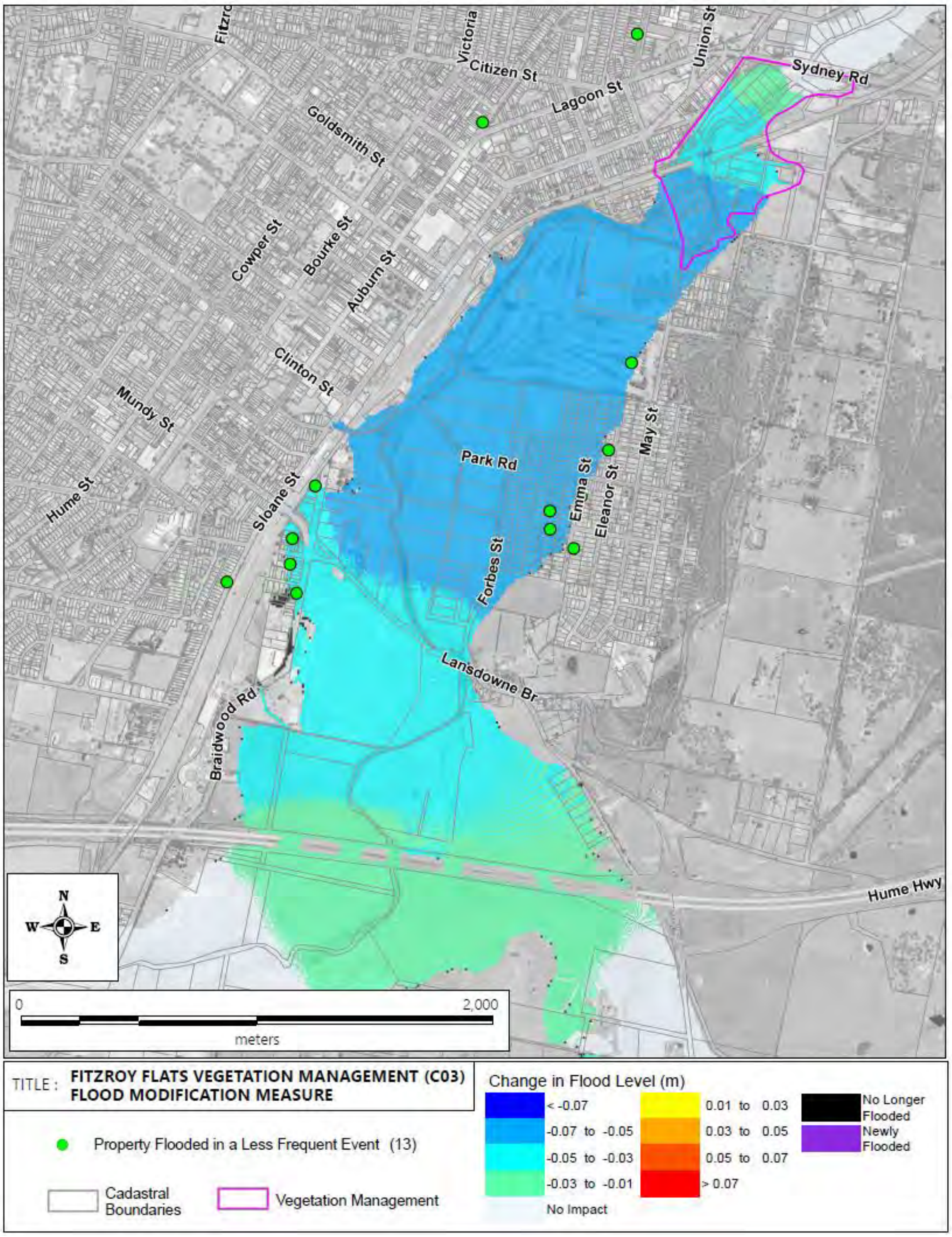
Event	Number of Properties No Longer Flooded Over Floor	Number of Newly Flooded Over Floor Properties	Reduction in Event Damages
20% AEP	0	0	$12,000
10% AEP	0	0	$51,000
5% AEP	0	0	$212,000
2% AEP	4	0	$245,000
1% AEP	1	0	$356,000
0.5% AEP	2	1	$299,000
0.2% AEP	3	1	$628,000
PMF	3	0	$1,785,000
Average Annual Damage reduction			$27,000

<u>Cost Estimate</u>

The measure will involve considerable modification of the existing floodplain environment with the potential for significant environmental impacts. A detailed environmental assessment is required to determine if there are any threatened or endangered flora or fauna potentially affected by the works.

It is recommended that a vegetation management plan be incorporated into the development of the proposed Fitzroy Flats park. The cost of proposed works will vary significantly depending on the degree of vegetation management proposed. The required environmental assessments and vegetation management implementation is estimated to cost in the order of $500,000 to $1,000,000 to provide a tangible benefit. Ongoing maintenance costs would also be required. Note that this cost estimate is order of magnitude accuracy only.

Image 26: Option C03 – 1% AEP flood level impact and change in property flood liability



Benefit / Cost Ratio Analysis

The option's reduction in Average Annual Damages, the Net Present Value (NPV) of this reduction (assuming 50 year design life and 7% discount rate) and the benefit-cost ratio are as follows:

- Average Annual Damage reduction: $27,000
- NPV of reduction: $400,000
- Cost estimate of option: $500,000 to $1,000,000
- Benefit-cost ratio: < 0.8

The benefit-cost ratio is estimated to be < 0.8, which means the option cannot be justified on economic grounds alone. However, a vegetation management plan, implemented in conjunction with future development of a proposed Fitzroy Flat park could provide a tangible benefit.

Social and Environmental Impacts

Option C03 has the potential to create significantly environmental impacts due to the removal of existing vegetation. However, focusing vegetation removal on exotic species could result in improved environmental outcomes. Care must also be taken to ensure that the removal of vegetation does not result in an increase in erosion of sedimentation which could impact on Wollondilly River water quality downstream. A detailed environmental assessment is required.

Implementing Options C03 in conjunction with a park at Fitzroy Flats would provide positive social impacts through increased amenity.

Constraints and Considerations

The following should be considered should Options C03 be implemented:

- A detailed Environmental Impact Statement is required.
- Consultation with Water NSW, NSW Waterwatch, Goulburn/Mulwaree Landcare, Local Land Services, Natural Resources Access Regulator and NSW Fisheries is to be undertaken.

Community Acceptance

The measure was assessed after residents raised it as part of community consultation. 61% of respondents were interested in assessing mitigation measures that modified the river channel to increase the capacity. This would indicate that community acceptance of the proposed option is high. Community acceptance would be investigated as part of an environmental impact assessment as the current feedback is for works in the river channel as a general category. Incorporation of the proposal into development of a future park would also improve community acceptance.

Summary and Recommendations

Implementation of Option C03 will provide small but widespread reductions in flood level for a range of events for residential areas in Eastgrove and on Braidwood Road. With effective implementation, a vegetation management plan could enhance the Mulwaree River floodplain from an environmental perspective. However, the economic benefit of Option C03 cannot justify the cost of implementation, unless undertaken in conjunction with development of the proposed park at Fitzroy Flats. With appropriate design, the park could be developed to reduce upstream flooding economically, whilst also providing social and environmental benefits.

Recommendation: Fitzroy Flats Vegetation Management Plan (Option C03) is not specifically recommended as part of the Floodplain Risk Management Plan, however, it may be incorporated into a Vegetation Management Plan, recommended in the Plan, or into development of a future park in the area.

9.3.3.7 Wollondilly River Dredging and Vegetation Management Plan (Option G01)

Option Overview

Option G01 aims to reduce flood levels on the Wollondilly River. The option potentially benefits the residential area surrounding League Park from Wollondilly River flooding, as described in Hotspot 1 (see Section 8.2.1).

The mitigation measure consists of dredging a 2.5 km reach of the Wollondilly River, along with targeted vegetation management, from near Wilmot Street and the Charles Sturt University Campus to just upstream of the confluence with the Mulwaree River. The dredging alignment is presented in Image 27 along with the existing and proposed channel invert long sections. The section has a significantly high channel invert, relative to other areas of the river, which reduces the channel conveyance.

Impact on Flood Liability

Option G01 reduces the flood liability of properties due to Wollondilly River flooding in the area defined as Hotspot 1 (see Section 8.2.1).

The option was simulated for a range of flood events with the results presented in Table 43 below. The table shows that the option has a benefit in rare floods in the 2% - 0.5% AEP range, with around $670,000 reduction in damages and 7 properties no longer flooded above floor in the 1% AEP event. The distribution of impacted properties is presented in Image 17.

There is a negligible effect in events smaller than the 2% AEP due to the limited existing flood liability of the region in frequent events. As such, the Annual Average Damages (AAD) reduction is modest ($30,000/year).

Image 27: Option G01 – channel dredging alignment and long section

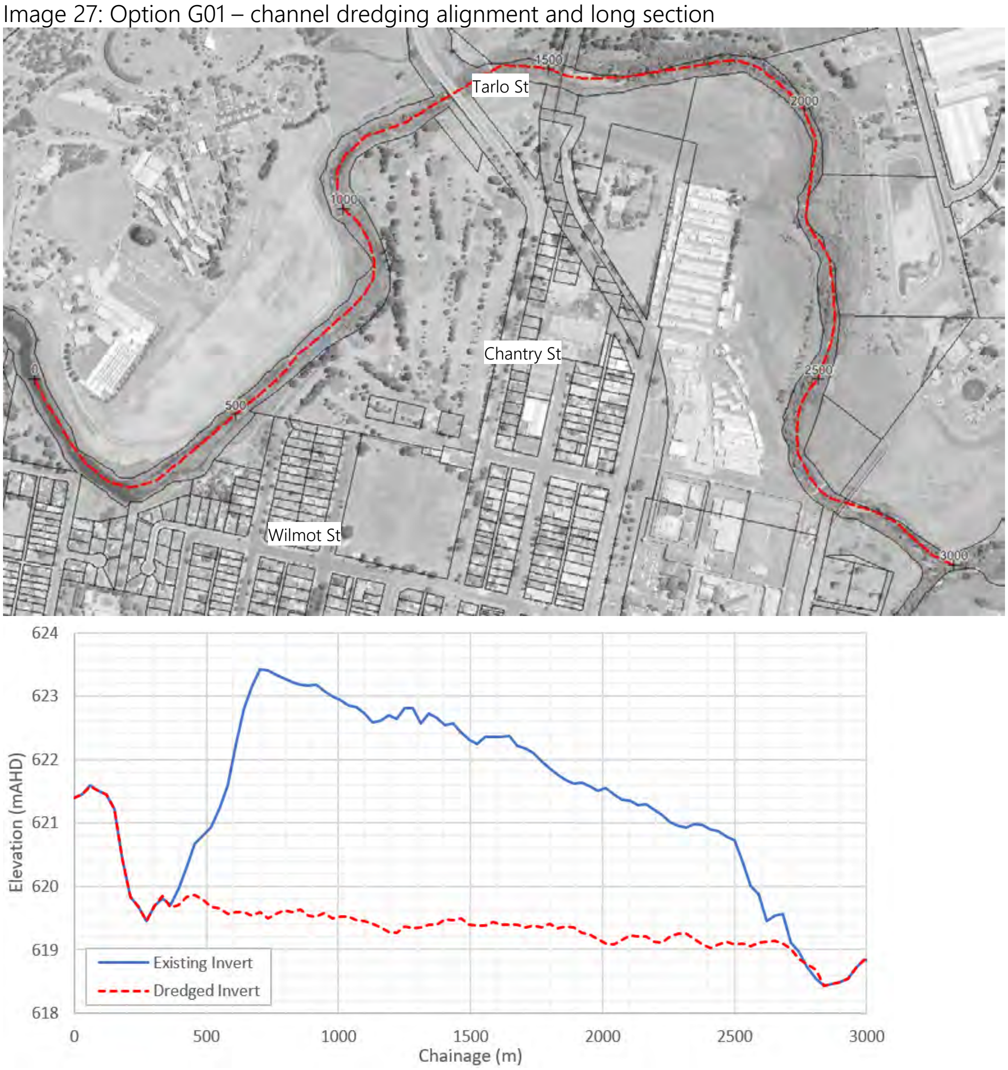
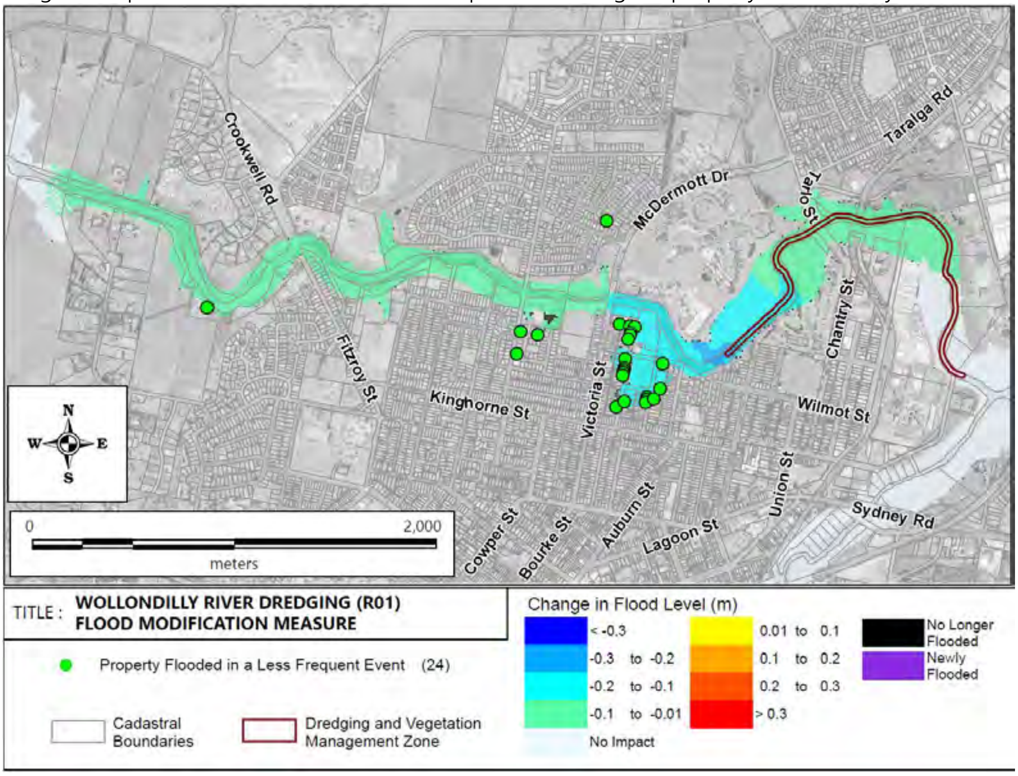


Table 43: Option G01, Reduction in Damages and Above-floor Flooding

Event	Number of Properties No Longer Flooded Over Floor	Number of Newly Flooded Over Floor Properties	Reduction in Event Damages
20% AEP	0	0	$0
10% AEP	0	0	$0
5% AEP	0	0	$0
2% AEP	5	0	$340,000
1% AEP	7	0	$670,000
0.5% AEP	9	0	$700,000
0.2% AEP	2	0	$450,000
PMF	1	0	$760,000
Average Annual Damage reduction			$30,000

Image 28: Option G01 – 1% AEP flood level impact and change in property flood liability



Cost Estimate

A preliminary cost estimate for the option is presented in Table 44 with further details presented in Appendix J. The cost estimate is indicative only and should not be relied on for reasons other than the purposes of this preliminary feasibility assessment.

The costing has been carried out assuming that the dredging is carried out via excavators on the river banks, which may impact small trees and bushes. Other methods of dredging of the river may be significantly cheaper, however, this will not substantially change the benefit-cost ratio (see following discussion).

Table 44 Option G01 Cost Estimate

Item	Cost Estimate
Pre-construction Costs	$600,000
Site Preparation	$150,000
Earthworks	$5,900,000
Total (incl. contingency and GST)	$8,700,000

<u>Benefit / Cost Ratio Analysis</u>

The option's reduction in Average Annual Damages, the Net Present Value (NPV) of this reduction (assuming 50 year design life and 7% discount rate) and the benefit-cost ratio are as follows:

- Average Annual Damage reduction: $30,000
- NPV of reduction: $190,000
- Cost estimate of option: $8,700,000
- Benefit-cost ratio: 0.02

The benefit-cost ratio is 0.02, which means the cost of the option is around fifty times its benefit, and so it cannot be justified on economic grounds alone. Cheaper options for dredging will not significantly improve the benefit-cost ratio.

<u>Social and Environmental Impacts</u>

Option G01 is expected to have a significant environmental impact due to the removal of existing vegetation. The measure is therefore strongly contingent on environmental assessment being carried out for the works. Environmental assessment will also determine if there are any threatened or endangered flora or fauna potentially affected by the works. It is highly likely that such significant modification of the river channel and riparian areas will not be allowed due to environmental and riparian protection policies and for this reason the measure is not considered feasible.

In addition, the amenity of the Wollondilly River in this area would be impacted until vegetation recovers which could take many years, resulting in social impacts and potentially low community support.

<u>Constraints and Considerations</u>

While the option is not recommended, the following constraints would need to be considered should Options C03 be investigated in the future:

- A detailed Environmental Impact Statement would be required.

- Vegetation that was removed during the excavation will be required to be replaced with low density vegetation to maximise conveyance and ensure there is no increase in erosion or sedimentation due to the changes.
- Consultation with NSW Waterwatch, Goulburn/Mulwaree Landcare, Local Land Services, Natural Resources Access Regulator and NSW Fisheries would be required.

Community Acceptance

The measure was assessed after residents raised it as part of community consultation. 61% of respondents were interested in assessing mitigation measures that modified the river channel to increase the capacity. This would indicate that community acceptance of general vegetation management and creek clearing is high. However, it is likely that the acceptance would be reduced significantly if the environmental and economic impacts were assessed and communicated to the local community.

Summary and Recommendations

Implementation of Option G01 would provides a benefit to the residential area around the park for rare flood events with an AEP ranging between ~2% - 1%. However, the significant economic cost does not justify implementation of this option. Further, major social and environmental impacts are expected, and it is doubtful that this proposal would be possible due to environmental and riparian policies. For these reasons this measure is not recommended.

Recommendation: Wollondilly River Dredging and Vegetation Management Plan (Option G01) is not recommended as part of the Floodplain Risk Management Plan.

9.3.3.8 Towrang Road Crossing Upgrade (Option R07)

Option Overview

Option R07 aims to reduce the risk of isolations of properties on Towrang Road by raising the existing crossing of the Wollondilly River which is situated approximately 10 km east of town. Isolation of properties along Towrang Road is described as Hotspot 5 (see Section 8.2.5).

Towrang Road crossing is noted to be overtopped when the Murrays Flat stream gauge reaches 3.25 m (as reported by the NSW SES) which has an estimated probability of exceedance of ~50% AEP.

The crossing is currently a low-level culvert crossing with a span of ~60 m. To provide 1% AEP flood immunity the crossing would need to be converted to a bridge type crossing with a deck level 7-8 m higher than the existing crossing level. It is estimated that this would require threefold increase in span length. Note that the Towrang Road crossing is situated outside of the current study model extent and detailed analysis has not been undertaken so all figures are estimates only.

Impact on Flood Liability

Appropriate design would ensure that the bridge does not adversely impact on nearby properties.

Cost Estimate

It is estimated that the construction of a bridge that provides 1% AEP flood immunity would cost more than $10 million. Reducing the flood immunity of the bridge could reduce the cost, however, even replacing the existing structure with a bridge of comparable size would cost several million dollars.

Benefit / Cost Ratio Analysis

The tangible benefits of Option R07 are not easily determined as the bridge does not offer a reduction in flood liability for existing properties. However, the bridge would result in an increase in productivity by allowing better flood access for residents of Towrang Road which currently may become isolated for days at a time during periods of flood. This would result in a tangible benefit, however calculation of this benefit is expected to be insignificant in the context of the estimated cost of the bridge.

Social and Environmental Impacts

The proposed works are not expected to have significant adverse environmental impacts.

The reduction in risk to life provides intangible benefits including reduced disruption, social stresses, trauma and impacts on emergency personal and health care facilities.

Community Acceptance

The measure was assessed after residents raised it with Council and the NSW SES. Residents on Towrang Road are expected to be strongly in favour of a bridge crossing. However, it is likely that general community may be less accepting once the economic impacts are understood.

Summary and Recommendations

Implementation of Option R07 will reduce risk to life for events for people who attempt to cross the Wollondilly River during times of flood. The bridge will also reduce the risk of isolation and provide improved emergency vehicle access. However, a bridge upgrade will have a significant economic impact.

Update in October 2021: At the time of writing (October 2021) Council have developed a design for the bridge upgrade and are scheduled to have it constructed by 2022. The bridge deck will be approximately 4.5 m higher than what currently exists which will improve the flood immunity of the bridge

Recommendation: The scheduled bridge upgrade will improve flood liability of the bridge at the location. The measure can be included in the Floodplain Risk Management Plan and recorded as implemented following construction (planned for 2022).

9.3.3.9 Eastgrove to Sydney Road Flood Access (Option R08)

Option Overview

Option R08 aims to improve flood access and reduce the risk of isolation of Eastgrove by formalising the existing roads that connect to Sydney Road to the east of Eastgrove. The flood liability of Eastgrove is described as Hotspot 3, and flooding of key access roads is discussed in Section 8.2.3.

Road access from Goulburn to Eastgrove is typically via May Street, Park Road or Bungonia Road. These roads are subject to frequent flooding in events as small as the 50% AEP which results in a risk to motorist who attempt to access these roads during times of flood. Emergency vehicle access may also be affected.

To improve flood access to Eastgrove, whilst not requiring major road raising and bridge construction works, an alternative access option has been investigated. Option R08 proposes the formalisation of the following roads as a dedicated flood access route:

- Hetherington Street;
- Chiswick Road; and
- Common Street.

These roads are not flood affected by riverine flooding, however, may be subject to overland flow flooding. Consideration of overland flow flooding is required.

Impact on Flood Liability

Appropriate design would ensure that the bridge does not adversely impact on nearby properties.

Cost Estimate

It is estimated that the cost of construction of road and culvert upgrades to provides 1% AEP flood access would cost approximately $2 million. Note that these roads are situated outside of the current study extent and a site-specific costing has not been undertaken.

Progressive road improvements undertaken as part of ongoing maintenance could reduce the cost, however, will delay implementation of the scheme.

Benefit / Cost Ratio Analysis

The tangible benefits of Option R08 are not easily determined as the bridge does not offer a reduction in flood liability for existing properties. However, the bridge would result in an increase in productivity by allowing better flood access for residents of Eastgrove which currently may become isolated during periods of flood.

Most significantly, Option R08 would reduce the risk to life for people who attempt to cross at existing road crossing during times of flood.

Social and Environmental Impacts

The proposed works are not expected to have significant adverse environmental impacts.

The reduction in risk to life provides intangible benefits including reduced disruption, social stresses, trauma and impacts on emergency personal and health care facilities.

Community Acceptance

Residents are likely to be in favour of proposed road upgrades. Further input from the community is required.

Summary and Recommendations

Implementation of Option R08 will reduce risk to life for people who attempt to cross the Mulwaree River during times of flood. The road upgrades will also reduce the risk of isolation and provide improved emergency vehicle access.

Recommendation: Council is recommended to investigate implementation of Option R07 as part of its long-term planning strategies.

9.3.4 Multi-criteria Assessment

The assessment of various flood modification measures is presented in Table 45. The measures are evaluated against various criteria and are scored in order to compare their relative advantages and disadvantages.

This evaluation enables options to be prioritised and is a useful tool for decision-makers and other stakeholders. It should be noted that scoring and ranking is only used for an indicative comparison and is not intended to act as a final verdict on the options. Also note that the scoring and ranking may be updated following the public exhibition period, especially in regard to community acceptance.

The results of the analysis are presented in Table 45. Each criteria corresponds to a column and has been scored between -3 (lowest score) and 3 (highest score).

Table 45: Multi-criteria Assessment

Ref.	Mitigation Measure	Impact on road flooding	Impact on property flooding	Impact on risk to life	Technical Feasibility	Community Acceptance	Economic Value	Cost and available funding	Environmental Impact	Impact on SES	Political Feasibility	Total Score	Rank
L02	Road raising along Marsden Weir Park	1	0	2	-1	2	-2	-1	0	2	2	5	7
L04	League Park Levee	2	3	1	-1	0	-2	-1	0	2	3	7	4
L05	Eastgrove Levee	3	3	2	-2	0	-2	-2	0	2	3	7	4
L06	Braidwood Road Levee	2	3	1	-1	1	-2	-1	0	2	3	8	3
VM01	Vegetation Management Plan	1	1	0	1	2	0	0	2	1	1	9	2
C02	Fitzroy Flats Vegetation Management	1	1	0	1	2	1	1	2	1	1	11	1
G01	Wollondilly River Dredging	1	1	0	-3	-1	-3	-3	-3	2	-1	-10	9
R07	Towrang River Crossing Upgrade	0	0	3	1	1	-2	-2	0	3	2	5	7
R08	Eastgrove to Sydney Road Access	0	0	3	1	1	-2	-2	0	3	2	6	6

The total score is highest for Fitzroy Flats Vegetation Management which provides limited benefits to reduction in flood liability, however can provide social and environmental benefits, particularly if incorporated into a future park design. The lowest scoring option is the dredging of Wollondilly River, which gives on minor benefits for flooding outcomes but is expensive to implemented and will have significant environmental impacts.

10. DRAFT FLOODPLAIN RISK MANAGEMENT PLAN

10.1 Plan Objectives

The objective of a Floodplain Risk Management Plan is to manage existing and future flood risk for riverine flooding at Goulburn in accordance with the NSW Floodplain Development Manual (2005).

The Plan aims to achieve the following overarching objectives:

- Reduce the flood hazard and risk to people and property, now and in the future;
- Protect, maintain and where possible enhance the floodplain environment; and
- Ensure floodplain risk management decisions integrate social, economic and environmental considerations.

10.2 Recommended Flood Management Measures

The flood management measures recommended for implementation are presented in Table 46. The measures have been prioritised with high, medium and low classifications as defined below:

- High – can be undertaken in the short term (<12 month) with minimal cost and/or have the potential to provide significant reductions in flood risk;
- Medium – can be undertaken in the medium term (1 to 5 years), require input from other studies or investigations, provide reductions in flood risk but could be expensive;
- Low – measures that are unlikely to be feasible to implement in the next 5 years or that are likely subject to significant financial constraints.

Responsibility for implementation and cost estimates are also presented, along with the relevant section of this report which provides details of each option.

Table 46: DRAFT Floodplain Risk Management Plan

Flood Management Measure	Section	Priority	Cost	Responsibility
Property Modification Measure				
Updated Section 10.7 Planning Certificates	9.1.2.3	High	Council cost estimate	Council
Update Council's LEP to include Clause '5.22 Special Flood Considerations'	9.1.2.4	Medium	Council cost estimate	Council
Revise Council's Development Control Plan Flood Policy	9.1.2.5	Medium	Council cost estimate	Council
Undertake Overland Flow Flood and Flood Risk Management Studies for Goulburn	9.1.2.6	Medium	$100,000	Council
Undertake a Voluntary Purchase Feasibility Assessment	9.1.3.1	High / Low	Feasibility assessment - $30,000 / VP implementation - ~$9.1 million	Council
Response Modification Measures				
Update Goulburn Flood Intelligence	9.2.3.2	High	SES cost estimate	NSW SES
Install flood warning signage at hazardous road crossings	9.2.3.3	Medium	$140,000	Council
Install automatic boom gates at key flooded crossings	9.2.3.4	Medium	$100,000 / gate	Council
Develop a community flood education program	9.2.3.5	Medium	Council cost estimate	Council / NSW SES
Install a historic flood marker	9.2.3.6	Medium	$8,000	Council
Scoping study for Total Flood Warning System	9.2.4.3	High	$60,000	Council / NSW SES
Flood Modification Measures				
Develop/implement a vegetation management plan	9.3.3.5	Medium	$1 million + ongoing costs	Council
Towrang Bridge upgrade	9.3.3.8	Low	$10 million	Council / RMS
Improve flood access to Eastgrove	9.3.3.9	Low	$2 million	Council / RMS

11. REFERENCES

1. Australian Institute for Disaster Resilience, *Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia*, Australian Institute for Disaster Resilience, 2017.

2. Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) *Australian Rainfall and Runoff: A Guide to Flood Estimation*, © Commonwealth of Australia (Geoscience Australia), 2016.

3. DECC (NSW Department of Environment and Climate Change), Floodplain Risk Management Guideline – Residential *Flood Damages*, DECC, 2007.

4. Flood Hazard Research Centre and Environment Agency, *Flood and Coastal Erosion Risk Management – A Manual for Economic Appraisal*, Middlesex University, United Kingdom, 2013

5. Goulburn Mulwaree Council, *Goulburn Flood Study*, Water Resources Commission of NSW, 1986.

6. Goulburn Mulwaree Council, *Goulburn Flood Study*, WMAwater, September 2016.

7. Goulburn Mulwaree Council, *Wollondilly River and Mulwaree Chain of Points Floodplain Risk Management Study and Plan*, SMEC, 2003.

8. Howells L, McLuckie D, Collings G, Lawson N, *Defining the Floodway – Can one Size Fit All?*, Lawson and Treloar, 2003.

9. Murtagh, J., Albert, N., Babister, M., McLuckie, D., Robinson, K., *Hydraulic Categorisation*, 2017 Floodplain Management Australia National Conference, 2017.

10. NSW Government, *Floodplain Risk Management Guide – Incorporating 2016 Australian Rainfall and Runoff in Studies*, Office of Environment and Heritage, 2019.

11. NSW Government, *NSW Floodplain Development Manual*, DIPNR, April 2005.

12. NSW Public Works, *Wagga Wagga Levee Upgrade – Flood Freeboard*, Wagga Wagga City Council, November 2010.

FIGURES

Appendix A – Flood Study Revision

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A1. MODELLING OVERVIEW

Computer models can be used to simulate a catchment's rainfall/runoff response and flood characteristics. The current study modelling system is comprised of a:

- Hydrologic model – which is a computer software tool that simulates catchment processes which affect how rainfall is converted into runoff; and a
- Hydraulic model – which is a computer software tool that simulates the flow characteristics of a river, creek, channel or overland flow path in terms of flood extent, depths, levels and velocities.

The Flood Study (Reference 6) developed a hydrologic/hydraulic modelling system that has been adopted and updated in the current study. The system was used to firstly convert rainfall into flow via the hydrologic model, and then the hydrologic model flows were applied to the hydraulic model to define flood behaviour.

With the update to the Australian Rainfall and Runoff Guidelines (ARR2019) along with various catchment changes that have occurred since the Flood Study was completed in 2016, a revision and update of the hydrologic/hydraulic modelling system has been undertaken in the current study. The details of the hydrologic model update are presented in Section A2, and the hydraulic model update is discussed in Section A3.

The Flood Study undertook a rigorous event-based model calibration/validation process. The WBNM hydrologic model was calibrated to the December 2010 flood event and validated using the March 2012 and June 2013 floods. The Flood Study calibrated model parameters (rainfall losses, routing parameters, Mannings etc.) have been applied, without modification, to the current study models. Model updates undertaken as part of the current study have been validated to Flood Frequency Analysis (FFA) to substantiate the revised design flow estimates associated with the application of ARR2019. This process is discussed in Section A2.5. Validation of the hydraulic model and comparison to previous studies has also been undertaken in Sections A3.4 and A3.5 respectively.

The methodology for determining the Probable Maximum Flood (PMF) has not changed with the release of ARR2019. As such, PMF flow estimate derived in the Flood Study have been adopted in the current study.

A2. HYDROLOGY UPDATE

This section discusses the hydrologic components of the current study with the key objective being the development of design flows for the hydraulic model (see Section A3).

There are a range of methods that can be applied to determine flows for design flood analysis. These include:

- Flood Frequency Analysis (FFA);
- Rainfall/runoff modelling or hydrologic modelling; and
- Regional methods and techniques such as ARR2019 RFFE and the Ration Method.

The current study has used the hydrologic modelling approach to define flows for the hydraulic model, with validation of design flow estimates being made through comparison of flows to FFA (see Section A3.4). Calibration of the hydrologic model to historic events is described in the Flood Study (Reference 6).

A2.1. Flood Study Overview

The Flood Study (Reference 6) developed a hydrologic (WBNM) model to convert applied rainfall, of a given probability, into flow hydrographs for input into the TUFLOW hydraulic model.

During the development of the hydrologic model, a rigorous event-based model calibration/validation process was undertaken to ensure that modelled flood behaviour matched gauged flows. The hydrologic model was calibrated to the December 2010 flood event and validated using the March 2012 and June 2013 floods. Continuing loss and WBNM routing parameters were kept consistent for each event and were maintained for design event modelling. A continuing loss of 1.95 mm/hr was applied and WBNM routing parameters (C) of 1.2 and 2.0 were applied for the Wollondilly and Mulwaree Rivers respectively.

As a verification of the hydrologic model, a comparison of design flow estimates was made to Flood Frequency Analysis (FFA) at three gauges in Goulburn, namely; Marsden Weir, Murrays Flat and The Towers. The study found that hydrologic model derived flows typically provided a good match to the flows derived by FFA, providing a high degree of confidence in design flow estimates.

The Flood Study model was developed in accordance with the ARR1987 and as such, the current study has updated the hydrologic model using ARR2019 methods.

A2.2. Revised Flood Frequency Analysis

Flood Frequency Analysis (FFA) consists of fitting a probability distribution to historical dataset at a stream gauge, so as to estimate the magnitude of a particular design events' discharge. FFA is particularly useful where a long gauge record is available with minimal data quality issues, as it provides a robust estimate of design discharges which takes into account factors such as rainfall intensity, temporal patterns, rainfall losses and hydraulic behaviour, which would otherwise have to be estimated and modelled.

FFA was undertaken during the Flood Study and has been updated in the current study with annual maximum flows for the years following the completion of the Flood Study (2015 to 2018). This update has been undertaken at the Marsden Weir, Murrays Flat and The Towers gauges. The methodology implemented in the Flood Study was maintained with the exception of the distribution applied to the Towers annual series, which was changed from Log-Pearson III to Log-Normal to improve the fit. The Regional Flood Frequency Estimation (RFFE) 'prior distribution' covariants were updated based on newly extracted data from the ARR2019 RFFE website. The 'prior distribution' covariants are presented in Table A 1 and Table A 2 for the Towers and Murrays Flat gauges respectively.

Table A 1: RFFE LPIII 'Prior Distribution' Covariants – The Towers Gauge (2122725)

Parameter	Mean	Standard Deviation	Correlation	
Mean of Log Q	5.183	0.428	1	
Standard Deviation of Log Q	0.881	0.138	-0.33	1
Skew of Log Q	0.092	0.026	0.17	-0.28

*Table A 2: RFFE Log Normal 'Prior Distribution' Covariants – Murrays Flat Gauge (2122711)**

Parameter	Mean	Standard Deviation	Correlation	
Mean of Log Q	5.382	0.648	1	
Standard Deviation of Log Q	0.89	0.167	-0.33	1

*Note that the catchment area to the Murrays Flat gauge exceeds 1,000 km^2 and has an 'unusual shape'. RFFE Results may not be directly applicable in practice.

Revised FFA estimates are presented in Image A 8 to Image A 10 (see Section A2.5) and are comparable to the Flood Study derived FFA estimates. Negligible differences are noted as there were no major flood events occurring during the period 2015 to 2018. The largest event to have occurred during the period had a peak flood of 55 m^3/s (~0.3EY) on the Mulwaree River and 162 m^3/s (< 1EY) on the Wollondilly River.

A2.3. Application of ARR2019 Methodology

The hydrologic model was updated using the methodology prescribed by ARR2019. ARR2019 is based on a series of research projects that aims to provide more accurate techniques for analysis of flood behaviour across Australia. Alongside the updated method of analysis, ARR2019 uses a dataset of rainfall and streamflow gauge data that is significantly expanded, spatially and temporally, from ARR1987. A summary of the main changes in the ARR2019 methodology, when compared to ARR1987, are as follows:

- Design rainfall data (i.e. intensity-frequency-duration data) across Australia has been updated (see Section A2.3.1);
- Where previously a single temporal pattern was used for a particular design event and duration, now an ensemble of 10 temporal patterns is modelled per storm probability and duration (see Section A2.3.2);
- Aerial Reduction Factor (ARF) have been revised based on Australian conditions (see Section A2.3.3); and

- Revision of applied Initial and Continuing Loss values.

A2.3.1. Design Rainfall

Design rainfall data has been obtained from the Bureau of Meteorology (BoM) as Intensity-Frequency-Duration (IFD) data. IFD data describes rainfall depths (mm) for a range of probabilities, durations and locations.

A design rainfall gradient is present across the Wollondilly and Mulwaree River catchments, with the Mulwaree River catchment experiencing an additional +20% rainfall than the Wollondilly River catchment for the 1% AEP event catchments critical duration of 36 hours (~198 mm compared to ~165 mm as a catchment maximum). Accordingly, a single uniformly applied rainfall depth is not appropriate for modelling of design rainfall for the catchments. Instead, spatially varying design rainfalls were applied across the catchment with each sub-catchment receiving a unique rainfall depth sampled from the BoM ARR2019 IFDs.

Image A 1 to Image A 3 present IFD relationships for the township of Goulburn, and the Mulwaree and Wollondilly River catchments respectively. The plots present a comparison of ARR87 and ARR2019 design rainfall depths. The comparison shows that ARR2019 rainfall depths have generally reduced (by up to -44%) for shorter durations (less than ~18 hours) and more frequent events (0.2 EY and 10% AEP). Shorter duration events in the Wollondilly River catchment are noted to have experienced the greatest decreases in rainfall intensity. Longer durations and rarer events are noted to experience increased rainfall depths of up to ~+17%. Most notably, for the Wollondilly and Mulwaree River catchments' critical duration of 36 hours, the ARR2019 rainfall depths have increased by 5% (8 mm) and 13% (23 mm) respectively. This increase in rainfall depth in the Mulwaree River catchment is similar to ARR87 0.5% AEP estimates.

Image A 1: Goulburn City - ARR87 and ARR2019 IFD Comparison

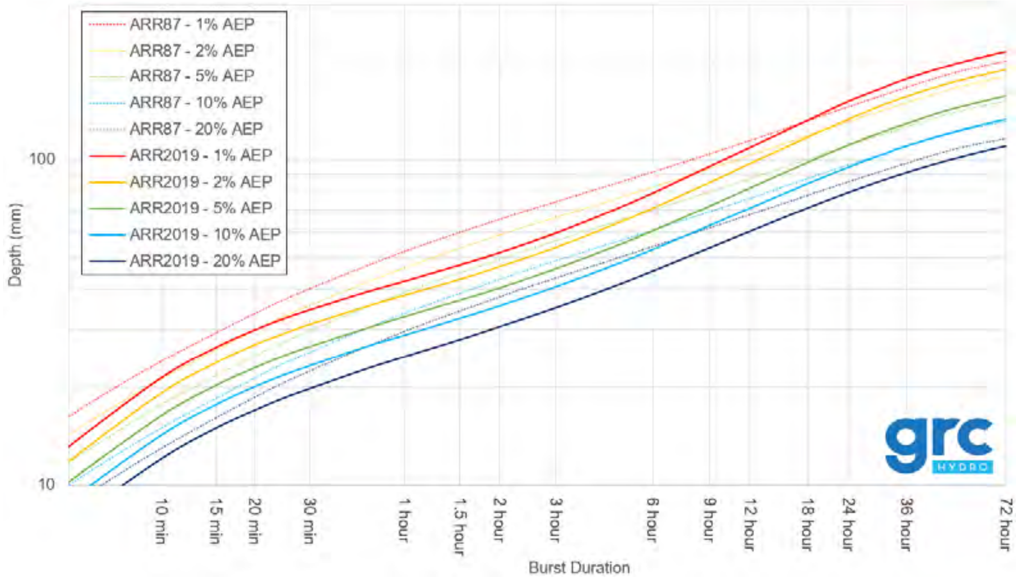


Image A 2: Mulwaree Catchment - ARR87 and ARR2019 IFD Comparison

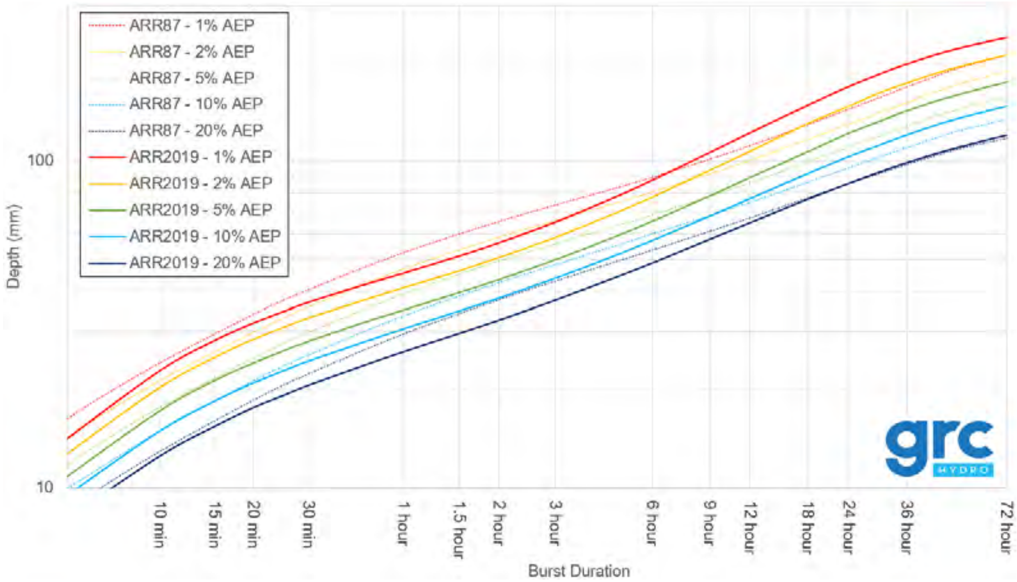
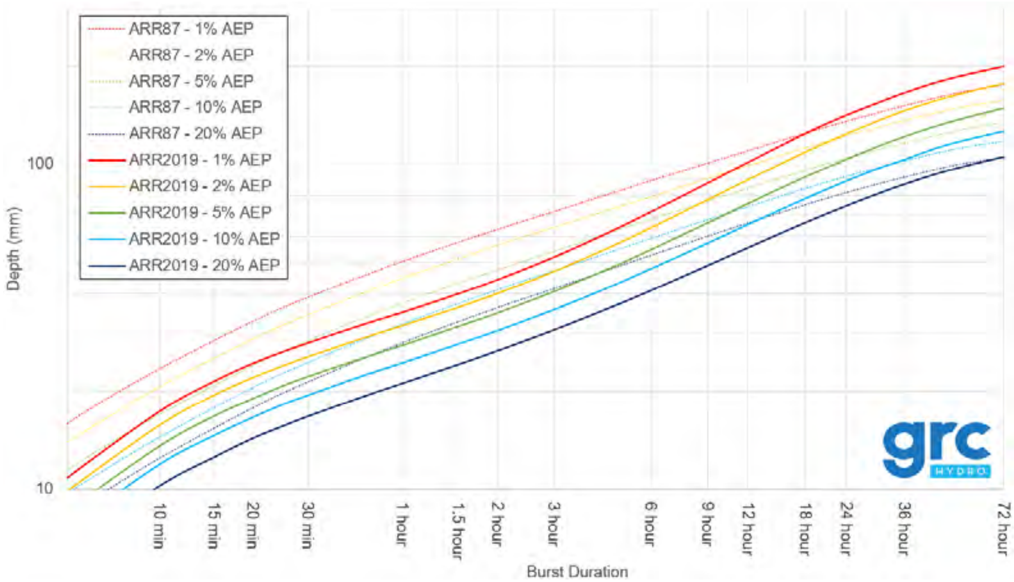


Image A 3: Wollondilly Catchment - ARR87 and ARR2019 IFD Comparison



<u>Review of IFD Data Accuracy Based on Local Gauge Data</u>

To assess the accuracy of the ARR2019 IFD data, rainfall frequency analysis of a historical pluviometer rain gauge data was undertaken and compared to IFD curves provided by the BOM. The analysis was undertaken for the Bungonia (Inverary Park) gauge (#070012) which has 53 years of continuous rainfall data and is situated ~25 km east-southeast of Goulburn. There are a number of pluviometer rainfall gauges closer to Goulburn, however these gauges were installed between 2002 and 2009, yielding a record period ranging between 10 to 17 years, which is not suitable for the estimation of rare event rainfall estimates such as the 1% AEP event.

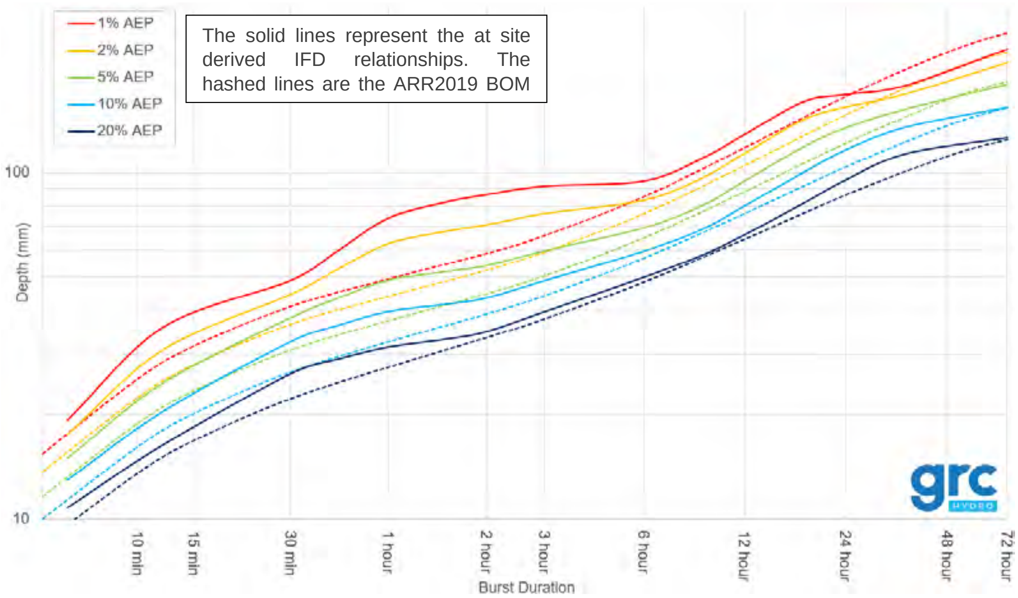
The gauge data was analysed and the annual maximum rainfall depth for various durations from 10 minutes to 72 hours was extracted to develop an annual maximum series for each duration. The rainfall frequency analysis consisted of fitting the Generalised Extreme Value distribution to the annual maximum series, using the technique of L-moments, which is consistent with methods implemented by the BOM in derivation of the IFD data.

The results of this analysis are presented in Image A 4. The IFD curves derived from the at site analysis are a reasonable match to the BOM IFD curves for durations exceeding 6 hours. However, for shorter duration events, particularly those between 30 minutes and 6 hours, the at site IFD curves are noted to greatly exceed the BOM estimates with the largest deviations being observed for the rarer events such as the 1% AEP.

Some difference between the at site analysis and BOM IFD curves is expected due to the BOM analysis including various regression techniques such as 'Bayesian Generalised Least Squares Regression for deriving sub-daily rainfall statistics from daily rainfall values; GIS-based methods for gridding data; and an 'index rainfall procedure' for regionalisation of point data' (BOM). However, the noted significant difference for the shorter duration events is unexpected and indicates that use of the ARR2019 IFDs should be carefully considered for shorter durations. This is particularly of concern given the comparison of ARR87 and ARR2016 IFD relationships presented in Image A 1 to Image A 3 which shows that ARR87 estimates are significantly higher for shorter duration events and provide a better match to the at site analysis.

The differences in ARR87 and ARR2019 IFDs for the catchments' critical durations of 36 hours is within the expected range for the different methodologies and the BOM IFDs are considered to provide a reliable representation of design rainfall estimates for the catchment.

Image A 4: Comparison of ARR2019 IFD curves to at site frequency analysis for Bungonia gauge (#070012)

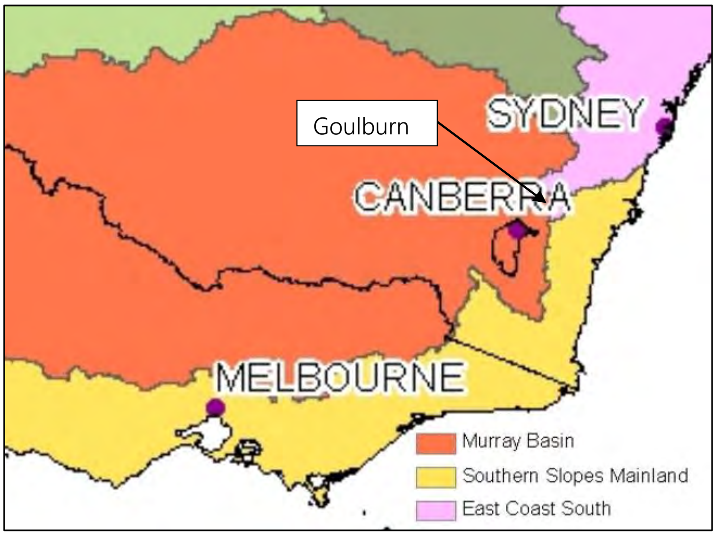


A2.3.2. Rainfall Temporal Patterns

Rainfall temporal patterns are used to describe how rainfall is distributed over time. ARR2019 recommends the ensemble approach to applying temporal patterns, which applies a suite of temporal patterns (typically 10) for each duration. The temporal pattern which produces the flow closest to the mean flow from the suite of temporal patterns is then selected for application to the hydraulic model. Areal Temporal Patterns are used for catchment areas greater than 75km^2 such as the Wollondilly and Mulwaree River catchments.

The Wollondilly and Mulwaree River catchments are situated in the area defined as 'East Coast South' by ARR2019. However, the catchments are bounded by the 'Murray Basin' and 'Southern Slopes Mainland' (see Image A 5) temporal pattern regions. Accordingly, the catchments likely experience a range of storm mechanisms and associated temporal patterns from all three regions.

Image A 5: ARR2019 Temporal Pattern Regions



Selection of the appropriate temporal pattern region is investigated in Appendix B. The analysis found that the Murray Basin temporal pattern suite was most appropriate and have been applied for use in the current study.

A2.3.3. Areal Reduction Factors

The design rainfall depths discussed in Section A2.3.1, provide rainfall information at a point rather than rainfall experienced across an entire catchment area. However, the Wollondilly and Mulwaree River catchments are sufficiently large that design rainfall intensities at a point are not representative of the average rainfall intensity across the catchment. The ratio of areal average rainfall and point rainfall, determined for a specific duration and Annual Exceedance Probability (AEP), is called the Areal Reduction Factor (ARF). The ARF accounts for the fact that larger catchments are less likely than smaller catchments to experience high intensity storms simultaneously over the whole of the catchment area (Reference 2).

The current study has applied ARR2019 ARF obtained from the ARR Data Hub. The Wollondilly and Mulwaree River catchments are situated in the "South East Coast" ARF region. Calculated ARFs were based on the overall catchment area and event duration and probability.

ARF were calculated dependant on upstream catchment area of the location of interest. For example, the model validation process compared WBNM model flows to FFA which required flows to be determined for stream gauge locations at Marden Weir, Murrays Flat and The Towers. In this instance, the ARF was calculated for the catchment upstream of these gauges. When determining design flows for application to the TUFLOW hydraulic model, ARF's for the Wollondilly and Mulwaree rivers were derived for the catchment area at Goulburn for both the Wollondilly and Mulwaree Rivers, as well as the combined catchment area at the confluence.

A2.3.4. Rainfall Losses

The ARR2019 recommended approach to applying rainfall losses has been superseded by the Floodplain Risk Management Guide (Reference 10) which outlines a hierarchy of approaches for determining appropriate loss coefficients for implementation in design flood estimation.

The hierarchy prioritises the application of calibrated losses where available. For Continuing Losses, direct application of the average calibrated losses value is recommended, whilst for Initial Losses, the preferred application is to transform calibrated losses using the equation presented in Reference 10.

The current study has applied the Flood Study 'Average Calibration' continuing loss of 1.95 mm/hr, however analysis of the Reference 10 method of applying Initial Losses found that the method overestimated losses for the catchments. Instead, application of the methods outlined in ARR2019 was found to be preferred for the current study. Details of this analysis are presented in Appendix B.

For the current study, rainfall losses were obtained from the ARR Data Hub. ARR2019 initial losses include pre-burst rainfall depths which must be deducted from the initial loss. These pre-burst rainfall depths vary based on event duration and magnitude. Table A 3 presents the median pre-burst depths obtained from the ARR Data hub and deducted from the initial loss of 17 mm.

Table A 3: ARR2019 Design Median Pre-burst Depths (mm)

Duration (hours) \ AEP (%)	50	20	10	5	2	1
12	0.1	4.7	7.8	10.8	10.8	10.8
18	0.2	2.6	4.2	5.7	8.8	11.1
24	0.0	0.5	0.9	1.2	4.3	6.7
36	0.0	0.0	0.0	0.0	1.5	2.7
48	0.0	0.0	0.0	0.0	0.0	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0

A2.3.5. Joint Probability

As discussed in the Flood Study (2016), simultaneous Wollondilly and Mulwaree River flooding can lead to exacerbation of flood levels. However, the coincidence of flooding of these two rivers is weakly correlated and accordingly, a joint probability model was developed with consideration of the semi-dependency of the systems. The current study has implemented the methodology outlined in the Flood Study (2016) which is consistent with the approach presented in the '*Development Of Practical Guidance For Coincidence Of Catchment Flooding And Oceanic Inundation*' (Toniato et al), as reproduced below:

- Model the 1% AEP flood in the Wollondilly River with a 5% AEP flood in the Mulwaree River;
- Model the 5% AEP flood in the Wollondilly River with the 1% AEP flood in the Mulwaree River; and
- Model the 1% AEP flood in both the Wollondilly and Mulwaree Rivers considering an ARF consistent with catchment area at the Wollondilly and Mulwaree River confluence.

The above scenarios have been assessed in the TUFLOW model, with a peak flood envelope created from the results.

A2.4. Revised Design Flow Estimates

Revised design flow estimates at Goulburn based on application of the methodology outlined in Section A2.3 are presented in Table A 4. Image A 6 and Image A 7 present the full ensemble results for the 1% AEP event on the Wollondilly River and Mulwaree River respectively.

The Floodplain Risk Management Guide (Reference 10) recommends that the storm above the mean ensemble flow is selected. This approach was adopted except for instances where the standard deviation of the storm above the mean was more than twice that of the standard deviation below mean. In these circumstances, the storm below the mean flow was selected.

The results indicate that a duration of 36 hours was found to be critical along both rivers for all design events.

Table A 4: Hydrologic model flow estimates at Goulburn (m^3/s)

Catchment	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
Wollondilly	301	447	610	842	1,030	1,224	1,492	11,032
Mulwaree	195	306	440	639	808	990	1,253	6,119

Image A 6: Wollondilly River at Goulburn - 1% AEP Ensemble Results

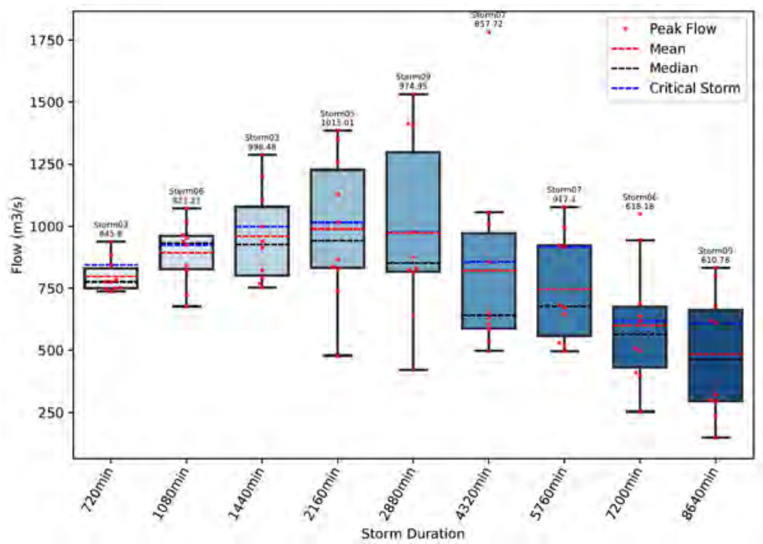
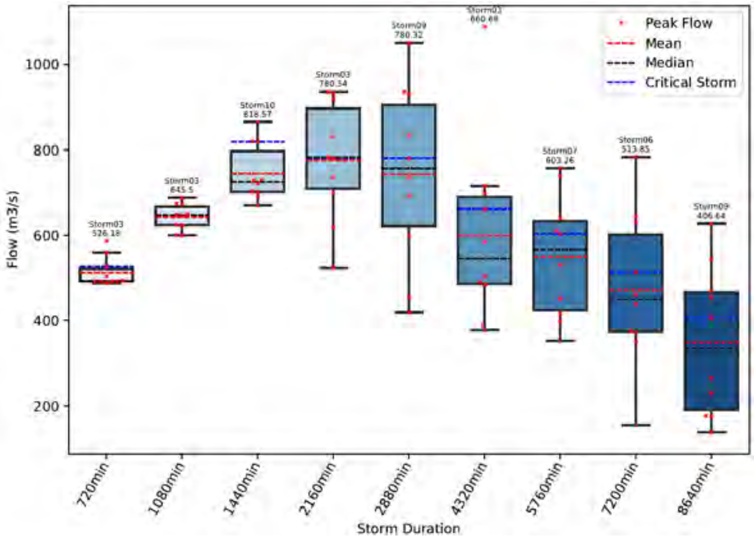


Image A 7: Mulwaree River at Goulburn - 1% AEP Ensemble Results



A2.5. Hydrologic Model Validation

A comparison of WBNM hydrologic model flows to the revised FFA estimates is presented in Image A 8 to Image A 10. Hydrological flows are typically a good match to the flows derived via FFA. However, as discussed in the Flood Study (Reference 6), due to the relatively short record periods of the Towers and Murrays Flat gauges, and the incomplete record of the Marsden Weir Gauge, there are limitations associated with the annual series data and resulting FFA. Notwithstanding, the analysis improves confidence in design flow estimates.

The design flows presented in Image A 8 to Image A 10 differ slightly from the design flows presented in Table A 4 as they are taken at different locations with ARF's that vary based on upstream catchment area.

Image A 8: Marsden Weir Gauge – FFA vs WBNM design flow estimates

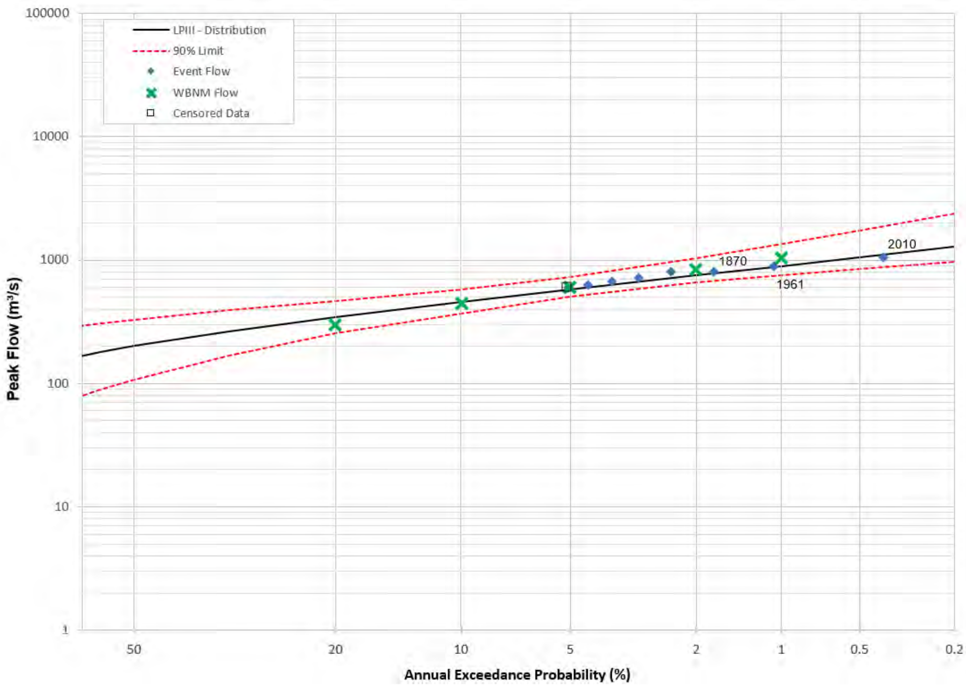


Image A 9: Murrays Flat Gauge (2122711) – FFA vs WBNM design flow estimates

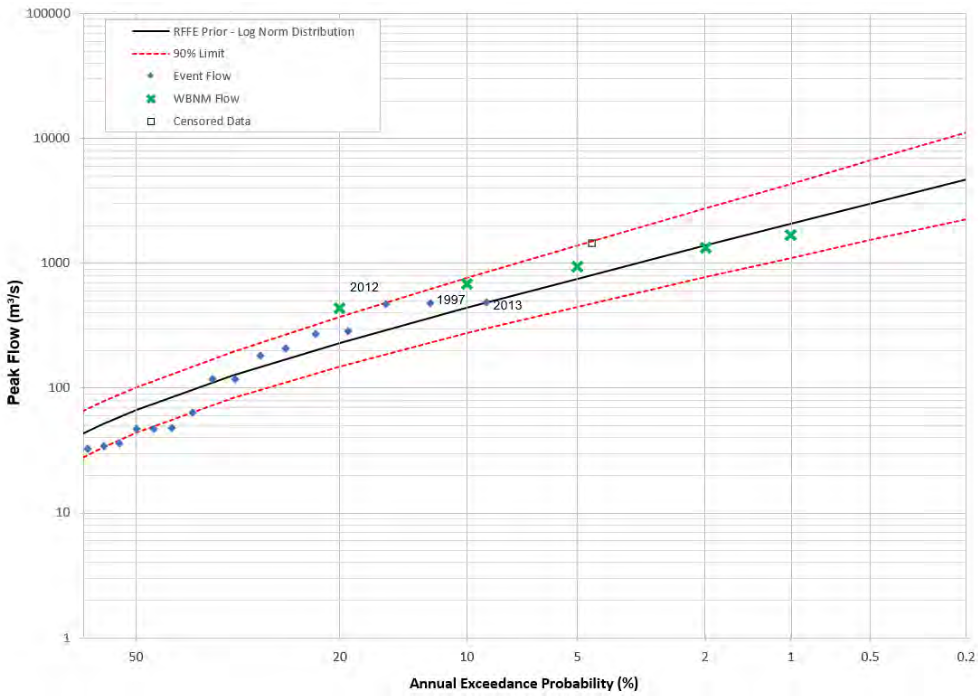
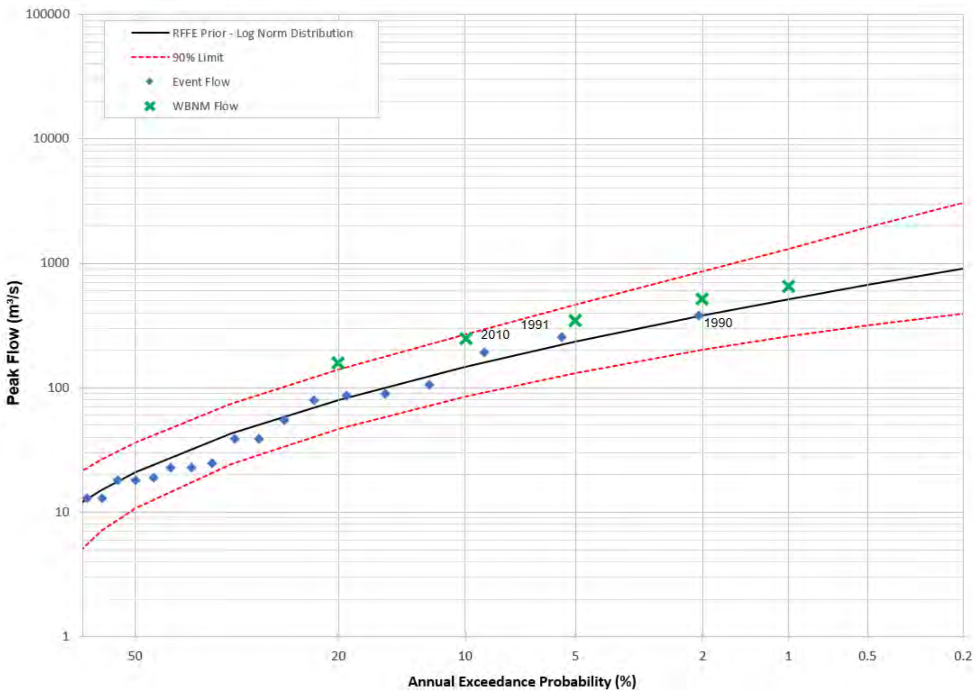


Image A 10: The Towers Gauge (2122725) – FFA vs WBNM design flow estimates



A2.6. Comparison to Previous Studies

A comparison of the current study design flow estimates to previous studies is presented in Table A 5. Similar to the Flood Study results, the current study flow estimates are significantly reduced relative to the 2003 Flood Study (SMEC). A discussion of the limitations of the 2003 Flood Study design flow estimates is presented in the Flood Study (Reference 6, Section 5.7.4.1) which notes that the more recent design estimates are preferred.

A comparison to the Flood Study (2016) results indicates the current study flow estimates are comparable. On the Wollondilly River, more frequent events are typically larger than in the 2016 study, whilst the 1% AEP estimate is reduced by approximately 8% (84 m^3/s). It is important to note that the current study results provide a closer match the FFA than the Flood Study results on the Wollondilly River at Goulburn.

On the Mulwaree River, a similar trend is noted, with more frequent event design flow estimates identified in the current study typically exceeding the Flood Study (2016) estimates. Mulwaree River 1% AEP flow estimates are similar with the current study flow being ~6% greater than the Flood Study estimate.

Table A 5: Comparison of previous study design flow estimates at Goulburn

Event (% AEP)	Wollondilly River at Goulburn (m^3/s)			Mulwaree River at Goulburn (m^3/s)		
	2003 Study	2016 Study	Current Study	2003 Study	2016 Study	Current Study
20%	258	203	301	258	152	195
10%	428	312	447	428	232	306
5%	648	487	610	648	347	440
2%	1,026	935	842	1,026	616	639
1%	1,415	1,114	1,030	1,415	762	808
0.5%	1,868	1,298	1,224	1,868	912	990
0.2%			1,492			1,253

A comparison of the resulting 1% AEP flood levels determined in the current study and 2016 Flood Study, are presented in Section A3.5.

A2.7. ARR87 vs ARR2019 – Parameter Sensitivity

As discussed in Section A2, the hydrologic analysis has been revised to incorporate the latest revision of Australian Rainfall and Runoff. The most significant changes to Australian Rainfall and Runoff between the 1987 and 2019 revisions are to changes to; design rainfall estimates (Section A2.3.1), application of a temporal pattern ensemble (Section A2.3.2), Aerial Reduction Factors (Section A2.3.3) and applied rainfall losses (Section A2.3.4).

Sensitivity analysis has been undertaken to determine the influence that each of these parameters have had on the revised design flow estimates. The analysis was undertaken using the Flood Study WBNM model and modifying one parameter at a time and comparing the results to the Flood Study derived flows at Goulburn. The results of this analysis are presented in Table A 6.

Table A 6: ARR87 vs ARR2019 – Parameter sensitivity on 1% AEP design flow estimates

Scenario	Wollondilly River at Goulburn		Mulwaree River at Goulburn	
	Flow (m^3/s)	% change relative to Flood Study	Flow (m^3/s)	% change relative to Flood Study
Complete ARR87 methodology	1,114	-	762	-
Complete ARR2019 method	1,030	-7.5%	808	+6.0%
ARR87 method with ARR2019 TP (mean flow)	772	-30.7%	637	-16.4%
ARR87 method with ARR2019 TP (max flow)	1,118	+0.3%	880	+15.5%
ARR87 method with ARR2019 IFD	1,469	+31.9%	962	+26.3%
ARR87 method with ARR2019 losses*	1,145	2.8%	774	+1.5%
ARR87 method with ARR2019 ARF**	1,219	+9.5%	829	8.8%

* The rainfall loss sensitivity was assessed for initial losses only as both the Flood Study and the current study applied the same continuing losses.

** The Flood Study applied the CRC-Forge method which superseded the ARR87 ARFs.

The application of ARR2019 methods, result in a 7.5% decrease in flow for the 1% AEP Wollondilly River event and a +6% increase for the 1% AEP Mulwaree River event.

Application of the ARR2019 temporal pattern ensemble results in a significant decrease in 1% AEP flow estimates (based on the mean flow from the temporal pattern ensemble) of -31% and -16% for the Wollondilly and Mulwaree Rivers respectively. The large reduction in flow is likely caused by reducing the risk of embedded bursts which were often present when using ARR87 methods. Using the peak flow from the ensemble (i.e. taking the max temporal pattern rather than the mean) results in a slight increase in peak flow relative to the Flood Study. Again, this is likely due to embedded bursts which exceed 1% AEP estimates.

Changes to design flow estimates associated with revised IFD estimates are significant with +32% and +26% increases in 1% AEP flow estimates for the Wollondilly and Mulwaree Rivers respectively. This result is not unexpected due to the significant increase in design rainfall intensities for longer duration events discussed in Section A2.3.1.

Changes to the applied ARF have a limited impact on design flow estimates. ARR2019 ARFs are based on a revised version of the CRC-Forge method that was applied in the Flood Study.

Applied initial losses have limited sensitivity on 1% AEP event results. However, the influence of applied initial losses is expected to be greater for more frequent events for two reasons:

1. The Flood Study varied initial losses based on rainfall AEP, with larger losses applied for more frequent events; and
2. The applied initial losses are greater when considering the ratio of applied losses to applied rainfall. i.e. losses will have a greater impact for events with lower rainfall volumes.

A3. HYDRAULIC MODEL UPDATE

Hydraulic models are used to produce flood depths, levels and velocities across the study area, based on the inflow hydrographs output from the hydrologic model. The Flood Study (Reference 6) developed a hydraulic model for the Wollondilly River and Mulwaree River at Goulburn, which has been used as the basis of the current study.

A3.1. Flood Study Overview

A TUFLOW hydraulic model of the Wollondilly River and Mulwaree River at Goulburn was developed as part of the Flood Study. TUFLOW is a hydrodynamic modelling program that represents the floodplain as a grid of cells and resolves flow behaviour using a finite difference method. The TUFLOW software used in the Flood Study was the 64-bit version 2013-12-AD. A 10 m grid cell size was adopted on the basis that it was fit for the purpose of representing key hydraulic features along these rivers over a large area.

The Flood Study undertook calibration and validation of the flood model. The December 2010 flood event was used for calibration, where flood observations by the community at 21 locations were compared to modelled flood behaviour at these points. An absolute average error of 0.08 m was achieved, giving confidence in the hydraulic and hydrologic models. Additionally, the December 2010 event was calibrated to observed stage hydrographs at the Rossi Weir and The Towers stream gauges where a good match was found at both gauges

The March 2012 and June 2013 events were used to validate the calibrated hydraulic model, by matching flood observations and the recorded stage hydrographs at Rossi Weir, The Towers and Murrays Flat. Overall, the model calibration and validation results provided a high degree of confidence in the hydraulic model and the subsequent design results.

The sensitivity of the model results to the adopted values (roughness and grid cell size) and climate change were investigated. This sensitivity analysis found that the flood model was sensitive to the adopted Manning's roughness values and an increase in rainfall intensity due to climate change.

The Flood Study hydraulic model has been used as the basis of the current study analysis with various updates made as discussed in Section A3.2.

A3.2. Model Update

A3.2.1. Application of ARR2019 Design Flows

The Flood Study hydraulic model utilised hydrologic model inflow hydrographs that were derived in accordance with ARR1987. The current study has updated the hydrologic model flows to ARR2019 (as discussed in Section A2.3) and the hydraulic model inflows have been updated accordingly.

A3.2.2. Hydraulic Model Updates

Hydraulic Structures

Since the completion of the Flood Study in 2016, changes to hydraulic structures across the floodplain have occurred (or will occur shortly). These structures include:

- Construction of the Gibson Street footbridge across the Wollondilly River;
- Upgrade to the Lansdowne Bridge across the Mulwaree River; and
- Upgrade to the May Street Bridge over the Mulwaree River.

Design plans for the Gibson Street and May Street bridges were provided by Council, and the Lansdowne Bridge plans were obtained from RMS. These structures were then implemented into the TUFLOW hydraulic model.

Model Extension

At Council's request, the following hydraulic model extensions were made:

- Mulwaree River: extended 1.1 km upstream of the Flood Study model boundary, inclusive of 5.4 km of Run O'waters Creek.
- Wollondilly River: extended 4.2 km upstream of the Flood Study model boundary.
- Downstream boundary: extended 2 km downstream of Flood Study model boundary.

These extensions were primarily made for planning purposes to ensure that flood affection is defined for potential future development area.

A3.3. Model Results

The following sections present the design flood behaviour on the Wollondilly River and Mulwaree River at Goulburn using the updated hydrologic/hydraulic modelling system. Design flood behaviour has been derived for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF events. This modelling has been undertaken utilising the methodologies outlined in ARR2019 for mainstream flood affectation.

A3.3.1. Flood Depths, Levels and Profiles

Wollondilly and Mulwaree peak flood depths and levels are presented in the following figures:

- Figure A *1*: Peak Flood Depths & Levels - 20% AEP Design Event;
- Figure A *2*: Peak Flood Depths & Levels - 10% AEP Design Event;
- Figure A *3*: Peak Flood Depths & Levels - 5% AEP Design Event;
- Figure A *4*: Peak Flood Depths & Levels - 2% AEP Design Event;
- Figure A *5*: Peak Flood Depths & Levels - 1% AEP Design Event;
- Figure A *6*: Peak Flood Depths & Levels – 0.5% AEP Design Event;
- Figure A *7*: Peak Flood Depths & Levels – 0.2% AEP Design Event; and
- Figure A *8*: Peak Flood Depths & Levels – PMF Design Event

Peak flood profiles along the Wollondilly River and Mulwaree River are presented in Figure A 9 and Figure A 10, respectively. Peak flood velocities are presented in figures:

- Figure A *11*: Peak Flood Velocity - 20% AEP Design Event;
- Figure A *12*: Peak Flood Velocity - 10% AEP Design Event;
- Figure A *13*: Peak Flood Velocity - 5% AEP Design Event;
- Figure A *14*: Peak Flood Velocity - 2% AEP Design Event;
- Figure A *15*: Peak Flood Velocity - 1% AEP Design Event;
- Figure A *16*: Peak Flood Velocity – 0.5% AEP Design Event;
- Figure A *17*: Peak Flood Velocity – 0.2% AEP Design Event; and
- Figure A *18*: Peak Flood Velocity – PMF Design Event.

Appendix C (Table C 1 to Table C 6) presents the design peak flood levels, velocities and flows for each flood magnitude at key locations throughout the study area. Figure 1 of the main body of the report presents the reporting locations where each of these flood characteristics were recorded.

A3.4. Hydraulic Model Validation

Validation of the flood model has been undertaken via analysis the 1% AEP design flood level estimates in the context of historic event flood levels.

Table A 7 provides a comparison of flood levels on the Mulwaree River at various locations in the vicinity of Goulburn. The 1% AEP estimates exceed all recorded flood events on the Mulwaree River with the exception of the 1959 event. The 1% AEP flood levels on the Mulwaree River, upstream of the railway viaduct, were found to typically be 0.25 m to 0.45 m lower than 1959 recorded flood levels. Toward the confluence of the Mulwaree and Wollondilly rivers, backwatering influences result in higher 1% AEP levels (approximately 0.1 m to 0.3 m high) than those recorded in the 1959 event.

The Flood Study (Reference 6) examined the magnitude of the 1959 event, finding that the rainfall magnitude from this event likely greatly exceeded the 1% AEP event. The Flood Study noted that the 1959 storm event produced a 1% AEP flood in the neighbouring Yass River catchment and that examination of daily read rainfall data indicated that 30% more rainfall was experienced in the Mulwaree River catchment for the same event. This was based on analysis undertaken as part of the Flood Study, since 1870 (148 years) only one event (1959) exceeds the current study 1% AEP estimate, and that rainfall analysis confirms that this event was likely larger than a 1% AEP event. This provides confidence in the current study Mulwaree River 1% AEP event estimate.

Table A 7: Comparison of 1% AEP flood level estimates to historic events on the Mulwaree River

Location	Mulwaree River Flood Levels (mAHD)			
	2010	1974	1% AEP	1959
Fitzroy Bridge	629.22	630.00	630.39	630.08*
Upstream of Golf Course, Eleanor Street	629.32	630.32	630.53	630.67
Corner Hercules & Genelg Street	629.34	630.35	630.56	630.66
Northern end of Emma Street	629.36	630.32	630.53	n/a

* Noted as the maximum recorded flood level at Fitzroy Bridge on Department of Main Roads NSW design plans. The Fitzroy Bridge approaches are large and provide a significant restriction to flow. If the 1959 event had occurred post construction of the bridge it is likely that the peak flood level would be significantly higher (WMAwater, 2016).

Table A 8 provides a comparison of flood levels at Marsden Weir on the Wollondilly River. The 1% AEP estimate exceeds all recorded flood events at Marsden Weir since at least 1870. At Marsden Weir, the 1% AEP flood level is approximately 1.4 m higher than the 1870 flood level.

Table A 8: Comparison of 1% AEP flood level estimates to historic events at Marsden Weir

Event (% AEP)	Gauge Level (m)
1959	3.13
1961	3.24
2010	4.13
1% AEP	4.25

* Gauge Zero = 630.46 mAHD

A3.5. Comparison to Previous Studies

The revised 1% AEP TUFLOW model results implementing ARR2019 were compared to the Flood Study results which used ARR1987. The results indicated that 1% AEP flood levels on the Mulwaree River are similar, yet slightly higher than the Flood Study results as would be expected due to the similarities in flow described previously. The Wollondilly River levels are reduced relative to the Flood Study due to the decrease in flow associated with the ARR2019 hydrology revision. The decrease in flood levels typically range from 0.1 to 0.3 m in the urban areas of Goulburn.

A comparison of 1% AEP peak flood levels has been undertaken between the current study, the Flood Study (Reference 6) and the 2003 SMEC Study (Reference 7). Table A 9 presents the 1% AEP peak flood levels at various locations from these studies. Generally, 1% AEP peak flood levels from the current study and the Flood Study are lower than the SMEC 2003 Study. The design estimates from these more recent studies are preferred as the overall methodology incorporated significantly more local data than the SMEC 2003 Study.

Table A 9: Comparison of 1% AEP Peak Flood Levels to Previous Studies

Location	Current Study (m AHD)	Flood Study (m AHD)	SMEC 2003 Study (m AHD)
Wollondilly River			
Marsden Weir	634.7	634.9	636.0
Marsden Bridge	634.5	634.7	635.6
Victoria Street Bridge	631.8	632.0	632.8
Kenmore Bridge	630.4	630.6	631.9
Mulwaree Confluence	629.9	629.9	631.1
Mulwaree River			
Hume Highway Bypass	631.0	631.0	632.4
Landsdowne Bridge	630.8	630.6	632.1
Railway Viaduct	630.4	630.3	631.8
Sydney Road Bridge	630.2	630.1	631.5
Wollondilly Confluence	629.9	629.9	631.1

A4. CLIMATE CHANGE ANALYSIS

Design flood results were used to assess the impact of climate change on flood producing rainfall, and by extension, flooding itself. The assessment used the IPCC (Intergovernmental Panel on Climate Change) greenhouse gas concentration scenarios and subsequent modelling estimating each scenario's effect on rare rainfall events. There are four IPCC greenhouse gas concentration projections named RCP 2.5, 4.5, 6.0 and 8.5, with the RCP 2.5 being the most optimistic and 8.5 the least optimistic. The ARR2016 methodology recommends the use of RCP 4.5 and 8.5, and their projected increase in precipitation intensity are obtained from the ARR2016 Data Hub and shown in Table A 10 for the 2090 estimate.

Table A 10: Climate Change Factors – Percentage Increase in Rainfall Intensity in 2090

Year	RCP 4.5	RCP 8.5
2090	+9.1 %	+18.6%

This indicates that, for example, under a relatively low emissions scenario (RCP 4.5), rainfall intensity will increase by 9.1% in Goulburn by 2090. The significance of this percentage is measured by comparing it to the range of design flood events. The results of this assessment are shown in Table A 11, which lists the total rainfall depth for the 1%, 0.5% and 0.2% AEP events and then compares those events with the increased rainfall caused by two emissions scenarios – RCP 4.5 and RCP 8.5.

Table A 11: Comparison between Design Rainfall Intensity and Projected Climate Change Rainfall Intensity

AEP	Total Rainfall Depth (mm)		
	ARR2016 IFD 36h	2090 RCP 4.5 +9.10%	2090 RCP 8.5 +18.60%
1%	177	193	210
0.50%	200	218	237
0.20%	231	252	274

The table shows that, overall, most 1% AEP floods will increase to a magnitude somewhere between a 0.5% and 0.2% AEP event, under both emissions scenarios. For example, under RCP 4.5 conditions, the new 1% AEP event rainfall will be close to the current 0.5% event rainfall. Under RCP 8.5 conditions, the 2090 1% AEP event rainfall will be between a 0.5% and 0.2% AEP event rainfall. The impact of these changes on peak flood levels can be determined by comparing the 1%, 0.5% and 0.2% AEP events (see Section A3.3.1).

A5. SENSITIVITY ANALYSIS

A5.1. Overview

Sensitivity analysis describes the sensitivity of model results to changes in model parameters. In hydraulic modelling, each model parameter is estimated based on the available data, guidance and knowledge of the catchment. These estimates, however, rely on a series of assumptions and therefore the hydraulic model has a degree of uncertainty. Sensitivity analysis quantifies assumptions made, by measuring their effect on model flood behaviour. Large changes in flood behaviour indicate parameters that the model is sensitive to.

In the current study the following parameters have been assessed:

- Rainfall losses (see Section A5.2);
- Hydrologic lag parameter (see Section A5.3);
- Hydraulic roughness (see Section A5.4);
- Structure blockage (see Section A5.5);
- Temporal pattern selection (see Section A5.6); and
- Areal reduction factor (see Section A5.7).

The model sensitivity is tested by varying each parameter within a reasonable estimate range, and then assessing the output from the hydraulic model to determine the change in peak flood level results for each scenario. This analysis has been undertaken for the 20% and 1% AEP events.

The sensitivity analysis results are presented in Appendix D, Table D 1 to Table D 4 and the following sections discuss the results of the analysis.

A5.2. Rainfall Losses

Sensitivity analysis was undertaken on the rainfall losses adopted in the hydrologic model. This analysis assessed an increase and decrease of 20% in both the initial and continuing losses for the 20% and 1 % AEP events.

On average, a 20% change in losses in the 1% AEP event caused a 0.21 m change in level on the Wollondilly River and 0.25 m change on the Mulwaree River. As such, the system is sensitive to loss parameters.

A5.3. Hydrologic Lag Parameter

The selected hydrologic lag parameter was varied to examine the model's sensitivity. The hydrologic lag parameter as increased and decreased by 20% and flood level differences were assessed for the 20% and 1% AEP events.

The modelling system was found to be sensitive to variations in the hydrologic lag parameter with a level difference of up to 0.45 m, on average, on the Wollondilly River and up to 0.32 m on the Mulwaree River.

A5.4. Hydraulic Roughness

Adopted hydraulic model roughness values were tested for their sensitivity. This assessment increased and decreased the adopted roughness values by 20% for the 20% and 1% AEP events.

Variations in hydraulic roughness caused an average change in level of up to 0.50 m on the Wollondilly River in the 1% AEP event and up to 0.42 m on the Mulwaree River. As such, the modelling system is sensitive to changes in hydraulic roughness.

A5.5. Structure Blockage

Sensitivity analysis was undertaken on the adopted blockage assumptions made in the hydraulic model. An additional 20% of blockage was added to and subtracted from structures in the floodplain and assessed for the 20% and 1% AEP events.

The modelling system was found to be relatively insensitive to changes in structure blockage with on average a change in flood level of 0.05 m on the Wollondilly River in the 1% AEP event and 0.03 m on the Mulwaree River. The Victoria Bridge was found to be most sensitivity to blockage with an increase in flood level of 0.2 m expected if the blockage factor is increased by +20%.

A5.6. Temporal Pattern Selection

The selection of a temporal pattern from a flow ensemble can influence the resulting design peak flood levels and as such, sensitivity analysis was undertaken. The current study has selected temporal patterns based on guidance from the Floodplain Risk Management Guide (Reference 10) (see Section A2.4). Sensitivity analysis of this selection process was undertaken whereby the temporal pattern that produced the minimum and maximum flows in the 20% and 1% AEP events were input in the hydraulic model and resulting flood levels were compared to design flood levels for these events.

Sensitivity to the selected temporal pattern was found with an average change in flood level of 1.45 m in the 1% AEP event on the Wollondilly River and 0.96 m on the Mulwaree River. Flood level differences from the design event were found to increase in downstream areas.

A5.7. Areal Reduction Factor

Sensitivity analysis of the calculated areal reduction factor (ARF) was undertaken by increasing and decreasing the calculated ARF value by 20% for the 1% and 20% AEP events.

The hydraulic model was found to be sensitive to the calculated ARF with an average change in flood level of 1.10 m in the 1% AEP event on the Wollondilly River and 0.90 m on the Mulwaree River. These flood level differences were noted to increase in downstream areas.

A6. CONCLUSION

The calibrated/validated Flood Study WBNM model has been modified to incorporate ARR2019 methods. A 30 temporal pattern ensemble (East Coast South, Murray Basin, Southern Slopes Mainland) was assessed to account for the catchments' proximity to several temporal pattern regions with the Murray Basin temporal patterns implemented. Areal Temporal Patterns have been implemented as the catchment areas of the Wollondilly and Mulwaree Rivers are greater than 75 km².

The revised design flow estimates have been compared to FFA with the analysis showing a good match between the WBNM and FFA derived flows, thus serving as verification of the design flow estimates. Comparison of the current study flows to the Flood Study indicates that there is negligible difference in 1% AEP flow estimates on the Mulwaree, however the Wollondilly 1% AEP flow has decreased by ~10%. However, the current study flows were noted to have a better match to FFA than the Flood Study flows on the Wollondilly River.

Design flows were applied to the Flood Study TUFLOW hydraulic model which was modified to extend the model domain and to incorporate new works on the floodplain. The 1% AEP results were compared to historic event peak flood levels. Examination of the ~150 year anecdotal historic flow record at Goulburn indicates that during this period one flood (1959) on the Mulwaree River exceeded the current study 1% AEP estimates. Additional analysis of the magnitude of the 1959 Mulwaree River event indicated that it was likely larger than any reasonable 1% AEP estimate. This analysis contextualises the current study 1% AEP estimates and adds further robustness to the design results. The Wollondilly River 1% AEP estimate is larger than any event that occurred during this period.

The revised 1% AEP flood level estimates indicate that the current study results are similar to the Flood Study for the Mulwaree River, however 1% AEP flood levels on the Wollondilly River have reduced by ~0.2 m on average in the urban areas of Goulburn.

It is recommended that the methods outlined in the current report are implemented and the current study move forward to assessment of flood management measures.

Appendix B – ARR2019 Additional Analysis

Job Number: 180068
Date: 07 May 2019

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Lucy Henze
Goulburn Mulwaree Council

Dear Lucy,

Re: Goulburn Mulwaree FRMS&P – Summary of Revised Flow Estimates based on ARR2016

Following the teleconference on 9 April 2019, we would like to confirm the applied modelling approach to be used to revise flood study results in accordance with ARR2016. Specifically, we are presenting the revised design flow estimates and 1% AEP hydraulic model results for discussion, prior to completing the Milestone 4 report.

A summary of the implemented approach is presented below:

1. Use of the Flood Study (WMAwater, 2016) calibrated WBNM model, maintaining calibrated parameters (continuing losses and WBNM routing parameter);
2. Application of ARR2016 techniques for model hydrology, implementing the ensemble approach to flood modelling with a total of 30 temporal patterns based on neighbouring temporal pattern regions;
3. Derivation of design flow estimates for the Wollondilly and Mulwaree Rivers;
4. Revision of the Flood Study Flood Frequency Analysis (FFA);
5. Comparison of design flow estimates to FFA;
6. Comparison of design flow estimates to previous studies;
7. Modelling of the 1% AEP event in the Flood Study TUFLOW hydraulic model;
8. Comparison of 1% AEP design flood levels to historic events;
9. Comparison of 1% AEP design flood levels to previous studies; and
10. Conclusions and recommendations.

Details of this analysis is discussed in the ensuing sections numbered according to the above list.

1. Flood Study WBNM Hydrologic Model

The Flood Study undertook a rigorous event-based model calibration/validation process. The WBNM hydrologic model was calibrated to the December 2010 flood event and validated using the March 2012 and June 2013 floods. Continuing Losses and WBNM routing parameters were kept consistent for each event and were maintained for design event modelling. A Continuing Loss of 1.95 mm/hr was applied and WBNM routing parameters (C) of 1.2 and 2.0 were applied for the Wollondilly and Mulwaree Rivers respectively.

Continuing Losses

It is proposed that the Flood Study derived Continuing Loss are maintained. This is consistent with the NSW Office of Environment and Heritage (OEH) released the *'Floodplain Risk Management Guide, Incorporating 2016 Australian Rainfall and Runoff in Studies'* (2018) which recognised that loss values for NSW from the ARR Data Hub have resulted in *"a significant bias toward underestimation of flows"*. The guidelines provide a hierarchical approach to loss and pre-burst estimation in NSW and preferentially recommend that the 'Average Calibration' continuing loss be implemented where model calibration was undertaken.

Initial Losses
The Initial Losses implemented in the Flood Study are not recommended for use. The OEH guidelines (2018) recommend that the 'Average Calibration' initial loss be implemented where model calibration was undertaken. However, the average calibration initial losses were determined to be 66 mm and 62 mm for the Wollondilly and Mulwaree Rivers respectively, which represent ~44% of the 1% AEP rainfall depth for the 24 hour critical duration event. Calibrated Initial Losses are not necessarily representative of a catchments 'true' initial loss values and can vary significantly based on the length of data examined during model calibration (i.e. if several hours/days of data are included in the modelling prior to the main storm burst, the calibrated initial loss will be greater than if only the storm burst is examined). Use of the 'Average Calibration' initial loss will result in the significant underestimate of design flow estimates and is therefore not recommended. Instead, the ARR2016 Initial Loss of 17 mm/hr adjusted for pre-burst will be applied.

WBNM Routing Parameter
The Flood Study derived WBNM routing parameters are within the range discussed in the WBNM User Manual and will be maintained.

2. **Application of ARR2016 techniques**

The Flood Study hydrologic model has been updated following the ARR2016 guidelines with the parameters discussed in the previous section applied.

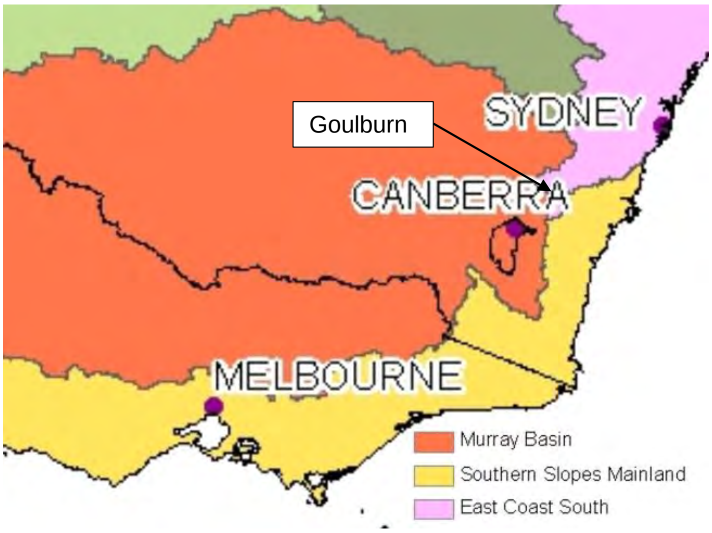
Design Rainfall
ARR2016 design rainfall depths for various durations were obtained from the Bureau of Meteorology (BoM). Due to a rainfall gradient across the Wollondilly and Mulwaree River catchments, a single uniformly applied rainfall depth was not appropriate for modelling of design rainfall. Instead, spatially varying design rainfalls were applied across the catchment with each sub-catchment receiving a unique rainfall depth.

Areal Reduction Factors
Areal Reduction Factors (ARF) were applied to design rainfall depths to adjust for the Catchment's areal average rainfall intensity. The ARFs were determined following the methods outlined in ARR2016 for the 'South East Coast' region. Calculated ARFs were based on the catchment's area and event duration and probability.

Rainfall Temporal Patterns
Rainfall temporal patterns are used to describe how rainfall is distributed over time. A modified version of the recommended ARR2016 ensemble approach to applying temporal patterns has been utilised in the current study.

The Wollondilly and Mulwaree River catchments are situated in the area defined as 'East Coast South' by ARR2016. However, the catchments are bounded by the 'Murray Basin' and 'Southern Slopes Mainland' (see Image 1) temporal pattern regions. Accordingly, the catchments likely experience a range of storm mechanisms and associated temporal patterns from all three regions. A 30 temporal pattern ensemble has been applied incorporating 10 temporal patterns from each of the proximate temporal pattern areas. Areal Temporal Patterns have been implemented as the catchment areas of the Wollondilly and Mulwaree Rivers are greater than 75 km².

Image 1: ARR2016 Temporal Pattern Regions



1% AEP ensemble design flow results from the analysis are presented in Image 2 and Image 3 for the Wollondilly and Mulwaree Rivers at Goulburn respectively. The ensemble results for other AEP will be presented in the Milestone 4 report.

Image 2: Wollondilly River – 1% AEP Hydrology Ensemble Results

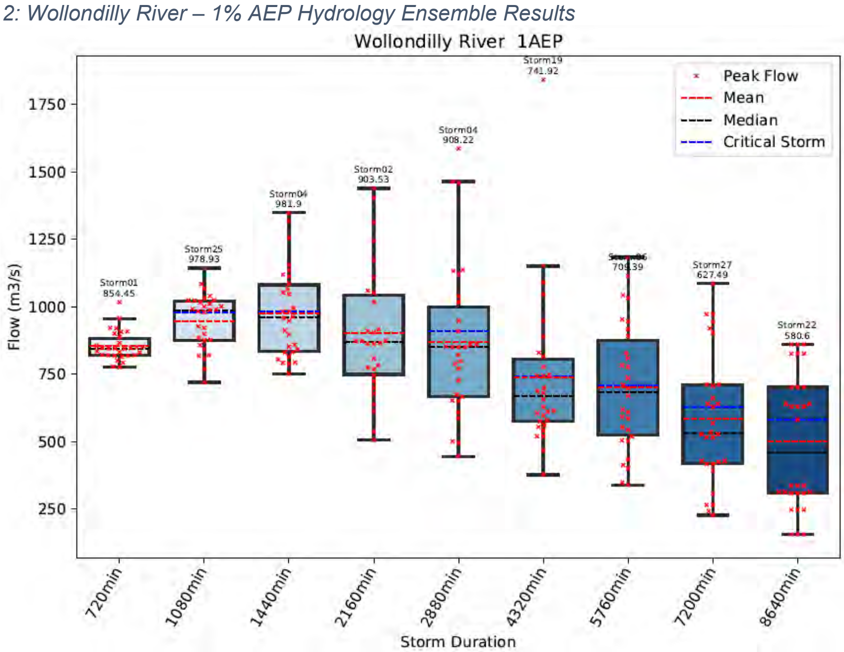
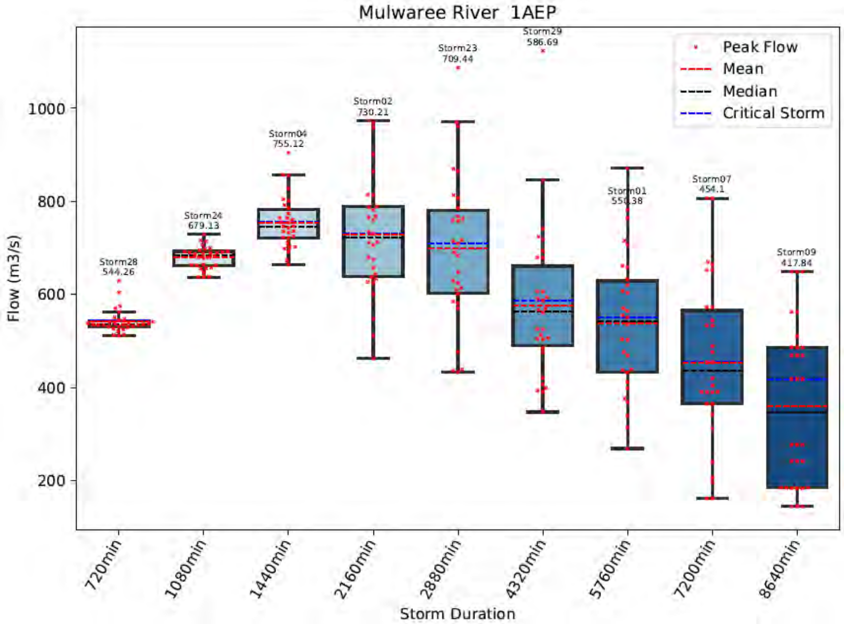


Image 3: Mulwaree River – 1% AEP Hydrology Ensemble Results



3. Derivation of Design Flow Estimates

Design flow estimates are presented in Table 1 and were derived using the methods described above.

Table 1: Hydrologic model flow estimates at Goulburn

Event (% AEP)	0.2 EY	10% AEP	5% AEP	2% AEP	1% AEP
Wollondilly	275	419	569	796	982
Mulwaree	169	278	400	588	755

4. Revision of the Flood Study FFA

The Flood Study FFA was updated with annual maximum flows for the years following the completion of the flood study (2015 to 2018). The methodology implemented in the Flood Study was maintained, with the exception of the distribution applied to the Towers annual series, which was changed from Log-Pearson III to Log-Normal to improve goodness of fit (see Chart 3). The Regional Flood Frequency Estimation (RFFE) 'prior distribution' covariants were updated based on newly extracted data from the ARR2016 RFFE website. The 'prior distribution' covariants are presented in Table 2 and Table 3 for the Towers and Murrays Flat gauges respectively.

Table 2: RFFE LPIII 'Prior Distribution' Covariants – The Towers Gauge (2122725)

Parameter	Mean	Standard Deviation	Correlation	
Mean of Log Q	5.183	0.428	1	
Standard Deviation of Log Q	0.881	0.138	-0.33	1
Skew of LogQ	0.092	0.026	0.17	-0.28

*Table 3: RFFE Log Normal 'Prior Distribution' Covariants – Murrays Flat Gauge (2122711)**

Parameter	Mean	Standard Deviation	Correlation	
Mean of Log Q	5.382	0.648	1	
Standard Deviation of Log Q	0.89	0.167	-0.33	1

*Note that the catchment area to the Murrays Flat gauge exceeds 1,000 km² and has an 'unusual shape'. RFFE Results may not be directly applicable in practice.

Revised FFA estimates are presented in Chart 1 to Chart 3 and are comparable to the Flood Study derived FFA estimates. Negligible differences are noted and expected as there were not major flood events occurring during the period 2015 to 2018. The largest event to have occurred during the period had a peak flood of 55 m³/s (~0.3EY) on the Mulwaree River and 162 m³/s (< 1EY) on the Wollondilly River.

5. Comparison of Design Flow Estimates to FFA

A comparison of WBNM hydrologic model flows using ARR2016 techniques and the revised FFA estimates is presented in Chart 1 to Chart 3. Hydrological model flows are typically a good match to the flows derived via FFA, acknowledging that there are limitations associated with the available annual series data as outlined in the Flood Study.

The analysis shows a good match between the WBNM and FFA derived flows serving as additional verification of the hydrologic model design flow estimates.

Chart 1: Marsden Weir Gauge - FFA vs WBNM design flow estimates

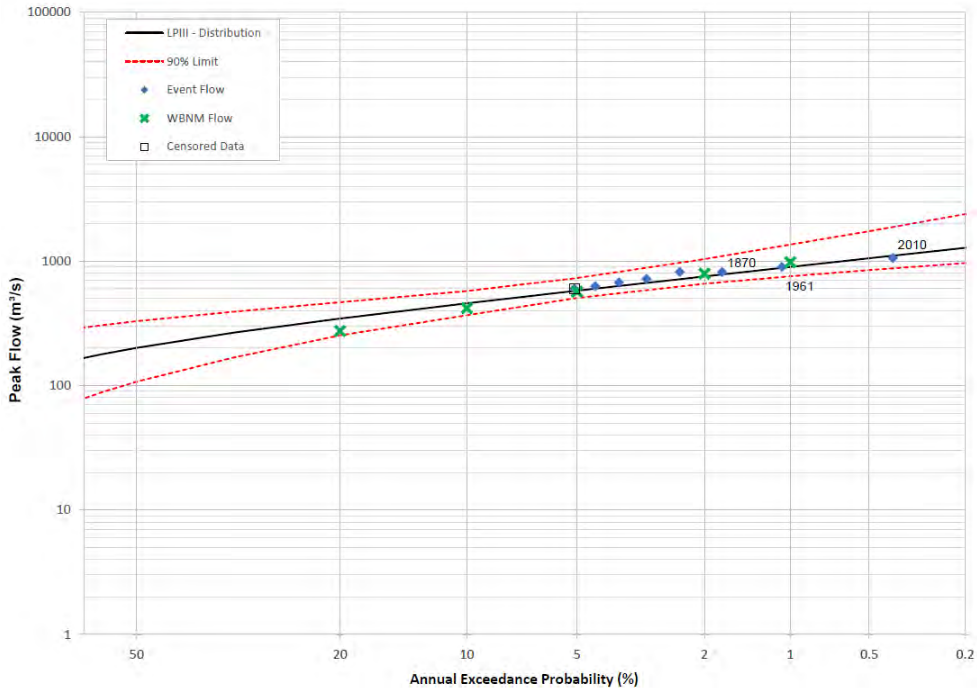


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Chart 2: Murrays Flat Gauge (2122711) - FFA vs WBNM design flow estimates

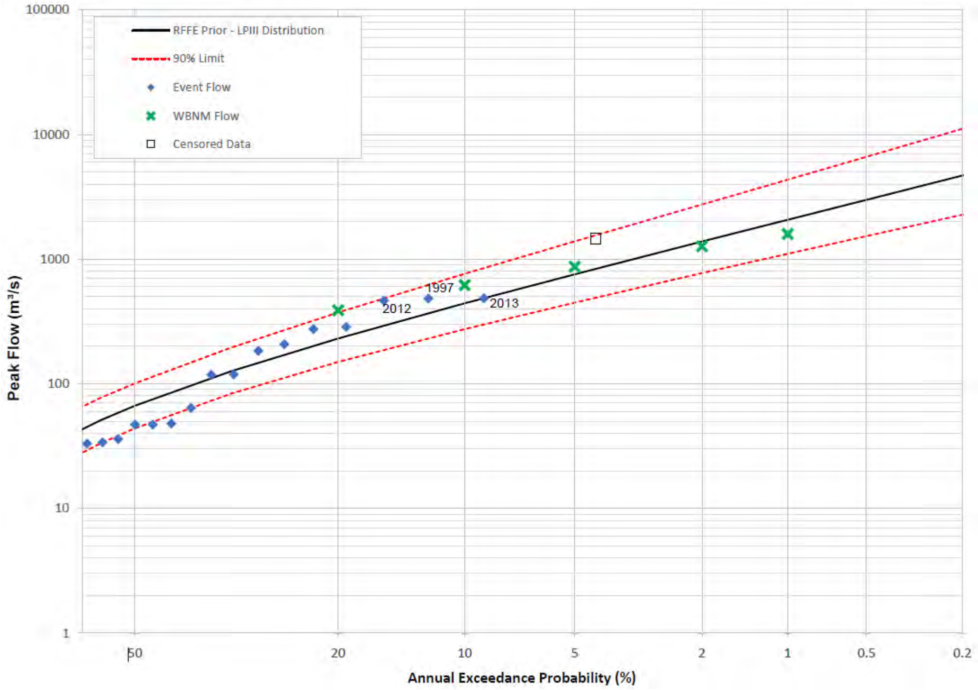
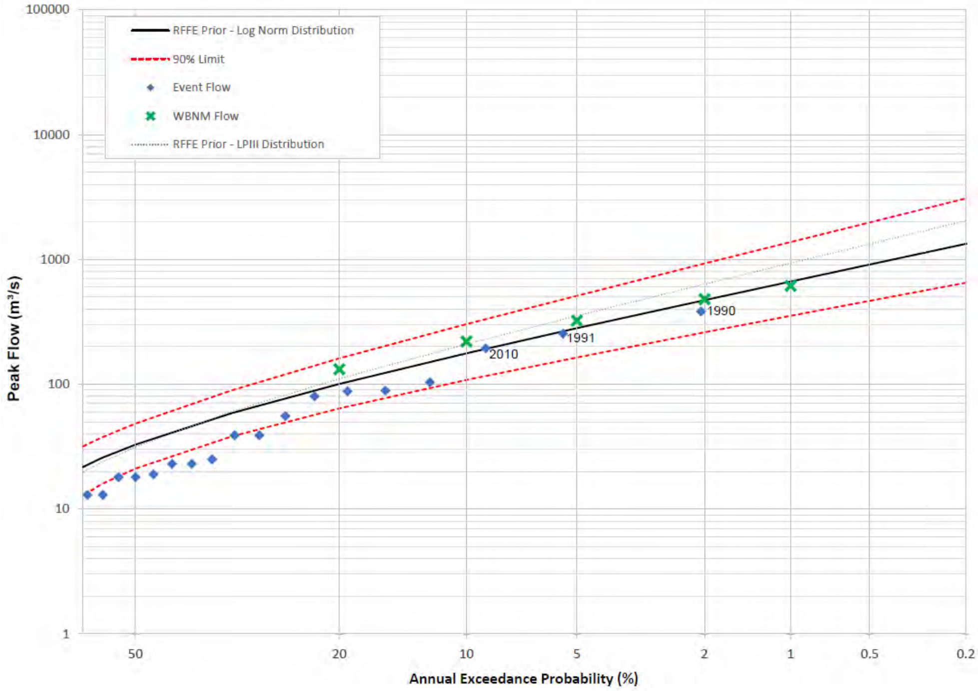


Chart 3: The Towers Gauge (2122725) - FFA vs WBNM design flow estimates



6. Comparison of Design Flow Estimates to Previous Studies

A comparison of the current study design flow estimates to previous studies is presented in Table 4. Similar to the Flood Study results, the current study flow estimates are significantly reduced relative to the 2003 Flood Study (SMEC). A discussion of the limitations of the 2003 Flood Study design flow estimates is presented in the Flood Study (Section 5.7.4.1) which notes that the more recent design estimates are preferred.

A comparison to the Flood Study (2016) results indicates the current study flow estimates are comparable. On the Wollondilly River, more frequent events are typically larger than in the 2016 study, whilst the 1% AEP estimate is reduced by approximately 12% (132 m³/s). It is important to note that the current study results provide a closer match the FFA than the Flood Study results on the Wollondilly River at Goulburn.

On the Mulwaree, a similar trend is noted, with more frequent event design flow estimates identified in the current study typically exceeding the Flood Study (2016) estimates. Mulwaree River 1% AEP flow estimates are the same with less than 1% difference between the two studies.

Table 4: Comparison of previous study design flow estimates at Goulburn

Event	Wollondilly River at Goulburn (m³/s)			Mulwaree River at Goulburn (m³/s)		
(% AEP)	2003 Study	2016 Study	Current Study	2003 Study	2016 Study	Current Study
20%	258	203	275	258	152	169
10%	428	312	419	428	232	278
5%	648	487	569	648	347	400
2%	1,026	935	796	1,026	616	588
1%	1,415	1,114	982	1,415	762	755

7. TUFLOW Hydraulic model setup

The 1% AEP design flow estimates presented in Table 1 were applied to the TUFLOW. Changes to the study area discussed with Council were not implemented in the TUFLOW model so that a comparison to the Flood Study (2016) results and historic events could be made without bias. The Gibson Street footbridge, Lansdowne Bridge and May Street Bridge will be implemented into the model for the Milestone 4 report.

8. Comparison of 1% AEP Design Flood Levels to Historic Events

Analysis of historic event flood levels has been undertaken to contextualise the 1% AEP design flood level estimates.

Table 5 provides a comparison of flood levels on the Mulwaree River at various locations in the vicinity of Goulburn. The 1% AEP estimates exceed all recorded flood events on the Mulwaree River with the exception of the 1959 event. The 1% AEP flood is noted to be smaller (0.1 m – 0.3 m lower) than the 1959 flood event upstream of the railway viaduct, downstream of which the 1% AEP becomes larger (0.1 m – 0.3 m higher) than the 1959 event due to the influence of Wollondilly River flows.

The magnitude of the 1959 event was examined in the Flood Study (2016) which indicated that the magnitude of rainfall associated with this event likely greatly exceeded 1% AEP. The Flood Study noted that 1959 storm event produced a 1% AEP flood in the neighbouring Yass River catchment and that examination of daily read rainfall data indicated that 30% more rainfall was experienced in the Mulwaree River catchment for the same event. The based on analysis undertaken as part of the Flood Study, since 1870 (148 years) only one event (1959) exceeds the current study 1% AEP estimate, and that rainfall analysis confirms that this event was likely larger than a 1% AEP event. This provides confidence in the current study Mulwaree River 1% AEP event estimate.

Table 5: Comparison of 1% AEP flood level estimates to historic events on the Mulwaree River

Location	Mulwaree River Flood Levels (mAHD)			
	2010	1974	**1% AEP**	1959
Fitzroy Bridge	629.22	630.00	**630.2**	630.08*
Upstream of Golf Course, Eleanor Street	629.32	630.32	**630.34**	630.67
Corner Hercules & Genelg Street	629.34	630.35	**630.43**	630.66
Northern end of Emma Street	629.36	630.32	**630.34**	n/a

* Noted as the maximum recorded flood level at Fitzroy Bridge on Department of Main Roads NSW design plans. The Fitzroy Bridge approaches are large and provide a significant restriction to flow. If the 1959 event had occurred post construction of the bridge it is likely that the peak flood level would be significantly higher (WMAwater, 2016).

Table 6 provides a comparison of flood levels at Marsden Weir on the Wollondilly River. The 1% AEP estimate exceeds all recorded flood events at Marsden Weir since at least 1870 with the exception of the December 2010 flood event.

Table 6: Comparison of 1% AEP flood level estimates to historic events at Marsden Weir on the Wollondilly River

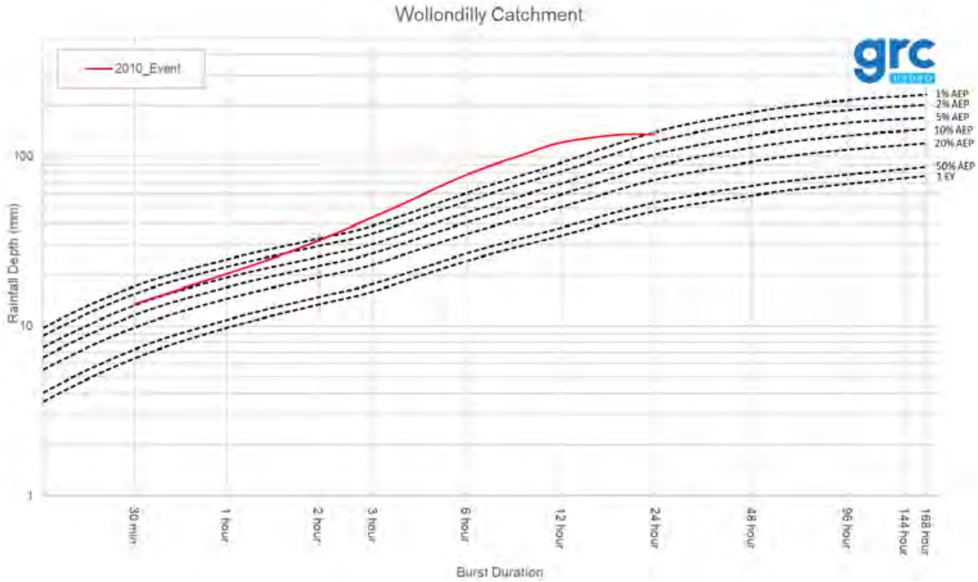
Event (% AEP)	Gauge Level (m)
1959	3.13
1961	3.24
1% AEP	3.82
2010	4.13

* Gauge Zero = 630.46 mAHD

Analysis of the rainfall from the December 2010 event indicates that the magnitude of the rainfall experienced in the Wollondilly catchment during this event far exceeded 1% AEP estimates for 3 to 12 hours duration. The catchment average rainfall for the event was determined following the methods outlined in the Flood Study, with the maximum burst intensities extracted for durations from 0.5 to 24 hours. A comparison of the event burst intensities to the average ARR2016 design rainfall depths (reduced based on the ARF for the Wollondilly River catchment to Goulburn) is presented in Image 4. The analysis indicates that the catchment average rainfall likely exceeds 0.2% AEP estimates for 6 to 12 hours duration.

Examination of the Marsden Weir FFA also indicated that the 2010 event exceeded 0.5% AEP flow estimates further confirming the magnitude of this event.

Image 4: Wollondilly River catchment – 2010 event storm burst comparison to ARR2016 IFD relationships



9. Comparison of 1% AEP Peak Flood Levels to Previous Studies

The revised 1% AEP TUFLOW model results were compared to the Flood Study results. Figure 1 presents a comparison of peak flood levels for the study area. The results indicated that 1% AEP flood levels on the Mulwaree River are typically similar to the Flood Study results as would be expected due to the similarities in flow described previously. The Wollondilly River levels are reduced relative to the Flood Study due to the decrease in flow associated with the ARR2016 hydrology revision. The decrease in flood level typically range from 0.1 to 0.4 m in the urban areas of Goulburn.

10. Conclusions and Recommendations

The calibrated/validated Flood Study WBNM model has been modified to incorporated ARR2016 methods. A 30 temporal pattern ensemble (East Coast South, Murray Basin, Southern Slopes Mainland) has been implemented to account for neighbouring temporal pattern regions. Areal Temporal Patterns have been implemented as the catchment areas of the Wollondilly and Mulwaree Rivers are greater than 75 km².

The revised design flow estimates have been compared to FFA with the analysis showing a good match between the WBNM and FFA derived flows, thus serving as verification of the design flow estimates. Comparison of the current study flows to the Flood Study indicates that there is negligible difference in 1% AEP flow estimates on the Mulwaree, however the Wollondilly 1% AEP flow has decreased. However, the current study flows were noted to have a better match to FFA than the Flood Study flows.

Design flows were applied to the Flood Study TUFLOW hydraulic model. The 1% AEP results were compared to historic event peak flood levels. Examination of the ~150 year anecdotal historic flow record at Goulburn indicates that during this period one flood (1959) on the Mulwaree River and one flood (2010) on the Wollondilly River exceeded the current study 1% AEP estimates. Additional analysis of the magnitude of the Wollondilly River 2010 event and 1959 Mulwaree River event indicated that both events were likely larger than any reasonable 1% AEP estimate. This analysis contextualises the current study 1% AEP estimates and adds further robustness to the design results.

The revised 1% AEP flood level estimates indicate that the current study results are similar to the Flood Study Mulwaree River results, however 1% AEP flood levels on the Wollondilly River have reduced by 0.1 – 0.4 m in the urban areas of Goulburn. Notwithstanding, comparison of flows to the FFA indicates that the current study results are likely an improvement (albeit non-conservative) on the Flood Study results.

It is recommended that the methods outlined in this letter are implemented and GRC Hydro move forward with completion of the Milestone 4 report using the prescribed methods.

Yours Sincerely

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Director

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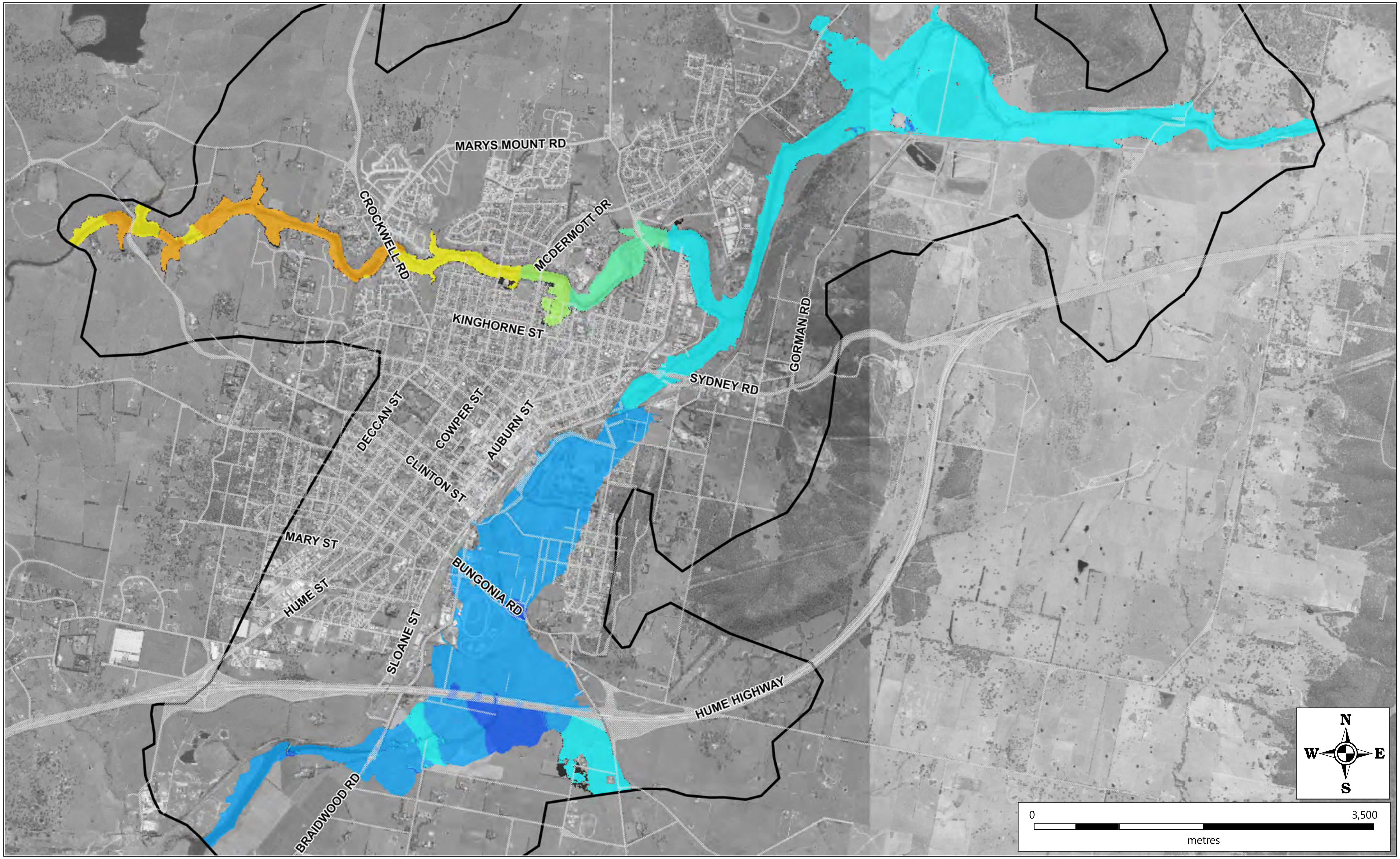
FIGURES



Flood Level Difference (m)

< -0.5	-0.3 to -0.2	-0.01 to 0.01
-0.5 to -0.4	-0.2 to -0.1	0.01 to 0.1
-0.4 to -0.3	-0.1 to -0.01	> 0.1

No Longer Flooded
Newly Flooded

Roads
Two Dimensional Model Boundary

TITLE : **ARR2016 AND ARR87 1% AEP PEAK FLOOD LEVEL COMPARISON**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: May 2019 | SCALE: 1:35,000 | FIGURE NUMBER: **01**

Job Number: *180068*
Date: *21 May 2019*

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Lucy Henze
Goulburn Mulwaree Council

Dear Lucy,

Re: Goulburn Mulwaree FRMS&P – Additional Information for ARR2016 Revision

Following the teleconference on 9 May 2019, we are providing additional requested information to assist in better understanding of the applied modelling approach outlined in the *'Re: Goulburn Mulwaree FRMS&P – Summary of Revised Flow Estimates based on ARR2016'* (GRC Hydro, 7 May 2019) letter. The information presented in this letter and the 7 May 2019 letter will be incorporated into the Milestone 4 report.

GRC Hydro request Council approval to proceed with completion of the Milestone 4 report following the methodology outlined in the 7 May 2019 letter, with consideration of the information presented in the current document.

A summary of the requested additional information/analysis is presented below:

1. Results for application of the preferred OEH loss model;
2. Comparison of proximate temporal region patterns;
3. Comparison of ARR87, ARR2016 and historic event temporal patterns;
4. Comparison of ARR87 and ARR2016 design rainfall depths;
5. Design flow estimates for the 0.5% and 0.2% AEP events;
6. Conclusions and recommendations.

Details of this analysis is discussed in the ensuing sections numbered according to the above list.

1. Application of the preferred OEH loss method

The Floodplain Risk Management Guide (OEH, 2019) outlines a hierarchy of approaches for determining appropriate loss coefficients for implementation in design flood estimation. The hierarchy is presented in Image 1.

As per Approach #1, the Flood Study 'Average Calibration' continuing Loss of 1.95 mm/hr has been applied. However, for the Initial Loss (IL) burst, a deviation from the methods outlined in the OEH 2019 document is proposed in the 7 May 2019 letter. The proposed approach follows the methodology outlined in ARR2016 which adjusts storm initial losses by considering median pre-burst depths.

Application of the OEH (2019) Approach #1 results in underestimated design flow estimates when compared to FFA. By comparison, application of the ARR2016 methodology leads to an improved match to FFA, albeit with slightly conservative results for more frequent events.

Image 1: Hierarch of approaches for loss implementation (OEH, 2019)

Equation 1

$$IL_{burst\ for\ design} = IL_{storm\ calibrated\ or\ transformed} \times \left(\frac{IL_{burst\ from\ ARR\ datahub}}{IL_{storm\ from\ ARR\ datahub}}\right)$$

Table 10 Hierarchy of approaches from most (1) to least (5) preferred

Approach	Storm initial loss	Pre-burst (transformational)	IL burst	Continuing loss
1	Average Calibration	Not required or back calculated using IL_{storm} - IL_{burst}	Calculated from Equation 1 above	Average Calibration
2	Average Calibration	Not required or back calculated using IL_{storm} - IL_{burst}	Calculated from Equation 1 above	Average Calibration
3	Average Calibration	Not required or back calculated using IL_{storm} - IL_{burst}	Calculated from Equation 1 above	Average Calibration
4	NSW FFA reconciled initial loss (see ARR Data Hub)	Not required or back calculated using IL_{storm} - IL_{burst}	Probability Neutral Burst Loss available through ARR Data Hub	NSW FFA reconciled continuing losses where available (see ARR Data Hub)
5	ARR Data Hub initial loss	Not required or back calculated using IL_{storm} - IL_{burst}	Probability Neutral Burst Loss available through ARR Data Hub	ARR Data Hub continuing losses multiplied x 0.4

Image 2 presents a comparison of the burst initial losses determined via both methods. OEH (2019) methodology results in significantly higher losses for the more frequent events and longer durations.

Image 2: Comparison of burst initial losses - OEH, 2019 approach #1 vs ARR2019 recommended

As per equation						
min (h)\A	50	20	10	5	2	1
60 (1.0)	43.3	28.1	27.2	28.5	25.6	19.8
90 (1.5)	43.3	29.7	28.1	29.7	26.4	18.2
120 (2.0)	41.3	29.7	28.9	33.0	28.9	18.6
180 (3.0)	49.1	34.2	31.4	31.8	29.3	21.5
360 (6.0)	42.9	32.6	34.7	34.2	29.3	16.1
720 (12.0)	48.3	35.1	35.1	32.2	27.6	7.4
1080 (18.0	58.2	41.3	39.2	34.2	31.4	8.3
1440 (24.0	64.4	52.0	51.6	51.6	36.3	15.3
2160 (36.0	63.9	54.9	56.1	61.9	43.7	29.7
2880 (48.0	63.1	55.7	54.9	62.7	46.6	37.5
4320 (72.0	73.4	65.6	66.8	74.7	68.9	53.6

As per ILs - median preburst						
min (h)\A	50	20	10	5	2	1
60 (1.0)	14.6	15.2	15.6	16	16	16
90 (1.5)	15.6	15.8	15.9	16	15.9	15.8
120 (2.0)	13.2	14.4	15.2	16	15.7	15.5
180 (3.0)	15.9	15.5	15.2	15	15.4	15.8
360 (6.0)	14	14.8	15.4	16	15.2	14.6
720 (12.0)	16	14.7	13.8	13	8.1	4.3
1080 (18.0	16	13.3	11.6	9.9	7	4.8
1440 (24.0	16	16	16	16	12	9
2160 (36.0	16	16	16	16	15.7	15.5
2880 (48.0	16	16	16	16	16	16
4320 (72.0	16	16	16	16	16	16

Results from the two methods are compared to FFA in Image 3 to Image 5 for the Marsden Weir, Murrays Flat and Towers Gauges respectively. The OEH (2019) methodology significant underestimates flows for the more frequent events, with flow estimates below the 90% CI noted. The ARR2016 methodology applied by GRC Hydro is preferred for the current study.

Image 3: Marsden Weir Gauge - FFA vs WBNM design flow estimates

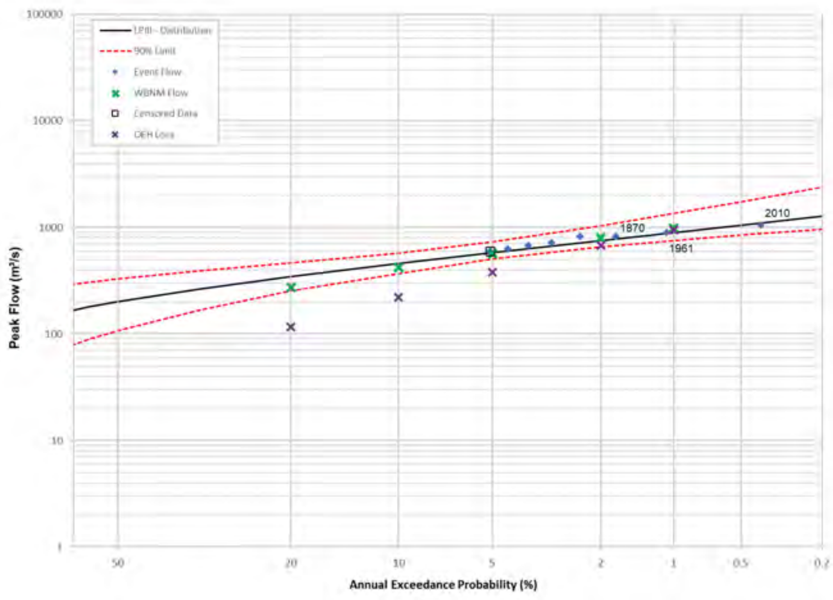


Image 4: Murrays Flat Gauge (2122711) - FFA vs WBNM design flow estimates

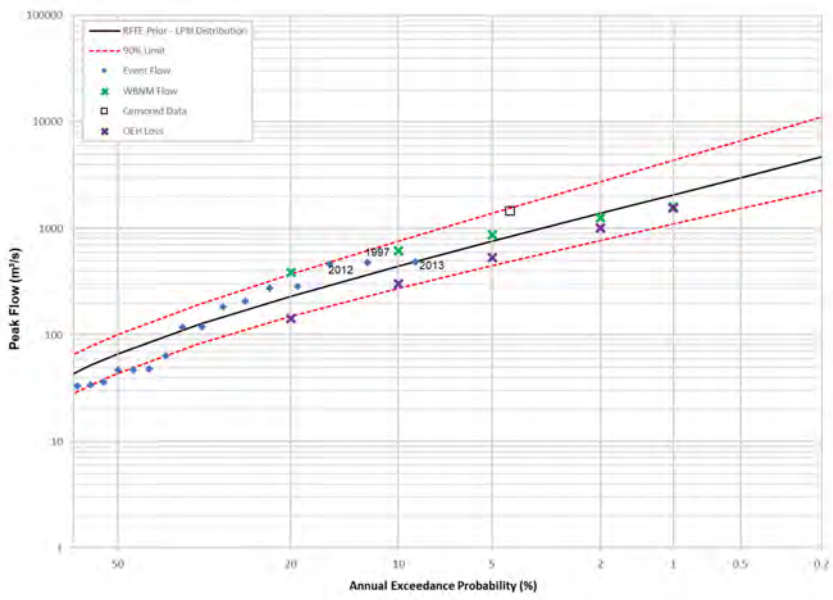
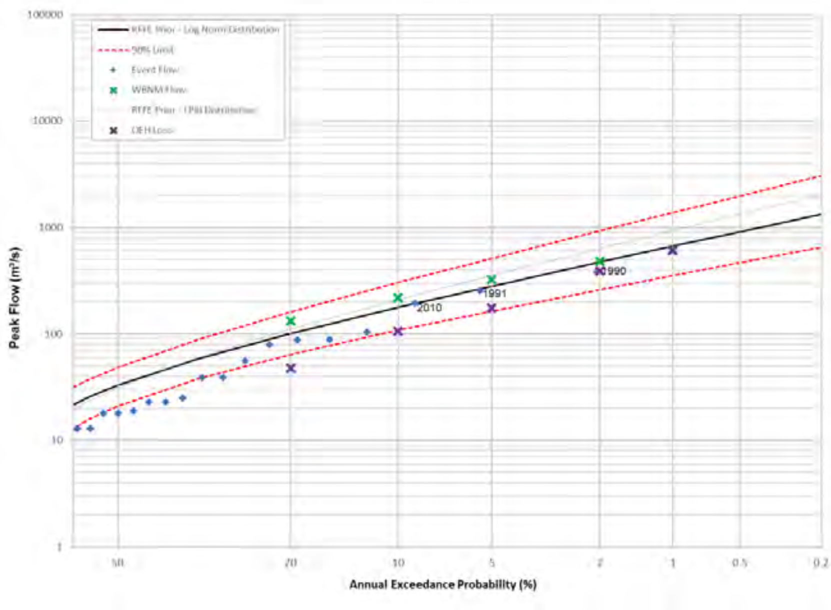


Image 5: The Towers Gauge (2122725) - FFA vs WBNM design flow estimates



2. **Comparison of Proximate Temporal Regions**

The application of 'East Coast South', 'Murray Basin' and 'Southern Slopes Mainland' temporal patterns has been examined. Image 6 and Image 7 present the full ensemble results colour coded to indicate which temporal region is responsible for each peak flow.

Image 6: Wollondilly River 1% AEP Ensemble Results

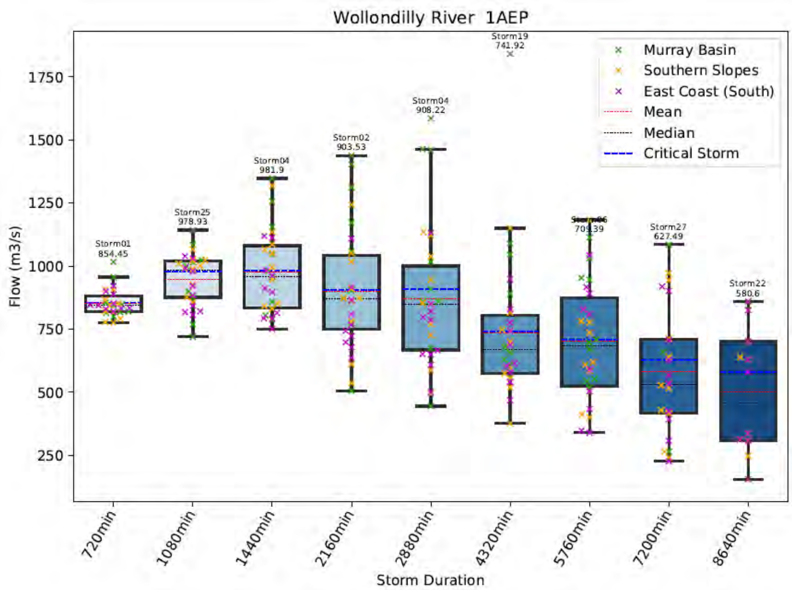
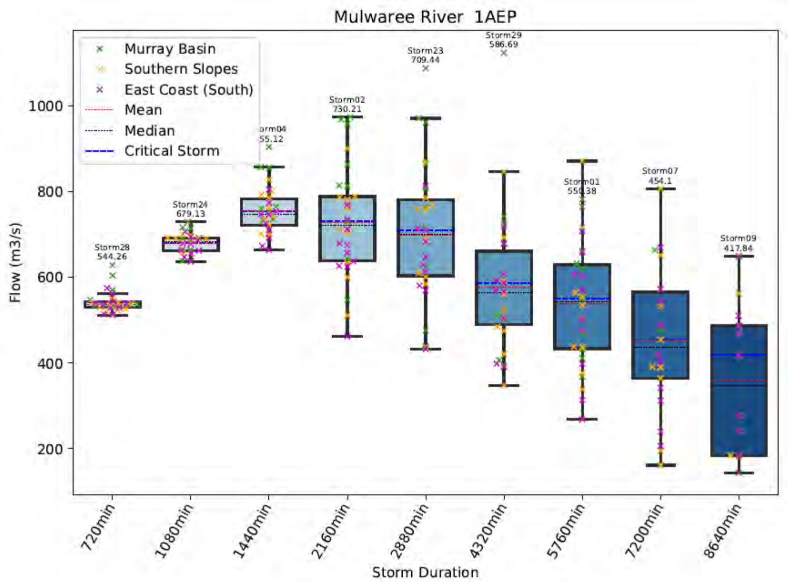


Image 7: Mulwaree River 1% AEP Ensemble Results



The results indicate that the Murray Basin temporal patterns are on average responsible for the highest peak flows for durations similar (18 to 48 hours) to the catchments critical duration of 24 hours. The southern slopes temporal patterns then typically produce the next highest flows followed by the East Coast (South) patterns. Both the Wollondilly and Mulwaree catchments are situated in the East Coast (South) region, which lead to low flows when only applying the 10 temporal pattern ensemble.

The 30 temporal pattern ensemble for the critical 24 hours duration is presented Image 8, with the timestep increased to 2 hours for ease of comparison to ARR87 and historic event temporal patterns in the following section. As expected, the Murray Basin temporal patterns have on average peak higher intensities than the temporal patters from the other regions. Rainfall intensities approaching 15mm/hr (30 mm over the two-hour timestep presented) are experienced for 7 of the 10 temporal patterns from this area. By comparison the East Coast (South) temporal patters are more uniform with rainfall intensities rarely exceeding 10 mm/hr (20 mm over the two-hour timestep presented).

Image 8: Comparison of Aerial Temporal Patterns for proximate temporal regions

GRC Hydro 6

3. Historic Event temporal patterns

For comparative purposes, historic event temporal patters for the 2010, 2012 and 2013 events, and ARR87 temporal patters are presented in images below. All three historic events are noted to have focused burst and are relatively non-uniform throughout their duration, showing similarities with the Murray Basin temporal patterns. This indicates that application of the 30 temporal pattern ensemble is appropriate for the region.

Image 9: 2010 Event Storm

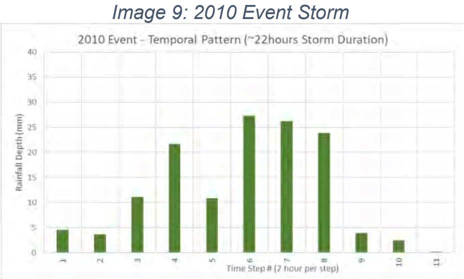


Image 10: ARR87 – 1% AEP, 48 hour duration

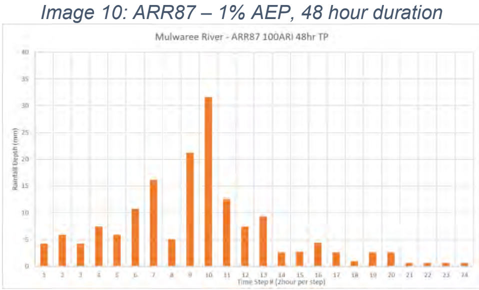


Image 11: 2012 Event Storm

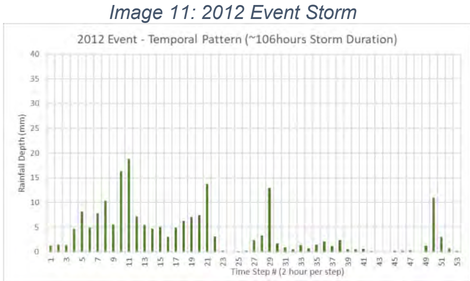


Image 12: ARR87 – 1% AEP, 36 hour duration

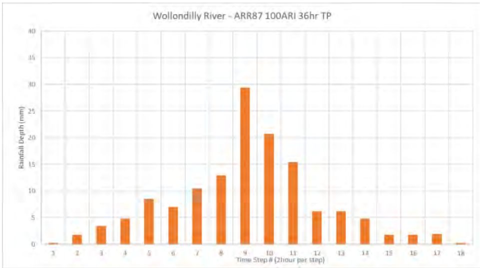
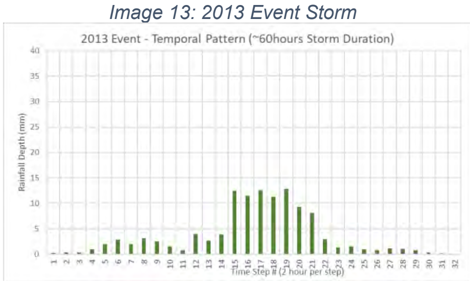


Image 13: 2013 Event Storm



The ARR87 temporal patterns have large embedded bursts which are likely responsible for the higher 1% AEP flows when comparing ARR87 and ARR2016 results.

4. Comparison of ARR87 and ARR2016 Design Rainfalls

A comparison of ARR87 and ARR2016 1% AEP design rainfall depths is presented in Table 1. The analysis shows that design rainfall depths have decreased for durations shorter than 24 hours, whilst longer duration rainfall depths have increased with implementation of ARR2016. The Wollondilly catchment has experienced a greater increase in design rainfall depth due to ARR2016 for longer durations, however the Mulwaree River experiences greater rainfall depths than the Wollondilly.

Table 1: Comparison of ARR87 and ARR2016 Design Rainfall Depths

Catchment	Wollondilly			Mulwaree		
Duration	ARR2016 (mm)	ARR87 (mm)	Difference (mm / %)	ARR2016 (mm)	ARR87 (mm)	Difference (mm / %)
6 hour	73	88.8	-15.8 / -17.8%	83.6	89.4	-5.8 / -6.5%
12 hour	104	110.2	-6.16 / -5.6%	114	110.9	3.1 / 2.8%
24 hour	146	137.3	8.72 / 6.4%	154	143.0	11 / 7.7%
48 hour	188	167.5	20.48 / 12.2%	195	186.2	8.8 / 4.7%

5. Design flow estimates for the 0.5% and 0.2% AEP events

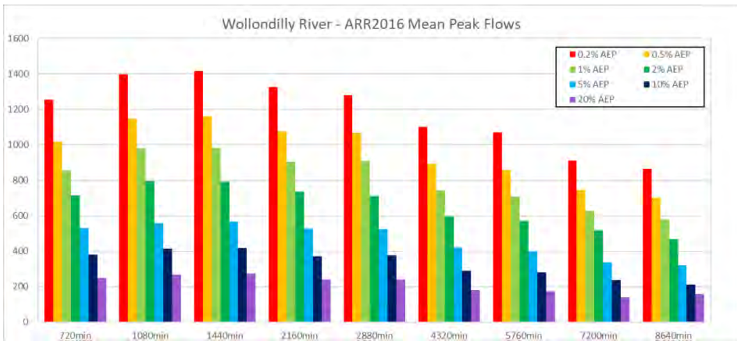
A comparison of the current study design flow estimates to previous studies is presented in Table 2, with design flow estimates for events rarer than the 1% AEP event presented as requested.

Table 2: Comparison of previous study design flow estimates at Goulburn

Event	Wollondilly River at Goulburn (m^3/s)			Mulwaree River at Goulburn (m^3/s)		
(% AEP)	2003 Study	2016 Study	Current Study	2003 Study	2016 Study	Current Study
20%	258	203	275	258	152	169
10%	428	312	419	428	232	278
5%	648	487	569	648	347	400
2%	1,026	935	796	1,026	616	588
1%	1,415	1,114	982	1,415	762	755
0.5%	1,868	1,298	1,162	1,868	912	932
0.2%			1,417			1,189

The 7 May 2019 letter presented the burst intensities for the 2010 event catchment average rainfall. The peak burst for the event was noted to exceed the 0.2% AEP estimate for the 12 hour duration. Examination of design event flows for various duration and AEP (see Image 14) indicates that a 0.2% AEP rainfall burst for 12 hours duration will result in a larger flood event than the 1% AEP event for the catchments critical duration of 24 hours. This provides further confidence in the magnitude of the 2010 flood on the Wollondilly, and hence the design flood estimates.

Image 14: Wollondilly River – Mean Ensemble Flow for Varying Duration and AEP



6. Conclusions and Recommendations

The addition information requested by Council/OEH during the teleconference on the 9 May 2019 is provided herein. The analysis shows that the proposed rainfall loss methodology presented in the 7

May 2019 letter provides a better match to FFA than the methodology outlined in the OEH (2019) document.

Examination of applied temporal patterns indicates the use of a 30 TP ensemble is appropriate for the study area. It was noted that historic event storms temporal distribution resemble Murray Basin temporal patterns providing further confidence in the applied methodology.

GRC Hydro request Council approval to proceed with completion of the Milestone 4 report following the methodology outlined in the 7 May 2019 letter, with consideration of the information presented in the current document.

Yours Sincerely

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Director

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Appendix C – Design Flood Results

The following tables present results of the Design Flood Modelling (see Appendix A, Section A3.3) with the Reporting Locations shown in Figure 1 of the main body of the report. These results present the design flood depths, levels, velocities and flows at various locations in the study area.

Design Flood Level Results

Table C 1: Wollondilly River – Design Flood Levels

ID	Location	Flood Level (mAHD)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
W01	Rossi Bridge Upstream	636.9	637.4	637.9	638.5	639.0	639.6	640.4	650.8
W02	Rossi Bridge Downstream	636.9	637.3	637.8	638.4	638.9	639.5	640.2	650.6
W03	Rossi Gauge	636.8	637.3	637.7	638.2	638.7	639.3	640.0	650.6
W04	Rossi Weir Upstream	636.8	637.3	637.7	638.2	638.7	639.2	639.9	650.5
W05	Rossi Weir Downstream	635.2	636.1	636.7	637.6	638.2	638.8	639.6	650.3
W06	Marsden Weir Upstream	632.2	632.5	633.0	633.9	634.7	635.3	636.1	646.0
W07	Marsden Weir Downstream	631.0	632.0	633.0	633.9	634.7	635.3	636.1	646.0
W08	Marsden Bridge Upstream	630.9	631.9	632.8	633.8	634.5	635.1	635.9	645.9
W09	Marsden Bridge Downstream	630.8	631.8	632.7	633.7	634.3	635.0	635.8	645.9
W10	Behind Properties on Fitzroy Street	-	-	632.4	633.3	633.9	634.5	635.3	643.7
W11	Victoria Bridge Upstream	628.6	629.5	630.3	631.2	631.8	632.5	633.4	640.9
W12	Victoria Bridge Downstream	628.5	629.4	630.2	631.0	631.7	632.3	633.1	640.6
W13	Avoca St Mid	-	-	-	630.6	631.3	632.0	632.8	640.3
W14	Kenmore Bridge Upstream	627.2	628.0	628.8	629.7	630.4	631.3	632.2	640.0
W15	Kenmore Bridge Downstream	627.1	627.9	628.7	629.7	630.4	631.2	632.1	639.9
W16	Crookwell Rail Bridge Upstream	627.0	627.8	628.6	629.6	630.3	631.1	631.9	639.9
W17	Crookwell Rail Bridge Downstream	626.9	627.7	628.5	629.5	630.2	631.0	631.9	639.9
W18	Sewer Aqueduct Upstream	625.9	627.0	628.1	629.2	629.9	630.6	631.6	639.8
W19	Sewer Aqueduct Downstream	625.8	627.0	628.0	629.1	629.9	630.6	631.5	639.8
W20	Wollondilly/Mulwaree Confluence	625.7	626.9	628.0	629.1	629.9	630.6	631.5	639.8
W21	Murrays Flat Gauge	620.7	622.0	623.3	624.7	625.7	626.6	627.8	637.5

Table C 2: Mulwaree River – Design Flood Levels

ID	Location	Level (mAHD)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
M01	The Towers Gauge	634.0	634.3	634.7	635.1	635.4	635.7	636.1	641.6
M02	The Towers Weir Upstream	633.9	634.2	634.5	634.8	635.0	635.2	635.6	641.0
M03	The Towers Weir Downstream	631.8	632.2	632.6	633.0	633.3	633.6	634.1	640.9
M04	Thornes Bridge Upstream	631.7	632.1	632.3	632.7	632.9	633.1	633.4	640.4
M05	Thornes Bridge Downstream	631.7	632.0	632.3	632.6	632.8	632.9	633.2	640.3
M06	Hume Highway Bridge 2 Upstream	630.0	630.2	630.4	630.7	631.1	631.5	632.4	640.3
M07	Hume Highway Bridge 2 Downstream	629.8	630.0	630.2	630.5	631.0	631.4	632.3	640.3
M08	Hume Highway Bridge 3 Upstream	629.5	629.8	630.1	630.6	631.0	631.5	632.3	640.3
M09	Hume Highway Bridge 3 Downstream	629.5	629.8	630.0	630.4	630.9	631.4	632.3	640.3
M10	Hume Highway Bridge 4 Upstream	630.0	630.2	630.4	630.8	631.2	631.6	632.4	640.3
M11	Hume Highway Bridge 4 Downstream	629.6	629.8	630.1	630.4	630.9	631.4	632.3	640.3
M12	Lansdowne Bridge Upstream	629.1	629.4	629.7	630.2	630.8	631.3	632.2	640.3
M13	Lansdowne Bridge Downstream	629.1	629.4	629.6	630.2	630.7	631.3	632.2	640.3
M14	Goulburn Brewery	-	-	-	630.0	630.7	631.2	632.2	640.3
M15	Park Road Roundabout	628.0	628.2	628.8	629.8	630.5	631.1	632.1	640.3
M16	Park Road Upstream	627.8	628.1	628.8	629.8	630.5	631.1	632.1	640.3
M17	Park Road Downstream	627.6	628.1	628.8	629.8	630.5	631.1	632.1	640.3
M18	Goulburn Golf Club Upstream	627.1	627.8	628.7	629.8	630.5	631.1	632.1	640.3
M19	Goulburn Golf Club Downstream	627.1	627.8	628.7	629.8	630.5	631.1	632.1	640.3
M20	May Street Bridge Upstream	626.7	627.7	628.6	629.7	630.5	631.1	632.1	640.2
M21	May Street Bridge Downstream	626.7	627.7	628.6	629.7	630.5	631.1	632.1	640.2
M22	Railway Viaduct Upstream	626.5	627.6	628.5	629.6	630.4	631.0	632.0	640.2
M23	Railway Viaduct Downstream	626.4	627.5	628.5	629.6	630.4	631.0	632.0	640.2
M24	Sydney Road Bridge Upstream	626.2	627.3	628.3	629.4	630.2	630.8	631.8	640.0
M25	Sydney Road Bridge Downstream	626.1	627.2	628.2	629.3	630.1	630.7	631.6	640.0

Design Flood Velocity Results

Table C 3: Wollondilly River – Design Flood Velocities

ID	Location	Flood Velocity (m/s)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
W01	Rossi Bridge Upstream	0.9	1.2	1.4	1.7	1.8	1.9	2.0	3.2
W02	Rossi Bridge Downstream	0.9	1.2	1.5	1.7	1.9	2.1	2.5	3.1
W03	Rossi Gauge	0.9	1.3	1.5	1.9	2.1	2.3	2.5	3.5
W04	Rossi Weir Upstream	0.7	1.1	1.4	1.7	2.0	2.1	2.4	3.8
W05	Rossi Weir Downstream	1.5	1.9	1.9	2.3	2.4	2.5	2.7	4.1
W06	Marsden Weir Upstream	1.3	1.7	2.2	2.2	2.3	2.4	2.5	4.6
W07	Marsden Weir Downstream	2.8	2.8	2.8	2.8	2.8	2.8	2.8	3.0
W08	Marsden Bridge Upstream	1.1	1.3	1.5	1.7	1.8	2.0	2.1	2.3
W09	Marsden Bridge Downstream	1.2	1.4	1.6	1.7	2.0	2.0	2.2	2.4
W10	Behind Properties on Fitzroy Street	-	-	0.7	0.7	0.8	0.8	0.8	2.3
W11	Victoria Bridge Upstream	1.4	1.7	1.9	2.1	2.2	2.4	2.5	3.2
W12	Victoria Bridge Downstream	1.3	1.5	1.7	1.9	2.1	2.3	2.5	3.4
W13	Avoca St Mid	-	-	-	0.0	0.0	0.1	0.1	0.3
W14	Kenmore Bridge Upstream	1.5	1.6	1.7	1.8	1.8	2.0	2.1	2.6
W15	Kenmore Bridge Downstream	1.2	1.3	1.4	1.6	1.7	1.9	2.0	3.1
W16	Crookwell Rail Bridge Upstream	1.3	1.5	1.7	1.8	1.8	2.1	2.2	3.3
W17	Crookwell Rail Bridge Downstream	1.5	1.7	1.9	2.2	2.1	2.4	2.5	4.0
W18	Sewer Aqueduct Upstream	1.6	1.7	1.7	1.8	1.7	1.8	1.8	3.2
W19	Sewer Aqueduct Downstream	1.8	1.9	2.0	2.1	2.0	2.2	2.3	3.8
W20	Wollondilly/Mulwaree Confluence	1.0	1.1	1.1	1.1	1.1	1.2	1.2	2.6
W21	Murrays Flat Gauge	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.1

Table C 4: Mulwaree River – Design Flood Velocities

ID	Location	Flood Velocity (m/s)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
M01	The Towers Gauge	0.6	0.8	1.0	1.3	1.6	1.8	2.0	4.1
M02	The Towers Weir Upstream	0.5	0.7	0.8	1.0	1.2	1.3	1.5	3.1
M03	The Towers Weir Downstream	0.8	0.8	0.8	0.8	0.8	0.8	0.8	3.9
M04	Thornes Bridge Upstream	0.7	1.0	1.3	1.5	1.7	1.9	2.1	3.0
M05	Thornes Bridge Downstream	1.3	1.3	1.4	1.7	1.9	2.1	2.3	3.0
M06	Hume Highway Bridge 2 Upstream	1.2	1.3	1.4	1.5	1.5	1.5	1.6	2.4
M07	Hume Highway Bridge 2 Downstream	1.4	1.6	1.7	1.8	1.8	1.8	1.9	2.7
M08	Hume Highway Bridge 3 Upstream	1.2	1.2	1.2	1.3	1.4	1.6	1.8	2.7
M09	Hume Highway Bridge 3 Downstream	0.7	0.9	1.1	1.3	1.4	1.6	1.7	2.5
M10	Hume Highway Bridge 4 Upstream	0.9	0.9	1.0	1.1	1.1	1.2	1.4	1.8
M11	Hume Highway Bridge 4 Downstream	0.5	0.6	0.6	0.7	0.8	0.9	1.0	2.1
M12	Lansdowne Bridge Upstream	0.7	0.7	0.8	0.8	0.8	0.8	0.8	1.0
M13	Lansdowne Bridge Downstream	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9
M14	Goulburn Brewery	-	-	-	0.1	0.2	0.3	0.4	0.9
M15	Park Road Roundabout	0.1	0.5	1.2	1.3	1.2	1.3	1.4	1.8
M16	Park Road Upstream	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
M17	Park Road Downstream	1.3	1.3	1.2	1.2	1.3	1.3	1.3	1.3
M18	Goulburn Golf Club Upstream	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9
M19	Goulburn Golf Club Downstream	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.9
M20	May Street Bridge Upstream	0.7	0.7	0.7	0.7	0.7	0.7	0.7	1.1
M21	May Street Bridge Downstream	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.2
M22	Railway Viaduct Upstream	0.8	0.8	0.8	0.8	0.8	0.9	1.0	1.9
M23	Railway Viaduct Downstream	0.7	0.8	0.8	0.8	0.7	0.9	0.9	1.7
M24	Sydney Road Bridge Upstream	1.2	1.3	1.4	1.6	1.4	1.7	1.8	3.2
M25	Sydney Road Bridge Downstream	1.3	1.5	1.7	1.9	1.7	2.2	2.4	4.2

Design Flow Results

ID	Location	Flow (m^3/s)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
W01	Rossi Bridge Upstream	280	440	610	840	1,040	1,240	1,520	10,540
W02	Rossi Bridge Downstream	280	440	610	840	1,040	1,240	1,520	10,510
W03	Rossi Gauge	280	440	610	840	1,040	1,240	1,520	10,510
W04	Rossi Weir Upstream	280	440	610	840	1,040	1,240	1,520	10,510
W05	Rossi Weir Downstream	290	470	620	840	1,040	1,240	1,520	10,510
W06	Marsden Weir Upstream	280	440	610	850	1,040	1,250	1,530	10,470
W07	Marsden Weir Downstream	280	440	610	850	1,040	1,250	1,530	10,470
W08	Marsden Bridge Upstream	280	440	610	850	1,040	1,250	1,530	10,470
W09	Marsden Bridge Downstream	280	440	610	850	1,040	1,250	1,530	10,470
W10	Behind Properties on Fitzroy Street	280	440	610	850	1,040	1,250	1,530	10,460
W11	Victoria Bridge Upstream	280	440	610	850	1,040	1,250	1,530	10,450
W12	Victoria Bridge Downstream	280	440	610	850	1,040	1,250	1,530	10,450
W13	Avoca St Mid	280	440	610	850	1,040	1,250	1,530	10,450
W14	Kenmore Bridge Upstream	280	440	610	850	1,040	1,250	1,530	9,430
W15	Kenmore Bridge Downstream	280	440	610	850	1,040	1,250	1,530	9,430
W16	Crookwell Rail Bridge Upstream	280	440	610	850	1,040	1,250	1,530	9,430
W17	Crookwell Rail Bridge Downstream	280	440	610	850	1,040	1,250	1,530	9,430
W18	Sewer Aqueduct Upstream	280	440	610	850	1,040	1,250	1,530	8,790
W19	Sewer Aqueduct Downstream	280	440	610	850	1,040	1,250	1,530	8,790
W20	Wollondilly/Mulwaree Confluence	440	670	920	1,280	1,560	1,850	2,260	9,090
W21	Murrays Flat Gauge	440	680	920	1,280	1,550	1,800	2,180	8,870

Table C 5: Wollondilly River – Design Flows

Table C 6: Mulwaree River – Design Flows

ID	Location	Flows (m^3/s)							
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
M01	The Towers Gauge	160	250	360	500	640	780	990	5,210
M02	The Towers Weir Upstream	160	250	360	520	640	780	1,000	5,210
M03	The Towers Weir Downstream	160	250	360	520	640	780	1,000	5,210
M04	Thornes Bridge Upstream	160	250	360	520	640	780	1,000	5,210
M05	Thornes Bridge Downstream	160	250	360	520	640	780	1,000	5,210
M06	Hume Highway Bridge 2 Upstream	80	110	130	160	180	210	240	6,050
M07	Hume Highway Bridge 2 Downstream	80	110	130	160	180	210	240	6,050
M08	Hume Highway Bridge 3 Upstream	50	90	130	190	240	300	350	6,050
M09	Hume Highway Bridge 3 Downstream	50	90	130	190	240	300	350	6,050
M10	Hume Highway Bridge 4 Upstream	20	30	50	70	100	130	160	6,050
M11	Hume Highway Bridge 4 Downstream	20	30	50	70	100	130	160	6,050
M12	Lansdowne Bridge Upstream	210	330	460	650	820	1,000	1,240	5,940
M13	Lansdowne Bridge Downstream	210	330	460	650	820	1,000	1,240	5,940
M14	Goulburn Brewery	210	330	460	650	820	1,000	1,240	5,940
M15	Park Road Roundabout	210	330	460	650	820	1,000	1,240	5,840
M16	Park Road Upstream	210	330	460	650	820	1,000	1,240	5,840
M17	Park Road Downstream	210	330	460	650	820	1,000	1,240	5,840
M18	Goulburn Golf Club Upstream	210	330	460	650	820	1,000	1,240	5,800
M19	Goulburn Golf Club Downstream	210	330	460	650	820	1,000	1,240	5,800
M20	May Street Bridge Upstream	210	330	460	650	820	1,000	1,240	5,800
M21	May Street Bridge Downstream	210	330	460	650	820	1,000	1,240	5,800
M22	Railway Viaduct Upstream	210	330	460	650	820	1,000	1,250	5,800
M23	Railway Viaduct Downstream	210	330	460	650	820	1,000	1,250	5,800
M24	Sydney Road Bridge Upstream	210	330	470	660	830	1,000	1,250	5,750
M25	Sydney Road Bridge Downstream	210	330	470	660	830	1,000	1,250	5,750

Appendix D – Sensitivity Analysis Results

The following Tables present results of the Sensitivity Analysis (see Appendix A, Section A5) with the Reporting Locations shown in Figure 1 of the main body of the report. These results are the change in flood level relative to the associated design flood event.

20% AEP Event Sensitivity Results

Table D 1: 20% AEP Sensitivity Results – Wollondilly River

ID	Description	Rainfall Losses		Hydrologic Lag Parameter		Hydraulic Roughness		Structure Blockage		Temporal Pattern		Areal Reduction Factor	
		-20%	+20%	-20%	+20%	-20%	+20%	-20%	+20%	Min	Max	-20%	+20%
W01	Rossi Bridge Upstream	+0.29	-0.22	-0.11	+0.24	-0.07	+0.12	+0.02	+0.01	-0.70	+0.68	-0.43	+0.49
W02	Rossi Bridge Downstream	+0.28	-0.21	-0.10	+0.23	-0.06	+0.11	+0.02	-0.01	-0.68	+0.66	-0.41	+0.48
W03	Rossi Gauge	+0.27	-0.18	-0.09	+0.22	-0.04	+0.11	+0.02	0.00	-0.63	+0.62	-0.38	+0.45
W04	Rossi Weir Upstream	+0.26	-0.18	-0.09	+0.22	-0.03	+0.10	+0.02	+0.00	-0.64	+0.62	-0.38	+0.45
W05	Rossi Weir Downstream	+0.54	-0.49	-0.14	+0.49	-0.11	+0.32	+0.00	+0.00	-1.69	+1.10	-0.99	+0.90
W06	Marsden Weir Upstream	+0.19	-0.19	-0.10	+0.17	-0.02	+0.01	0.00	0.00	-0.57	+0.49	-0.35	+0.35
W07	Marsden Weir Downstream	+0.56	-0.64	-0.34	+0.48	-0.37	+0.31	-0.01	+0.04	-2.09	+1.31	-1.24	+1.01
W08	Marsden Bridge Upstream	+0.57	-0.65	-0.34	+0.49	-0.36	+0.31	-0.01	+0.04	-2.11	+1.30	-1.25	+1.03
W09	Marsden Bridge Downstream	+0.57	-0.65	-0.33	+0.48	-0.37	+0.32	+0.00	+0.00	-2.09	+1.26	-1.24	+1.01
W10	Behind Properties on Fitzroy Street	-	-	-	-	-	-	-	-	-	+0.06*	-	-
W11	Victoria Bridge Upstream	+0.52	-0.56	-0.29	+0.45	-0.32	+0.30	-0.02	+0.06	-2.04	+1.18	-1.14	+0.96
W12	Victoria Bridge Downstream	+0.51	-0.55	-0.29	+0.44	-0.32	+0.31	-0.00	+0.02	-2.00	+1.16	-1.11	+0.94
W13	Avoca St Mid	-	-	-	-	-	-	-	-	-	-	-	-
W14	Kenmore Bridge Upstream	+0.45	-0.45	-0.21	+0.39	-0.30	+0.28	-0.03	+0.08	-1.83	+1.07	-0.98	+0.81
W15	Kenmore Bridge Downstream	+0.44	-0.47	-0.22	+0.37	-0.30	+0.26	-0.01	+0.05	-1.88	+1.06	-1.02	+0.80
W16	Crookwell Rail Bridge Upstream	+0.44	-0.47	-0.22	+0.34	-0.30	+0.26	-0.01	+0.05	-1.90	+1.06	-1.02	+0.81
W17	Crookwell Rail Bridge Downstream	+0.44	-0.47	-0.22	+0.31	-0.30	+0.26	+0.01	-0.02	-1.88	+1.04	-1.01	+0.81
W18	Sewer Aqueduct Upstream	+0.65	-0.71	-0.36	+0.41	-0.36	+0.33	-0.01	+0.03	-2.77	+1.29	-1.56	+1.15
W19	Sewer Aqueduct Downstream	+0.66	-0.72	-0.36	+0.42	-0.37	+0.34	+0.01	-0.01	-2.76	+1.29	-1.57	+1.16

W20	Wollondilly/Mulwaree Confluence	+0.69	-0.77	-0.40	+0.45	-0.39	+0.36	+0.00	0.00	-2.78	+1.33	-1.66	+1.21
W21	Murrays Flat Gauge	+0.74	-0.79	-0.42	+0.47	-0.41	+0.36	0.00	+0.00	-2.33	+1.45	-1.58	+1.34
	Average	+0.48	-0.49	-0.24	+0.37	-0.25	+0.25	+0.00	+0.02	-1.76	+1.05	-1.02	+0.85

*Newly Flooded

Table D 2: 20% AEP Sensitivity Results – Mulwaree River

ID	Description	Rainfall Losses		Hydrologic Lag Parameter		Hydraulic Roughness		Structure Blockage		Temporal Pattern		Areal Reduction Factor	
		-20%	+20%	-20%	+20%	-20%	+20%	-20%	+20%	Min	Max	-20%	+20%
M01	The Towers Gauge	+0.18	-0.17	-0.12	+0.15	-0.07	+0.07	0.00	-0.00	-0.50	+0.28	-0.36	+0.33
M02	The Towers Weir Upstream	+0.15	-0.15	-0.10	+0.13	-0.06	+0.05	0.00	0.00	-0.45	+0.23	-0.32	+0.27
M03	The Towers Weir Downstream	+0.20	-0.21	-0.15	+0.17	-0.13	+0.12	-0.00	+0.01	-0.76	+0.32	-0.46	+0.37
M04	Thornes Bridge Upstream	+0.17	-0.19	-0.13	+0.14	-0.10	+0.09	-0.00	+0.01	-0.64	+0.26	-0.45	+0.31
M05	Thornes Bridge Downstream	+0.16	-0.18	-0.12	+0.13	-0.10	+0.09	0.00	+0.00	-0.72	+0.24	-0.43	+0.29
M06	Hume Highway Bridge 2 Upstream	+0.14	-0.14	-0.09	+0.12	-0.08	+0.07	-0.02	+0.05	-0.47	+0.21	-0.31	+0.24
M07	Hume Highway Bridge 2 Downstream	+0.12	-0.12	-0.09	+0.10	-0.09	+0.08	+0.01	-0.02	-0.42	+0.18	-0.27	+0.20
M08	Hume Highway Bridge 3 Upstream	+0.18	-0.20	-0.13	+0.16	-0.11	+0.11	-0.01	+0.03	-0.68	+0.27	-0.46	+0.32
M09	Hume Highway Bridge 3 Downstream	+0.16	-0.19	-0.12	+0.14	-0.11	+0.10	-0.00	+0.01	-0.66	+0.25	-0.44	+0.29
M10	Hume Highway Bridge 4 Upstream	+0.10	-0.10	-0.06	+0.07	-0.07	+0.06	-0.01	+0.03	-0.36	+0.21	-0.21	+0.20
M11	Hume Highway Bridge 4 Downstream	+0.08	-0.07	-0.04	+0.07	-0.05	+0.05	+0.01	-0.01	-0.27	+0.14	-0.15	+0.18
M12	Lansdowne Bridge Upstream	+0.14	-0.16	-0.10	+0.13	-0.08	+0.08	+0.00	+0.02	-0.64	+0.22	-0.39	+0.26
M13	Lansdowne Bridge Downstream	+0.14	-0.15	-0.10	+0.12	-0.09	+0.08	0.00	-0.01	-0.62	+0.22	-0.37	+0.26
M14	Goulburn Brewery	-	-	-	-	-	-	-	-	-	-	-	-
M15	Park Road Roundabout	+0.06	-	-0.05	+0.05	-0.04	+0.04	0.00	0.00	-	+0.10	-	+0.13
M16	Park Road Upstream	+0.16	-0.14	-0.10	+0.13	-0.08	+0.09	-0.00	+0.00	-0.35	+0.28	-0.26	+0.34
M17	Park Road Downstream	+0.20	-0.19	-0.14	+0.16	-0.13	+0.12	-0.00	0.00	-0.58	+0.36	-0.38	+0.42
M18	Goulburn Golf Club Upstream	+0.35	-0.25	-0.18	+0.27	-0.16	+0.19	-0.01	+0.01	-0.79	+0.63	-0.52	+0.69
M19	Goulburn Golf Club Downstream	+0.36	-0.26	-0.19	+0.27	-0.17	+0.19	-0.01	+0.01	-0.81	+0.64	-0.53	+0.70
M20	May Street Bridge Upstream	+0.54	-0.51	-0.35	+0.41	-0.29	+0.28	-0.02	+0.02	-1.27	+0.93	-0.94	+0.97
M21	May Street Bridge Downstream	+0.54	-0.51	-0.35	+0.41	-0.29	+0.28	-0.02	+0.02	-1.29	+0.93	-0.95	+0.97

M22	Railway Viaduct Upstream	+0.58	-0.56	-0.37	+0.44	-0.32	+0.30	-0.03	+0.02	-1.49	+1.01	-1.09	+1.03
M23	Railway Viaduct Downstream	+0.59	-0.58	-0.38	+0.44	-0.34	+0.32	-0.00	+0.01	-1.51	+1.03	-1.13	+1.05
M24	Sydney Road Bridge Upstream	+0.63	-0.67	-0.40	+0.46	-0.38	+0.34	-0.00	+0.02	-1.99	+1.14	-1.35	+1.11
M25	Sydney Road Bridge Downstream	+0.63	-0.67	-0.39	+0.45	-0.38	+0.34	+0.00	-0.00	-2.05	+1.16	-1.37	+1.11
	Average	+0.27	-0.28	-0.18	+0.21	-0.15	+0.15	-0.00	+0.01	-0.84	+0.47	-0.57	+0.50

1% AEP Event Sensitivity Results

Table D 3: 1% AEP Sensitivity Results – Wollondilly River

ID	Description	Rainfall Losses		Hydrologic Lag Parameter		Hydraulic Roughness		Structure Blockage		Temporal Pattern		Areal Reduction Factor	
		-20%	+20%	-20%	+20%	-20%	+20%	-20%	+20%	Min	Max	-20%	+20%
W01	Rossi Bridge Upstream	+0.30	-0.26	-0.38	+0.51	-0.28	+0.44	-0.02	+0.06	-1.40	+1.14	-0.87	+1.06
W02	Rossi Bridge Downstream	+0.27	-0.25	-0.35	+0.46	-0.26	+0.42	+0.02	-0.03	-1.34	+0.98	-0.83	+0.90
W03	Rossi Gauge	+0.27	-0.24	-0.34	+0.46	-0.24	+0.42	0.00	+0.01	-1.24	+0.97	-0.77	+0.89
W04	Rossi Weir Upstream	+0.26	-0.23	-0.33	+0.46	-0.21	+0.41	0.00	+0.01	-1.22	+0.96	-0.75	+0.88
W05	Rossi Weir Downstream	+0.29	-0.30	-0.43	+0.50	-0.58	+0.51	-0.00	+0.01	-1.90	+1.04	-1.10	+0.96
W06	Marsden Weir Upstream	+0.30	-0.34	-0.49	+0.53	-0.63	+0.52	-0.04	+0.11	-1.99	+1.12	-1.25	+1.04
W07	Marsden Weir Downstream	+0.30	-0.34	-0.49	+0.54	-0.59	+0.50	-0.04	+0.11	-2.19	+1.13	-1.26	+1.05
W08	Marsden Bridge Upstream	+0.30	-0.33	-0.47	+0.53	-0.58	+0.50	-0.04	+0.12	-2.15	+1.11	-1.24	+1.03
W09	Marsden Bridge Downstream	+0.31	-0.31	-0.45	+0.54	-0.58	+0.53	-0.00	+0.02	-2.12	+1.12	-1.20	+1.04
W10	Behind Properties on Fitzroy Street	+0.28	-0.29	-0.42	+0.48	-0.60	+0.52	-0.01	+0.05	-2.03	+1.03	-1.13	+0.96
W11	Victoria Bridge Upstream	+0.31	-0.27	-0.41	+0.51	-0.50	+0.49	-0.05	+0.19	-2.00	+1.16	-1.10	+1.03
W12	Victoria Bridge Downstream	+0.30	-0.25	-0.39	+0.48	-0.52	+0.49	-0.01	+0.07	-1.94	+1.06	-1.07	+0.93
W13	Avoca St Mid	+0.31	-0.26	-0.40	+0.48	-0.50	+0.47	-0.03	+0.11	-	+1.13	-1.07	+0.97
W14	Kenmore Bridge Upstream	+0.31	-0.32	-0.32	+0.38	-0.57	+0.50	-0.03	+0.12	-1.72	+1.30	-1.20	+1.08
W15	Kenmore Bridge Downstream	+0.31	-0.32	-0.32	+0.34	-0.58	+0.51	-0.01	+0.05	-1.71	+1.24	-1.20	+1.05
W16	Crookwell Rail Bridge Upstream	+0.32	-0.32	-0.33	+0.32	-0.59	+0.51	-0.01	+0.04	-1.72	+1.21	-1.22	+1.07
W17	Crookwell Rail Bridge Downstream	+0.32	-0.32	-0.34	+0.33	-0.60	+0.52	+0.01	-0.03	-1.71	+1.18	-1.23	+1.07

W18	Sewer Aqueduct Upstream	+0.33	-0.34	-0.39	+0.35	-0.58	+0.51	+0.00	+0.01	-1.77	+1.13	-1.32	+1.11
W19	Sewer Aqueduct Downstream	+0.33	-0.34	-0.39	+0.35	-0.59	+0.51	+0.01	-0.01	-1.76	+1.12	-1.32	+1.11
W20	Wollondilly/Mulwaree Confluence	+0.34	-0.34	-0.40	+0.35	-0.59	+0.51	+0.01	-0.00	-1.77	+1.12	-1.33	+1.12
W21	Murrays Flat Gauge	+0.46	-0.46	-0.50	+0.46	-0.37	+0.37	+0.01	+0.00	-2.12	+1.35	-1.72	+1.54
Average		+0.31	-0.31	-0.40	+0.45	-0.50	+0.48	-0.01	+0.05	-1.79	+1.12	-1.15	+1.04

Table D 4: 1% AEP Sensitivity Results – Mulwaree River

ID	Description	Rainfall Losses		Hydrologic Lag Parameter		Hydraulic Roughness		Structure Blockage		Temporal Pattern		Areal Reduction Factor	
		-20%	+20%	-20%	+20%	-20%	+20%	-20%	+20%	Min	Max	-20%	+20%
M01	The Towers Gauge	+0.19	-0.16	-0.20	+0.22	-0.17	+0.21	0.00	+0.00	-0.50	+0.41	-0.48	+0.55
M02	The Towers Weir Upstream	+0.15	-0.11	-0.14	+0.18	-0.02	+0.10	-0.00	+0.00	-0.35	+0.31	-0.33	+0.44
M03	The Towers Weir Downstream	+0.16	-0.10	-0.14	+0.19	-0.19	+0.27	-0.02	+0.04	-0.56	+0.34	-0.55	+0.48
M04	Thornes Bridge Upstream	+0.11	-0.11	-0.13	+0.13	-0.13	+0.14	-0.03	+0.07	-0.41	+0.23	-0.40	+0.32
M05	Thornes Bridge Downstream	+0.10	-0.10	-0.12	+0.12	-0.15	+0.16	+0.00	+0.01	-0.36	+0.21	-0.35	+0.30
M06	Hume Highway Bridge 2 Upstream	+0.22	-0.18	-0.25	+0.24	-0.29	+0.34	-0.02	+0.05	-0.53	+0.72	-0.51	+0.83
M07	Hume Highway Bridge 2 Downstream	+0.24	-0.20	-0.27	+0.26	-0.35	+0.38	+0.01	-0.02	-0.61	+0.77	-0.58	+0.88
M08	Hume Highway Bridge 3 Upstream	+0.24	-0.22	-0.30	+0.26	-0.35	+0.37	-0.02	+0.07	-0.75	+0.76	-0.69	+0.87
M09	Hume Highway Bridge 3 Downstream	+0.25	-0.24	-0.31	+0.27	-0.41	+0.39	-0.00	+0.00	-0.76	+0.80	-0.70	+0.90
M10	Hume Highway Bridge 4 Upstream	+0.23	-0.20	-0.26	+0.25	-0.30	+0.34	-0.04	+0.10	-0.66	+0.71	-0.59	+0.82
M11	Hume Highway Bridge 4 Downstream	+0.25	-0.22	-0.30	+0.27	-0.38	+0.40	-0.01	+0.02	-0.74	+0.81	-0.68	+0.91
M12	Lansdowne Bridge Upstream	+0.28	-0.26	-0.34	+0.31	-0.44	+0.43	-0.01	+0.02	-0.95	+0.89	-0.86	+0.99
M13	Lansdowne Bridge Downstream	+0.29	-0.27	-0.35	+0.31	-0.46	+0.44	-0.01	+0.01	-0.97	+0.90	-0.87	+1.00
M14	Goulburn Brewery	+0.31	-0.30	-0.39	+0.33	-0.53	+0.47	-0.01	+0.02	-2.21	+0.94	-1.13	+1.05
M15	Park Road Roundabout	+0.33	-0.33	-0.42	+0.35	-0.55	+0.49	-0.01	+0.03	-1.52	+0.99	-1.25	+1.09

M16	Park Road Upstream	+0.33	-0.33	-0.42	+0.35	-0.55	+0.49	-0.02	+0.03	-1.52	+0.99	-1.25	+1.09
M17	Park Road Downstream	+0.33	-0.33	-0.42	+0.35	-0.55	+0.49	-0.02	+0.02	-1.53	+0.99	-1.25	+1.09
M18	Goulburn Golf Club Upstream	+0.33	-0.33	-0.42	+0.36	-0.55	+0.49	-0.02	+0.03	-1.57	+1.00	-1.27	+1.10
M19	Goulburn Golf Club Downstream	+0.33	-0.33	-0.42	+0.36	-0.55	+0.49	-0.02	+0.03	-1.57	+1.00	-1.27	+1.10
M20	May Street Bridge Upstream	+0.33	-0.33	-0.42	+0.36	-0.56	+0.49	-0.02	+0.03	-1.60	+1.01	-1.29	+1.10
M21	May Street Bridge Downstream	+0.33	-0.34	-0.43	+0.36	-0.56	+0.49	-0.02	+0.03	-1.60	+1.01	-1.29	+1.10
M22	Railway Viaduct Upstream	+0.33	-0.34	-0.42	+0.36	-0.56	+0.49	-0.02	+0.03	-1.62	+1.02	-1.30	+1.11
M23	Railway Viaduct Downstream	+0.33	-0.34	-0.43	+0.36	-0.58	+0.50	-0.00	+0.03	-1.65	+1.03	-1.31	+1.11
M24	Sydney Road Bridge Upstream	+0.33	-0.34	-0.41	+0.36	-0.60	+0.51	-0.01	+0.03	-1.68	+1.06	-1.31	+1.11
M25	Sydney Road Bridge Downstream	+0.33	-0.33	-0.40	+0.35	-0.60	+0.52	+0.00	+0.00	-1.67	+1.06	-1.29	+1.09
Average		+0.26	-0.25	-0.32	+0.29	-0.42	+0.40	-0.01	+0.03	-1.12	+0.80	-0.91	+0.90

Appendix E – Flood Function Derivation

The methodology for assigning flood function categories to the Wollondilly and Mulwaree River floodplains is presented herein.

The floodway has been derived using the staged process outlined below:

1. For the 1% AEP design event, derive an estimate of the flood function categories in accordance with Howells et al, 2003 (Reference 8), which defined flood function categories based on thresholds for the velocity-depth product, velocity and depth to define each category.
    a. Isolated areas (<0.3 ha) of flood storage or flood fringe, surrounded by floodway were converted to floodway.
    b. Channels or flow paths of floodway were made continuous in instances where discontinuity occurred due to man-made changes
2. An encroachment analysis was undertaken in the hydraulic model whereby all areas outside of the floodway were blocked out of the model to simulate the effect of fully developing these areas.
    a. A resulting flood level increase of around 0.1 m in the 1% AEP event was considered reasonable,
    b. Where flood levels were changed by considerably more or less than 0.1 m, the thresholds outlined in Step 1 were revised and Steps 1 - 2 were repeated. Where necessary, the floodplain was split into sections with different depth and velocity thresholds, as recommended by Murtagh et al, 2017 (Reference 9).
3. Once a reasonable estimate is achieved via the encroachment analysis, confirmation of the flood function categories was undertaken by measuring the percentage of flow in areas of floodway and comparing these to the total flow.
    a. The floodway was expected to convey approximately 80-90% of the total flow across a flow path.
4. Once the thresholds of velocity-depth product, velocity and depth are determined for the 1% AEP event, the same criteria were applied to derive the flood function for the 5% AEP and PMF events.

The floodway was derived using the methodology described above. The results of the assessment are shown in Figure E1 and Table E 1 presents the adopted floodway thresholds. This figure shows the afflux from blocking the adopted mainstream flood storage area, as well as a comparison of flow percentages between the floodway and non-floodway areas. The figure shows that the adopted threshold would achieve the 0.1 m afflux for large areas (see yellow areas of impact) and the floodway is between 80% and 100%. While the target afflux was not achieved for all sections of the channel, these thresholds were adopted after iterative analysis of various thresholds and any further splitting of areas was deemed to have limited returns for the added complexity.

Encroachment analysis found that different floodway criteria best fit the Wollondilly and Mulwaree rivers. This is primarily due to the topographic differences between the two waterways. Higher floodway thresholds were required along parts of the river where the channel is steep and confined and lower thresholds were used where the channel is flatter, and flow is widespread. The floodway thresholds along the Wollondilly and Mulwaree rivers are summarised in Table E 1.

Table E 1: Study area flood function floodway thresholds

Floodway Area	River	Velocity Depth Product (m^2/s)	Velocity (m/s)
FC - A	Mulwaree River	0.80	0.80
FC - B		0.55	0.55
FC - C		0.40	0.40
FC - D	Wollondilly River	0.60	0.60
FC - E		0.95	0.95
FC - F		0.80	0.80
FC - G		0.50	0.50

Flood affected areas outside of the floodway were categorised as either flood storage or flood fringe based on a flood depth threshold, whereby depths greater than 0.5 m were classified as flood storage and flood fringe for depths less than 0.5 m.

Figure 5 to Figure 7 of the main body of the report present the flood function for the 5% AEP, 1% AEP and PMF events, respectively.

Appendix F – Freeboard Analysis

Assessment of a range of factors which influence the level of freeboard has been considered. The analysis implements the joint probability framework outlined in NSW Public Works study (2010, Reference 12) to determine an appropriate level of freeboard for the FPA. The joint probability analysis is presented herein.

Wave Action

Wave action during a flood event can significantly affect the level to which a property floods. Large waves can be generated from wind action as well as other factors such as rescue efforts in flood waters. Given this potential for exacerbation of flood affectation, these factors have been accounted for in an assessment of freeboard.

The analysis below pertains to the Mulwaree River as the floodplain provides a significant fetch which could result in waves forming during a flood event. The analysis was not required for the Wollondilly River, however a design wave height of 0.3 m was considered in the joint probability analysis to account for bow waves created by NSW SES boats that may traverse the river during times of flood.

Design Wind Speed

The Australian/New Zealand Standards for Structural Design Actions – Part 2: Wind Actions (AS/NZS 1170.2:2011) provides guidance for deriving design wind speeds. The wind speed is calculated for 8 cardinal directions (β) and given by the formula:

$$V_\beta = V_r M_d (M_s M_t M_{z,cat})$$

where:

V_r = regional gust wind speed for annual probability of exceedance of 1/R

M_d = wind directional multipliers for the 8 cardinal directions (β)

M_s = shielding multiplier

M_t = topographic multiplier

$M_{z,cat}$ = terrain/height multiplier

The following sections will explain each of these parameters and the values selected for the Mulwaree River.

Regional Wind Speed

The regional wind speed (V_r) is based on peak gust wind for a range of Average Recurrence Intervals and regions (shown in Table 3.1 of AS/NZS 1170.2:2011). The wind speed for an average recurrence interval of 1 year ARI was considered so as to skew the magnitude of the event being examined (i.e. the assumption that a rarer wind speed would occur in conjunction with a 1% AEP flood event would likely result in an overall event probability of less than 1%).

Goulburn was found to be located in the non-cyclonic region A3 from these guidelines. Based on this information regional wind speed of 30 m/s was adopted.

Wind Directional Multiplier

Section 3.3 of AS/NZS 1170.2:2011 provides wind direction multipliers (M_d) for the 8 cardinal directions and regions. This information provided 8 wind direction multipliers for Region A3 with the critical direction having a multiplier of 1.00

Shielding Multiplier

Shielding accounts for protection provided by upwind buildings or structures. The current study assumed that the shielding provided by upwind structures is negligible and as such a shielding multiplier (M_s) of 1.00 was adopted.

Topographic Multiplier

A topographic multiplier (M_t) of 1.00 has been adopted for the current study based on the flat topography of the Mulwaree River floodplain.

Terrain/height Multiplier

The terrain/height ($M_{z,cat}$) multiplier accounts for the terrain over which the wind would move and the height variation of the terrain which would ultimately affect the wind speed. Terrain Category 2 was selected for the Mulwaree River. This category is described in the Standards as "*Open terrain, including grassland, with well scattered obstructions having heights generally from 1.5 m to 5 m, with no more than two obstructions per hectare, e.g. farmland and cleared subdivisions with isolated trees and uncut grass*". Given the topography of the Mulwaree river floodplain, a height variation of ≤ 3 m was selected. These factors result in a terrain/height multiplier of 0.91.

Design Wind Speed

Using the formula and parameters described above, 8 cardinal design wind speeds were derived for the Mulwaree River. A wind speed of 27.3 m/s was calculated for the critical direction.

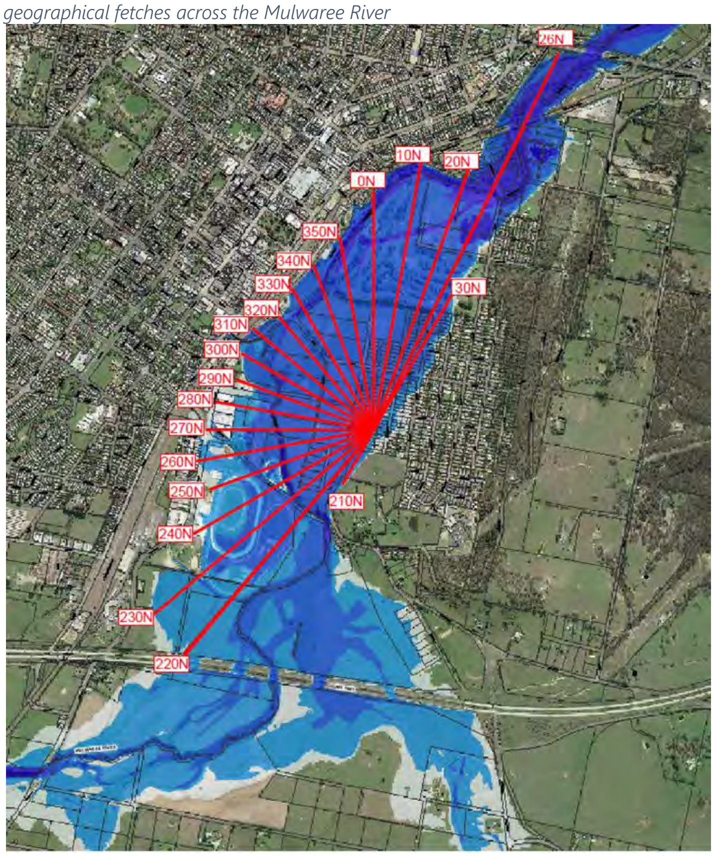
Wave Height

The potential wave height on the Mulwaree River has been calculated using the design wind speed, fetch and duration. For the current study, the wind field was assumed to be fairly stationary and with a duration long enough to develop the fully arisen sea conditions. Under this assumption, the wave heights and period are controlled by the given fetch.

Geographical Fetch

The geographical fetch refers to the length of water over which wind blows. The geographical fetch across the Mulwaree river was drawn at 10 degree intervals (see Image F 1). The fetch lengths range from 0 metres to 2.3 km.

Image F 1: Typical geographical fetches across the Mulwaree River



Effective Fetch

An effective fetch is calculated to account for the irregular "shoreline" caused by the flood extent. The effective fetch length (X_{eff}) for each direction was calculated using the Seville formula shown below:

$$X_{eff} = \frac{\sum X_i \cos^2 \alpha_i}{\sum \cos \alpha_i}$$

Where:
X_{eff} = the effective fetch (km)
X_i = the length of the straight-line fetch (km)
α_i = angle from mean wind direction (in radians)

Wave Height

Wave height for each direction was calculated using the Sverdrup-Munk and Bretschneider (SMB) equations for deep water (depth > 90 m) and shallow water. The shallow water equation was adopted as outlined below.

$$\frac{gH_s}{u^2} = 0.283 \tanh\left[0.53\left(\frac{gd}{u^2}\right)^{0.75}\right] \tanh\left[\frac{0.0125\left(\frac{gF}{u^2}\right)^{0.42}}{\tanh\left[0.833\left(\frac{gd}{u^2}\right)^{0.75}\right]}\right]$$

Where:

g = acceleration due to gravity (9.81 m/s^2)
u = design wind speed for given direction
d = depth of water (taken from hydraulic model results)
F = effective fetch for given direction
H_s = wave height

The direction that produced the greatest wave height was utilised for the freeboard assessment. Using the SMB equation above for each direction, a maximum wave height of 0.61 m was calculated for a 1 year ARI.

Wave Set-up

Wave setup refers to the cumulative horizontal shear stress applied as wind moves over a water surface causing a change in the water level. The Zuider Zee equation, shown below, has been utilised to calculate the wave set up.

$$S = \frac{U^2F}{1400D}$$

Where:
S = wind set-up (feet)
U = design wind speed for given direction (miles/hr)
F = effective fetch for given direction (miles)
D = depth of water (taken from hydraulic model results)

The direction that produced the greatest wave set-up was utilised for the freeboard assessment. Using the equation above for each direction, a maximum wave set-up of 0.04 m was calculated.

The key factors used to calculate the wind and wave action on the Mulwaree River are presented in Table F 1.

Table F 1: Mulwaree River key parameters for calculating wind and wave action

Parameter	Value
Design Wind Speed for 1 year ARI (in the critical direction)	27.3 m/s
V_r Regional Wind Speed for 1 year ARI (in the critical direction)	30 m/s
M_d Wind Directional Multiplier (in the critical direction)	1.00
M_s Shielding Multiplier	1.00
M_t Topographic Multiplier	1.00
$M_{z,cat}$ Terrain/height Multiplier	0.91
Wave Height (in the critical direction)	0.61 m
Geographical Fetch (in the critical direction)	0.96 km
Effective Fetch (in the critical direction)	0.92 km
Wave Set up (in the critical direction)	0.04 m

Due to the narrow width of the Wollondilly River, it was found that there was insufficient fetch distance to develop any wave action due to wind. A bow wave allowance of 0.3 m was applied to the Wollondilly River to account for waves generated from NSW SES rescue efforts.

Local Water Surge

Local water surge can result in localised flood levels that are higher than the general flood level. Surge can occur due to changes in flow velocity associated with variation in flow direction and/or flow regime. These changes can potentially occur due to ground level changes, or obstruction of flow due to buildings. In these cases, kinetic energy may be converted to potential energy, which results in localised increased flood levels. If it is assumed that the kinetic energy is reduced to zero, the follow equation can be used to determine the resulting increase in local water level:

$$h_s = \frac{v^2}{2g}$$

Where:

h_s = surge height (m)
v = local velocity (m/sec)

Table F 2 provides the peak velocities on the Wollondilly and Mulwaree Rivers and the calculated surge height based on the equation above.

Table F 2: Calculated local water surge on the Wollondilly and Mulwaree rivers

River	Average Velocity (m/s)	Surge Height (m)
Wollondilly River	1.14	0.07
Mulwaree River	0.51	0.01

The probability that the full expression of energy loss will occur is low, however some surge is likely to occur. To approximate the likely surge conditions, 75% probability has been applied to the joint probability analysis. This probability has been selected as it considers that surge is likely, however the maximum surge associated with conversion of all kinetic energy to potential energy is unlikely.

Uncertainties in Flood Level Estimates

The results of the sensitivity analysis undertaken during the current study (see Appendix A, Section A5) found that variation of model parameters increased flood levels on the average by 0.58 m on the Wollondilly River and 0.45 m on the Mulwaree River. Furthermore, the LiDAR data used in the hydraulic model has an accuracy of ±0.15 m (1st confidence interval) in the vertical direction. The hydraulic model calibration was also assessed with an absolute average difference between the model and observed flood levels of ±0.08 m noted in the Flood Study (Reference 6). A neutral probability (50%) has been applied to LiDAR accuracy and calibration accuracy as these variables that consider the uncertainty in flood level could equally result in lower flood levels, rather than high flood levels. There is less uncertainty regarding parameter sensitivity so a 10% probability was used.

Post construction settlement and defects

Settlement and defects can occur after the construction of a building which can affect the eventual height of a floor level. To account for these factors, a settlement of 0.02 m has been adopted and a neutral probability (50%) has been applied.

Climate Change

The impact of climate change has been considered in the current study (see Appendix A, Section A4) by undertaking a rainfall comparison based on two emissions conditions. This assessment found that under low emissions conditions the 1% AEP event rainfall will be close to the 0.5% AEP event rainfall and under higher conditions the 1% AEP rainfall would be between 0.5% and 0.2% AEP event rainfall. Based on these higher emissions conditions, peak flood levels would be expected to increase by approximately 0.45 m on the Wollondilly River and 0.5 m on the Mulwaree River. Given the uncertainty associated with the predicted climate change impacts on flood producing rainfall, a neutral probability (50%) has been considered in the joint probability analysis as the impact of climate change on rainfall intensities is not completely understood for longer duration events.

Freeboard Allowance

The joint probability analysis considers the variables and probabilities previously discussed, with the analysis presented above. Individual freeboards for the Wollondilly and Mulwaree have been calculated as presented in Table F 3.

Table F 3: Joint Probability Freeboard Analysis

Freeboard Item	Allowance (m)		Probability	Joint Probability (m)	
	Wollondilly River	Mulwaree River		Wollondilly River	Mulwaree River
Wind and Wave Action	0.30	0.65	50%	0.15	0.33
Local Water Surge	0.07	0.01	75%	0.05	0.01
Uncertainties in Flood levels - Sensitivity to parameters - Lidar accuracy - Calibration accuracy	 ±0.58 ±0.15 ±0.08	 ±0.45 ±0.15 ±0.08	 10% 50% 50%	0.17	0.16
Post Construction Settlement and Defects	0.02	0.02	50%	0.01	0.01
Climate Change	0.45	0.50	50%	0.23	0.25
Wollondilly River - Freeboard Allowance				0.61	-
Mulwaree River - Freeboard Allowance				-	0.76

Based on the results of the freeboard assessment, the more conservative freeboard estimate of 0.8 m has been adopted and used to derive the Flood Planning Area presented in Figure 8 of the main body of the report.

Appendix G – Community Consultation

Goulburn Mulwaree Council
Locked Bag 22
Goulburn NSW 2580

Civic Centre
184 - 194 Bourke Street
Goulburn NSW 2580
t (02) 4823 4444
e council@goulburn.nsw.gov.au
www.goulburn.nsw.gov.au

16 August 2019

Contact: Utilities
Reference: FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

Name
Postal
City, State, Postcode

Dear Sir/Madam

Subject: Floodplain Risk Management Study and Plan Survey

Goulburn Mulwaree Council is in the process of developing a new Floodplain Risk Management Study and Plan with the assistance of GRC Hydro and the NSW Government's Floodplain Risk Management Program. This study and plan will include modelling of riverine flooding in Goulburn and recommend appropriate actions to manage or minimise flood risk.

You have been contacted because you live in or own land within the study area that is likely to be affected by riverine flooding.

Enclosed in this letter is a survey. By completing this survey and providing feedback you will help us to develop measures that may reduce the impact or risk of local flooding in your area.

You may provide your survey via the following methods:

- Completing it online at https://yoursay.goulburn.nsw.gov.au/
- Email to goulburn@grchydro.com.au
- Handed into the front counter at the Civic Centre (184 Bourke Street, Goulburn)

Please return your surveys by close of business **Friday 13 September 2019**.

If you have any questions, please do not hesitate to contact me on ph:4823 4444 or by email to Elise.Henze@goulburn.nsw.gov.au.

Yours faithfully,

Lucy Henze
Engineer Water & Wastewater

Have Your Say on Flooding in Your Area

Goulburn Mulwaree Floodplain Risk Management Study and Plan

Goulburn Mulwaree Floodplain Risk Management Study & Plan

Goulburn Mulwaree Council are undertaking a Floodplain Risk Management Study & Plan for the Wollondilly and Mulwaree Rivers at Goulburn. The study is being prepared with assistance from GRC Hydro & is being undertaken as part of the NSW Government's Floodplain Risk Management Program. This study will identify & recommend appropriate actions to manage riverine flooding in Goulburn.

What is the Floodplain Risk Management Program?

The Floodplain Risk Management Program is run by the NSW Government. This program helps councils to make informed decisions about managing flood risk and to provide essential information to the SES to coordinate flood emergency response.

This program consists of five stages, Stages 1 & 2 are completed, the current study will undertake the third and fourth stages of this process being the; Floodplain Risk Management Study and Plan.

The stages of the Floodplain Risk Management Program are presented below:

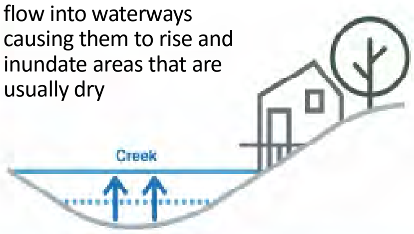
What is Flooding?

Flooding is often associated with inundation from large rivers; however, there are other flood mechanisms that can cause inundation. Two of these mechanisms are overland flow flooding and mainstream flooding.

The Goulburn Mulwaree Floodplain Risk Management Study will focus on both types of flooding from the Wollondilly River and the Mulwaree River.

<u>Overland flow flooding</u> occurs as rainfall runoff moves toward downstream waterways.

<u>Mainstream flooding</u> occurs when runoff from streets and drains flow into waterways causing them to rise and inundate areas that are usually dry



What is a Floodplain Risk Management Study and Plan?

A floodplain risk management study and plan (FRMS&P) follows a flood study (completed 2016). A flood study is a comprehensive technical investigation of flood behaviour which defines the nature of flood risk in Goulburn by providing information on the extent, level and velocity of floodwaters for a full range of flood magnitudes.

A FRMS&P draws on the results of the flood study to identify, assess and compare various flood risk management options and opportunities aimed at improving the existing flood situation in Goulburn. It provides information and tools to allow considered assessment of flood impacts of management options and provides a strategic plan for implementation.

Have Your Say on Flooding in Your Area

Goulburn Mulwaree Floodplain Risk Management Study and Plan

What is a FRMS&P used for?

A FRMS&P provides key information for Council, the SES & the community for effectively managing & mitigating flood risk.

For Council, FRMS&P's are primarily a planning tool for future development in Goulburn and implementing flood risk mitigation measures for existing development areas. Examples of applications for Council are listed below:

- Examination of Council's local flood risk management policies, strategies and planning instruments; and
- Identification and assessment of floodplain risk management measures for existing development areas aimed at reducing social, environmental and economic loss due to flooding on development and the community.

Information from the FRMS&P will assist the SES in its evacuation and logistics planning. The outcomes of the study will provide the SES with:

- a clear description of flood behaviour in the study area for a full range of flood events;
- a description of flood warning times for Goulburn; and
- identification of critical evacuation issues in Goulburn such as warning times where road access is cut.

Why your feedback is important

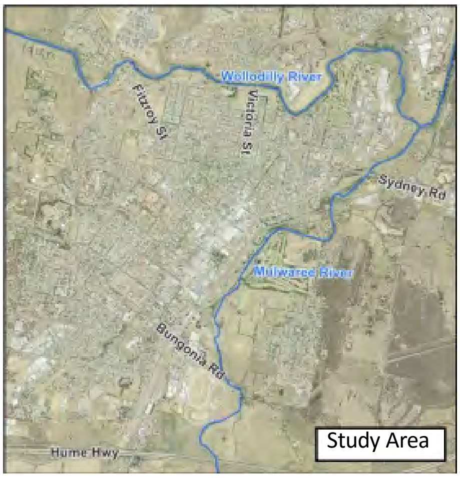
GRC Hydro will use computer models developed in the Goulburn Mulwaree Flood Study to assess flood risk mitigation measures. This process involves identifying areas that are flood affected and assessing flood modification measures to relieve the flood risk at these locations. Community input and knowledge of measures that might mitigate flooding from the Wollondilly and Mulwaree Rivers is invaluable to this study.

What happens next?

GRC Hydro will assess flood modification measures and produce a draft FRMS&P report for Council. It will be on Public Exhibition in 2019.

The Study Area

The Goulburn Mulwaree Flood Study was undertaken in 2016 and outcomes from the flood study have formed the basis of the current study. The Wollondilly and Mulwaree rivers meet downstream of Goulburn township and have a combined catchment of approximately 1500 km^2. During significant rainfall events, each of these rivers can break their banks and inundate areas of Goulburn.



How can you help us?

Your feedback is important in helping us get a complete picture of the communities knowledge of flood behaviour and mitigation in your area. There are a variety of ways you can share your experiences and knowledge with us. These are as follows:

01. Fill out the questionnaire included with this letter and send it back using the self-addressed envelope provided or email it to goulburn@grchydro.com.au.

02. Fill out the questionnaire online by going to the website listed below. Website: www.yoursay.goulburn.nsw.gov.au

03. For more information, please do not hesitate to contact the representatives nominated at the bottom of this page.

Who can we contact?

If you have any further questions regarding the study or any further flood information/photos please attach them to your questionnaire or contact the following representatives.

Beth Marson
Senior Engineer
GRC Hydro
goulburn@grchydro.com.au
02 90300342

Lucy Henze
Engineer Water & Wastewater
Goulburn Mulwaree Council
Elise.Henze@goulburn.nsw.gov.au
02 4823 4444

Please return your questionnaire by 13 September 2019 to ensure that it is counted.

GRC Hydro: Water Engineers and Hydrologists grchydro.com.au

Have Your Say on Flooding in Your Area
Goulburn Mulwaree Floodplain Risk Management Study and Plan Questionnaire

Contact Details

Name

Address:

Phone Number:

Email:

Can we contact you for more information? ◯ Yes ◯ No

Please note: Your personal details will be kept confidential

Your Property

What building type is your property?

◯ Residential (House/Terrace) ◯ Residential (Apartment)

◯ Commercial ◯ Industrial

Business Name:

How long have you lived or worked at this property? ____ Years ____ Months

Has your property ever been affected by flooding?

◯ Yes, above the floor level ◯ Yes, in the yard or garage ◯ No

If yes, could you please provide more information in the space below or attached to this questionnaire. Information such as dates and photos of flooding are very helpful.

Community Engagement

This study will identify properties that are subject to flood risk. How do you suggest Council notify residents/property owners affected by the potential flood risk?

◯ This information should be publicly available on Council's website

◯ All affected residents/property owners should be notified by mail

◯ Notify only those residents/property owners who enquire with Council about the potential flood risk

◯ I should enquire at Council if I am interested in a properties flood risk

◯ Council should not provide this information

◯ Other (please detail below)

Have Your Say on Flooding in Your Area
Goulburn Mulwaree Floodplain Risk Management Study and Plan Questionnaire

New Development

The current study will provide advice on flood related development controls. How do you suggest Council should manage controls for developments on the floodplain?

- ◯ Prevent development on land subject to any flood risk (including events rarer than the 1 in 100 year ARI flood)
- ◯ Prevent any new development in areas where the flood risk is dangerous for people/property (i.e. deep fast moving water).
- ◯ Inform property owners of the potential flood risks and the related flood development controls and allow development provided the controls are adhered to
- ◯ Provide no advice or development controls
- ◯ Other (please specify)____

Flood Management Options

The current study is assessing a range of measures aimed at managing the current flood risk. The study is looking for input from residents to better understand local preferences for floodplain management.

Which of the following options do you prefer for managing flood risk? (tick box based on preference)

- ◯ Construct, repair and/or increase the size of existing levee banks
- ◯ Modify creek channels to increase their capacity
- ◯ Impose greater flood-related development controls and increase strategic flood planning
- ◯ Increase flood awareness and education in the community
- ◯ Upgrade flood warning, evacuation planning and emergency response measures
- ◯ Property modification measures for severely affected properties such as voluntary purchase or voluntary house raising.
- ◯ Other suggestions (describe below)

Please use the space below to describe other flood management options or add detail on the preferences selected above.

____

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Please return your questionnaire by 13 September 2019 to ensure that it is counted.
If your information does not fit in the space provided, please email it to **goulburn@grchydro.com.au**

Appendix H – Draft Flood Policy

Introduction

This draft flood policy defines planning controls to be applied to development on flood prone land within the Goulburn Mulwaree Local Government Area. The content of this document is outlined below:

- Section H1 - Objectives
- Section H2 - What are the Flood Planning Constraint Categories?
- Section H3 - How To Use This Document
- Section H4 - Definitions
- Section H5 - Land Use Categories
- Section H6 - Flood Planning Controls
- Section H7 - Flood Compatible Materials
- Section H8 - Frequently Asked Questions
- Figure H1 - Flood Planning Constraint Category Maps

H1 - Objectives

This draft flood policy aims to minimise the impact of flooding on development situated on flood prone land within the Goulburn Mulwaree Local Government Area. The policy applies controls that consider both the type of development and the associated flood risk.

The policy considers the range of possible flood events that can occur, up to and including the Probable Maximum Flood, which is the largest flood event that could conceivably occur at a given location and which delineates the extent of flood prone land.

The overarching objectives of the plan are:

- To reduce the risk to life and damage to property caused by flooding through controlling development on land affected by potential floods.
- To incorporate the risk of flooding up to the Probable Maximum Flood in the planning and design of critical facilities and sensitive land uses.
- To prevent intensification of inappropriate land uses within areas of high flood risk.
- To permit certain types of development in portions of the floodplain with low to moderate flood risk, provided that suitable planning controls are applied that ensure the flood risk is managed.
- To ensure that ongoing development of the floodplain does not have a significant cumulative effect on flood storage or floodway, leading to increased flood risk.
- To address the risk of riverine flooding through appropriate flood planning controls. The current policy does not include areas of overland flow flooding. These areas may be included in the future when the relevant flood study and floodplain risk management study and plan has been completed.

- To provide a framework to manage the risk of flooding on future development, whilst acknowledging that flood prone land is a valuable asset which should not be unnecessarily sterilised.

H2 - What are the Flood Planning Constraint Categories?

This flood policy implements the Flood Planning Constraint Category (FPCC) approach to flood planning as recommended in the 'Australian Disaster Resilience Guideline 7-5, Flood Information to Support Land-use Planning'.

FPCCs group similar types and scales of flood-related constraints to support land-use planning. They have been developed for use across Australia to understand the flooding constraints of flood prone land. Flood investigations typically produce a large number of maps, each focusing on a particular event magnitude and/or element of the flood behaviour. FPCCs use these findings to produce a succinct set of information that breaks the floodplain down into areas with similar degrees of constraint.

Four FPCCs have been developed to separate areas of the floodplain from the most constrained (and therefore least suitable for intensification of land use or development—FPCC1), to the least constrained (and therefore more suitable for intensification of land use or development—FPCC4). Details of the four FPCCs are presented in Table 47. Areas situated outside of FPCC4 are not flood prone and flood planning controls do not apply to these areas.

Table 47: Flood Planning Constraint Categories Overview

Category	Summary
FPCC1	FPCC1 identifies the most significantly constrained areas, with high hazard or significant flood flows present. Intensification of use in FPCC1 is generally very limited except where uses are compatible with flood function and hazard.
FPCC2	FPCC2 areas are the next least suitable for intensification of land use or development because of the effects of flooding on the land, and the consequences to any development and its users. In this document, FPCC2 is split into FPCC2 (Subcategory a,b,c,e) or FPCC2 (Subcategory d)
FPCC3	FPCC3 areas are suitable for most types of development. This is the area of the floodplain where more traditional flood-related development constraints, based on minimum floor and minimum fill levels, will apply.
FPCC4	FPCC4 is the area inundated by the PMF (extent of flood prone land), but outside FPCC1-3. Few flood-related development constraints would be applicable in this area for most development types. Constraints may apply to key community facilities and developments where there are significant consequences to the community if failed evacuations occur.

H3 - How To Use This Document

Flood planning controls depend on the type of development proposed, and what Flood Planning Constraint Category (or categories) are present at the site. The following procedure can be used to determine the controls for development:

1. Determine if the proposed development is situated on flood prone land. Council has flood information available for some locations within their Local Government Area. The FPCC map contained in Figure H 1 of this document show the extent of available information.
2. For areas where no existing flood information is available, a flood assessment is required to be undertaken to determine the flood liability of the development site. If the development is not flood prone, flood planning controls do not apply.
3. Determine which Flood Planning Constraint Categories (FPCCs) are present at the development site. Some development sites may be situated in multiple FPCCs. There are four different FPCC and FPCC2 is split into FPCC2 (Subcategory a,b,c,e) or FPCC2 (Subcategory d).
4. Determine what category (or categories) of land use are proposed as part of the development. Land Use categories are presented in Table 49.
5. List the flood planning controls that apply to the development using the controls listed under Table 50. Some sites will also be located outside all FPCC and therefore have no flood planning controls that apply.

Council will then assess whether the development complies with each of the flood planning controls. The applicant is required to provide relevant information to Council as part of the Development Application, demonstrating compliance.

H4 - Definitions

Table 48: Definitions

Annual Exceedance Probability (AEP)	The probability of an event being equalled or exceeded within a given year. The 1% AEP flood is approximately equal to 1 in 100 year Average Recurrence Interval (ARI) flood event (or simply 100 year flood).
Flood Planning Constraint Categories (FPCC)	FPCCs group similar types and scales of flood-related constraints to support land-use planning activities.
FPCC1	FPCC1 identifies the most significantly constrained areas, with high hazard or significant flood flow. Intensification of use in FPCC1 is generally very limited except where uses are compatible with flood function and hazard.
FPCC2	FPCC2 areas are the next least suitable for intensification of land use or development because of the effects of flooding on the land, and the consequences to any development and its users. Note that FPCC2 is split into FPCC2 (Subcategory a,b,c,e) or FPCC2 (Subcategory d).
FPCC3	FPCC3 areas are suitable for most types of development. This is the area of the floodplain where more traditional flood-related development constraints, based on minimum floor and minimum fill levels, will apply.
FPCC4	FPCC4 is the area inundated by the PMF (extent of flood prone land), but outside FPCC1-3. Few flood-related development constraints would be applicable in this area for most development types. Constraints may apply to key community facilities and developments where there are significant consequences to the community if failed evacuations occur.

Mainstream Flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain.
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; cumulative impacts of fill in floodplains and other effects such as changes in rainfall patterns as a result of climate change. Freeboard for the Flood Planning Level in areas of mainstream flooding has been determined to be 0.8 m at Goulburn. This value is based on the findings of a joint probability analysis as part of the Goulburn Floodplain Risk Management Study and Plan. For unstudied catchments outside the Goulburn Floodplain Risk Management Study and Plan's study area, a freeboard of 0.5 m shall be used.
Flood Planning Area	The Flood Planning Area defines properties that are subject to flood related development controls. The use of FPCC does not rely on the Flood Planning Area but its definition has been included here for clarity.
Flood Planning Level	The Flood Planning Level is a height used to set minimum floor levels for flood affected properties. It is based on a design flood event with freeboard added.

H5 - Land Use Categories

Flood planning controls will vary depending on the proposed land use category. There are 8 categories of land use, as set out in Table 49. The development types are based on the Goulburn Mulwaree Local Environment Plan 2009 land use categories.

Table 49: Land Use Categories

Land Use	Development Types
Critical Uses and Facilities	• Emergency services including police, fire, rescue and ambulance • Medical facilities that provide a critical role • Community facilities that provide a critical role during a flood event, in relation to notifications or evacuation • Airstrips or air transport facilities that provide a critical role • Electricity generating works
Sensitive Uses and Facilities	• Correctional centres • Centre-based child care facilities • Medical facilities that provide care outside normal working hours, including any facilities that provide for overnight stays

Land Use	Development Types	
	• Schools • Seniors housing • Group homes and other care facilities that house vulnerable groups • Respite day care centres	
Lot Subdivisions	• Subdivision of land, which involves the creation of new allotments, with potential for further development	
Residential Development	• Attached dwellings • Bed and breakfast accommodation • Boarding houses • Community facilities that include habitable space • Dual occupancies • Dwelling houses • Exhibition homes • Home based child care • Home industries	• Home occupations • Home occupations (sex services) • Hostels • Multi dwelling housing • Residential flat buildings • Rural workers' dwellings • Semi-detached dwellings • Serviced apartments • Shop top housing • Tourist and visitor accommodation
Commercial and Industrial *Commercial and Industrial (Cont.)*	• Air transport facilities • Airstrips • Amusement centres • Animal boarding or training establishments • Boat building and repair facilities • Business premises • Camping grounds • Cellar door premises • Charter and tourism boating facilities • Commercial premises • Community facilities • Crematoria • Entertainment facilities • Environmental protection works • Food and drink premises • Freight transport facilities • Function centres • Funeral homes • Garden Centres • Hardware and building supplies • Highway service centres • Home industries • Industrial retail outlets • Industrial training facilities	• Kiosks • Light industries • Mortuaries • Neighbourhood shops • Passenger transport facilities • Places of public worship • Plant nurseries • Recreation Facility (indoor) • Registered clubs • Restricted premises • Roadside stalls • Rural industries • Self-storage units • Service stations • Sewerage systems • Storage premises • Tank-based aquaculture • Timber yards • Transport depots • Vehicle body repair workshops • Vehicle repair stations • Veterinary hospitals • Warehouse or distribution centres • Waste or resource management facilities • Water supply systems

Land Use	Development Types	
	• Industries	• Wholesale supplies
Recreation and Non-urban	• Agriculture • Aquaculture • Boat sheds • Environmental facilities • Extractive Industries • Extensive Agriculture • Forestry • Open cut mining • Helipads • Intensive livestock agriculture • Intensive plant agriculture	• Jetties • Landscaping material supplies • Marinas • Moorings • Oyster Aquaculture • Pond-based aquaculture • Recreation facility (outdoor) • Swimming pools • Roads • Water recreation structures • Wharf or boating facilities
Sheds & Outbuildings	• Sheds and outbuildings of up to 40 m^2 area. • Farm buildings that are not used to store vehicles and other equipment	
Minor Additions	• An addition in habitable floor area to an existing development of not more than $40m^2$ or 10% of existing floor area, whichever is greater. Only one addition can be categorised as a minor addition per property.	

Appendix H – Draft Flood Policy

H6 - Flood Planning Controls

After determining the FPCC present at the site, and the land use category, the Flood Planning Controls are set out in Table 50 . The full controls are listed below the table. FPCC are shown on Figure H 1.

Table 50: FPCC Development Controls Matrix

	FPCC 1							
	Critical Uses & Facilities	Sensitive Uses & Facilities	Lot Subdivisions	Residential Development	Commercial & Industrial	Recreation & Non-urban	Sheds & Outbuildings	Minor Additions
Floor Level						A1	A1	
Building Components								
Structural Soundness								
Parking & Driveway Access						F2 F5	F1 F3 F4	
Evacuation and Refuge						G1 G3 G4	G1	
Management and Design						H2 H3 H4	H2 H3 H4	
Flood Impacts						J1	J1	

	FPCC 2 (Subcategory a,b,c,e)							
	Critical Uses & Facilities	Sensitive Uses & Facilities	Lot Subdivisions	Residential Development	Commercial & Industrial	Recreation & Non-urban	Sheds & Outbuildings	Minor Additions
Floor Level					A2 A6	A1	A2	A2
Building Components					D1	D1	D1	D1
Structural Soundness					E1	E1	E1	E1
Parking & Driveway Access					F1 F3 F4 F5	F2 F5	F1 F3 F4	F5
Evacuation and Refuge					G2 G3	G1 G3 G4	G1	G1 G3
Management and Design					H2 H3 H4	H2 H3 H4	H2 H3 H4	
Flood Impacts					J1	J1	J1	J1

	FPCC 2 (Subcategory d)							
	Critical Uses & Facilities	Sensitive Uses & Facilities	Lot Subdivisions	Residential Development	Commercial & Industrial	Recreation & Non-urban	Sheds & Outbuildings	Minor Additions
Floor Level				A4 A6	A2 A6	A1	A2	A3
Building Components				D1	D1	D1	D1	D1
Structural Soundness				E1	E1	E1	E1	E1
Parking & Driveway Access			F1 F3 F4 F5	F1 F3 F4 F5	F1 F3 F4 F5	F2 F5	F1 F3 F4	
Evacuation and Refuge			G3 G4	G3	G3	G3		
Management and Design			H1 H5		H2 H3 H4	H2 H3 H4	H2 H3 H4	
Flood Impacts			J1	J1	J1	J1	J1	J1

	FPCC 3							
	Critical Uses & Facilities	Sensitive Uses & Facilities	Lot Subdivisions	Residential Development	Commercial & Industrial	Recreation & Non-urban	Sheds & Outbuildings	Minor Additions
Floor Level				A4 A6	A2 A6	A1	A2	A3
Building Components				D1	D1	D1	D1	D1
Structural Soundness				E1	E1	E1	E1	E1
Parking & Driveway Access			F1 F3 F4 F5	F1 F3 F4 F5	F1 F3 F4 F5	F2 F5	F1 F3 F4	
Evacuation and Refuge			G2 G3 G4	G2 G3	G2 G3	G3 G4	G1	
Management and Design			H1 H5		H2 H3 H4	H2 H3 H4	H2 H3 H4	
Flood Impacts			J1	J1	J1	J1	J1	J1

	FPCC 4							
	Critical Uses & Facilities	Sensitive Uses & Facilities	Lot Subdivisions	Residential Development	Commercial & Industrial	Recreation & Non-urban	Sheds & Outbuildings	Minor Additions
Floor Level	A5 A6	A5 A6						
Building Components	D2	D2						
Structural Soundness	E2	E2						
Parking & Driveway Access	F2 F3	F2 F3						
Evacuation and Refuge	G2 G3 G4	G2 G3 G4	G2 G3 G4					
Management and Design			H1 H5					
Flood Impacts								

Unsuitable Land Use   Not Relevant   Potentially unsuitable. Significant risk management required to manage flood risk

<u>Floor Level Controls</u>

A1. All floor levels to be no lower than the 5% AEP flood unless justified by site-specific assessment.

A2. All floor levels to be equal to or greater than the FPL (1% AEP flood level plus 0.8 m freeboard). If significant access issues or other constraints are present, a reduced floor level no lower than the 1% AEP flood level may be considered if justified by a site-specific assessment.

A3. Additions with a habitable floor area of up to 30 m² may be approved with floor levels below the 1% AEP flood level if the applicant can demonstrate that no practical alternatives exist for constructing the extension above the 1% AEP flood level. For additions with habitable floor areas exceeding 30 m², floor levels are to be equal or greater than the FPL (1% AEP flood level plus 0.8 m freeboard).

A4. All floor levels to be equal to or greater than the FPL (1% AEP flood level plus 0.8 m freeboard).

A5. All floor levels to be equal to or greater than the PMF flood level.

A6. Entrance levels to underground spaces (basements, carparking etc.) are required to be above the level of the FPL (1% AEP flood level plus 0.8 m freeboard) or PMF level, whichever is higher.

<u>Building Components</u>

D1. All structures to have flood compatible building components below the FPL (1% AEP flood level plus 0.8 m freeboard).

D2. All structures to have flood compatible building components below the FPL (1% AEP flood level plus 0.8 m freeboard) or the PMF level, whichever is the highest.

<u>Structural Soundness</u>

E1. Engineers report to certify that any structure can withstand the forces of floodwater, debris and buoyancy up to and including the FPL (1% AEP flood level plus 0.8 m freeboard).

E2. Engineers report to certify that any structure can withstand the forces of floodwater, debris and buoyancy up to and including the FPL (1% AEP flood level plus 0.8 m freeboard) or a PMF, whichever is greater.

Parking and Driveway Access

F1. The minimum surface level of open car parking spaces or carports shall be as high as practical, but no lower than the 5% AEP flood or the level of the crest of the road at the location where the site has access. In the case of garages, the minimum surface level shall be as high as practical but no lower than the 5% AEP flood.

F2. The minimum surface level of open car parking spaces, carports or garages shall be as high as practical. The driveway providing access between the road and parking space shall be as high as practical and generally rising in the egress direction.

F3. Garages capable of accommodating more than three motor vehicles on land zoned for urban purposes, or enclosed car parking, must be protected from inundation by floods up to the FPL (1% AEP flood level plus 0.8 m freeboard).

F4. The level of the driveway providing access between the road and parking space shall be no lower than 0.3 m below the 1% AEP flood or such that the depth of inundation during a 1% AEP flood is not greater than either the depth at the road or the depth at the car parking space. A lesser standard may be accepted for single detached dwelling houses where it can be demonstrated that risk to human life would not be compromised.

F5. Enclosed car parking and car parking areas accommodating more than three vehicles (other than on Rural zoned land), with a floor level below the 5% AEP flood or more than 0.3 m below the 1% AEP flood level, shall have adequate warning systems, signage and exits. Restraints or vehicle barriers are to be provided to prevent floating vehicles leaving the site during a 1% AEP flood.

Evacuation and Refuge

G1. Reliable access for pedestrians or vehicles required to a publicly accessible location above the PMF via a rising road.

G2. Reliable access for pedestrians or vehicles required during a 1% AEP flood to a publicly accessible location above the PMF.

G3. The development is to be consistent with any relevant flood evacuation strategy or similar plan.

G4. The evacuation requirements of the development are to be considered. An engineer's report will be required if circumstances are possible where the evacuation of persons might not be achieved within the effective warning time.

Management and Design

H1. Applicant to demonstrate that potential development as a consequence of a subdivision proposal can be undertaken in accordance with this DCP.

H2. Site Emergency Response Flood Plan required where floor levels are below the FPL (1% AEP flood level plus 0.8 m freeboard), except for single dwelling-houses.

H3. Applicant to demonstrate that area is available to store goods above the FPL (1% AEP flood level plus 0.8 m freeboard).

H4. No storage of materials below the FPL (1% AEP flood level plus 0.8 m freeboard) which may cause pollution or be potentially hazardous during any flood.

H5. Finished land levels in new release areas shall be not less than the 1% AEP mainstream flood plus 0.5 m, unless justified by site specific assessment. A surveyor's certificate will be required upon completion certifying that the final levels are not less than the required level.

Flood Impacts

J1. Provision of a report developed by an engineer who specialises in hydrology and floodplain modelling is required to certify that the development will not adversely affect flooding elsewhere. The report must show the:

1. Loss of storage in the floodplain. For sites located in areas of 1% AEP flood storage, assessment is to include consideration of the loss of storage resulting from cumulative development of the area.
2. Changes in flood levels and flow velocities caused by alteration of conveyance of flood waters. The capacity and conveyance of existing flowpaths shall be maintained.
3. Impacts of urbanisation on peak flood flows and volumes.

There is an exception to this requirement – no report is required for small developments such as a car port, in ground swimming pool or backyard shed less than 9 m^2, that do not alter the existing ground level.

H7 - Flood Compatible Materials

For areas where flood planning controls require the use of flood compatible materials, the materials outlined in Table 51 shall be used. Materials not listed may be accepted by Council subject to certification of the suitability of the material of the manufacturer.

Table 51: Flood Compatible Materials

Component	Flood Compatible Material
Flooring and sub-floor	• Concrete slab-on-ground monolith construction • Suspended reinforced concrete slab
Floor Covering	• clay tiles • concrete, precast or in situ concrete tiles • epoxy, formed–in– place • mastic flooring, formed–in–place • rubber sheets or tiles with chemical set adhesives • silicone floors formed–in–place • vinyl sheets or tiles with chemical–set adhesive • ceramic tiles, fixed with mortar or chemical–set adhesive • asphalt tiles, fixed with water resistant adhesive
Wall Structure	• Solid brickwork, blockwork, reinforced concrete or mass concrete
Wall and Ceiling Linings	• Fibro-cement board • Brick, face or glazed • Clay tile glazed in waterproof mortar • Concrete • Concrete block • Steel with waterproof applications • Stone, natural solid or veneer, waterproof grout • Glass blocks • Glass • Plastic sheeting or wall with waterproof adhesive
Roof Structure	• Reinforced concrete construction • Galvanised metal construction
Insulation	• Closed cell solid insulation • Plastic/polystyrene boards
Doors	• Solid panel with water proof adhesives • Flush door with marine ply filled with closed cell foam • Painted metal construction • Aluminium or galvanised steel frame
Windows	• Aluminium frame with stainless steel rollers or similar corrosion and water-resistant material.
Nails, Bolts, Hinges and Fittings	• Brass, nylon or stainless steel • Removable pin hinges • Hot dipped galvanised steel wire nails or similar

Main Power Supply	• Subject to the approval of the relevant authority the incoming main commercial power service equipment, including all metering equipment, shall be located above the designated flood planning level. Means shall be available to easily disconnect the dwelling from the main power supply.
Wiring	• All wiring, power outlets, switches, etc., shall be located above the designated flood planning level. All electrical wiring installed below this level shall be suitable for continuous underwater immersion and shall contain no fibrous components. This will not be applicable for below-ground car parks where the car park complies with flood planning level requirements. • Earth leakage circuit-breakers (core balance relays) or Residual Current Devices (RCD) must be installed. • Only submersible type splices shall be used below maximum flood level. • All conduits located below the relevant designated flood level must be so installed that they will be self-draining if subjected to flooding.
Electrical Equipment	• All equipment installed below or partially below the designated flood planning level shall be capable of disconnection by a single plug and socket assembly.
Heating and Air Conditioning Systems	• Heating and air conditioning systems shall be installed in areas and spaces of the house above the designated flood planning level
Fuel storage for heating purposes	• Heating systems using gas or oil as a fuel shall have a manually operated valve located in the fuel supply line to enable fuel cut-off. • The heating equipment and related fuel storage tanks should be mounted on and securely anchored to a foundation pad of sufficient mass to overcome buoyancy and prevent movement that could damage the fuel supply line. The tanks should be vented above the flood planning level.
Ducting for heating/cooling purposes	• All ductwork located below the relevant flood level shall be provided with openings for drainage and cleaning. Self-draining may be achieved by constructing the ductwork on a suitable grade. Where ductwork must pass through a water-tight wall or floor below the relevant flood level, a closure assembly operated from above relevant flood level shall protect the ductwork.
Fencing	• Fencing must be designed to minimise flow obstruction and ensure that fencing does not become unsafe during flood. Fence design must ensure that the integrity of the fence structure is maintained during flood and that flood behaviour is not adversely affected.

H8 - Frequently Asked Questions

The following section is not part of the draft DCP section and has been provided to assist Council in community awareness of the FRMS&P and planning changes.

Q: What is Council's role in managing flooding in Goulburn?

A: Goulburn Mulwaree Council has a responsibility to manage flood risk with its Local Government Area (LGA) as per the requirements of the NSW Flood Prone Land Policy and NSW Floodplain Development Manual (2005). This means that Council undertakes studies to understand the range of flood events that can occur, with technical and financial assistance from the NSW government. Council can then develop a Floodplain Risk Management Plan for flood-affected areas, which aims to reduce or otherwise manage flood risk in the long term. This Plan could include flood managements measures ranging from large-scale civil works, such as the construction of levees, to non-works interventions, such as planning controls for new developments.

Q: Why is Council proposing different planning controls for different areas of Goulburn, based on their flood risk?

A: Flood planning controls are used by Council to ensure that new development does not increase flood risk. For example, flood risk to new buildings is managed by requiring that floor levels are set at or above the Flood Planning Level, or that new buildings are not constructed in hazardous flood areas. In accordance with national guidance on flood planning, Council is proposing to use different planning controls in areas with high flood risk, compared to areas with low risk. Examples of how this applies in practice are:

- Hospitals, aged care and emergency services can only be built in areas above the Probable Maximum Flood (the largest possible flood that can occur)
- Houses can be built in areas with low flood risk but will need to have a floor level at or above the Flood Planning Level. Houses would not be able to be built in areas that are considered too dangerous from a flood risk perspective.
- Subdivisions can be made on flood-prone land provided that new houses as a result of the subdivision can be built to ensure safety and that access and evacuation is considered in the design.

By using these different areas, Council aims to allow development of the floodplain while ensuring flood risk does not increase. This means preventing most types of development in low-lying areas with hazardous flow, while allowing for some development on the fringes of the floodplain.

Q: Will new flooding mapping increase my home insurance?

A: Council does not have a say in insurance prices, however, in general, the location of flood-liable land in Goulburn has been well-established for a number of years and new mapping is unlikely to affect insurance prices. Insurance companies estimate the risk of flooding using a range of sources. This could include information presented as part of the Flood Study completed in 2016, which have not changed significantly as part of the current study. Insurance companies and the Insurance Council of Australia can provide more information on this matter.

Q: Will new flooding mapping affect my property value?

A: It is possible that flood risk is a factor in valuing a property. Mapping of flood-liable land in Goulburn has been publicly available as part of the Flood Study completed in 2016, and for this reason, flood mapping in this study is unlikely to affect property prices.

Q: Why do Council's flood extent maps extend beyond any recorded flood event?

A: In mapping flood-liable areas, Council is obliged to consider the full range of possible floods that can occur. This includes small floods that happen every few years on average, but also very rare floods that may occur once or less in a person's lifetime. The state government's definition of flood liable land is all land affected in a Probable Maximum Flood, which is an extremely rare event. Use of this extreme flood event means that many properties in Goulburn will lie on what is technically flood-liable land despite not necessarily experiencing flooding in the last two hundred years.

Appendix I – Suggested Mitigation Measures

Appendix J – Cost Estimates

All cost estimates are prepared for the purposes of feasibility assessment only and rely on various assumptions. They are not based on a detailed design, nor do they incorporate any existing studies, regarding geotechnical or environmental analysis. While the cost estimates can be used at a later stage of the project, all changes in scope that may have occurred must be included in a revised estimate, and item costs should be updated to reflect up-to-date market conditions.

Costing Estimate - League Park Levee (Option L04)					
No.	**Item**	**Unit rate ($)**	**Amount**	**Units**	**Cost**
1	**Pre-construction Costs**				
1.1	Detailed Survey		1		
1.2	Contractor setup including WHS		1		
1.3	Project Management		1		
	Assume 10% of construction cost				$ 67,774.32
1.4	Detailed Design (assumed 10% of construction cost)				$ 67,774.32
2	**Site Preparation**				
2.1	Clear site of light vegetation and cart away	$0.38	9107.0	m2	$ 3,460.66
2.2	Large trees removal (~10)	$944.00	10.0	m3	$ 9,440.00
3	**Earthworks**				
3.1	Excavation for concrete levee	$22.00	1021.0	m3	$ 22,462.44
3.2	Placement, compaction and shaping	$6.50	9578.4	m2	$ 62,259.82
3.3	Excavation of fill for earth levee	$22.00	9164.9	m3	$ 201,628.89
3.4	Haulage of fill (assumed <10 km)	$13.80	9164.9	m3	$ 126,476.30
3.5	Topsoil and grass placement	$10.60	6385.6	m2	$ 67,687.60
3.6	Hydro mulch, sprayed grass seed compound	$3,250.00	0.6	ha	$ 2,075.33
4	**Civil Construction**				
4.1	40 Mpa Concrete in levee	$224.00	382.9	m3	$ 85,765.70
4.2	Steel reinforcement in levee (allow 100 kg/m3)	$2,520.00	38.3	tonne	$ 96,486.41
5	**Contingency**				
5.1	Assume 20% of construction cost				$ 162,658.36
				Subtotal	$ 975,950.14
				GST	$ 97,595.01
				Total	$ 1,073,545.15

Appendix J – Options Costing

Costing Estimate - Eastgrove Levee (Option L05)					
No.	**Item**	**Unit rate ($)**	**Amount**	**Units**	**Cost**
1	**Pre-construction Costs**				
1.1	Detailed Survey		1		
1.2	Contractor setup including WHS		1		
1.3	Project Management		1		
	Assume 10% of construction cost				$ 230,446.25
1.4	Detailed Design (assumed 10% of construction cost)				$ 230,446.25
2	**Site Preparation**				
2.1	Clear site of light vegetation and cart away	$0.38	4267.3	m2	$ 1,621.56
2.2	Demolition of roads (130m on Park Rd & 140m on Glenelg St)	$3.50	5312.5	m3	$ 18,593.92
2.3	Small trees removal (~10)	$100.00	10.0	m3	$ 1,000.00
3	**Earthworks**				
3.1	Excavation for concrete levee	$22.00	544.7	m3	$ 11,982.79
3.2	Placement, compaction and shaping	$6.50	18745.7	m2	$ 121,847.08
3.3	Excavation of fill for earth levee	$22.00	37808.0	m3	$ 831,775.88
3.4	Haulage of fill (assumed <10 km)	$13.80	37808.0	m3	$ 521,750.32
3.5	Topsoil and grass placement	$10.60	18745.7	m2	$ 198,704.48
3.6	Hydro mulch, sprayed grass seed compound	$3,250.00	1.9	ha	$ 6,092.35
3.7	Excavation of Glenelg St and Park Rd Bridge	$22.00	5312.5	m3	$ 116,876.10
3.8	Placement, compaction and shaping for bridge	$6.50	5312.5	m3	$ 34,531.57
3.9	Haulage of fill for bridges	$13.80	5312.5	m3	$ 73,313.19
4	**Civil Construction**				
4.1	40 Mpa Concrete in levee	$224.00	408.5	m3	$ 91,504.96
4.2	Steel reinforcement in levee (allow 100 kg/m3)	$2,520.00	40.9	tonne	$ 102,943.08
4.3	Reinstate Glenelg St and Park Rd Surface	$41.65	3343.3	m2	$ 139,250.23
4.4	Kerbs and markings (~150m)	$42.25	300.0	m	$ 12,675.00
4.5	Traffic control for Glenelg St and Park Rd	$4,000.00	5.0	days	$ 20,000.00
5	**Contingency**				
5.1	Assume 20% of construction cost				$ 460,892.51
				Subtotal	$ 3,226,247.55
				Total	$3,548,872.30

Appendix J – Options Costing

Costing Estimate - Braidwood Road Levee (Option L04)					
No.	**Item**	**Unit rate ($)**	**Amount**	**Units**	**Cost**
1	**Pre-construction Costs**				
1.1	Detailed Survey		1		
1.2	Contractor setup including WHS		1		
1.3	Project Management		1		
	Assume 10% of construction cost				$ 44,261.84
1.4	Detailed Design (assumed 10% of construction cost)				$ 44,261.84
2	**Site Preparation**				
2.1	Clear site of light vegetation and cart away	$0.38	4368.4	m2	$ 1,659.99
2.2	Break up and remove bitumen paving with basecourse	$3.50	3202.9	m2	$ 11,210.00
2.3	Large trees removal (~5)	$944.00	10.0	m3	$ 9,440.00
3	**Earthworks**				
3.1	Excavation of fill for earth levee	$22.00	5685.8	m3	$ 125,086.99
3.2	Haulage of fill (assumed <10 km)	$13.80	5685.8	m3	$ 78,463.66
3.3	Placement, compaction and shaping	$6.50	5685.8	m2	$ 36,957.52
3.4	Topsoil and grass placement	$10.60	1560.1	m2	$ 16,536.63
3.5	Hydro mulch, sprayed grass seed compound	$3,250.00	0.2	ha	$ 507.02
4	**Civil Construction**				
4.1	Reinstate road Surface	$41.65	3021.8	m2	$ 125,856.57
4.2	Kerbs and markings (~400m)	$42.25	400.0	m	$ 16,900.00
4.3	Traffic control	$4,000.00	5.0	days	$ 20,000.00
5	**Contingency**				
5.1	Assume 20% of construction cost				$ 106,228.41
				Subtotal	$ 637,370.46
				GST	$ 63,737.05
				Total	$ 701,107.50

Appendix J – Options Costing

Costing Estimate – Wollondilly River Dredging and Vegetation Management (Option R01)					
No.	**Item**	**Unit rate ($)**	**Amount**	**Units**	**Cost**
1	**Pre-construction Costs**				
1.1	Detailed Survey		1		
1.2	Contractor setup including WHS		1		
1.3	Project Management		1		
	Assume 5% of construction cost				$ 302,624.42
1.4	Detailed Design and Environmental Assessment (assumed 5% of construction cost)				$ 302,624.42
2	**Site Preparation**				
2.1	Clear site of light vegetation and cart away	$0.38	151000.0	m2	$ 57,380.00
2.2	Large trees removal (~50)	$944.00	100.0	m3	$ 94,400.00
3	**Earthworks**				
3.1	Excavation for the volume of Cut	$22.00	107678.1	m3	$ 2,368,919.08
3.2	Placement, compaction and shaping	$6.50	151000.0	m2	$ 981,500.00
3.3	Haulage of Net Cut/Fill (assumed <10 km)	$13.80	107220.2	m3	$ 1,479,639.31
3.4	Topsoil and grass placement	$10.60	98000.0	m2	$ 1,038,800.00
3.5	Hydro mulch, sprayed grass seed compound	$3,250.00	9.8	ha	$ 31,850.00
4	**Contingency**				
4.1	Assume 20% of construction cost				$ 1,210,497.68
				Subtotal	$ 7,868,234.91
				GST	$ 786,823.49
				Total	$ 8,655,058.40

Appendix K – Public Exhibition Submissions

This appendix contains a summary of the public exhibition submissions described in Section 5.2, and a response to each submission.

Submission	Response (GRC Hydro)
Resident noting that: • New levees for the area are not a cost-effective option • The estimate of the probable maximum flood (PMF) event appears to be too high (and is excessive).	The cost-effectiveness of each option was assessed in this study. The three levees investigated were shown to not be cost-effective which is in agreement with comments made by the resident. See Section 9.3.3 for further information on each measure's cost versus its likely benefit. The PMF was estimated using the Generalised Short Duration Method which is considered best practise in NSW. It is an exceptionally rare event that is used in emergency management and flood planning. It is not uncommon for PMF estimates of large river systems to be many metres above the 1% AEP flood level.
Resident with several comments and questions including: • Will the modelling and reporting be available for assessing flooding at a site? • Can lower freeboards (0.5m) be used for certain types of development, regarding the Flood Planning Level? • Can certain types of car parking be permitted (i.e., open under croft areas above or at minimum flood levels)? • The Flood Planning Constraint Categories (FPCC) need to be investigated further to ensure that land is not unnecessarily sterilised	Yes, modelling can be made available to assess flooding at a particular site. Regarding reporting, the current study will be available on Council's website. The freeboard in the Flood Planning Level has been determined by estimating all relevant components of freeboard and is presented in detail in Appendix F. Goulburn has certain characteristics which mean a freeboard of 0.8 m is needed to protect against riverine flooding. It is important this freeboard is used for residential, commercial and industrial floor levels affected by 1% AEP riverine flooding. Similarly, car parking controls have been set to reduce the risk of damaging vehicles or endangering the occupants. Car parking is permitted as part of development in some flood-affected areas noting that flood risk management measures may be required (see Appendix H for the specific controls).
Representative of Goulburn Golf Club with several comments: • Supports the vegetation management-related measure, and the Total Flood Warning System measure • Suggests raising a low section of Blackshaw Road due to a flooding issue involving overland flow from the rail underpass • Levees at Eastgrove and Braidwood	Blackshaw Road has been identified by the study as having significant flooding issues and risk to pedestrians and vehicles. The study recommends installing a reliable boom gate to stop vehicles entering floodwaters (see Section 9.2.3.4). Raising the road was also considered but was not considered feasible (see Section 9.3.2). The levees assessed by the study were considered for their impact on other areas. The Eastgrove levee was found to have widespread impacts which meant it was not recommended (along with other factors). The Braidwood

Road may adversely impact the golf club	Road levee was not found to have significant impacts but was also not recommended, for other reasons.
Resident with several comments including: • Recent changes have affected flood behaviour, including the new Lansdowne Bridge, raising Bungonia Road and the stormwater drain at Forbes Street. • There is a drainage issue on Bungonia Road where water is accumulating before reaching the river. • Clearing of the river would be more effective than a levee in the Eastgrove area. There has been significant erosion on the respondent's property in the last five years, due to the blocked river. • River clearing would also be more effective than flood warning signage.	The current study made significant updates to the modelling established in the 2016 study. These are set out in Section 6 of this report and the Executive Summary notes there have changes to the catchment and Goulburn area. The new Lansdowne Bridge is included in the current modelling. Overland flow flooding at Bungonia Road has not been covered in the current study, which looks at riverine flooding, but the issue can be noted by Council for any future work or studies in the area. The effect of clearing of the river was given significant focus in the current study. Three separate measures were assessed including modelling for their effect on flooding: a vegetation management plan for the area, vegetation management for the Fitzroy Flats area, and dredging and vegetation management of Wollondilly River. Debris clearing along the Mulwaree River was also considered. Measures involving dredging or debris clearing were found to either have limited effected in reducing flooding or were found to be unfeasible on other grounds. The study does recommend a Vegetation Management Plan (see Floodplain Risk Management Plan in Section 10). Levees and warning signage were investigated as the study is required to consider all reasonable measures before certain measures can be recommended. Assessment of several levee options found each had significant constraints and so they were not recommended.
Resident with several comments including: • What is the FPCC on Gibson Street? • No flooding at the end of Gibson Street has been seen in 32 years and changing the designation is unnecessary • Changes to insurance premiums may put pressure on elderly residents	The large majority of Gibson Street is FPCC 4. This covers a large portion of land in Goulburn and means the land is not affected by 1% AEP flooding but can be flooded in an extreme flood event (PMF). FPCC 4 has no planning controls on standard residential or commercial development and is only for sensitive use and critical land use such as hospitals and aged care. Regarding insurance premiums, the area was also shown as flood liable in an extreme event in the previous study from 2016. While this report nor Council have any input on how insurance rates are set, the current study is not showing increased flood risk in this area relative to the 2016 study.
Water NSW submission • The FPL approach presented in the study is supported • The use of FPCC is also supported but believe it can obscure the location and function of the FPA and makes suggestions on how to present the information to avoid this. Also suggest changing FPCC controls around	The suggestions around presenting the Flood Planning Area are noted and will be considered by Council when preparing the DCP section. To clarify on the industrial land use and use of the Special Flood Consideration clause, Council have requested that the optional 5.22 clause be applied to the LEP 2009 which would include hazardous and offensive industries, which should meet the suggested approach.

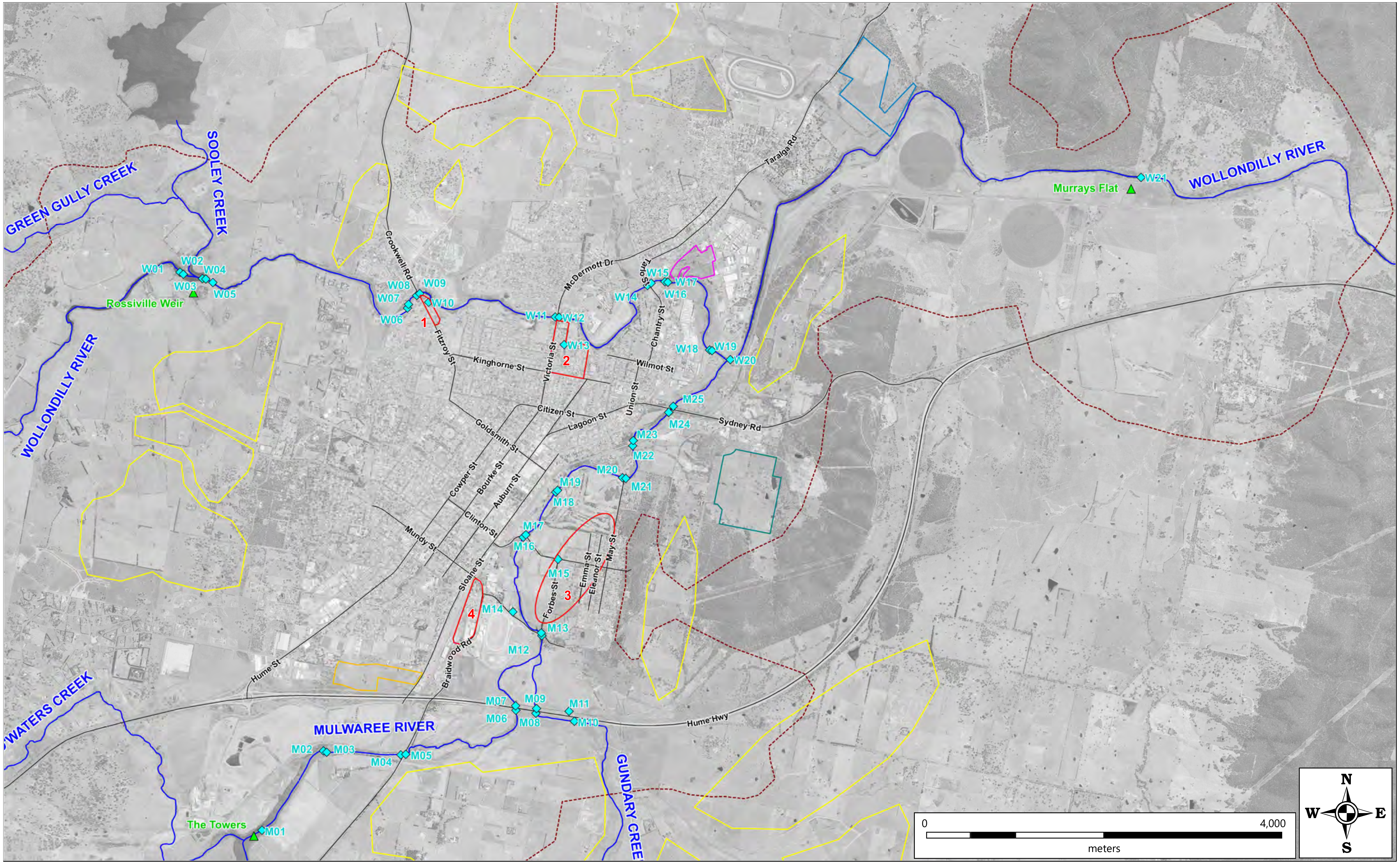
industrial use in FPCC 2d and FPCC 3. • The Special Flood Consideration clause is supported as well, and Water NSW would support it being applied to the full range of uses permissible by the instrument. • The Study area be expanded to include Urban and Fringe Housing Strategy (UFHS) areas. Given ongoing development in Goulburn, would like to see UFHS areas overlaid with a flood risk map. • It is recommended that the Considering flooding in land use planning guideline 2021 be taken into account and this document be included in Table 3. • That section 4.2.2.1 be expanded noting that clause 7.1 has since been repealed and replaced by clause 5.21. • That the FRMS include a brief analysis regarding how new clause 5.21 does or does not address the issues raised in the appraisal of former clause 7.1. • That the FRMS defines what it means by 'extreme events' for the uses and sites described used in Tables 24-27. • That the information presented in Tables 24-27 be accompanied by relevant maps showing the location of the sites in relation to the FPCC categories (Figure H1) and the FPA (Figure 8). • It is recommended Council explore how to manage risk associated with the flood-affected evacuation centres, SES office, sewage treatment plant and the correctional centre • It is recommended that the Option PM02 (Updated Section 10.7 Planning Certificates) be used to provide information to all flood-affected lots, including up to the PMF, and that information on FPCC at a lot be provided as supplementary information. • The recommendation of Option PM04 should include the updated FPA/FPL in the revised DCP. • The FPCC definitions be clarified to better explain what is included in the FPA and also explain how FPCC2d was derived. • Various questions and comments on UFHS	The UFHS has been considered as part of this study, specifically the Review of Future Development Areas (Option PM07). This looked at the estimated riverine FPCC, the likelihood of tributary or overland flooding, and the estimated suitability of the area from a flooding perspective, for each of the UFHS areas. The majority of the principles presented in the guideline have been included in the current study's risk assessment and recommendations. However, it came into effect in July 2021 after the assessment had been carried out and the report prepared, and so was not referenced for that reason. Please see Section 9.1.2.4 which notes the repeal of 7.1 and comments on the suitability of Clause 5.2.1. Definition of 'extreme' has been added to the report section. A figure has been added showing the location of the sensitive/critical uses and the 1% AEP and PMF extent. The FPA and FPCC are typically used in assessing existing flood risk, so they have been kept separate. Regarding Option PM02 and Section 10.7, the 2021 legislation in its Schedule 2 states flood related development controls be provided for lots in the FPA, and also "If the land or part of the land is between the flood planning area and the probable maximum flood and subject to flood related development controls.". Most lots outside the FPA will not have flood related development controls, as only Sensitive/Critical Use and Subdivision have controls in FPCC4. By our understanding Council are not required to provide Section 10.7 certificates to properties outside the FPA (apart from the above land uses). The report recommends that the DCP be updated with the new FPL and FPA. This has been included in Option PM01 while PM04 is concerning the FPCC. Both options are included in the Plan. The report text has been updated to better explain the FPCC derivation and their relationship to FPA. To clarify, Brisbane Grove UFHS area has area above the PMF (report table also updated), the location of the wastewater treatment farm potential rezoning has been noted. Report text has been updated; flood proofing is only recommended for new development. Prioritisation of certain areas for vegetation management can

• Clarification is sought on if flood proofing is only recommended for new development. • Regarding vegetation management, the measure is supported, and it is suggested to look at prioritising certain areas based on the location of flood hazard. There is significant concern regarding Option G01. • Suggestion to number recommendation boxes • Suggestion to add a summary table of all measures and comment on those that are recommended or disregarded. • Suggestion to be consistent in reference to the plan. • Suggestion to better establish why certain measures are recommended in the Plan • Suggestion to refer to a consistent number of FPCC in Appendix H and to add FPA and FPL definitions in Appendix H • Suggestion to add a clause to Appendix H flood planning controls to consider the water quality risks arising from a development, having regard to the land use type and the FPCC.	be considered as part of the measure. The report analysis does not justify targeting particular areas (i.e., this was not modelled or otherwise assessed) but that could be undertaken in the future. Regarding Option G01, this measure is not recommended and not included in the Plan. Recommendation boxes in the report are each tied to a particular measure (Option L03, etc.) and this can be referenced, if required. The requested information is available in Table 35 – a longlist of the measures – and the Draft Floodplain Risk Management Plan, which presents the recommended measures. Information on a particular measure can be searched using the measure's code (L04, L05 etc). The text has been updated and all references are now to Floodplain Risk Management Plan. The report has been updated with additional text boxes with the final recommendation for each option, to explain their inclusion/exclusion in the Plan. The number of FPCC has been made consistent. The intention is for Appendix H to be a standalone document describing FPCC and their controls. The FPA/FPL are set out in this report. The proposed flood planning controls include a requirement for storage of hazardous goods that may cause pollution. Other controls aimed at water quality risks arising from a development would likely be better applied separately to the flood planning controls.
NSW SES submission: • Request for various information relating to property flooding, Voluntary Purchase • Can the modelling be used to determine Minor, Moderate and Major flood levels on the two rivers, and noting the Wollondilly is the priority if only one is possible. • Can design heights be related to the Marsden and Lansdowne gauges rather than AHD? Similarly, can road inundation be related to gauge heights?	All requested information, where available, will be provided in a response to the SES submission. The modelling can be used to determine the three warning levels. Information in this report describing road and property flooding would provide sufficient information. The warning levels would also be considered as part of the Total Flood Warning System recommended by this study (see Section 9.2.4.3). The various design flood levels and road inundation levels cannot be currently related to a gauge height, as the gauge zero is not known. Survey of the gauge zeros at both locations would be required. This could be undertaken as part of the Total Flood Warning System recommended by this study.

Transport for NSW submission: • TfNSW has reviewed all documents and has no objection or significant comments to make regarding the documents content. • TfNSW suggests that the town maps could be amended slightly to show the Sloane/Grafton/Reynolds Streets road swap that will be happening with Auburn/Lagoon Streets in the near future. This is a matter for consideration of the strategic planner handling the amendment, however it is noted that this suggestion would not materially change anything in the report.	TfNSW submission noted. The amendment of the town maps is a Council consideration outside the scope of this Study.

Goulburn Floodplain Risk Management Study and Plan

Report Figures



Hotspots (IDs in Report)
Hydraulic Model Extent
Cadastral Boundary
Stream Gauge Location
Reporting Location
Creeks and Rivers

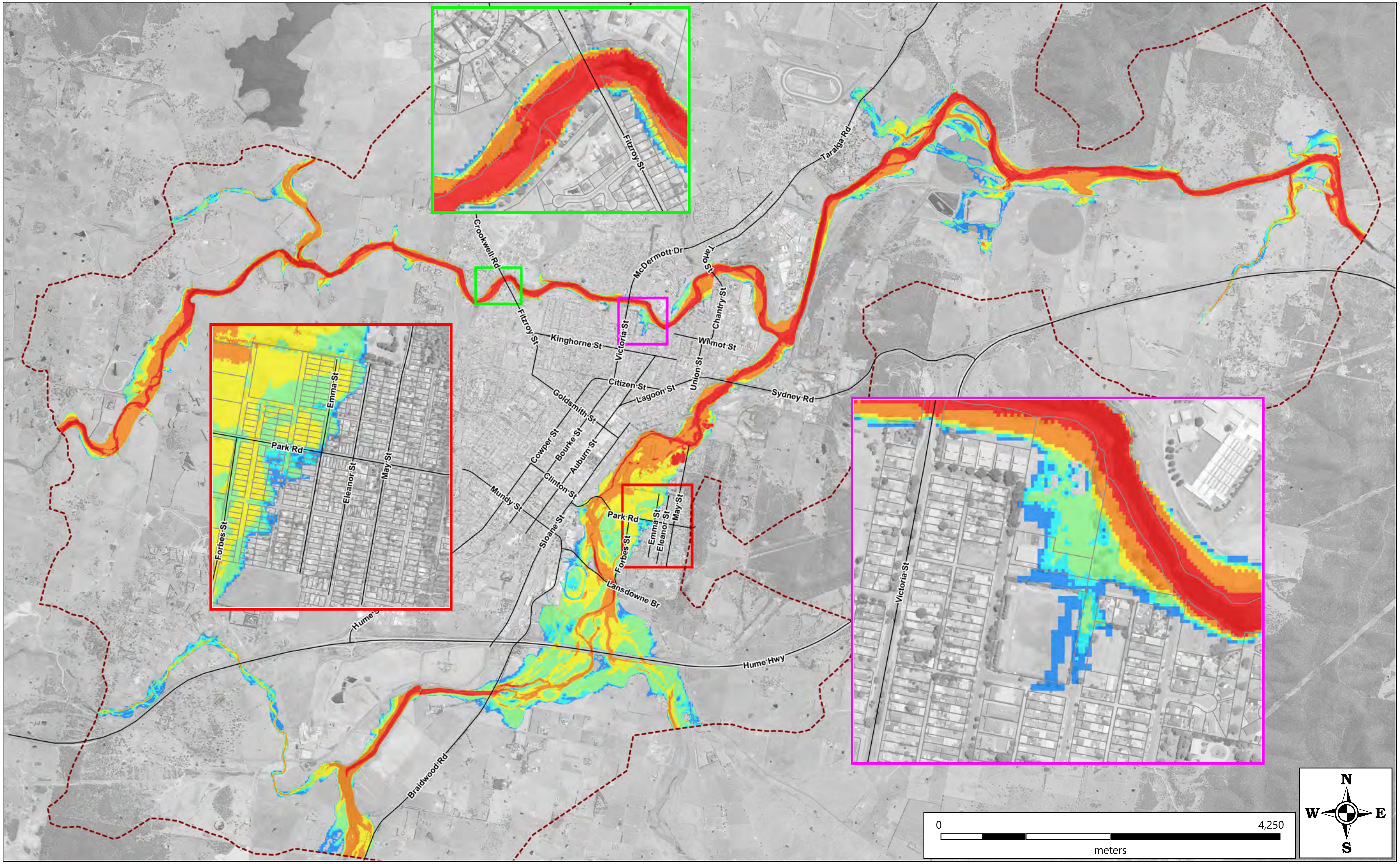
Future Development Areas
- Urban and Fringe Housing Strategy for Goulburn and Marulan
- North East Enterprise Corridor
- Dossie Street Planning Proposal
- Goulburn Health Hub on Ross Street
- Wastewater Treatment Farm

TITLE : **Study Area**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1: 42500 | FIGURE NUMBER: **01**



Hydraulic Model Extent

Cadastral Boundary

Flood Hazard (AIDR 2017)

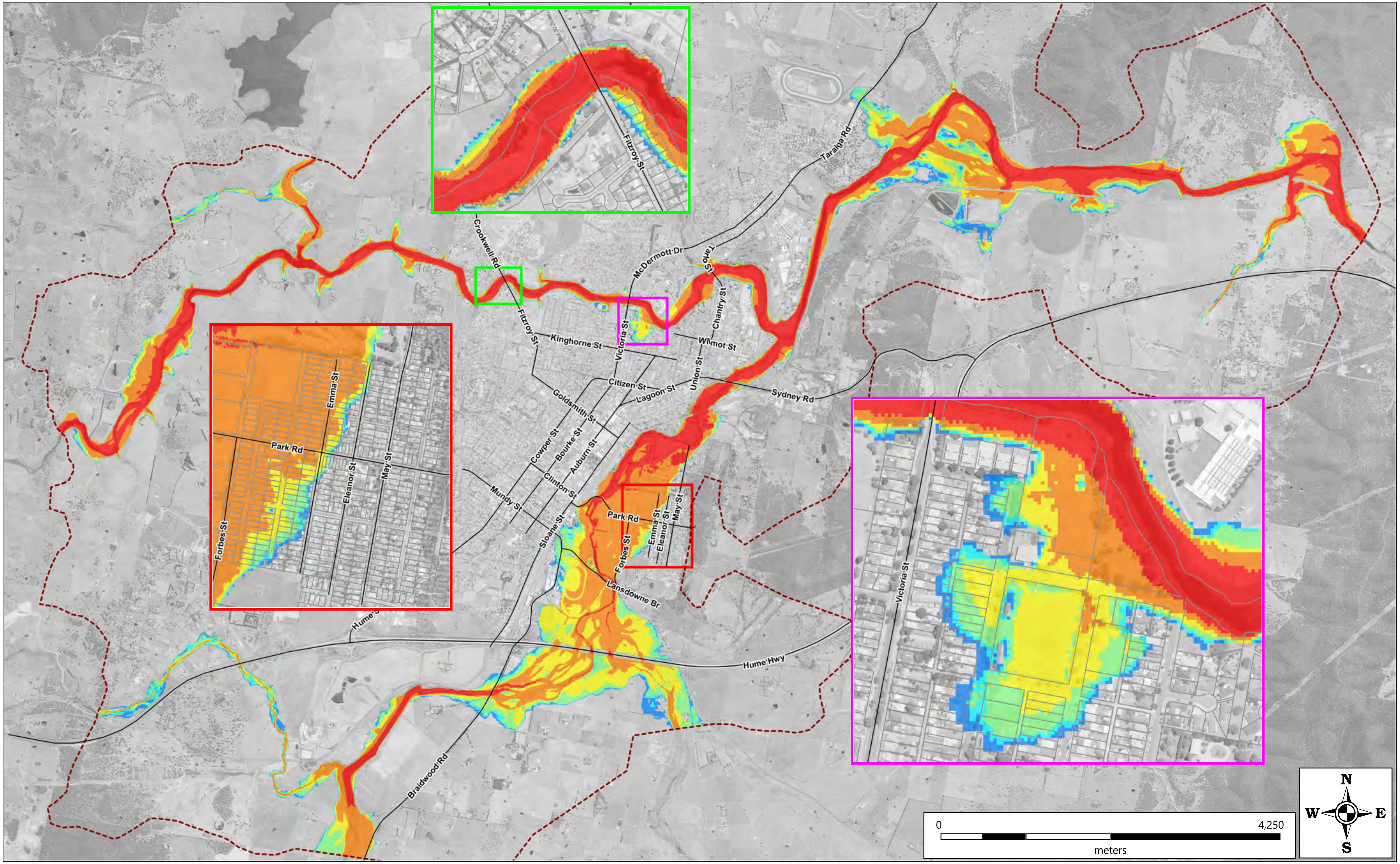
H1	H4
H2	H5
H3	H6

TITLE : **5% AEP Design Event Flood Hazard Categories**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **02**



Goulburn Mulwaree Council

Hydraulic Model Extent

Cadastral Boundary

Flood Hazard (AIDR 2017)

H1	H4
H2	H5
H3	H6

TITLE : **1% AEP Design Event Flood Hazard Categories**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 SCALE: 1:42,500 FIGURE NUMBER: **03**

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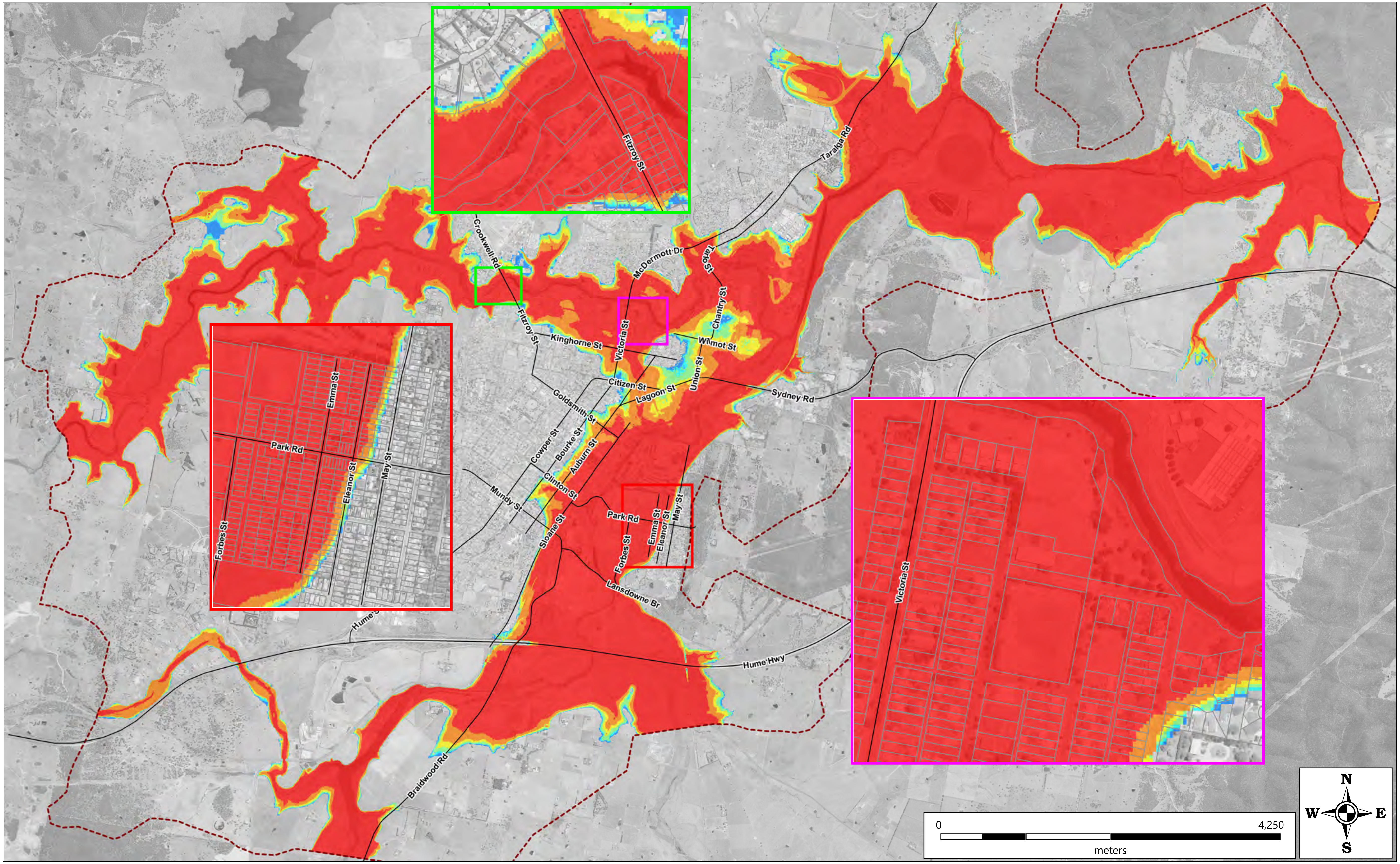

Hydraulic Model Extent

Cadastral Boundary

Flood Hazard (AIDR 2017)

H1 H2 H3 H4 H5 H6

GOULBURN MULWAREE COUNCIL

TITLE : **PMF Design Event Flood Hazard Categories**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **04**

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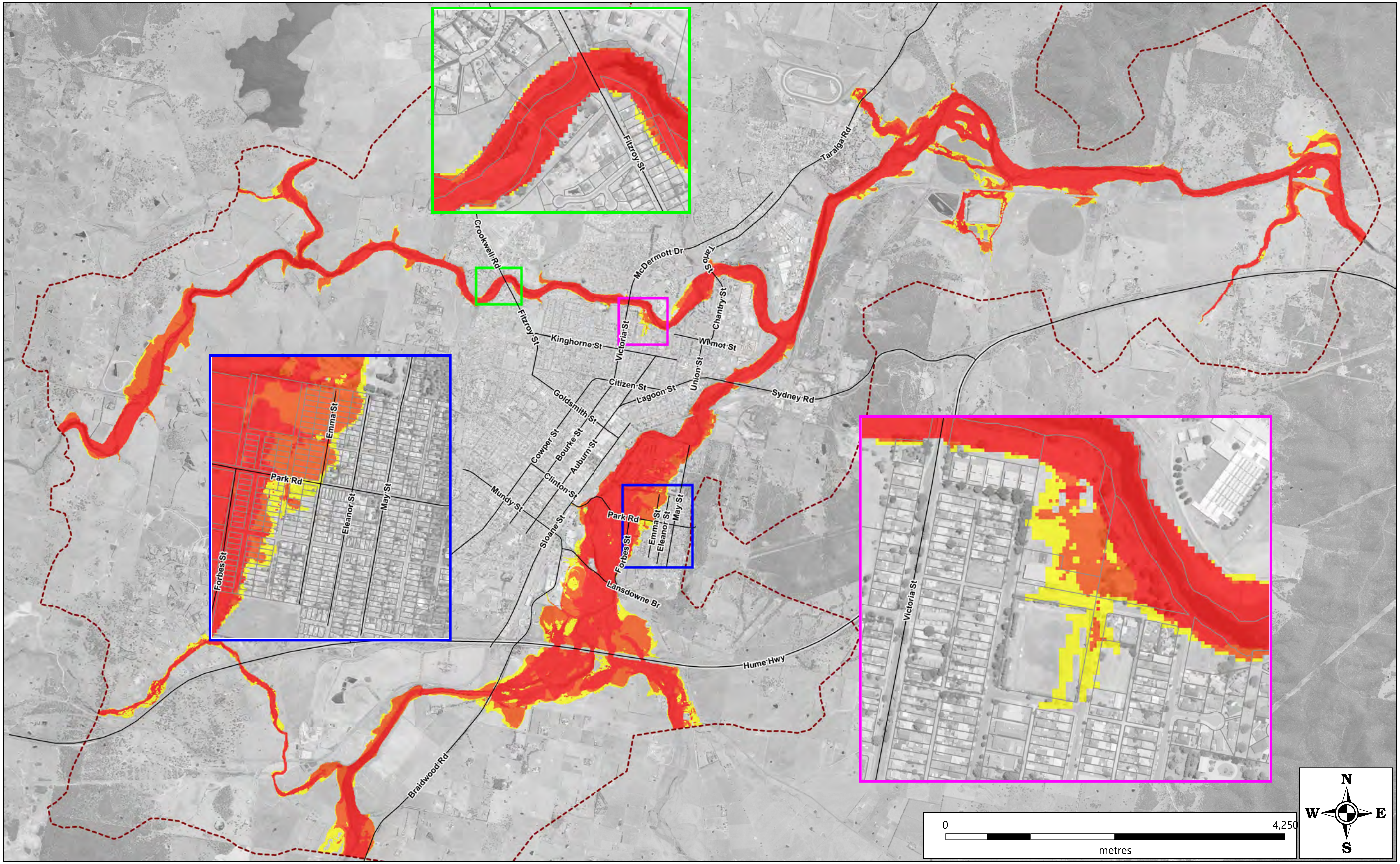


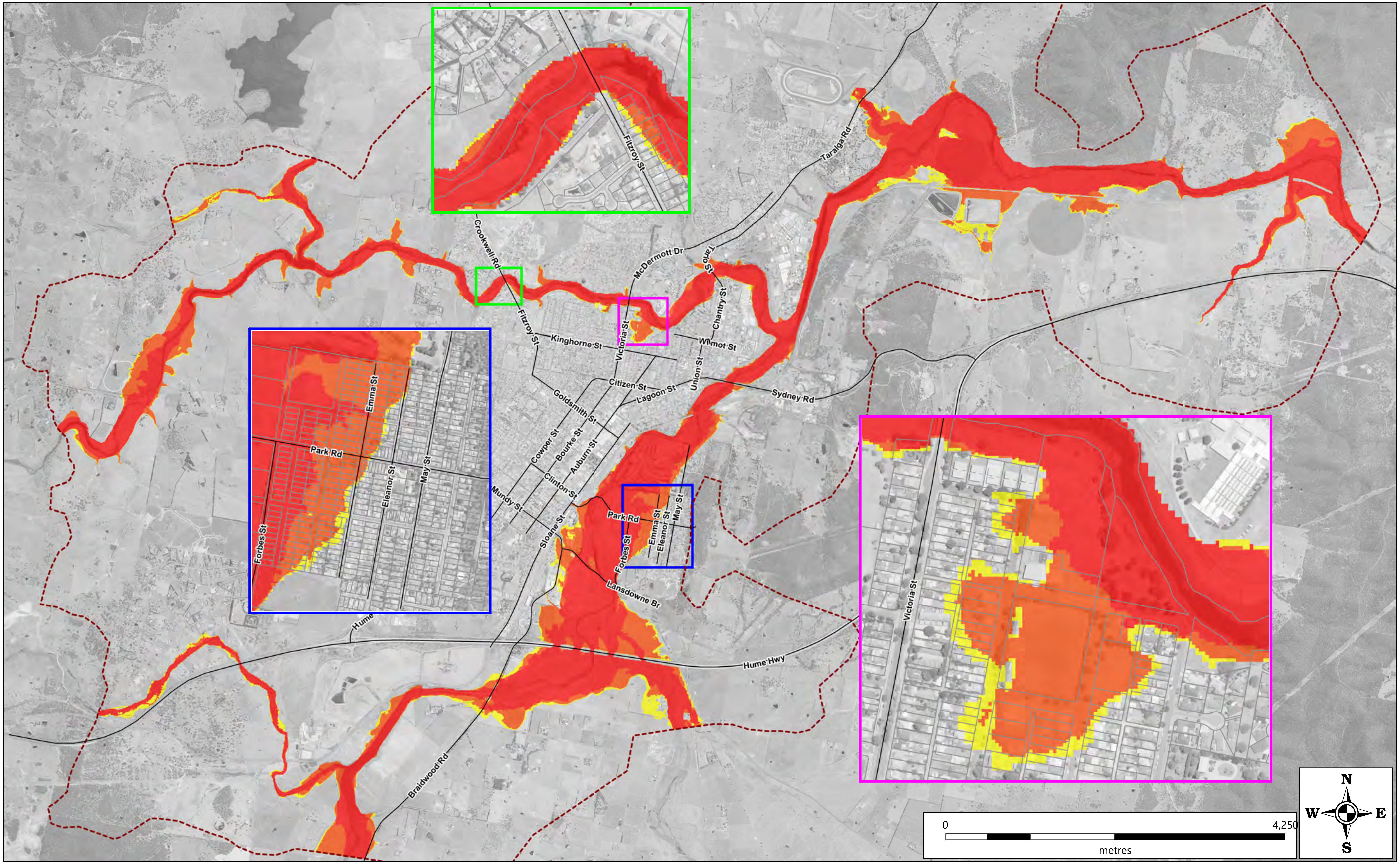
Preliminary Flood Function

- Flood Fringe
- Flood Storage
- Floodway

Hydraulic Model Extent

Cadastral Boundary

TITLE : **5% AEP Design Event Preliminary Flood Function**		
PROJECT:Goulburn Mulwaree FRMS&P		
PROJECT No. 180068		
DATE:March 2020	SCALE: 1:42,500	FIGURE NUMBER:**05**



GOULBURN MULWAREE COUNCIL

Hydraulic Model Extent

Cadastral Boundary

Preliminary Flood Function

- Flood Fringe
- Flood Storage
- Floodway

TITLE : **1% AEP Design Event Preliminary Flood Function**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020

SCALE: 1:42,500

FIGURE NUMBER: **06**

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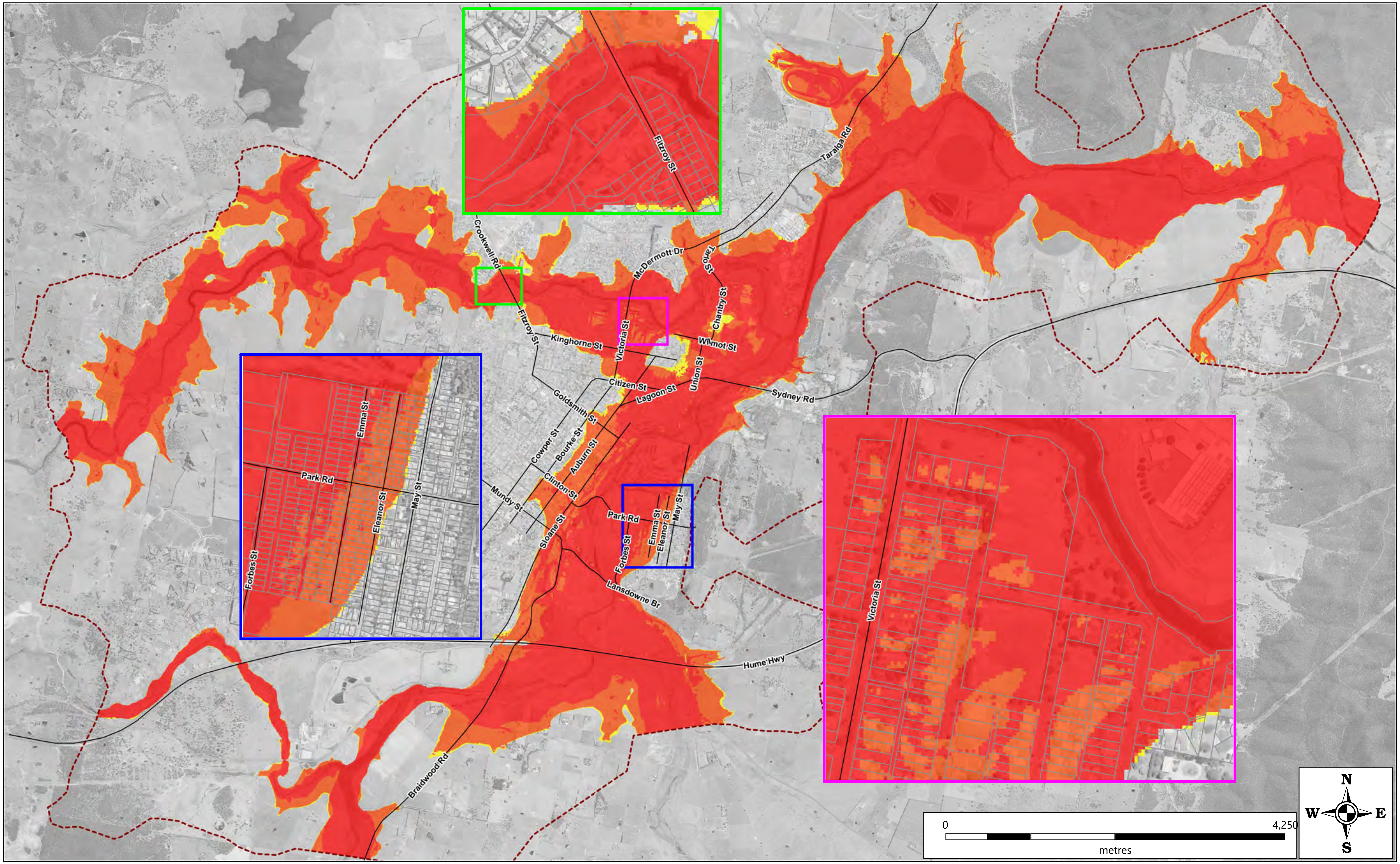


Hydraulic Model Extent
Cadastral Boundary

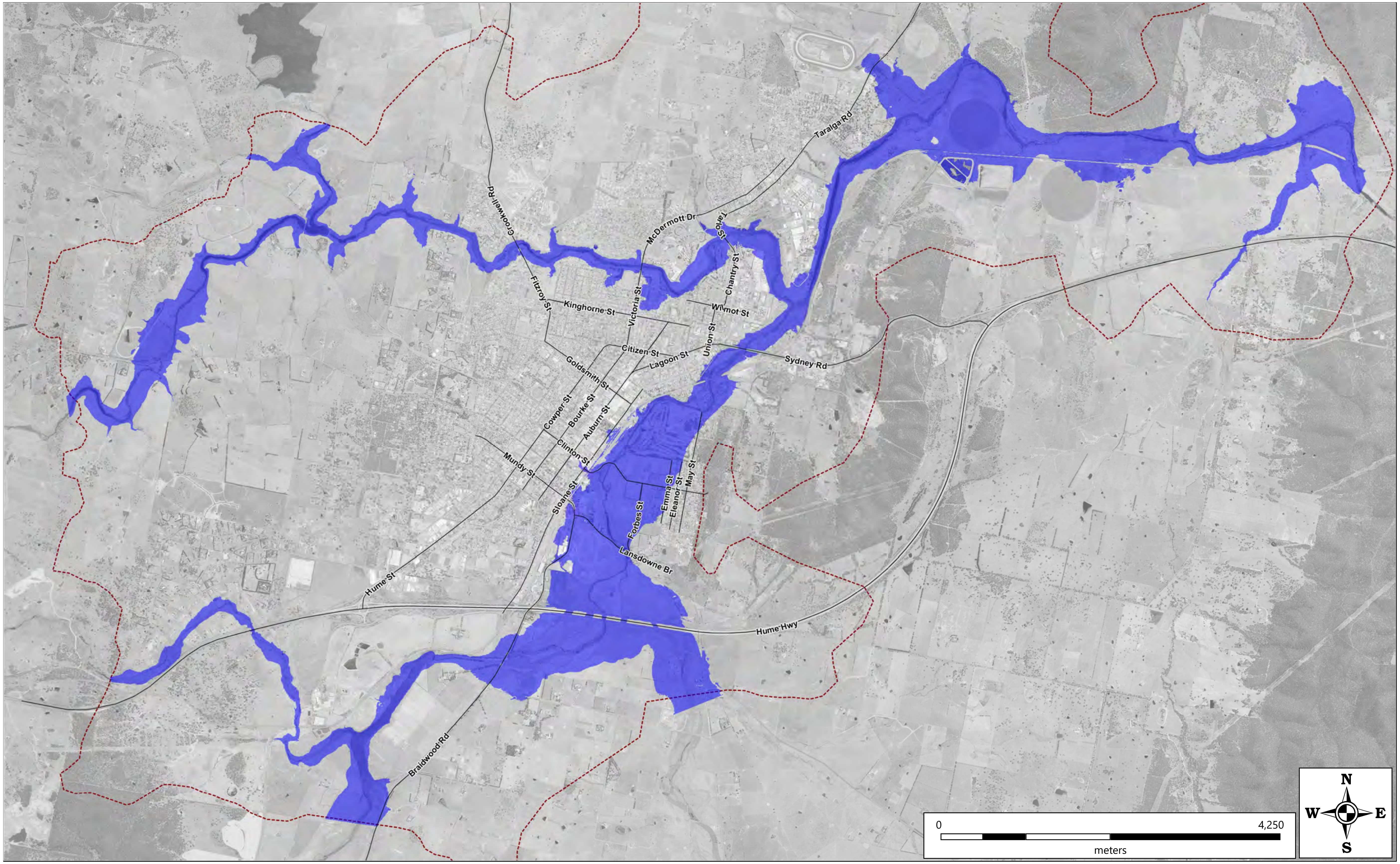
Preliminary Flood Function
Flood Fringe
Flood Storage
Floodway

TITLE : **PMF Design Event Preliminary Flood Function**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: 07



Hydraulic Model Extent

Cadastral Boundary

Flood Planning Area

TITLE : **Flood Planning Area**

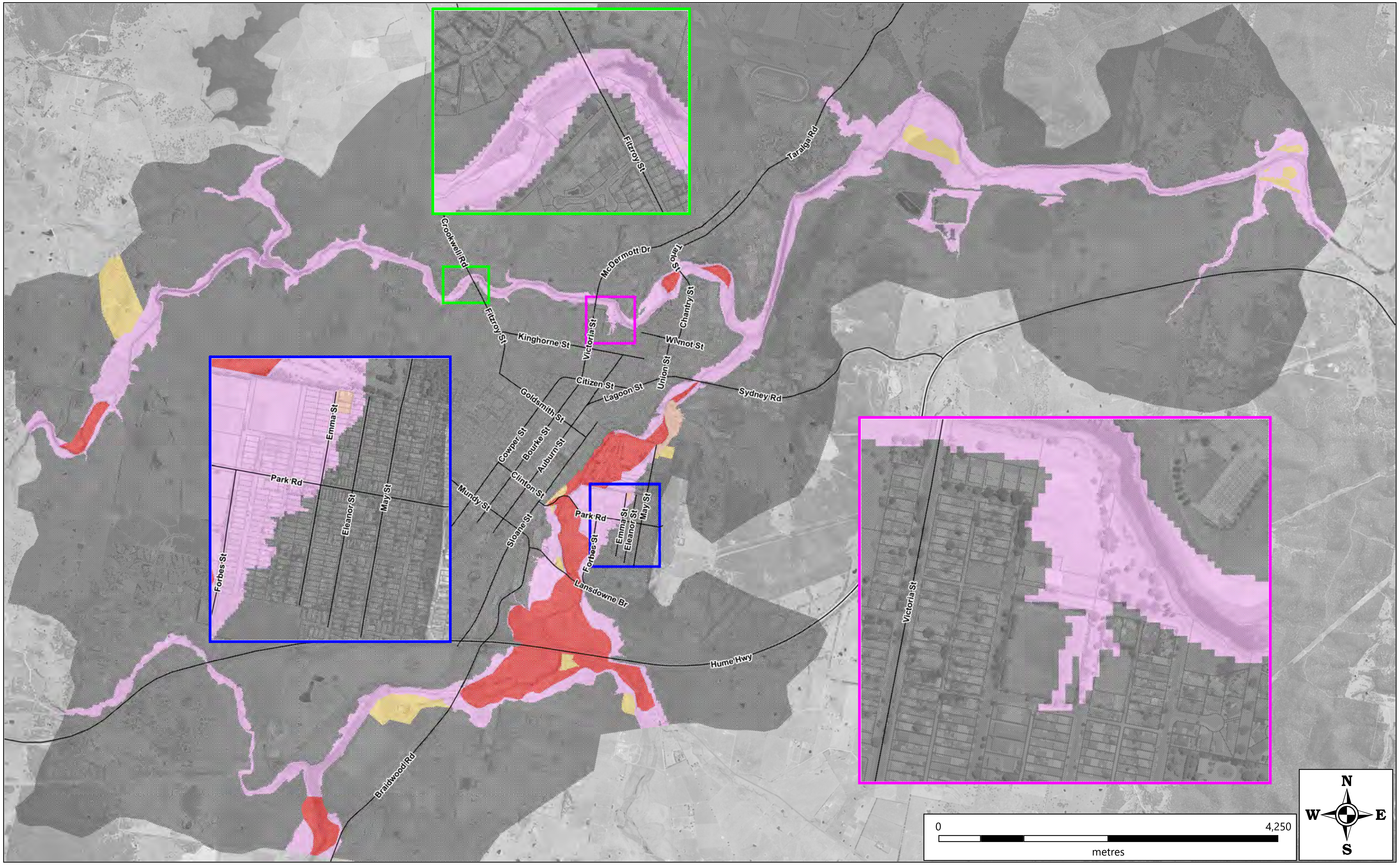
PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020

SCALE: 1:42,500

FIGURE NUMBER: **08**

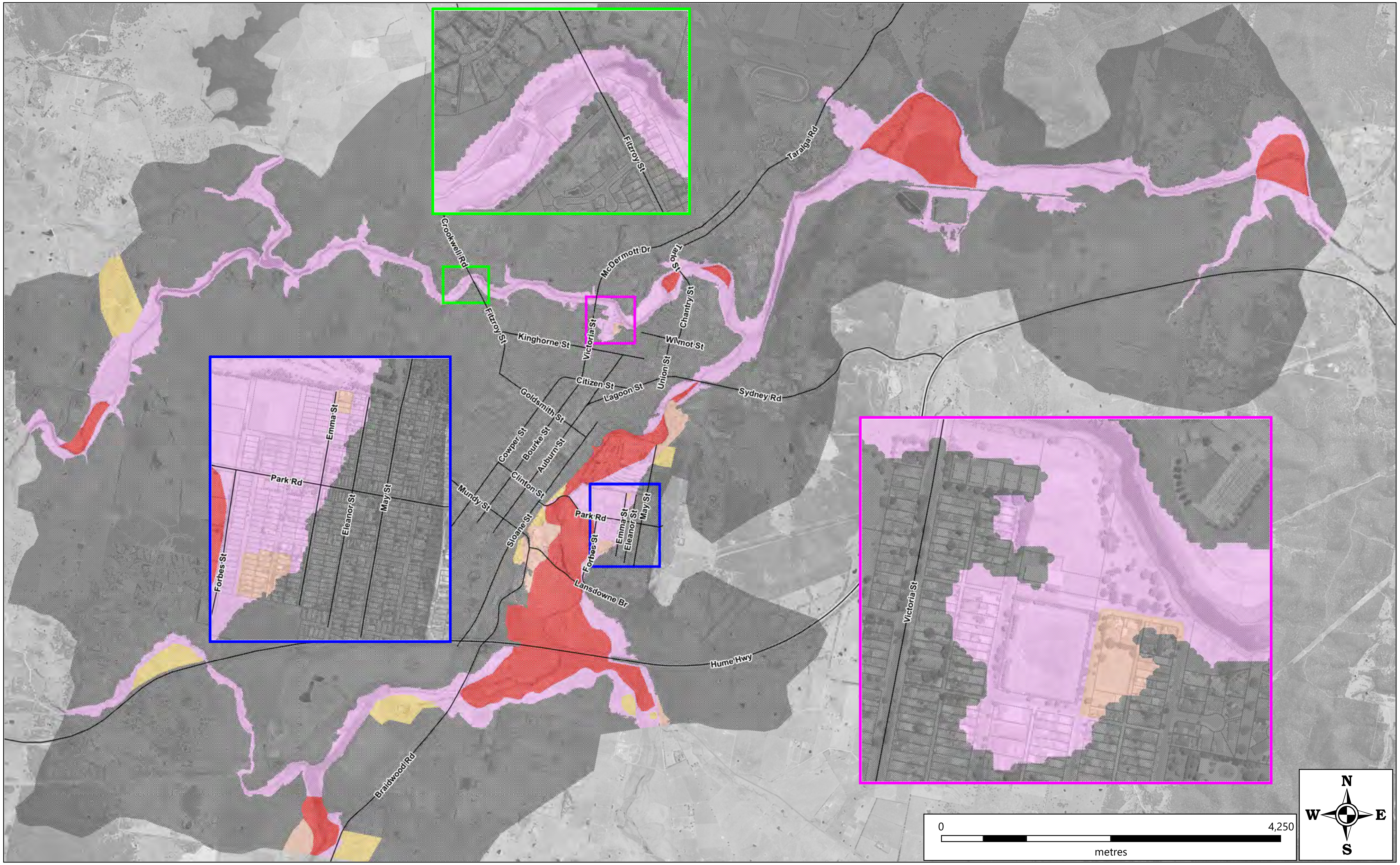


TITLE :	**5% AEP Design Event Flood Emergency Response Classification**
PROJECT:	Goulburn Mulwaree FRMS&P
PROJECT No.	180068
DATE: March 2020	SCALE: 1:42,500
FIGURE NUMBER:	**09**

Cadastral Boundary

Flood Emergency Response Classification

- Indirect Consequence (NIC)
- Isolated Elevated (FIE)
- Rising Road (FER)
- Submerged (FIS)
- Overland Escape (FEO)



Cadastral Boundary

Flood Emergency Response Classification

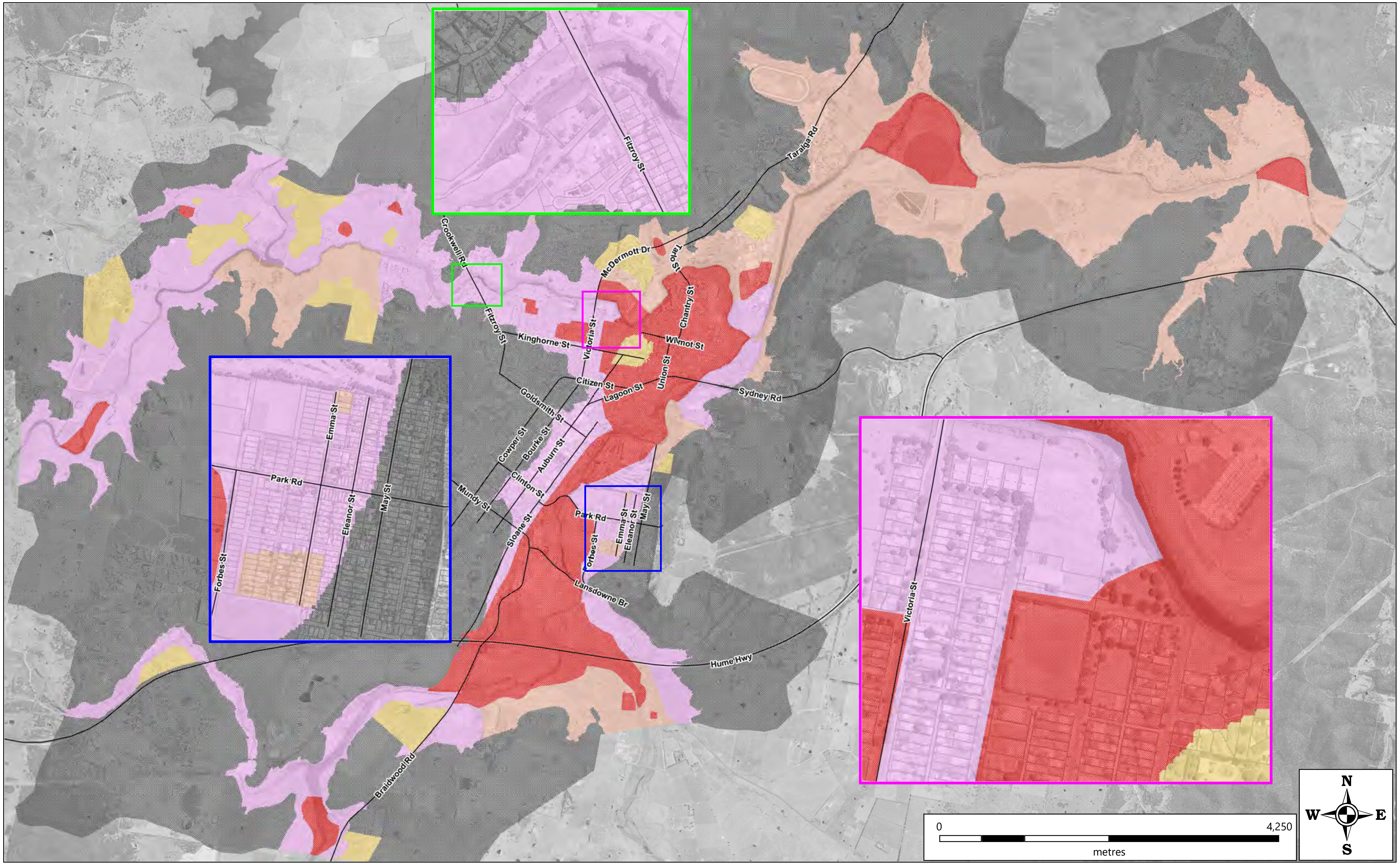
- Indifrect Consequence (NIC)
- Rising Road (FER)
- Overland Escape (FEO)
- Isolated Elevated (FIE)
- Submerged (FIS)

TITLE : **1% AEP Design Event Flood Emergency Response Classification**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **10**



Goulburn Mulwaree Council

Cadastral Boundary

Flood Emergency Response Classification

- Overland Escape (FEO)
- Rising Road (FER)
- Isolated Elevated (FIE)
- Isolated Submerged (FIS)
- Indirect Consequence (NIC)

TITLE : **PMF Design Event Flood Emergency Response Classification**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **11**

grc HYDRO

Cadastral Boundary

Evemt First Flooded Above Floor
- 10% AEP
- 5% AEP
- 2% AEP
- 1% AEP
- 0.5% AEP
- 0.2% AEP
- PMF
- Not Flooded

GOULBURN MULWAREE COUNCIL

TITLE : **Flood Damages - First Event Inundated Above Floor Level**

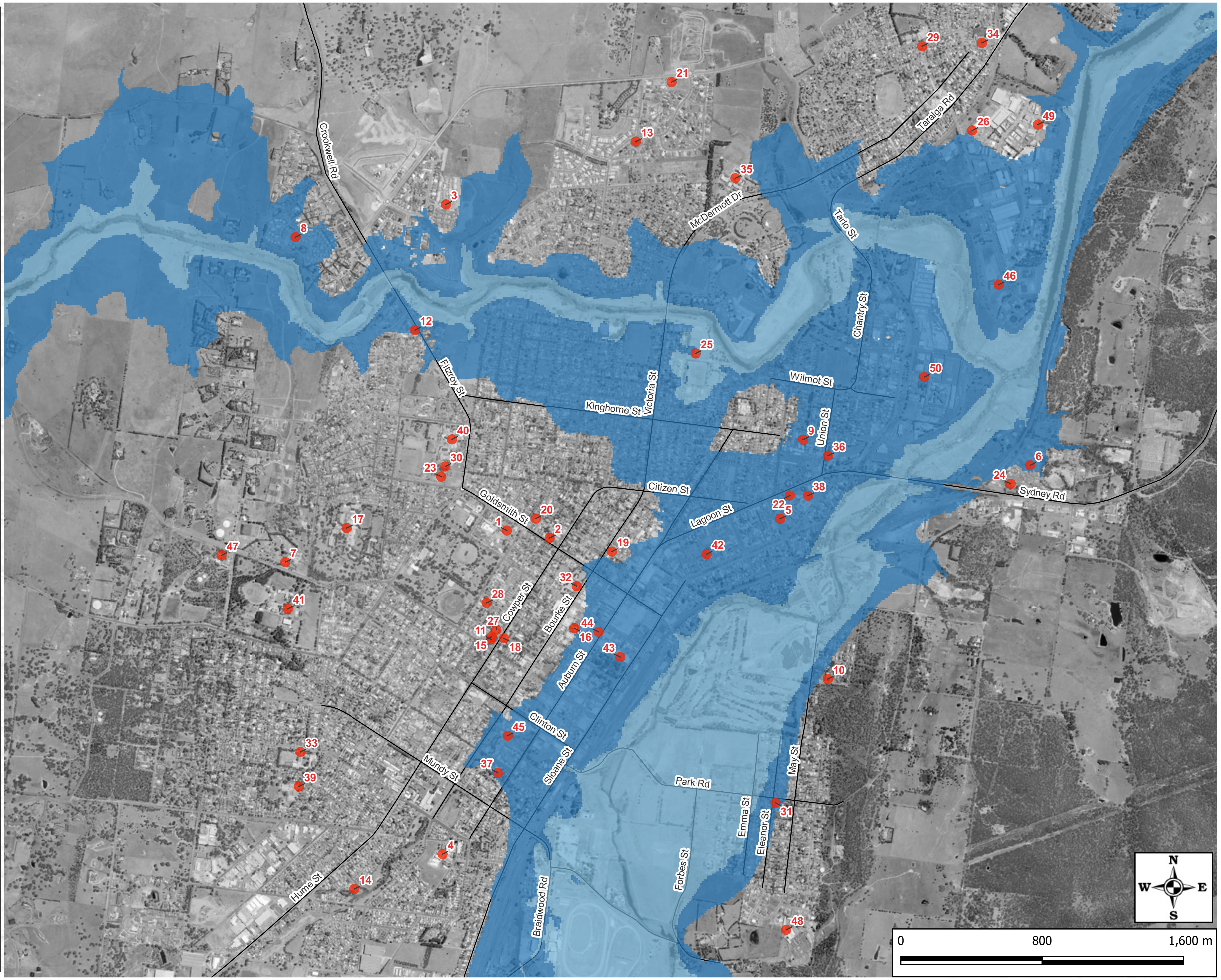
PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: February 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **12**

grc HYDRO

No	Facility
1	Goulburn Base Hospital
2	Goldsmith Street Surgery
3	Warrigal
4	Gill Waminda Aged Care Centre
5	Southern Cross Care Tenison Residential Aged Care
6	RFBI Goulburn Masonic Village
7	BaptistCare Home Services
8	Wollondilly Gardens Retirement Village
9	Ingenia Gardens Goulburn
10	Eastgrove Child Care Centre
11	Goulburn Family Day Care
12	River Heights Child Care Centre
13	Kindy Patch Goulburn
14	Scallywags Children's Centre
15	Orana Pre-School
16	SDN Goulburn Children's Education and Care Centre
17	Goulburn TAFE Children's Centre
18	St Saviour's Long Day Care
19	Cool Kids OSHC
20	Goodstart Early Learning
21	Lilac Early Learning
22	The Learning Tree Child Care Centre
23	Goulburn Pre School
24	New Horizons Pre School
25	PCYC OSHC Goulburn
26	Romp & Stomp
27	St Saviours Vacation Care
28	Goulburn High School
29	Bradfordville Public School
30	The Crescent School
31	East Goulburn Primary School
32	Goulburn Public School
33	Goulburn West Primary School
34	Goulburn Junior College
35	Mulwaree High School
36	Goulburn North Public School
37	Goulburn South Public School
38	St Josephs Primary School
39	St Peters and St Pauls Primary School
40	Wollondilly Public School
41	Trinity Catholic College
42	Tambelin Independent School
43	Goulburn Soldiers Club
44	Goulburn Works Club
45	Goulburn SES
46	Sewage Works
47	Water Filtration Plant
48	Essential Energy Depot
49	Allstate Power Pty Ltd
50	Goulburn Correctional Centre



1% AEP Flood Extent

PMF Flood Extent

Disclaimer: All locations were recorded at the time of writing. Facilities may change location over time. Individual locations should be checked before this map is used for emergency response planning.

TITLE: **Location of Sensitive Land Uses and Critical Infrastructure**

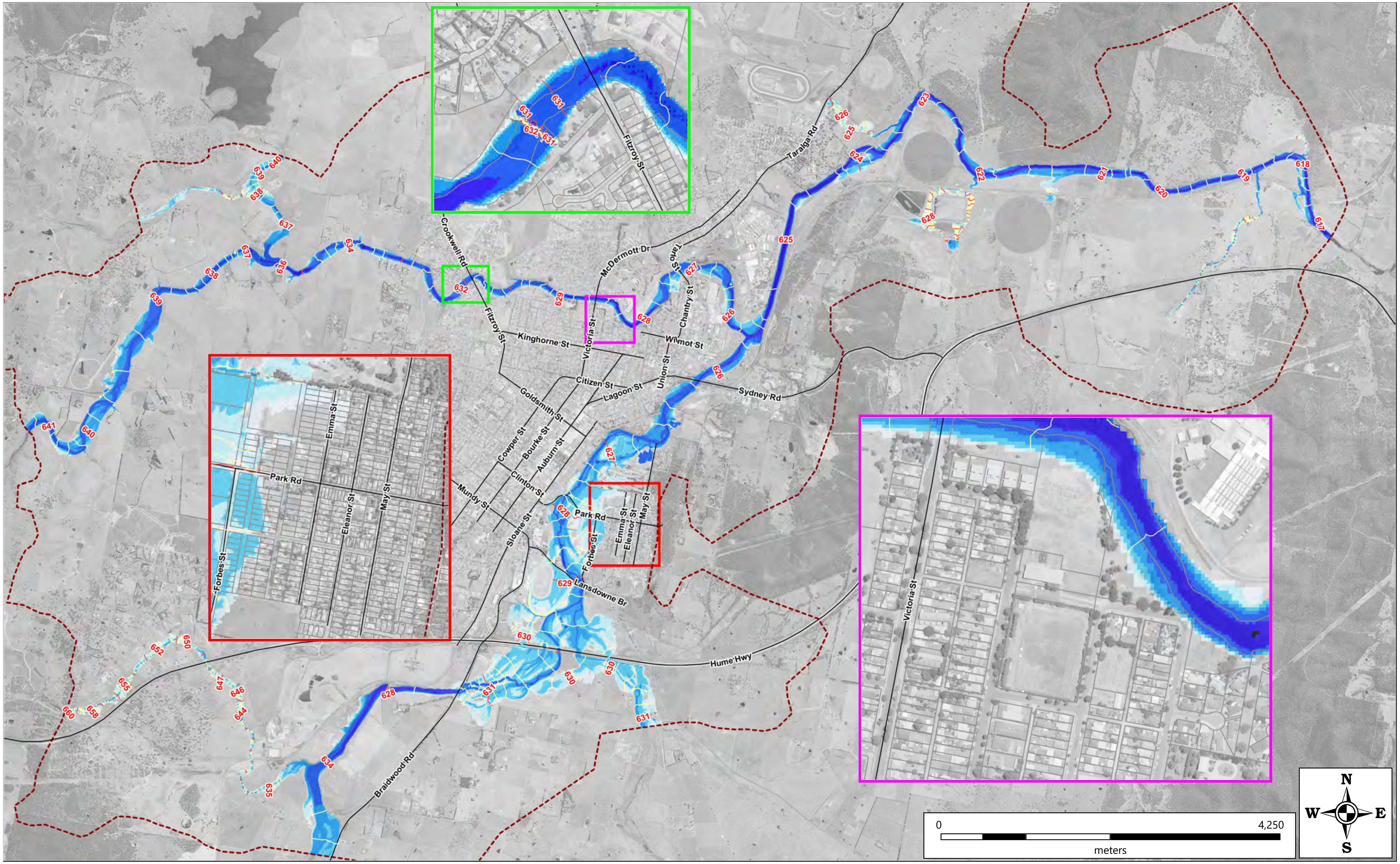
PROJECT: **Goulburn Mulwaree FRMS&P**

PROJECT No. **180068**

DATE: **07-2022** SCALE: 1:22,000 FIGURE No. **13**

Goulburn Floodplain Risk Management Study and Plan

AppendixA Figures



Hydraulic Model Extent	Water Level (mAHD) Major Contour Spacing = 1.0m
Cadastral Boundary	Water Level (mAHD) Minor Contour Spacing = 0.2m

Flood Depth (m)

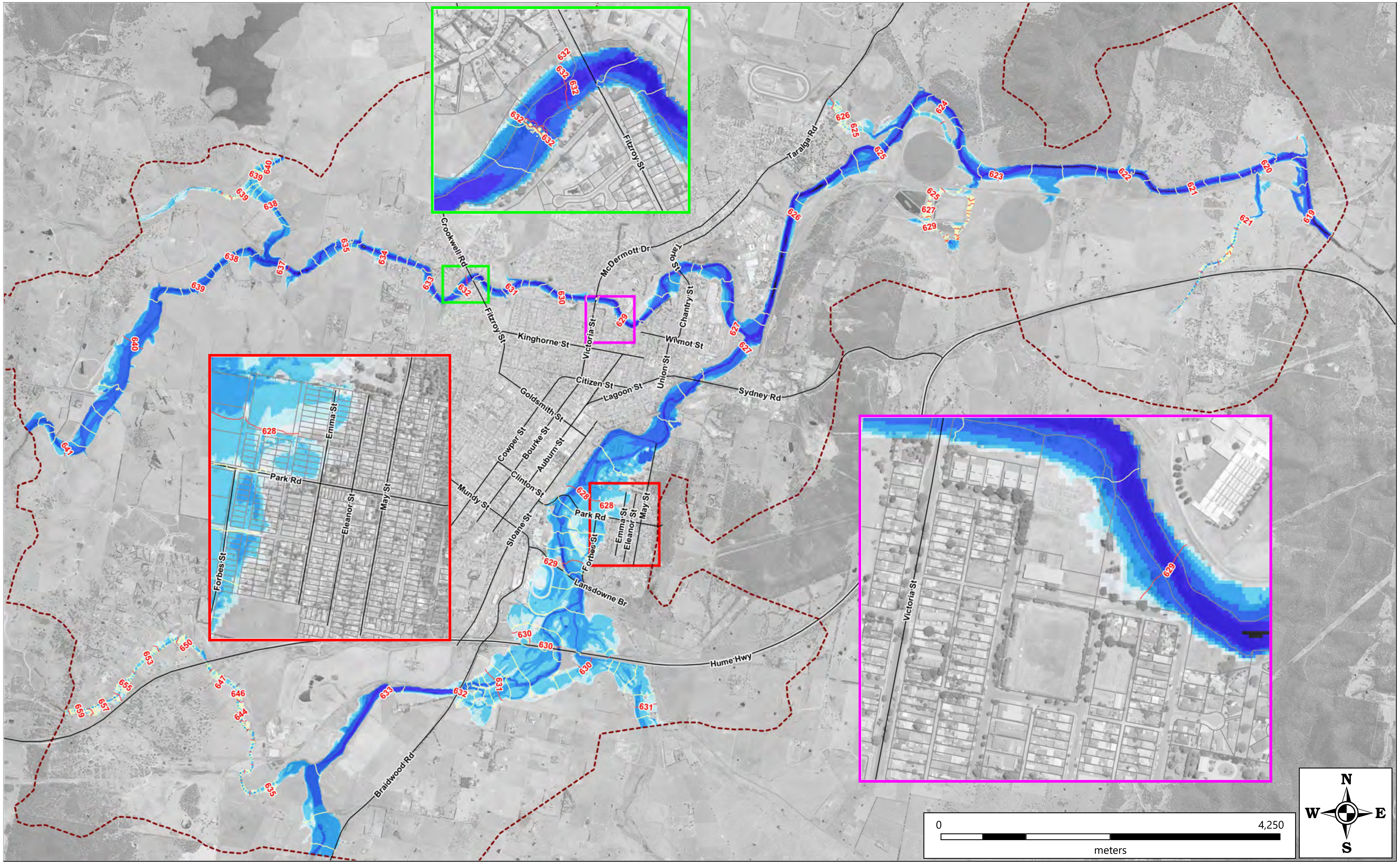
0.0 to 0.2	2.0 to 5.0
0.2 to 0.5	5.0 to 10.0
0.5 to 1.0	> 10.0
1.0 to 2.0	

TITLE : **20% AEP Design Event Peak Flood Depths and Levels**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-01**



Hydraulic Model Extent

Cadastral Boundary

Water Level (mAHD) Major Contour Spacing = 1.0m

Water Level (mAHD) Minor Contour Spacing = 0.2m

Flood Depth (m)

0.0 to 0.2	2.0 to 5.0
0.2 to 0.5	5.0 to 10.0
0.5 to 1.0	> 10.0
1.0 to 2.0	

TITLE : **10% AEP Design Event Peak Flood Depths and Levels**

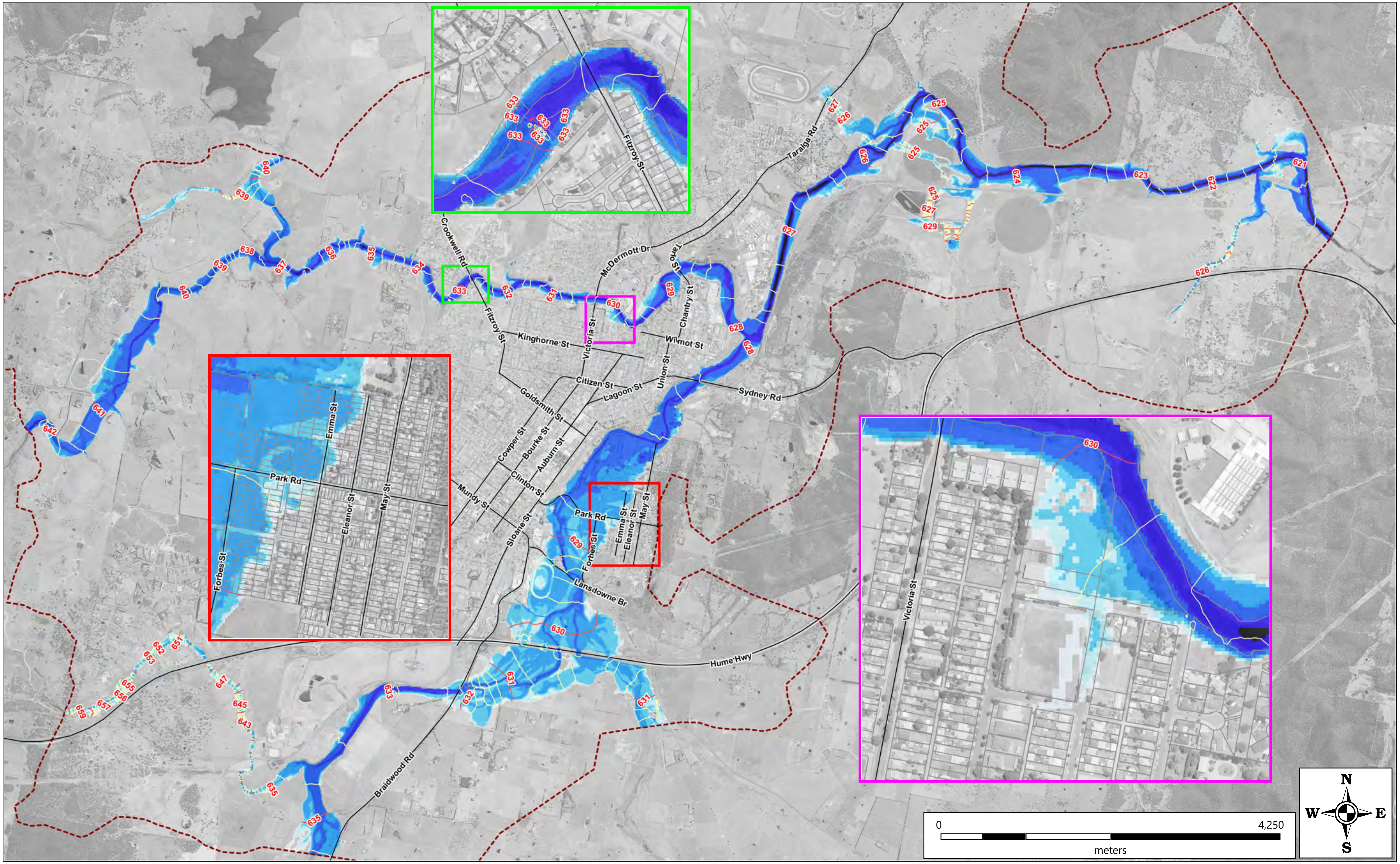
PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020

SCALE: 1:42,500

FIGURE NUMBER: **A-02**



Hydraulic Model Extent	Water Level (mAHD) Major Contour Spacing = 1.0m
Cadastral Boundary	Water Level (mAHD) Minor Contour Spacing = 0.2m

Flood Depth (m)

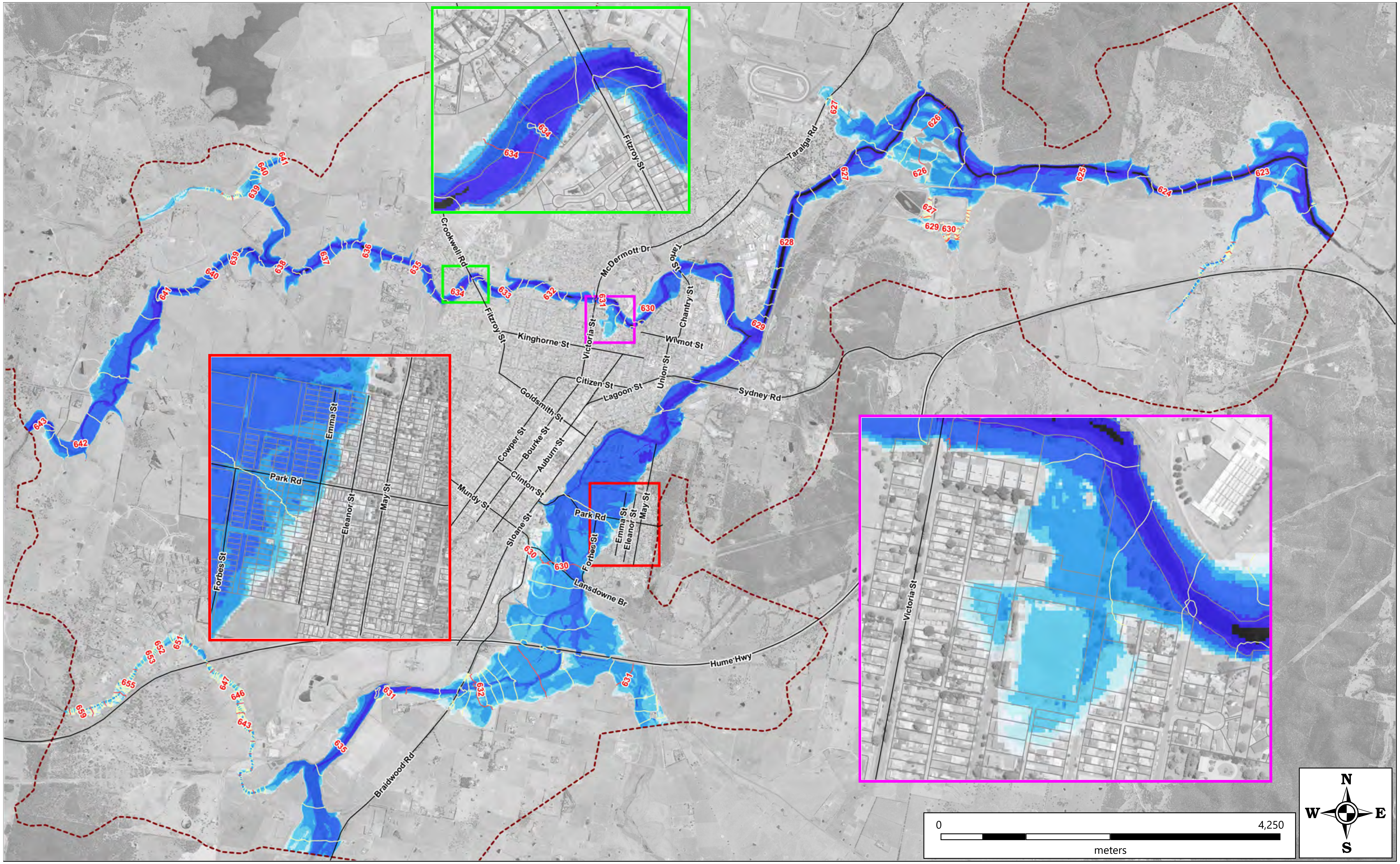
0.0 to 0.2	2.0 to 5.0
0.2 to 0.5	5.0 to 10.0
0.5 to 1.0	> 10.0
1.0 to 2.0	

TITLE : **5% AEP Design Event Peak Flood Depths and Levels**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-03**



Cadastral Boundary

Water Level (mAHD) Major Contour Spacing = 1.0m

Water Level (mAHD) Minor Contour Spacing = 0.2m

Flood Depth (m)

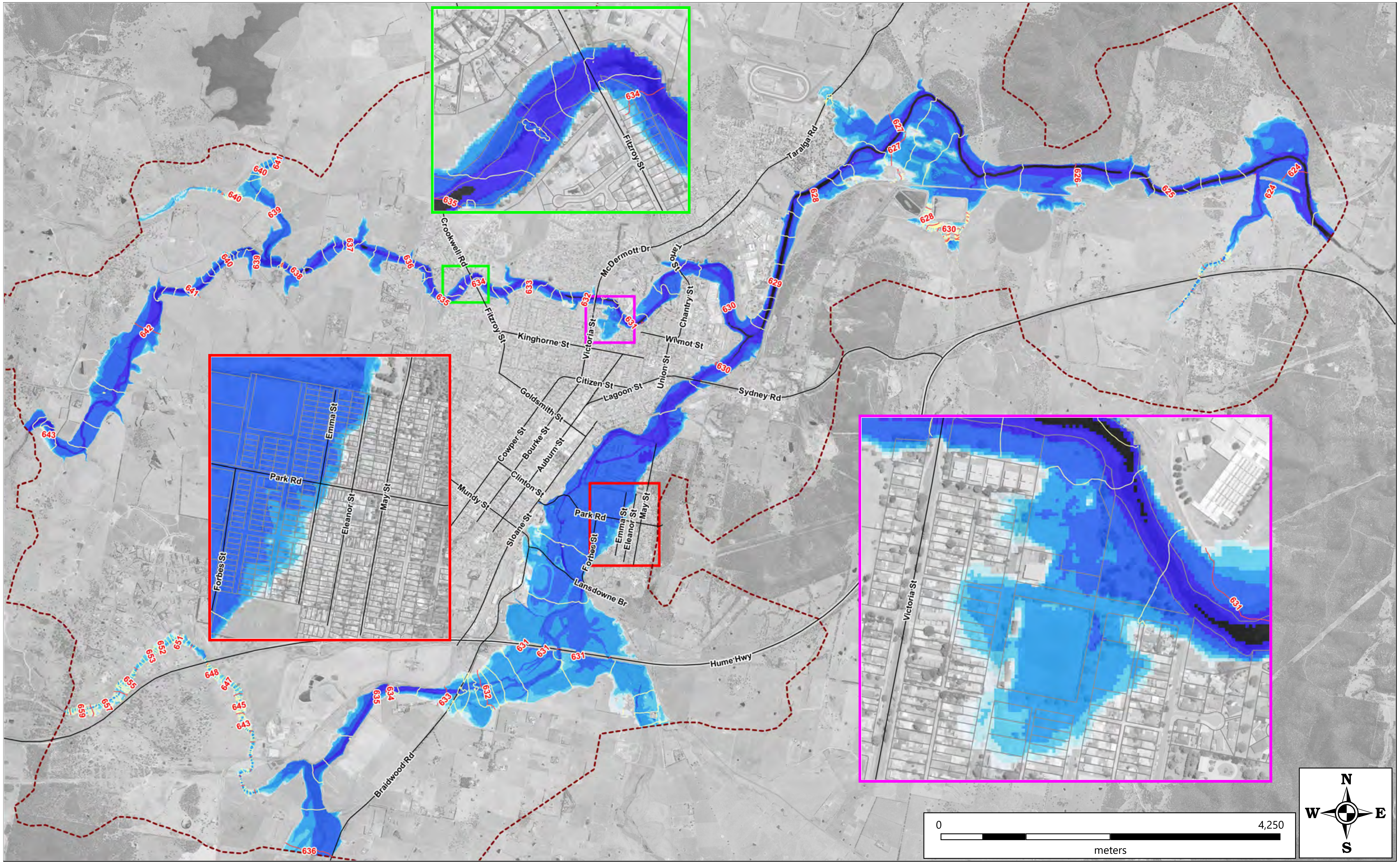
0.0 to 0.2	2.0 to 5.0
0.2 to 0.5	5.0 to 10.0
0.5 to 1.0	> 10.0
1.0 to 2.0	

TITLE : **2% AEP Design Event Peak Flood Depths and Levels**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: September 2019 | SCALE: 1:42,500 | FIGURE NUMBER: **A-04**



Hydraulic Model Extent	Water Level (mAHD) Major Contour Spacing = 1.0m	
Cadastral Boundary	Water Level (mAHD) Minor Contour Spacing = 0.2m	

Flood Depth (m)

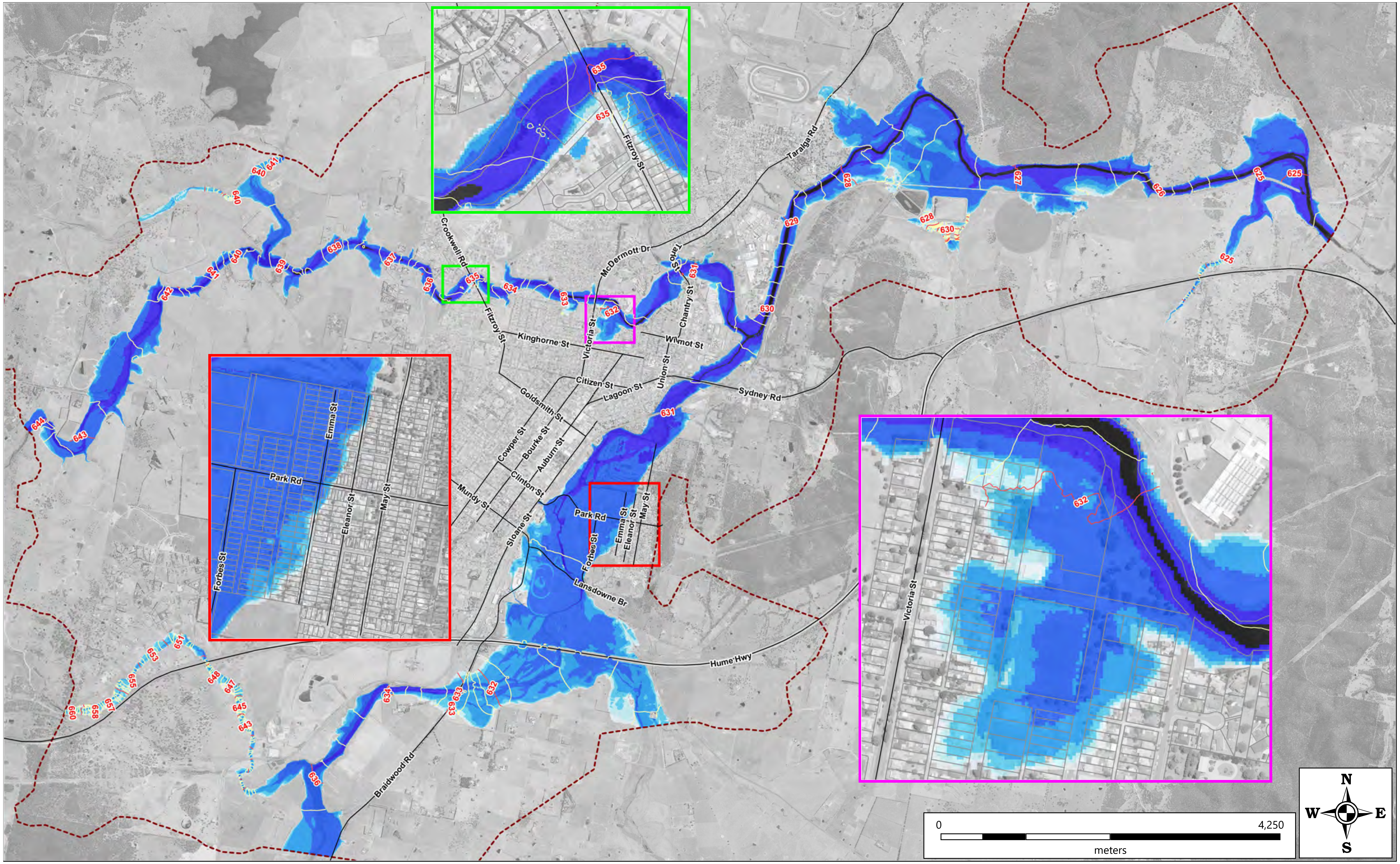
0.0 to 0.2	2.0 to 5.0
0.2 to 0.5	5.0 to 10.0
0.5 to 1.0	> 10.0
1.0 to 2.0	

TITLE : **1% AEP Design Event Peak Flood Depths and Levels**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-05**



Hydraulic Model Extent	Water Level (mAHD) Major Contour Spacing = 1.0m
Cadastral Boundary	Water Level (mAHD) Minor Contour Spacing = 0.2m

Flood Depth (m)

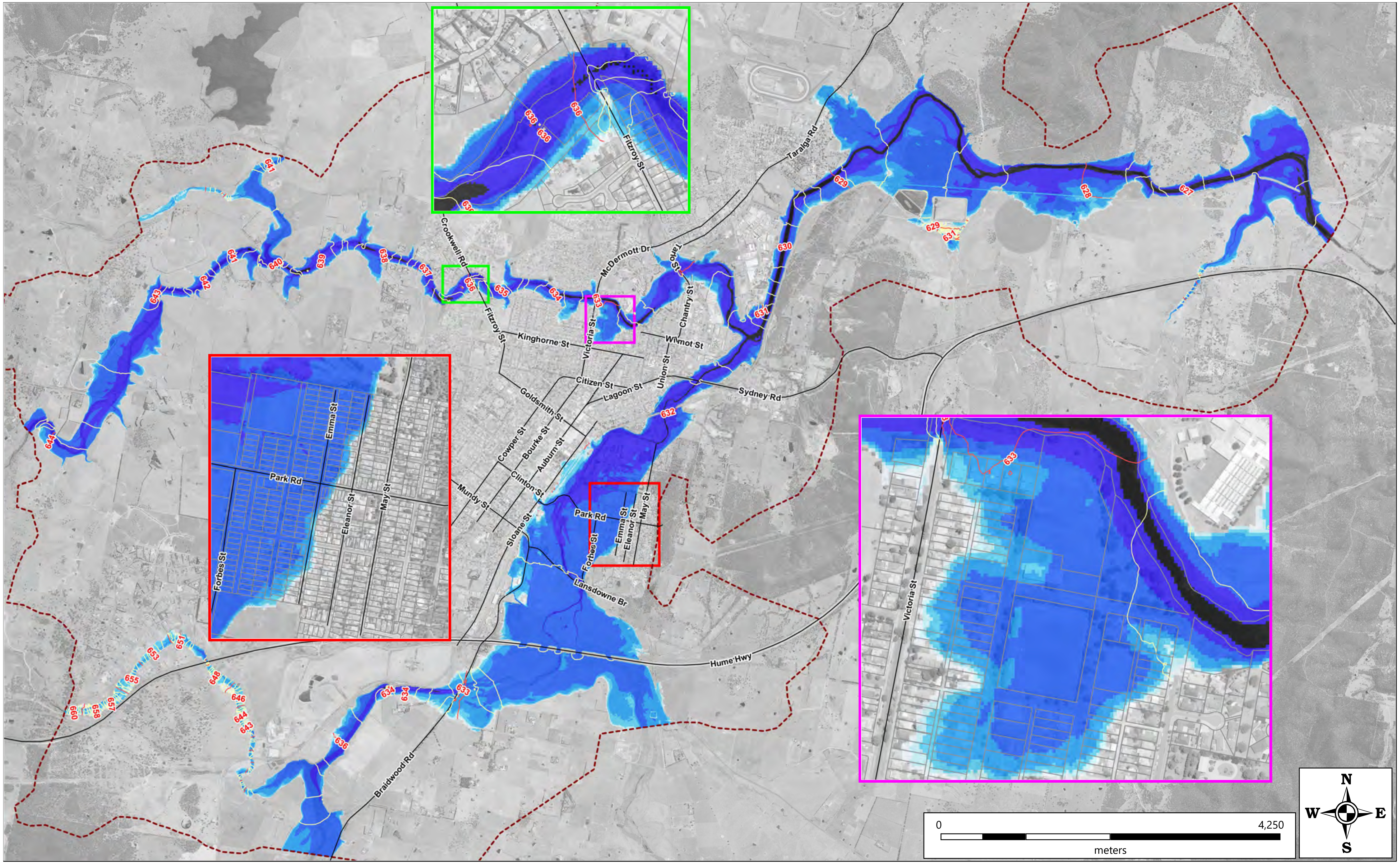
0.0 to 0.2	2.0 to 5.0
0.2 to 0.5	5.0 to 10.0
0.5 to 1.0	> 10.0
1.0 to 2.0	

TITLE : **0.5% AEP Design Event Peak Flood Depths and Levels**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-06**



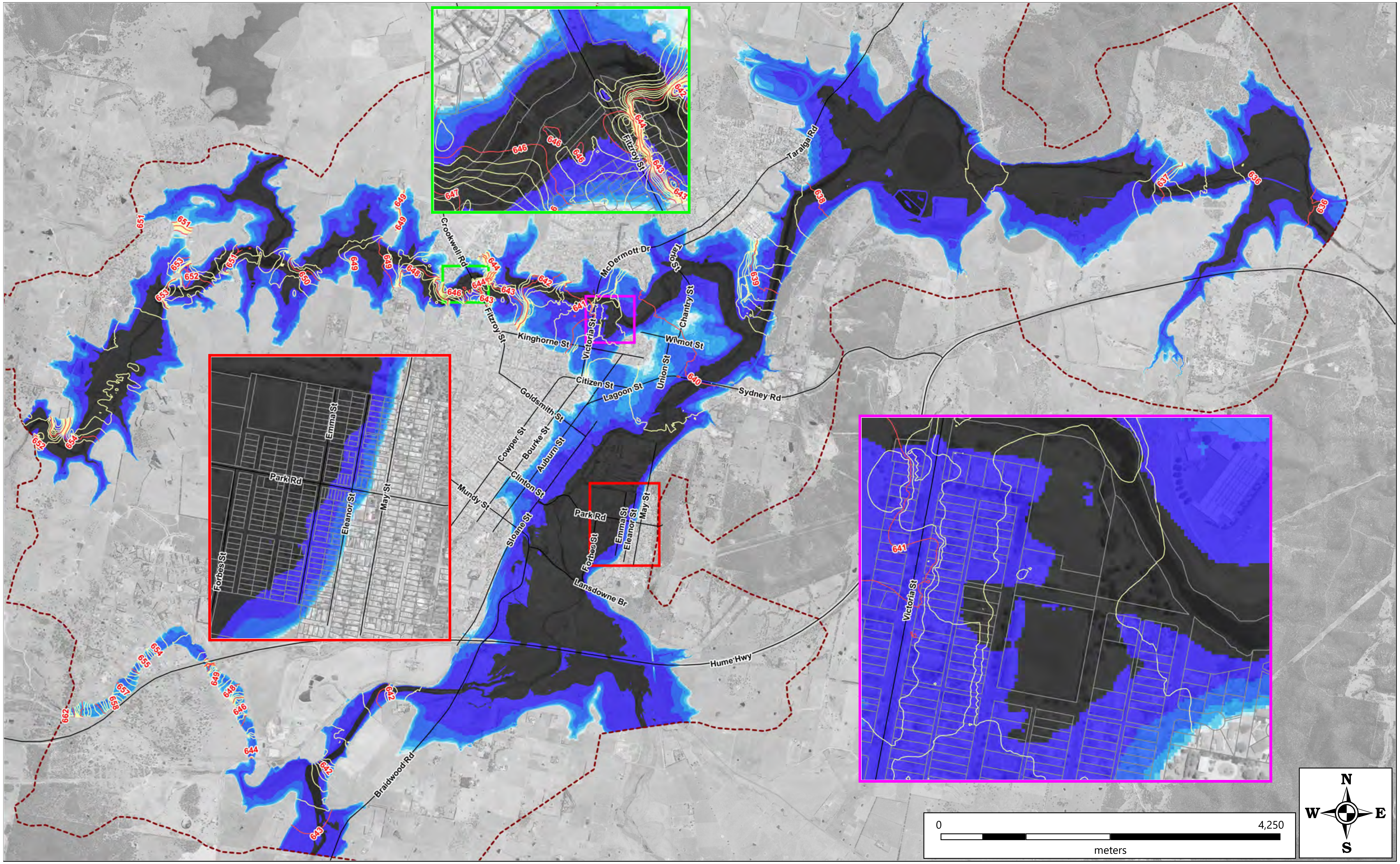
Hydraulic Model Extent	Water Level (mAHD) Major Contour Spacing = 1.0m	Flood Depth (m) 0.0 to 0.2	2.0 to 5.0
Cadastral Boundary	Water Level (mAHD) Minor Contour Spacing = 0.2m	0.2 to 0.5	5.0 to 10.0
		0.5 to 1.0	> 10.0
		1.0 to 2.0	

TITLE : **0.2% AEP Design Event Peak Flood Depths and Levels**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-07**



Hydraulic Model Extent
Cadastral Boundary
Water Level (mAHD) Major Contour Spacing = 1.0m
Water Level (mAHD) Minor Contour Spacing = 0.2m

Flood Depth (m)

0.0 to 0.2	2.0 to 5.0
0.2 to 0.5	5.0 to 10.0
0.5 to 1.0	> 10.0
1.0 to 2.0	

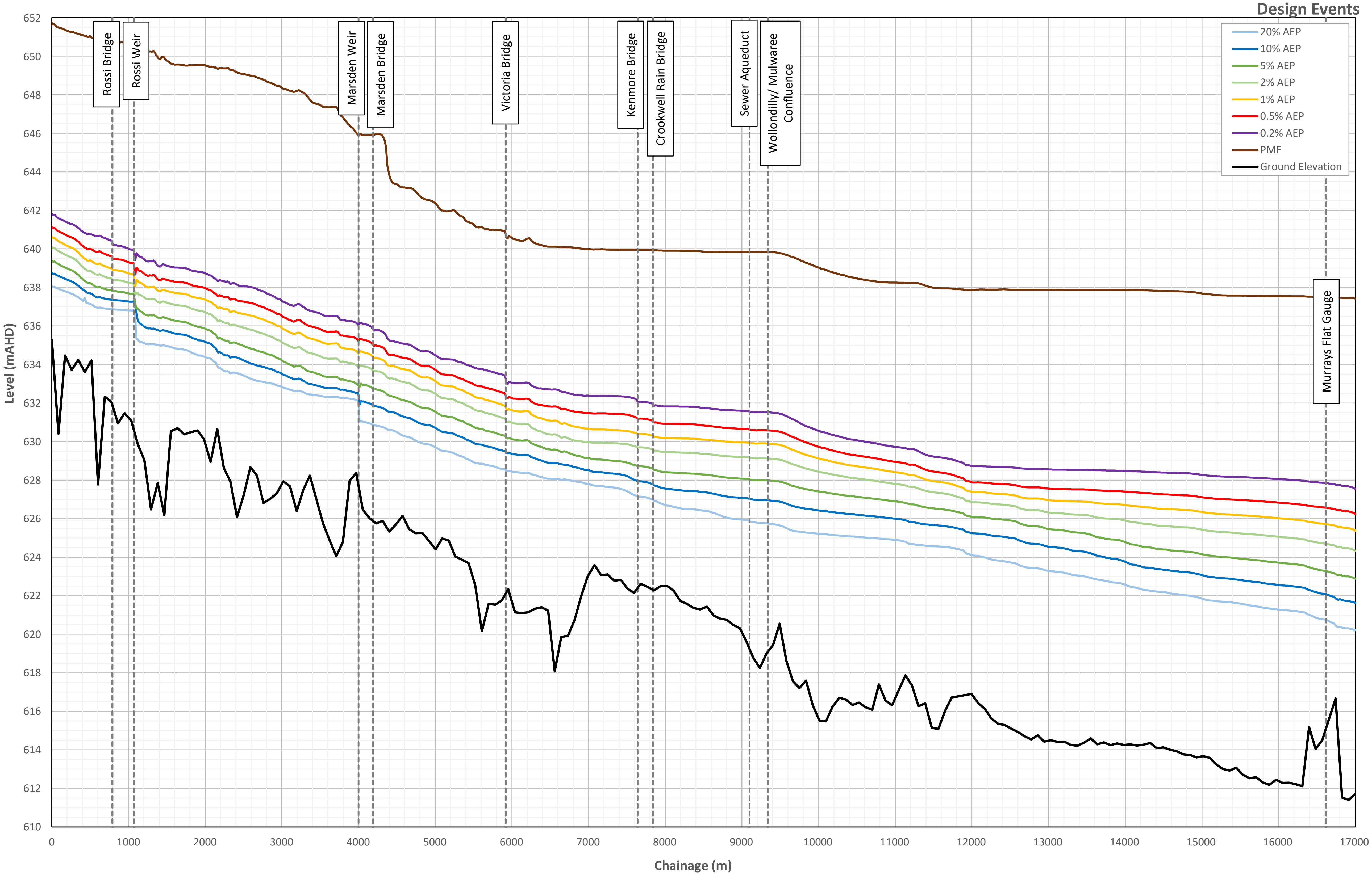
TITLE : **PMF Design Event Peak Flood Depths and Levels**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 SCALE: 1:42,500 FIGURE NUMBER: **A-08**

Figure A-09
Wollondilly River Peak Flood Profile
Design Events



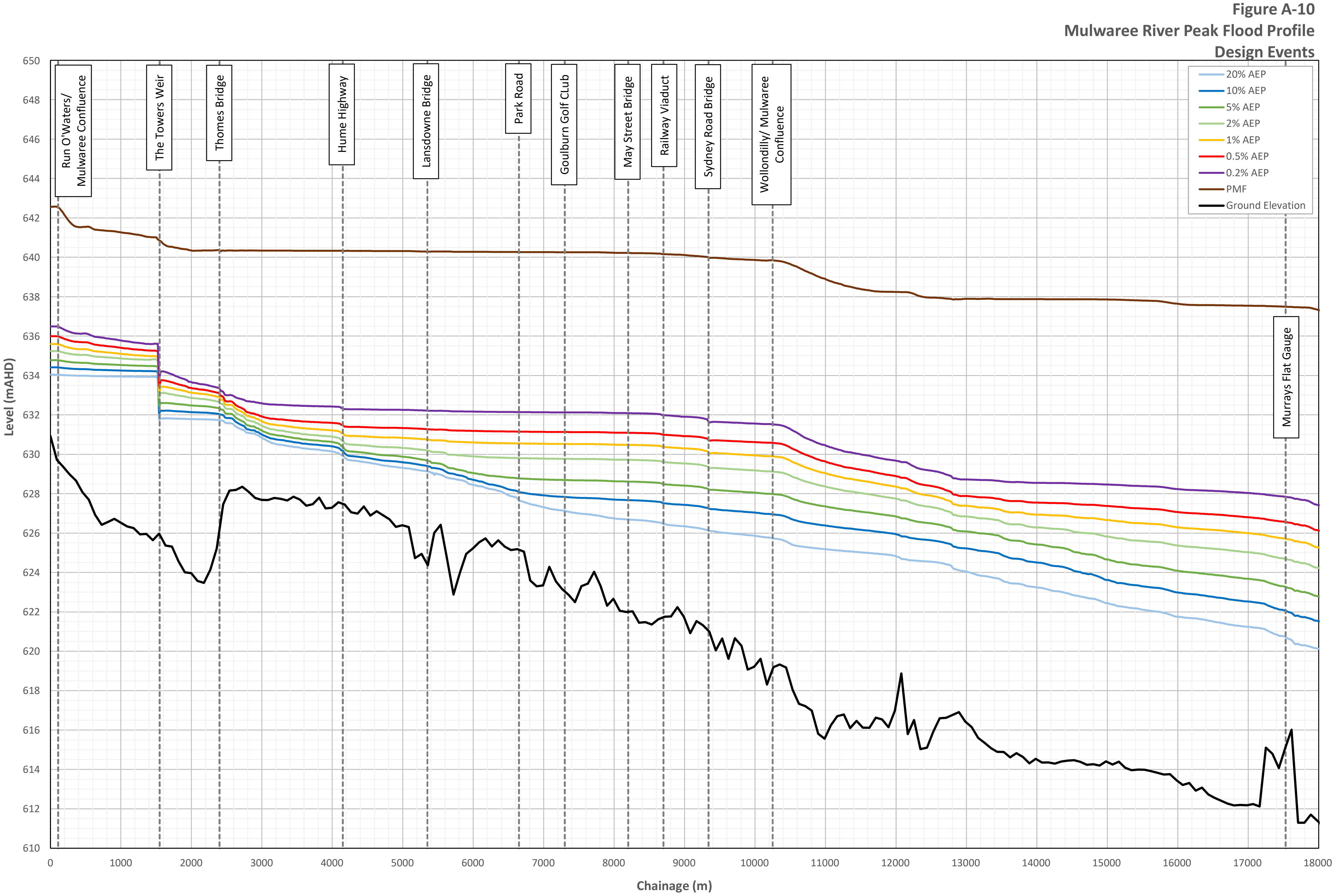
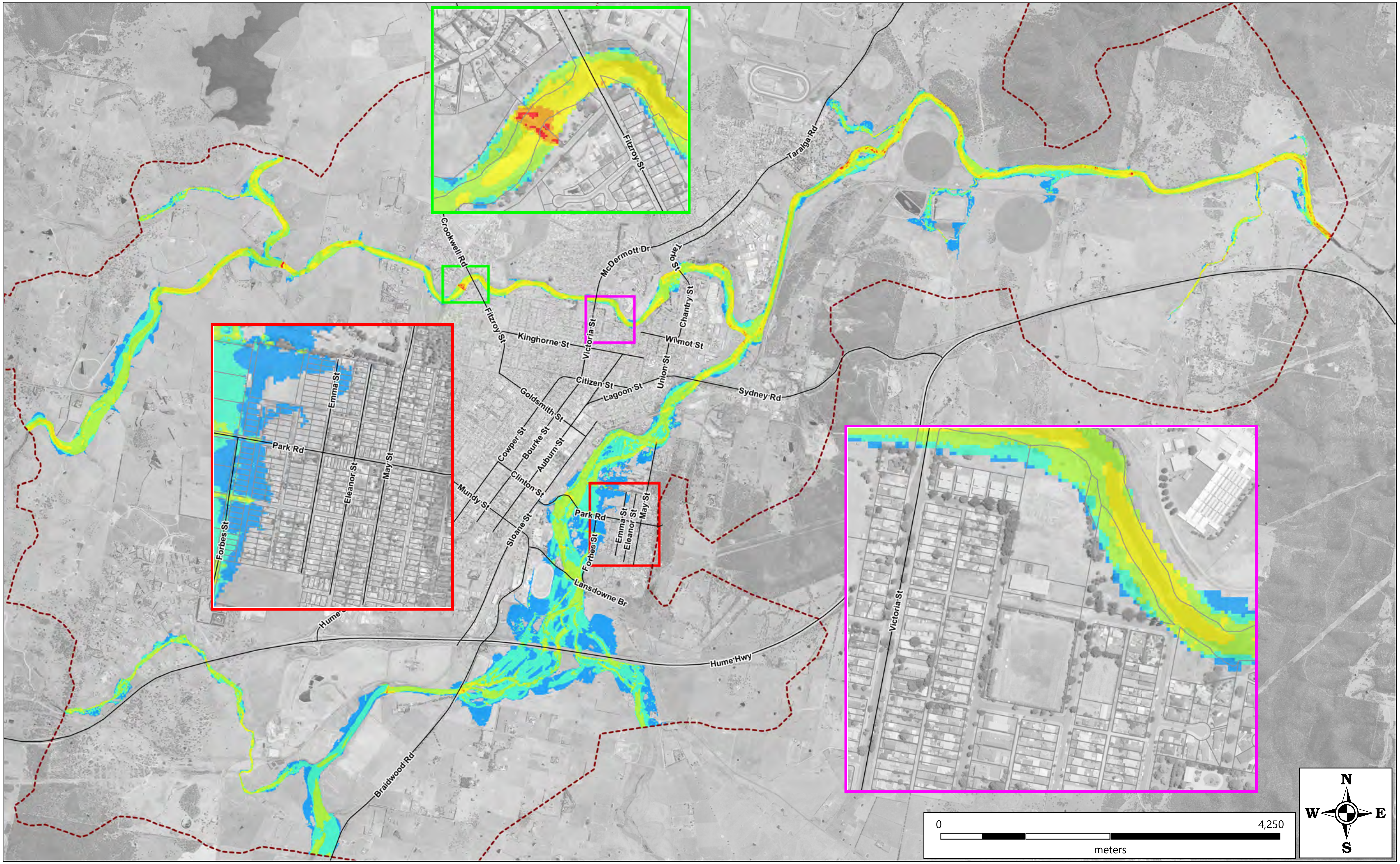


Figure A-10
Mulwaree River Peak Flood Profile
Design Events
Run O'Waters/ Mulwaree Confluence
The Towers Weir
Thomes Bridge
Hume Highway
Lansdowne Bridge
Park Road
Goulburn Golf CLub
May Street Bridge
Railway Viaduct
Sydney Road Bridge
Wollondilly/ Mulwaree Confluence
Murrays Flat Gauge
20% AEP
10% AEP
5% AEP
2% AEP
1% AEP
0.5% AEP
0.2% AEP
PMF
Ground Elevation
Level (mAHD)
Chainage (m)
650
648
646
644
642
640
638
636
634
632
630
628
626
624
622
620
618
616
614
612
610
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000



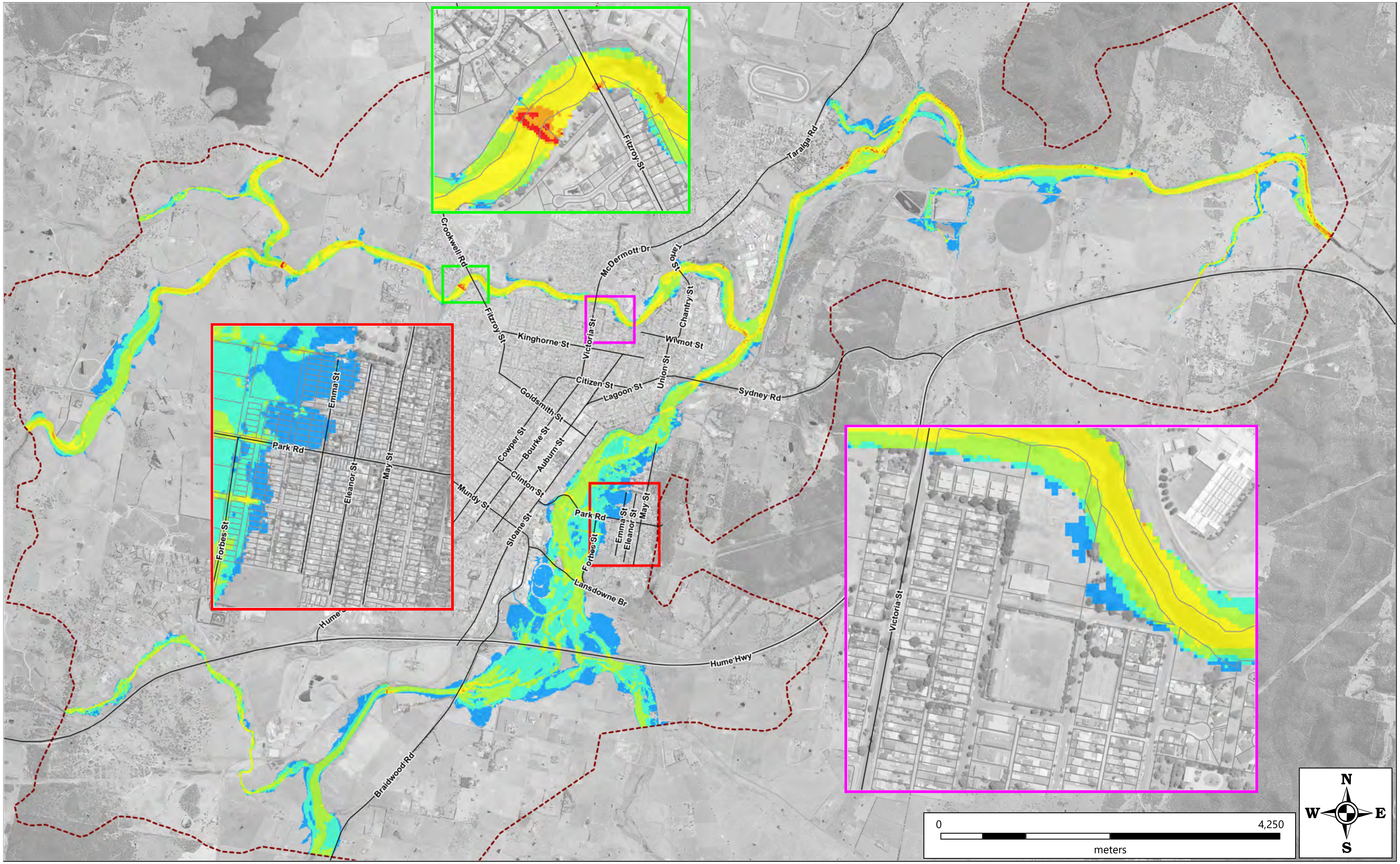
Hydraulic Model Extent	Water Velocity (m/s)	
Cadastral Boundary	0.00 to 0.25	1.00 to 2.00
	0.25 to 0.50	2.00 to 3.00
	0.50 to 1.00	> 3.00

TITLE : **20% AEP Design Event Peak Flood Velocity**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-11**



Hydraulic Model Extent

Cadastral Boundary

Water Velocity (m/s)

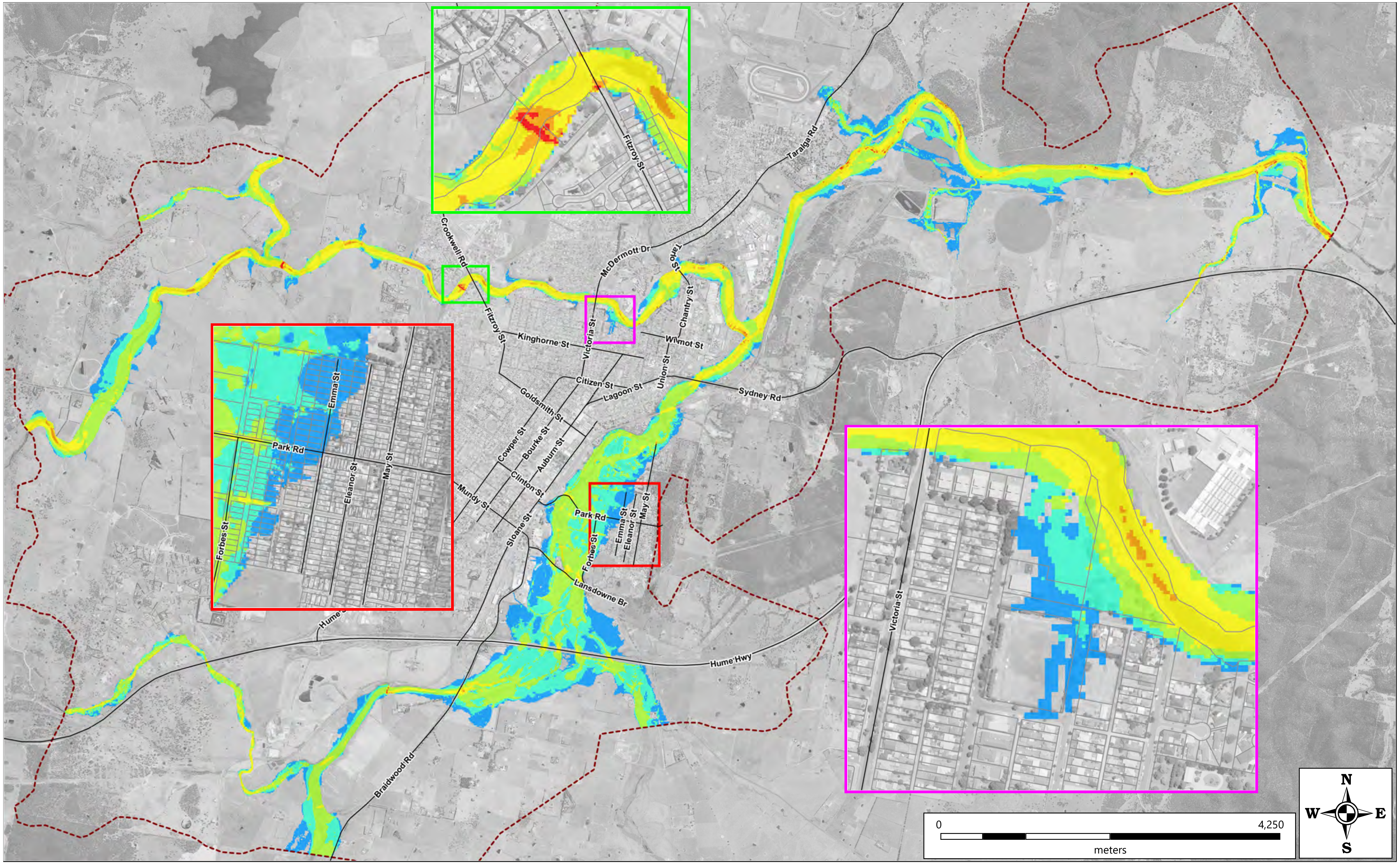
0.00 to 0.25	1.00 to 2.00
0.25 to 0.50	2.00 to 3.00
0.50 to 1.00	> 3.00

TITLE : **10% AEP Design Event Peak Flood Velocity**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 SCALE: 1:42,500 FIGURE NUMBER: **A-12**



Hydraulic Model Extent
Cadastral Boundary

Water Velocity (m/s)

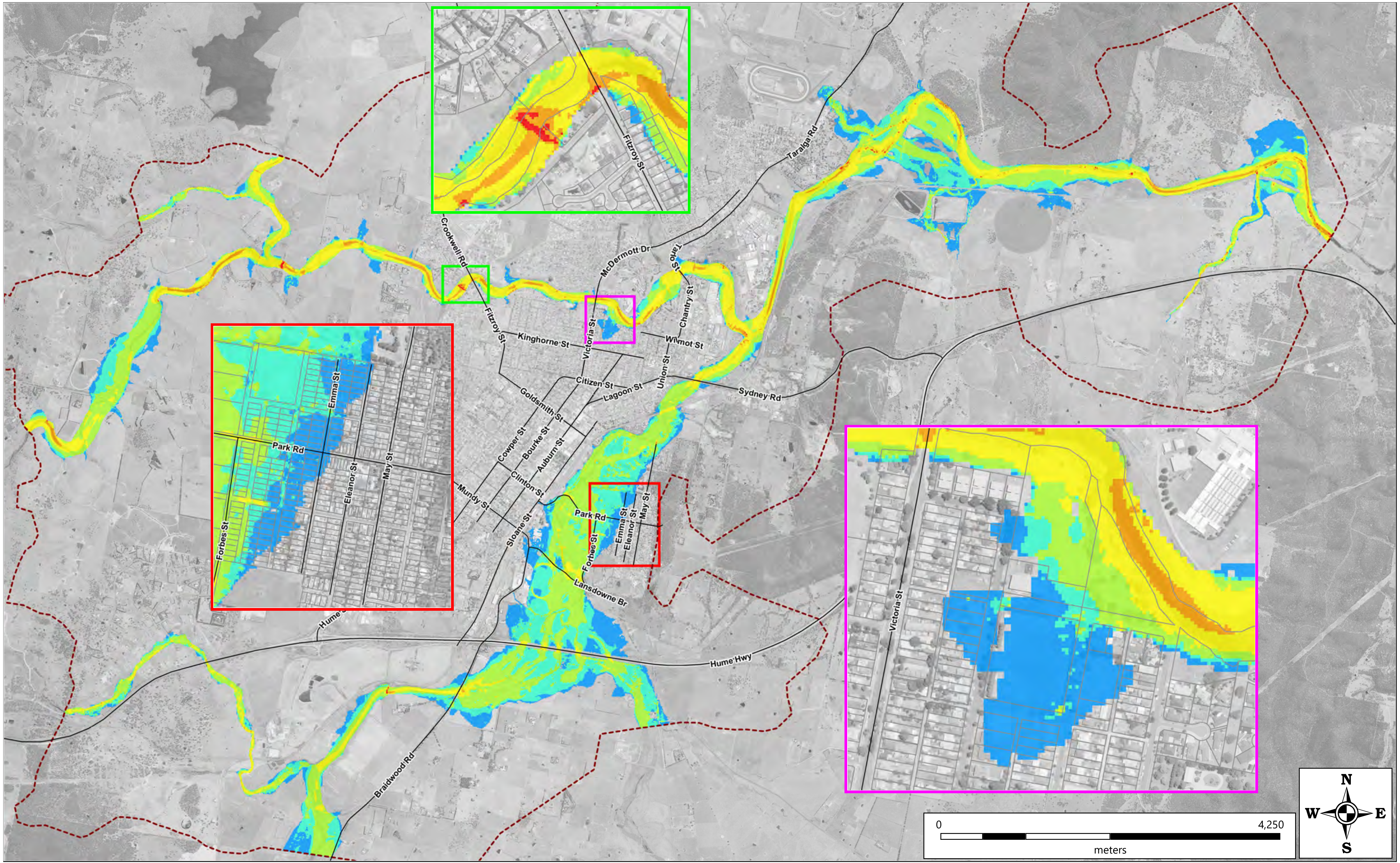
0.00 to 0.25	1.00 to 2.00
0.25 to 0.50	2.00 to 3.00
0.50 to 1.00	> 3.00

TITLE : **5% AEP Design Event Peak Flood Velocity**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-13**



Hydraulic Model Extent
Cadastral Boundary

Water Velocity (m/s)

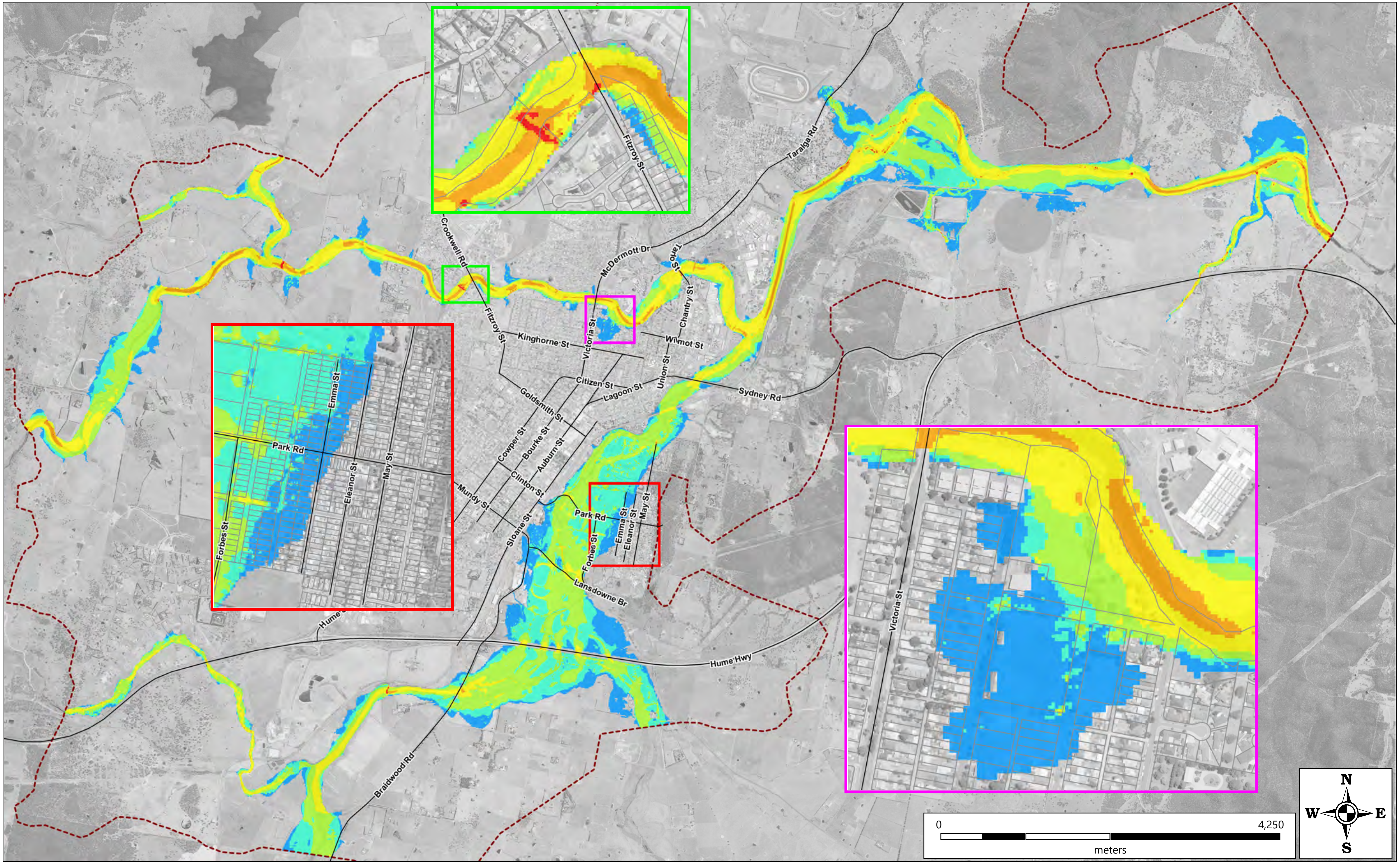
0.00 to 0.25	1.00 to 2.00
0.25 to 0.50	2.00 to 3.00
0.50 to 1.00	> 3.00

TITLE : **2% AEP Design Event Peak Flood Velocity**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-14**



Hydraulic Model Extent
Cadastral Boundary

Water Velocity (m/s)

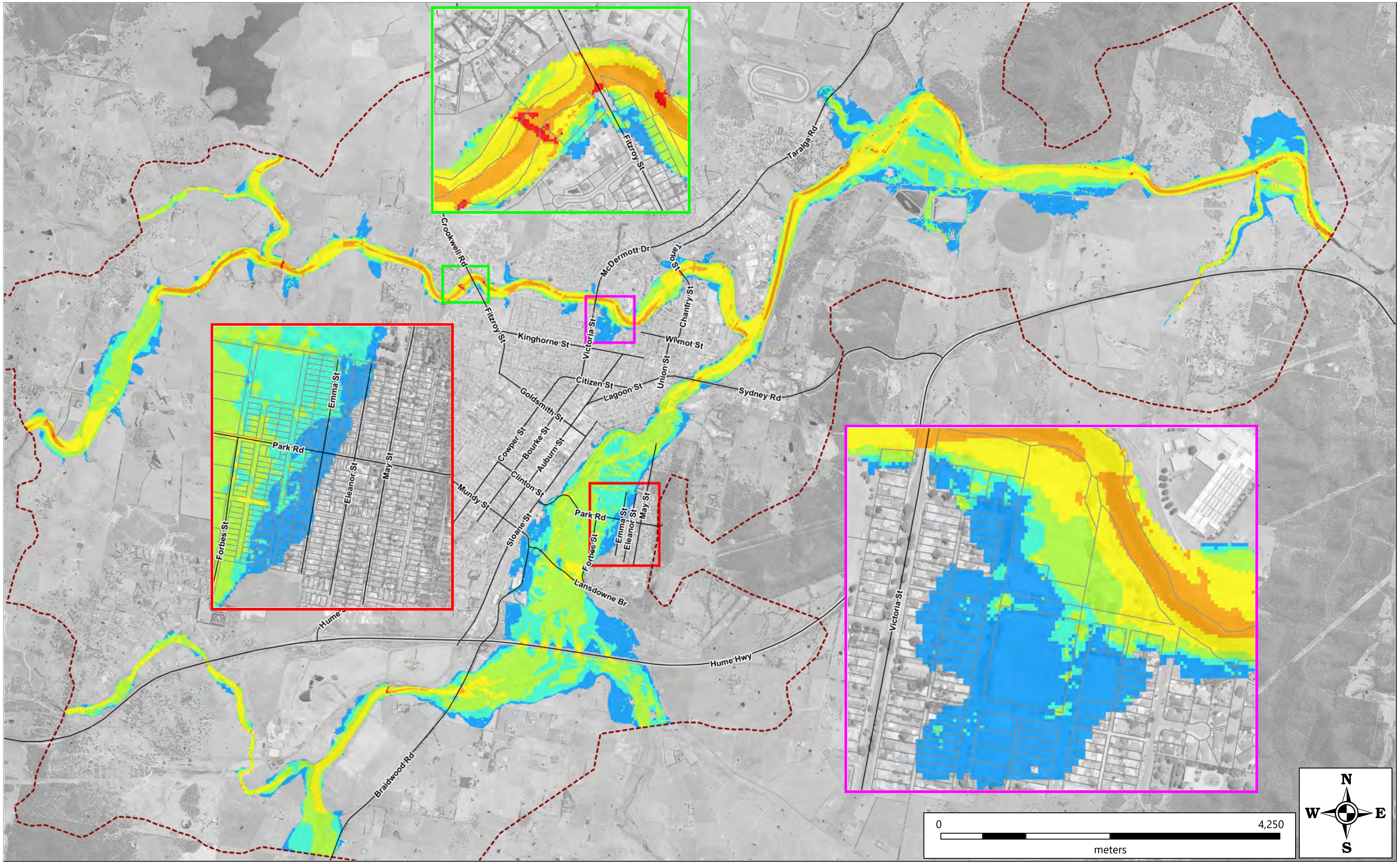
0.00 to 0.25	1.00 to 2.00
0.25 to 0.50	2.00 to 3.00
0.50 to 1.00	> 3.00

TITLE : **1% AEP Design Event Peak Flood Velocity**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-15**



GOULBURN MULWAREE COUNCIL

Hydraulic Model Extent

Cadastral Boundary

Water Velocity (m/s)

0.00 to 0.25	1.00 to 2.00
0.25 to 0.50	2.00 to 3.00
0.50 to 1.00	> 3.00

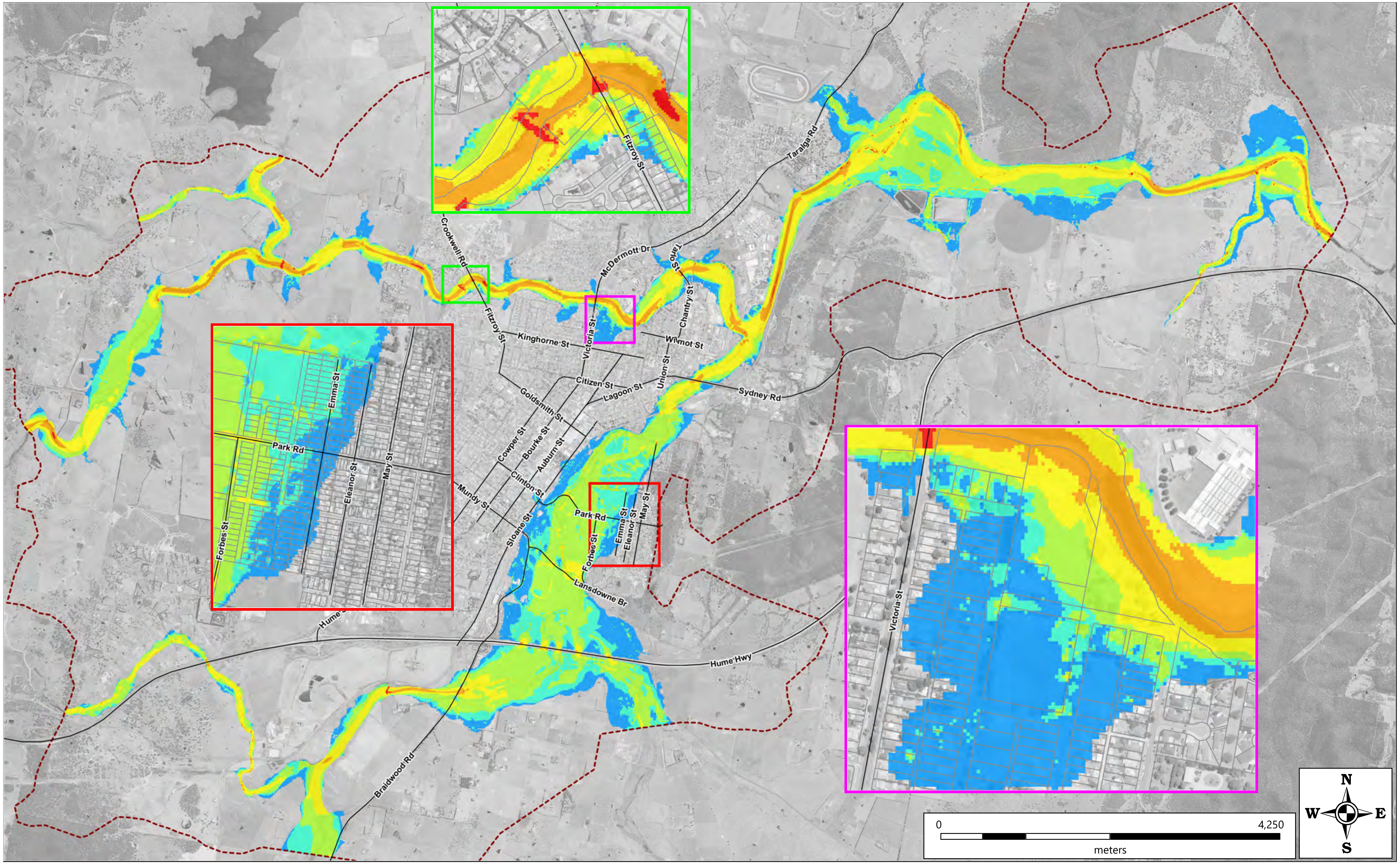
TITLE : **0.50% AEP Design Event Peak Flood Velocity**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-16**

grc HYDRO



Hydraulic Model Extent
Cadastral Boundary

Water Velocity (m/s)

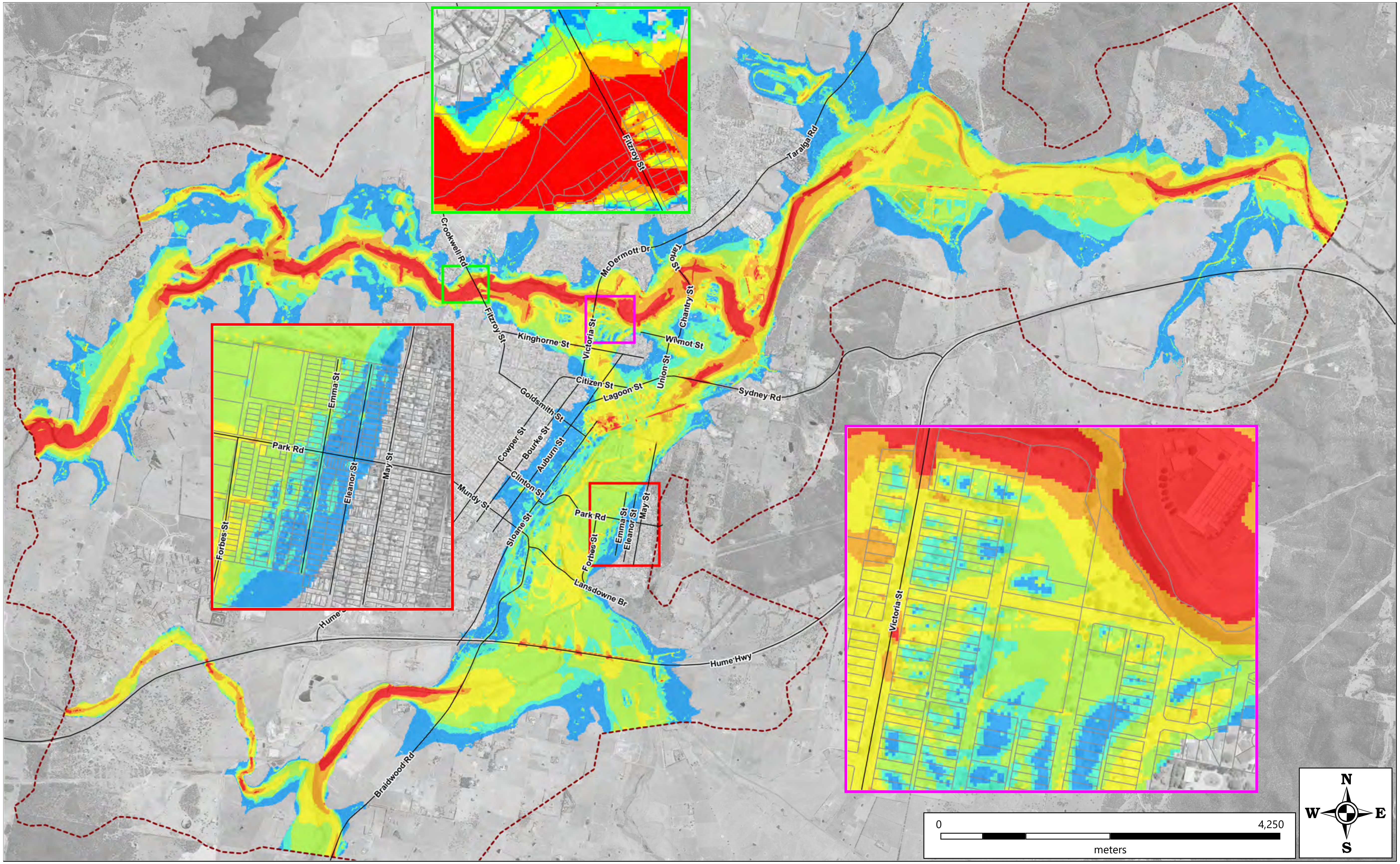
0.00 to 0.25	1.00 to 2.00
0.25 to 0.50	2.00 to 3.00
0.50 to 1.00	> 3.00

TITLE : **0.20% AEP Design Event Peak Flood Velocity**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 | SCALE: 1:42,500 | FIGURE NUMBER: **A-17**



Hydraulic Model Extent
Cadastral Boundary

Water Velocity (m/s)

0.00 to 0.25	1.00 to 2.00
0.25 to 0.50	2.00 to 3.00
0.50 to 1.00	> 3.00

TITLE : **PMF Design Event Peak Flood Velocity**

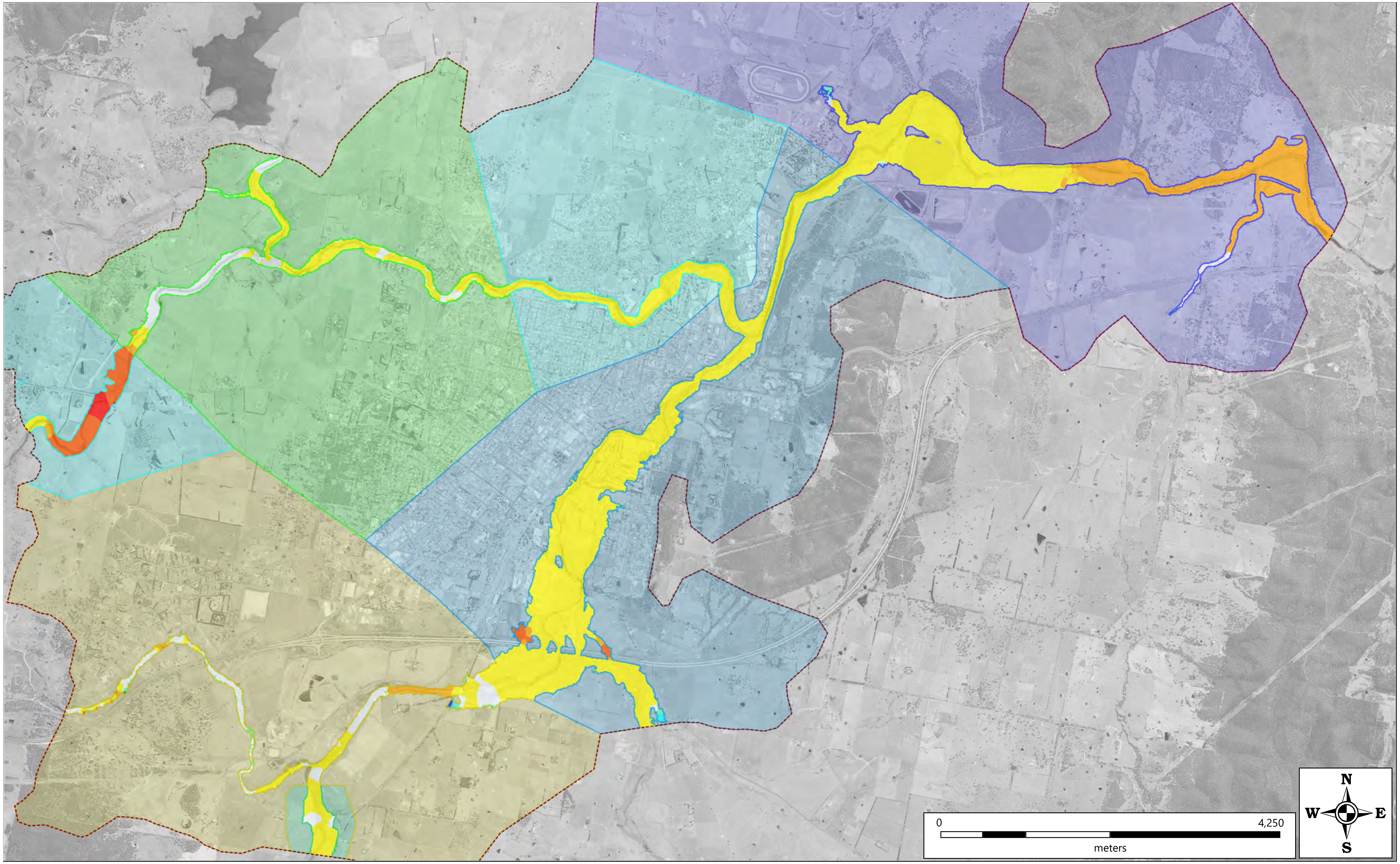
PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 SCALE: 1:42,500 FIGURE NUMBER: **A-18**

Goulburn Floodplain Risk Management Study and Plan

Flood Function Encroachment Analysis



Encroachment Criteria VxD > 0.20
Encroachment Criteria VxD > 0.33
Encroachment Criteria VxD > 0.45
Encroachment Criteria VxD > 0.50
Encroachment Criteria VxD > 0.55
Encroachment Criteria VxD > 0.65
Hydraulic Model Extent

Change in Flood Level (m)
0.20 to 0.30
0.15 to 0.20
0.05 to 0.15
No Impact
-0.1 to -0.01
-0.20 to -0.10
-0.30 to -0.20

TITLE : **Flood Function Encroachment Analysis**

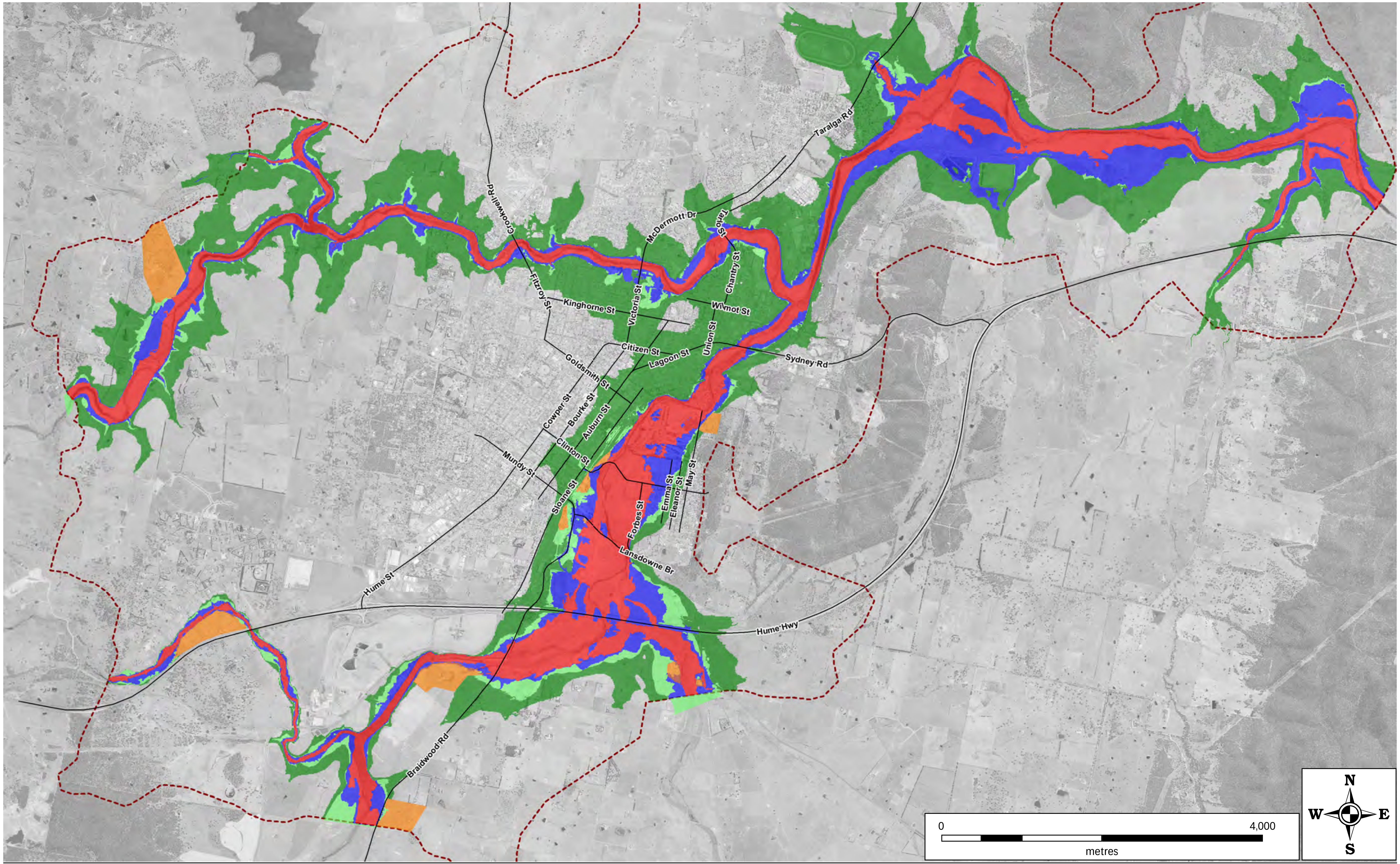
PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: March 2020 SCALE: 1:42,500 FIGURE NUMBER: **E-01**

Goulburn Floodplain Risk Management Study and Plan

Appendix H
Figure Report



Flood Planning Constraint Category 1	Flood Planning Constraint Category 3
Flood Planning Constraint Category 2a,b,c,e	Flood Planning Constraint Category 4
Flood Planning Constraint Category 2d	
Hydraulic Model Extent	

TITLE : **Flood Planning Constraint Category**

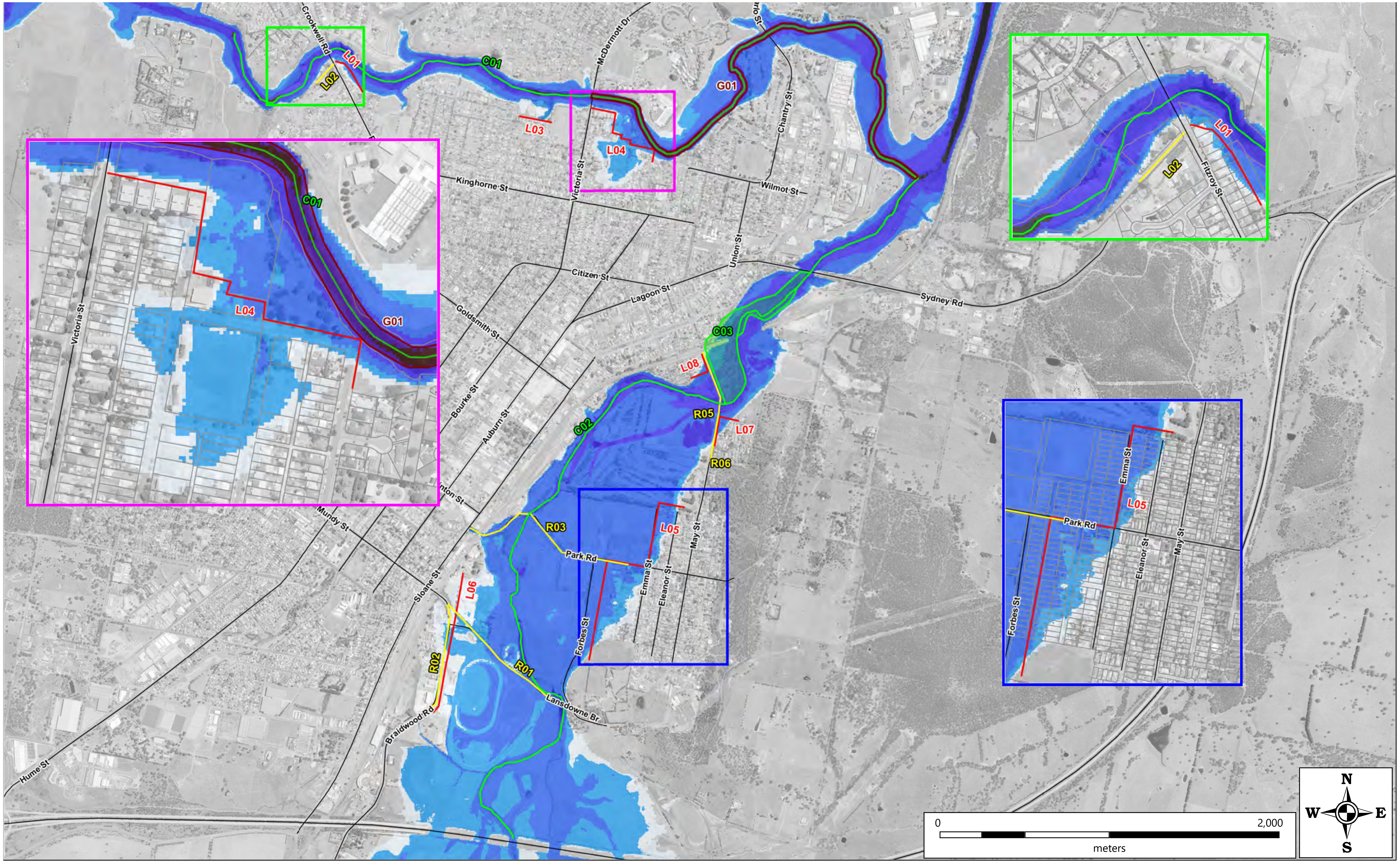
PROJECT:Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE:March 2020 SCALE: 1:42,500 FIGURE NUMBER:**H1**

Goulburn Floodplain Risk Management Study and Plan

Appendix I
Figure Report



Red line	Potential Levees
Yellow line	Potential Road Regrading
Green line	Potential Vegetation Clearing
Green hatched	Potential Vegetation Clearing
Red hatched	Potential Waterway Regrading

1% AEP Flood Depth (m)

0.0 to 0.3	2.0 to 5.0
0.3 to 0.5	5.0 to 10.0
0.5 to 2.0	> 10.0

TITLE : **Goulburn Mulwaree Potential Flood Mitigation Measures**

PROJECT: Goulburn Mulwaree FRMS&P

PROJECT No. 180068

DATE: January 2020 | SCALE: 1:20,000 | FIGURE NUMBER: **1**

Goulburn Floodplain Risk Management Study and Plan

Peer Review Report

Peer Review – Goulburn Floodplain Risk Management Study and Plan

Overview

GRC Hydro's Peer Review process consists of checking a project against a standard checklist, developed internally. The checklist ensures that a minimum standard of quality is maintained across all aspects of a project. Where the checklist reveals a significant issue, the relevant project aspects are amended prior to the project being finalized.

The checklist is broken into seven categories:

- Project Background
- Data Collection
- Hydrologic Model
- Hydraulic Model
- Flood Risk Assessment
- Mitigation Measures
- Deliverables

Each area contains a number of subcategories. Based on the results, each subcategory is classed as either:

- "No Issues"
- "Minor issues that have minimal or negligible effect on study outcomes"
- "Significant Issues"

The results for the Goulburn FRMS&P are provided in the following table. This is the final review of the project and follows on from earlier reviews where minor or significant issues have been identified and rectified.

	No Issues	**Minor Issues**	**Significant Issues**
Project Background			
Project objectives are identified and addressed by the overall scope			
All relevant previous studies are identified and utilized where appropriate			
Main stakeholders and their needs are identified			
Data Collection			
Appropriate use of raw data including hydrologic data, observed flooding, survey including LiDAR and bathymetry			
Appropriate use of processed data including past models, model results and Council GIS data.			
Data collection includes review of each dataset and any issues or gaps identified			
Hydrologic Model			
Each choice of model and model parameter is documented and based on best-practice approach. Model is suitably calibrated.			
Considers historical events and full range of design flood events. Results at key locations are reviewed.			
Hydraulic Model			
All hydrologic model outputs are correctly applied as inputs to the hydraulic model			

Each choice of model and model parameter is document and based on best practice approach. Model is suitably calibrated.			
The primary hydraulic model outputs across a range of events are reviewed across the study area			
Flood Risk Assessment			
Flood risk assessment considers the full range of design flood events, spans the study area and incorporates features of the flood risk that are specific to the study area.			
Range of checks are carried out on flood damages estimates and assumptions and limitations are documented.			
Vulnerable and critical facilities are incorporated into the assessment including for extreme flooding			
Mitigation Measures			
Mitigation measures are developed with Council via an iterative process			
Each assessed measure is suitably documented and recommendation for each is justified.			
Measures consider the full range of possible approaches to managing flood risk, in accordance with the Floodplain Development Manual			
Deliverables			
Reporting is both comprehensive and functional, and report sections are reviewed for accuracy. Draft reports are provided for feedback and final report incorporates feedback from relevant stakeholders.			
Model files and outputs, along with any other deliverables, are in accordance with the project brief.			
Total	**19**	**0**	**0**

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