NORTHERN LAKES FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

PLAN IN RESPONSE TO OVERLAND FLOODING

Report MHL2571
October 2020

Prepared for:

Central Coast Council

Department of Planning, Industry and Environment

Cover Photograph: Photograph of road flooding at San Remo in December 2011 provided by F. Blume

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Foreword

The Northern Lakes FRMS&P has been prepared in accordance with the New South Wales Government's *Floodplain Development Manual* (2005). The manual guides implementation of the NSW Government's *Flood Prone Land Policy* (2005), the primary objective of which is to:

> *reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods wherever possible.*

Under the policy, primary responsibility for floodplain risk management rests with local government. Financial and technical assistance is provided to councils by the Environment, Energy and Science group (EES) of the Department of Planning, Industry and Environment (DPIE; previously Office of Environment and Heritage/OEH).

The *Floodplain Development Manual* defines the following steps in the Floodplain Risk Management Process:

- Formation of a Floodplain Risk Management Committee
- Data Collection
- Flood Study Preparation
- Floodplain Risk Management Study Preparation
- Floodplain Risk Management Plan Preparation
- Floodplain Risk Management Plan Implementation.

Council is responsible for management of flood prone land throughout the Central Coast Local Government Area (LGA). In accordance with the floodplain risk management process, CCC (Wyong Shire Council at the time) oversaw the completion and adoption of the *Northern Lakes Flood Study* in 2013 to define flood behaviour and risk throughout the study area.

Council engaged MHL to complete the Floodplain Risk Management Study and Floodplain Risk Management Plan phases of the process for the Northern Lakes study area, with funding from the then Office of Environment and Heritage (OEH) through the NSW Government's Floodplain Management Program. Flood modelling has been updated in the current study and provided a basis to assess options to manage flood risk. The ultimate outcome of the study is the delivery of this Floodplain Risk Management Study and Draft Plan, with the draft plan detailing options recommended for adoption by Council in managing flood risk.

The Northern Lakes Floodplain Risk Management Working Group (the Working Group) was formed by Council in 2017 to fulfil the functions of a Floodplain Risk Management Committee as described in the *Floodplain Development Manual* (NSW Government 2005).

The Working Group comprises of representatives from:

- Central Coast Council
- NSW Department of Planning, Industry and Environment (DPIE)
- NSW State Emergency Services (SES)

The report was prepared by Matthieu Glatz and Bronson McPherson.

Executive summary

Description of Study

Central Coast Council (CCC) commissioned NSW Government's Manly Hydraulics Laboratory (MHL), with financial assistance from the NSW State Government, to prepare the Northern Lakes Floodplain Risk Management Study and Plan. The study area includes the local catchments surrounding Lake Munmorah, Budgewoi Lake and the northern half of Tuggerah Lake.

Central Coast Council has been managing flood risks within the study area over many years. Council's DCP ensures that proposed developments in the floodplain consider flood risk. The current study draws upon state-of-the-art flood modelling techniques to reassess potential flood problems and to re-evaluate the suite of available floodplain management measures to better manage the risk to life and property posed by flooding.

The study was overseen by the Northern Lakes Floodplain Risk Management Working Group, which comprises of councillors and staff from Council, officers from the Department of Planning, Industry and Environment (then the Office of Environment and Heritage) and the NSW State Emergency Service. There has also been opportunity for residents and businesses within the study area to provide input to the investigation through the engagement process (**Section 5**).

Principal Outcomes

The principal outcomes of this study include:

- The 2015 Northern Lakes Flood Study was reviewed and updated (**Section 6**) and estimates of flood extents, levels, depths and velocities were provided for the 20% Annual Exceedance Probability (AEP), 5% AEP, 1% AEP and probable maximum flood (PMF) events;
- Mapping of the Flood Life Hazard categories and hydraulic categories were provided to inform the Central Coast DCP (**Section 7**);
- Definition of the flood problem by assessment of building inundation, road inundation, emergency response classifications and flood damages; about 278 dwellings and 17 other buildings would be flooded above floor in the 1% AEP event, though generally to shallow depths (230 residential and 17 commercial are flooded by less than 300 mm); the estimated average annual damages is $6.9 million and the net present value of damage is $102.6 million (**Section 8**);
- Further definition of the flood problem by a formal risk assessment; this shows that catastrophic damage to houses is largely confined to very rare events (medium risk) but moderate damage is expected in frequent events (high risk); areas of pronounced risk in the study area include Gascoigne Rd and Lett St in Gorokan, Karangal Cres in Buff Point, and the back of the dune at Canton Beach;
- An assessment of potential floodplain management measures (Section 10) and detailed evaluation of flood modification options (Section 11), property modification options (Section 12) and response modification options (Section 13);

- An assessment of the potential impacts of climate change (Section 14);
- A recommended Floodplain Risk Management Plan (FRMP) for the Northern Lakes study area (Section 15).

Floodplain Risk Management Plan

The draft Northern Lakes FRMP is summarised in **Table ES.1** and **Figure ES.1**. The recommended measures have been selected from a range of available options, after an assessment of the impacts on flooding, as well as economic, environmental and social considerations.

The recommended measures are summarised below:

Flood modification measures

- Greenacre Ave, Lake Munmorah culvert upgrade
- Crossingham St, Canton Beach culvert upgrade
- Pathway and culvert upgrade between Lett St, Gorokan and Tuggerah Lake
- Woodland Parkway Reserve entrance excavation

Property modification measures

- Prepare a scoping study including detailed floor level survey, consultation and site inspections to further assess feasibility of establishing a small voluntary house raising scheme
- Prepare Council's flood-proofing Guidelines as suggested; prepare a one-page, graphic summary of the Guidelines
- Review and adopt the revised flood risk management provisions of Central Coast DCP including freeboards for the study area

Response modification measures

- Improve emergency response planning:
  - Update Local Flood Sub-Plan in view of the flood risk information in the Northern Lakes FRMS&P;
  - Encourage and assist community members who are likely to be impacted by flooding to prepare and update their own flood emergency plans.
- Develop an optimised flood warning system:
  - Alarm the Toukley rain gauge so that it issues email/SMS when rain triggers are reached;
  - A new real-time rain gauge in the vicinity of Lake Munmorah/Freemans;
  - Transition towards a system where people living or working in the floodplain can be stay informed via a web portal that allows access to data;

  - Devise appropriate messages to accompany the rainfall alerts;
  - Although outside of the scope of an overland flood study, develop a Tuggerah Lakes flood warning system as questionnaire results showed that community perception links significant flooding to management of the Tuggerah Lakes.
- Prepare dam break analyses for both existing Gorokan Park basin and sport fields directly east of Lake Haven Shopping Centre
- Flood Education:
  - Develop a library or mobile display using historical flood photos, modelled flood extents and appropriate messaging;
  - Develop an accessible flood emergency plan template suitable for use by Northern Lakes businesses, in conjunction with Wyong Regional Chamber of Commerce;
  - Hold a Business FloodSafe Breakfast in conjunction with Wyong Regional Chamber of Commerce;
  - Conduct 'meet-the-street' type events for residents at four key locations in catchment;
  - Engage with students at Local Schools to help them understand flood behaviour near the school and to promote safe responses;
  - Install signage in flood prone carparks;
  - Install flood depth indicators at ~5 low-points on roads;
  - Install signage in any detention basins where flooding could pond.

Funding

The total capital cost of implementing the Plan is about $4.1M, comprised mainly of the four flood modification measures. Upgrade of the pathway and culvert under Lett St in Gorokan would have a Benefit Cost Ratio (BCR) of 1.48 while the Woodland Parkway Reserve channel excavation would have a BCR of 1.6. The Greenacre Rd culvert upgrade in Lake Munmorah and the Crossingham St culvert upgrade in Canton Beach would have BCR of 0.76 and 0.89 respectively.

Table ES.1 - Draft Northern Lakes Floodplain Risk Management Plan

Report section	Floodplain Management Measure	Implementation Responsibility	Initial cost	Ongoing cost	Priority	Timing	Resourcing	Comments
	FLOOD MODIFICATION MEASURES							
11.3.1	Greenacre Ave, Lake Munmorah culvert upgrade	CCC	$829K	$0*	Medium	1-2 yrs	CCC, DPIE	
11.3.2	Crossingham St, Canton Beach culvert upgrade	CCC	$1,344K	$0*	Medium	1-2 yrs	CCC, DPIE	
11.3.4	Pathway and culvert upgrade between Lett St, Gorokan and Tuggerah Lake	CCC	$1,085K	$0*	High	0-1 yr	CCC, DPIE	
11.3.5	Woodland Parkway Reserve entrance excavation	CCC	$642K	$0	High	0-1 yr	CCC, DPIE	Subject to environmental impact assessment of excavation
	PROPERTY MODIFICATION MEASURES							
12.1, 12.2, 12.3	Prepare a scoping study including detailed floor level survey, consultation and site inspections to further assess feasibility of establishing a small voluntary house raising scheme	CCC	$20K	$0	Low	> 2 yrs	DPIE, CCC	
12.3	Prepare Council's flood-proofing Guidelines as suggested; prepare a one-page, graphic summary of the Guidelines	CCC	$15K	$0	Medium	1-2 yrs	DPIE, CCC	
12.4	Review and adopt the revised flood risk management provisions of Central Coast DCP including freeboards for the study area	CCC	Staff costs	$0	High	0-1 yr	CCC	
	RESPONSE MODIFICATION MEASURES							
13.2	Improve emergency response planning: • Update Local Flood Sub-Plan in view of the flood risk information in the Northern Lakes FRMS&P; • Encourage and assist key floodplain community members who are likely to be impacted by flooding to prepare and update their own flood emergency plans	NSW SES, Local Emergency Management Committee (LEMC)	Staff costs	$0	High	0-1 yr	NSW SES, Local Emergency Management Officers (LEMOs)	

Report section	Floodplain Management Measure	Implementation Responsibility	Initial cost	Ongoing cost	Priority	Timing	Resourcing	Comments
13.1	Improve flood warning system: • Alarm the Toukley rain gauge so that it issues email/SMS when rain triggers are reached; • a new real-time rain gauge in the vicinity of Lake Munmorah/Freemans • Transition towards a system where people living or working in the floodplain can stay informed via a web portal that allows access to data • Devise appropriate messages to accompany the rainfall alerts • Tuggerah Lake Warning System	CCC, NSW SES	$70K	$20K p.a.	Medium	1-2 yrs	DPIE, CCC, NSW SES	
13.2	Prepare dam break analyses for both existing Gorokan Park basin and sport fields directly east of Lake Haven Shopping Centre	CCC	$10K	$0	Medium	1-2 yrs	CCC	
13.3	Flood Education: • Develop a library or mobile display using historical flood photos, modelled flood extents and appropriate messaging; • Develop an accessible flood emergency plan template suitable for use by Northern Lakes businesses, in conjunction with Wyong Regional Chamber of Commerce; • Hold a Business FloodSafe Breakfast in conjunction with Wyong Regional Chamber of Commerce; • Conduct 'meet-the-street' type events for residents at four key locations in catchment; • Engage with students at Local Schools to help them understand flood behaviour near the school and to promote safe responses; • Install signage in flood prone carparks; • Install flood depth indicators at ~5 low-points on roads; • Install signage in any detention basins where flooding could pond	NSW SES, CCC	$90K ($5K display, $5K template, $20K breakfast, $40K four meet-the-street events, $20K for ~15 signs)	$0	High	1-2 yrs	DPIE, NSW SES, CCC	Signage may require community concurrence at each location
TOTAL			$4,105K	$20K p.a.				

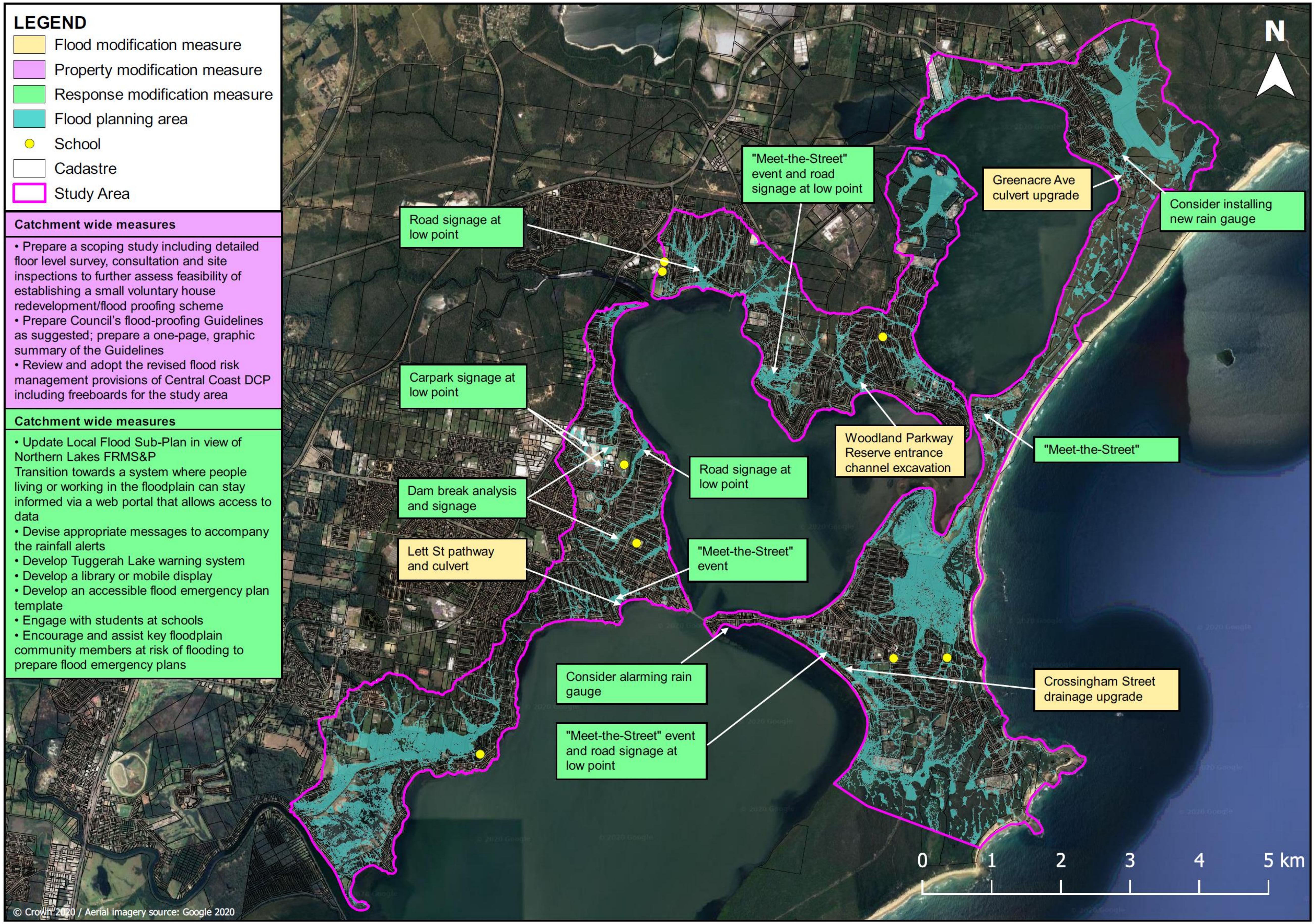

Figure ES.1 – Floodplain Risk Management Plan

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1. Introduction

NSW Government's Manly Hydraulics Laboratory (MHL) was engaged by Central Coast Council (Council) to undertake the Northern Lakes Floodplain Risk Management Study and Plan (FRMS&P) with funding from the Environment, Energy and Science group (EES) of the Department of Planning, Industry and Environment (DPIE), then Office of Environment and Heritage (OEH) through the NSW Government's Floodplain Management Program.

There have been various hydrologic and hydraulic studies undertaken for the Northern Lakes catchments. The most recent was the Northern Lakes Flood Study (Cardno, 2015). This flood study documents flood behaviour across the catchment for a range of design floods for existing topographic and development conditions.

The objective of this project is to undertake a Floodplain Risk Management Study and to develop a Floodplain Risk Management Plan for the Northern Lakes catchment focusing on overland flooding. Mainstream flooding generated by elevated levels in the Northern Lakes is not part of this study.

2. Background

2.1 The study area

The Northern Lakes catchments are located on the Central Coast of New South Wales and occupy a combined area of 33.5km^2. **Figure 2.1** illustrates the extent of the study area.

The study area comprises a number of suburbs that surround the inter-connected Lake Munmorah, Budgewoi Lake and Tuggerah Lake; namely Wyongah, Gorokan, Lake Haven, Charmhaven, San Remo, Buff Point, Budgewoi, Halekulani, Lake Munmorah, Noraville, Toukley and Norah Head. The study area is comprised largely of residential development, with areas of commercial, light industrial, open space and bushland occurring in smaller amounts throughout the area. The downstream areas of the catchment are impacted by flooding from Tuggerah Lakes.

The area is fast growing. **Figure 2.2** illustrates the urbanisation of areas around the Tuggerah Lakes between 1941 and 1998 (based on CSIRO, 1999).

2.2 History of flooding and rainfall

A number of historical floods were reported by local ecologists and fishermen in *"Ecology of the Tuggerah Lakes – An Oral Story" (CSIRO, 1998)* as it impacted the local aquatic ecology. Floods occurred fairly regularly in the 1920-50 period with events in 1927, 1928, 1931, 1947 and 1949 mentioned multiple times. Other floods that were mentioned included the 1954, 1956, 1964, 1972, 1974 and 1990 events.

The 1927, 1946, 1949 and 1964 events appear to be the largest floods. However, it is important to note that most of the floods mentioned in this report appear to be lake flooding rather than overland floods, with elevated lake levels generated by closed lake entrance.

Based on existing rainfall gauges within the catchment (more details are provided in **Section 3.1**), over 100mm of daily rainfall occurred in June 1991, August 1998, October 2004, June 2007, January 2013 and June 2016.

CSIRO (1999) presented a summary of the major rainfall events recorded for Wyong between 1885 and 1998. The list of rainfall has been reproduced in **Table 2.1**. It can be observed that the various heavy rainfalls occur at regular interval with some occasional clusters of heavy rainfalls over a few years and some gaps with no heavy rainfall for 10-15 years.

Figure 2.1 – Study area location

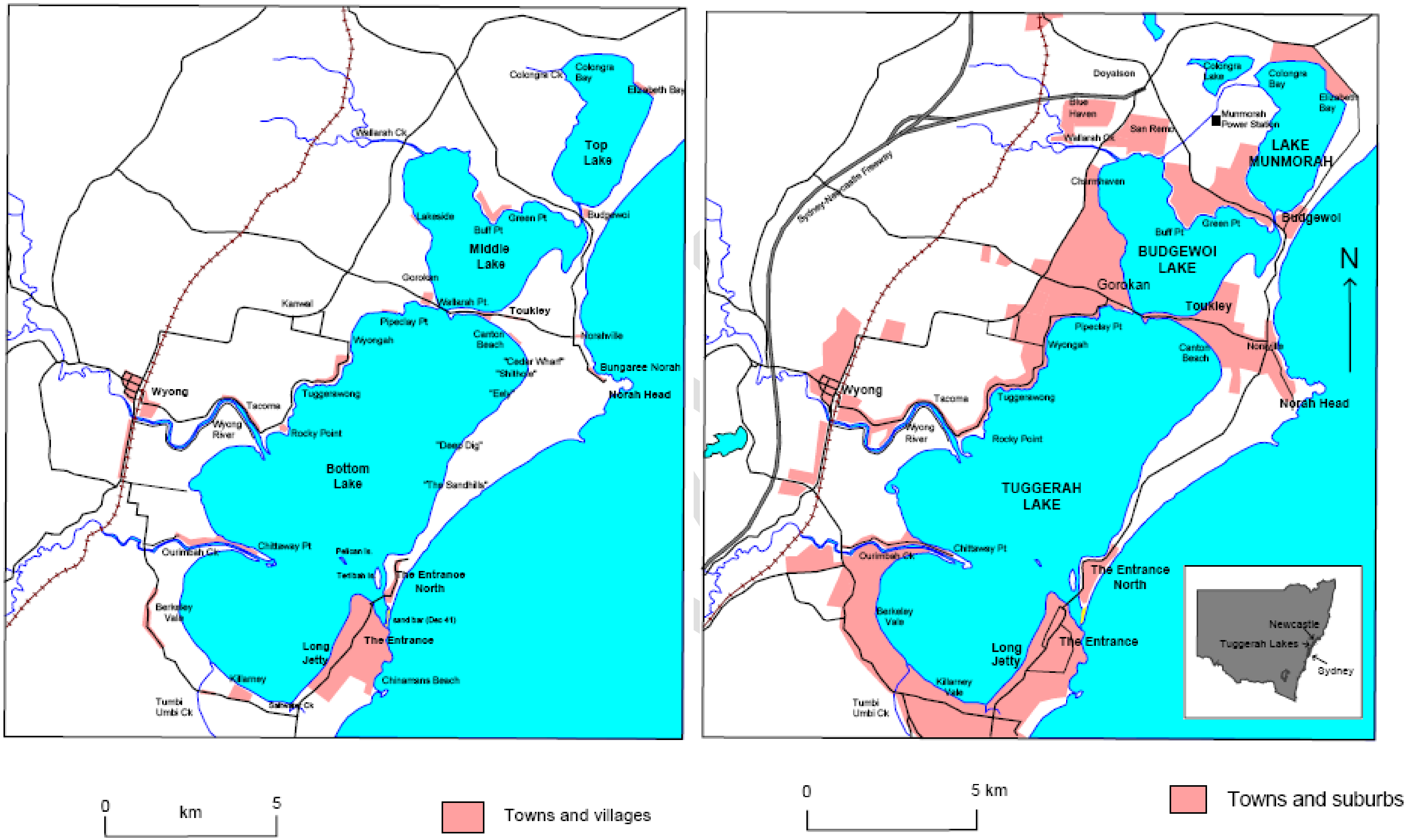

Figure 2.2 – Urbanisation between 1941 (Left) and 1998 (Right) around Tuggerah Lakes

Source: CSIRO, 1999

Table 2.1 – Major Rainfall events over 200mm for Wyong between 1885 and 1998

Source: CSIRO, 1999

Date	Rainfall (mm)
June 1885	274 mm in 3 days
May 1889	440 mm in 4 days
March 1894	215 mm in 6 days
January 1895	246 mm in 4 days
August 1899	251 mm in 4 days
June 1900	212 mm in 4 days
April 1905	389 mm in 2 days
March 1907	261 mm in 4 days
December 1920	341 mm in 8 days (242 mm in 4 days)
Dec 1921 - Jan 1922	410 mm in 14 days
January 1924	268 mm in 4 days
May 1925	311 mm in 10 days
December 1926	298 mm in 3 days
April 1927	390 mm in 5 days
February 1929	264 mm in 5 days
October 1929	290 mm in 7 days
March 1930	267 mm in 8 days
June 1930	284 mm in 3 days
March 1942	461 mm in 8 days
May 1943	376 mm in 13 days (246 mm in 4 days)
June 1945	304 mm in 7 days
April 1946	658 mm in 5 days
January 1948	206 mm in 5 days
January 1949	293 mm in 2 days
June 1949	321 mm in 6 days
June 1950	270 mm in 5 days
July 1952	284 mm in 4 days
May 1953	473 mm in 8 days (248 mm in 3 days)
February 1956	215 mm in 3 days
March 1958	201 mm in 4 days
May 1962	276 mm in 5 days
April 1963	250 mm in 4 days
June 1964	432 mm in 8 days
January 1972	218 mm in 5 days
March 1977	261 mm in 3 days
March 1978	247 mm in 8 days
May 1978	207 mm in 5 days
May/June 1978	217 mm in 3 days
February 1981	218 mm in 2 days
November 1984	203 mm in 4 days
July 1988	204 mm in 2 days
December 1989	292 mm in 3 days (266 mm in 1 day)
February 1990	405 mm in 2 days
April 1990	202 mm in 6 days
February 1992	214 mm in 3 days
May 1998	237 mm in 5 days

Note: some events may be missing due to gaps in records

2.3 Previous studies

Previous studies relevant to this report have been reviewed and key findings are reported below.

2.3.1 Northern Lakes Flood Study

This flood study was completed in 2015 and is the first stage of the current project.

Community consultation was undertaken as part of this study and it was found that respondents had a relatively high flood awareness. However, it was noted that residents who have experienced flooding are more likely to complete and return the questionnaire and as such, it is possible that the wider community has a lower flood awareness.

The study consisted of the construction of a two-dimensional TUFLOW hydraulic model based on a 2007 LiDAR dataset and complemented by survey of key hydraulic structures and channel/creek cross sections. The model used a 2m cell size and was separated into 5 sub-models. The model included pipes with a diameter over 0.15m and adopted the following pits opening due to lack of existing data:

- Combination inlets with a 2.4m lintel and a 0.9m by 0.6m grate for road pits; and,
- An inlet with a 0.9m by 0.6m (0.54m^2) grate for pits located in open space.

An on-grade and sag inlet curve were developed for both of these pits. The model used a 10% blockage rate for culverts and structures with a diagonal length greater than 6m and a 50% blockage rate for culverts and structures with a diagonal length less than 6m.

For the design events, lake levels of 0.5m AHD for the 20% and 5% AEP events and 0.6m AHD for the 1% AEP and PMF events were adopted.

The TUFLOW model was validated by using three independent methods:

- Sub-catchment flows were verified using an independent hydrological model (XP-RAFTS) and comparison with the Probabilistic Rational Method (PRM), as described in AR&R (1987).
- Model results were compared against community observations to ensure that the results accurately depict what the community has experienced in past floods.
- The results were ground-truthed to ensure that the flow behaviour shown in the models was reasonable given the catchment conditions.

Critical duration for all events up to 1% AEP was found to be 1.5 hour while the PMF event had two main critical durations depending on the location so an envelope of the 15 minute and 30-minute durations was adopted for this event. This confirms the independence from the Lake flooding that peaks after 2 to 5 days.

The direct rainfall approach was applied for the TUFLOW model and filtering was applied using the following criteria:

- Depths greater than 0.15m; OR
- Velocities greater than 2m/s.

Table 2.2 presents the number of flood-affected properties in the Northern Lakes catchments area as calculated in the flood study.

Table 2.2 – Flood affected properties

Source: Northern Lakes Flood Study, 2015

Flood Event	Number of property lots affected by flood
PMF	6,625
1% AEP	2,142
5% AEP	1,569
20% AEP	992

Flood hazard, hydraulic categories and performance of detention basins were defined, and key facilities' flood affectations were listed.

Climate change was also assessed by applying 15% and 30% increases in rainfall intensity, which generated 35% and 70% increases in the number of affected lots for the 1% AEP flood event. However, the increase in flood depth was reported to be generally insignificant.

Preliminary flood damage assessments were also completed.

2.3.2 Tuggerah Lakes Floodplain Risk Management Study and Plan

This study was adopted by Council in March 2015. It analyses the flooding generated by Budgewoi Lake, Lake Munmorah and Tuggerah Lake. This study is complementary to the current study as it focuses on the lake (mainstream) flooding while the current study focuses on the overland flooding.

The level of the three lakes was found to be identical with a typical level of 0.30m AHD ±0.05m. The study covered the surroundings of the Northern Lakes shoreline up to 3m AHD. The maximum recorded lake level was 2.1m AHD in 1949. Peak design flood levels were reported as presented in **Table 2.3**. The flood modelling for this study showed that a uniform peak water level was applicable to all three lakes.

Table 2.3 – Northern Lakes Flood Levels

Source: Tuggerah Lakes FRMSP, 2014

Event	Flood Level (m AHD)
PMF	2.70
1% AEP	2.23
5% AEP	1.80
20% AEP	1.36
50% AEP	0.91

Flood modelling was completed using a WBNM hydrologic model and a MIKE11 hydraulic model. The study determined a critical duration for the flooding of the lakes of 2 to 5 days and highlighted that water levels in the lakes are influenced by the entrance condition at The Entrance.

2.4 Relevant policies, legislation and guidance

Appropriate land use planning is one of the most effective measures available to floodplain managers, especially to control future risk but also to reduce existing flood risks as redevelopment occurs. The following sections discuss existing planning legislation and policies that affect the development of land within the Central Coast Council Local Government Area.

2.4.1 National provisions

2.4.1.1 Australian Rainfall & Runoff, 2019

Australian Rainfall and Runoff (AR&R) is a national guideline document, data and software suite that is used for the estimation of design flood characteristics in Australia. This is the 4th edition of AR&R, after the 1st edition was released by Engineers Australia in 1958. Geoscience Australia supports AR&R as part of its role to provide authoritative, independent information and advice to the Australian Government and other stakeholders to support risk mitigation and community resilience.

AR&R is pivotal to the safety and sustainability of Australian infrastructure, communities and the environment. It is an important component in the provision of reliable and robust estimates of flood risk. Consistent use of AR&R ensures that development does not occur in high risk areas and that infrastructure is appropriately designed.

2.4.1.2 Building Code of Australia

The 2016 edition of the Building Code of Australia (BCA) introduced new requirements related to building in Flood Hazard Areas (FHAs), which provide a minimum construction standard across Australia for specified building classifications in FHAs up to the Defined Flood Event (DFE).

The DFE is analogous to the planning flood event and is most commonly the 1% AEP flood. FHAs are defined in the BCA as encompassing land lower than the flood hazard level (FHL), which in turn is defined as ‘the flood level used to determine the height of floors in a building and represents the DFE plus the ‘freeboard’. Therefore, FHAs would typically be defined as those areas falling within the flood planning area.

Volume One, BP1.4 and Volume Two, P2.1.2 specify the Performance Requirements for the construction of buildings in FHAs. They only apply to buildings or parts of buildings of Classes 1, 2, 3, 4 (residential), 9a (healthcare) and 9c (aged-care). These Performance Requirements require a building in an FHA to be designed and constructed to resist flotation, collapse and significant permanent movement resulting from flood actions during the DFE. The actions and requirements to be considered to satisfy this performance requirement include but are not limited to:

- Flood actions;
- Elevation requirements;

- Foundation and footing requirements;
- Requirements for enclosures below the flood hazard level;
- Requirements for structural connections;
- Material requirements;
- Requirements for utilities; and
- Requirements for occupant egress.

The Deemed-to-Satisfy (DTS) provisions of Volume One, B1.6 and Volume Two, 3.10.3.0 require buildings in the classes described above and located in FHAs to comply with the ABCB Standard for Construction of Buildings in Flood Hazard Areas 2012 (the ABCB Standard).

The ABCB Standard specifies detailed requirements for the construction of buildings to which the BCA requirements apply, including:

- Resistance in the DFE to flood actions including hydrostatic actions, hydrodynamic actions, debris actions, wave actions and erosion and scour;
- Floor height requirements, for example that the finished floor level of habitable rooms must be above the Flood Hazard Level (FHL);
- The design of footing systems to prevent flotation, collapse or significant permanent movement;
- The provision in any enclosures of openings to allow for automatic entry and exit of floodwater for all floods up to the FHL;
- Ensuring that any attachments to the building are structurally adequate and do not reduce the structural capacity of the building during the DFE;
- The use of flood-compatible structural materials below the FHL;
- The siting of electrical switches above the FHL, and flood proofing of electrical conduits and cables installed below the FHL; and
- The design of balconies etc. to allow a person in the building to be rescued by emergency services personnel, if rescue during a flood event up to the DFE is required.

Building Circular BS13-004 (NSW Department of Planning and Infrastructure, 2013) summarises the scope of the BCA and how it relates to NSW planning arrangements. The scope of the ABCB Standard does not include parts of FHA that are subject to flow velocities exceeding 1.5 m/s or are subject to mudslide or landslide during periods of rainfall and runoff or are subject to storm surge or coastal wave action.

It is particularly noted that the Standard applies only up to the DFE, which typically will correspond to the level of the 1% AEP flood plus 0.5 m freeboard. The Building Circular emphasises that because of the possibility of rarer floods, the BCA provisions do not fully mitigate the risk to life from flooding.

The ABCB has also prepared an Information Handbook for the Construction of Buildings in Flood Hazard Areas. This Handbook provides additional information relating to the construction of buildings in FHA but is not mandatory or regulatory in nature.

In the NSW planning system, the BCA takes on importance for complying development under the State Environmental Planning Policy (Exempt and Complying Development Codes) 2008. Certain development on the floodplain is also required to satisfy the requirements of the BCA under Wyong Development Control Plan 2013 (currently being revised). The Building Circular also indicates that following development approval, an application for a construction certificate (CC) will require assessment of compliance with the BCA.

2.4.2 State provisions

2.4.2.1 Environmental Planning and Assessment Act 1979

General

The NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) creates the mechanism for development assessment and determination by providing a legislative framework for development and protection of the environment from adverse impacts arising from development. The EP&A Act outlines the level of assessment required under State, regional and local planning legislation and identifies the responsible assessing authority.

Prior to development taking place in NSW a formal assessment and determination must be made of the proposed activity to ensure it complies with relevant planning controls and, according to its nature and scale, conforms with the principles of environmentally sustainable development.

Section 7.11 Development Contributions

Section 7.11 (previously Section 94) of the EP&A Act enables councils to collect contributions from developers for the provision of infrastructure that is necessary as a consequence of development. This can include roads, drainage, open space and community facilities. Each council must develop a Section 94 Contributions Plan which demonstrates a quantifiable link between the development intensification and the need for the additional infrastructure as well as a detailed costing of such infrastructure and formulae to be used to determine contributions from each type of development.

Section 9.1 Directions – Direction No. 4.3 (Flood Prone Land)

NSW flood-related planning requirements for local councils are set out in Ministerial Direction No. 4.3 Flood Prone Land, issued in 2007 under the then Section 117 (now Section 9.1) of the EP&A Act. It requires councils to ensure that development of flood prone land is consistent with the NSW Government's Flood Prone Land Policy as set out in the *Floodplain Development Manual* (NSW Government, 2005). It requires provisions in a Local Environmental Plan on flood prone land to be commensurate with the flood hazard of that land. In particular, a planning proposal must not contain provisions that:

- Permit development in floodway areas;
- Permit development that will result in significant flood impacts to other properties;
- Permit a significant increase in the development of that land;
- Are likely to result in a substantially increased requirement for government spending on flood mitigation measures, infrastructure or services; and
- Permit development to be carried out without development consent except for the purposes of agriculture, roads or exempt development.

The Direction also requires that councils must not impose flood related development controls above the residential flood planning level (FPL, typically the 1% AEP flood plus 0.5m freeboard) for residential development on land, unless a relevant planning authority provides 'adequate justification' for those controls to the satisfaction of the Director-General.

Section 10.7 Planning Certificates

Planning certificates are a means of disclosing information about a parcel of land. Two types of information are provided in planning certificates: information under Section 10.7(2) and information under Section 10.7(5) of the EP&A Act. (Note that previously this clause was Section 149).

A planning certificate under Section 10.7(2) discloses matters relating to the land, including whether or not the land is affected by a policy that restricts the development of land. Those policies can be based on identified hazard risks (*Environmental Planning and Assessment Regulation 2000*, Clause 279 and Schedule 4 Clause 7), and whether development on the land is subject to flood-related development controls (EP&A Regulation, Schedule 4 Clause 7A). If no flood-related development controls apply to the land (such as for residential development in so-called 'low' risk areas above the FPL, unless 'adequate justification' has been satisfied), information describing the flood affectation of the land would not be indicated under Section 10.7(2). A lot that is a 'flood control lot' under the Codes SEPP is a prescribed matter for the purpose of a certificate under section 10.7(2).

A planning certificate may also include information under Section 10.7(5). This allows a council to provide advice on other relevant matters affecting land. This can include past, current or future issues.

Inclusion of a planning certificate containing information prescribed under section 10.7(2) is a mandatory part of the property conveyancing process in NSW. The conveyancing process does not mandate the inclusion of information under section 10.7(5) but any purchaser may request such information be provided, pending payment of a fee to the issuing council.

2.4.2.2 State Environmental Planning Policies (SEPPs)

SEPPs are the highest level of planning instrument and generally prevail over Local Environmental Plans.

SEPP (Housing for Seniors or People with a Disability) 2004

State Environmental Planning Policy (Housing for Seniors or People with a Disability) 2004 aims to encourage the provision of housing (including residential care facilities) that will increase the supply of residences that meet the needs of seniors or people with a disability. This is achieved by setting aside local planning controls that would prevent such development.

Clause 4(6) and Schedule 1 indicate that the policy does not apply to land identified in another environmental planning instrument as being, amongst other descriptors, a floodway or high flooding hazard.

SEPP (Infrastructure) 2007

State Environmental Planning Policy (Infrastructure) 2007 aims to facilitate the effective delivery of infrastructure across the State by identifying development permissible without consent. *SEPP (Infrastructure) 2007* allows Council to undertake stormwater and flood mitigation work without development consent.

SEPP (Exempt and Complying Development Codes) 2008

A very important SEPP is *State Environmental Planning Policy (Exempt and Complying Development Codes) 2008*, which defines development which is exempt from obtaining development consent and other development which does not require development consent if it complies with certain criteria.

Clause 1.5 of this 'Codes' SEPP defines a 'flood control lot' as 'a lot to which flood related development controls apply in respect of development for the purposes of dwelling houses, dual occupancies, multi dwelling housing or residential flat buildings (other than development for the purposes of group homes or seniors housing)'. These development controls may apply through a LEP or DCP. Exempt development is not permitted on flood control lots, but some complying development is permitted.

Clause 3.5 states that complying development is permitted on flood control lots where a Council or professional engineer can certify that the part of the lot proposed for development is not a flood storage area, floodway area, flow path, high hazard area or high-risk area. The Codes SEPP specifies various controls in relation to floor levels, flood compatible materials, structural stability (up to the PMF if on-site refuge is proposed), flood affectation, safe evacuation, car parking and driveways.

In addition, Clause 1.18(1)(c) of the Codes SEPP indicates that complying development must meet the relevant provisions of the Building Code of Australia.

SEPP (Coastal Management) 2018

SEPP (Coastal Management) 2018 aims to promote an integrated and co-ordinated approach to land use planning in the coastal zone. For areas mapped as 'coastal wetland and littoral rainforests' – including sizeable areas in the study area near the three lakes – development consent is required for the clearing of native vegetation, and for earthworks, construction of a levee, draining the land and environmental protection works, and for any other development. For areas mapped as 'coastal environment areas' – covering much of the study area – development consent must not be granted unless the consent authority has considered whether the proposed development is likely to cause an adverse impact on "the integrity and resilience of the biophysical, hydrological (surface and groundwater) and ecological environment" amongst other factors. The development must be designed, sited and managed to either avoid, minimise or mitigate adverse impacts.

2.4.2.3 NSW Flood Related Manuals

Floodplain Development Manual, 2005

The *Floodplain Development Manual* 2005 (the Manual) was gazetted on 6 May 2005 and relates to the development of flood liable land. It incorporates the NSW Flood Prone Land Policy, which aims to reduce the impacts of flooding and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods, using ecologically positive methods wherever possible. To implement this policy and achieve these objectives, the Manual espouses a merit approach for development decisions in the floodplain, taking into account social, economic, ecological and flooding considerations. The

Manual confirms that responsibility for management of flood risk remains with local government. It assists councils in their management of the use and development of flood prone land by providing guidance in the development and implementation of local floodplain risk management plans.

At the time of preparing this report, the *Floodplain Development Manual* is being updated.

Guideline on Development Controls on Low Flood Risk Areas, 2007

The *Guideline on Development Controls on Low Flood Risk Areas – Floodplain Development Manual* (the Guideline) was issued on 31 January 2007 as part of Planning Circular PS 07-003 at the same time as the Section 117 (now Section 9.1) Directive described previously. The Guideline is intended to be read as part of the *Floodplain Development Manual*.

It stipulates that unless there are exceptional circumstances, councils should adopt the 100-year flood as the flood planning level (FPL) for residential development and that '*unless there are exceptional circumstances, councils should not impose flood related development controls on residential development on land … that is above the residential FPL*'.

An adequate freeboard should then be applied to the 100-year flood level to allow for potential inaccuracies in available data and limitation of the flood models.

Flood related development controls are not defined but would include any development standards relating to flooding applying to land, that are a matter for consideration under Section 4.15 (previously Section 79C) of the EP&A Act.

The Guideline states that councils should not include a notation for residential development on Section 10.7 (previously Section 149) certificates for land above the residential FPL if no flood related development controls apply to the land. However, the Guideline does include the reminder that councils can include 'such other relevant factors affecting the land that the council may be aware [of]' under Section 10.7(5) of the EP&A Act.

In proposing a case for exceptional circumstances, a council would need to demonstrate that a different FPL was required for the management of residential development due to local flood behaviour, flood history, associated flood hazards or a particular historic flood. Justification for exceptional circumstances would need to be agreed by relevant State Government departments prior to exhibition of a draft local environmental plan or a draft development control plan that proposes to introduce flood related development controls on residential development above the default FPL.

At the time of preparing this report, the Guideline is being reviewed.

2.4.3 Local provisions

In NSW, local government councils are responsible for managing flood risk within their Local Government Areas (LGAs). A Local Environmental Plan (LEP) is used to establish what land uses are permissible and/or prohibited on land within the LGA and sets out high level flood planning objectives and requirements. A Development Control Plan (DCP) sets the standards, controls and regulations that apply when carrying out development or building work on land.

A merger between Wyong Shire Council and Gosford City Council to form the Central Coast Council was announced in May 2016. At the time of preparing this report (September 2019), development applications within the study area continue to be assessed based on the former Wyong Shire planning controls.

This section briefly describes and reviews the flood-related controls within the Wyong Shire policies, with a view to flood behaviour in the Northern Lakes study area.

2.4.3.1 Wyong Local Environmental Plan 2013

Wyong Local Environmental Plan 2013 (Wyong LEP 2013) outlines the zoning of land, what development is allowed in each land use zone and any special provisions applying to land.

Flood planning and floodplain risk management are addressed in clauses 7.2 and 7.3. These are reproduced in **Figure 2.3**. Clause 7.2 relates to land at or below the flood planning level (FPL), sometimes called the 'flood planning area'. Clause 7.3 relates to land between the FPL and the PMF. The FPL is defined in Wyong LEP 2013 as 'the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metre freeboard'.

The appropriateness of the existing Wyong LEP 2013 for managing flood risk in the Northern Lakes local catchments is considered under the following headings:

- Flood planning area definition
- Evacuation challenges

Flood planning area definition

Flood planning levels (FPLs) and the flood planning area (FPA) are important tools in the management of flood risk. The FPA is used to define the area where flood-related development controls apply. For those areas contained within the FPA, the FPLs are frequently used to establish the elevation of critical components of a development, such as minimum floor levels.

The FPL is typically derived by adding a freeboard to a specific design flood. This specific design flood is frequently referred to as the "planning" flood. The freeboard is intended to account for any uncertainties in the derivation of the planning flood level.

The adoption of the 1% AEP flood for setting the flood planning level (FPL) is considered appropriate for the Northern Lakes local catchments. A more frequent design flood would expose communities to too great a risk, while a rarer event is not considered warranted given the modest flood height range between the 1% AEP flood and the PMF across most of the catchment.

Traditionally a 0.5 metre freeboard has been added to the planning flood to define the FPL and this FPL has been extended laterally until it encounters higher ground to define the FPA. While this approach is suitable for areas bound by higher ground (e.g., lakes, creek, rivers), it is not necessarily appropriate for urban catchments where the FPL may not be contained by higher ground.

7.2 Flood planning

(1) The objectives of this clause are as follows:
- (a) to minimise the flood risk to life and property associated with the use of land,
- (b) to allow development on land that is compatible with the land's flood hazard, taking into account projected changes as a result of climate change,
- (c) to avoid significant adverse impacts on flood behaviour and the environment.

(2) This clause applies to land at or below the flood planning level.

(3) Development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the development:
- (a) is compatible with the flood hazard of the land, and
- (b) is not likely to significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, and
- (c) incorporates appropriate measures to manage risk to life from flood, and
- (d) is not likely to significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, and
- (e) is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

(4) A word or expression used in this clause has the same meaning as it has in the *Floodplain Development Manual* (ISBN 0 7347 5476 0*)* published by the NSW Government in April 2005, unless it is otherwise defined in this Plan.

7.3 Floodplain risk management

(1) The objectives of this clause are as follows:
- (a) in relation to development with particular evacuation or emergency response issues, to enable evacuation of land subject to flooding in events exceeding the flood planning level,
- (b) to protect the operational capacity of emergency response facilities and critical infrastructure during extreme flood events.

(2) This clause applies to land between the flood planning level and the level of a probable maximum flood.

(3) Development consent must not be granted to development for the following purposes on land to which this clause applies unless the consent authority is satisfied that the development will not, in flood events exceeding the flood planning level, affect the safe occupation of, and evacuation from, the land:
- (a) air strips,
- (b) air transport facilities,
- (c) child care centres,
- (d) correctional centres,
- (e) educational establishments,
- (f) electricity generating works,
- (g) emergency services facilities,
- (h) group homes,
- (i) helipads,
- (j) home-based child care,
- (k) hospitals,
- (l) hostels,
- (m) public utility undertakings,
- (n) respite day care centres,
- (o) (Repealed)
- (p) seniors housing,
- (q) sewerage systems,
- (r) water supply systems.

(4) A word or expression used in this clause has the same meaning as it has in the *Floodplain Development Manual* (ISBN 0 7347 5476 0*)*, published by the NSW Government in April 2005, unless it is otherwise defined in this Plan.

Figure 2.3 – Extract from Wyong LEP 2013 Clauses 7.2 and 7.3

Note: version dated 28 February 2019

In recognition of the challenges involved in mapping the FPA in an urban catchment, studies for other nearby catchments (e.g., 'Tuggerah Lakes Southern Catchments Flood Study', WMAwater, 2018; 'Killarney Vale and Long Jetty Catchments Floodplain Risk Management Study', Catchment Simulation Solutions, in progress) have defined the FPA by incorporating a rainfall intensity increase to the 1% AEP event and using the inundation extent from this simulation to define the FPA. The rainfall intensity increase serves as a factor of safety (i.e., freeboard), thereby incorporating an allowance for uncertainty while ensuring a hydraulically realistic FPA is provided. For this study, a similar approach was adopted whereby the FPA was defined by re-simulating the 1% AEP flood with a 30% increase in rainfall to account for uncertainties (see **Section 9.1**).

For FPLs relevant to minimum floor levels, a variable freeboard (i.e. 0.3 metre freeboard across the majority of the study area affected by overland flows with modest flood height ranges, and 0.5 metre freeboard across localised areas and the lakes' foreshores) may be appropriate.

However, the model LEP clause taken up in Wyong LEP 2013 – stipulating only a 0.5 metres freeboard – does not allow this flexibility. As Central Coast Council consolidates the Wyong and Gosford LEPs into a single instrument, and as it considers the diversity of flood mechanisms across the LGA, it is possible that even more flexibility will be considered appropriate to define flood planning areas. It is therefore recommended that Council seek to amend the definition of flood planning level to cater for flexible requirements. For example:

'Flood planning level means the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metres freeboard, or other freeboard as determined in relevant studies and plans.'

Evacuation challenges

Flood modelling undertaken for the Flood Study and this Floodplain Risk Management Study identifies a number of features of flood behaviour that indicate evacuation in advance of, or during, a flood is likely to be impractical, and that on-site refuge may be an acceptable or safer emergency response:

- The worst flooding in these local catchments results from short storms (<60 minutes)
- Roads may be flooded in less than 30 minutes after the commencement of a storm. As a result, there is unlikely to be sufficient time to evacuate from parts of the catchments before roadways are inundated
- For overland flooding, the roadways are likely to be impassable for a relatively short time, which means a limited period of isolation
- Depths of inundation across most of the study area are typically shallow and the flood hazard indicates that most buildings are unlikely to suffer structural damage. It is noted that a number of properties, in the order of 20, have flooding for the 1% AEP flood above 0.5m.

Clause 7.3 of Wyong LEP is focussed on the evacuation of land subject to flooding in events exceeding the flood planning level. If this clause is strictly applied, any development application for the listed land uses in the Northern Lakes local catchments is likely to fail because the very fast-rising inundation prevents safe evacuation. Council may wish to seek approval to amend this clause to provide Council with discretion to be assured of safe evacuation *or* safe on-site refuge above the PMF.

2.4.3.2 Wyong Development Control Plan 2013

Supporting Wyong LEP 2013 is the *Wyong Development Control Plan 2013* (Wyong DCP 2013), which at the time of writing continues to set the design and construction standards that apply when carrying out development within the Northern Lakes study area.

This section considers controls that may be appropriate to manage overland flow inundation risks in the Northern Lakes local catchments, which along with recommendations for similar overland flow catchments, could be considered as a new Central Coast DCP is prepared.

Floor level

Given the modest flood height range, a freeboard of 0.3m rather than the normal 0.5m is considered appropriate for setting the flood planning level (FPL) across the majority of the study area. The FPL, in turn, sets minimum habitable floor levels for new dwellings.

Historically, concessions to floor level controls were sometimes permitted for commercial or industrial land uses, reasoning that businesses have capacity to tolerate more risk. Recent floods however have shown that flooding can cause severe damage to modern equipment and to livelihoods that depend on that business, which argues against lower floor levels for these uses.

Sensitive uses and critical infrastructure typically have the PMF level as the minimum habitable floor level, which is considered appropriate.

Given the observation from past floods that significant damage to precious contents can occur in garages, sheds or "storage areas", it is also considered appropriate to set minimum floor levels for non-habitable buildings or rooms. This could be to a lesser standard such as the 5% AEP flood. For example:

> *Floor levels to be 300mm above the finished ground level or equal to or greater than the 5% AEP flood level (whichever is higher).*

Parts of the Northern Lakes overland flow floodplains that are also subject to flooding from the lakes should be subject to the higher FPL that applies to the land.

Building components

It is considered appropriate that any part of buildings constructed below the FPL should be installed with flood-compatible components. This is also consistent with the requirement in the Codes SEPP.

Structural soundness

It could be argued that in areas of shallow overland flow, a requirement to demonstrate the structural soundness of a building is unnecessary. However, since such a provision is contained in the Codes SEPP, it would be inconsistent to apply a lesser standard in the DCP for land below the flood planning level.

Inundation effects

It is considered appropriate that new buildings should not worsen inundation on adjacent properties. This also is consistent with a requirement in the Codes SEPP. However, there is an argument for defining what constitutes a significant adverse flood impact (e.g. >20 mm rise).

Car parking and driveway access

Car parking controls are important given the ease with which vehicles can become buoyant and float and then become floating debris with potential to block culverts and pose environmental hazards. Carport floor levels could arguably be set at the 5% AEP level or 300mm above the ground level, whichever is higher.

Driveway access controls are considered less critical (for single dwellings) for land subject to short-lived, shallow overland flows since there may be negligible warning of floods, no opportunity for safe evacuation, and relatively short durations of isolation—suggesting that for this catchment, on-site refuge above the PMF may be safer than evacuation.

Evacuation

Given the impracticality and perhaps even the danger of evacuation—if flood conditions on roads are worse than those encountered at a property—and the relatively short duration of isolation—having controls for the Northern Lakes overland flow catchments that *require* evacuation may be inappropriate. In addition, the incremental difference in flood depths between the 1% AEP event and the PMF suggest that requiring a proportion of floor space within new dwellings to be above the PMF level to serve as an on-site refuge in extreme floods is not essential for this catchment. It would, however, be a desirable feature, given the fickleness of human behaviours during floods, which could see people get into difficulties if their houses commence to flood and result in a burden for rescuers. The cost of providing a higher floor space may not be prohibitive and would be a sensible long-term resilience measure.

Fencing

Fencing can have a significant impact on overland flows. Ideally, it should not impede the flow of floodwaters so as to result in additional flood impacts on surrounding land and should be able to withstand flooding or to collapse in a controlled manner to prevent a 'wave' causing additional problems downstream. Council could consider introducing specific controls for fencing on land below the FPL, such as prohibiting brick/masonry fences (likely to create impediments). It is recognised however that implementing fencing controls can be difficult.

3. Data collection and review

Available data were collated and reviewed to develop a better understanding of the study area and determine the adequacy and currency of the existing data.

3.1 Available data

3.1.1 Historic data

Historic flooding data are limited and were found from anecdotal publication and community consultation.

3.1.2 Rainfall and water level data

MHL manages a number of rainfall and water level recording stations within or in the vicinity of the study area these gauges include:

- Toukley Rainfall and Water Level Station (211401) since February 1985
- Wyee Rainfall Station (561097) since May 1992
- Hamlyn Terrace Rainfall Station (561133) since March 2010
- Wallarah Creek Bridge Water Level Station (211420) since May 1994

The daily rainfall data and 15-minute water level data for the various stations are provided in **Figure 3.1** and **Figure 3.2** respectively.

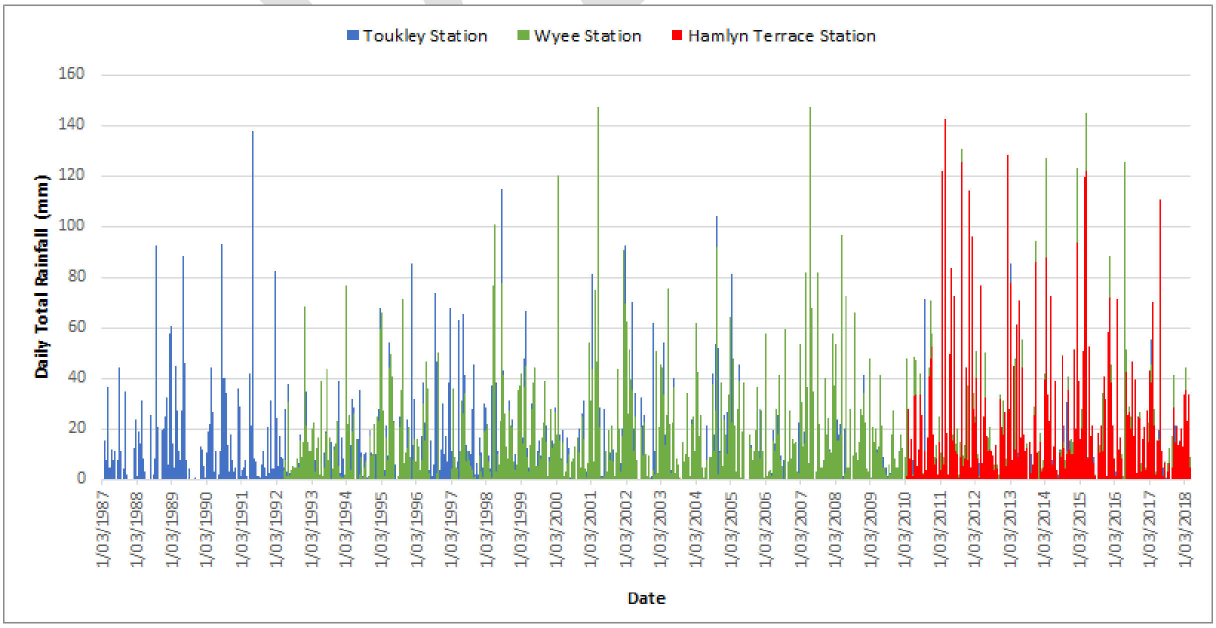

Figure 3.1 – Hourly rainfall data in vicinity of study area

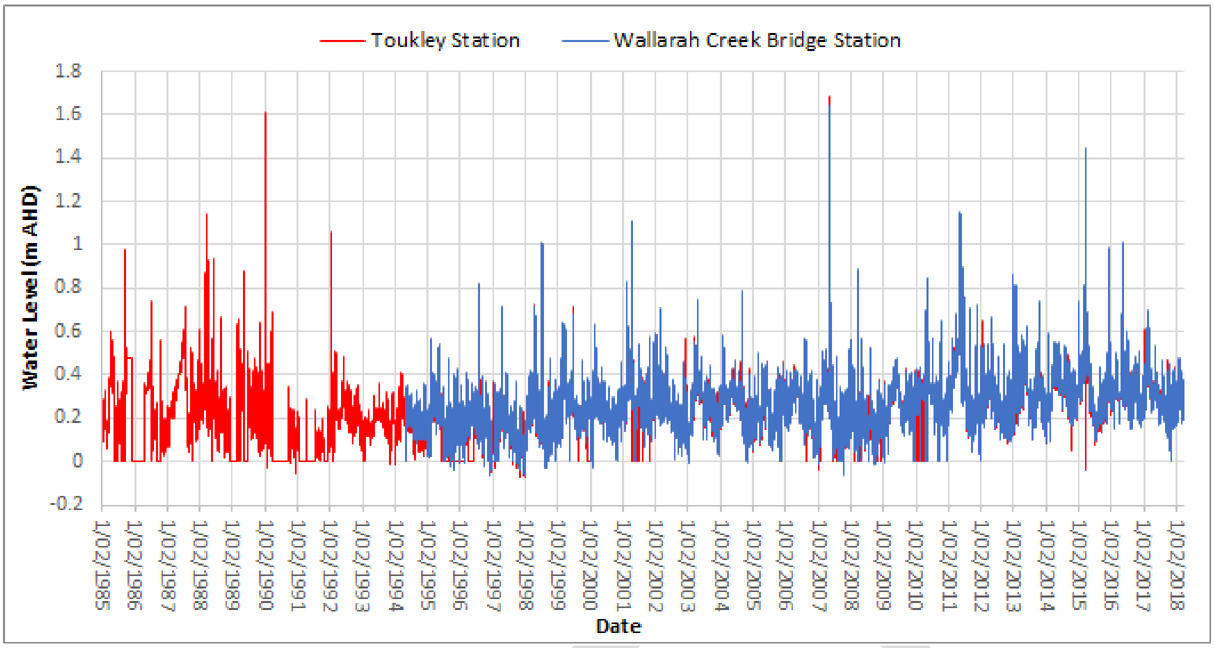

Figure 3.2 – 15-min water level data in the vicinity of study area

3.2 Topographic data

A digital elevation model (DEM) was provided by Council at the beginning of the study. This DEM was compared to the DEM extracted from the TUFLOW model constructed as part of the 2015 flood study and the following observations were made:

- Some discrepancies in the order of ±0.2m were relatively common throughout the study area and some areas had changes larger than ±0.5m;
- Council's latest DEM was generally lower than the model's DEM with some emphasis in highly vegetated sections as the latest DEM is expected to better capture the ground level through the vegetation;
- Some higher levels were observed in a few places and appeared to represent low-lying or ponding area that may have contained water at the time of the LiDAR investigation;
- Some steps in the topographic data provided by Council were observed (typically in the order of ~0.25m). These steps do not appear to be present in the DEM used into the model; and
- A large discrepancy in level was observed along the northern boundary of TUFLOW Sub-Model 2 which represented an area where the modelled DEM was dropped to 2 m AHD.

Following review of the DEM, it was found that correcting the steps present in the DEM would involve a significant amount of work while these steps were unlikely to generate any significant impact on flood depth and flood classification. The latest DEM from Council was therefore adopted and the flood model was updated accordingly.

The TUFLOW model extent was also required to be extended at a few locations within the catchment and this is discussed in more details in **Section 6**.

3.3 Survey for flood damage assessment

3.3.1 Floor survey criteria

A number of criteria were used to prioritise buildings for floor level survey. These criteria consider the level of risk as shown by the results of the emergency response classification, flood hazard and hydraulic categorisation. The criteria are:

- Inclusion of any property classified as a Flood Island or Trapped Perimeter Area
- Inclusion of any property located in the floodway of the 1% AEP flood event
- Inclusion of any property with a flood hazard category larger or equal to H4 (i.e. unsafe for people and vehicles) during a 1% AEP flood event
- Inclusion of high-risk properties (e.g. school, aged care facility) with a flood hazard category larger or equal to H4 during a PMF flood event
- Inclusion of properties with more than 0.15m flood depth at the building during a 1% AEP event.

3.3.2 Survey methodology

The floor level survey was completed using a desktop analysis approach. The properties matching the criteria described above were checked using aerial photographs, available DEM data, Google Street View and other property information available online. This included approximately 1650 residential property and over 30 commercial/industrial properties. A number of these properties had multiple buildings/businesses present on their lot and each individual building/business was counted as a stand-alone property for the purpose of floor level estimation and calculation of flood damages. It is noted that a number of properties matched the selection criteria but the building on the property was not impacted by the flood and so was not considered.

The following information was gathered into a spreadsheet:

- The location of the main entrance of the building on each lot. A point was placed at the appropriate location to determine the local flood level.
- The location of the most representative ground level based on building location and quality of available DEM (e.g. should a property be on a slope the appropriate side of the lot most representative of the floor level was selected). A point was placed at this location to obtain a ground level point.
- A level difference between the ground level and the floor level was then estimated and was typically based on the number of steps leading to the front door assuming a 0.15 m step height. Ground level was directly used for slab-on-ground type properties.
- Type of property (commercial, industrial or residential)
- Construction type (slab-on-ground or high-set)
- Number of stories of the building
- An estimate of the wall type (e.g. fibro or brick)
- A comment describing the quality of the estimation based on visibility or availability of the

data

- Comments about the property (e.g. poor visibility, multiple units)

A site visit was conducted on 21 January 2019 to ground truth the survey results and check some of the properties that were not visible using the desktop approach.

It is noted that some properties were inaccessible and floor level was estimated using the ground level assuming two steps difference to the floor levels (this is the most common type of property) or a similar number of steps to the neighbouring properties when all the properties of an area have similar elevation. Moreover, some of the available data may have been a few years old and sporadic changes to some properties may have occurred. However, while this may potentially vary the flood damage results for some individual properties, it should not change the general observations of key areas of interest where high damages are occurring.

More details on the flood damage assessment which uses these data is provided in **Section 8.6**.

4. Site visit and meetings

4.1 Initial site visit

MHL project team undertook a site inspection of the study area on 13 September 2017. The purpose of this inspection was to familiarise the team with the local area and understand where the key areas of concern are located. Areas that were highlighted by the flood study as at flood risk and areas where a large number of survey respondents mentioned that flooding issues occurred were inspected as a priority. Photographic records of key hydraulic structures were also gathered. A map presenting the location of the photographic records is presented in **Figure 4.1**.

The main observations that were made during the initial site visit are:

- Several locations are very low lying
- A number of locations may require drainage upgrades as part of the management options
- Some trash racks/GPTs require maintenance.

4.2 Pits and pipes inspection

A second site inspection was completed on 6 March 2018 to ground truth the pits and pipes layers. The locations that were inspected are also presented in **Figure 4.1**. More details on the ground-truthing inspection are provided as part of the pits and pipes review in **Section 6.3.2.**

4.3 Meetings with Council and working group

4.3.1 Inception meeting

An inception meeting with Council and DPIE was organised at the time of the initial site visit on 13 September 2017 to develop an understanding of the study area and hot spots.

4.3.2 Progress meeting 1

A progress meeting was held between Council, DPIE and MHL on 17 May 2018. The objective of the meeting was to discuss the work completed to date, key flooding areas, mapping criteria, flood hazards, emergency response classifications and flood planning area, determine best methodology for community questionnaire distribution and identify the next steps of the project.

4.3.3 Progress meeting 2

A progress meeting was held between Council, DPIE, NSW SES and MHL on 10 April 2019. The objective of the meeting was to discuss the work completed to date, community consultation results, flood damage assessment and preliminary management option analysis. Another objective was to obtain an agreement on the preferred 10 management options to analyse in detail as part of the next steps of the project.

Figure 4.1 – Photographs and pits/pipes inspection locations

5. Community consultation

5.1 Consultation process

Consultation provides an opportunity for various stakeholders, including the community, to collaborate together in developing the Northern Lakes FRMS&P. Engaging the community throughout the process provides both an opportunity to garner useful feedback and ideas regarding potential floodplain management measures, and to increase community acceptance of the floodplain risk management plan.

The consultation program for the FRMS&P has included the following activities:

- Inception and progress meetings between the consultant and Council
- Meetings of the Northern Lakes Floodplain Risk Management Working Group
- Consultation with agencies and stakeholders
- Development of a project website
- Letter and questionnaire for property owners
- Letter and questionnaire for business proprietors
- Public Exhibition of the Draft Northern Lakes FRMS&P Report including:
    - Community information sessions
    - Collation and review of community submissions.

These activities are described at greater length below.

5.2 Working group

The Northern Lakes Floodplain Risk Management Study & Plan Working Group (the Working Group) was formed by Council in order to provide a forum that brings together the diverse expertise and community knowledge that is needed to address technical, social, economic and ecological issues concerning floodplain risk management in the study area. The Working Group fulfils the functions of a Floodplain Risk Management Committee as described in the *Floodplain Development Manual* (NSW Government, 2005).

The Working Group comprises of representatives from:

- Central Coast Council
- DPIE
- NSW State Emergency Services (SES)

5.3 Agency/stakeholder consultation

The consultant has engaged with a number of relevant agencies and stakeholders with an interest in the study, as listed in **Table 5.1**.

Table 5.1 – Agency/Stakeholder consultation summary

Agency/stakeholder	Mode of contact	Issues
Central Coast Council	Meetings, telephone, email	Multiple
DPIE NSW	Meetings, email	General
NSW SES	Meetings	Flood Response Planning
Business Proprietors	Questionnaire	General

5.4 Website

A website was developed to provide information about the study including a link to the online community questionnaire (**Figure 5.1**).

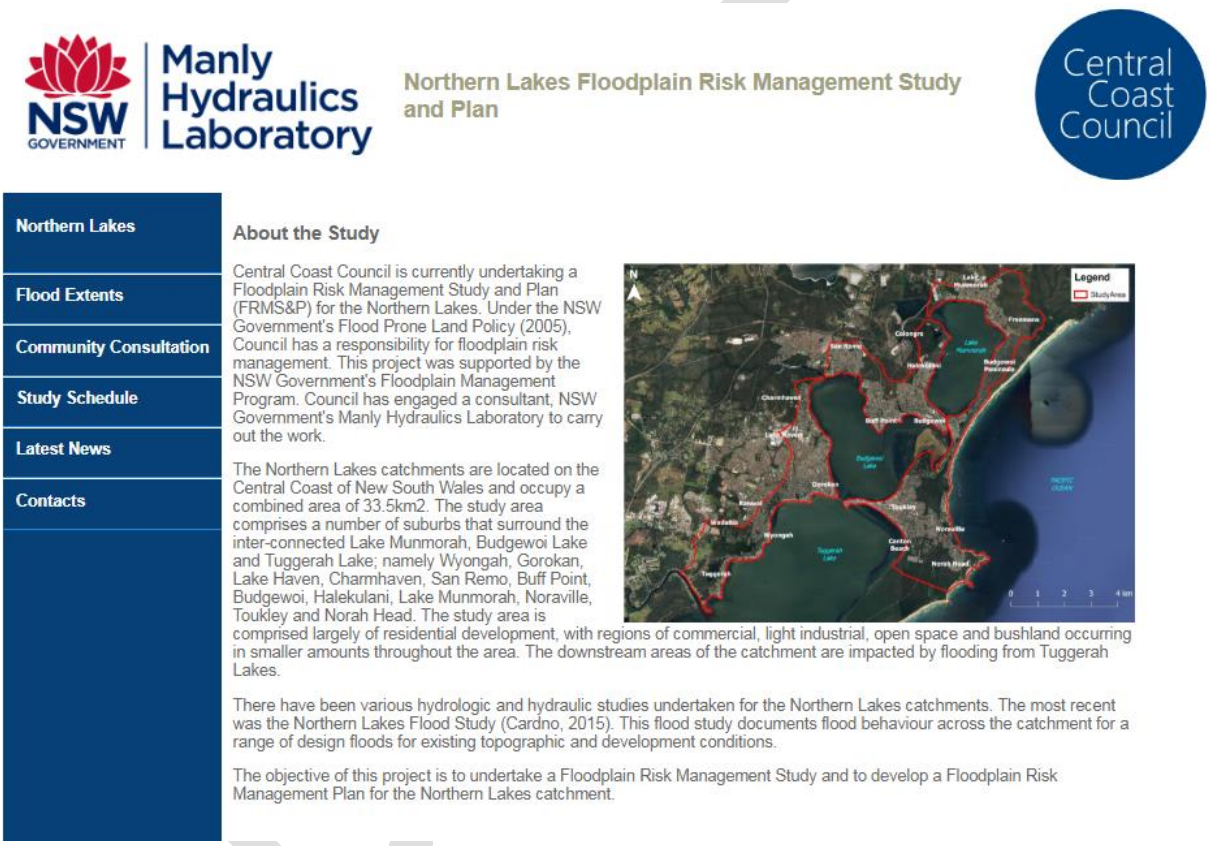

Figure 5.1 – Study Website

5.5 Letter and questionnaires

5.5.1 Approach

On 3 August 2018, a total of 4948 letters were distributed to all property owners (excluding Council or Government) identified as being flood affected (i.e. within the PMF flood extent). The letter alerted the residents and businesses of the online survey that was available to complete. A copy of the letter is included in **Appendix A** of this report.

The survey was also advertised through social media and on the project website.

From 3 August to 14 September 2018 an online survey was made available seeking community input about historic flood flooding and ideas about floodplain management options in the study area. The survey is included in **Appendix A**. A hardcopy of the survey was mailed to a number of residents at the same time as the community letter.

The online survey used the Floodengage platform as it provides information about the various management options which allows building up the awareness of local residents. This platform also allows the community and stakeholders to assign ten importance criteria that help to rank the pre-selected management options. This helps to identify a recommended set of options. The weightings were developed by Floodengage with inputs from various experts to assign justifiable and consistent scores to the floodplain management options for social, safety, environmental/ecological, economic and flood behaviour constraints.

5.5.2 Survey results

A total of 462 responses were received. This represents a response rate of 9.3%. A total of 19 responses were provided using the online Floodengage and 443 hardcopy responses were submitted. Results of the survey are provided in **Figure 5.2, Figure 5.3, Table 5.2** and **Table 5.3**.

Figure 5.2 presents the location of the respondents to the survey. This map also presents if the property has been impacted by flooding or not according to the residents. On this figure, green lots highlight the properties that have been classified as flood-free by the resident and red lots highlight the properties that have been impacted by flood according to the resident. It is noted that this is the perception of the residents and that interpretation of impact can vary (e.g. property considered not flooded when building has not been flooded while property is actually impacted).

Figure 5.3 presents the summary of the answers to the community questions. The majority of the respondents are local residents with only 10 commercial/industrial respondents, 4 farming/rural and 8 people did not respond. There is a majority of people having lived at their address for over 20 years. About 44% of respondents have been affected by floods with the primary impacts being flooding of garage/sheds (26.2%) or flooding of access road (18.8%). 7.4% of the respondents mentioned that their property was flooded above building floor and 8% experienced sewerage system failure.

The response behaviour also varies with the main responses including remain at property (34.8%) and secure valuables and goods at risk (35.1%).

The critical factors influencing the decisions to evacuate or stay at the property include primarily the family safety with close to 54% of the respondents as well as availability of access road, care for pets/animals and provision of a flood warning (all with approximately 25% of respondents). About a quarter of respondent believe that their house cannot be flooded.

Just over half of the respondents provided comments and suggestions and the majority provided their contact details. The most recurrent suggestions from the community include:

- kerb and gutter construction where non-existent (12.8% of respondents);
- upgrade of drainage system (17.5%);
- maintenance of drainage systems and GPTs (13.6%);
- development of an entrance management or dredging plan for the lakes (13.6%);

- investigation of a secondary lake opening (2.8%);
- maintenance of creeks/wetlands (3.2%); and
- improved development control/prevent overdevelopment (3.5%).

Other suggestions are listed in **Table 5.2.**

Table 5.3 summarises the importance of each selection criteria as well as the associated recommended management options ranking based on the weighting developed by Floodengage. The preferred option appears to be development of local flood policies and development controls and local flood disaster plans, and that large structural options are typically at the bottom of the list.

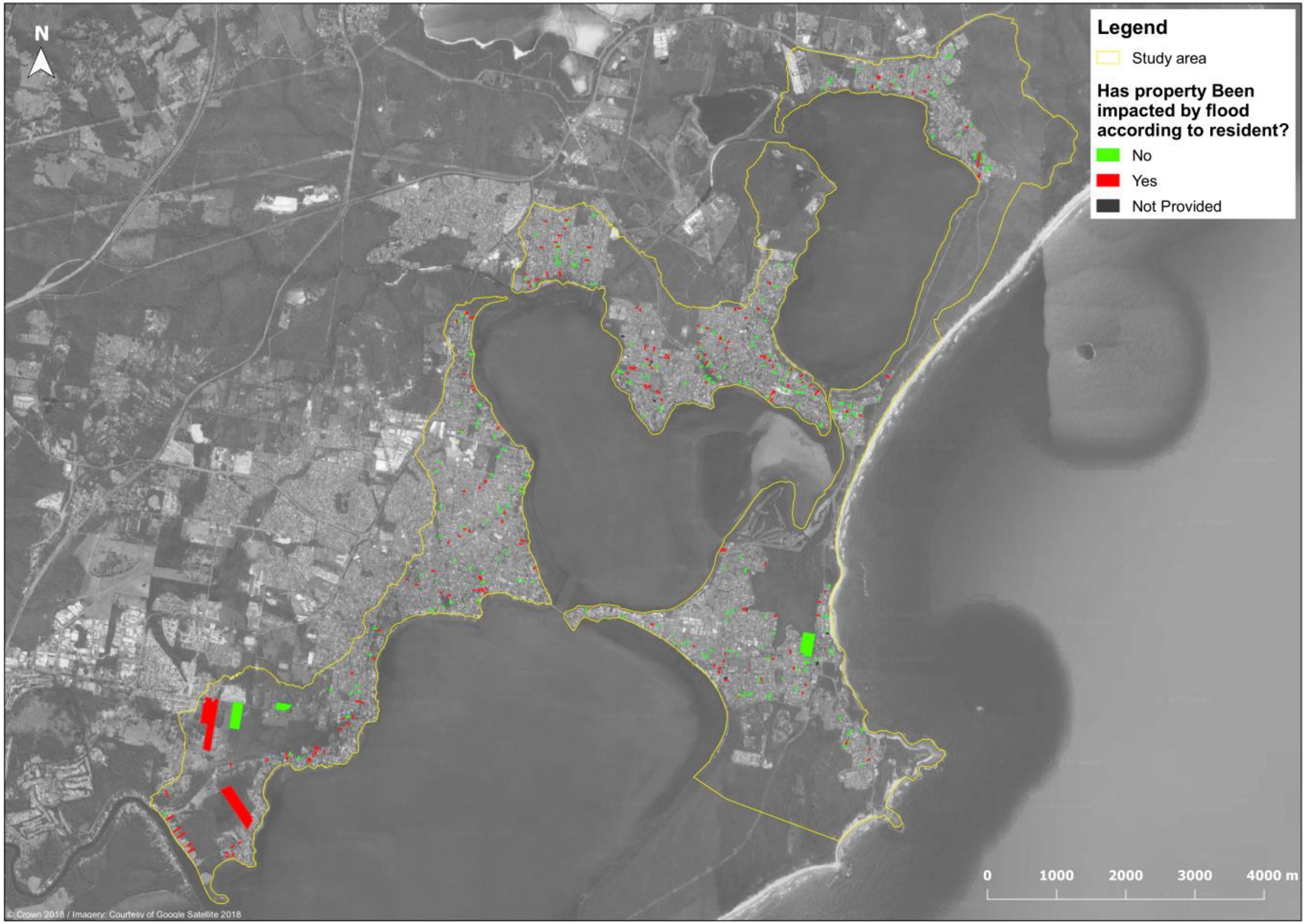

Figure 5.2 – Location of Respondents to the Survey

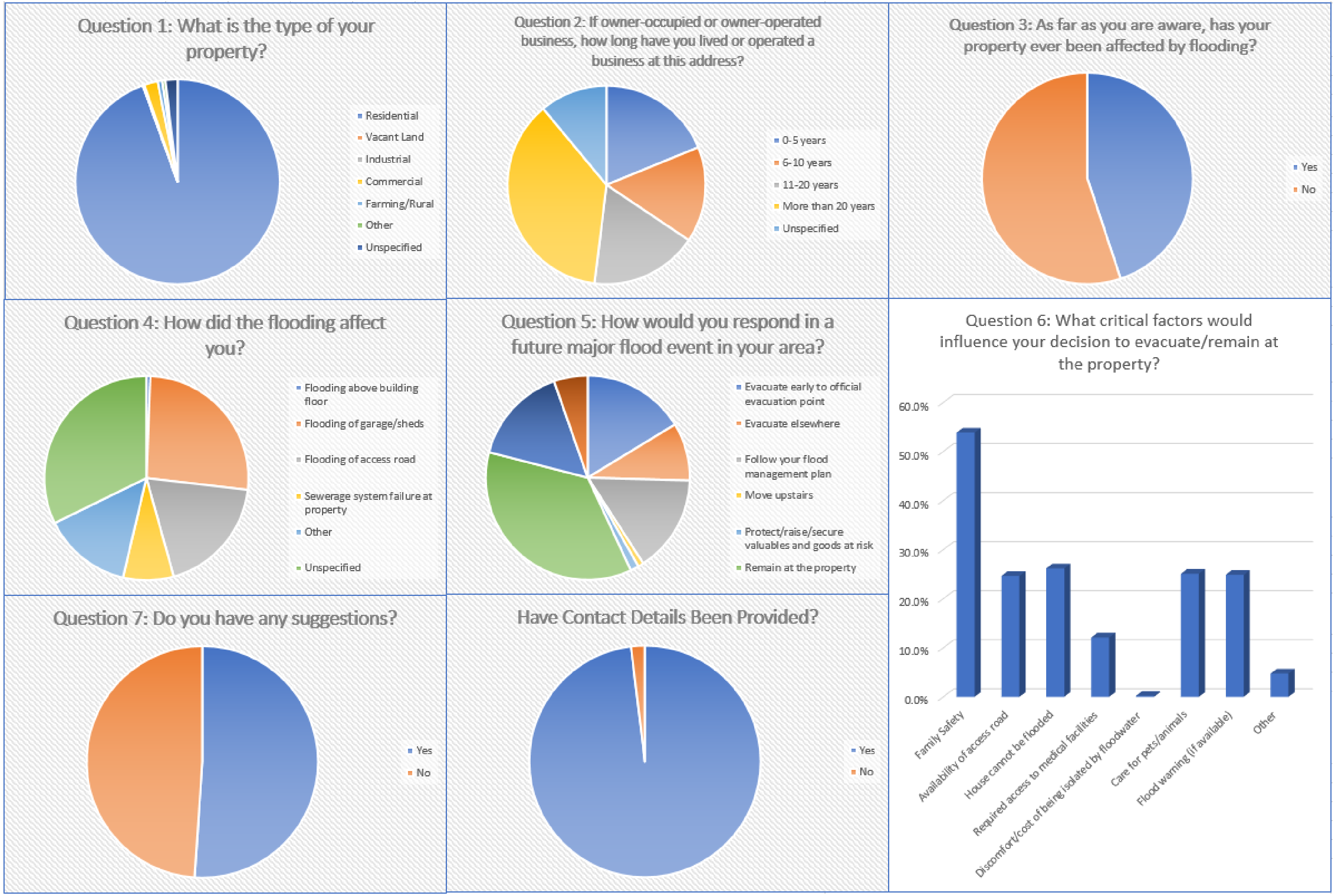

Figure 5.3 – Summary of Questionnaire Responses

Table 5.2 – Community Consultation Suggestions

Suggestions	Percentage of Respondents
Stormwater / Drainage Upgrade	17.5%
Maintenance of drainage / channels/ maintenance plan	13.6%
Kerb and Gutter	12.8%
Dredging / maintenance of Lake Entrance / widening of channel	9.5%
Better Development control / Less development	3.5%
Clearing / Cleaning of wetlands / creeks	3.2%
Second opening in lake system	2.8%
Properties to deal with own runoff	1.5%
Train entrance of lakes / Breakwall(s) at entrance	1.5%
Build Dam / levee / elevated banks or side of channel or drains	1.3%
Rock wall or levee around lake / raise shoreline	0.9%
Sewerage upgrade / GPT	0.6%
No open drain channels as drainage system	0.4%
Additional community consultation	0.4%
Construction of Detention Basin	0.4%
Review drainage design at property (as new drainage system increased flooding issue)	0.4%
Analyse effect of wrecks and debris	0.2%
Build up front lawns	0.2%
Relocate dredge spoil placement location	0.2%
Dredge Wyong River Mouth	0.2%
Road regrading	0.2%
Reduce lake level	0.2%
Develop flood warning system	0.2%
Consideration of future conditions	0.2%
More open spaces used as flow path	0.2%
Build swales	0.2%
Voluntary purchase	0.2%
Fence off gullies (drowning risk for children)	0.2%
Close off key roads during flood to reduce car generated waves	0.2%
Better flood education and how to reduce impact of property on flooding	0.2%
Creation of wildlife pond for flood mitigation	0.2%
Dredge entire lake	0.2%
pump water out of lake	0.2%

Table 5.3 – Selection Criteria ratings from the community and resulting recommended managements options

Source of score: Floodengage

SELECTION CRITERIA					
How Important is it that the flood management option addresses the following criteria?	**Importance**				
	None	**Slight**	**Moderate**	**High**	**Extreme**
Improves community access and recreational use	29.4%	29.4%	17.7%	11.8%	11.8%
Does not disadvantage individual members of the community:	41.2%	17.7%	29.4%	0.0%	11.8%
Provides safety to the community during flooding	70.6%	23.5%	0.0%	5.9%	0.0%
Raises community awareness and understanding of the local flood risk:	47.1%	23.5%	23.5%	0.0%	5.9%
Does not threaten local plants and animals and their habitat:	29.4%	11.8%	23.5%	35.3%	0.0%
Does not cause water quality issues:	52.9%	23.5%	5.9%	11.8%	5.9%
Initial costs (i.e. design / construction) require minimal council expenditure:	11.8%	5.9%	52.9%	17.7%	11.8%
Requires minimal ongoing council expenditure after implementation	23.5%	17.7%	41.2%	11.8%	5.9%
Reduces flood damages to the community:	70.6%	17.7%	11.8%	0.0%	0.0%
Does not cause negative flood impacts to other areas (both upstream and downstream):	58.8%	23.5%	17.7%	0.0%	0.0%

RECOMMENDED OPTIONS	
Flood Management Options	**Score**
Local Flood Policies and Development Controls	340
Local Flood and Disaster Plans	321
Voluntary Purchase / Removal	280
Upper Storey Flood Free Refuge	278
Flood Awareness	274
Local Flood Warning and Flood Forecasting Systems	274
Notifying Prospective Buyers and Developers of Flood Prone Land (Section 149 Certificate)	250
Flood Proofing	221
Voluntary House Raising	209
Riparian Vegetation Management	187
Debris Control Structure	159
Stormwater Upgrades	158
Culvert / Bridge Upgrade	143
Flood Detention Basin	119
Concrete Levee	100
Channel Realignment	86
Concrete Lined Channel	61
Earthen Levee	59
Increased Infiltration Capacity	34
Rainwater Tank	17

5.6 Public exhibition

The final stage of the community consultation for this study is the public exhibition of the draft Northern Lakes FRMS&P report. This document will be exhibited for a period of four to six weeks, so that the community has a further opportunity to comment on the recommended floodplain management measures.

6. Review of current flood study

6.1 Preamble

The first step of this study consisted of reviewing the existing data. As part of this review, an important component is the review of the hydrologic and hydraulic models that have been used in the Flood Study. Details of the review are provided in this section.

6.2 Hydrologic analysis

6.2.1 AR&R 2019 comparison

Since the completion of the flood study in 2015, a new set of Australian Rainfall and Runoff guidelines have been developed in 2016 and further amended in 2019 (AR&R 2019). The 2015 Flood Study hydrologic analysis was completed using the AR&R 1987 guidelines and were applied to a direct rainfall TUFLOW model. It was therefore required to compare existing model to the latest guidelines from AR&R 2019.

For the purpose of the AR&R 2019 discussion, the model was trimmed down to a representative subcatchment to undertake a comparison between existing 2015 Flood Study and AR&R 2019 results. **Figure 6.1** presents the subcatchment selected for the flood model review. This subcatchment was selected as it has a size similar to a number of catchments within the study area and is also subject to a number of flood issues (e.g. there was a relatively large number of survey respondents affected by flooding in this catchment according to the 2015 Flood Study).

Design rainfall depths for the 20%, 5% and 1% AEP events were obtained from the Bureau of Meteorology (BoM) online Intensity-Frequency-Duration (IFD) tool, as derived from standard procedures defined in AR&R 2019. The Probable Maximum Precipitation (PMP), as used to determine the PMF, was calculated using the Generalised Short Duration Method (GSDM) as defined by BoM (2003) and this method is also recommended in AR&R 2019 so the PMF would therefore not change.

Flood modelling data such as IFDs, temporal patterns, areal patterns and areal reduction factors are available on the data hub page of AR&R 2019 for multiple events and durations. For each design event and each duration, 10 temporal patterns were recommended to be applied by AR&R 2019. The TUFLOW model was then run using the direct rainfall method for each set of pattern, duration and event. For each duration, an average of the peak water level of each temporal pattern was calculated at four locations and the pattern with the water level closest to this average level was selected as design temporal pattern. The largest of these design temporal patterns allowed the determination of the critical duration. **Figure 6.2** illustrates the location of the reference points where the water levels results were compared between the AR&R 2019 and the 2015 Flood Study. The points were chosen to cover the downstream end of the eastern branch of the catchment, the western branch of the catchment and the area where both branches are merging.

Figure 6.1 – Subcatchment used for flood model review

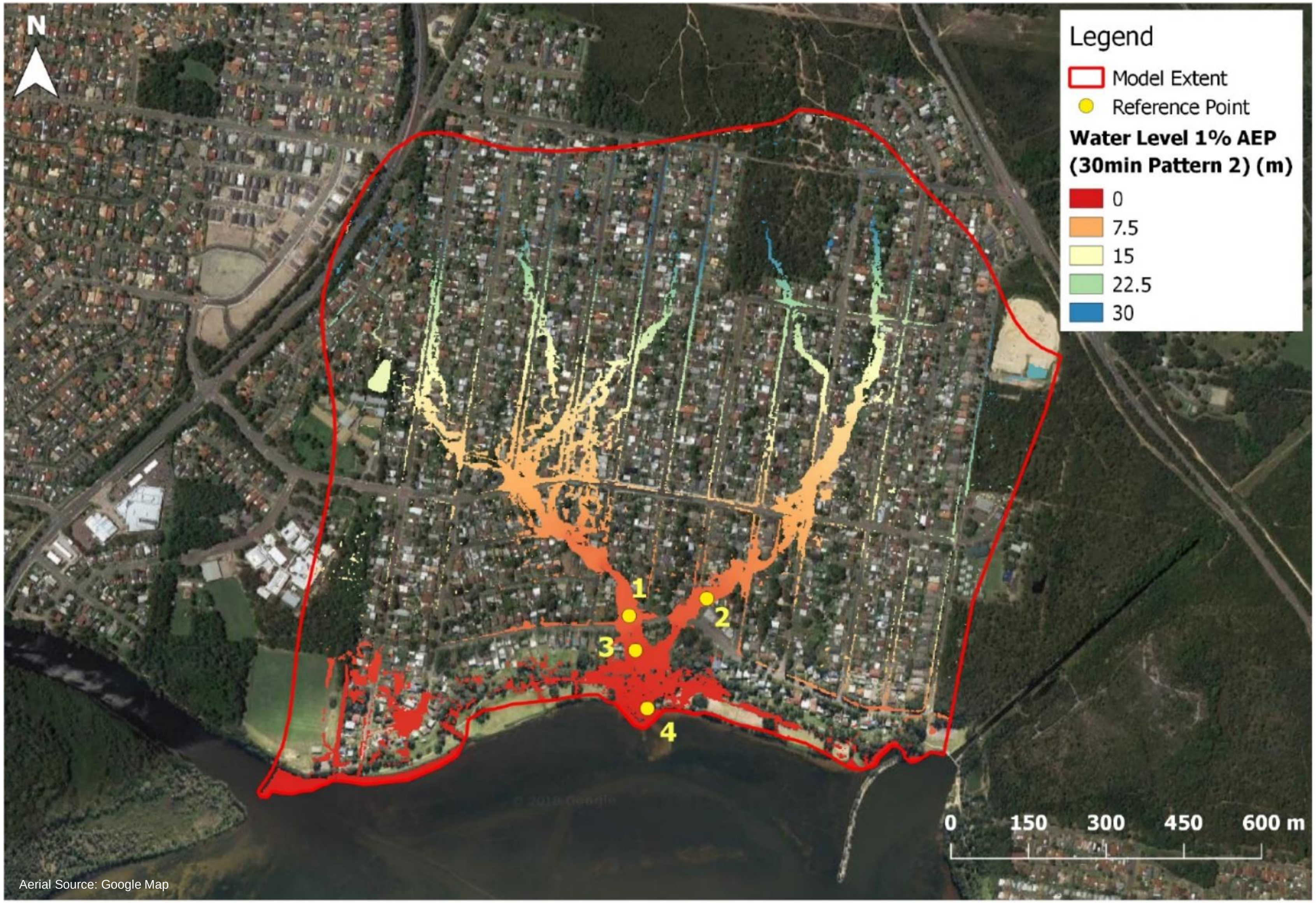

Figure 6.2 – Locations of points for result comparison

6.2.2 Results

Once all the scenarios were run, the results were consolidated in a graphical format. **Figure 6.3** presents the results of the comparison at the four reference points for the 1% Annual Exceedance Probability (AEP). On each graph:

- The red circle represents the 1% AEP water level and critical duration as calculated by the existing 2015 flood study;
- The green triangles are the results of the 10 patterns for each duration (10, 15, 30, 60, 90 and 120 minutes);
- The black triangles represent the average water levels; and
- The blue diamonds highlight the level of the pattern closest to this average value for each duration.

It can be noted that the critical duration for the 1% AEP is 30 minutes. Critical durations based on these water levels for all design events ranged between 30 minutes and 60 minutes for the 20%, 5% and 1% AEP events. Critical duration from the 2015 Flood Study by Cardno was 90-minute duration for these three events.

The difference in level between the results of the existing study (red circle) and of the method applying the AR&R 2019 guidelines (highest blue diamond) are very similar. Results were also similar for the 20% AEP and the 5% AEP. The difference in water level typically varies between ±0.00m and ±0.06m.

Given the small difference in flood levels between the existing and updated models, the existing model was adopted for the development of management options instead of developing a new model using the AR&R 2019 guidelines.

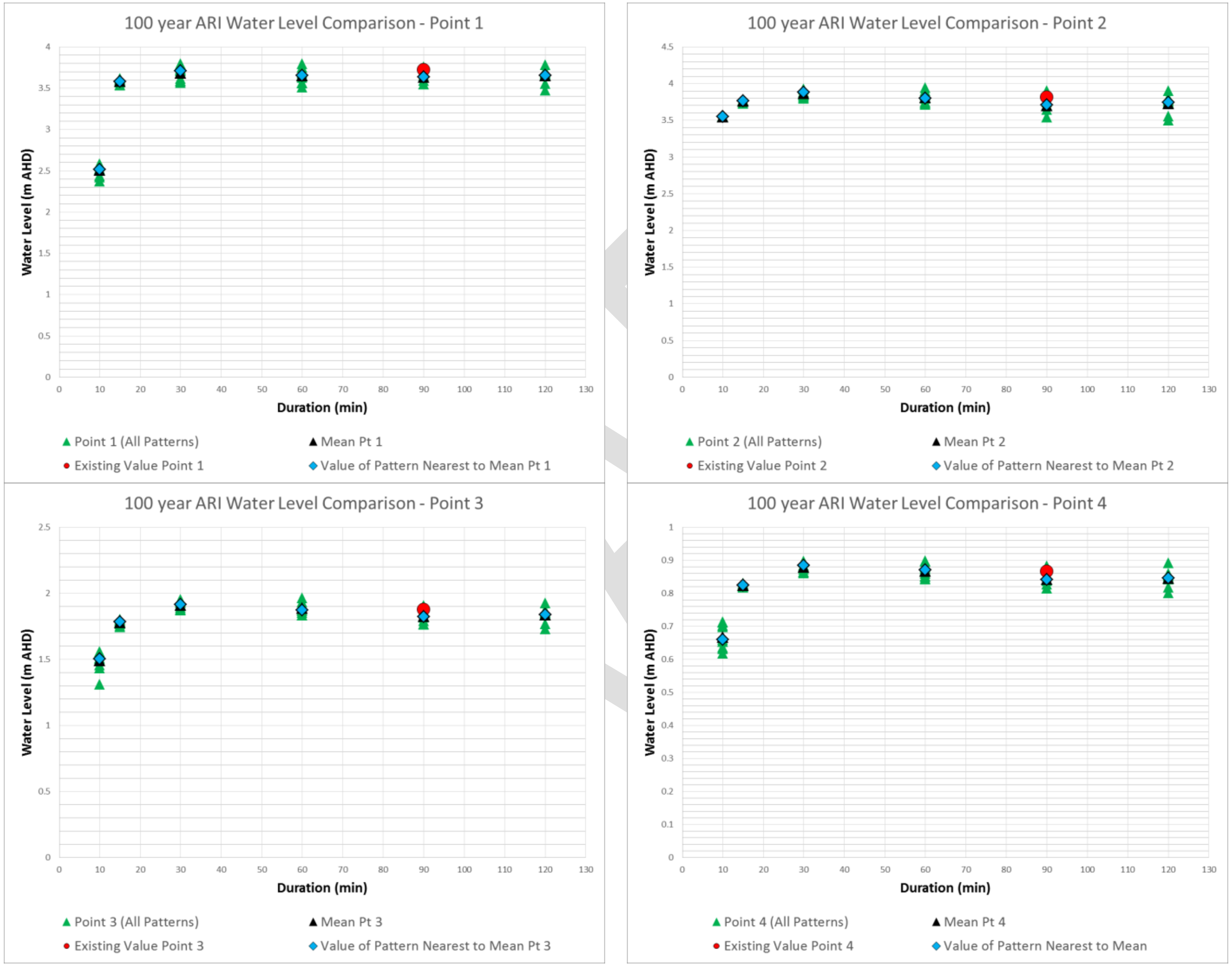

Figure 6.3 – Water level comparison results

6.3 Hydraulic analysis

The model used in the 2015 Flood Study is the two-dimensional model TUFLOW. This model is widely used in flood modelling as it allows complex 1D/2D interactions and modelling of drainage system.

The catchment was subdivided into 5 sub-catchments in the TUFLOW hydraulic model to optimise the computing time. Each of the five subdivisions of the model has been numbered and highlighted in red in **Figure 6.4.** The model appears generally adequate for use in the development of the management options apart from a few boundary conditions and pits/pipes issues that are further described below.

6.3.1 Boundary conditions review

A number of issues were identified as part of the review along the boundaries of the model. The issue areas that were extended as part of this study are highlighted in green in **Figure 6.4** and further details are provided below:

- There is a part of the catchment that was not fully covered by the hydraulic model at the south-western corner of the catchment near Wadalba as illustrated in **Figure 6.4** (Issue Area 1) and **Figure 6.5**. In this figure, the red line represents the boundary of the hydraulic model and it can be noted that the western section of the local drainage catchment was not included, hence underestimating the flooding at this location. Extension of the catchment to include the green area (approx. 5km^2) was therefore required.
- Instabilities were found along some of the upstream boundaries of the hydraulic model in subdivision 2. These were due to modified ground levels reduced to 2m AHD generating a significant step from levels higher than 30m AHD at the top of the catchment. While these steps should not have impacted the existing results as they occurred beyond the ridges of the catchment, they generated stability issues and these levels along the limits of the model were therefore corrected.
- The flood extent appeared prematurely cut at some location along the boundary of the model.
- The culvert under Greenacre Ave, Lake Munmorah was misrepresented into the model with only one 3600mm x 1800mm cell instead of two. This was corrected as described in the following section.
- At Issue Areas 2 and 3 in **Figure 6.4, Figure 6.6** and **Figure 6.7**, the top of the catchment was not included into the model and extension was therefore required.
- At Issue Area 4 (**Figure 6.4** and **Figure 6.8**), while the flood water typically flows down in an eastward direction, a part of the flood water also flows down in a northwards direction into the Colongra Catchment during extreme events (e.g. PMF). Extension of the model at this location was undertaken to determine the impact of this spill on the neighbouring catchment.
- Issue Area 5 (**Figure 6.4** and **Figure 6.9**) represents a local 43ha sub-catchment that was not included into the model and could have impacted the flood level into the

Colongra Swamp directly at the back of Sunnylake Shores.

- Issue Areas 6 and 7 (**Figure 6.4, Figure 6.10** and **Figure 6.11**) are minor sections of the pacific highway that were not included into the hydraulic model. Some of the flood water may potentially flow along the road and back into the catchment.
- Issue Area 8 (**Figure 6.4** and **Figure 6.12**) is a 55ha sub-catchment leading to a reservoir generated by Birdie Beach Road. Impact of this reservoir on the water level west of Birdie Beach Road and potential overtopping of the road during large flood event was investigated.
- One of the upstream boundary condition type in Model 4 was set up as an ocean boundary condition (HT condition or lake level vs time) instead of a head flow condition (HQ condition or stage discharge) to allow the water to flow out of the model past the ridge without imposing an incorrect water level. This was corrected.

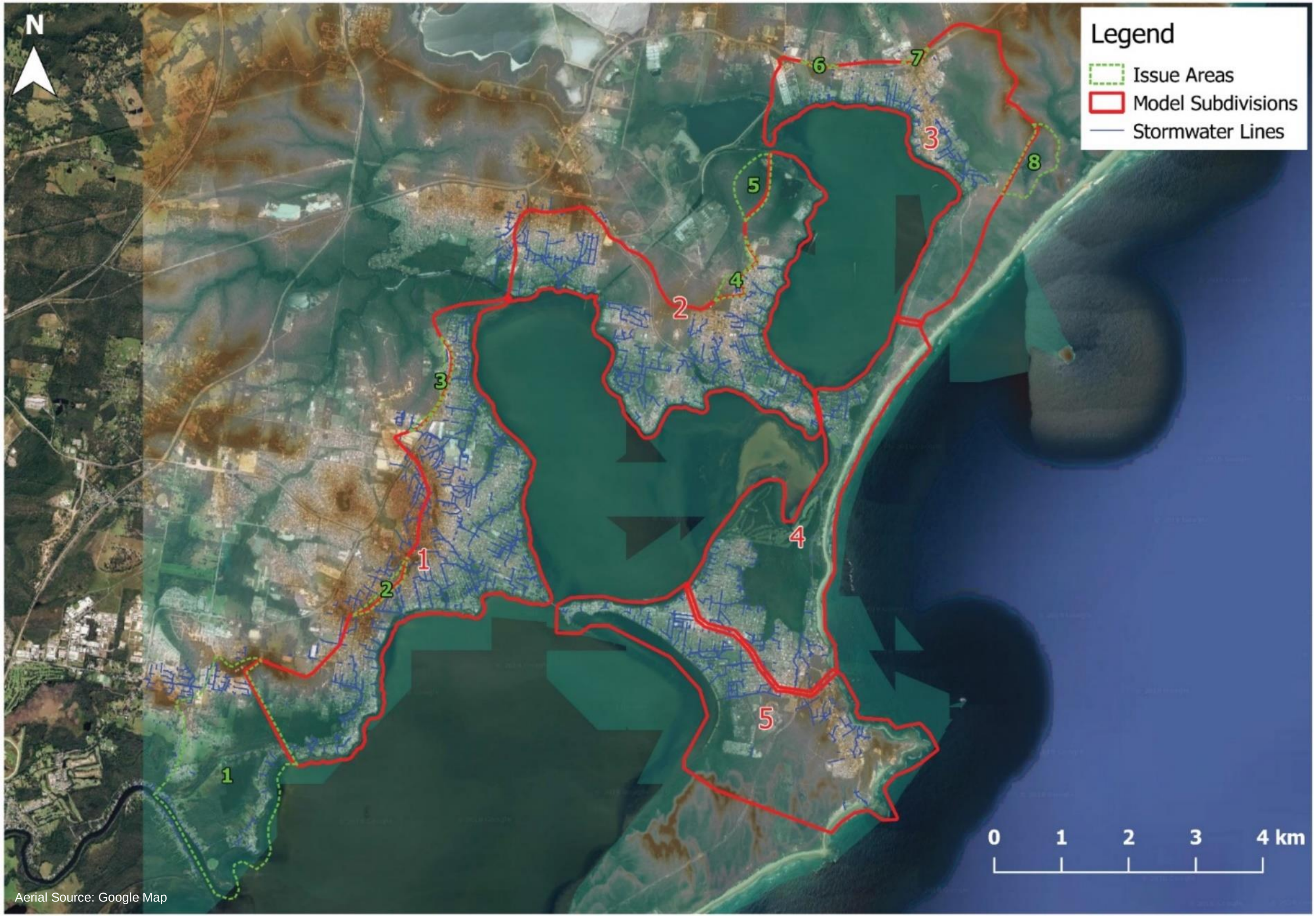

Figure 6.4 – Boundary issues in existing model

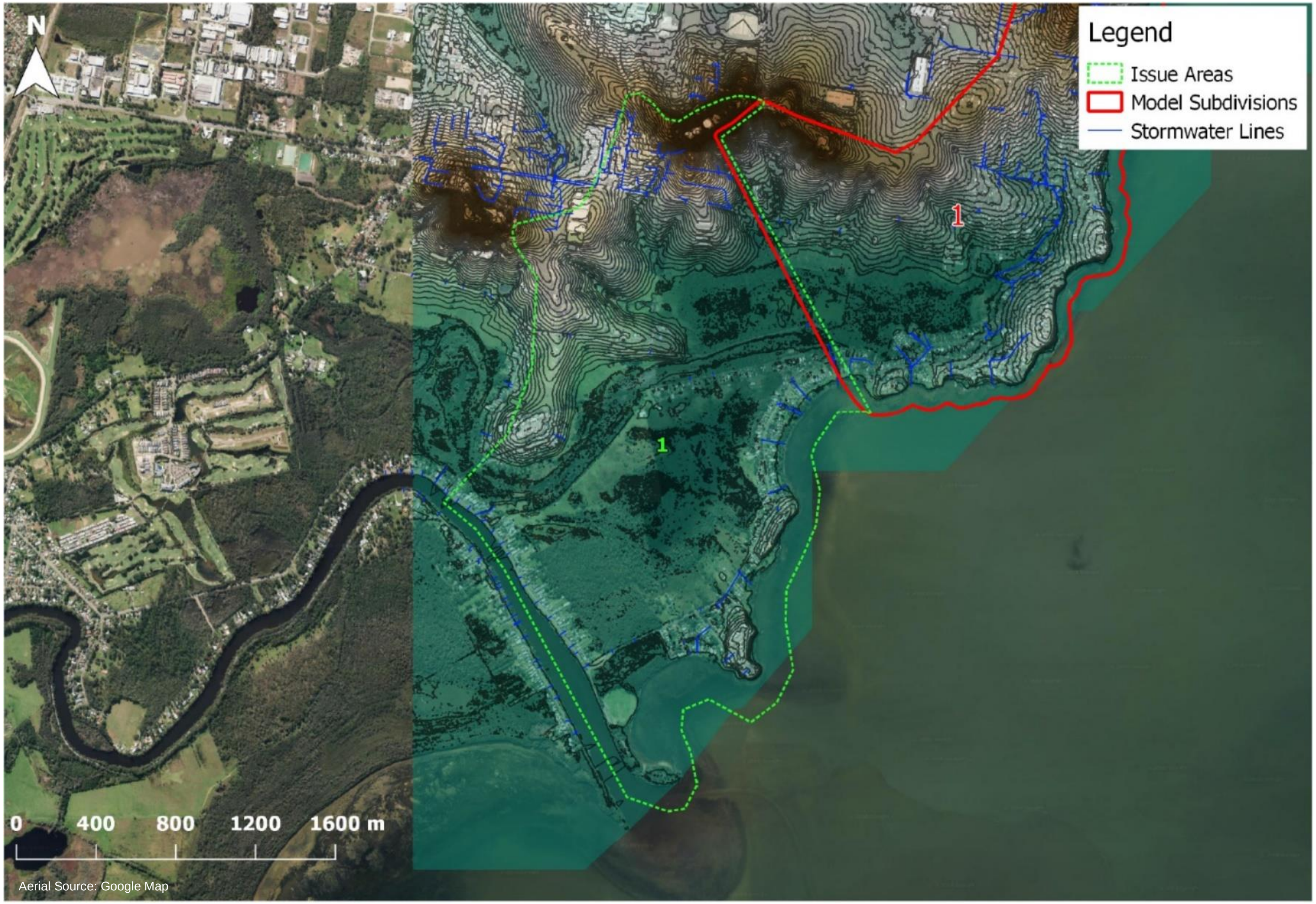

Figure 6.5 – Issue Area 1

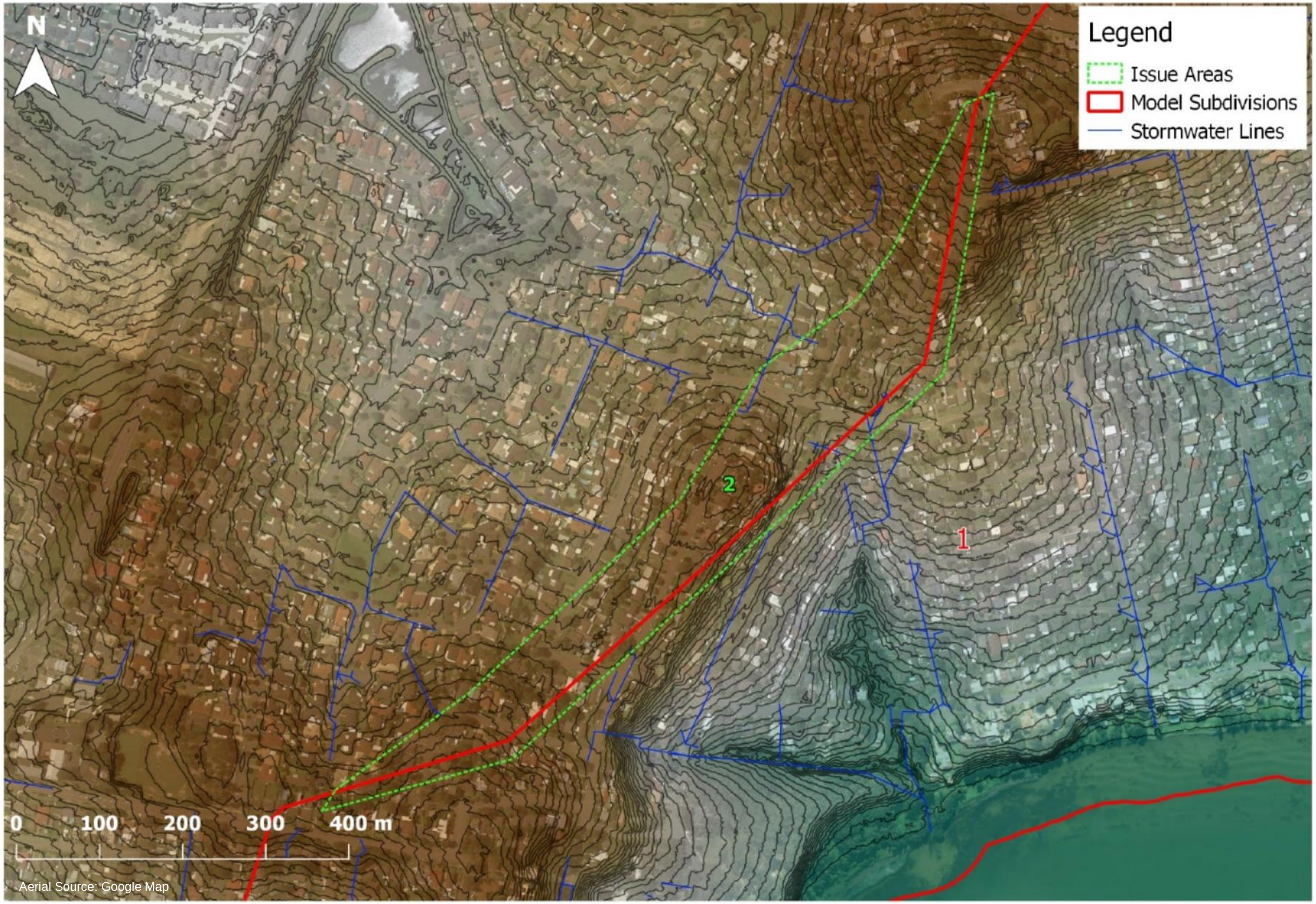

Figure 6.6 – Issue Area 2

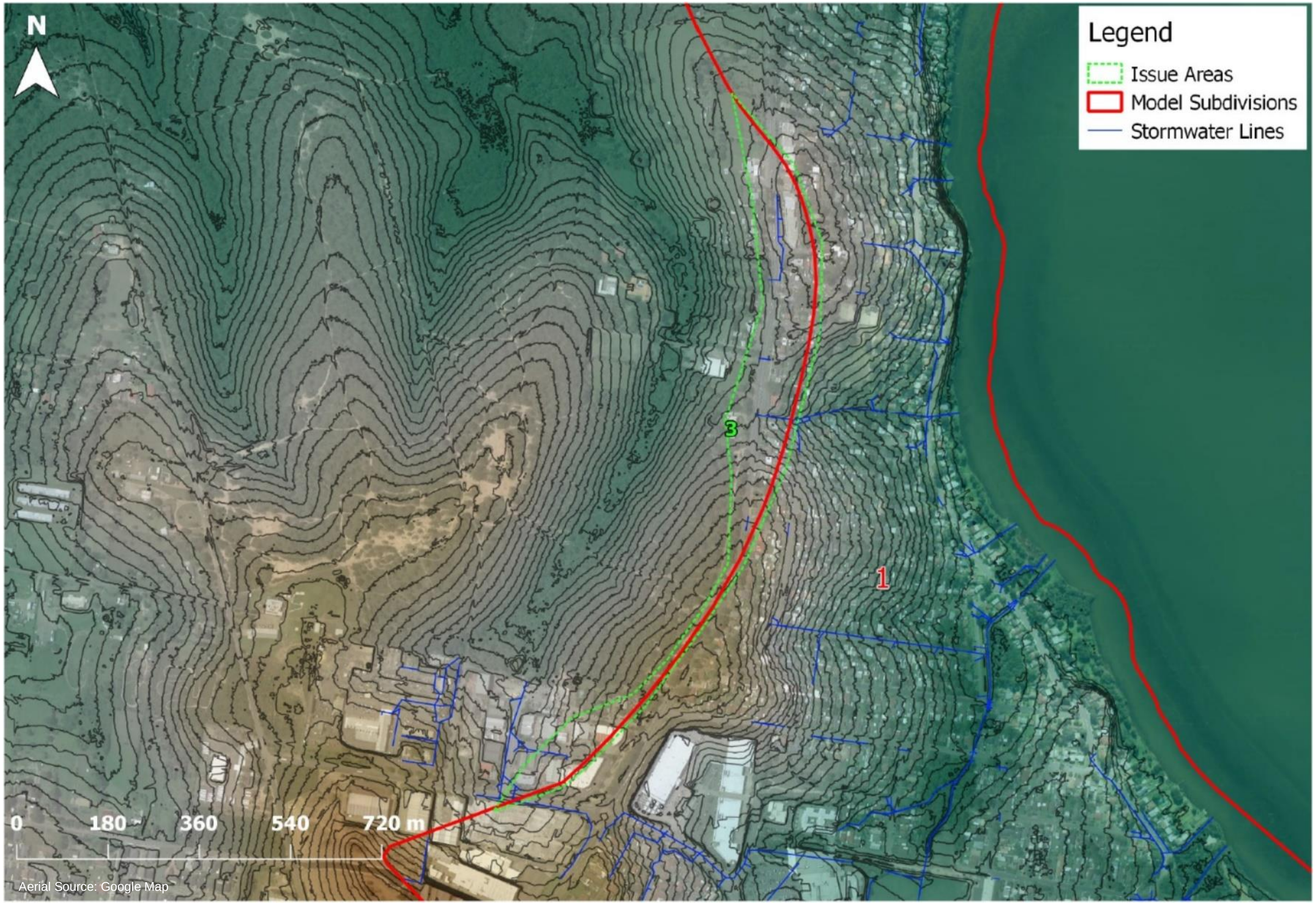

Figure 6.7 – Issue Area 3

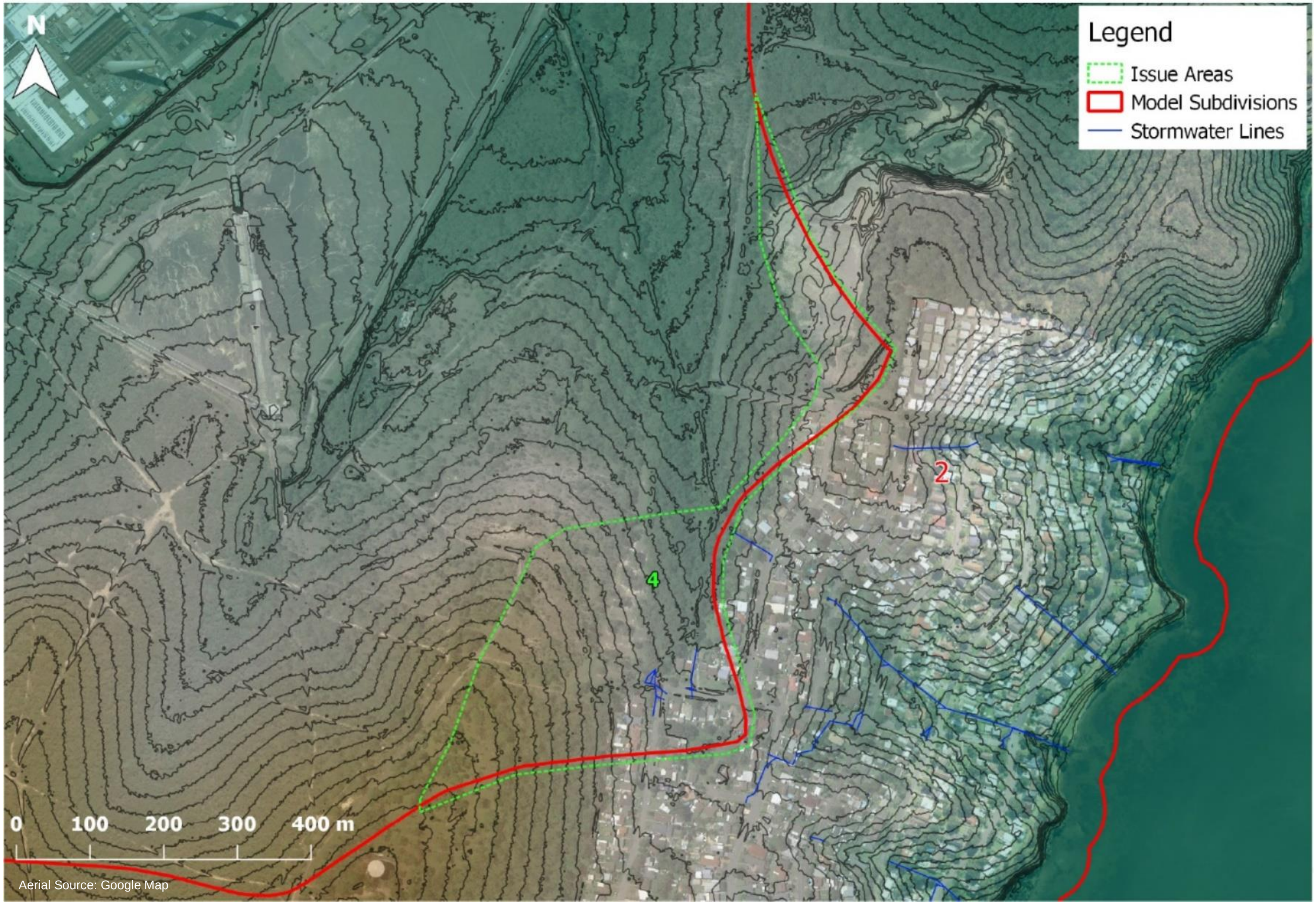

Figure 6.8 – Issue Area 4

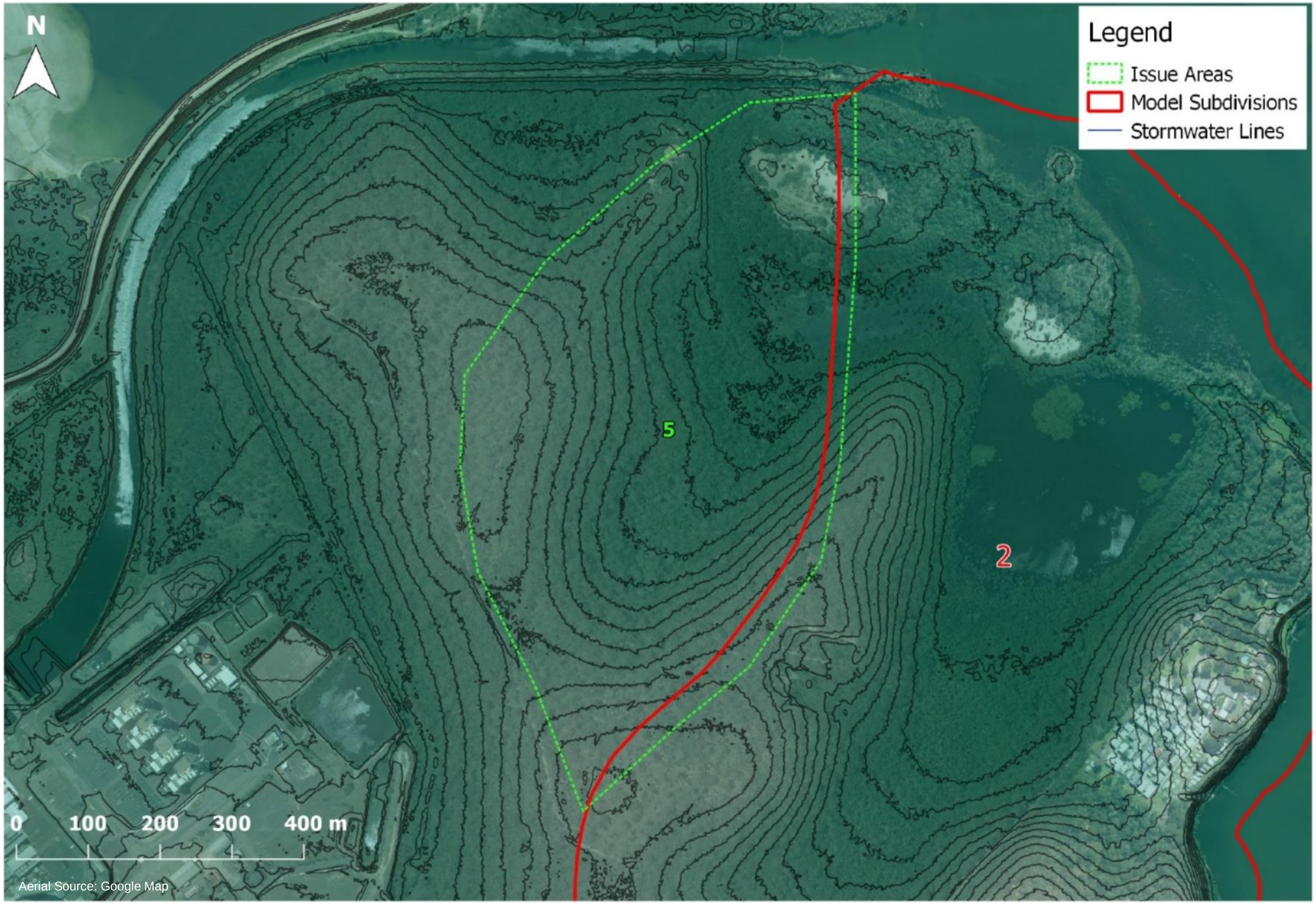

Figure 6.9 – Issue Area 5

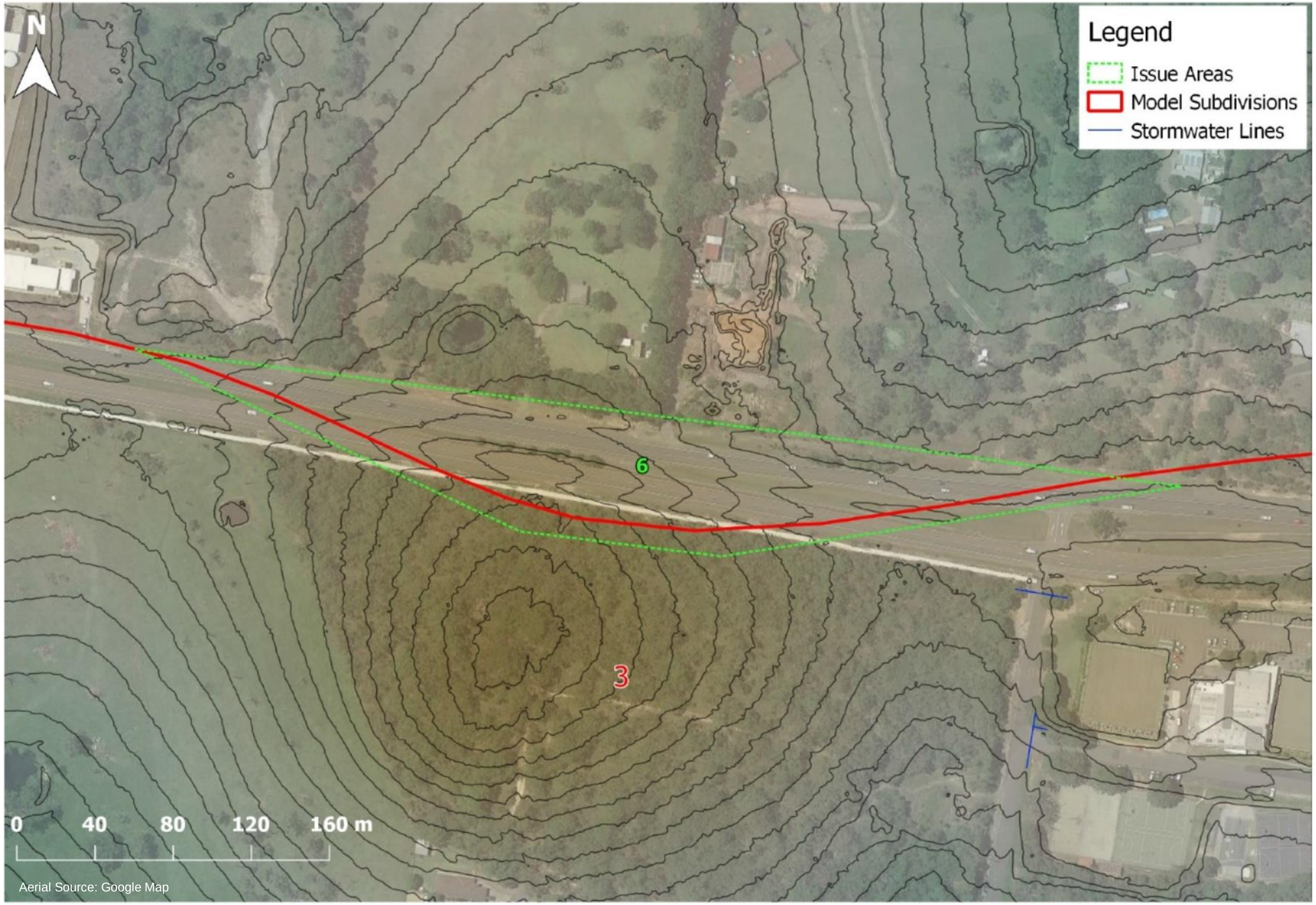

Figure 6.10 – Issue Area 6

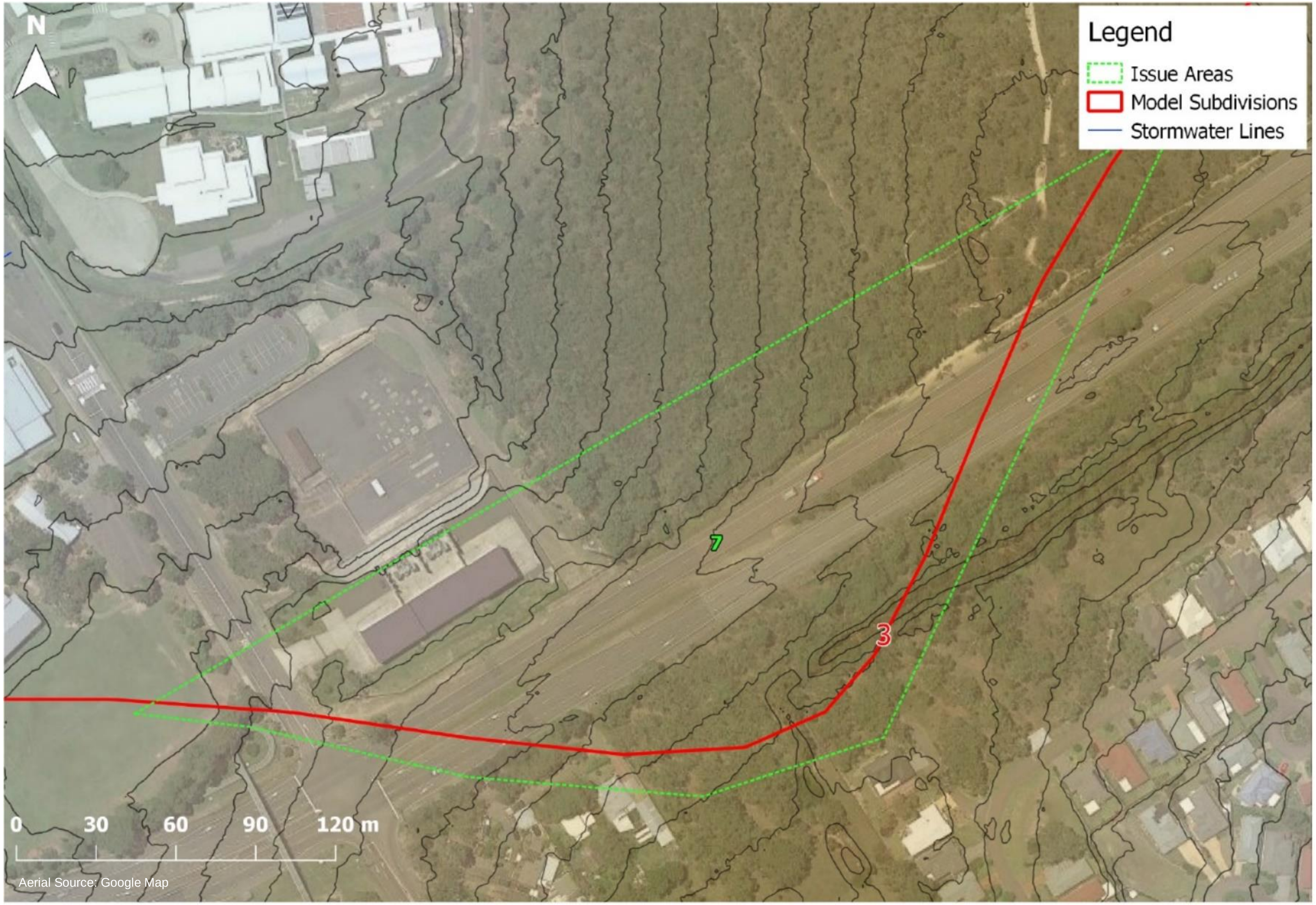

Figure 6.11 – Issue Area 7

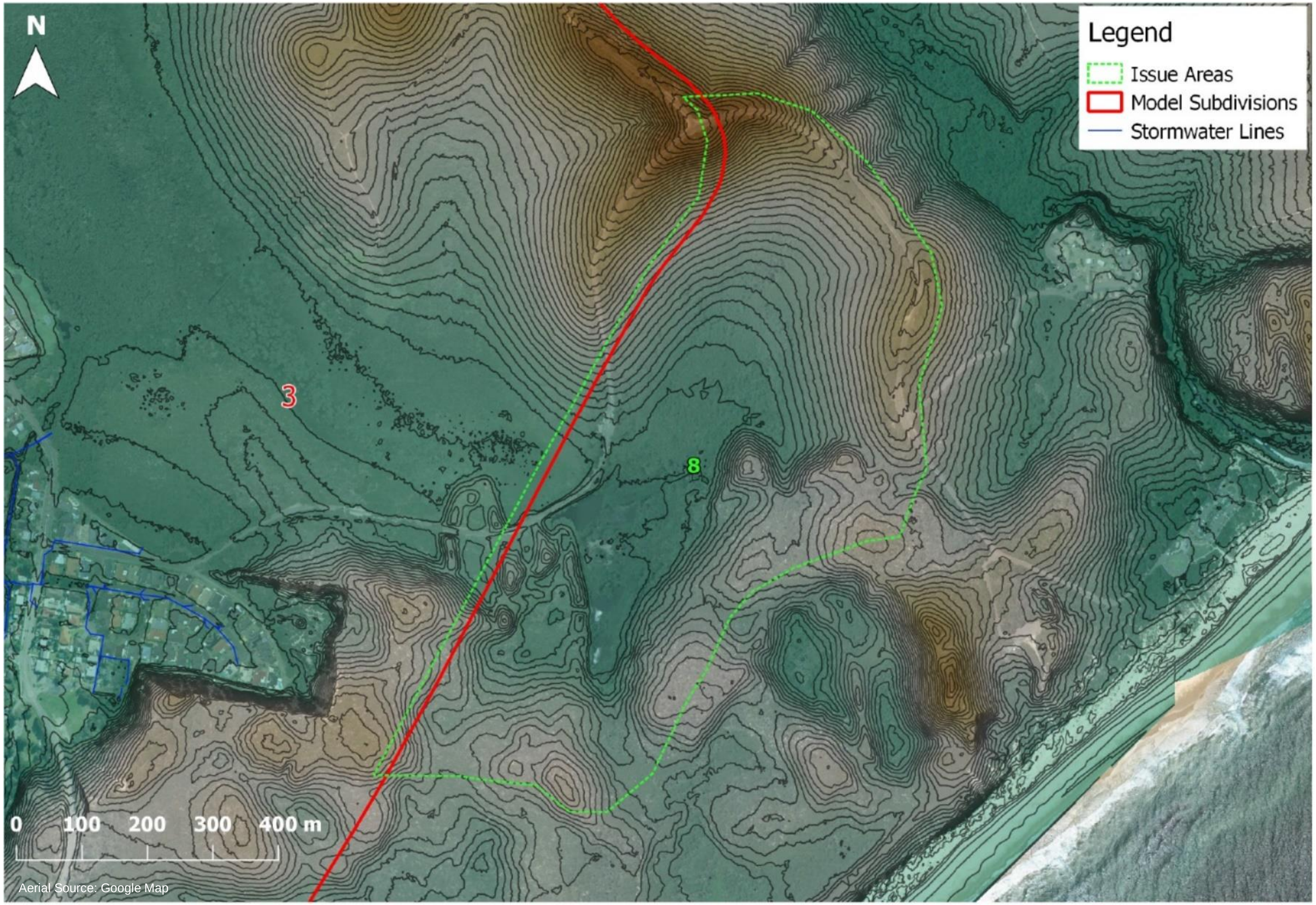

Figure 6.12 – Issue Area 8

6.3.2 Pits and pipes data

A new set of pits and pipes layers was provided by Council at the start of the study. These layers were compared to the layers applied in the TUFLOW model. There were numerous locations where there were discrepancies between the pipes/pits layers that have been provided by Council and the ones used in the 2015 Flood Study TUFLOW model. **Figure 6.13** and **Figure 6.14** present some examples of discrepancies with Council provided pipe layer in blue, modelled pipe layer in red and model extent in yellow.

Following comparison of the latest pits/pipes layers provided by Council with the layer used in the Flood Study, the model was updated as follows:

- For minor discrepancies where:
  - the alignment was not exactly the same, but the pipes/pits numbers and characteristics were the same, the existing model was accepted.
  - the alignment was correct, but the pipe/culvert sizes were incorrect, the pipe size from the latest layer provided by Council was adopted.
- For major discrepancies where:
  - the pipes/pits alignments were totally different between the two layers, the latest layer provided by Council was adopted.
  - some areas included new pits/pipes not incorporated into the existing model, the latest layer provided by Council was adopted.
- The culvert under Greenacre Ave, Lake Munmorah was updated to include the two 3600mm x 1800mm cells.
- A short 450 mm diameter culvert was placed at the top of a 900 mm pipe at a key ponding area on Moss Avenue, Toukley. This resulted in the 900 mm pipe not flowing at capacity and small increases in local flood level. The short 450 mm pipe was adjusted.

The upstream inverts of the various pits were updated to match the latest DEM provided by Council as described in **Section 3.2**. A number of pits from the original model appeared to include measured downstream inverts and these values were adopted. When the difference between the upstream and the downstream invert level used in the existing model appeared estimated (e.g. difference between upstream and downstream invert level is a number rounded to the nearest 1 decimal), this estimate was applied in the updated model to obtain the downstream invert of each pit from the updated elevation of the upstream invert.

MHL team members completed a site inspection as part of this review to undertake some ground-truthing at key locations where flooding occurs, where significant differences between existing model and the latest data provided existed or where some new alignments were included in the latest data but did not include all the metadata.

The ground-truthing exercise focused on measuring the pit depth at the various locations. Some pipe diameters were also measured where accessible and where data was neither available in Council layer nor in the existing model. Locations where ground-truthing was completed are presented in **Figure 6.15** and a summary of the results of the ground-truthing is presented in **Appendix B**.

It can be observed that, out of the 170 locations reported, 89 locations had a difference in depths of less than ±0.1m and only 21 locations were found to have differences in pit depth greater than ±0.4m. It is therefore noted that some inaccuracies are found for the depth of a number of pits in the model. However, the impact that such inaccuracies in pit depths on the hydraulic modelling of the study area would be lower than the 100% blockage sensitivity scenario completed as part of the 2015 flood study. This fully blocked scenario was found to have a minor impact on flood levels and therefore, inaccuracies over a small number of pits would also have a minor impact. Hence, the modelled pit depths were found to be generally acceptable for the purpose of flood modelling. A number of pits were also found to have some sediments or vegetation blocking fully or partially the pit which can contribute to some differences in depth.

The pipe diameters used in the model were very close to the measured diameters. A few pipes have been assigned a pipe slightly larger or smaller, but they were found to be generally acceptable.

6.3.3 Blockages

Blockage recommendations provided in AR&R 2019 are focusing on major structures such as large culverts and bridges. No specific advice has been provided for pits and pipes. Moreover, as mentioned in the previous section, the flood study undertook a sensitivity analysis of the blockages by running a fully blocked scenario. This scenario was found to have minor impact on the flood level. Blockage was therefore found to be of minor impact in the study area and application of new blockages would have a similar minor impact on water levels.

6.3.4 Losses

At the time of the study, the AR&R 2019 data hub provided initial and continuing losses of -99mm and 2.4mm respectively. Since these values appears erroneous and following recommendation from AR&R 2019 developers to prioritise calibrated values over the data hub values, the values modelled as part of the flood study were considered appropriate as they were developed following calibration against historical events.

6.3.5 Miscellaneous updates to the hydraulic model

A number of other updates were completed in the model including:

- Incorporation of the swale/gabion channel located under Lake Haven commercial centre. This channel was included by using the Work-As-Executed (WAE) drawings provided by Council. The cross-sections were applied at 10m interval from Chainage 0m to 110m.
- During the site inspection, a footbridge was observed across the above swale/gabion channel. It was found to span approximately 0.4m above the creek invert with a deck height of approximately 0.8m. This bridge was incorporated in the model.
- The 1D channel located around the Lake Haven Oval directly east of the Lake Haven Commercial Centre was found to be highly unstable. This was due to discrepancies in

the 1D/2D levels and width. This 1D channel was adjusted to obtain a better match with the surveyed cross-sections provided alongside the model. This significantly improved stability and allowed reduction in run-time.

- Declaration of the active/inactive cells of the model and of the topography was optimised in the geometry file to prevent overlapping of active 1D and 2D elements which would duplicate the local storage volume.
- The inverts of a concrete channel upstream of Lett St was found to be misrepresented, limiting the flow to the culvert across Lett St. Moreover, the DEM downstream of the culvert was not showing the existing channel adequately. The inverts and channel representation were corrected.

Figure 6.13 – Major Discrepancies between Council (Blue) and Modelled (Red) Data
Top: San Remo; Bottom: Buff Point

Aerial source: Google Maps

Figure 6.14 – Minor Discrepancies between Council (Blue) and Modelled (Red) Data (Diameters displayed along pipes are in mm) Top Budgewoi; Bottom: Halekulani

Aerial source: Google Maps

Figure 6.15 – Ground-truthing locations

6.4 Modelling events

The TUFLOW model was run to obtain the flood depth, level and velocity for the 20% AEP, 5% AEP, 1% AEP and PMF flood events and mapping was updated to include the changes completed as part of this study. Updated mapping is presented in **Appendix C**.

This data was then used to determine the provisional flood hazard and hydraulic categories for the 1% AEP and PMF flood events as described in **Section 7**.

Some sensitivity testing was carried out as part of the 2015 Flood Study to assess the impact of climate change by running the 1% AEP with a 15% and 30% rainfall intensity increase. The magnitude of the flood level increases due to climate change was found to be relatively minor.

Parameter sensitivity analysis was also completed as part of the 2015 Flood Study for:

- roughness changes of ±20%: Such changes in roughness were found to have relatively minor impact on flood levels.
- a number of downstream boundary conditions (i.e. lake level): this change did not impact flood level in the upstream flowpaths as the backwater effect up the flowpaths is minimal.
- 0% and 100% blockage: No blockage had minor impact on flood behaviour and full blockage increase the flood level by 0.08m on average across flood affected properties.

6.5 Mapping update

Following updates of the models, re-issuing of the flood maps was necessary. Prior to issuing the maps, a number of steps were completed including filtering and optimisation of mapping layout.

6.5.1 Filtering

The flood extents were filtered to remove shallow depths area generated by the rain-on-grid methodology. Two main filtering options were compared:

- **Option 1**: mapping based on: Depth > 0.15 m OR Velocity > 2 m/s
- **Option 2**: mapping based on: Depth > 0.10 m OR Velocity > 2 m/s OR (Depth > 0.05m AND Velocity x Depth > 0.025m^2/s)

The first option was applied as part of the Northern Lakes Flood Study while the second option was established in collaboration with Council to suit the needs of the local area.

In addition to these filtering options, some sensitivity was completed to undertake the impact of "puddle" removal from the model and the following three sub-options were run:

- **Sub-option a:** No puddle removal
- **Sub-option b:** Removal of puddles less than 50m^2
- **Sub-option c:** Removal of puddles less than 100m^2

Results of this filtering sensitivity analysis are presented in **Table 6.1**. This table presents the number of properties affected by the 1%AEP flood event as well as the flooded area in sub-model 1, the largest TUFLOW sub-model out of the 5. Following comparison of the various options, Option 2c was adopted for the filtering of all flood event results. This option removes puddles that may inadequately flag a property as flood affected and also includes slightly shallower depth to consider flooding of properties with a slab on ground.

Table 6.1 – Filtering sensitivity analysis for the 1% AEP event for Model 1

Option	Number of properties affected	% of total number of properties	Area flooded (km^2)	% of study area
Option 1a – D > 0.15m OR V > 2m/s	1738	24.5%	1.53	13.1%
Option 1b – D > 0.15m OR V > 2 m/s + No puddle < $50m^2$	1147	16.2%	1.49	12.7%
Option 1c – D > 0.15m OR V > 2 m/s + No puddle < $100m^2$	1065	15.0%	1.47	12.5%
Option 2a – D > 0.1m OR (D > 0.05m AND VxD > $0.025m^2/s$) OR V > 2m/s	3455	48.8%	2.16	18.4%
Option 2b – D > 0.1m OR (D > 0.05m AND VxD > $0.025m^2/s$) OR V > 2m/s + No puddle < $50m^2$	1960	27.7%	2.08	17.8%
Option 2c – D > 0.1m OR (D > 0.05m AND VxD > $0.025m^2/s$) OR V > 2m/s + No puddle < $100m^2$	1754	24.8%	2.05	17.5%

6.5.2 Mapping Optimisation

The flood mapping completed as part of the Flood Study included a mosaic of 38 sub-maps for each event and each parameter which made navigating the maps difficult and impractical. The mapping was therefore reorganised to be location-based for clarity during the community consultation period. The number of maps was reduced to 20 maps and the maps were colour coded to identify four (4) independent management areas. Mapping sub-divisions are provided in **Figure C0 in Appendix C**. The four management areas are:

- Catchment 1 (colour-coded in blue) encompasses the western embankment of the Tuggerah and Budgewoi Lakes from the mouth of the Wyong River in the south to the mouth of Wallarah Creek in the north. It includes the suburbs of:
  - Rocky Point
  - Tuggerawong
  - Wadalba
  - Wyongah
  - Kanwal
  - Gorokan
  - Lake Haven

- Charmhaven

- Catchment 2 (colour-coded in green) spans from the Wallarah Creek mouth in the west to the Budgewoi/Munmorah separation channel in the east and Colongra Swamp in the north. It includes the suburbs of:
  - San Remo
  - Buff Point
  - Budgewoi (west of the Munmorah/Budgewoi separation channel)
  - Halekulani
- Catchment 3 (Colour-coded in orange) encompasses the northern and eastern embankment of Lake Munmorah, north of Colongra Lake entrance and east of the Munmorah/Budgewoi separation channel. It includes the suburbs of:
  - Lake Munmorah
  - Freemans
  - Budgewoi Peninsula
  - Budgewoi (east of the Munmorah/Budgewoi separation channel)
- Catchment 4 (Colour-coded in red) covers the area south of Budgewoi, east of the Toukley Bridge and north of the Wyrrabalong National Park. It includes the suburbs of:
  - Toukley
  - Noraville
  - Norah Head
  - Canton Beach

7. Post-processing of results

7.1 Preamble

Once the flood mapping completed for the main parameters (water level, depth and velocity), it was possible to determine the flood function, flood hazard and flood emergency response classification resulting from these data. Development of such categorisations is described in this section.

7.2 Flood function (hydraulic categorisation)

Hydraulic categorisation is a useful tool in assessing the suitability of land use and development in flood-prone areas. The Floodplain Development Manual (NSW Government, 2005) describes the following three hydraulic categories of flood-prone land:

- **Floodway** – Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage** – Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood storage areas, if completely blocked, would cause peak flood levels to increase by 0.1 m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe** – Remaining area of flood-prone land, after floodway and flood storage areas have been defined. Blockage or filling of this area will not have any significant impact on the flood pattern of flood levels.

These qualitative descriptions do not prescribe specific thresholds for determining the hydraulic categories in terms of model outputs, and such definitions may vary between floodplains depending on flood behaviour and associated impacts. For the purposes of the Northern Lakes Floodplain Risk Management Study and Plan, hydraulic categories have been defined as per the criteria in **Table 7.1**. MHL have reviewed these criteria, particularly the definition of floodway with respect to simulated flow behaviour and found them to be appropriate and in-line with industry practice (e.g. Howell et al. 2003).

Hydraulic category mapping for the PMF and 1% AEP design events is presented in **Appendix D**.

Table 7.1 – Hydraulic category criteria

Hydraulic Category	Criteria	Description
Floodway	Velocity x Depth > 0.25 m^2/s	Flowpaths and channels where a significant proportion of flood flows are conveyed. Manual adjustments were made to ensure continuity of main floodways and remove isolated small floodways.
Flood Storage	Depth > 0.15 m, Not Floodway	Areas that temporarily store floodwaters and attenuate flood flows. Threshold selected for consistency with recent studies completed within the Tuggerah Lakes catchments.
Flood Fringe	Depth < 0.15 m, Not Floodway or Flood Storage	Generally shallow, low velocity areas within the floodplain that have little influence on flood behaviour

7.3 Flood hazard and true final flood hazard

A starting point for the assessment of Flood Life Hazard categories is to better understand the flood hazard. National Best Practice Guidelines present a set of hazard vulnerability curves shown in **Figure 7.1**.This shows how flood depths, velocities and depth-velocity product threaten the stability of vehicles, pedestrians and buildings.

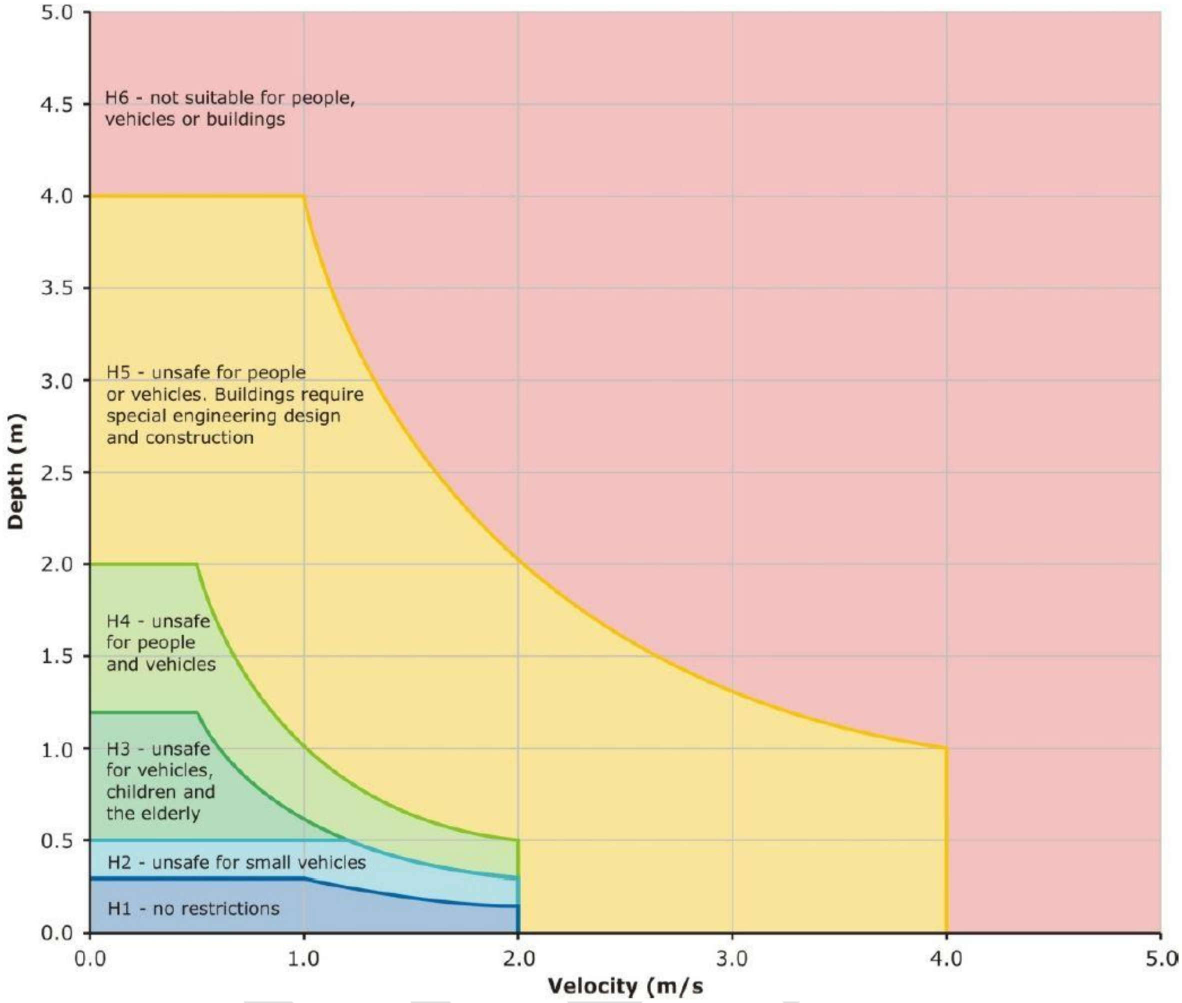

Figure 7.1 – General flood hazard vulnerability curves

Source: NFRAG (2014)

The above hazard vulnerability categories have been mapped for the 1% AEP and the PMF for the entire study area and are presented in **Appendix D**.

During a 1% AEP flood event, the vast majority of the study area is classified as Hazard H1 to H2. Hazard condition H5 and H6 are very rare throughout the Northern Lakes catchments and are typically observed within main natural/concrete channels or open spaces acting as detention basins as would be expected. Hazard conditions H3 and H4 can be observed at a few locations where ponding occurs or in the vicinity of existing streams or channels.

During a PMF flood event, the majority of the study area is classified as Hazard H1 to H3 and the classification is typically increased by one level in comparison to the 1% AEP flood event (i.e. H1 becomes H2, H2 becomes H3, etc.). Hazard conditions H5 and H6 are observed in most flowpaths but typically still within the main channels. Such conditions remain rare throughout the study area. Hazard conditions H3 and H4 are much more common and extend further from the existing streams or channels, particularly at the downstream end of the various flowpaths.

This Northern Lakes catchments appear to be mainly impacted by shallow depth or "nuisance" flooding that have the potential to impact slab-on-ground or other low-level types of properties.

The provisional hazard as described in the NSW Government's Floodplain Development Manual (2005) was also calculated for comparison with the latest flood life hazard categories. It was found that the extent of the high provisional hazard category was slightly less than the H3 category extent and therefore, the high provisional hazard appears to generally be equivalent to a flood life hazard category located between H3 and H4. Therefore, the H1 to H3 categories could potentially be used as an alternative for the previous low provisional hazard category and the H4 to H6 categories could be used as an alternative to the previous high provisional hazard categories.

8. Consequences of flooding on community

8.1 Preamble

The impact of flooding on the community is described in this section. The first step of understanding the impact of flooding on the community is to define the flood behaviour within the catchment and identify key problem areas. Flood impact, road closure and flood damages can then be assessed, and more details are provided in this section.

8.2 Flood behaviour

The study area comprises of a number of small catchments where overland flow flooding can occur and a few larger catchments such as the Bears Creek catchment (3km^2) north-east of Lake Munmorah and the large vegetated area south of Wadalba.

The nature and impact of flooding differs throughout the area, associated largely with differences in the size and topography of the various catchments, as well as the nature of development and effectiveness of drainage infrastructure.

Flooding in the study area is 'flashy' in nature, with flood levels rising rapidly in response to relatively short durations of high intensity rainfall as opposed to extended periods of rainfall of lower intensity. For example, in the simulated 1% AEP 90-minute duration design event, flood levels in most locations around the Northern Lakes catchments peak within 0.5-1.0 hour after the storm commences, while flood levels higher in the catchment may peak even more rapidly. The potential for rapid inundation of properties and numerous roads in response to short durations of rainfall means that time available to disseminate flood warning is limited, and that emergency response may occur after the event. Flood waters generally recede quite quickly following the simulated storms except in some low-lying areas where flooding persists for a number of hours.

As presented in **Figure 6.3**, the events with durations between 15 minutes and 90 minutes result in very similar peak flood levels which means that some flooding could occur in less than 15 minutes for some section of the catchment.

The study area contains various small, steep catchments which drain rapidly toward receiving waters (Lake Munmorah, Budgewoi Lake and Tuggerah Lake) through small well-defined valleys. The impact of flooding in such catchments (e.g. Kanwal, Charmhaven, Gorokan, Budgewoi, Noraville, Lake Munmorah) is generally low except where development has encroached upon these natural drainage lines (e.g. Budgewoi Rd in Noraville).

A number of concrete channels also convey the flow in a number of locations, and some can be impacted by road crossing (e.g. flowpath between the Gorokan Park and Budgewoi Lake).

The very flat, low lying foreshore areas (e.g. area between Tuggerawong and Wadalba) may be subject to fairly widespread but relatively shallow and slow-moving inundation. Overland flows draining from the small steep catchments above collect in these areas and drainage is limited by a lack of gradient to the lakes.

Other large ponding areas have been identified at Buff Point (previous swamp area) and Villa Cl (Budgewoi) where the flood waters appear to be trapped in local low points. Ponding was also observed at the back of Canton Beach. At this location, the beach dunes are more elevated than the land at the back generating a “reservoir” that can reach depths up to almost 1m during a 1% AEP flood event. This “reservoir” only breaches at a couple of locations along the beach once the depth at the back of the dune accumulates.

A number of locations directly placed along existing channel (natural or concrete) or open area accumulating flow, can be flooded once the channel spills during larger events.

8.3 Identification of existing flood problem areas

Based on the flood mapping, a number of key flood problem areas have been identified. **Figure 8.1** illustrated the main areas where properties are affected when for which flood event the affectation commences. This map only highlights the areas affecting properties and not open areas or bushlands. It also includes any area noted as flooded even if depth is relatively shallow.

Areas showing some flood depth but being entirely classified as H1 hazard (i.e. no restriction) were not highlighted as key flood problem area.

It can be observed that the majority of the flood issues occur as early as the 20% AEP flood event. The majority of the areas have relatively shallow flood depth with water spilling from neighbouring natural or concreted flowpaths.

8.4 Key infrastructures

There are two main types of key infrastructures as presented below:

- The first type includes facilities that are occupied by emergency responders such as police stations, fire stations or SES Centres.
- The second type includes facilities with particularly vulnerable residents such as schools, childcare centres, aged care facilities and hospitals.

The locations of these key infrastructures are illustrated in **Figure 8.2**. A list of these facilities is also provided in **Table 8.1** along with a brief description of the flood affectation of each infrastructure.

Toukley Sewerage Treatment Plant is the main STP of the study area and is located on the higher ground along Central Coast Highway at Bungaree Norah. This infrastructure is not impacted by major flooding with hazard categories H1 or H2 during a 1% AEP flood event and only some section of the property being impacted by H3 category hazard during a PMF.

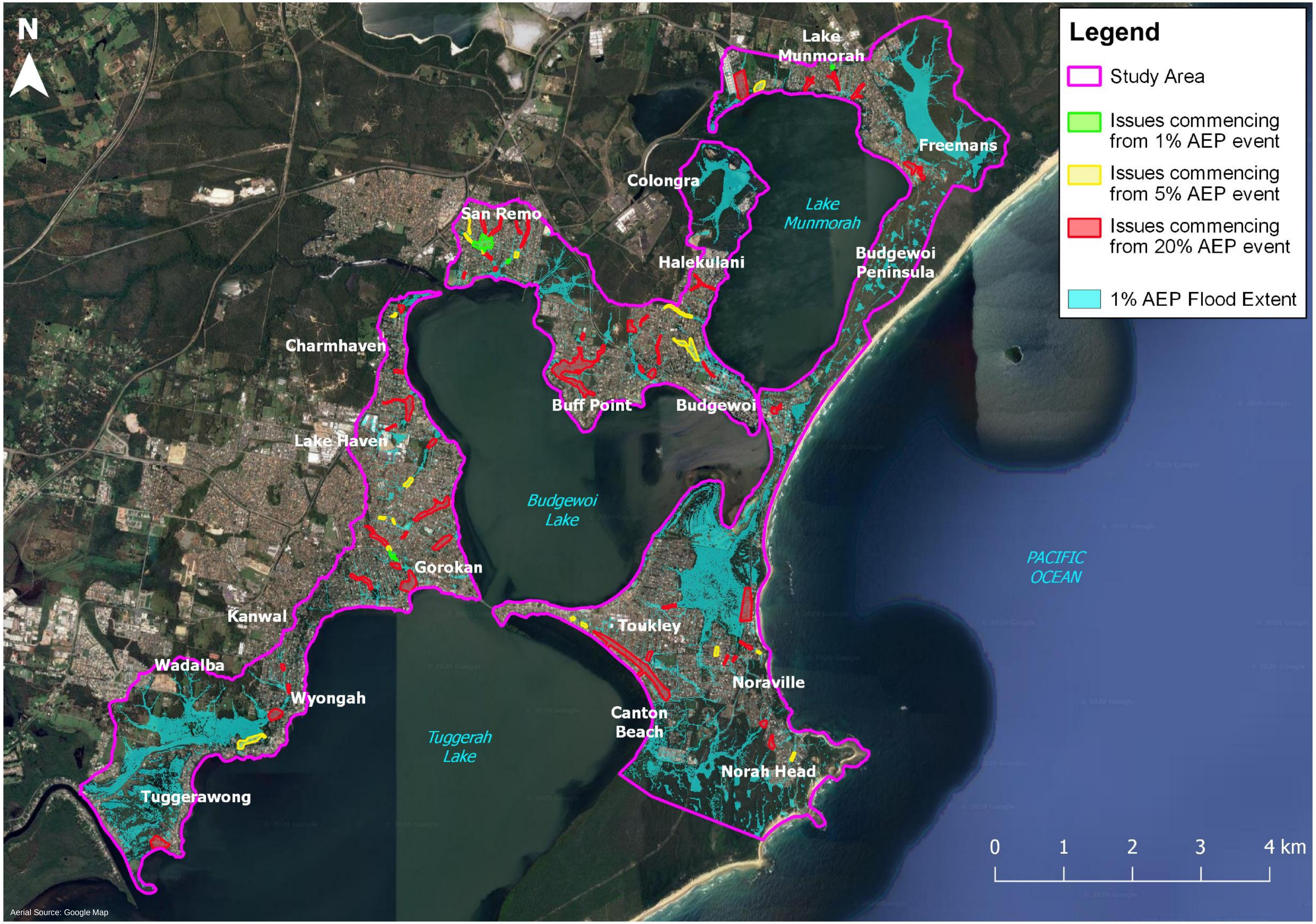

Figure 8.1 – Key Flood Problem Areas

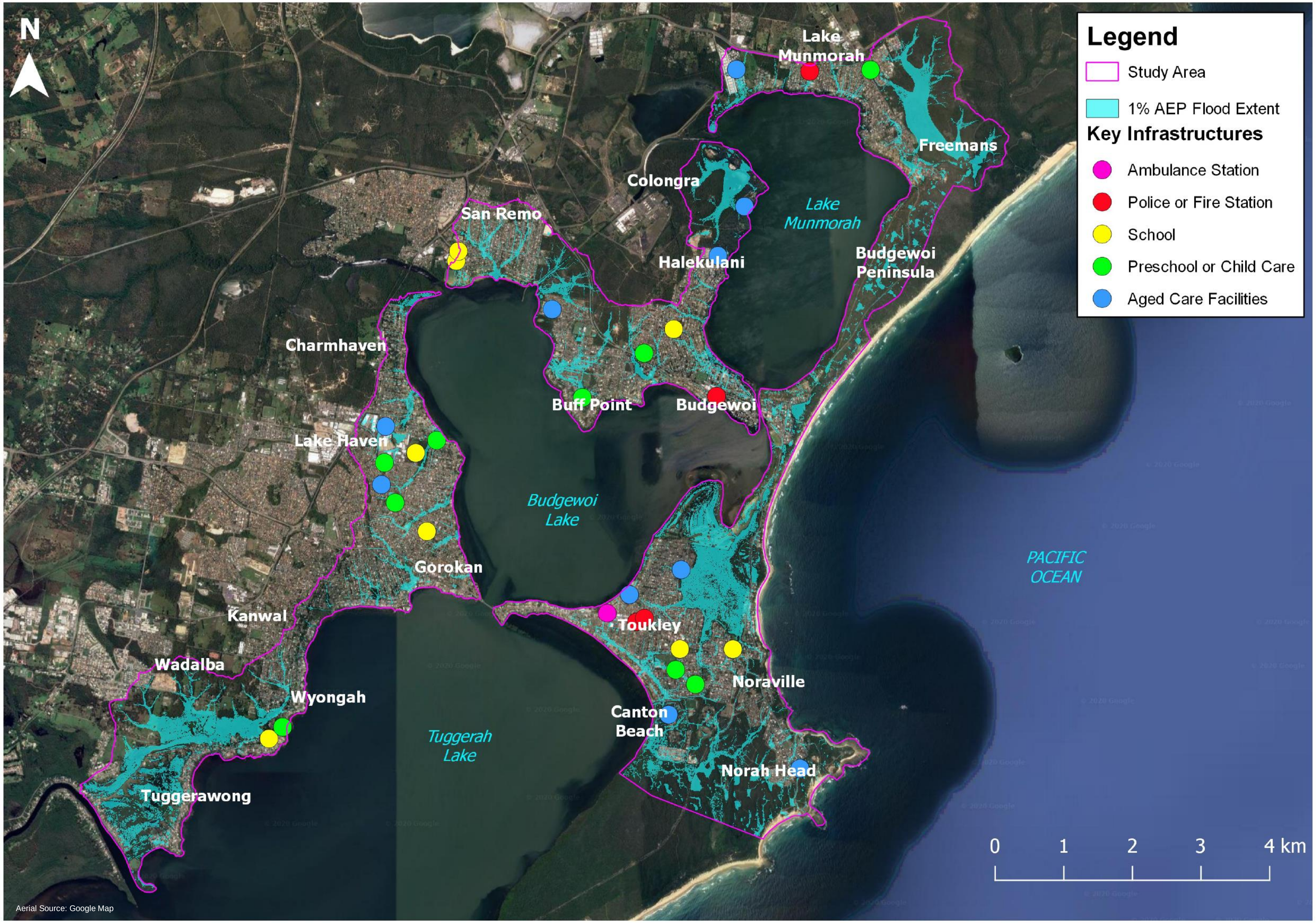

Figure 8.2 – Key Infrastructures Locations

Table 8.1 – List of Key Infrastructures

Location	Comments on Flood Risk
Police and Fire Stations	
Toukley Police Station	The police station is located outside of the PMF extent and access from the station is not flood affected
Toukley Fire Station	The fire station is located outside of the PMF extent and access from the station is not flood affected
Budgewoi Fire Station	The fire station is located outside of the PMF extent and access from the station is not flood affected
Lake Munmorah Fire Station	The fire station is located outside of the PMF extent and access from the station is not flood affected
SES Centres	
SES	There are no SES facilities located within the study area
Hospital and Ambulance Stations	
Toukley Ambulance Station	The ambulance station is located outside of the PMF extent and access from the station is not flood affected
Hospitals	There are no hospitals located within the study area
Schools	
Gorokan High School	The high school is located outside of the PMF extent and access from the school is not flood affected
North Lakes Primary & High School	The school is located outside of the PMF extent and access from the school is not flood affected
Toukley Primary School	The primary school is located outside of the PMF extent and access from the school is not flood affected
St Mary's Toukley Catholic Primary School	The school experiences flow through the grounds in the PMF event, although the buildings remain out of the PMF extent. Access is also cut by floodwaters in the PMF event.
Budgewoi Primary School	The primary school is located outside of the PMF extent. Access from the school to the east along Lukela Avenue is cut by flood waters in the PMF, but access remains to the west.
Tuggerawong Public School	The school is located outside of the PMF extent and access to school is cut during PMF
Gorokan Public School	The school is located outside of the PMF extent and access to school from the North is cut during PMF
Childcare Facilities	
Koala Preschool Tuggerawong	The preschool is located outside of the PMF extent and access to school is cut during PMF
Bright House Preschool Buff Point	The preschool is impacted by shallow depths during a 1% AEP and PMF events and access to school remains during PMF
Toukley Preschool Kindergarten	Preschool impacted by shallow depths during 1% AEP and impacted by deeper flood waters cutting access during PMF
Noraville Child Care	Child Care Centre impacted by shallow depths during 1% AEP

Location	Comments on Flood Risk
Centre	and impacted by deeper flood waters cutting access during PMF
Budgewoi Jelli-Beanz Kindergarten	The kindergarten is located outside of the PMF extent and access to centre is cut during PMF
Goodstart Learning Lake Munmorah	The kindergarten is located outside of the PMF extent and access to centre remains during PMF
Future Stars Early Learning Centres Lake Haven	The kindergarten is located outside of the PMF extent and access to centre remains during PMF
Dinky Di Children's Learning Centre Gorokan	The kindergarten is located outside of the PMF extent and access to centre remains during PMF
Spotted Frog Kindergarten Lake Haven	Child Care Centre impacted by shallow depths during 1% AEP and impacted by deeper flood waters cutting access during PMF
Aged Care Facilities and Retirement Villages	
RFBI Lake Haven Masonic Village	The development is located outside of the PMF extent. Access from the development to the east along Christopher Crescent is cut by flood waters in the PMF, but access remains to the west.
Lakeland Park	The development is located outside of the PMF extent and access from the development is not flood affected.
Sunnylake Shores	Properties are located out of the PMF extent. However, access to the development is cut by flood waters in the PMF event.
RSL Lifecare Lakefront Retirement Village	Properties are located out of the PMF extent. However, access to the development is cut by flood waters in the PMF event.
Toukley Aged Care Facility	The development is located outside of the PMF extent and access from the development is not flood affected.
Opal Norah Head	The centre is located outside of the PMF extent and access to facility remains during PMF
Aurrum Aged Care Norah Head	The centre is located outside of the PMF extent and access to facility is cut during PMF
Central Coast Community Care Association Limited	Impacted by shallow depths from the 20% AEP event and access from eastern road cut from 20% AEP event
Lakeside Leisure Village	Southern half of the Leisure Park impacted by shallow depths from 20% AEP event and access remains during PMF
Bevington Shores Lifestyle Village	The centre is located outside of the PMF extent and access to facility remains during PMF

8.5 Road closure

An assessment of the frequency and hazard of road inundation is important for understanding the risk of vehicles becoming unstable, posing a risk to life for their drivers and passengers. It is also important for understanding evacuation risks, informing the classification of communities according to flood emergency response planning considerations. Measures to increase the flood immunity of critical roads could be considered as a result of this assessment.

Figure 8.3 and **Figure 8.4** describes the flood hazard for 36 road low-points for the 20% AEP design event, 48 low points for the 5% AEP design event, 68 low points for the 1% AEP design event and 206 locations for the PMF. Hazard category 'H3' (and H4–H6) is considered unsafe for all vehicles whereas 'H2' is considered unsafe for small vehicles (see **Figure 7.1**). **Appendix G** details the results of the road closure at each location including for the PMF. This table also includes an assessment of the time to peak and duration of above-road inundation for the modelled design event (note that the results are sensitive to the adopted critical duration and temporal patterns used in the model) as well as the duration for which the depth is over 0.3m above road.

It can be noted that a large number of locations get some water over road very rapidly in the study area, although it may not become a significant issue every time. This is fairly common during overland flooding events.

In the 1% AEP flood, the majority of roads that are inundated are minor roads with secondary access by-passing the flooded area. Larger roads that are impacted include Lett St, Leichhardt St, Dudley St and Malvina Pde in Gorokan, Goobarabah Ave, Chelmsford Ave and Panorama Ave in Lake Haven as well as Elizabeth Bay Dr in Lake Munmorah.

In the PMF, The above locations experience H3+ hazard conditions. Moreover, a number of additional roads become inundated including Scenic Dr at Buff Point.

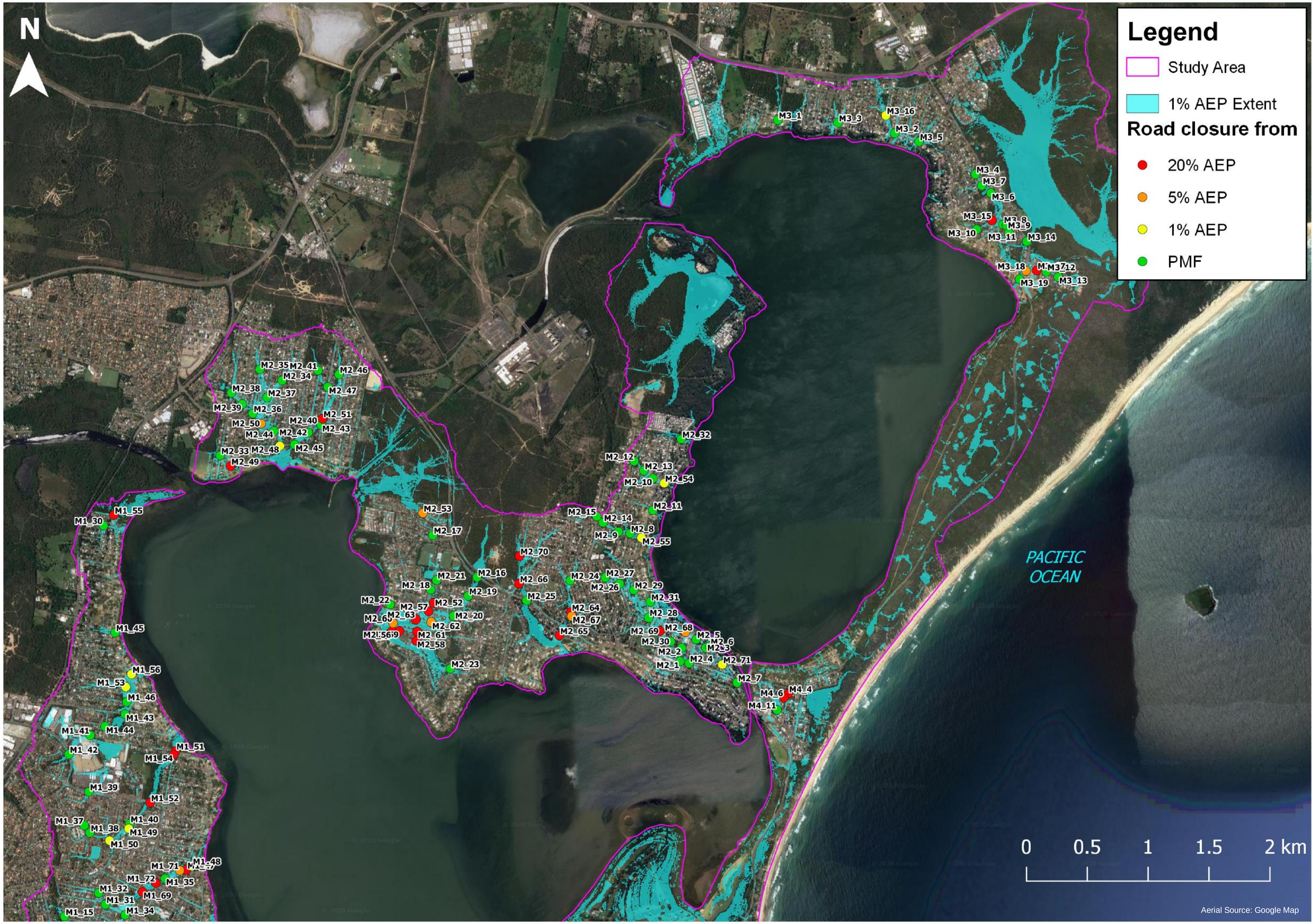

Figure 8.3 – Road Closures Locations (Northern Half of Catchment)

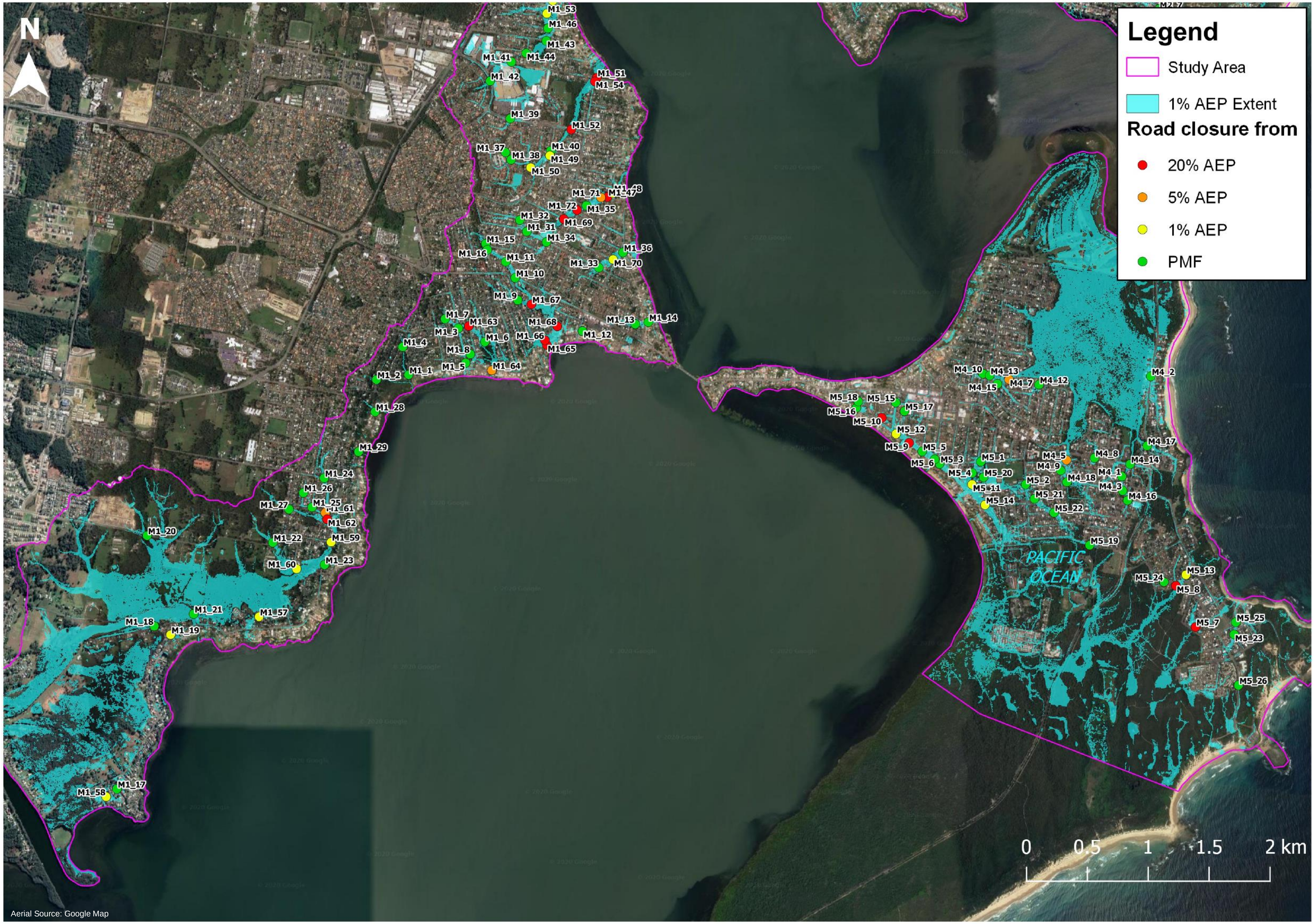

Figure 8.4 – Road Closures Locations (Southern Half of Catchment)

8.6 Flood damage assessment

8.6.1 General approach

The flood damage assessment has been undertaken using a step-by-step approach:

- The extent of the floor level survey has been estimated based on the criteria described in **Section 3.3**. This allowed to minimise the extent of the survey and to focus on area where potential damages can occur.
- A preliminary desktop assessment of the floor level has then been completed to provide a basis for a preliminary damage assessment.
- A preliminary assessment has been completed using these floor levels to allow comparison of the various management options.

8.6.2 Type of flood damage

The definitions and methodology used in estimating flood damages are well established. **Figure 8.5** summarises all the types of flood damages examined in this study. The two main categories are tangible and intangible damages. Tangible flood damages are those that can be more readily evaluated in monetary terms. Intangible damages relate to the social cost of flooding and therefore are much more difficult to quantify.

Tangible flood damages are divided further into direct and indirect damages. Direct flood damages relate to the loss or loss in value of an object or a piece of property caused by direct contact with floodwaters, flood-borne debris or sediment deposited by the flood. Indirect flood damages relate to loss in production or revenue, loss of wages, additional accommodation and living expenses, and any extra outlays that occur because of the flood.

8.6.3 Basis of flood damages calculations

Flood damages have been estimated by applying one of several stage-damage curves to every property included in the database. These curves relate the amount of flood damage that would potentially occur at different depths of inundation, for a particular property type, whether residential or commercial/industrial.

Residential damages

In October 2007, the then Department of Environment and Climate Change (now DPIE) released Guidelines to facilitate a standard methodology for assessing residential flood damages. This involves tailoring stage-damage data for the particular floodplain of interest and is recommended for use throughout NSW so that the results from one floodplain can be compared with another.

Inputs for the Northern Lakes study area are listed in **Table 8.2**, together with explanations for each selection. The resultant stage-damage data are provided in **Appendix H** of this report.

It is noted that the DPIE residential stage-damage curves make allowance for both clean-up costs ($4,000 per flooded house) and the cost of time in alternative accommodation. Based on previous experience on past studies, an allowance of 5% has been applied for additional indirect costs for the residential sector for this study. The flood damages curve of low set properties was adjusted to start generating damages from 100mm below floor level instead of 500mm.

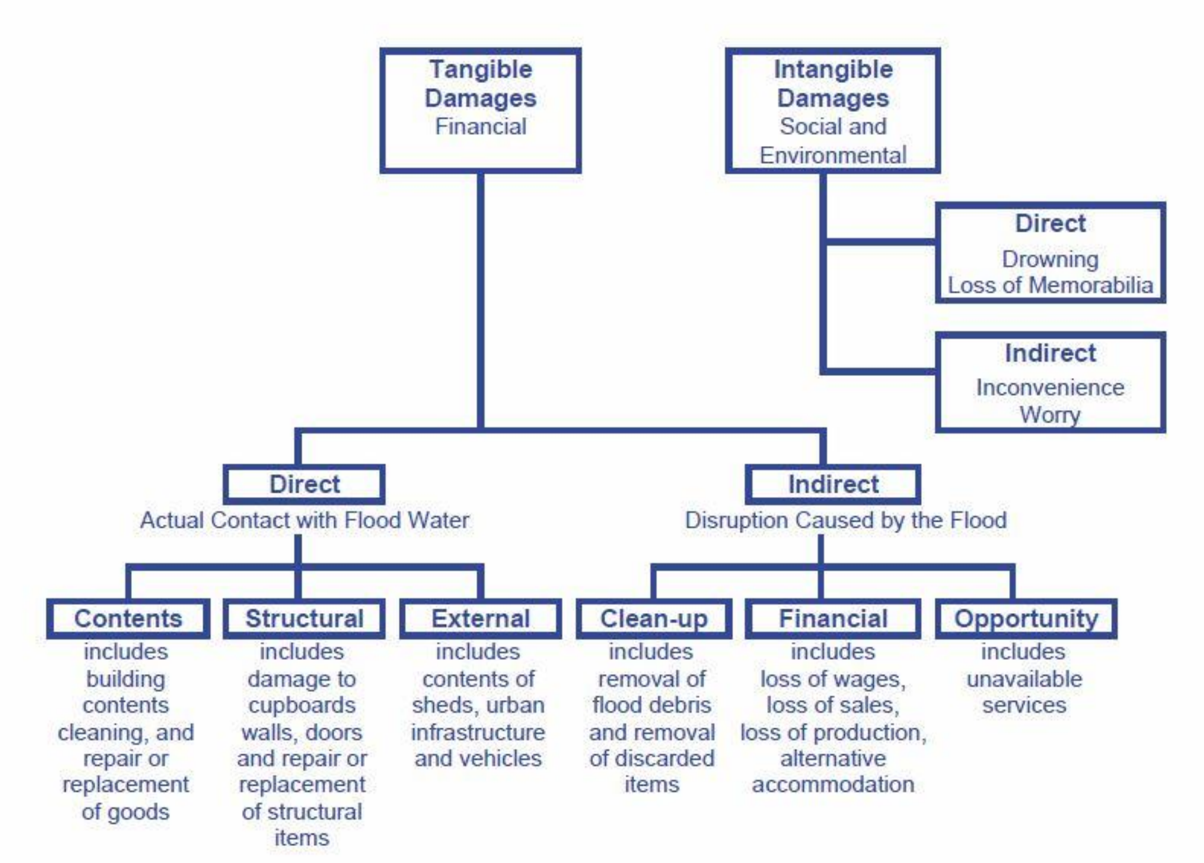

Figure 8.5 – Types of flood damage

Source: Floodplain Development Manual (NSW Government, 2005)

Table 8.2 - Input variables for residential damages assessment

Input	Value	Explanation
Regional Cost Variation Factor	1.0	Rawlinsons
Post late 2001 adjustments	1.86	Changes in AWE from Nov 2001 to Nov 2019
Post Flood Inflation Factor	1.40	Regional city
Typical Duration of Immersion	1 hour	Flash flooding scenario
Building Damage Repair Limitation Factor	0.85	Short duration
Typical House Size	240 m^2	Recommended for use by DPIE
Contents Damage Repair Limitation Factor	0.75	Short duration
Level of Flood Awareness	Low	
Effective Warning Time	0 hour	Flash flooding scenario with small catchments
Typical Table/Bench Height	0.90	Standard
External Damage	$6,700	Standard
Clean-up costs	$4,000	Standard
Likely Time in Alternative Accommodation	3 weeks	Typically, shallow flooding
Additional Accommodation Costs	$220	Standard

Commercial/Industrial damages

No standard stage-damage curves have been issued for commercial and industrial damages. The stage-damage relationships used to estimate these damages in this study are based on investigations by Water Studies (1992) and incorporated into waterRIDE. Stage-damage data were factored up to Nov 2019 values using changes in Average Weekly Earnings (AWE). The stage-damage data are reported in $\$/m^2$ for each of six value categories (see **Appendix H**). Research suggests that commonly adopted commercial and industrial stage-damage data may err on the low side, particularly for a place like Lake Haven where there are several specialist stores likely to contain higher-value contents than the shops – predominately from inland NSW towns – where the damage data was first derived.

Based on previous experience on past studies, an allowance of 50% for indirect costs for the commercial sector – covering clean-up costs and disruption to trade – was deemed appropriate.

Other damages

In some previous floodplain risk management studies, DPIE has advised that damages to infrastructure (roads, etc.) be estimated as 15% of total direct residential and commercial/ industrial damages. This allowance has been included as a separate item for this study.

A number of studies also include basic stage-damage assumptions to cater for damage to motor vehicles. However, DPIE has made clear that damages to vehicles should not influence the BCR of potential flood reducing measures, which are particularly intended to address damages to houses and to a lesser extent businesses (and associated livelihoods). Accordingly, no allowance has been made to assess damage to vehicles for this study.

Flooding can have various impacts on people's health, both physical and emotional. These include stress-related ailments, influenza, viral infections, heart problems and back problems (from lifting and cleaning). Although it is difficult to quantify the cost of disruption, illness, injury and hospitalisation, in keeping with advice previously received from DPIE, social damages have been estimated (as a separate item) as 25% of 'total damages', which are interpreted as the sum of direct residential damages and direct non-residential damages.

Damage mapping

Maps summarising the results of the flood damage assessment for both residential and commercial/industrial are presented in **Appendix I**. The damages are colour coded and results are provided for the 20% AEP, 5% AEP, 1% AEP and PMF flood events as well as the AAD. These maps identify key areas where high damage is occurring and hence, highlights areas where management options are likely to have a significant beneficial impact.

8.6.4 Economic analysis

An economic appraisal is required for all proposed capital works in NSW, including flood mitigation measures, in order to attract funding from the State Government's Capital Works Program. The NSW Government has published two Treasury Policy Papers to guide this process: *NSW Government Guidelines for Economic Appraisal* (NSW Treasury, 2007a) and a summary in *Economic Appraisal Principles and Procedures Simplified* (NSW Treasury, 2007b).

An economic appraisal is a systematic means of analysing all the costs and benefits of a variety of proposals. In terms of flood mitigation measures, benefits of a proposal are generally quantified as *the avoided costs associated with flood damages*. The avoided costs of flood damage are then compared to the capital (and on-going) costs of a particular proposal in the economic appraisal process.

Average annual damage (AAD) is a measure of the cost of flood damage that could be expected each year by the community, on average. It is a convenient yardstick to compare the economic benefits of various proposed mitigation measures with each other and the existing situation. **Figure 8.6** describes how AAD relates to actual flood losses recorded over a long period. For the current study, AAD is assessed using the potential damages derived for each design event (i.e. 20% AEP, 5% AEP, 1% AEP and PMF). It is assumed that damages to buildings can commence at the 50% AEP event; the PMF is set to an ARI of once in 100,000 years.

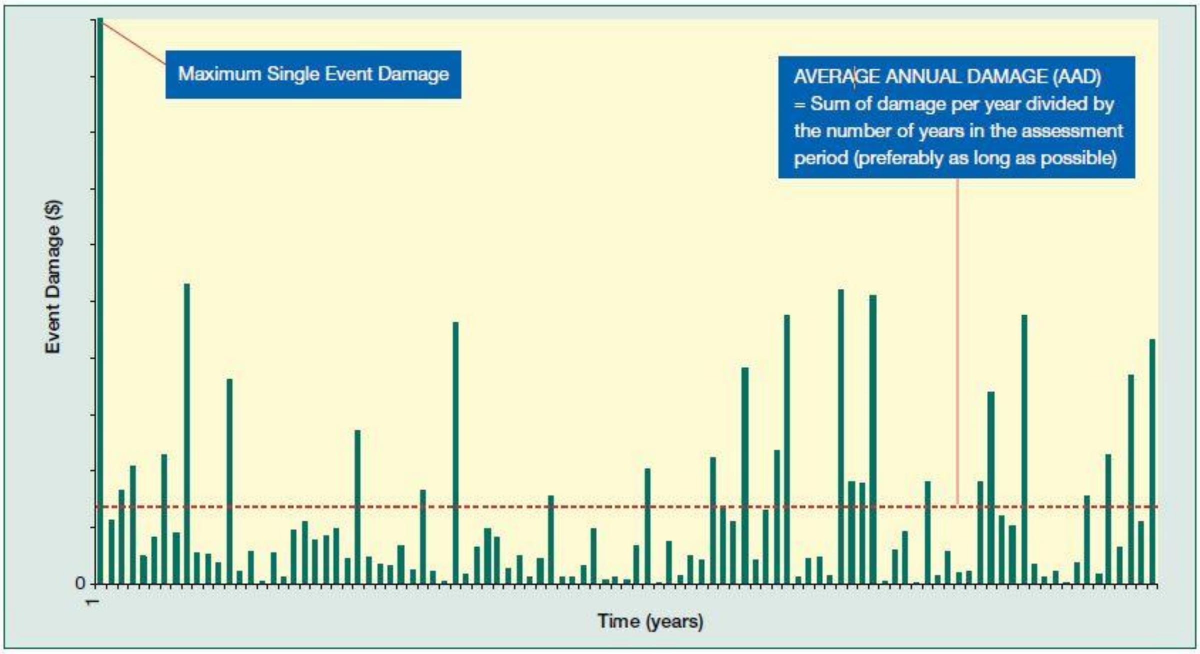

Figure 8.6 - Randomly occurring flood damage as annual average damage

Source: Managing Flood Risk through Planning Opportunities (HNFMSC, 2006a)

The present value of flood damage is the sum of all future flood damages that can be expected over a fixed period (usually 50 years) expressed as a cost in today's value. The present value is determined by discounting the future flood damage costs back to the present-day situation, using a discount rate (typically 7%).

A flood mitigation proposal may be considered to be potentially worthwhile if the benefit–cost ratio (the present value of benefits divided by the present value of costs) is greater than 1.0. In other words, the present value of benefits (in terms of flood damage avoided) exceeds the present value of (capital and on-going) costs of the project.

However, whilst this direct economic analysis is important, it is not unusual to proceed with urban flood mitigation schemes largely on social grounds, that is, on the basis of the reduction of intangible costs and social and community disruption. In other words, the benefit–cost ratio could be calculated to be less than 1.0.

8.7 Summary of flood damages

Calculated flood damages and AAD for the Northern Lakes FRMSP study area are presented in **Table 8.3** and **Table 8.4**. Distinctive features include:

- The 20% AEP flood is expected to cause damages of $13.2 million;
- The 1% AEP flood is expected to cause damages just over $34.2 million;
- The annual average damage within the study area is about $6.9 million, which is a measure of the cost of flood damage that could be expected each year, on average, by the community;
- The flood with the highest contribution to the AAD is the 5% AEP flood event followed by the 20% AEP flood event;
- The net present value of damages (discounted at 7% over a 50-year period) is $102.6 million, which represents the maximum sum that could be spent on flood mitigation measures if an economic benefit/cost ratio of 1.0 is required and all flood damages can be avoided. The reality is that mitigation works to address damages from events as rare as the PMF are rarely pursued;
- The largest contributor to flood damages is direct residential damage that contributes 54% of the damages followed by social damages that contributes 16% and commercial damages that represent 12%. This reflects the inundation patterns, with many more houses flooded above floor level than businesses. It is also likely to reflect the adopted commercial/industrial stage-damage data, which are believed to err on the low side.

Table 8.3 - Summary of flood damage by design event

Flood Event	Number of Impacted Properties+		Direct Damage Only ($2019)		Total Predicted Actual Damage ($2019)#	Total Average Annual Damage ($2019)*	Total Net Present Value of Damage ($2019)*
	Residential	Commercial	Residential	Commercial			
20% AEP	103	7	$6.8M	$1.8M	$13.2M	$2.0M	$29.4M
5% AEP	176	12	$11.8M	$2.6M	$22.1M	$2.6M	$39.2M
1% AEP	278	23	$18.9M	$3.6M	$34.2M	$1.1M	$16.7M
PMF	1409	34	$121.0M	$13.5M	$201.0M	$1.2M	$17.4M
TOTAL	**1409**	**34**	**$158.4M**	**$21.5M**	**$270.5M**	**$6.9M**	**$102.6M**

* Based on treasury guidelines of a 7% discount rate and expected life of 50 years
# Includes residential direct and indirect, commercial direct and indirect, infrastructure and social damages
+ Residential properties have been separated into building where multiple buildings are on the same property and commercial properties into separate businesses. However, where commercial buildings are the same company (e.g. industrial area with 5 warehouse or caravan park) the damages were consolidated as one property.

Table 8.4 – Components of flood damage for the Northern Lakes FRMSP study area (AAD)

	Damage Component	Method Assessed	Number of Impacted Properties	Cost ($2019)	
A.	Direct Residential Damage	DECC (2007) curves	1409	$3,720K	54%
B.	Indirect Residential Damage	5% of A	1409	$186K	3%
C.	Direct Commercial/Industrial Damage	FLDAMAGE	34	$809K	12%
D.	Indirect Commercial Damage	50% of C	34	$405K	6%
E.	Infrastructure Damage	15% of (A + C)	N/A	$679K	10%
F.	Social Damage	25% of (A + C)	N/A	$1,132K	16%
	TOTAL AAD			**$6,932K**	100%

9. Information to support decisions on activities in the floodplain and managing flood risk

9.1 Flood planning area

The flood planning area (FPA) is the area of land subject to flood related development controls. It was defined as the extent of the 1% AEP flood event including an increase in rainfall intensity of 30%. This criterion was adopted following discussion with Council. Such type of criteria appears more appropriate than adding a 0.5m freeboard followed by stretching of the elevated water level in overland flooding studies as the majority of the 1% AEP flooding is relatively shallow and stretching this elevated flood level would significantly alter the extent of the flood planning area and may propagate it beyond the PMF extent.

It is noted that a Flood Planning Level of 2.7 m AHD was adopted as part of the Tuggerah Lakes FRMSP and the area of the catchment below this level would represent the mainstream flood planning area in the catchment.

The flood planning level for this study is therefore recommended to be the largest of:

- The overland 1% AEP flood level as defined in this study including a freeboard of 300 mm; and
- The mainstream 1% AEP flood level as defined in the Tuggerah Lakes FRMSP of 2.7 m AHD.

The FPA for both this study (overland flooding) and the Tuggerah Lakes FRMSP study (mainstream flooding) is mapped in **Appendix F**.

9.2 Flood emergency response classification

In order to assist in the planning and implementation of response strategies, the NSW SES in conjunction with DPIE developed guidelines to classify communities according to the ease of evacuation (DECC, 2007). The guidelines classify communities as either 'Flood Islands' (either 'High Flood Island' if isolated but not flooded or 'Low Flood Island' if first isolated then flooded), 'Trapped Perimeter' (either 'High' if isolated but not flooded or 'Low' if first isolated then flooded), 'Overland Escape Route' (people can walk to nearby road or refuge above flood level), Rising Road Access or Indirectly Affected areas.

Some consideration has been given to building locations on a block affected by flooding, but no consideration has been given to building styles. A raised building effectively represents a Low Flood Island if the floor level is not above PMF. Or a raised building may facilitate shelter-in-place where the floor level is above PMF and the structure can withstand PMF forces (effectively representing a High Flood Island). Mapping Flood Emergency Response Planning classes is to a degree a subjective exercise. Nevertheless, it serves to highlight areas most at risk in the event of severe flooding where people fail to evacuate early or shelter in houses is unsuitable for that purpose.

Summary of the Flood Emergency Response Classification is presented in **Appendix E**.

It can be noted that the vast majority of the flood affected properties have a rising road classification or overland escape route classification. This is primarily due to the fact the study area is relatively low-lying and overland flows generated shallow ponding. Such shallow depths allow local residents to evacuate either by car or by foot should the depth increase.

10.Preliminary options assessment

10.1 Identification of potential management options

In accordance with the 2005 Floodplain Development Manual, MHL has investigated a range of floodplain risk management measures that aim to reduce the social, environmental and economic impacts of flooding in the Northern Lakes study area.

Floodplain risk management measures may be classified into three groups:

- *Flood modification (FM) measures* – measures that modify the behaviour of the flood itself, typically through structural works that reduce flood levels or velocities, or exclude floodwaters from areas that would otherwise flood;
- *Property and planning modification (PM) measures* – measures that modify existing development (e.g. voluntary purchase schemes, voluntary house raising schemes, flood proofing) and/or ensure appropriate future development of property and community infrastructure through application of flood-related development controls;
- *Emergency response Modification (EM) measures* – measures that modify the response of the community to better cope with a flood event (e.g. flood warning, emergency management, community flood education).

Initially a full list of potential options was developed in consideration of:

- Distribution of high flood risk areas, potential over floor flooding and flood damages,
- Hydraulic flood behaviour, existing drainage capacity and the availability of open space for storage
- Community input from the community questionnaire and Northern Lakes Working Group
- Central Coast Council recommendations
- Review of recommended options from Tuggerah Lakes Floodplain Risk Management Plan (2014) to prevent duplication
- Review of Council flood policy and flood-related development controls
- Review of emergency response and evacuation issues.

Figure 10.1 shows the locations of mappable flood risk management options including flood modification options and flood warning.

The majority of the study area being impacted by relatively shallow depth flooding, most areas would require some culvert or drainage upgrade.

Detention basins can potentially be undertaken at Freemans upstream of Elizabeth Bay Drive, at Budgewoi Soccer Club and in the park located between Gascoigne Road and Mary Street at Gorokan. The detention basin upstream of Scenic Drive in Buff Point could potentially be upgraded.

An embankment could be created at the back of the properties located along the western side of Budgewoi Rd at Noraville to stop flood water from the bushland area.

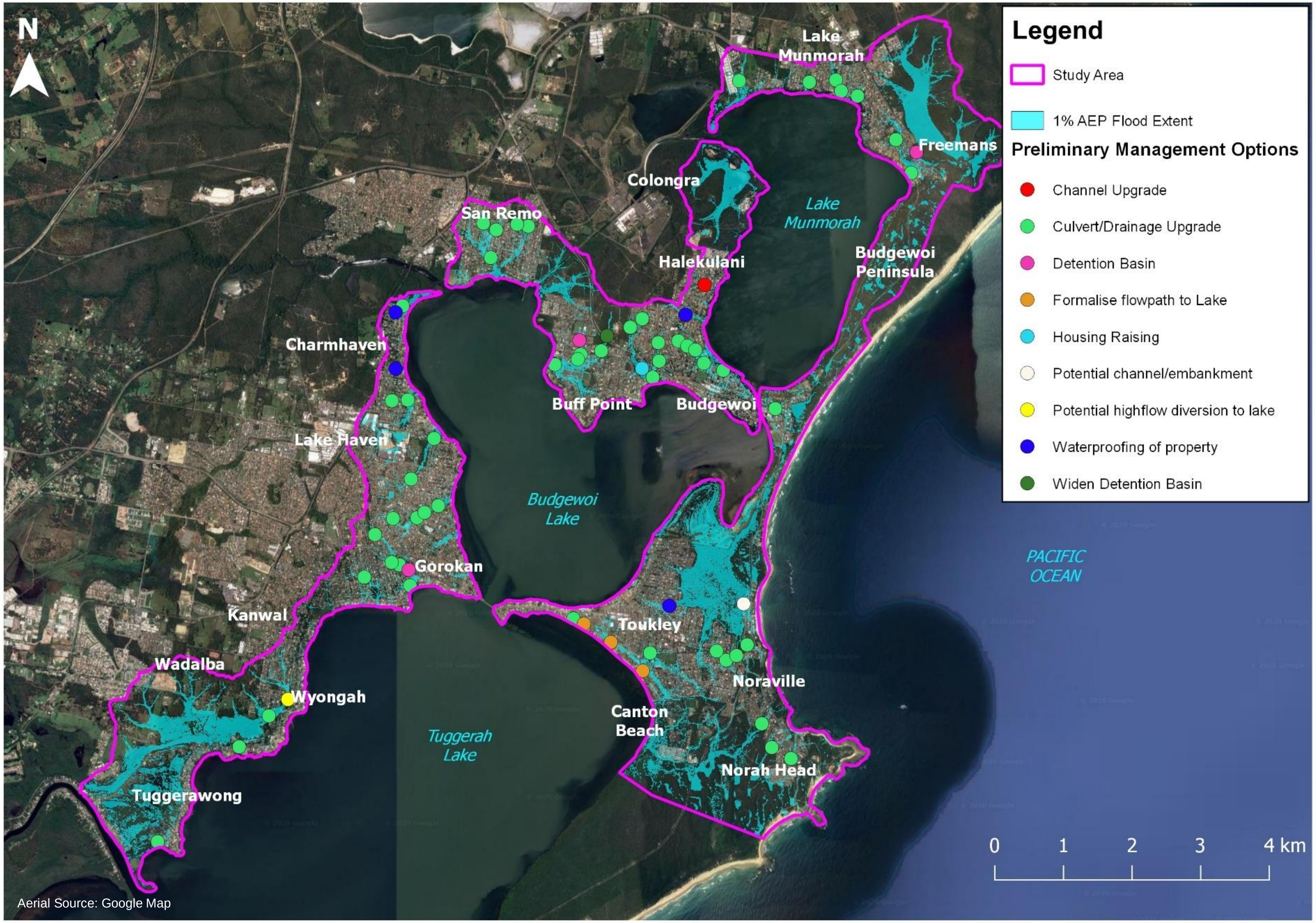

Figure 10.1 – Location of preliminary flood risk management options

Canton Beach is subject to severe ponding and this issue may be resolved by formalising flow path to the lake at regular interval allowing the flood water to drain to the lake instead of banking up.

A highflow diversion to the lake at Wyongah could potentially be investigated although it may be subject to environmental restriction downstream of the diversion if environmental flows are reduced.

A number of locations are subject to flooding and may require some waterproofing or raising.

While this presents a thorough list of potential options, a number of these options may not be valuable due to low return on investment (e.g. considerable expense to only have a minor reduction in flood impact). The following sections are presenting a preliminary assessment of management options allowing a selection of preferred management options.

10.2 Preliminary assessment of management options

In order to formulate preferred management options for inclusion in a floodplain risk management plan, the advantages and disadvantages of all options must be assessed in a comparative manner. The decision process involves assessment of multiple, potentially conflicting objectives. A matrix is a useful tool for formalising a multi-criteria analysis so that the options that best satisfy the various objectives can be identified. The multi-criteria assessment matrix developed for this study is shown in **Table 10.1**. The criteria were developed and weighted in consideration of Appendix G of the NSW Floodplain Development Manual and the study team's engineering judgement and industry experience. A score from 1 to 5 is given to each option for each criterion to assess the benefits or disbenefits it would be expected to provide.

The resulting preliminary assessment of options is presented in **Table 10.2**. This assessment helped identify which options warranted further investigation. Options that were considered worthy of further investigation or requiring further explanation are described and discussed in following chapters.

Table 10.1 – Option assessment criteria

Item	Score				
	1	2	3	4	5
	Negative		Neutral	Positive	
Impact on Flood Behaviour (Hydraulic Hazard)	Significant increase in hydraulic hazard	Some increase in hydraulic hazard	Neutral	Some decrease in hydraulic hazard	Significant decrease in hydraulic hazard
Number of Properties Benefited	>5 properties negatively impacted	1-5 properties negatively impacted	Neutral or 1-2 properties positively impacted	3-5 properties positively impacted	>5 properties positively impacted
Technical Feasibility	Significant issues (unproven, high risks)	Some issues (complex, some difficulty)	Minor issues	Negligible issues	No issues (proven, well established, no risks)
Economic Merit (benefit/cost ratio)	Very low (0-0.5)	Low (0.5-0.8)	Neutral (0.8-1.2)	High (1.2-2.0)	Very high (>2)
Financial Feasibility (funding, Government assistance & grants)	Very unlikely to receive funding	Unlikely to receive funding	Neutral	Likely to receive funding	Very likely to receive funding
Environmental and Ecological Benefits	Significant disbenefits	Some disbenefits	Neutral	Some benefits	Significant benefits
Impact on Risk to Life	Significant increase in risk to life	Some increase in risk to life	Neutral	Some decrease in risk to life	Significant decrease in risk to life
Impacts on SES	Significant disbenefit to SES	Some disbenefit to SES	Neutral	Some benefit to SES	Significant benefit to SES
Long-term Performance (design life & climate change)	Very low	Low	Neutral	High	Very high
Legislative & Permissibility Requirements (including political & administrative issues)	Significant issues affecting implementation	Some issues affecting implementation	Minor issues affecting implementation	Negligible issues affecting implementation	No issues affecting implementation
Social Impact / Community Acceptance	Majority against, minimal support	Some against	Neutral	Some for	Majority for, few opposed
Existing Flood Damages (AAD) of Area	<$50K	$50K to $100K	$100K to $150K	$150K to $200K	Over $200K

Table 10.2 – Preliminary option assessment matrix shown from highest to lowest ranking

ID	Option Location	Assessment Criteria													
		Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Economic Merit	Financial Feasibility	Environmental and Ecological Benefits	Impact on Risk to Life	Impacts on SES	Long-term Performance	Legislative & Permissibility Requirements	Social Impact / Community Acceptance	AAD of Area	TOTAL SCORE	RANKING
1	Drainage Upgrade - Hastings St, Rocky Point	4	4	2	1	1	3	3	3	1	4	3	1	30	40
2	Drainage Upgrade - Cadonia Rd, Tuggerawong	4	4	2	1	2	3	3	3	1	4	3	2	32	38
3	**Culvert Upgrade - Cooranga Rd, Wyongah**	5	5	4	3	3	3	4	4	3	3	4	2	43	7
4	Highflow Diversion to Lake, Wyongah	4	5	1	1	1	2	4	4	3	2	3	2	32	38
5	Drainage Upgrade - Georgina Ave, Gorokan	4	4	3	1	1	3	3	3	3	4	3	2	34	26
6	Drainage Upgrade - Gascoigne Rd and Brennon Rd, Gorokan	4	4	3	1	1	3	3	3	3	4	3	2	34	26
7	**Detention Basin between Gascoigne Rd and Mary St, Gorokan**	5	5	2	3	4	2	5	5	3	3	4	5	46	3
8	**Drainage Upgrade - Cnr Gascoigne Rd and Lett St**	5	5	2	3	4	3	5	5	2	3	4	5	46	3
9	Drainage Upgrade - Middlesex Ave	4	4	3	1	1	3	3	3	3	4	3	1	33	32
10	Drainage Upgrade - Coraldeen Ave, Gorokan	4	4	3	1	1	3	3	3	3	4	3	1	33	32
11	Drainage Upgrade - Cornwall Ave, Gorokan	4	4	3	1	1	3	3	3	3	4	3	1	33	32
12	**Detention Basin Upgrade - Downstream of Gorokan Park, Gorokan**	4	5	3	2	2	3	3	3	3	4	4	5	41	9
13	Culvert Upgrade - Carinya St, Charmhaven	4	4	3	1	1	3	3	3	3	4	3	1	33	32
14	Drainage Upgrade - Chelmsford Rd, Lake Haven	4	4	3	2	3	3	4	4	3	4	4	2	40	10
15	**Culvert/Drainage Upgrade - Wirriga Ave, Charmhaven**	4	5	2	3	4	3	4	4	3	4	4	4	44	6
16	Waterproofing - Lake Haven	3	4	2	3	3	3	3	3	3	2	2	5	36	18
17	Drainage Upgrade - Lowana Ave, Charmhaven	4	4	3	2	2	3	3	3	3	4	4	1	36	18
18	Drainage Upgrade - Upstream Catchments, San Remo	4	4	3	1	1	3	3	3	3	4	3	5	37	14
19	Drainage Upgrade - Downstream Iluka Ave, San Remo	4	4	3	2	2	3	3	3	3	4	3	2	36	18
20	Drainage Upgrade - Upstream Catchment Buff Point	4	4	3	1	1	3	3	3	3	4	3	5	37	14
21	Culvert upgrade - Downstream of Buff Point Ave, Mandalong Point, Buff Point	3	5	3	3	2	3	3	3	2	3	5	5	40	10

ID	Option Location	Assessment Criteria: Impact on Flood Behaviour	Number of Properties Benefited	Technical Feasibility	Economic Merit	Financial Feasibility	Environmental and Ecological Benefits	Impact on Risk to Life	Impacts on SES	Long-term Performance	Legislative & Permissibility Requirements	Social Impact / Community Acceptance	AAD of Area	TOTAL SCORE	RANKING
22	Detention Basin - Budgewoi Soccer Club	4	4	3	2	2	3	3	3	3	4	3	5	39	12
23	Drainage Upgrade - Natuna Ave to Woodlawn Dr, Budgewoi	4	4	3	1	1	3	3	3	3	4	3	5	37	14
24	Drainage Upgrade -Upstream of Scenic Drive, Budgewoi	4	4	3	1	1	3	3	3	3	4	3	2	34	26
25	Detention Basin Upgrade - Upstream of Scenic Drive, Buff Point	4	5	2	1	2	3	5	5	3	2	4	3	39	12
26	House Raising - Sonoma Rd, Budgewoi	3	4	1	1	1	3	3	3	3	1	1	1	25	43
27	**Culvert Upgrade - Woodland Parkway, Budgewoi**	5	5	3	3	3	3	5	5	3	3	4	3	45	5
28	Waterproofing - Halekulani	3	4	2	1	1	3	3	3	3	2	1	3	29	41
29	Channel Upgrade - Near Lilo Ave, Halekulani	4	4	3	2	2	3	3	3	3	4	3	2	36	18
30	Drainage Upgrade - Villa Cl, Budgewoi	4	4	3	1	1	3	3	3	1	4	3	3	33	32
31	Drainage Upgrade - Anita Ave Near Alister Ave, Lake Munmorah	4	4	3	1	1	3	3	3	3	4	3	3	35	24
32	Drainage Upgrade - Queens Rd to Lauren Ave, Lake Munmorah	4	4	3	1	1	3	3	3	3	4	3	4	36	18
33	Drainage Upgrade - Rosemount Avenue, Lake Munmorah	4	4	3	1	1	3	3	3	3	4	3	3	35	24
34	**Culvert Upgrade - Greenacre Ave, Lake Munmorah**	5	5	3	3	4	3	4	4	3	3	5	5	47	1
35	Detention Basin - Upstream Elizabeth Bay Dr, Freemans	4	4	2	1	2	2	3	3	3	1	4	5	34	26
36	Drainage Upgrade - Maitland St to Victoria St, Norah Head	4	4	3	1	1	3	3	3	3	4	3	2	34	26
37	Drainage Upgrade - Barton St, Norah Head	4	4	3	1	1	3	3	3	3	4	3	2	34	26
38	Drainage Upgrade - Paterson St, Norah Head	4	4	3	1	1	3	3	3	3	4	3	1	33	32
39	Waterproofing - Toukley	3	4	2	1	1	3	3	3	3	2	1	3	29	41
40	Drainage Upgrade - Main Rd and Kelsey Rd, Noraville	4	4	3	1	1	3	3	3	3	4	3	4	36	18
41	Drainage Upgrade - Toukley	4	4	3	1	1	3	3	3	3	4	3	5	37	14
42	**Formalisation of flowpath to lake - Canton Beach**	5	5	2	4	4	3	5	5	3	2	4	5	47	1
43	**Embankment Construction - Budgewoi Rd, Noraville**	5	5	2	2	4	2	5	5	3	1	4	5	43	7

10.3 Options selected for preliminary modelling

Based on the assessment undertaken in the previous section, the preliminary flood damage assessment and discussion with Council, a number of options were short-listed to proceed to the preliminary modelling stage. The preliminary modelling consisted of modelling the 1% AEP flood event for each of the options and comparing the results. The 10 best options were then selected to proceed to the detailed design stage. The options short-listed for preliminary modelling included:

- *Option 1*: Culvert Upgrade under Greenacre Ave, Lake Munmorah. This upgrade would mitigate the water ponding north of Greenacre Ave and through Elizabeth Bay Dr, Mercator Cl and Mainsail Ct.
- *Option 2*: Formalisation of flowpath to lake along Canton Beach. The local dune is acting as a barrier and generating a significant ponding behind most of the beach. It appears that three locations can be modified in the vicinity of the beach to allow the ponding water to drain to the lake. This includes:
  a) Culvert construction along Belbowrie St
  b) Upgrading the culvert under Crossingham St and Beach Pde
  c) Culvert construction along Moss Ave and Yaralla Rd, Toukley, within a few hundred metres north-west of the beach.
- *Option 3*: Upgrades in the vicinity of Gascoigne Rd and Mary St, Gorokan. This area is subject to significant damages and management options should significantly reduce the local flooding by both allowing a better drainage of the flood water to the lake and reducing the amount of flood water reaching the low-lying area at the southern end of Gascoigne Rd. Potential options include:
  a) Upgrade of existing pathway to lake between the intersection of Lett St, Gascoigne Rd and Leichhardt Rd, and the lake.
  b) Upgrade of culvert under Lett St near the intersection with Gascoigne Rd with widening of local channel.
  c) Use of the park located between Gascoigne Rd and Mary St, Gorokan as a detention basin.
  d) Combination of the above.
- *Option 4*: Upgrade of channel at Woodland Parkway Reserve, Buff Point. The flood water is currently accumulating between Woodland Pkwy and Sonoma Rd. Upgrade of the channel would improve drainage of the flood water to the lake.
- *Option 5*: Upgrade of culvert under Panorama Ave near Wirriga Ave, Charmhaven. The flood water is currently accumulating upstream of Panorama Ave and upgrading the culvert under this road would provide a better drainage of the flood water to the lake and reduce the flood level along Wirriga Ave.
- *Option 6*: Embankment construction along Budgewoi Dr, Noraville. A number of properties located on the western side of Budgewoi Dr in Noraville are being impacted by rising

water in the bushland area west of the properties. Construction of an elevated embankment at this location would protect these properties from the rising water level at the back of the properties.

- *Option 7*: Upgrade in the area upstream of Cooranga Rd, Wyongah including:
  a) Culvert upgrade under Cooranga Rd, Wyongah. The limited capacity of the current culvert under Cooranga Rd is limiting the drainage of the flood water to the downstream bushland area. An upgraded culvert would reduce the flood levels between Cooranga Rd and Murrawal Rd.
  b) Diversion of flow to lake from Darri Road near Cottam Rd by construction a culvert to the lake via Stanley St and Tuggerawong Rd.
  c) Combination of the above.
- *Option 8*: Upgrade of Gorokan Park detention basin, Gorokan. Significant flooding occurs between Gorokan Park and Budgewoi Lake. Upgrading Gorokan Park detention basin would further reduce flood water from reaching the downstream properties and reduce the flood level downstream of the basin.

Another two options not requiring modelling were short-listed from the preliminary option assessment matrix and include:

- *Option 9*: Waterproofing of properties. A number of locations are located on steep and fully developed grounds where construction of upgraded drainage is not practical. Other areas are also too low-lying for any management options to generate significant improvements. Provision of waterproofing advice is therefore recommended at these locations. Examples of such areas include:
  - Flowpath between Ocean View Rd and The Corso, Gorokan.
  - Catchment upstream of Goorama Ave, San Remo.
  - Low-lying area between Buff Point Oval and Mandalong Point.
  - Flowpath along Delia Ave, Manoa Rd, Sunrise Ave and Natuna Ave, Budgewoi.
  - Small ponding area near Budgewoi shops, Budgewoi.
  - Flowpath along Lilo Ave, Halekulani
  - Flowpaths along Alister Ave, Queens Rd and Rosemount Ave, Lake Munmorah
  - Low-lying area at Villa Cl, Budgewoi
  - Flowpaths between Oleander St, Noraville and Harry Moore Oval, Toukley, and along Michele Ave, Noraville
- *Option 10*: Update of Development Control Plans and Flood Education to reduce the amount of development that can be at risk of flooding.

10.4 Preliminary modelling results

Following the short-listing of the preferred options in collaboration with Council, the 1% AEP flood event was run, and an afflux was calculated for each variation of each option 1 to 8 and are presented in **Appendix K**.

The following observation were made for each option:

- Option 1 – Greenacre Ave Culvert Upgrade, Lake Munmorah (**Figure K.1**): This preliminary run showed a significant reduction in flood level. However, it was completed prior to fixing the culverts' size. The bridge appears to still act as a control and adding a third barrel to the culvert appeared to be a good option to further investigate in the detailed modelling stage.
- Option 2 – Canton Beach Culvert Upgrade:
  - Option 2a - Belbowrie St Culvert (**Figure K.2**): Construction of a 2.4m by 1.2m culvert across the dune along Belbowrie St through to the lake would reduce the flood level by only about 0.02-0.05m during a 1% AEP event.
  - Option 2b - Crossingham St Culvert (**Figure K.3**): Upgrade of the culverts across and along Crossingham St, down to the lake would reduce the flood level by up to 0.10m during a 1% AEP event.
  - Option 2c – Moss Ave Culvert (**Figure K.4**): Construction of a culvert along Moss Ave and down to the lake, would reduce the flood level by up to 0.15m. While analysing this option in more detail, it was found that one of the existing pipes linking Moss Ave to the lake may have been misrepresented (a very short section was entered as 0.45m diameter instead of 0.9m) and fixing this pipe size reduced the level by about 0.05m. The 0.15m decrease in level is additional to this 0.05m decrease.
  - While Option 2a impact has a large extent, it only has a minor amplitude in comparison to Options 2b and 2c. Only Options 2b and 2c were therefore recommended for further analysis in the detailed modelling stage.
- Option 3 – Lett St, Gorokan:
  - Option 3a – Existing pathway upgrade from Lett St to lake (**Figure K.5**): Reducing this pathway would reduce the flood level by 0.10-0.15m over most of the flooded area located between the upstream park and Lett St.
  - Option 3b – Existing culvert upgrade under Lett St (**Figure K.6**): Upgrading the culvert would reduce the flood level by 0.05m over most of the flooded area located between the upstream park and Lett St. Once the culvert upgraded, it was found that the control of the flood level appeared to be the constriction of the channel downstream of the culvert and widening this channel is likely to provide further reduction in water level.
  - Option 3c – Construction of abutment to use park upstream of Lett St as detention basin (**Figure K.7**): Conversion of the park as a detention basin would not generate any significant reduction in flood level downstream and would generate a risk of worsening the flooding in the vicinity of the park. This option was therefore not recommended to be pursued for detailed analysis.
  - Option 3d – Pathway and culvert upgrade from Lett St to Lake (**Figure K.8**): This option would generate reduction in level similar to Option 3a with only a further 0.02m reduction. Once again, this could have been influenced by the constriction described as part of Option3b.

- The pathway option appears to be the most effective option with the culvert upgrade having potential to further reduce the level, particularly if the downstream channel is widened. Options 3a and 3d were therefore recommended for further analysis in the detailed modelling stage. The detention basin option was not recommended at this location.

- Option 4 – Channel clearing near Woodland Parkway Reserve, Budgewoi (**Figure K.9**): Removal of the constriction and clearing the outlet channel would provide significant reduction in flood level upstream of the channel (up to 0.5m). This option was recommended for further analysis in the detailed modelling stage.
- Option 5 – Upgrade of the culverts and widening of the downstream channel downstream of Wirriga Ave, Charmhaven (**Figure K.10**): This option only reduced the flood level by 0.02-0.05m upstream of Panorama Ave. Drainage between Wirriga Ave and the concrete channel along the avenue is impacted by a 0.3-0.4m high berm along the channel and the intersection of Tingira St with Wirriga Ave appeared higher than the rest of Wirriga Ave which also generated a control. Given the limited improvement, an additional option of reducing the level of the dirt road across the park downstream of Panorama Ave was modelled to check if this would provide any further improvement. However, it also had minor impact only. Option 5 was therefore not recommended for further analysis in the detailed modelling stage.
- Option 6 – Allowance of properties along Budgewoi Road, Noraville to build up to FPA level (**Figure K.11**): allowing properties to build up along the western side of Budgewoi Rd would generate significant afflux along the eastern side if no major drainage is put in place. This option was therefore not recommended for further analysis in the detailed modelling stage without any drainage work.
- Option 7 – Cooranga Rd, Wyongah
  - Option 7a – Culvert upgrade under Cooranga Rd (**Figure K.12**): Upgrading this culvert would provide reduction in flood level of about 0.05-0.10m upstream of the road.
  - Option 7b – Flow diversion to lake approx. 600m upstream of Cooranga Rd (**Figure K.13**): Construction of a flow diversion channel in the upper catchment leading to Cooranga Rd would reduce flow level by up to approx. 0.05 - 0.18m over 500m upstream of Cooranga Rd and some minor reduction in flood level (<0.05) were observed about 2km downstream of Cooranga Rd.
  - Option 7c – Option 7a + 7b (**Figure K.14**): This combination of the above options would reduce the flood level by approx. 0.15-0.18m over 500m upstream of Cooranga Road and with minor reduction in flood level observed about 1.7km downstream of the road.
  - Both the culvert and the flow diversion generate some reduction in flows and all three options were recommended for further investigation in the detailed modelling stage.
- Option 8 – Gorokan Park Detention Basin upgrade, Gorokan (**Figure K.15**): Upgrading the detention basin would reduce the flood level by 0.05-0.10m directly downstream of

the basin and by 0.02-0.05m further down the flowpath. It should be noted that a preliminary dam break analysis may be required for this basin, particularly if some work needs to be completed on the basin. This option was recommended for further analysis in the detailed modelling stage.

Based on the above observations and following discussion with Council the final short-list of options to be investigated as part of the detailed modelling include the 10 options listed below:

- Option 1 – Greenacre Ave Culvert upgrade to three barrels, Lake Munmorah
- Option 2b – Culvert upgrade at Crossingham St, Canton Beach
- Option 2c – Culvert upgrade at Moss Ave, Toukley
- Option 3a – Existing pathway regrading from Lett St, Gorokan to Tuggerah Lake
- Option 3d – Pathway regrading and culvert upgrade from Lett St to Lake
- Option 4 – Channel clearing near Woodland Parkway Reserve, Budgewoi
- Option 7a – Culvert upgrade under Cooranga Rd, Wyongah
- Option 7b – Flow diversion to lake approx. 600m upstream of Cooranga Rd
- Option 7c – Combination of Option 7a and 7b
- Option 8 – Gorokan Park detention basin upgrade

10.5 Introduction to detailed option assessment

Following approval from Council to proceed with the detailed modelling of the short-list of the ten (10) preferred options as described in **Section 10.4**. These options are named flood modification options. Each of the ten options was modelled for the 20% AEP, 5% AEP, 1% AEP and PMF to understand the overall impact of the option on the flooding behaviour during various type of events. This allowed the completion of updated flood damage assessment for each option. An indicative cost was then estimated for each option to compare with the potential savings in flood damages and an analysis of benefit-cost ratio (BCR) was completed. This analysis is described in **Section 11**.

Other types of management options include property modification options and response modification options and these types are described in **Section 12** and **Section 13** respectively.

11. Flood modification options

11.1 Introduction

Based upon the preliminary multi-criteria assessment described in **Section 10.2** and following Council approval on the short-list, flood modification options deemed to warrant further consideration are evaluated in this section. Particular focus is given to drainage upgrades and detention basins. An analysis of benefit-cost ratio (BCR) has been undertaken for a number of these options. The results are summarised in **Table 11.1** at the end of this section, together with an assessment of the benefits each option provides in terms of reduction of the incidence of above-floor flooding.

11.2 Detention Basins

Detentions basins, also known as detention storages or retarding basins, are areas of open space or ponds that collect and temporarily store floodwaters for release at a controlled rate. This results in reduced peak flow rates and levels downstream and typically more efficient utilisation of the existing trunk drainage network capacity. The options considered in this study are 'dry' basins which fill intermittently during floods and drain when the flood has passed.

Gorokan Park is currently acting as a detention basin and the potential to augment the existing detention basin was investigated as an option to alleviate flooding in the area downstream of the basin. It was found that deepening the basin by 1m over the entire surface of approximately 6,000m^2 and reducing the pipe capacity at the outlet (Option 8) would reduce the downstream flooding. A conceptual representation of this option is presented in **Figure 11.1**.

Reductions in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $577,000 were calculated.

The capital cost of this augmentation was estimated at approximately $2.95M.

This would result in a BCR of approximately 0.20.

Figure 11.1 – Option 8 conceptual layout

11.3 Drainage Upgrades

Opportunities to alleviate flooding problems by the upgrade of existing drainage systems or construction of new drainage systems have been investigated throughout the study area and are discussed below.

11.3.1 Culvert upgrade under Greenacre Avenue, Lake Munmorah

This option was investigated to alleviate flooding upstream of Greenacre Avenue, Lake Munmorah where several properties could potentially be affected by over floor flooding in events as frequent as the 20% AEP.

An existing drainage channel is flowing at the back of the properties on Elizabeth Bay Drive, leading to a 2 x 3600 mm x 1800 mm culvert that passes under Greenacre Avenue and then flows to the Lake. A large water level difference was observed between upstream and downstream of the culvert and it was suggested to construct a third cell on the western side at this location and widen the drainage channel accordingly around the culvert to reduce flooding.

A conceptual representation of this option is presented in **Figure 11.2**.

Cost of construction of an additional barrel to the existing culvert under Greenacre Avenue (Option 1) was estimated at $829,000.

Based on the modelling a reduction in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $630,000 would be expected which would result in a BCR of approximately 0.76.

Figure 11.2 – Option 1 conceptual layout

11.3.2 Culvert upgrade under Crossingham Street, Canton Beach

This option was investigated to alleviate flooding occurring at the back of Canton Beach where a large ponding area accumulates flood waters. Drainage network in this area is reaching capacity even during a 20% AEP flood event.

It consists of upgrading the drainage network along and across Crossingham Street in Canton Beach to a few 1800mm x 900mm culverts. Intakes to the culverts should be adjusted to soak in ponding areas located passed the elevated kerb at the corner of Crossingham Street and Victoria Avenue as well as along the southern side of Crossingham Street. A larger 2700mm x 1200mm culvert would then replace the current pipe network to carry the flow to the lake.

A conceptual representation of this option is presented in **Figure 11.3**.

Cost of construction of the drainage upgrade under Crossingham Street, Canton Beach (Option 2b) was estimated at $1.34M.

Based on the modelling a reduction in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $1.19M would be expected which would result in a BCR of approximately 0.89.

Figure 11.3 – Option 2b conceptual layout

11.3.3 Culvert construction along Moss Avenue and Yaralla Road, Toukley

Similar to the previous option, this option was investigated to alleviate flooding occurring at the back of Canton Beach where a large ponding area accumulates flood waters. Drainage network in this area is reaching capacity even during a 20% AEP flood event.

This option consists of constructing a new 2700mm x 1200mm culvert along Moss Avenue leading from the lowest point along the street to the lake via Yaralla Road.

A conceptual representation of this option is presented in **Figure 11.4**.

Cost of construction of the culvert along Moss Avenue and Yaralla Road, Toukley (Option 2c) was estimated at $1.50M.

While this option showed some reduction in level during the preliminary assessment of the 1% AEP, it was found that it only reduces the extent of the local flooding and over the road flooding during more frequent events and most of the properties within the flood extent of such frequent storms have high floor levels. This option only reduces the flooding for events like the 1% AEP or larger event. This significantly reduces the option's beneficial value.

Based on the modelling a reduction in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $19,000 would be expected which would result in a BCR of approximately 0.01.

Figure 11.4 – Option 2c conceptual layout

11.3.4 Drainage upgrade between Lett Street, Gorokan and Tuggerah Lake

The area near the intersection of Lett Street and Gascoigne Road is subject to significant ponding due to water being unable to drain to the lake via the existing culvert under Lett Street.

The first option (Option 3a) consists of regrading the existing pathway between the intersection of the two roads and the lake. This 4-metre wide pathway would allow ponding water to flow down to the lake more efficiently by providing a low path for the flood water.

The second option (Option 3d) consists of upgrading the culvert under Lett Street to a 2 x 3200mm x 1200mm culvert and widening of the downstream channel in addition to the pathway regrading. The widening will be limited due to the existing developed properties on either side of the channel.

A conceptual representation of these two options is presented in **Figure 11.5**.

Cost of regrading the pathway between Lett Street and the lake at Gorokan (Option 3a) was estimated at $549,000.

Based on the modelling a reduction in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $1.25M would be expected which would result in a BCR of approximately 2.29.

Including the upgrade of the culvert under Lett Street to the pathway upgrade (Option 3d) would increase the cost to $1.09M and further reduce the flood damages to an approximate reduction of $1.61M. This would result in a BCR of approximately 1.48.

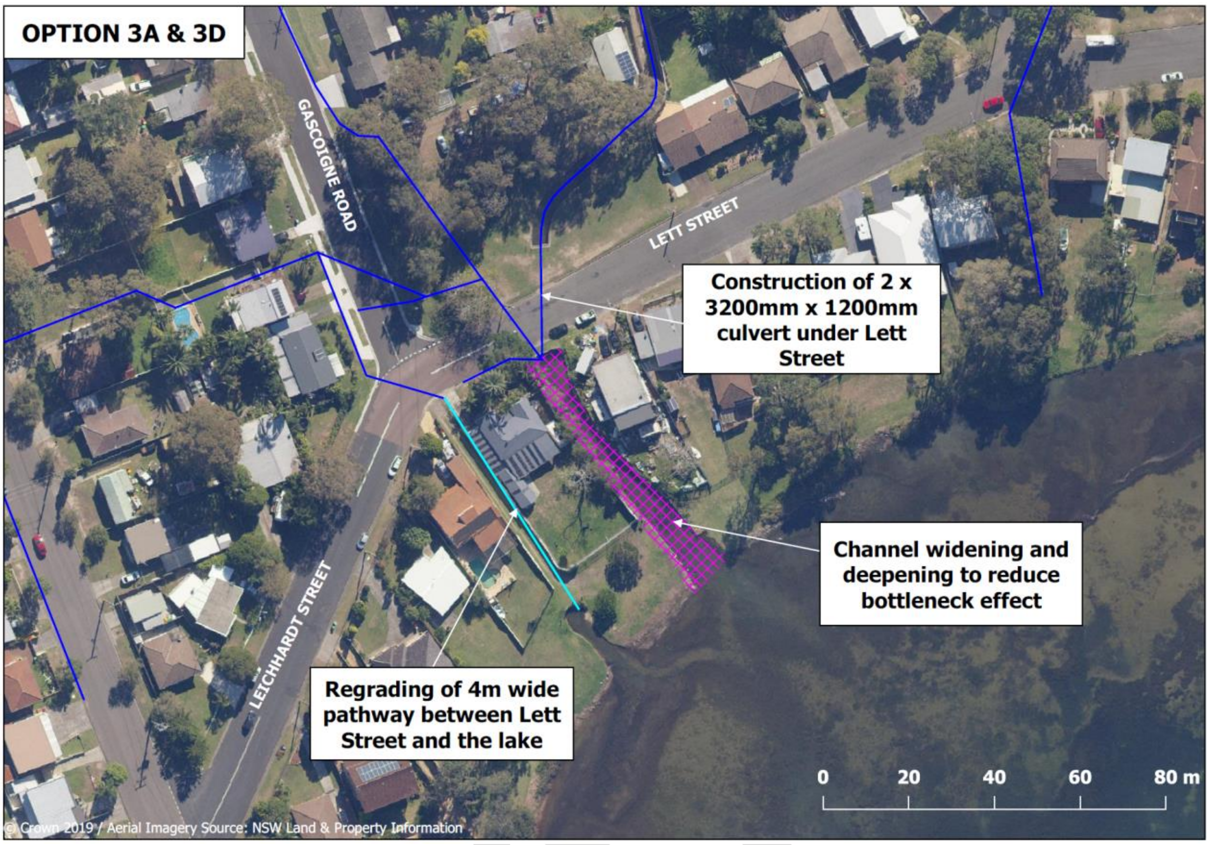

Figure 11.5 – Option 3a and 3d conceptual layout

11.3.5 Entrance channel excavation at Woodland Parkway Reserve, Budgewoi

The floodwater is currently accumulating at the back of Woodland Parkway due to reduced flow capacity within the channel located along the Woodland Parkway Reserve. Clearing the entrance by excavating the channel to a level of approximately 0.15m AHD to allow a clear passage for flood water would reduce accumulation of water at this location.

A conceptual representation of this option is presented in **Figure 11.6**.

Cost of excavating the entrance channel along Woodland Parkway Reserve, Budgewoi (Option 4) was estimated at $642,000.

Based on the modelling a reduction in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $1.03M would be expected which would result in a BCR of approximately 1.60.

Figure 11.6 – Option 4 conceptual layout

11.3.6 Drainage upgrade under and upstream of Cooranga Road

A number of properties are impacted by flooding upstream of Cooranga Road. This is due to the limited capacity of the culvert under Cooranga Road as well as the upstream catchment flood water leading to this location. Therefore, two methods were analysed. The first method consists of upgrading the culvert under Cooranga Road to a 2 x 4500mm x 1500mm to improve flood water drainage. A conceptual representation of this first method (Option 7a) is presented in **Figure 11.7**.

The second method consists of constructing a large 3200mm x 1200mm culvert diversion between Darri Road and the lake via Stanley Street and Tuggerawong Road to capture some of the flow from the upper catchment and reduce the volume of water flowing downstream. A conceptual representation of this option is presented in **Figure 11.8**.

Cost of upgrading the culvert under Cooranga Road (Option 7a) was estimated at $688,000.

Based on the modelling a reduction in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $91,000 would be expected which would result in a BCR of approximately 0.13.

Figure 11.7 – Option 7a conceptual layout

Figure 11.8 – Option 7b conceptual layout

Cost of the high flow diversion between Darri Road and the lake (Option 7b) was estimated at $6.10M. It is noted that, given the depth of excavation, excavated material was assumed as half soil, half rock and cost may vary should the excavation be in rock or soil only. Deep excavation as such may also be subject to additional complexities in construction.

Based on the modelling a reduction in the net present value of flood damages (at 7% discount rate over 50 years) of approximately $337,000, would be expected which would result in a BCR of approximately 0.06.

Combining these two options (Option 7c) would have a total cost of $6.79M and would reduce the net present value of flood damages by $404,000. This would represent a BCR of 0.06.

11.4 Summary

An analysis of benefit-cost ratio (BCR) has been undertaken for a number of flood modification options that were deemed to warrant further investigation based upon the preliminary multi-criteria assessment in **Section 10**.

The results are summarised in **Table 11.1**. The modification options at Lett Street in Gorokan (Options 3a and 3d) and Woodland Parkway Reserve in Budgewoi (Option 4) show strong economic merit with BCR larger than 1. The proposed options at Greenacre Avenue in Lake Munmorah (Option 1) and Crossingham Street in Canton Beach (Option 2b) show moderate economic merit with a BCR of 0.76 and 0.89 respectively. Flood modification at Moss Avenue (Option 2c), Cooranga Road (Option 7a, 7b and 7c) and Gorokan Park (Option 8) show poor economic merit with BCR of less than 0.2.

11.5 Recommendations

The most beneficial flood modification options that may warrant inclusion in the Northern Lakes Floodplain Risk Management Plan are the regrading of the pathway (with or without culvert upgrade) in Lett Street, Gorokan, excavation of the channel at Woodland Parkway Reserve, upgrade of the culvert under Greenacre Avenue, Lake Munmorah, and upgrade of the drainage system under Crossingham Street, Canton Beach. These options demonstrate a level of flood benefit and economic merit through the reduction of flood damages with BCRs between 0.76 and 2.29.

Further investigations of environmental impacts are recommended for the Woodland Parkway Reserve excavation work and further community acceptance investigation is recommended for the pathway upgrade at Lett Street.

If adopted, the detailed designs should look to minimise environmental impact and maintain or improve public amenity for the various options.

Table 11.1 – Flood modification options BCR assessment & premises protected

	Base Case	Option 1 Greenacre Ave, Lake Munmorah culvert upgrade	Option 2b Crossingham St, Canton Beach culvert upgrade	Option 2c Moss Ave, Toukley culvert upgrade	Option 3a Pathway upgrade between Lett St, Gorokan and Tuggerah Lake	Option 3d Pathway and culvert upgrade between Lett St, Gorokan and Tuggerah Lake	Option 4 Woodland Parkway Reserve entrance excavation	Option 7a Culvert upgrade under Cooranga Rd, Wyongah	Option 7b Flow diversion 600m upstream of Cooranga Rd	Option 7c Combination of Options 7a and 7b	Option 8 Gorokan Park Detention Basin
Residential											
Reduction in no. houses flooded over floor in PMF	*1409**	1	2	0	2	3	1	0	7	7	2
Reduction in no. houses flooded over floor in 1% AEP	*278**	0	5	1	6	9	5	1	2	4	0
Reduction in no. houses flooded over floor in 5% AEP	*176**	0	3	0	3	4	3	1	2	2	1
Reduction in no. houses flooded over floor in 20% AEP	*103**	1	2	0	1	1	2	0	0	0	2
Residential AAD	$3,720K	$3,691K	$3,665K	$3,720K	$3,662K	$3,646K	$3,673K	$3,716K	$3,705K	$3,702K	$3,694K
Residential NPV (7%, 50y)	$55,065K	$54,630K	$54,245K	$55,052K	$54,199K	$53,958K	$54,356K	$55,002K	$54,833K	$54,786K	$54,667K
Direct Res Benefits (reduced NPV of flood damages)	-	$630K	$820K	$13K	$865K	$1,107K	$709K	$63K	$232K	$279K	$398K
Non-residential											
Reduction in no. premises flooded over floor in PMF	*34**	0	0	0	0	0	0	0	0	0	0
Reduction in no. premises flooded over floor in 1% AEP	*17**	0	0	0	0	0	0	0	0	0	0
Reduction in no. premises flooded over floor in 5% AEP	*12**	0	0	0	0	0	0	0	0	0	0
Reduction in no. premises flooded over floor in 20% AEP	*7**	0	0	0	0	0	0	0	0	0	0
Non-residential AAD	$809K	$809K	$809K	$809K	$809K	$809K	$809K	$809K	$809K	$809K	$809K
Non-residential NPV (7%, 50y)	$11,978K	$11,978K	$11,977K	$11,978K	$11,978K	$11,978K	$11,978K	$11,978K	$11,978K	$11,978K	$11,978K
Direct Non-res Benefits (reduced NPV of flood damages)	-	$0	$1K	$0K	$0	$0	$0	$0K	$0	$0K	$0
Total (including direct residential and non-residential, indirect residential and non-residential, infrastructure and social)											
Total AAD	$6,932K	$6,890K	$6,852K	$6,931K	$6,847K	$6,824K	$6,863K	$6,926K	$6,909K	$6,905K	$6,893K
Total NPV (7%, 50y)	$102,601K	$101,971K	$101,411K	$102,582K	$101,347K	$100,996K	$101,574K	$102,510K	$102,265K	$102,197K	$102,024K
Total benefits (reduced NPV of flood damages)	-	$630K	$1,191K	$19K	$1,255K	$1,605K	$1,027K	$91K	$337K	$404K	$577K
Estimated Capital Cost	-	$829K	$1,344K	$1,499K	$549K	$1,085K	$642K	$688K	$6,098K	$6,786K	$2,948K
Benefit-cost ratio	-	**0.76**	**0.89**	**0.01**	**2.29**	**1.48**	**1.60**	**0.13**	**0.06**	**0.06**	**0.20**

**Total number of houses/premises flooded over floor for base case*

12. Property modification options

Property modification measures involve modifying or removing existing properties from flood affected areas and imposing controls on future property and infrastructure development. These are aimed at steering inappropriate development away from areas with a high potential for damage and ensuring that potential damage to developments likely to be affected by flooding is limited to acceptable levels by means of minimum floor levels, flood proofing requirements, etc.

12.1 Voluntary House Purchase (VP)

For existing properties which face a high flood hazard and where no significant reduction of the hazard is practicable, the physical removal of the building from the property, or its demolition, may be the only alternative. Voluntary house purchase (often referred to as 'VP') is an expensive option generally reserved for sites where the risk to life is unacceptable.

Consideration has been given to the eligibility and practicality of VP in the Northern Lakes study area.

DPIE has prepared *Guidelines for Voluntary Purchase Schemes* (OEH, 2013a). This describes the eligibility criteria for NSW Government funding for VP schemes, which include:

- no other feasible flood risk management options are available to address the risk to life at the property;
- residential properties and not commercial and industrial properties;
- buildings were approved and constructed prior to 1986;
- properties are located either 1) within high hazard areas where there is a significant risk to life for occupants and those who may have to evacuate or rescue them, 2) within a floodway where the removal of the house may be part of a floodway clearance program aimed to reduce the significant impacts caused by the existing development on flood behaviour elsewhere in the floodplain, or 3) within the footprint of a proposed flood mitigation measure or where a flood mitigation measure may result in a significant increase in flood risk to a house that cannot be protected.

Inclusion of a property in a council's VP scheme places no obligation on the owner to sell the property or on the council or NSW Government to fund the purchase of the property. Owner participation in the scheme is voluntary and there are limitations on the availability of funding.

Considering the eligibility of residential properties within the study area, there are about 20 houses that significantly intersect the 1% AEP high hazard category, including Gascoigne Road and Marks Road in Gorokan, Dudley Street in Lake Haven, Buff Point Avenue in Buff Point, Elizabeth Bay Drive in Lake Munmorah and the area between Belbowrie Street and Kantara Road in Canton Beach.

In general, depths of above floor inundation in the study area are relatively shallow, which suggests that the risk to life is not excessive and might be more cost effectively managed through redevelopment or flood proofing than VP. For example, for the 1% AEP event, only 16 dwellings are estimated to be flooded above floor by more than 0.5m (and up to 1.05m) at the locations listed above. Seven of these properties are flooded by more than 0.5m during a 20% AEP flood event on Gascoigne Road, Marks Road and Buff Point Avenue. These seven properties may be potentially put forward for Voluntary Purchase.

No property is located within the floodway of the 1% AEP flood event.

Regarding the basis of being within the footprint of a proposed mitigation measure, one additional property along Lett Street could be eligible as an alternative to the pathway upgrade as removing the property next to the channel is likely to significantly improve the drainage of the local area and significantly reduce flood levels north of Lett Street.

The impracticality of a State-funded VP scheme in the Northern Lakes study area is underlined by the median house prices in **Table 12.1**. These median prices show that VP is highly unlikely to be economically viable.

Table 12.1 – Median house prices in study area

Source: realestate.com.au, updated 5/02/2020

Suburb	Median house price	Suburb	Median house price
Budgewoi	$466,000	Lake Munmorah	$500,000
Buff Point	$483,000	Norah Head	$870,000
Canton Beach	$525,000	Noraville	$536,000
Charmhaven	$472,500	San Remo	$436,000
Gorokan	$446,000	Toukley	$511,500
Halekulani	$473,750	Wadalba	$600,000
Kanwal	$475,000	Wyongah	$485,000
Lake Haven	$517,500		

12.2 Voluntary House Raising (VHR) or Redevelopment

Raising houses with low-set floor levels has proved to be an effective floodplain management measure for various locations throughout NSW.

Advantages of house raising include:

- reducing tangible flood damages and alleviating anxiety about future floods;
- providing under-house space for non-habitable uses such as garages and laundries; and
- an enhanced resale values.

Disadvantages of house raising include:

- an altered streetscape unless all the houses in an area are raised;
- difficult access for some people (e.g. elderly, people with a disability); and
- people living in raised houses are often less likely to evacuate, which can exacerbate risk to life in rare floods that overtop the raised floor or when people panic with water below the house.

Various forms of house raising schemes can be considered. The easiest form of house raising occurs where houses are of either timber or fibro construction. Fairfield Council's experience in Prospect Creek has shown that such houses can be raised by 1-2m for a cost of about $80K.

Physically raising houses of brick veneer or full brick construction is more costly, and in most cases impractical. Fairfield Council developed a scheme for such 'difficult' houses whereby a limited subsidy was available to homeowners to demolish and rebuild a new house with appropriate building controls in accordance with the flood risk management provisions in the DCP (Frost & Rice, 2003).

DPIE has prepared *Guidelines for Voluntary House Raising (VHR) Schemes* (OEH, 2013). This describes the eligibility criteria for NSW Government funding of VHR schemes including:

- not located in floodways;
- limited to areas of low flood hazard;[1]
- the suitability of individual houses for raising;[2]
- residential properties and not commercial and industrial properties;
- buildings were approved and constructed prior to 1986;
- properties cannot be benefiting substantially from other floodplain mitigation measures;
- VHR should generally return a positive net benefit in damage reduction relative to its cost (benefit–cost ratio greater than 1).

Inclusion of a house in a VHR scheme as part of a FRMP adopted by the council places no obligation on the owner of the property to raise the house or on the council or NSW Government to fund the raising. Owner participation in the scheme is voluntary and there are limitations on the availability of funding.

Consideration has been given to a potential VHR scheme for the Northern Lakes study area. The following points are noted:

- Assessment is made difficult by a lack of certainty over floor levels (many were estimated), the suitability of houses (some could not be seen via Street View) and the age of houses, which is one of the criteria for eligibility. Houses for which floor heights have not been viewed have been excluded from the preliminary assessment described here. If it is decided to pursue a VHR scheme, detailed survey will be required to capture this information.
- Houses in floodways or regions of high hazard are not regarded as sufficient reason to disqualify their inclusion in this assessment. Modelling for the Northern Lakes study area depicts many overland flowpaths, which often convey relatively modest flows and for which design options may be available to provide conveyance around or under buildings. A building located in a floodway or region of high hazard does not necessarily mean that the structural integrity of a raised building would be threatened, or that people would be trapped.
- Properties with other management options or recommended for the VP have not been included in this assessment.
- The generally shallow depths of flooding and low flood height range associated with overland flow inundation suggest that for many houses the flood risk might be more efficiently addressed through flood proofing techniques.

A sample assessment was done using a threshold of more than 0.1m of water above floor in

[1] The Guideline does not stipulate the design event upon which hazard is based, but presumably 1% AEP is intended.
[2] The Guideline does not explicitly discuss the possibility of funding 'knock down and rebuild', but Fairfield's experience suggests that this variant of VHR may be eligible for State funding.

the 20% AEP event, since damage to property is closely aligned with frequency of above floor inundation. The list of known candidates for inclusion in a VHR and/or flood-proofing scheme is shown in **Table 12.2**. A total of 43 properties were highlighted but 38 of them are either slab on ground and/or brick and/or two-storey, so none of those are suitable for house raising, but could be knocked down and rebuilt to flood compatible standards. Five of them are fibro and high set and may be raised. For the 38 others, flood proofing techniques could be applied to either prevent the ingress of water into a dwelling ('dry' flood proofing) or so as to minimise damage to the structure and fittings of a dwelling when flooded ('wet' flood proofing). However, a redevelopment scheme is unlikely to be supported by Council funding.

The analysis therefore focused on the five properties able to be raised and it was found that the house-raising works would yield benefits (reductions in net present value of damage over 50 years with a 7% discount) of over $1.81M.

If house raising can be achieved for $200K/house, the costs would be about $1.0M, yielding a benefit-cost ratio (BCR) of approximately 1.81.

The precise works would need to be investigated and tailored to each location and dwelling structure. Also, since participation in VHR schemes is by definition voluntary, the views of the owners would need to be canvassed. This preliminary analysis suggests that options are available and, if able to be funded, would provide economic benefits in terms of reduced flood damages. It is recommended that Council undertake an LGA-wide scoping study including floor level survey and consultation to understand where such voluntary house-raising scheme may be applicable.

Recommendation

Prepare an LGA-wide scoping study including floor level survey, consultation and site inspections to further assess the feasibility of establishing a small voluntary house raising proofing scheme (Council).

Table 12.2 – List of potential candidates for VHR

Street	Suburb	Construction Type (slab on ground/High Set)	Number of storeys	Wall type (Timber/Brick/Concrete)	Depth of Inundation above Floor Level (m)			
					PMF	1.00%	5.00%	20.00%
Crossingham St	Canton Beach	High Set	1	Fibro	0.55	0.23	0.19	0.14
Nicholson Cres	Toukley	High Set	1	Fibro	0.57	0.39	0.37	0.34
Conden Pl	Canton Beach	High Set	1	Fibro	0.97	0.41	0.29	0.16
Suncrest Pde	Gorokan	High Set	1	Fibro	0.54	0.21	0.19	0.15
Manoa Rd	Halekulani	High Set	1	Fibro	0.47	0.29	0.27	0.25

12.3 Flood-proofing

Individual properties can be modified to reduce the impacts of flooding through flood-aware design. Particularly for the relatively shallow depths of inundation observed in most floods in the Northern Lakes study area, flood proofing measures may substantially reduce damages to building structures and fittings. A book called *Reducing Vulnerability of Buildings to Flood Damage* (HNFMSC, 2006) details the many ways buildings and components can be designed to minimise the impact of flooding.

While the guidelines may help reduce flood damages for future dwellings, there may also be opportunity for owners of existing houses to flood proof their dwellings to some extent. Fairfield City Council provided subsidies of up to $20K for double-brick or two storey houses (i.e. houses unable to be raised) to assist in flood proofing the lower ground floor by raising electrical power points, installing a water sensor device to shut off power, replacing building materials liable to flood damage, and constructing local flood walls so long as adjoining properties were not adversely affected (Frost & Rice, 2003). It is, however, doubtful that a similar scheme across the LGA would be financially viable for Central Coast Council. But this preliminary analysis suggests that options are available and, if able to be funded, would provide significant economic benefits in terms of reduced flood damages. It is recommended that Council undertake an LGA-wide scoping study to investigate this option further.

Recommendations

The following actions are recommended:

- Prepare flood-proofing guidelines for residents and businesses
- Prepare a one-page, graphic summary of the Guidelines
- Recognise the cost-effectiveness of flood proofing techniques and further investigate specific design options through a proposed LGA-wide scoping study

12.4 Advice on land-use planning

12.4.1 Zoning suitability

A map of current zoning in the study area is provided in **Figure 12.1**. An assessment was undertaken to establish what proportion of land located within the FPA and the PMF extent was given over to various land use zones.

The results are presented in **Figure 12.2**.

The various zoning categories present within the study area include:

- Business
  - B1: Neighbourhood centre
  - B2: Local centre
  - B4: Mixed use
- Environment protection
  - E1: National parks and nature reserves

- E2: Environmental conservation
- E3: Environmental management
- E4: Environmental living

- Industrial
  - IN2: Light industrial
- Residential
  - R1: General residential
  - R2: Low density residential
  - R3: Medium density residential
- Recreation
  - RE1: Public recreation
  - RE2: Private recreation
- Rural
  - RU6: Transition
- Special conditions
  - SP2: Infrastructure
  - SP3: Tourist
- Waterways
  - W1: Natural Waterways
  - W2: Recreational Waterways

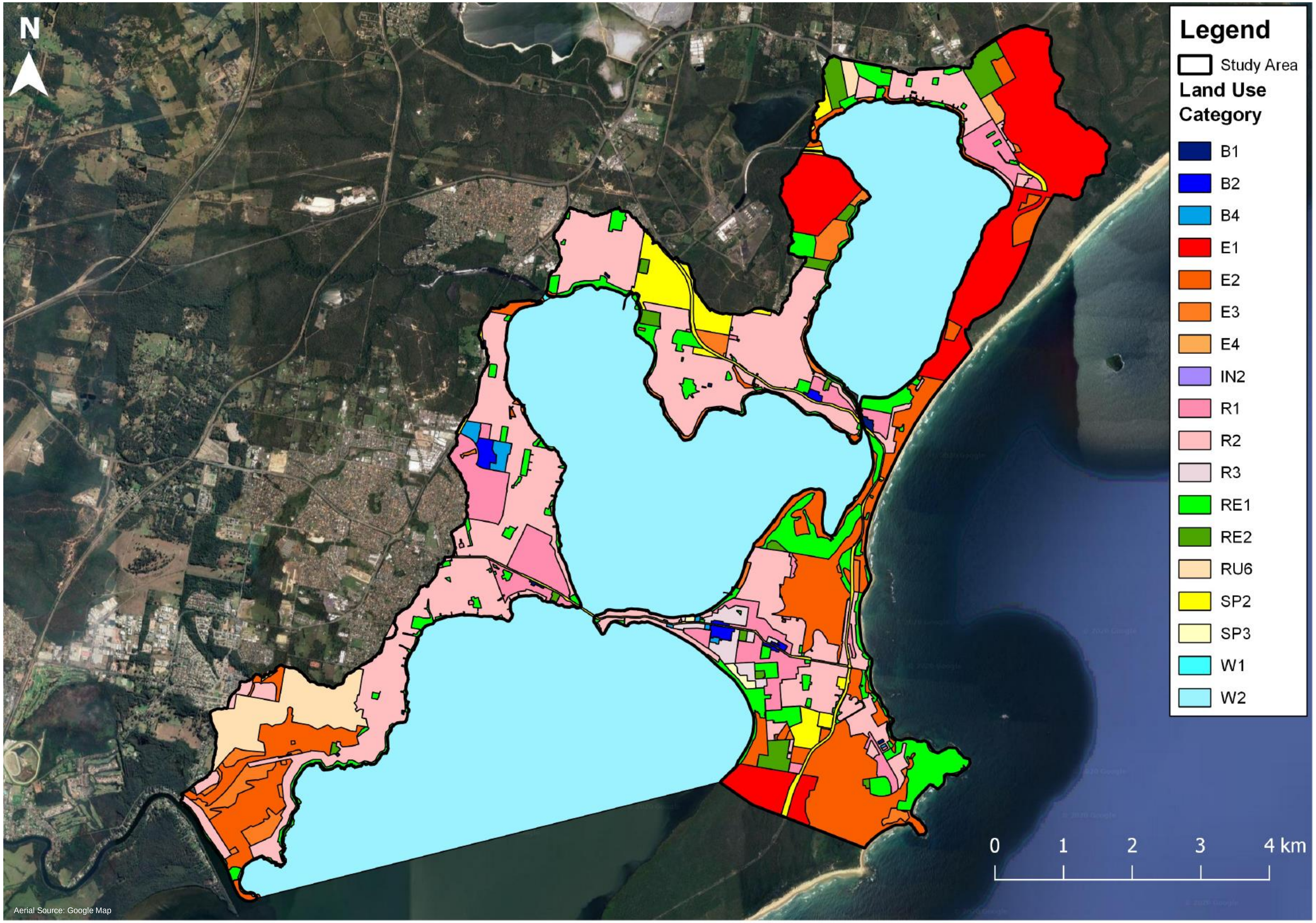

Figure 12.1 – Land Use Map

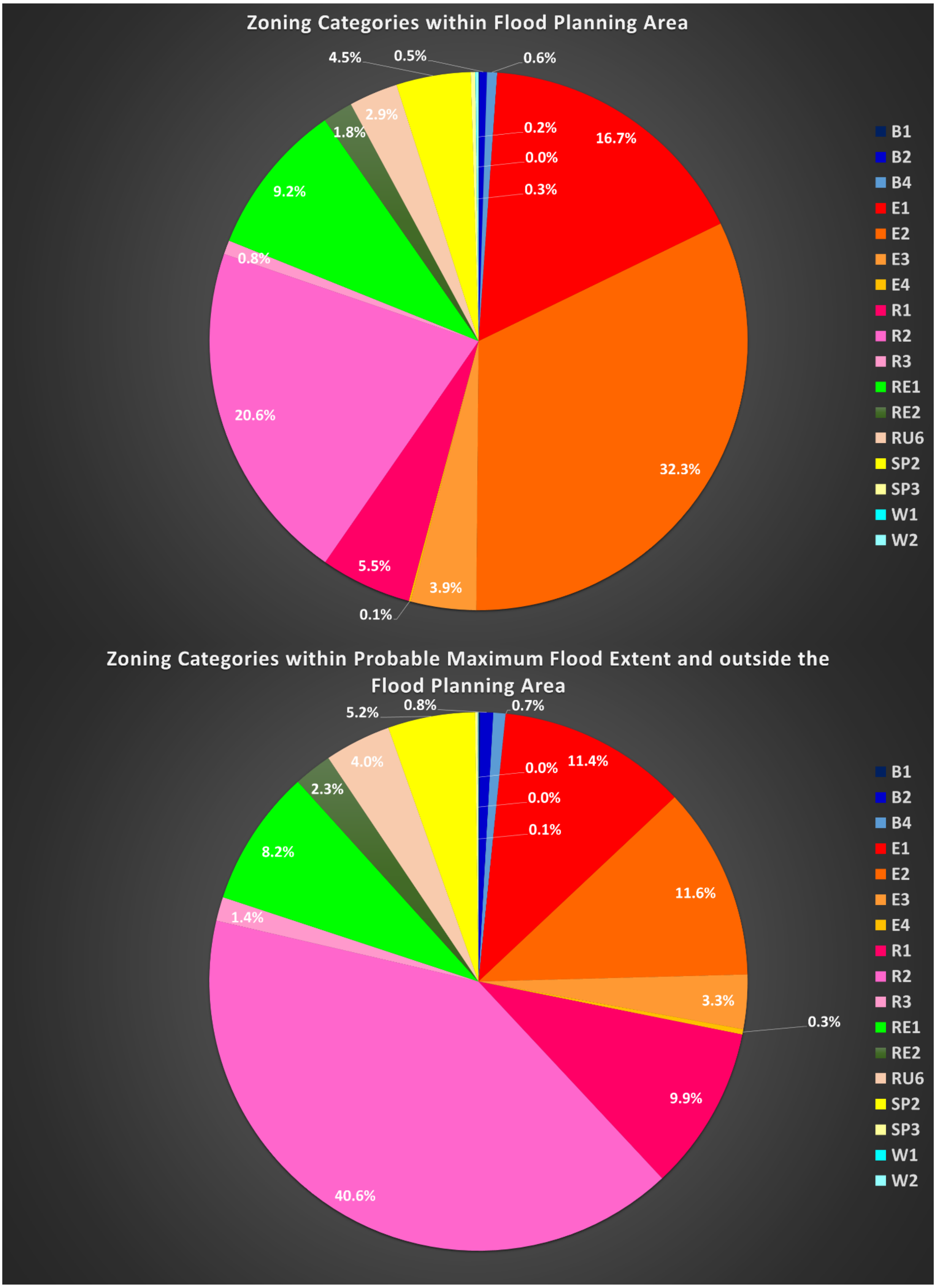

Figure 12.2 – Land use zoning within PMF and FPA

About 53% of land within the flood planning area is zoned for Environment Conservation (E1-3) and 11% is recreational (RE1-2). This is fitting for land where there are flood risks. About 27% of land within the FPA is zoned as Residential (R1-3) or Environmental Living (E4). But a reasonable proportion of the latter appears to occur on roadways rather than on private property.

When looking at the zoning outside of the FPA but within the PMF extent, the proportion of environmental uses and residential uses switches with about 26% of zoning E1 to E3 and 52% of Zoning R1 to R3 and E4. The recreational proportion remains unchanged at approximately 11%. This area is subject to lower flood risks.

This trend of an increasing proportion of land zoned for environmental conservation and recreational uses with increasing flood hazard suggests that *broadly* the LEP zonings are appropriate to the flood risk. But on a smaller scale, some residential properties are located within the higher risk areas as can be observed from the flood hazard and hydraulic categories maps in **Appendix D**.

Ideally residential areas within the high flood risk precinct (or within H5-H6 Flood Life Hazard categories) could be gradually converted to environmental conservation or recreational uses.

12.4.2 General land use considerations

A key objective of the study is to provide better flood information to support land use planning activities in the study area.

Use of the latest hydraulic categories and hazard information would allow a more informed decision on potential land uses based on existing constraints.

Two main types of flooding occur within the Northern Lakes catchment: overland flooding and lake flooding. This study focuses on the overland flooding while the lake flooding was covered in the Tuggerah Lakes FRMSP.

It has become more common to vary the freeboard to be used to define the floor planning level based on the type of flooding and the type of land use. Potential land use type that could have different freeboard may include:

- Critical and Vulnerable Uses: such land use may require stricter freeboard or planning restriction
- Subdivision and all Residential Uses: this type of use can use the more typical freeboard values with potentially slightly lower freeboard values for overland flooding when compared to lake flooding.
- Business and Industrial Uses: type of commercial land use should be considered. For example, driveways, loading docks and other equivalent trafficked areas may not require strict freeboard restriction.
- Recreational and Environmental Uses: Reduced freeboard may be applied to such uses (e.g. parks, ovals)
- Concessional Uses: Such land use type may be treated separately should the certain properties require specific freeboard due to special use requiring more or less protection.

Climate change should also be taken into consideration when planning the land use. It is noted that the areas subject to overland flooding may be impacted by slightly elevated levels due to increase in rainfall intensities while properties subject of the lagoon flooding may be more impacted by rising sea level.

The current Wyong DPC requires negligible flood affectation elsewhere in the floodplain for a full range of flood events up to the PMF. Council may consider having less stringent controls outside the FPA as in this area, floodplain management typically focuses on risk to life rather than property damage. A potential criterion may be requiring an afflux of less than 10 mm of flood affectation elsewhere in the floodplain for:

- Critical and vulnerable uses for flood events up to the PMF flood event;
- Other land uses for flood events up to the 1% AEP flood event;
- Emergency management for flood events up to the PMF flood event as discussed in Chapter 5 and Sections 7.2 and 7.5 of Chapter 7 of *Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIDR, 2017)*.

12.4.3 Location specific development provisions

Location specific development provisions (LSDPs) were reviewed to determine any potential impacts on such provisions. LSDPs located within the study area include:

1. Old Service Station Site and Adjoining Carpark, Toukley (Chapter 6.1 of DCP)
2. Toukley Caravan Park, Toukley (Chapter 6.1 of DCP)
3. Waterfront Tourist Park, Canton Beach (Chapter 6.1 of DCP)
4. Lakedge Caravan Park, Canton Beach (Chapter 6.1 of DCP)
5. Rumstrum site (Chapter 6.1 and 6.26 of DCP)
6. Toukley RSL, Toukley (Chapter 6.1 of DCP)
7. Lake Haven Bulky Goods, Lake Haven (Chapter 6.1 of DCP)
8. Buff Point Residential (Chapter 6.6 of DCP)
9. Beachcomber Key site, Toukley (Chapter 6.27 of DCP)

Out of the above locations, sites 1 and 2 are mainly subject to flooding during a PMF event with minor ponding in lower events. Sites 3 and 7 have small ponding occurring from 20% AEP event and deepening with increasing events. Sites 5, 6 and 9 and minor flooding even during a PMF event. Sites 4 and 8 are subject to significant flooding from a 20% AEP event.

12.5 General property modification considerations

Other property modifications that should be considered to minimise impact on overland flow paths include:

- The use of pervious and permeable fencing is recommended across flowpath to allow flood water to flow through the fence and prevent local ponding or flood water diversion.
- Allowing conveyance under buildings in the floodplain by constructing dwelling on piers or allowing conveyance around buildings by strategically placing fill.

13. Response Modification Options

Response modification measures aim to reduce risks to life and property in the event of flooding through improvements to flood prediction and warning, through improvements to emergency management capabilities and planning, and through better flood-educated communities.

13.1 Flood Warning Systems

13.1.1 General

Flood warning systems aim to provide advice on impending flooding so people can take action to minimise its negative impacts. Where effective flood warnings are provided, risk to life and property can be significantly reduced. Studies have shown that flood warning systems generally have high BCRs if sufficient warning time is provided and if the population at risk is aware of the threat and prepared to respond appropriately.

Due to the small local catchments size and steep terrain, inundation in the Northern Lakes study area is typically ‘flash flooding’, occurring within minutes of heavy rain.

For flash flood catchments like these, the provision of an effective flood warning service is problematic. The ‘total flood warning system’ has five components that need to be completed during a flood emergency – prediction, interpretation, message construction, communication and appropriate response (Commonwealth of Australia, 2009). But several challenges to the effective operation of such a system have been identified for flash flood catchments (McKay, 2004, 2008):

- Flash floods are less predictable than larger scale flooding. Rainfall over small catchments is usually not well predicted by numerical weather prediction models.
- For flash floods, there is insufficient time to develop reliable flood warnings and for effective dissemination and response to the flood warnings. More rapid user response is required, which necessitates specialised communication systems and a high level of public flood awareness.
- A reliance on rainfall triggers increases the frequency of false alarms.
- The use of water level triggers does not allow sufficient time for response.

For these reasons, the Bureau of Meteorology traditionally has not issued specific flood predictions for flash flood catchments. The Bureau does offer more general services that may be of some benefit in alerting the emergency services and community to the threat of flooding (**Table 13.1**).

Table 13.1 – Bureau of Meteorology warning services of potential benefit in flash flood catchments

Sources: McKay, 2004, p.3; www.bom.gov.au

General Weather forecast General weather forecasts may indicate the likelihood of heavy rain from synoptic scale events, typically with more than 24 hours' notice. *Flood Watch* A Flood Watch is issued by the NSW Flood Warning Centre, typically providing 24 to 48 hours' notice that flooding is *possible* based upon current catchment conditions and future rainfall, which is predicted by computer models of the atmosphere. *Severe Weather Warning* A Severe Weather Warning is issued for synoptic scale events when one or more of the following hazardous phenomena are forecast: • Gale force winds (average 10-minute wind speed exceeding 62 km/hr) • Damaging winds (peak wind gusts exceeding 89 km/hr) • Destructive winds (peak wind gusts exceeding 124 km/hr) • Torrential rain and/or flash flooding • Damaging surf conditions leading to significant beach erosion *Severe Thunderstorm Warning* A Severe Thunderstorm Warning is issued by the Severe Weather Team, typically providing 0.5 to 2 hours' notice of impending severe storms. These forecasts are based upon radar and, if available, data from field stations, reports from storm spotters, as well as an analysis of the synoptic situation. For the Greater Sydney region, the Bureau issues more detailed graphical Severe Thunderstorm Warnings when actual thunderstorms have been detected.

13.1.2 Evaluation

Consideration has been given to the need and practicality of enhancing the flood warning system in the Northern Lakes study area.

In terms of the need, there are a few areas within the floodplain where, given the current style of houses, evacuation off site would be of high priority for saving lives. Some examples include Gascoigne Road in Gorokan during moderate to large floods and in Buff Point during extreme floods. Other areas may also require evacuation to a higher storey, which may not be straightforward given the lack of internal access and vulnerable populations. These exposures could benefit from enhanced flood warnings to reduce the risk to life. Business proprietors could also benefit from enhanced warnings that provide time to raise stock.

But oftentimes the safest course of action in a flood will be for people to shelter in place and to avoid entering floodwaters. One of the risks of providing flood warnings for commercial districts could be for patrons to rush outside when an alarm is sounded in attempt to relocate their vehicles from low-lying carparks or to reach their homes. If the carparks and local roads have begun to flood, a warning without appropriate interpretation could lead to unsafe behaviours and actually increase the risk to life.

In terms of the practicality, it is clear from the critical duration of storms that available warning times are very short. The rate of rise in a PMF would be faster still, allowing negligible time to respond. As recognised by the Bureau of Meteorology, relying on rainfall triggers will lead to a higher proportion of false alarms, which may over time erode confidence in the warning system causing people to disregard future alerts. But relying on water level recorders would reduce the time available to respond to just a few minutes. Maintaining a water level recorder in a channel or depression that is dry most of the time is also technically demanding. Selecting a secure location for a water level recorder could also be difficult.

Recommendations

Considering the existing warning infrastructure and marginal opportunities to improve the flood warning system in a way that enhances protective behaviours, the following measures are recommended:

- Alarm the Toukley rain gauge so that it issues email/SMS when rain triggers are reached. This is justified on the basis of the significant flood risks in extreme events in Buff Point;
- Consider installing a new real-time rain gauge in the vicinity of Lake Munmorah/Freemans, to provide more comprehensive coverage of the north-eastern end of the catchment. This area is located approximately 10km from the nearest rain gauge at Toukley. This is recommended due to the high spatial variability of rainfall in the catchment.
- Transition towards a system where people living or working in the floodplain can stay informed via a web portal that allows access to data. This is justified because every additional chain in a flood warning dissemination system (even having NSW SES personnel interpret or 'add value to' the rain gauge information) tends to delay the process when for flash flood situations time is invariably short.
- Devise appropriate messages to accompany the rainfall alerts, making clear to users that rainfall is a 'heads up' of possible flooding and that residents/proprietors should not drive/ride/walk through floodwater.
- Although outside of the scope of an overland flood study, develop a Tuggerah Lakes flood warning system as questionnaire results showed that community perception links significant flooding to management of the Tuggerah Lakes.

13.2 Emergency Response Planning

13.2.1 Prepare Local Flood Sub-Plan

Effective planning for emergency response is a vital way of reducing risks to life and property. The NSW State Emergency Service (SES) is the legislated combat agency for floods in NSW and is responsible for the control of flood operations. This role is undergirded by detailed flood planning.

At the current time, the main plan giving some attention to flooding in the Northern Lakes study area is the Wyong Shire Flood Emergency Sub Plan developed by the NSW SES and Wyong Shire Council in 2013.

13.2.2 Prepare and update private flood plans

As well as preparing a Local Flood Sub-Plan, there would be benefit in NSW SES and Council encouraging and helping key floodplain community members who are likely to be impacted by flooding to prepare and update their own flood emergency response plans. The process of preparing plans would in itself be an important process of raising awareness and preparedness.

Among the higher priorities for flood plans are:

- Key flood effected areas;
- Schools and pre-schools.

Recommendations

- Consider the information in the Northern Lakes FRMS&P in completing Emergency Management planning.
- Update Local Flood Sub-Plan, recognising the limits to evacuation in the Northern lakes study area, identifying evacuation shelters that people in the key flooding area such as Karangal Cres, Buff Point could access at short notice, using the flood intelligence contained in this study and identifying hotspots requiring attention (NSW SES)
- Encourage and assist key floodplain community members who are likely to be impacted by flooding to prepare and update their own flood emergency plans (NSW SES, Council)
- Prepare dam break analyses for both existing Gorokan Park basin and the sport fields directly east of Lake Haven Shopping Centre to understand potential impact on downstream properties (Council)

13.3 Flood Education

13.3.1 General

Actual flood damages can be reduced, and safety increased, where communities are flood-ready:

> *'People who understand the environmental threats they face and have considered how they will manage them when they arise will cope better than people who lack such comprehension… Many people who live and work in flood liable areas have little idea of what flooding could mean to them – especially in the case of large floods of severities well beyond their experience or if a long period has elapsed since flooding last occurred. It falls to the [SES], with assistance from councils and other agencies, to raise the level of flood consciousness and to ensure that people are made ready for flooding. In other words, flood-ready communities must be purposefully created. Once created, their flood-readiness must be purposefully maintained and enhanced'* (Keys, 2002, p.52).

Although a number of flood and property modification measures are available to manage flood risk, communities living and working in floodplains in the Northern Lakes study area will never be totally protected from the impacts of flooding. Nor can emergency authorities such as the NSW SES ensure the safety of all residents. Therefore, it is critical that through community education the flood-affected communities are aware of the flood risk, are prepared for floods, know how to respond appropriately and are able to recover as quickly as possible.

Based on learnings from recent disasters, the focus of community disaster education has now turned from a concentration on raising awareness and preparedness to *building community resilience through learning*. Simply disseminating information to the community does not necessarily trigger changed attitudes and behaviours. Flood education programs are most effective when they:

- Are participatory i.e. not consisting only of top-down provision of information but where the community has input to the development, implementation and evaluation of education activities;
- Involve a range of learning styles including experiential learning (e.g. field trips, flood commemorations), information provision (e.g. via pamphlets, DVDs, the media), collaborative group learning (e.g. scenario role plays with community groups) and community discourse (e.g. forums, post-event de-briefs);
- Are aligned with structural and other non-structural methods used in floodplain risk management and with emergency management measures such as operations and planning; and
- Are ongoing programs rather than one-off, unintegrated 'campaigns', with activities varied for the learner.

Based on MHL experience the following four criteria are important to improve flood education and awareness:

- Increased community concern for the potential risk and impact of flooding and coastal storm hazards in the Northern Lakes catchment
- Increased community preparedness for flood and coastal storm hazards evidenced by owning a home emergency kit and establishing an evacuation plan
- Increased community understanding of, and willingness to engage in, appropriate emergency response behaviour
- Strengthened regional networks with stakeholders for ongoing support and adaptive capacity within the community

Consideration should be given to the flood education messages and methods that may be of particular benefit for the Northern Lakes study area.

13.3.2 Messages

A basic message to continue to communicate is that floods are a genuine hazard within the study area and that effort should be made to prepare for flooding. People also need to understand that bigger and faster-rising floods than have been experienced previously will one day occur, which may pose significant risk to life and property.

Business proprietors in the Northern Lakes area are a community who may need special effort to persuade that planning for floods is a worthy investment, in line with the NSW SES's 'Don't let your business go under'. Low levels of interest in flooding are suggested by the relatively low response rate to the business questionnaire prepared for this study.

Some roads, including Buff Point Avenue or Moss Avenue, may be flooded to dangerous depths and velocities even in relatively frequent events. This suggests that messages such as the NSW SES's 'Never drive, ride or walk through floodwater' are especially pertinent. But there is also a need for messages to confront the reasons people may reject that guidance. For example, that cars float in just 30cm of still water, that even 4WDs float and may wash downstream, and that every flood is different. A UNSW Newsroom Article (by Wilson da Silva, dated 20/06/2016) "How floodwaters can turn cars into death traps" mentioned the following: "a small car like a Toyota Yaris, weighing 1.05 tonnes, was moved by water only 15 cm deep and with a flow speed of just 3.6 km/h. It completely floats away in 60 cm of water".

Messages to combat people playing in floodwaters include the danger of doing so since children have drowned playing in drains and that floodwaters can carry harmful bacteria.

13.3.3 Methods

General methods

If Council possess any historical flood photos, these could be drawn upon for flood education. The flood history reported in **Section 2.2** could also be extended by further research of local newspapers. This historical material could be developed into a library or mobile display, which could be accompanied by maps showing the extent and depth of design floods and relevant educational messages. Where needed, surrogates (e.g. Dungog) could be used to make the case that extreme floods happen.

Creating a guide that sets out the different styles of flooding in the LGA, how people may be advised of flooding and what people can do to prepare their family and property for floods could be a good option. Advertising the "Preparing for flood emergency" webpage from Council's website could also be a possibility. Another option is the referral to SES FloodSafe information website to obtain key information about how to act before, during and after a flood event (https://www.ses.nsw.gov.au/disaster-tabs-header/flood/).

Business

A strategy consisting of distributing business-specific flood toolkits and guides can be developed. The *Business FloodSafe Toolkit and Plan – Flash Flooding* developed by the NSW SES aim to persuade businesses of the importance of planning for floods and to help proprietors prepare an action plan. It is a comprehensive 28-page document that if completed and maintained would significantly increase businesses' awareness and readiness for floods. However, may not always take the effort to complete this lengthy plan. For this reason, there would be benefit in developing a more accessible, condensed version of the Business FloodSafe toolkit. This exercise was undertaken for the Eastwood commercial district, which also has a significant flash flood risk, resulting in a 5-page template (Bewsher Consulting, 2010a). Ryde Council requires that this template be completed whenever there is a change of business use in the Eastwood commercial district's floodplain.

NSW SES can hold Business Breakfasts to present the Business FloodSafe toolkit and to discuss local flood risks and responses. These are usually held in conjunction with a local Chamber of Commerce and provide a free breakfast for attending business managers and owners.

Residents

One option to directly engage residents is via 'meet-the-street' events, which involves NSW SES and Council setting up a 'stall' at an appropriate and visible location at a time that people will be at home. The 'meet-the-street' should be advertised through a specific letter box drop to the targeted neighbourhood or vulnerable site. The stall could consist of flood maps on boards, NSW SES banners and NSW SES materials (FloodSafe guide) to hand out. These materials are used to engage with people and make them aware of flood risk, encourage preparedness behaviours (e.g. develop emergency plans) and help them understand what to do during and after a flood. A meeting could also encourage property owners to develop self-help networks and particularly people checking on neighbours if a flood is imminent. Longer-term residents with flood experience could be used to help other residents understand flooding. Considering the existing flood risk, at least the following sites may benefit from this approach:

- Gascoigne Rd and Lett St, Gorokan;
- Karangal Cres and Regent St, Buff Point;
- The area behind the dunes of Canton Beach; and
- Villa Cl, Budgewoi.

One point of caution for meet-the-street events relates to the potential for conflicting advice in relation to whether to attempt to evacuate or to shelter-in-place. Council and NSW SES will need to ensure that they are presenting a clear and consistent message for each location, so that residents know how they need to respond in a flood emergency.

Schools

Another action consists of presentations in schools. Innovative approaches to communicating the dangers of playing in floodwater would be beneficial.

Signage

Permanent signage can be of value in a variety of contexts, showing:

- that an area or road is subject to flooding;
- the potential depths of flooding;
- evacuation routes;
- safety messages (e.g. don't enter floodwater).

It is advisable to install signage in flood prone carparks. This could indicate that the areas are subject to flooding but also include safety advice to discourage people from attempting to relocate their vehicles if flooding has commenced.

Flood depth indicators up to 1m high could be of value where flood modelling shows important roads to be inundated to serious levels in relatively frequent events. The analysis of road inundation identified the following sites flooded to >0.5m in the 20% AEP flood:

- Gascoigne Rd and Lett St, Gorokan;
- Dudley St near Chelmsford Rd, Lake Haven;
- Iluka Ave between Nerida Ave and Wyndora Ave, San Remo;

- Karangal Cres near Buff Point Ave, Buff Point;
- Moss Ave, Toukley.

Consultation may need to be conducted to gain the acceptance of nearby residents, given fears of adverse impacts of signage on property values.

Detention basins may also require signage to warn of potentially deep flooding.

Recommendations

The following is recommended:

- Develop a library or mobile display using historical flood photos, modelled flood extents and appropriate messaging;
- Develop an accessible flood emergency plan template suitable for use by Northern Lakes businesses, in conjunction with the Wyong Regional Chamber of Commerce;
- Hold a Business FloodSafe Breakfast in conjunction with Wyong Regional Chamber of Commerce (NSW SES);
- Conduct ‘meet-the-street’ type events for residents at the four locations listed above (NSW SES);
- Engage with students at local schools to help them understand flood behaviour near the school and to promote safe responses, including not to play in flooded creeks and drains (Council in collaboration with NSW SES);
- Install signage in flood prone carparks;
- Install flood depth indicators at low-points of the roads listed above;
- Install signage in any detention basins where flooding could pond to dangerous depths.

14. Implication of climate change

14.1 Climate Change Impacts Relevant to Flood Risk

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC, 2019) is currently being developed and builds on the Fifth Assessment Report (IPCC, 2014). A number of special reports of the AR6 have already been published including the *Special Report on Climate Change and Land* and the *Special Report on the Ocean and Cryosphere in a Changing Climate*. The reports confirm that human influence on the climate system is clear and growing, with impacts observed across all continents and oceans. These reports highlight that projected changes in climate that would have implications on flood risk are sea level rise and changes in the hydrologic cycle, namely an anticipated increase in the frequency and intensity of heavy rainfall events.

14.1.1 Sea Level Rise

According to the IPCC Sixth Assessment Report (IPCC 2019), global mean sea level (GMSL) is rising and accelerating. The dominant cause of GMSL rise since 1970 is anthropogenic forcing. GMSL rose by 0.16 m over the period 1902–2015 (likely range of 0.12-0.21 m) and with mean rate of global averaged sea level rise of 3.2 mm/yr between 1993 and 2015, and of 3.6 mm/yr over the 2006-2015 period being significantly larger than the mean rate during the previous two millennia. This process is driven primarily by thermal expansion of the ocean due to warming, and the melting of glaciers and ice sheets.

The NASA satellite have been measuring the mean sea level since January 1993 and the latest measurement from October 2019 shows the level 95 (±4) mm above the January 1993 level.

It is notable that rates of sea level rise over broad regions can be several times larger or smaller than the global mean sea level rise for periods of several decades due to fluctuations in ocean circulation and, since 1993, the regional rates for the Western Pacific are up to three times larger than the global mean (IPCC 2014).

While there is a consensus among many scientists on the occurrence of sea level rise, projected increases vary considerably. The AR6 states that future sea level rise is expected to proceed at rates exceeding those observed to 2015, with climate modelling estimating a rate of rise of up to 10 to 20 mm/yr during the period 2081–2100 in the Representative Concentration Pathway (RCP) 8.5, equivalent to a range of sea level rise of 0.61 to 1.10 m.

14.1.2 Frequency and Intensity of Heavy Rainfall Events

The AR6 found that the frequency and intensity of heavy precipitation events has likely increased over the second half of the 20th century.

The observation and prediction of this phenomenon presents difficulties due to factors such as natural seasonal and longer-term variations, limited observational coverage, and the non-uniformity of changes across the globe. There is therefore significant variation in projected increases in the intensity of heavy rainfall events.

Australian rainfall is particularly variable, making it difficult to identify significant trends over time, and understanding changes to rainfall intensity is an area of ongoing research. AR&R 2019 data hub provides some guidance on potential increases in rainfall intensity based on the RCPs 4.5, 6 and 8.5 as presented in the https://www.climatechangeinaustralia.gov.au/ website. Values nearing 20% are expected by 2090 in the Central Coast area if the RCP 8.5 is adopted.

14.1.3 Central Coast Council Approaches

Climate change sensitivity analyses undertaken in floodplain risk management studies under the DPIE Floodplain Management Program typically adopt sea level rise (SLR) values of between 0.4 m and 0.9 m and increases in rainfall intensity of between 10% and 30% as per the Floodplain Risk Management Guidelines Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW 2010) and Practical Consideration of Climate Change (DECC 2007). The ranges of values recommended in these documents were based upon studies from the IPCC and CSIRO for the period to 2100.

In 2012 the NSW Government announced its Stage One Coastal Management Reforms, a result of which is that the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils. The NSW Chief Scientist and Engineer's report titled *Assessment of the Science behind the NSW Government's Sea Level Rise Planning Benchmarks* (2012) however identified that the science behind sea level rise benchmarks from the 2009 NSW Sea Level Rise Policy Statement was adequate.

Due to the merging of former Wyong and Gosford Councils, Central Coast Council does not yet have an adopted Climate Change Policy but is currently in the consultation process to develop a Draft Climate Change Policy. Former Wyong Council did not have any Climate Change Policy and adopted an interim Sea Level Rise (SLR) position as part of the Coastal Zone Management Plan on February 8, 2012, that aligned with the 2009 NSW Government Policy of 0.4m Sea Level Rise. In March 2015, Former Gosford Council resolved to adopt medium sea level rise projections including 0.2m by 2050, 0.39m by 2070 and 0.74m by 2100. This was due to the Council adopting a Climate Change Mitigation Strategy with a carbon reduction target of 20 per cent by 2025, based on 2010 levels.

For the purpose of sensitivity analysis for this study, two scenarios have been run to understand the potential of climate change in the Northern Lakes area and consist of increase in rainfall intensity by 30% and an increase in sea level by 0.74m. Based on the Tuggerah Lakes FRMSP, the lake level is expected to increase by the same level as the ocean and this increase in sea level was directly applied to the lake level.

14.2 Impact of Climate Change on Local Flood Behaviour and Impacts

For the purpose of sensitivity analysis for this study, two scenarios have been run to understand the potential of climate change in the Northern Lakes area and consist of increase in rainfall intensity by 30% and an increase in sea level by 0.74m. Based on the Tuggerah Lakes FRMSP, the lake level is expected to increase by the same level as the ocean and this increase in sea level was directly applied to the lake level.

Changes in comparison to the 1% AEP peak flood levels associated with the simulated climate change scenarios are presented in **Appendix L**.

In comparison with current design conditions, simulation of sea level rise of 0.74 m and a 30% increase in rainfall intensity highlighted the following impacts on 1% AEP design flood conditions:

Increase in rainfall intensity by 30%:

- The vast majority of the study area is subject to increases in flood levels of less than 0.10 m.
- The largest increases are typically confined within the environmental protection areas around the catchment.
- Areas with increases between 0.1 m and 0.2 m were observed along the channel upstream of Cooranga Rd in Tuggerawong, in the Lett St and Gascoigne Rd area and downstream of Gorokan Park in Gorokan, directly upstream of Chelmsford Rd in Lake Haven, in a few locations in the lower catchment of San Remo, in the Karangal Cres and Regent St area in Buff Point, in the vegetated area upstream of Woodland Parkway Reserve in Budgewoi, upstream of Main Rd in Noraville and in the ponding areas at the back of the dune of Canton Beach.
- peak flood level increases in the order of 0.20 to 0.25 m were observed upstream of Greenacre Ave in Lake Munmorah.

Increase in sea level by 0.74 m:

- most of the significant increase in flood level are located along uninhabited areas such as the lake foreshore public areas and within the wetland areas in the Tacoma, Tuggerawong and Wadalba area and north of Toukley and Noraville. However, a number of properties are impacted along The Corso and Malvina Pde in Gorokan, Panorama Ave in Charmhaven, Kallaroo Rd in San Remo, Diamond Head Dr, Budgewoi Holiday Park and Mimosa Rd in Budgewoi, as well as the northern end of Leonard Ave in Toukley.
- Some increases of up to 0.12 m have been observed at the back of the properties along the southern half of Wolseley Ave, Tacoma and further increases of up to approximately 0.40 m occur at the back of properties along the northern half of the same road.
- Flood level increases by about 0.08 m in Bayview Ave and Hastings St, Rocky Point.
- Flood level increases by about 0.15 m along Jensen Rd in Wadalba
- Minor increases in the order of 0.02-0.03 m were observed along January St and Cadonia Rd in Tuggerawong, Karangal Cres, Regent St and Narrunga Ave in Buff Point, Sonoma Rd in Budgewoi.
- Increases in flood level up to over 0.3 m at the back of the Natuna Ave properties would occur in Budgewoi.
- Most of the increases typically occur at the back of the properties and would not directly impact the buildings. Moreover, most of the properties along the lake typically

have elevated floor level.

Table 14.1 shows the number and depths of over floor flood affectation by the 1% AEP event under existing conditions and the climate change scenario, with this data presented graphically for the residential sector in **Figure 14.1** and the non-residential sector in **Figure 14.2**.

Under the simulated climate change scenarios, the number of residential dwellings flooded above floor in the 1% AEP event would increase from 278 to 291 due to increase in sea level and from 278 to 389 due to increase in rainfall intensity. The number of non-residential premises will increase from 17 to 18 due to increase in rainfall intensity and sea level will not impact the number of properties flooded over floor level. Depths of over floor flooding also increased markedly due to rainfall intensity increases.

Direct residential damages for the 1% AEP event would increase by around 44% from $18.9M to $27.2M due to increase in rainfall intensity and by around 6% from $18.9M to $19.9M due to sea level rise, direct non-residential by around 34% from $3.6M to $4.9M due to increase in rainfall intensity and would not change due to sea level rise, and total damages by approximately 42% from $34.2M to $48.6M due to increase in rainfall intensity and by approximately 5% from $34.2M to $35.8M due to sea level rise (**Table 14.2**).

In summary, the implications of climate change on flood impacts within the Northern Lakes area could be significant. Under the investigated climate change scenario of 0.74 m sea level rise and 30% increase in rainfall intensity, significant increases in peak flood depths, inundation extent, number of buildings flooded over floor and flood damages were simulated for the 1% AEP event. It is noted that rainfall intensity is the most influential climate change factor in the study area which is expected for this type of overland flooding modelling.

Table 14.1 – Number of residential and non-residential buildings affected by above floor depth in a 1% AEP event

	Present Conditions		Climate Change Rainfall intensity increase by 30%		Climate Change Sea level increase of 0.74m	
Depth over (below) floor in 1% AEP event	**Res.**	**Non-res.***	**Res.**	**Non-res.***	**Res.**	**Non-res.***
0.0-0.1m	112	6	154	10	119	7
0.1-0.3m	118	11	159	11	124	11
0.3-0.5m	31	5	51	3	32	5
0.5-1.0m	17	1	24	4	17	1
>1.0m	0	0	1	0	0	0
TOTAL flooded over floor	**278**	**23**	**389**	**28**	**291**	**24**

**All buildings in properties like caravan parks or holiday parks have been counted as a single property*

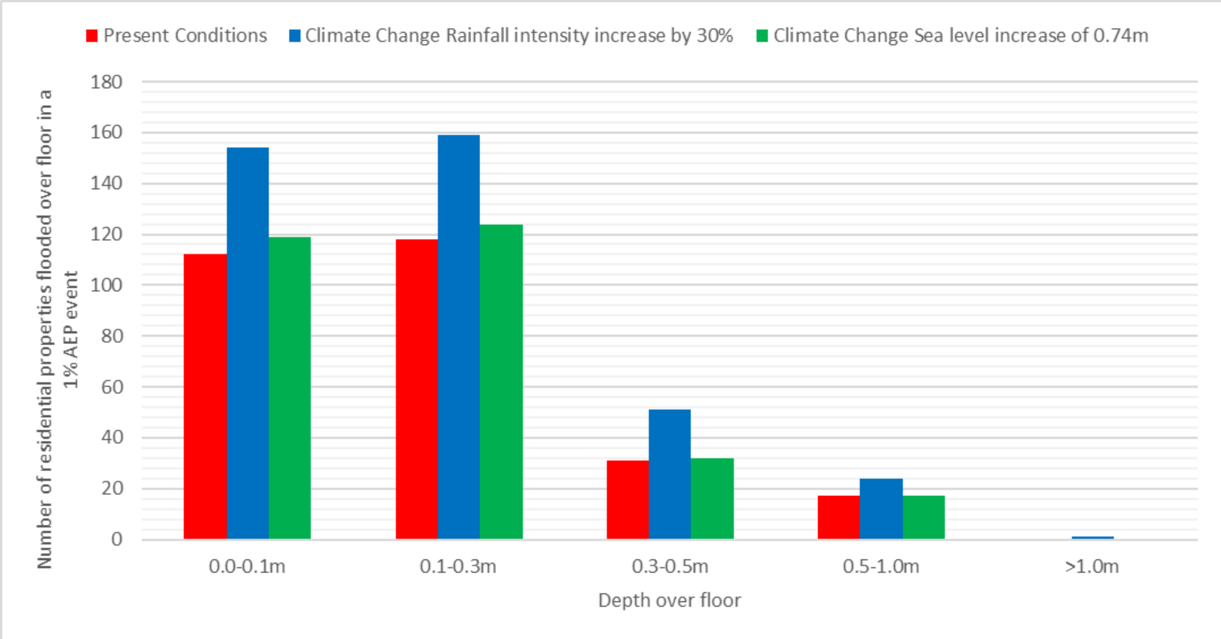

Figure 14.1 – Depths of above floor inundation in 1% AEP event, residential sector

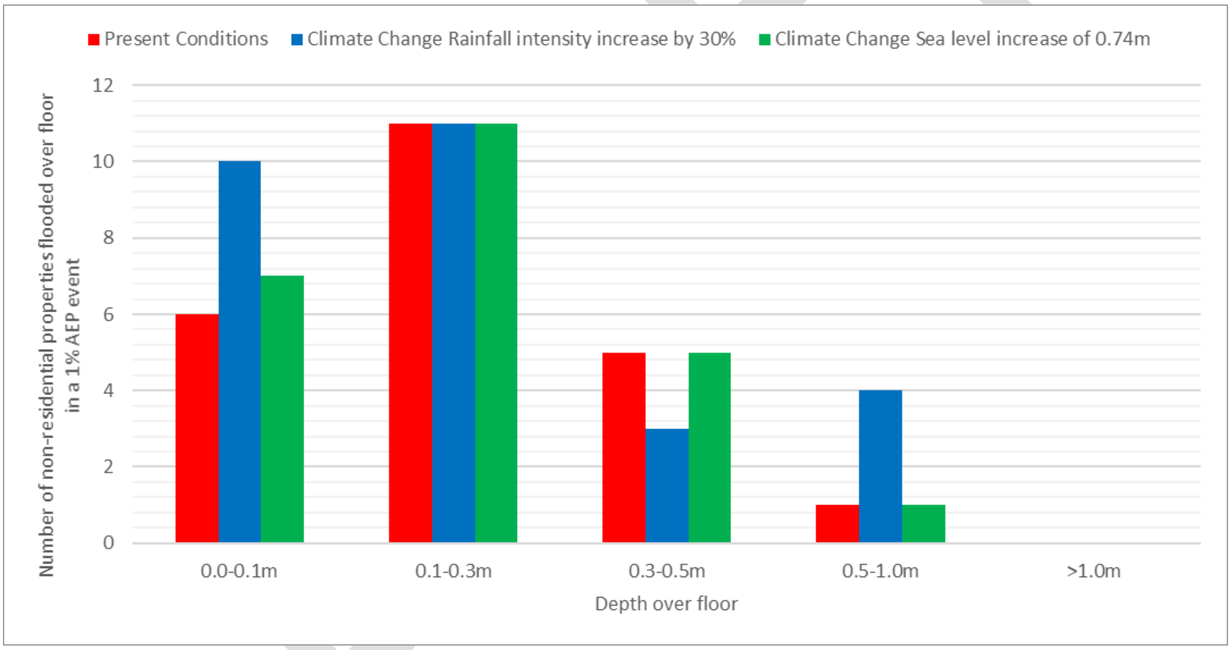

Figure 14.2 – Depths of above floor inundation in 1% AEP event, non-residential sector

14.3 Influence on Flood Modification Options

The impact of climate change on the performance of proposed flood modification options was investigated. The results of an analysis of 1% AEP flood damages and over floor flooding are presented in **Table 14.2**, comparing the benefits of the proposed options under existing conditions and the climate change scenario. The driver for changes in flood benefits associated with these options is the 30% increase in rainfall intensity rather than sea level rise.

Table 14.2 – Flood modification options BCR assessment & premises protected for the 1% AEP under climate change conditions (30% increase in rainfall intensity)

	Base Case	Option 1 Greenacre Ave, Lake Munmorah culvert upgrade	Option 2b Crossingham St, Canton Beach culvert upgrade	Option 2c Moss Ave, Toukley culvert upgrade	Option 3a Pathway upgrade between Lett St, Gorokan and Tuggerah Lake	Option 3d Pathway and culvert upgrade between Lett St, Gorokan and Tuggerah Lake	Option 4 Woodland Parkway Reserve entrance excavation	Option 7a Culvert upgrade under Cooranga Rd, Wyongah	Option 7b Flow diversion 600m upstream of Cooranga Rd	Option 7c Combination of Options 7a and 7b	Option 8 Gorokan Park Detention Basin
Residential											
Reduction in no. houses flooded over floor in 1% AEP	*278**	0	5	1	6	9	5	1	2	4	0
Reduction in no. houses flooded over floor in 1% AEP with 30% increase in rainfall intensity	*389**	3	4	5	6	11	6	1	1	2	4
Direct Res Benefits in 1% AEP (reduced damages)	-	$57K	$320K	$33K	$482K	$677K	$357K	$73K	$199K	$323K	$40K
Direct Res Benefits in 1% AEP with 30% increase in rainfall intensity (reduced damages)		$241K	$334K	$288K	$524K	$857K	$470K	$88K	$169K	$242K	$309K
Non-residential											
Reduction in no. premises flooded over floor in 1% AEP	*17**	0	0	0	0	0	0	0	0	0	0
Reduction in no. premises flooded over floor in 1% AEP with 30% increase in rainfall intensity	*18**	0	0	0	0	0	0	0	0	0	0
Direct Non-res Benefits in 1% AEP (reduced damages)	-	$0	$1K	$0	$0	$0	$0	$0	$0	$0	$0
Direct Non-res Benefits in 1% AEP with 30% increase in rainfall intensity (reduced damages)	-	$0	$1K	$0	$0	$0	$0	$0	$0	$0	$0
Total (including direct residential and non-residential, indirect residential and non-residential, infrastructure and social)											
Total 1% AEP Damages	$34,214K	$34,130K	$33,748K	$34,166K	$33,514K	$33,231K	$33,696K	$34,107K	$33,925K	$33,746K	$34,155K
Total 1% AEP Damages with 30% increase in rainfall intensity (7%, 50y)	$48,641K	$48,291K	$48,153K	$48,222K	$47,881K	$47,398K	$47,960K	$48,512K	$48,396K	$48,289K	$48,192K
Reduction in Total 1%AEP Damage	-	$83K	$465K	$48K	$699K	$982K	$517K	$106K	$289K	$468K	$58K
Reduction in Total 1%AEP Damage with 30% increase in rainfall intensity	-	$349K	$487K	$418K	$760K	$1,242K	$681K	$128K	$245K	$351K	$448K

**Total number of houses/premises flooded over floor for base case in present and climate change conditions*

The results presented in **Table 14.2** can be summarised as follows:

- flood benefits in terms of reduction in the number of buildings flooded over floor in the 1% AEP event show some improvement in Options 1, 2c, 3d, 4 and 8 and decreases for Options 2b, 7b and 7c. Options 3a and 7a are unchanged
- flood benefits in terms of reduction in total 1% AEP event flood damages were typically increased under climate change except for Options 7b and 7c due to the flow diversion to the lake becoming less effective with larger flows.
- Options 1, 2c and 8 are significantly improving their impact. This is due to Option 1 and 2c being more effective during more severe events and Option 8 having the basin retaining more water and further increasing the difference in flood level with and without the detention basin upgrade.
- all options continue to provide flood benefits under climate change in terms of reduction in the number of buildings flooded over floor in the 1% AEP event and reduction in 1% AEP event flood damages.

When interpreting these results, it is important to note the following considerations:

- the simulated reductions in flood benefits are in the context of a 30% increase in rainfall intensity for the 1% AEP design event
  - projections of increase in rainfall intensity for heavy rainfall events are highly uncertain, and actual increases may be considerably lower than 30%
  - the timeframe over which such increases in rainfall intensity may occur is likely to be considerable, during which time the basins would continue to provide a high level of flood benefit and indeed would continue to provide a lower level of benefit thereafter
- increases and reductions in 1% AEP flood damages only under the climate change scenario may not always be representative of changes in AAD and NPV

It is therefore considered that the long-term performance of these options remains viable and the recommendation for their further investigation and adoption remains warranted.

14.4 Influence on Property Modification Options

The impact of climate change on the performance of proposed property modification options was also investigated.

Increased depths of above floor flooding with climate change suggest that a voluntary house raising or redevelopment scheme, or flood-proofing scheme may become more pressing. **Table 14.1** and **Figure 14.1** indicate that 25 houses could be flooded to depths of more than 0.5m over floor under a warmer climate compared to 17 under existing conditions. The majority of the additional properties with significant flooding over floor due to climate change are located in the same areas as the ones already impacted without climate change. This count of properties is beset by the same issues that were evident for the assessment of property modification measures to address existing risk, particularly estimated and unsighted floor levels. It is considered that the recommendation for a scoping study to further assess the feasibility of a small scheme remains appropriate. When the effects of climate change begin to manifest themselves, this scheme may need to be expanded and would then benefit from lessons learned via implementation of the 'pilot' program that has been considered for the treatment of existing risk.

If subsidies for house raising or ‘knock down and rebuild’ development are offered through State/Council funding, it is recommended that consideration be given to incorporating into the new floor levels an allowance for climate change, since this would be cost effective, practical and in keeping with the precautionary principle. This allowance would not necessarily need to be for the 0.74 m SLR and 30% increase in rainfall intensity scenario that was modelled for the climate change simulation described in this chapter. For houses subject to overland flows where the flood height range is typically small, it could be cost effective to raise floors to the PMF level. For houses subject to sea level rise or lake flooding, consideration could be given to the levels defined as part of the Tuggerah Lakes Floodplain Risk Management plan as this document focuses on lake flooding while the current study focuses on overland flooding. Lifespan of the building should also be considered. A conservative approach would be to set the floor level at the projected FPL at the conclusion of the lifespan.

14.5 Influence on Response Modification Options

A heightened flood problem with climate change would add weight to the recommendations proposed to improve flood warning systems, emergency response planning and flood education. Since Local Flood Plans are intended to be reviewed and updated at regular intervals, it is not considered necessary to document projected changes to flood behaviour and impacts as a result of climate change.

15. Floodplain management plan

15.1 Objective

The overall objective of the Northern Lakes Floodplain Risk Management Plan (FRMP) is to develop a long-term approach to overland flood and floodplain management in the Northern Lakes study area that addresses the existing and future flood risks in accordance with the general desires of the community and in line with the principles and guidelines laid out in the NSW Government's *Floodplain Development Manual*.

This will ensure that the following broad needs are met:

- Manage the flood hazard and the flood risk to people and property generated by overland flooding, now and in the future; and
- Ensure floodplain risk management decisions integrate economic, environmental and social considerations.

15.2 Recommended Measures

The recommended measures for the FRMP have been selected from the suite of options identified and evaluated in **Chapters 11 to 13**, after an assessment of each measure's impact on flood risk, as well as consideration of economic, environmental and social factors. The recommended measures are listed in **Table 15.1** and presented in **Figure 15.1**.

Table 15.1 – Draft Northern Lakes Floodplain Risk Management Plan

Report section	Floodplain Management Measure	Implementation Responsibility	Initial cost	Ongoing cost	Priority	Timing	Resourcing	Comments
	FLOOD MODIFICATION MEASURES							
11.3.1	Greenacre Ave, Lake Munmorah culvert upgrade	CCC	$829K	$0*	Medium	1-2 yrs	CCC, DPIE	
11.3.2	Crossingham St, Canton Beach culvert upgrade	CCC	$1,344K	$0*	Medium	1-2 yrs	CCC, DPIE	
11.3.4	Pathway and culvert upgrade between Lett St, Gorokan and Tuggerah Lake	CCC	$1,085K	$0*	High	0-1 yr	CCC, DPIE	
11.3.5	Woodland Parkway Reserve entrance excavation	CCC	$642K	$0	High	0-1 yr	CCC, DPIE	Subject to environmental impact assessment of excavation
	PROPERTY MODIFICATION MEASURES							
12.1, 12.2, 12.3	Prepare a scoping study including detailed floor level survey, consultation and site inspections to further assess feasibility of establishing a small voluntary house raising scheme	CCC	$20K	$0	Low	> 2 yrs	DPIE, CCC	
12.3	Prepare Council's flood-proofing Guidelines as suggested; prepare a one-page, graphic summary of the Guidelines	CCC	$15K	$0	Medium	1-2 yrs	DPIE, CCC	
12.4	Review and adopt the revised flood risk management provisions of Central Coast DCP including freeboards for the study area	CCC	Staff costs	$0	High	0-1 yr	CCC	
	RESPONSE MODIFICATION MEASURES							
13.2	Improve emergency response planning: • Update Local Flood Sub-Plan in view of the flood risk information in the Northern Lakes FRMS&P; • Encourage and assist key floodplain community members who are likely to be impacted by flooding to prepare and update their own flood emergency plans	NSW SES, Local Emergency Management Committee (LEMC)	Staff costs	$0	High	0-1 yr	NSW SES, Local Emergency Management Officers (LEMOs)	

Report section	Floodplain Management Measure	Implementation Responsibility	Initial cost	Ongoing cost	Priority	Timing	Resourcing	Comments
13.1	Improve flood warning system: • Alarm the Toukley rain gauge so that it issues email/SMS when rain triggers are reached; • a new real-time rain gauge in the vicinity of Lake Munmorah/Freemans • Transition towards a system where people living or working in the floodplain can stay informed via a web portal that allows access to data • Devise appropriate messages to accompany the rainfall alerts • Tuggerah Lake Warning System	CCC, NSW SES	$70K	$20K p.a.	Medium	1-2 yrs	DPIE, CCC, NSW SES	
13.2	Prepare dam break analyses for both existing Gorokan Park basin and sport fields directly east of Lake Haven Shopping Centre	CCC	$10K	$0	Medium	1-2 yrs	CCC	
13.3	Flood Education: • Develop a library or mobile display using historical flood photos, modelled flood extents and appropriate messaging; • Develop an accessible flood emergency plan template suitable for use by Northern Lakes businesses, in conjunction with Wyong Regional Chamber of Commerce; • Hold a Business FloodSafe Breakfast in conjunction with Wyong Regional Chamber of Commerce; • Conduct 'meet-the-street' type events for residents at four key locations in catchment; • Engage with students at Local Schools to help them understand flood behaviour near the school and to promote safe responses; • Install signage in flood prone carparks; • Install flood depth indicators at ~5 low-points on roads; • Install signage in any detention basins where flooding could pond	NSW SES, CCC	$90K ($5K display, $5K template, $20K breakfast, $40K four meet-the-street events, $20K for ~15 signs)	$0	High	1-2 yrs	DPIE, NSW SES, CCC	Signage may require community concurrence at each location
TOTAL			$4,105K	$20K p.a.				

* No increment to existing maintenance costs expected

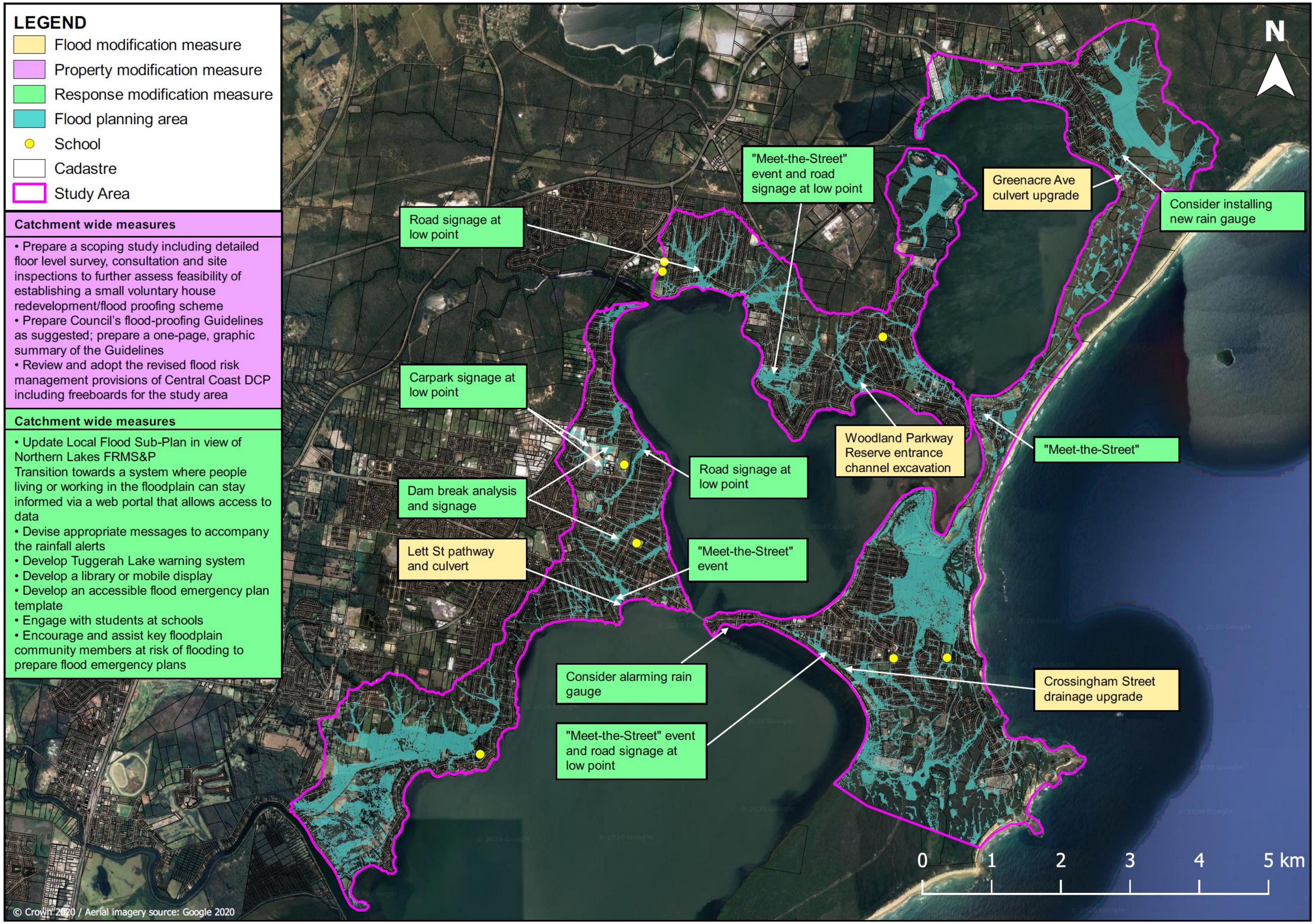

Figure 15.1 – Recommended measures

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Appendix A – Community newsletter and questionnaire

Appendix B – Ground-truthing

ID	Pit Depth (m)		Difference in Depth (%)	Pipe Diameters (m)				Difference in Pipe Diameter (%)	
				Measured		Modelled			
	Measured	Modelled		U/S	D/S	U/S	D/S	U/S	D/S
BL107.AZ.PIT.1.0	1	1	0.0						
BL107.AZ.PIT.2.0	0.75	0.8	-0.1						
BL107.BA.PIT.1.0	1.2	1.08327	0.1						
BL107.BA.PIT.2.0	0.85	0.7988	0.1						
BL107.BA.PIT.3.0	0.8	0.71882	0.1						
BL107.S.PIT.1.0	1.6	1.075	0.5						
BL107.S.PIT.2.0	1.65	1.075	0.6						
BL107.U.PIT.1.0	1.5	1.075	0.4						
BL107.U.PIT.3.0	1.65	1.075	0.6						
BL108.AJ.PIT.3.0	0	0	0.0		0.5		0.525		5%
BL108.AK.PIT.1.0	1.1	1.1	0.0						
BL108.AK.PIT.2.0	0.9	1	-0.1						
BL108.AK.PIT.3.0	0.8	0.8	0.0						
BL108.AK.PIT.4.0	0.85	1	-0.2						
BL79.BE.PIT.4.0	2.15	2.2	-0.1						
BL79.BJ.PIT.1.0	2.1	2.1782	-0.1						
BL79.BJ.PIT.2.0	1.65	1.8	-0.2						
BL81.L.PIT.1.0	0.85	0.53231	0.3						
BL81.L.PIT.2.0	0.95	0.53761	0.4						
BL81.P.PIT.2.0	1.55	1.6	-0.1						
BL81.P.PIT.3.0	1.2	1.3	-0.1	0.9		0.9		0%	
BL81.Q.PIT.1.0	1.75	1.8	-0.1						
BL82.K.PIT.2.0	0.4	0.7716	-0.4						
BL82.L.PIT.2.0	0.7	0.7	0.0						
BL82.L.PIT.3.0	0.7	0.7	0.0	0.375		0.45		20%	
BL82.L.PIT.4.0	0.7	0.8	-0.1		0.375		0.45		20%
BL82.L.PIT.5.0	0.4	0.6	-0.2						
BL82.ZB.PIT.1.0	0.9	1.2	-0.3						
BL83.BD.PIT.1.0	0.9	0.574859	0.3						
BL83.BD.PIT.2.0	0.95	0.56476	0.4						
BL83.BD.PIT.3.0	0.85	0.49341	0.4						
BL83.BE.PIT.2.0	0.95	1.075	-0.1						
BL83.BF.PIT.1.0	0.4	1.075	-0.7						
BL83.F.PIT.2.0	1	1.1048	-0.1						
BL83.F.PIT.4.0	0.65	0.6	0.1						
BL83.OA.PIT.3.0	0.95	0.90637	0.0						
BL83.U.PIT.3.0	1.6	1.8	-0.2						
BL83.V.PIT.1.0	0.4	1.269	-0.9						
BL83.W.PIT.1.0	0.6	1.248	-0.6						
BL83.X.PIT.1.0	0.4	0.7	-0.3						
BL83.X.PIT.2.0	0.4	0.6	-0.2						
BL83.Z.PIT.1.0	0.6	1.006	-0.4						
BL84.AR.PIT.3.0	1.1	1	0.1						

ID	Pit Depth (m)		Difference in Depth (%)	Pipe Diameters (m)				Difference in Pipe Diameter (%)	
				Measured		Modelled			
	Measured	Modelled		U/S	D/S	U/S	D/S	U/S	D/S
BL84.AR.PIT.4.0	1	1.5	-0.5	0.75	0.75	0.75	0.75	0%	0%
BL84.AR.PIT.5.0	0.8	0.634	0.2	0.6	0.75	0.6	0.75	0%	0%
BL84.AR.PIT.6.0	0.75	0.8	-0.1	0.6	0.6	0.6	0.6	0%	0%
BL84.DF.PIT.2.0	1	1	0.0	0.375		0.375		0%	
BL84.DF.PIT.3.0	0.9	0.9	0.0	0.375	0.375	0.375	0.375	0%	0%
BL84.DF.PIT.4.0	1.1	1.1	0.0	0.375		0.375		0%	
BL84.DF.PIT.5.0	1.1	1.1	0.0						
BL84.M.PIT.2.0	0.9	0.8	0.1						
BL85.J.PIT.3.0	0.45	0.454	0.0		0.45		0.45		0%
BL86.AS.PIT.1.0	0.9	0.732	0.2						
BL86.AS.PIT.2.0	0.75	1.075	-0.3						
BL86.AS.PIT.3.0	0.9	1.075	-0.2						
BL86.S.PIT.6.0	1	0.462	0.5						
BL86.S.PIT.7.0	1.1	1.3	-0.2		0.6		0.6		0%
BL86.S.PIT.8.0	0.6	1.225	-0.6		0.6		0.525		13%
BL87.EA.PIT.5.0	1.3	1.064	0.2						
BL87.EB.PIT.1.0	1.4	0.847	0.6						
BL87.EB.PIT.2.0	1	0.690	0.3						
BL87.EC.PIT.1.0	1.2	0.861	0.3						
BL87.EC.PIT.2.0	1	0.692	0.3						
BL87.EF.PIT.1.0	1.3	0.704	0.6						
BL87.EF.PIT.2.0	1.1	0.607	0.5						
BL87.EG.PIT.1.0	1.5	1.022	0.5						
BL87.EG.PIT.2.0	1.4	1.111	0.3						
BL87.EL.PIT.4.0	1.85	1.075	0.8						
ML121.AL.PIT.2.0	1.1	1.220	-0.1						
ML121.AL.PIT.3.0	0.65	1.099	-0.4						
ML121.BJ.PIT.1.0	1	1.2	-0.2						
ML121.H.PIT.2.0	1.1	1.4	-0.3						
ML121.H.PIT.3.0	0.85	1.2	-0.4						
ML121.H.PIT.4.0	0.9	1.2	-0.3						
ML121.H.PIT.5.0	1	1.195	-0.2						
ML121.H.PIT.6.0	1.1	1.1886	-0.1						
ML121.H.PIT.7.0	1.1	1.1	0.0						
ML121.I.PIT.2.0	0.8	0.8	0.0						
ML121.I.PIT.3.0	0.85	1.055	-0.2						
ML123.A.PIT.2.0	0.7	0.800	-0.1						
ML123.A.PIT.3.0	0.9	1	-0.1						
ML123.B.PIT.1.0	0.7	0.8	-0.1						
ML123.C.PIT.2.0	0.85	1	-0.2						
ML123.D.PIT.1.0	0.55	0.9	-0.4						
ML125.E.PIT.3.0	0.45	1.088	-0.6						
ML125.E.PIT.4.0	0.55	1.006	-0.5						
ML125.E.PIT.5.0	0.55	1.084	-0.5						
ML125.E.PIT.6.0	0.5	0.972	-0.5						
ML125.E.PIT.7.0	0.8	1.234	-0.4						
ML125.E.PIT.9.0	0.35	0.373	0.0						

ID	Pit Depth (m)		Difference in Depth (%)	Pipe Diameters (m)				Difference in Pipe Diameter (%)	
				Measured		Modelled			
	Measured	Modelled		U/S	D/S	U/S	D/S	U/S	D/S
O2.L.PIT.2.0	Vegetation	1.4	N/A						
O2.L.PIT.2A.0	0.75	1.4	-0.7						
O2.L.PIT.3.0	0.9	0.8	0.1						
O2.O.PIT.1.0	0.85	0.9	-0.1						
O2.O.PIT.2.0	1.1	1	0.1						
O2.Q.PIT.1.0	0.8	0.8	0.0						
O2.R.PIT.1.0	0.85	0.7	0.2						
O2.R.PIT.2.0	0.65	0.498	0.2						
TL65.AH.PIT.3.0	1.7	1.7	0.0						
TL65.AP.PIT.1.0	1.45	1.4	0.1						
TL65.CD.PIT.1.0	1.6	1.6	0.0						
TL65.CD.PIT.2.0	1.5	1.45	0.1	0.75	0.75	0.75	0.75	0%	0%
TL65.CD.PIT.3.0	1.7	1.45	0.3	0.75		0.75		0%	
TL65.CE.PIT.1.0	1.2	1.3	-0.1	0.45	0.6	0.45	0.6	0%	0%
TL65.CE.PIT.2.0	1	1.45	-0.5		0.45		0.45		0%
TL65.CF.PIT.1.0	1.1	1	0.1						
TL65.H.PIT.2.0	0.3	0.4	-0.1						
TL65.H.PIT.5.0	0.5	0.603	-0.1						
TL65.H.PIT.6.0	0.5	0.400	0.1						
TL65.H.PIT.7.0	0.3	0.456	-0.2						
TL65.HA.PIT.1.0	0.1	0.3	-0.2						
TL65.I.PIT.1.0	0.1	0.4	-0.3						
TL70.A.PIT.5.0	1.2	1.15	0.1		0.45		0.45		0%
TL70.A.PIT.6.0	1.9	1.104	0.8						
TL70.M.PIT.1.0	1.15	1.15	0.0						
TL70.M.PIT.2.0	0.9	0.9	0.0		0.6		0.45		25%
TL70.M.PIT.3.0	0.8	0.8	0.0	0.375	0.375	0.375	0.375	0%	0%
TL70.M.PIT.4.0	0.9	1.075	-0.2						
TL70.N.PIT.1.0	0.75	1.075	-0.3						
TL70.N.PIT.2.0	1.1	1	0.1						
TL70.O.PIT.1.0	0.5	0.5	0.0		0.375		0.375		0%
TL70.T.PIT.1.0	0.95	1.075	-0.1						
TL70.T.PIT.2.0	0.9	1.075	-0.2	0.375	0.45	0.375	0.375	0%	17%
TL70.T.PIT.3.0	0.85	0.85	0.0		0.375		0.375		0%
TL70.U.PIT.1.0	2.4	2.4	0.0						
TL71.AF.PIT.1.0	1.1	1.1	0.0	0.375		0.375		0%	
TL71.AF.PIT.2.0	1.1	1.1	0.0	0.375	0.375	0.375	0.375	0%	0%
TL71.AF.PIT.3.0	1.1	1.1	0.0	0.375	0.375	0.375	0.375	0%	0%
TL71.AF.PIT.4.0	1.1	1.1	0.0	0.375		0.375		0%	
TL71.AF.PIT.5.0	1	1	0.0	0.375	0.375	0.375	0.375	0%	0%
TL71.AF.PIT.6.0	1	1	0.0						
TL71.AL.PIT.1.0	1.7	1.7	0.0						
TL71.AL.PIT.2.0	1.5	1.5	0.0	0.375		0.375		0%	
TL71.AL.PIT.3.0	1.5	1.5	0.0						
TL71.AL.PIT.4.0	1.2	1.2	0.0		0.375		0.375		0%
TL71.ALA.PIT.1.0	0.8	0.8	0.0		0.375		0.375		0%
TL71.I.PIT.8.0	0.7	0.7	0.0	0.45	0.45	0.375	0.525	17%	17%

ID	Pit Depth (m)		Difference in Depth (%)	Pipe Diameters (m)				Difference in Pipe Diameter (%)	
				Measured		Modelled			
	Measured	Modelled		U/S	D/S	U/S	D/S	U/S	D/S
TL71.IA.PIT.1.0	0.7	0.598	0.1		0.45		0.375		17%
TL71.T.PIT.8.0	1	0.9	0.1	0.6		0.6		0%	
TL71.U.PIT.1.0	1	0.705	0.3						
TL72.AB.PIT.1.0	1.1	1.1	0.0						
TL72.AC.PIT.2.0	0.8	1	-0.2						
TL72.AD.PIT.1.0	0.75	0.826	-0.1						
TL72.AD.PIT.2.0	0.6	0.750	-0.2						
TL72.Z.PIT.1.0	1.6	1.366	0.2						
TL72.Z.PIT.2.0	1	1.122	-0.1						
TL72.Z.PIT.3.0	1	0.643	0.4						
TL72.ZA.PIT.1.0	0.9	1.286	-0.4	0.45		0.45		0%	
TL74.BD.PIT.9.0	1	1.157	-0.2	0.45	0.45	0.45	0.375	0%	17%
TL74.BH.PIT.3.0	0.5	0.5	0.0						
TL74.BH.PIT.4.0	0.5	0.4	0.1						
TL74.BI.PIT.1.0	Blocked	0.506	N/A						
TL74.BI.PIT.2.0	0.6	0.468	0.1						
TL74.BM.PIT.2.0	N/A	0.5	N/A		0.375		0.375		0%
TL74.BM.PIT.4.0	N/A	0.546	N/A		0.45		0.45		0%
TL74.CA.PIT.3.0	0.6	0.723	-0.1						
TL74.CA.PIT.4.0	0.5	0.5	0.0						
TL74.CB.PIT.1.0	0.45	0.5	-0.1						
TL74.CB.PIT.2.0	0.5	0.438	0.1						
TL74.CB.PIT.3.0	0.55	0.449	0.1						
TL74.CC.PIT.1.0	0.4	0.4	0.0						
TL74.CD.PIT.1.0	0.45	0.746	-0.3						
TL74.N.PIT.1.0	0.65	0.7	0.0						
TL74.N.PIT.2.0	0.7	0.7	0.0						
TL74.N.PIT.3.0	0.7	0.7	0.0						
TL74.N.PIT.4.0	0.55	0.8	-0.3						
TL74.O.PIT.1.0	0.55	0.6	0.0						
TL75.AC.PIT.6.0	N/A	1.740	N/A		0.9		0.9		0%
TL75.E.PIT.1.0	0.2	0.6	-0.4						
TL75.F.PIT.2.0	Blocked	0.9	N/A						

Appendix C – Flood mapping

Appendix D – Hydraulic category and hazards

Appendix E – Flood emergency response classifications

Appendix F – Flood planning area

Appendix G – Road closure

Road Closure ID	Depth (m)				Velocity (m/s)				Velocity x Depth (m2/s)				H1-H6 Hazard				Time to Peak (hour)				Duration Water Above Road (min)				Duration Water Above Road over 0.3m Depth (min)			
	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*
M1_1	0.11	0.13	0.49	0.49	1.35	1.49	1.49	2.24	0.15	0.19	0.21	1.09	H1	H1	H1	H4	0.58	0.50	0.50	0.17 to 0.25	35	55	70	30 to 45	0	0	0	10 to 20
M1_2	0.19	0.4	0.52	0.52	0.71	1.16	0.84	1.29	0.13	0.47	0.2	0.67	H1	H2	H1	H4	0.50	0.58	0.50	0.17 to 0.25	135	135	140	60	0	130	0	20 to 35
M1_3	0.22	0.27	0.63	0.63	0.34	0.4	0.44	0.92	0.08	0.11	0.13	0.58	H1	H1	H2	H3	0.58	0.58	0.58	0.17 to 0.25	60	50	65	35 to 45	0	0	0	15 to 25
M1_4	0.19	0.21	0.46	0.46	0.61	0.67	0.73	1.31	0.11	0.14	0.17	0.61	H1	H1	H1	H3	0.50	0.50	0.50	0.17	105	105	110	55 to 60	0	0	0	15 to 20
M1_5	0	0.1	0.33	0.33	0	0.35	0.4	0.72	0	0.03	0.05	0.23	H0	H1	H1	H2	0.67	0.58	0.58	0.17 to 0.25	20	30	40	35 to 45	0	0	0	10
M1_6	0	0.11	0.61	0.61	0	0.22	0.29	0.88	0	0.02	0.05	0.54	H0	H1	H1	H3	0.67	0.67	0.58	0.25	20	30	25	25 to 40	0	0	0	15 to 25
M1_7	0	0	0.36	0.36	0	0	0.48	1.03	0	0	0.05	0.36	H0	H0	H1	H2	0.00	0.50	0.50	0.17	0	10	20	20 to 30	0	0	0	5 to 10
M1_8	0.16	0.19	0.41	0.41	0.29	0.33	0.37	0.59	0.05	0.06	0.08	0.24	H1	H1	H1	H2	0.67	0.58	0.58	0.25	45	45	65	40 to 55	0	0	0	15 to 20
M1_9	0.22	0.28	0.75	0.75	0.48	0.56	0.64	1.39	0.11	0.15	0.21	1.05	H1	H1	H2	H5	0.58	0.58	0.58	0.17 to 0.25	95	105	110	60	0	0	15	25 to 30
M1_10	0	0.1	0.49	0.49	0	0.37	0.43	0.93	0	0.04	0.06	0.46	H0	H1	H1	H2	0.67	0.67	0.58	0.25	10	20	30	25 to 40	0	0	0	15 to 20
M1_11	0.12	0.18	0.57	0.57	0.37	0.44	0.48	0.93	0.05	0.08	0.11	0.53	H1	H1	H1	H3	0.58	0.58	0.58	0.17 to 0.25	25	40	55	35 to 40	0	0	0	15 to 25
M1_12	0.22	0.26	0.44	0.44	0.13	0.14	0.15	0.22	0.02	0.02	0.03	0.1	H1	H1	H1	H2	0.58	0.58	0.58	0.17 to 0.25	90	100	100	50 to 60	0	0	10	20 to 25
M1_13	0	0.13	0.39	0.39	0	0.2	0.24	0.56	0	0.03	0.04	0.22	H0	H1	H1	H2	0.58	0.58	0.58	0.17 to 0.25	90	100	105	60	0	0	0	10 to 20
M1_14	0	0.11	0.4	0.4	0	0.25	0.3	0.58	0	0.03	0.05	0.23	H0	H1	H1	H2	0.67	0.67	0.67	0.25 to 0.33	20	30	45	35 to 45	0	0	0	15 to 20
M1_15	0.09	0.12	0.4	0.4	0.44	0.54	0.61	1.29	0.04	0.06	0.09	0.51	H1	H1	H1	H2	0.58	0.50	0.50	0.17	10	20	25	25 to 30	0	0	0	5
M1_16	0.18	0.22	0.55	0.55	0.22	0.3	0.36	0.82	0.04	0.07	0.09	0.45	H1	H1	H1	H3	0.58	0.50	0.50	0.17	25	40	55	30 to 40	0	0	0	15 to 25
M1_17	0.14	0.17	0.32	0.32	0.02	0.02	0.02	0.07	0	0	0	0.02	H1	H1	H1	H2	0.75	0.67	0.58	0.25 to 0.33	125	130	135	60	0	0	0	5 to 10
M1_18	0	0	0.53	0.53	0	0	0	0.16	0	0	0	0.04	H0	H0	H0	H3	0.50	0.50	0.50	0.83 to 1.00	90	140	140	60	0	0	0	25 to 35
M1_19	0.27	0.3	0.54	0.54	0.02	0.02	0.03	0.11	0	0.01	0.01	0.06	H1	H2	H2	H3	1.00	0.75	0.75	0.25 to 1.00	135	135	140	60	0	50	70	55
M1_20	0	0.12	0.45	0.45	0	0.38	0.5	1	0	0.05	0.07	0.45	H0	H1	H1	H2	0.58	0.58	0.58	0.17 to 0.25	65	80	90	40 to 55	0	0	0	10 to 20
M1_21	0	0.21	0.74	0.74	0	0.18	0.28	0.32	0	0.04	0.07	0.16	H0	H1	H1	H3	0.00	2.50	2.50	0.83 to 0.92	0	45	90	50 to 55	0	0	0	30 to 35
M1_22	0.17	0.21	0.45	0.45	0.6	0.73	0.82	1.52	0.1	0.15	0.19	0.69	H1	H1	H1	H3	0.58	0.58	0.50	0.17 to 0.25	125	130	130	55 to 60	0	0	0	10 to 25
M1_23	0.18	0.23	0.59	0.59	0.13	0.14	0.16	0.34	0.02	0.03	0.04	0.18	H1	H1	H1	H3	0.58	0.58	0.50	0.33 to 0.42	60	65	80	40 to 55	0	0	0	20 to 30
M1_24	0.17	0.2	0.49	0.49	0.46	0.55	0.62	1.14	0.08	0.11	0.14	0.56	H1	H1	H1	H2	0.58	0.58	0.50	0.17 to 0.25	105	110	115	60	0	0	0	10 to 25
M1_25	0.19	0.22	0.61	0.61	0.44	0.51	0.57	1.11	0.08	0.11	0.15	0.68	H1	H1	H1	H4	0.58	0.58	0.58	0.17 to 0.25	110	115	115	60	0	0	0	20 to 25
M1_26	0.14	0.17	0.44	0.44	0.31	0.36	0.41	0.75	0.04	0.06	0.08	0.34	H1	H1	H1	H2	0.50	0.50	0.50	0.17	55	65	80	30 to 45	0	0	0	15 to 20
M1_27	0.16	0.23	0.59	0.59	0.39	0.42	0.44	0.83	0.06	0.1	0.12	0.49	H1	H1	H1	H3	0.58	0.58	0.58	0.17 to 0.25	90	100	105	50 to 60	0	0	0	15 to 25
M1_28	0.2	0.26	0.64	0.64	0.76	0.84	0.91	1.53	0.15	0.21	0.27	0.98	H1	H1	H1	H4	0.50	0.50	0.50	0.17	105	115	115	60	0	0	0	15 to 25
M1_29	0.17	0.19	0.44	0.44	0.22	0.26	0.31	0.72	0.04	0.05	0.06	0.32	H1	H1	H1	H2	0.50	0.50	0.50	0.17	140	140	140	60	0	0	0	15 to 25
M1_30	0	0.11	0.31	0.31	0	0.3	0.32	0.55	0	0.03	0.04	0.17	H0	H1	H1	H2	0.58	0.58	0.58	0.17 to 0.25	40	60	70	35 to 55	0	0	0	10
M1_31	0	0.11	0.5	0.5	0	0.42	0.52	1.1	0	0.05	0.09	0.54	H0	H1	H1	H2	0.67	0.58	0.58	0.17 to 0.25	35	50	60	35 to 50	0	0	0	10 to 20
M1_32	0.16	0.22	0.66	0.66	0.2	0.22	0.27	0.75	0.03	0.05	0.07	0.49	H1	H1	H1	H3	0.58	0.58	0.58	0.17 to 0.25	60	75	85	40 to 50	0	0	0	15 to 25
M1_33	0	0.08	0.43	0.43	0	0.34	0.42	0.81	0	0.03	0.04	0.35	H0	H1	H1	H2	0.58	0.58	0.58	0.17 to 0.25	30	40	60	35 to 45	0	0	0	10 to 15
M1_34	0.24	0.27	0.51	0.51	0.23	0.29	0.34	0.66	0.05	0.08	0.1	0.33	H1	H1	H2	H3	0.58	0.58	0.58	0.17 to 0.25	115	120	130	60	0	0	5	20 to 30
M1_35	0.16	0.21	0.97	0.97	0.57	0.69	0.69	1.48	0.09	0.13	0.2	1.41	H1	H1	H1	H5	0.83	0.75	0.67	0.33 to 0.42	40	65	80	50 to 55	0	0	0	30 to 35
M1_36	0.3	0.39	1	1	0.24	0.25	0.31	0.75	0.06	0.09	0.14	0.75	H2	H2	H2	H4	0.75	0.67	0.67	0.25 to 0.33	115	125	130	60	5	20	35	35 to 45
M1_37	0	0.08	0.35	0.35	0	0.35	0.43	0.97	0	0.03	0.05	0.34	H0	H1	H1	H2	0.00	0.58	0.50	0.17 to 0.25	0	15	20	25 to 35	0	0	0	5

Road Closure ID	Depth (m)				Velocity (m/s)				Velocity x Depth (m2/s)				H1-H6 Hazard				Time to Peak (hour)				Duration Water Above Road (min)				Duration Water Above Road over 0.3m Depth (min)			
	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*
M1_38	0	0	0.35	0.35	0	0	0	0.7	0	0	0	0.24	H0	H0	H0	H2	0.00	0.00	0.58	0.17 to 0.25	0	0	5	20 to 30	0	0	0	0 to 5
M1_39	0	0	0.35	0.35	0	0	0.41	0.89	0	0	0.04	0.31	H0	H0	H1	H2	0.58	0.58	0.58	0.17 to 0.25	5	15	25	25 to 35	0	0	0	10
M1_40	0.15	0.21	0.66	0.66	0.36	0.44	0.51	0.98	0.05	0.09	0.13	0.65	H1	H1	H1	H4	0.67	0.67	0.67	0.25 to 0.33	40	60	80	50 to 55	0	0	0	20 to 35
M1_41	0	0	0.62	0.62	0	0	0	0.88	0	0	0	0.54	H0	H0	H0	H3	1.17	1.00	0.83	0.25 to 0.42	25	45	65	60	0	0	0	10 to 20
M1_42	0.28	0.33	0.68	0.68	0.29	0.37	0.42	0.83	0.08	0.12	0.15	0.57	H1	H2	H2	H3	0.58	0.58	0.58	0.17 to 0.25	80	85	95	50 to 55	0	0	5	15 to 30
M1_43	0.15	0.19	0.76	0.76	0.52	0.58	0.64	1.52	0.08	0.11	0.14	1.16	H1	H1	H1	H5	0.83	0.75	0.67	0.42 to 0.50	115	120	125	55	0	0	0	35 to 45
M1_44	0	0	0.65	0.65	0	0	0	1.09	0	0	0	0.71	H0	H0	H0	H4	0.00	0.00	0.58	0.33 to 0.42	0	0	10	40 to 50	0	0	0	15 to 25
M1_45	0.15	0.19	0.51	0.51	0.53	0.61	0.68	1.26	0.08	0.12	0.15	0.65	H1	H1	H1	H4	0.58	0.58	0.58	0.17 to 0.25	35	50	70	30 to 45	0	0	0	10 to 20
M1_46	0	0	0.62	0.62	0	0	0	1.12	0	0	0	0.69	H0	H0	H0	H4	0.00	0.00	0.00	0.42 to 0.50	0	0	0	40 to 45	0	0	0	10 to 25
M1_47	0.53	0.61	1.58	1.58	0.29	0.36	0.43	0.92	0.15	0.22	0.3	1.45	H3	H3	H3	H5	0.92	0.83	0.75	0.33 to 0.42	140	140	145	60	110	120	130	55 to 60
M1_48	0.19	0.28	1.35	1.35	1.35	1.53	1.6	1.75	0.25	0.36	0.45	1.88	H1	H2	H2	H5	0.92	0.83	0.83	0.33 to 0.42	125	130	130	55	0	0	40	45 to 50
M1_49	0.19	0.28	0.77	0.77	0.46	0.58	0.68	1.19	0.09	0.16	0.24	0.92	H1	H1	H2	H4	0.67	0.67	0.67	0.25 to 0.33	55	75	85	55 to 60	0	0	15	25 to 40
M1_50	0.23	0.28	0.6	0.6	0.19	0.22	0.25	0.56	0.04	0.06	0.08	0.33	H1	H1	H2	H3	0.67	0.58	0.58	0.17 to 0.42	70	90	105	60	0	0	0	25 to 35
M1_51	0.4	0.48	1.07	1.07	0.62	0.72	0.81	1.47	0.25	0.35	0.45	1.57	H2	H2	H3	H5	0.83	0.75	0.67	0.25 to 0.33	125	125	130	55 to 60	45	60	70	50 to 55
M1_52	0.44	0.51	1.1	1.1	0.42	0.48	0.54	1.04	0.19	0.25	0.31	1.14	H2	H3	H3	H5	0.67	0.67	0.58	0.25 to 0.33	135	140	140	60	40	60	75	50 to 55
M1_53	0.23	0.28	0.96	0.96	0.08	0.1	0.13	0.38	0.02	0.03	0.04	0.25	H1	H1	H2	H3	0.67	0.67	0.58	0.25 to 0.50	110	125	130	55 to 60	0	0	20	50 to 55
M1_54	0.56	0.66	1.41	1.41	0.31	0.37	0.43	0.86	0.17	0.24	0.32	1.22	H3	H3	H3	H5	0.83	0.75	0.67	0.25 to 0.33	135	135	140	60	75	90	105	55
M1_55	0.36	0.4	0.59	0.59	0.08	0.11	0.13	0.31	0.03	0.04	0.06	0.18	H2	H2	H2	H3	0.75	0.67	0.67	0.25 to 0.33	130	135	135	60	40	55	70	45 to 55
M1_56	0.18	0.29	0.95	0.95	0.23	0.31	0.37	0.78	0.04	0.09	0.14	0.74	H1	H1	H2	H4	1.08	0.92	0.83	0.33 to 0.50	95	115	125	60	0	0	35	50 to 55
M1_57	0.23	0.26	0.82	0.82	0.06	0.06	0.06	0.23	0.01	0.01	0.01	0.18	H1	H1	H2	H3	0.83	0.75	1.00	0.58	130	135	135	60	0	0	70	55
M1_58	0.31	0.35	0.61	0.61	0.03	0.03	0.05	0.14	0	0.01	0.02	0.08	H2	H2	H2	H3	1.50	1.25	1.25	0.33 to 0.42	135	135	140	60	0	75	110	55
M1_59	0	0.14	0.97	0.97	0	0.21	0.41	1.09	0	0.03	0.13	1.06	H0	H1	H2	H5	0.00	0.75	0.67	0.25 to 0.33	0	15	25	35 to 40	0	0	5	25 to 35
M1_60	0.14	0.24	0.95	0.95	0.1	0.16	0.22	0.43	0.01	0.04	0.08	0.4	H1	H1	H2	H3	0.92	1.00	0.92	0.33 to 0.42	110	120	125	55	0	0	20	35 to 45
M1_61	0.19	0.31	0.93	0.93	0.24	0.26	0.28	0.53	0.05	0.08	0.11	0.49	H1	H2	H2	H3	0.58	0.58	0.58	0.25	120	125	130	60	0	10	20	20 to 35
M1_62	0.32	0.51	1.32	1.32	0.16	0.24	0.32	0.9	0.05	0.12	0.2	1.19	H2	H3	H3	H5	0.75	0.67	0.67	0.25	100	100	110	60	5	20	30	30 to 40
M1_63	0.24	0.3	0.87	0.87	0.51	0.57	0.61	1.07	0.12	0.17	0.2	0.93	H1	H1	H2	H4	0.58	0.58	0.50	0.17 to 0.25	120	120	65	30 to 45	0	0	10	20 to 30
M1_64	0.26	0.33	0.9	0.9	1	1.1	1.2	1.96	0.26	0.36	0.48	1.75	H1	H2	H2	H5	0.75	0.75	0.67	0.25 to 0.33	80	95	100	55	0	15	25	30 to 40
M1_65	0.61	0.74	1.44	1.44	0.11	0.11	0.14	0.42	0.05	0.08	0.12	0.61	H3	H3	H3	H4	1.00	0.92	0.83	0.33 to 0.42	100	110	115	60	65	75	90	55
M1_66	1	1.13	1.86	1.86	0.14	0.15	0.15	0.2	0.05	0.07	0.09	0.37	H3	H3	H4	H4	1.00	0.92	0.83	0.33 to 0.42	135	135	140	60	125	130	130	55 to 60
M1_67	0.3	0.4	1.04	1.04	0.37	0.47	0.56	1.06	0.11	0.19	0.27	1.11	H1	H2	H2	H5	0.83	0.75	0.67	0.25 to 0.33	90	95	105	60	0	25	35	30 to 40
M1_68	0.36	0.43	1.24	1.24	0.05	0.08	0.1	0.26	0.02	0.03	0.04	0.31	H2	H2	H3	H4	0.75	0.92	0.83	0.33 to 0.42	130	130	135	60	75	85	90	55
M1_69	0.3	0.37	1.11	1.11	0.27	0.34	0.46	1.4	0.08	0.12	0.21	1.56	H2	H2	H2	H5	0.67	0.58	0.92	0.25 to 0.33	135	140	140	60	0	25	60	45 to 50
M1_70	0.22	0.27	0.73	0.73	0.26	0.32	0.36	0.6	0.06	0.09	0.11	0.43	H1	H1	H2	H3	0.67	0.67	0.58	0.25 to 0.33	120	125	130	60	0	0	10	25 to 35
M1_71	0.27	0.35	1.29	1.29	0.29	0.35	0.39	0.78	0.08	0.12	0.17	0.99	H1	H2	H2	H4	0.83	0.75	0.75	0.33 to 0.42	110	125	130	55 to 60	0	25	50	45 to 55
M1_72	0.46	0.5	1.21	1.21	0.31	0.35	0.35	1.27	0.12	0.16	0.19	1.54	H2	H2	H3	H5	0.75	0.75	0.92	0.25 to 0.33	105	125	135	60	70	90	95	55
M2_1	0	0.13	0.36	0.36	0	0.1	0.1	0.18	0	0.01	0.01	0.05	H0	H1	H1	H2	0.67	0.58	0.58	0.25 to 0.33	45	60	75	55	0	0	0	10 to 15
M2_2	0	0.11	0.48	0.48	0	0.15	0.19	0.38	0	0.02	0.03	0.18	H0	H1	H1	H2	0.75	0.75	0.75	0.25 to 0.42	80	90	105	60	0	0	0	25 to 35

Road Closure ID	Depth (m)				Velocity (m/s)				Velocity x Depth (m2/s)				H1-H6 Hazard				Time to Peak (hour)				Duration Water Above Road (min)				Duration Water Above Road over 0.3m Depth (min)			
	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*
M2_3	0	0	0.38	0.38	0	0	0.2	0.45	0	0	0.03	0.17	H0	H0	H1	H2	0.00	0.83	0.75	0.25 to 0.42	0	25	50	50 to 55	0	0	0	0 to 15
M2_4	0	0.14	0.41	0.41	0	0.1	0.11	0.2	0	0.01	0.02	0.06	H0	H1	H1	H2	0.67	0.67	0.67	0.25 to 0.33	45	65	75	55	0	0	0	15 to 20
M2_5	0.15	0.19	0.42	0.42	0.06	0.08	0.09	0.2	0.01	0.01	0.02	0.08	H1	H1	H1	H2	1.00	0.92	0.83	0.33 to 0.42	70	85	95	55 to 60	0	0	0	15 to 25
M2_6	0	0	0.35	0.35	0	0	0.14	0.22	0	0	0.02	0.08	H0	H0	H1	H2	0.67	0.75	0.75	0.25 to 0.42	55	70	80	60	0	0	0	10 to 20
M2_7	0.19	0.22	0.37	0.37	0.04	0.03	0.05	0.11	0.01	0.01	0.01	0.04	H1	H1	H1	H2	0.58	0.58	0.50	0.17 to 0.25	135	140	140	60	0	0	0	10 to 20
M2_8	0.15	0.19	0.57	0.57	0.44	0.57	0.7	1.33	0.06	0.11	0.17	0.76	H1	H1	H1	H4	0.58	0.58	0.58	0.25	40	55	70	40 to 55	0	0	0	15 to 25
M2_9	0.24	0.3	0.71	0.71	0.35	0.45	0.54	1.06	0.09	0.14	0.19	0.75	H1	H1	H2	H4	0.67	0.58	0.58	0.17 to 0.25	75	90	95	45 to 60	0	0	15	25 to 30
M2_10	0.17	0.22	0.64	0.64	0.48	0.55	0.61	1.06	0.08	0.12	0.16	0.68	H1	H1	H1	H4	0.58	0.58	0.58	0.17 to 0.25	70	75	90	40 to 55	0	0	0	15 to 25
M2_11	0.12	0.14	0.39	0.39	0.53	0.59	0.63	1.23	0.06	0.08	0.1	0.47	H1	H1	H1	H2	0.50	0.50	0.50	0.17	35	50	70	25 to 40	0	0	0	0
M2_12	0.21	0.23	0.4	0.4	0.14	0.17	0.18	0.35	0.03	0.04	0.05	0.14	H1	H1	H1	H2	0.50	0.50	0.50	0.17	30	45	60	30 to 40	0	0	0	5 to 10
M2_13	0.18	0.23	0.52	0.52	0.27	0.35	0.41	0.82	0.05	0.08	0.11	0.42	H1	H1	H1	H3	0.58	0.50	0.50	0.17 to 0.25	85	95	95	45 to 60	0	0	0	15 to 25
M2_14	0	0.08	0.37	0.37	0	0.41	0.54	1.18	0	0.03	0.06	0.43	H0	H1	H1	H2	0.67	0.58	0.58	0.17 to 0.25	5	15	25	30 to 35	0	0	0	10
M2_15	0.15	0.19	0.5	0.5	0.25	0.26	0.29	0.53	0.04	0.05	0.07	0.26	H1	H1	H1	H3	0.58	0.58	0.58	0.17 to 0.25	45	60	70	35 to 50	0	0	0	10 to 20
M2_16	0	0.16	0.64	0.64	0	0.16	0.22	0.73	0	0.02	0.06	0.47	H0	H1	H1	H3	0.58	1.33	1.00	0.25 to 0.33	10	65	100	55 to 60	0	0	0	20 to 30
M2_17	0	0.16	0.49	0.49	0	0.26	0.3	0.56	0	0.04	0.06	0.27	H0	H1	H1	H2	0.58	0.58	0.50	0.17 to 0.25	15	30	40	25 to 40	0	0	0	10 to 25
M2_18	0.16	0.19	0.51	0.51	0.11	0.13	0.15	0.53	0.02	0.02	0.03	0.27	H1	H1	H1	H3	0.58	0.58	0.50	0.25 to 0.33	85	125	135	60	0	0	0	15 to 30
M2_19	0.13	0.16	0.67	0.67	0.17	0.21	0.27	0.87	0.02	0.04	0.06	0.58	H1	H1	H1	H3	0.67	0.58	1.08	0.25 to 0.33	110	135	135	60	0	0	0	25 to 40
M2_20	0.1	0.14	0.63	0.63	0.28	0.34	0.39	0.88	0.03	0.05	0.07	0.56	H1	H1	H1	H3	0.67	0.58	0.58	0.33 to 0.42	30	45	80	50 to 55	0	0	0	20 to 35
M2_21	0	0.08	0.57	0.57	0	0.41	0.45	1.21	0	0.03	0.04	0.69	H0	H1	H1	H4	0.50	0.50	0.50	0.25 to 0.33	20	30	65	35 to 45	0	0	0	15 to 20
M2_22	0	0	0.53	0.53	0	0	0	0.39	0	0	0	0.22	H0	H0	H0	H3	0.00	0.00	0.00	0.50 to 0.58	0	0	0	55 to 60	0	0	0	10 to 30
M2_23	0.1	0.12	0.32	0.32	0.32	0.37	0.42	0.74	0.03	0.05	0.06	0.24	H1	H1	H1	H2	0.58	0.58	0.50	0.17 to 0.25	70	80	90	40 to 55	0	0	0	0 to 5
M2_24	0.11	0.14	0.39	0.39	0.39	0.43	0.47	0.82	0.04	0.06	0.08	0.33	H1	H1	H1	H2	0.58	0.50	0.50	0.17	45	55	70	30 to 45	0	0	0	5 to 15
M2_25	0.21	0.26	0.75	0.75	0.91	1.01	1.1	1.8	0.19	0.26	0.34	1.35	H1	H1	H2	H5	0.75	0.67	0.58	0.25 to 0.33	120	120	125	55	0	0	0	20 to 25
M2_26	0.19	0.23	0.65	0.65	0.35	0.41	0.46	0.92	0.07	0.09	0.12	0.6	H1	H1	H1	H3	0.58	0.58	0.58	0.17 to 0.25	70	80	85	40 to 50	0	0	0	15 to 25
M2_27	0.15	0.17	0.43	0.43	0.36	0.41	0.44	0.79	0.05	0.07	0.09	0.34	H1	H1	H1	H2	0.58	0.50	0.50	0.17	40	55	70	30 to 40	0	0	0	10 to 15
M2_28	0.14	0.18	0.45	0.45	0.15	0.18	0.2	0.4	0.02	0.03	0.04	0.18	H1	H1	H1	H2	0.75	0.67	0.67	0.25 to 0.33	55	70	85	55	0	0	0	15 to 20
M2_29	0.17	0.22	0.81	0.81	0.3	0.36	0.43	0.81	0.05	0.08	0.12	0.66	H1	H1	H1	H4	0.58	0.58	0.58	0.25	55	70	80	45 to 60	0	0	0	20 to 30
M2_30	0.15	0.21	0.53	0.53	0.18	0.22	0.25	0.34	0.03	0.05	0.06	0.18	H1	H1	H1	H3	0.75	0.67	0.67	0.25 to 0.33	110	115	125	60	0	0	0	25 to 35
M2_31	0	0.11	0.44	0.44	0	0.2	0.3	0.78	0	0.02	0.05	0.34	H0	H1	H1	H2	0.00	0.67	0.67	0.25 to 0.33	0	15	25	30 to 40	0	0	0	5 to 15
M2_32	0.16	0.2	0.52	0.52	0.45	0.54	0.62	1.22	0.07	0.11	0.14	0.63	H1	H1	H1	H4	0.50	0.50	0.50	0.17	40	55	65	25 to 40	0	0	0	15 to 20
M2_33	0.17	0.2	0.4	0.4	0.24	0.27	0.3	0.47	0.04	0.05	0.07	0.19	H1	H1	H1	H2	0.58	0.58	0.50	0.17 to 0.25	110	115	120	60	0	0	0	10 to 20
M2_34	0.13	0.17	0.54	0.54	0.49	0.57	0.63	1.16	0.07	0.09	0.13	0.62	H1	H1	H1	H4	0.58	0.58	0.58	0.17 to 0.25	80	85	95	45 to 60	0	0	0	10 to 25
M2_35	0.05	0.08	0.34	0.34	0.71	0.48	0.53	1.05	0.03	0.06	0.07	0.36	H1	H1	H1	H2	0.58	0.58	0.50	0.17	15	25	35	25 to 40	0	0	0	5 to 10
M2_36	0	0	0.63	0.63	0	0	0.42	1.05	0	0	0.05	0.66	H0	H0	H1	H4	0.00	0.67	0.58	0.25	0	25	30	35 to 45	0	0	0	15 to 20
M2_37	0.1	0.15	0.5	0.5	0.35	0.44	0.51	0.97	0.04	0.07	0.1	0.49	H1	H1	H1	H3	0.67	0.58	0.58	0.17 to 0.25	20	30	45	35 to 40	0	0	0	10 to 25
M2_38	0.19	0.24	0.54	0.54	0.56	0.64	0.7	1.1	0.11	0.16	0.19	0.6	H1	H1	H1	H3	0.67	0.58	0.58	0.17 to 0.25	95	100	110	55 to 60	0	0	0	15 to 25
M2_39	0	0.16	0.47	0.47	0	0.45	0.54	1.11	0	0.07	0.1	0.52	H0	H1	H1	H2	0.67	0.67	0.58	0.17 to 0.25	20	30	45	30 to 40	0	0	0	15 to 20

Road Closure ID	Depth (m)				Velocity (m/s)				Velocity x Depth (m2/s)				H1-H6 Hazard				Time to Peak (hour)				Duration Water Above Road (min)				Duration Water Above Road over 0.3m Depth (min)			
	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*
M2_40	0.14	0.19	0.68	0.68	0.37	0.44	0.5	1.11	0.05	0.08	0.11	0.75	H1	H1	H1	H4	0.67	0.67	0.67	0.25	60	70	80	45 to 50	0	0	0	15 to 25
M2_41	0	0.08	0.33	0.33	0	0.53	0.6	1.07	0	0.04	0.06	0.36	H0	H1	H1	H2	0.58	0.50	0.50	0.17	10	15	20	20 to 30	0	0	0	0 to 5
M2_42	0.23	0.51	1.29	1.29	0.14	0.34	0.49	1.18	0.03	0.17	0.32	1.52	H1	H3	H3	H5	0.67	0.67	0.58	0.25 to 0.33	135	135	140	60	0	15	25	25 to 40
M2_43	0.24	0.28	0.66	0.66	0.07	0.1	0.15	0.76	0.01	0.03	0.05	0.51	H1	H1	H2	H3	0.58	0.58	0.58	0.25	45	60	75	40 to 55	0	0	10	20 to 30
M2_44	0.56	0.56	0.98	0.98	1.59	1.57	1.58	2.1	0.83	0.81	0.83	2.06	H4	H4	H4	H5	0.75	0.42	0.67	0.25 to 0.33	80	85	95	55 to 60	10	30	35	30 to 45
M2_45	0	0	0.86	0.86	0	0	0.26	1.07	0	0	0.05	0.92	H0	H0	H1	H4	0.00	0.00	0.67	0.25 to 0.33	0	0	25	35 to 40	0	0	0	20 to 30
M2_46	0.14	0.18	0.55	0.55	0.36	0.4	0.44	0.86	0.05	0.07	0.1	0.47	H1	H1	H1	H3	0.58	0.58	0.50	0.17	80	85	95	40 to 55	0	0	0	15 to 20
M2_47	0	0	0.43	0.43	0	0	0.41	1.1	0	0	0.04	0.47	H0	H0	H1	H2	0.00	0.58	0.58	0.17 to 0.25	0	5	15	20 to 30	0	0	0	10 to 20
M2_48	0.25	0.27	0.84	0.84	0.63	0.59	0.71	1.53	0.15	0.16	0.26	1.28	H1	H1	H2	H5	0.83	0.75	0.67	0.25 to 0.33	20	35	50	35 to 50	0	0	10	25 to 35
M2_49	0.4	0.43	0.59	0.59	0.03	0.03	0.03	0.12	0.01	0.01	0.01	0.06	H2	H2	H2	H3	0.83	0.75	0.67	0.25 to 0.33	135	135	140	60	115	125	125	55 to 60
M2_50	0.26	0.36	0.96	0.96	0.4	0.5	0.56	1	0.11	0.18	0.25	0.95	H1	H2	H2	H4	0.75	0.67	0.67	0.25 to 0.33	40	50	70	40 to 50	0	20	30	30 to 40
M2_51	0.48	0.55	1.11	1.11	0.54	0.66	0.75	1.36	0.26	0.36	0.45	1.51	H2	H3	H3	H5	0.67	0.67	0.58	0.25	120	130	135	60	40	55	65	40 to 45
M2_52	0.48	0.53	0.91	0.91	0.1	0.04	0.17	0.42	0.05	0.07	0.1	0.38	H2	H3	H3	H3	0.67	0.58	0.58	0.25 to 0.33	135	140	140	60	85	105	120	55 to 60
M2_53	0.27	0.35	0.96	0.96	0.5	0.6	0.69	1.31	0.13	0.21	0.3	1.26	H1	H2	H2	H5	0.58	0.58	0.58	0.17 to 0.25	115	120	120	60	0	15	20	25 to 35
M2_54	0.28	0.34	0.81	0.81	0.36	0.46	0.54	1.05	0.1	0.16	0.21	0.85	H1	H2	H2	H4	0.58	0.58	0.58	0.17 to 0.25	80	90	100	50 to 60	0	5	15	20 to 30
M2_55	0.19	0.25	0.74	0.74	0.54	0.63	0.74	1.39	0.1	0.16	0.24	1.03	H1	H1	H2	H5	0.58	0.58	0.58	0.25	45	60	70	40 to 55	0	0	10	20 to 30
M2_56	0.56	0.62	1.22	1.22	0.08	0.1	0.12	0.43	0.03	0.05	0.08	0.52	H3	H3	H3	H4	1.33	1.17	1.08	0.42 to 0.50	130	130	135	60	100	110	120	55
M2_57	0.33	0.38	0.83	0.83	0.2	0.21	0.25	0.56	0.05	0.08	0.11	0.47	H2	H2	H2	H3	0.75	0.67	0.67	0.25 to 0.42	115	130	135	55 to 60	10	30	65	45 to 55
M2_58	0.3	0.39	1.24	1.24	0.01	0.08	0.09	0.26	0.01	0.01	0.01	0.31	H1	H2	H2	H4	1.58	1.50	1.42	0.42 to 0.50	135	135	140	60	0	85	110	55
M2_59	0.46	0.53	1.18	1.18	0.02	0.08	0.1	0.15	0.02	0.03	0.04	0.24	H2	H3	H3	H3	1.33	1.17	1.08	0.42 to 0.50	140	140	140	60	95	105	110	55
M2_60	0.29	0.35	0.89	0.89	0.26	0.32	0.39	0.8	0.07	0.11	0.16	0.71	H1	H2	H2	H4	1.33	1.17	1.08	0.42 to 0.50	100	125	130	55	0	50	80	45 to 50
M2_61	0.38	0.46	1.3	1.3	0.05	0.05	0.02	0.42	0.01	0.01	0.03	0.46	H2	H2	H3	H4	1.42	1.25	1.08	0.42 to 0.50	135	140	140	60	65	100	110	55
M2_62	0.25	0.32	1.02	1.02	0.09	0.14	0.2	0.54	0.02	0.05	0.07	0.54	H1	H2	H2	H3	0.83	0.75	0.75	0.33 to 0.42	115	135	135	60	0	10	35	50
M2_63	0.48	0.57	1.36	1.36	0.09	0.12	0.15	0.37	0.04	0.06	0.08	0.49	H2	H3	H3	H4	1.17	1.00	0.92	0.42 to 0.50	140	140	140	60	120	125	130	55 to 60
M2_64	0.34	0.43	1.06	1.06	0.28	0.37	0.44	0.95	0.1	0.16	0.22	1	H2	H2	H2	H5	0.58	0.58	0.58	0.17 to 0.25	85	90	100	50 to 60	15	25	35	30 to 35
M2_65	0.5	0.67	1.59	1.59	1.94	1.95	1.98	2.42	0.29	0.37	0.46	1.5	H3	H3	H3	H5	1.42	1.17	1.00	0.33 to 0.42	130	130	135	55 to 60	100	110	115	55
M2_66	0.4	0.47	0.99	0.99	0.63	0.73	0.82	1.56	0.25	0.35	0.44	1.55	H2	H2	H3	H5	0.67	0.67	0.58	0.25	120	130	135	60	25	35	55	35 to 45
M2_67	0.22	0.3	0.92	0.92	0.32	0.4	0.49	1.14	0.07	0.12	0.18	1.06	H1	H1	H2	H5	0.58	0.58	0.58	0.17 to 0.25	95	100	105	55 to 60	0	5	15	25 to 30
M2_68	0.27	0.31	0.56	0.56	0.05	0.07	0.09	0.21	0.01	0.02	0.03	0.12	H1	H2	H2	H3	1.00	0.92	0.83	0.33 to 0.42	135	135	140	60	0	30	50	50 to 55
M2_69	0.33	0.36	0.55	0.55	0.15	0.17	0.19	0.34	0.05	0.06	0.07	0.19	H2	H2	H2	H3	0.67	0.58	0.58	0.25 to 0.33	135	140	140	60	20	35	50	30 to 45
M2_70	0.55	0.59	0.91	0.91	0.3	0.37	0.42	0.8	0.17	0.22	0.26	0.74	H3	H3	H3	H4	0.58	0.58	0.58	0.17 to 0.25	135	140	140	60	130	135	135	55 to 60
M2_71	0.25	0.29	0.51	0.51	0.07	0.08	0.1	0.21	0.02	0.02	0.03	0.1	H1	H1	H2	H3	0.75	0.67	0.67	0.25	110	115	125	60	0	0	0	20 to 35
M3_1	0	0.07	0.23	0.23	0	1.16	1.27	2.97	0	0.08	0.12	0.67	H0	H1	H1	H4	0.58	0.50	0.50	0.17	10	10	25	20 to 35	0	0	0	0
M3_2	0.19	0.25	0.64	0.64	0.18	0.25	0.31	0.72	0.03	0.06	0.09	0.46	H1	H1	H1	H3	0.67	0.58	0.58	0.25 to 0.33	35	50	65	40 to 45	0	0	0	15 to 30
M3_3	0.12	0.16	0.59	0.59	0.35	0.42	0.46	0.74	0.04	0.07	0.09	0.44	H1	H1	H1	H3	0.67	0.50	0.50	0.17 to 0.25	40	55	70	30 to 45	0	0	0	10 to 20
M3_4	0.13	0.15	0.39	0.39	0.36	0.4	0.44	0.75	0.05	0.06	0.07	0.29	H1	H1	H1	H2	0.58	0.50	0.50	0.17	80	90	90	35 to 50	0	0	0	5
M3_5	0.09	0.13	0.42	0.42	0.35	0.43	0.48	0.96	0.03	0.06	0.07	0.4	H1	H1	H1	H2	0.67	0.50	0.50	0.17	30	60	70	30 to 45	0	0	0	10 to 15

Road Closure ID	Depth (m)				Velocity (m/s)				Velocity x Depth (m2/s)				H1-H6 Hazard				Time to Peak (hour)				Duration Water Above Road (min)				Duration Water Above Road over 0.3m Depth (min)			
	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*
M3_6	0.16	0.21	0.54	0.54	0.29	0.36	0.42	0.95	0.05	0.08	0.1	0.51	H1	H1	H1	H3	0.67	0.58	0.58	0.17 to 0.25	40	50	70	35 to 50	0	0	0	15 to 25
M3_7	0.12	0.17	0.53	0.53	0.29	0.35	0.4	0.81	0.04	0.06	0.08	0.43	H1	H1	H1	H3	0.67	0.58	0.58	0.17	95	100	100	45 to 60	0	0	0	10 to 20
M3_8	0	0.21	0.55	0.55	0	0.08	0.13	0.28	0	0.02	0.03	0.15	H0	H1	H1	H3	0.00	0.75	0.67	0.25 to 0.33	0	30	45	40 to 55	0	0	0	25 to 30
M3_9	0	0.14	0.55	0.55	0	0.18	0.26	0.53	0	0.03	0.06	0.29	H0	H1	H1	H3	0.58	0.83	0.75	0.25 to 0.33	50	55	70	40 to 55	0	0	0	20 to 25
M3_10	0	0	0.37	0.37	0	0	0.42	0.82	0	0	0.04	0.31	H0	H0	H1	H2	0.58	0.50	0.50	0.17	15	25	40	20 to 40	0	0	0	5 to 10
M3_11	0	0	0.37	0.37	0	0	0.29	0.47	0	0	0.04	0.17	H0	H0	H1	H2	0.67	0.50	0.75	0.25 to 0.33	15	40	50	40 to 50	0	0	0	5 to 10
M3_12	0	0	0.48	0.48	0	0	0.23	0.5	0	0	0.03	0.23	H0	H0	H1	H2	0.00	0.67	0.58	0.25 to 0.42	0	10	20	40 to 55	0	0	0	15 to 30
M3_13	0	0	0.35	0.35	0	0	0	0.35	0	0	0	0.12	H0	H0	H0	H2	0.00	0.58	0.58	0.17 to 0.42	0	15	20	25 to 40	0	0	0	10 to 15
M3_14	0.17	0.21	0.52	0.52	0.34	0.42	0.5	1.03	0.06	0.09	0.13	0.53	H1	H1	H1	H3	2.50	2.25	2.00	0.75 to 0.83	45	80	100	50 to 55	0	0	45	35
M3_15	0.36	0.4	0.6	0.6	0.13	0.14	0.14	0.25	0.05	0.05	0.06	0.15	H2	H2	H2	H3	0.67	0.58	0.58	0.25	90	100	105	60	25	35	50	35 to 40
M3_16	0.19	0.26	0.77	0.77	0.35	0.45	0.54	1.13	0.07	0.12	0.18	0.87	H1	H1	H2	H4	0.67	0.58	0.58	0.17 to 0.25	80	90	95	50 to 60	0	0	5	20 to 30
M3_17	0.46	0.51	1.32	1.32	0.13	0.14	0.14	0.37	0.02	0.04	0.07	0.35	H2	H3	H3	H4	1.08	0.83	0.83	0.42 to 0.50	125	135	135	60	110	120	125	55
M3_18	0.12	0.15	1.04	1.04	0.24	0.31	0.37	0.58	0.03	0.05	0.07	0.32	H1	H1	H1	H3	1.08	0.92	0.92	0.42 to 0.50	100	120	125	55 to 60	0	0	0	50
M3_19	0	0	0.94	0.94	0	0	0	1.25	0	0	0	1.18	H0	H0	H0	H5	0.58	0.50	0.50	0.42 to 0.50	50	60	75	60	0	0	0	45 to 50
M4_1	0	0.14	0.68	0.68	0	0.24	0.28	0.83	0	0.03	0.08	0.56	H0	H1	H1	H3	0.67	0.83	0.75	0.25 to 0.33	40	60	70	50 to 60	0	0	0	25 to 35
M4_2	0	0	0.39	0.39	0	0	0	0.23	0	0	0	0.08	H0	H0	H0	H2	1.00	1.42	1.25	0.50 to 0.58	55	70	85	55	0	0	0	0 to 25
M4_3	0	0.2	0.54	0.54	0	0.4	0.5	0.9	0	0.08	0.13	0.49	H0	H1	H1	H3	0.50	0.75	0.67	0.25 to 0.33	85	90	95	45 to 60	0	0	0	20 to 30
M4_4	0.4	0.49	0.74	0.74	0.02	0.02	0.03	0.17	0	0.01	0.02	0.13	H2	H2	H3	H3	1.75	1.67	1.50	0.33 to 0.42	130	135	140	60	100	115	125	55
M4_5	0.26	0.32	0.64	0.64	0.14	0.18	0.22	0.45	0.04	0.06	0.08	0.29	H1	H2	H2	H3	0.92	0.83	0.75	0.25 to 0.33	140	140	140	60	0	15	30	40 to 45
M4_6	0.44	0.53	0.79	0.79	0.01	0.04	0.05	0.14	0.01	0.01	0.02	0.08	H2	H3	H3	H3	1.75	1.67	1.50	0.33 to 0.42	140	140	145	60	105	120	125	55
M4_7	0.28	0.32	0.81	0.81	0.09	0.14	0.2	0.79	0.02	0.04	0.07	0.63	H1	H2	H2	H4	0.67	0.67	0.58	0.25 to 0.33	70	80	95	60	0	5	20	25 to 40
M4_8	0.17	0.19	0.39	0.39	0.07	0.1	0.11	0.31	0.01	0.02	0.02	0.12	H1	H1	H1	H2	0.58	0.58	0.50	0.17 to 0.25	35	45	60	35 to 50	0	0	0	10 to 20
M4_9	0	0	0.3	0.3	0	0	0.22	0.53	0	0	0.03	0.16	H0	H0	H1	H2	0.83	0.75	0.67	0.25 to 0.33	45	60	75	55	0	0	0	0 to 5
M4_10	0.11	0.16	0.44	0.44	0.14	0.25	0.32	0.72	0.02	0.04	0.06	0.31	H1	H1	H1	H2	0.67	0.58	0.58	0.17 to 0.25	80	85	95	50 to 60	0	0	0	15 to 25
M4_11	0	0.11	0.37	0.37	0	0.07	0.08	0.2	0	0.01	0.01	0.05	H0	H1	H1	H2	0.58	0.58	1.50	0.25 to 0.42	85	135	140	60	0	0	0	10 to 25
M4_12	0.17	0.21	0.53	0.53	0.26	0.29	0.32	0.59	0.04	0.06	0.08	0.31	H1	H1	H1	H3	0.67	0.58	0.58	0.17 to 0.25	140	140	140	60	0	0	0	15 to 30
M4_13	0.17	0.22	0.54	0.54	0.27	0.37	0.44	0.89	0.05	0.08	0.11	0.48	H1	H1	H1	H3	0.67	0.67	0.58	0.25	30	45	60	35 to 50	0	0	0	15 to 25
M4_14	0	0.16	0.7	0.7	0	0.34	0.44	0.88	0	0.05	0.11	0.61	H0	H1	H1	H4	0.75	0.67	0.75	0.25 to 0.33	15	40	55	45 to 50	0	0	0	25 to 35
M4_15	0.11	0.12	0.34	0.34	0.15	0.17	0.18	0.47	0.02	0.02	0.02	0.16	H1	H1	H1	H2	0.67	0.58	0.50	0.25	85	90	100	55 to 60	0	0	0	5 to 10
M4_16	0	0	0.59	0.59	0	0	0.35	0.88	0	0	0.05	0.52	H0	H0	H1	H3	0.00	0.58	0.58	0.25	0	10	25	25 to 40	0	0	0	15 to 25
M4_17	0.17	0.23	0.57	0.57	0.22	0.31	0.39	0.9	0.04	0.07	0.11	0.51	H1	H1	H1	H3	0.75	0.67	0.58	0.25	30	45	60	40 to 50	0	0	0	20 to 30
M4_18	0.2	0.24	0.51	0.51	0.13	0.19	0.26	0.64	0.03	0.04	0.07	0.33	H1	H1	H1	H3	0.75	0.67	0.58	0.25 to 0.33	140	140	140	60	0	0	0	20 to 35
M5_1	0	0.13	0.47	0.47	0	0.2	0.23	0.47	0	0.03	0.04	0.22	H0	H1	H1	H2	0.67	0.67	0.58	0.25 to 0.33	25	35	55	35 to 45	0	0	0	15 to 20
M5_2	0.12	0.17	0.36	0.36	0.09	0.11	0.13	0.32	0.01	0.02	0.03	0.12	H1	H1	H1	H2	0.67	0.67	0.58	0.25 to 0.33	30	50	65	45 to 55	0	0	0	10 to 20
M5_3	0	0	0.31	0.31	0	0	0	0.23	0	0	0	0.05	H0	H0	H0	H2	0.00	0.00	0.67	0.33 to 0.42	0	0	10	35 to 45	0	0	0	0 to 10
M5_4	0.18	0.25	0.55	0.55	0.23	0.36	0.44	0.83	0.04	0.09	0.13	0.46	H1	H1	H1	H3	0.75	0.75	0.67	0.25 to 0.33	100	110	120	60	0	0	10	30 to 35
M5_5	0	0	0.35	0.35	0	0	0	0.48	0	0	0	0.13	H0	H0	H0	H2	0.00	0.00	0.75	0.25 to 0.42	0	0	15	35 to 45	0	0	0	0 to 15

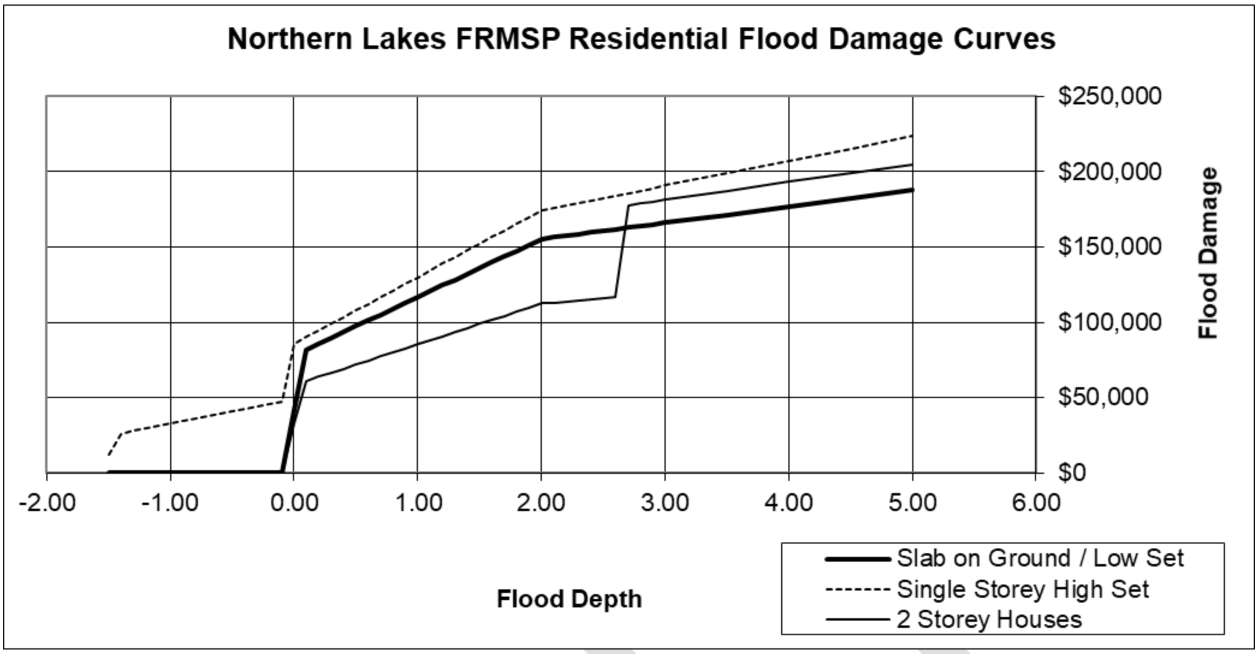
Road Closure ID	Depth (m)				Velocity (m/s)				Velocity x Depth (m2/s)				H1-H6 Hazard				Time to Peak (hour)				Duration Water Above Road (min)				Duration Water Above Road over 0.3m Depth (min)			
	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*	20% AEP	5% AEP	1% AEP	PMF*
M5_6	0	0	0.35	0.35	0	0	0	0.3	0	0	0	0.09	H0	H0	H0	H2	1.08	0.83	0.67	0.25 to 0.42	90	95	105	55 to 60	0	0	0	0 to 15
M5_7	0.33	0.42	0.9	0.9	0.05	0.06	0.06	0.15	0.01	0.01	0.01	0.03	H2	H2	H3	H3	1.00	1.00	1.00	0.25 to 0.42	105	135	140	60	35	80	115	55
M5_8	0.48	0.52	0.98	0.98	0.18	0.13	0.12	0.39	0.05	0.07	0.1	0.38	H2	H3	H3	H3	0.67	0.58	0.67	0.25 to 0.33	135	140	140	60	120	130	135	55 to 60
M5_9	0.26	0.49	1.17	1.17	0.15	0.12	0.12	0.28	0.04	0.05	0.05	0.33	H1	H2	H3	H3	0.92	1.00	0.92	0.33 to 0.42	100	110	120	60	0	50	70	55
M5_10	0.35	0.41	0.72	0.72	0.07	0.08	0.11	0.29	0.02	0.03	0.05	0.21	H2	H2	H2	H3	0.92	0.83	0.75	0.25 to 0.42	130	135	135	60	45	65	80	55
M5_11	0.16	0.27	0.93	0.93	0.2	0.22	0.22	0.4	0.02	0.04	0.06	0.3	H1	H1	H2	H3	1.17	1.00	0.92	0.33 to 0.42	100	115	130	55 to 60	0	0	35	45 to 50
M5_12	0.18	0.24	0.76	0.76	0.09	0.13	0.16	0.36	0.02	0.03	0.05	0.27	H1	H1	H2	H3	0.83	0.83	0.83	0.33 to 0.42	65	80	90	55 to 60	0	0	5	35 to 45
M5_13	0.2	0.3	0.52	0.52	0.01	0.04	0.07	0.27	0	0.01	0.02	0.14	H1	H1	H2	H3	0.83	0.67	0.58	0.17 to 0.25	50	65	80	55 to 60	0	25	40	30 to 40
M5_14	0.15	0.27	0.82	0.82	0.13	0.18	0.23	0.52	0.02	0.04	0.08	0.42	H1	H1	H2	H3	1.50	1.25	1.08	0.33 to 0.50	130	130	135	60	0	0	35	50
M5_15	0.15	0.21	0.53	0.53	0.13	0.14	0.07	0.42	0.02	0.02	0.03	0.22	H1	H1	H1	H3	0.67	0.58	0.58	0.25 to 0.33	75	80	90	40 to 55	0	0	0	15 to 30
M5_16	0	0.16	0.46	0.46	0	0.07	0.07	0.13	0	0.01	0.01	0.06	H0	H1	H1	H2	0.75	0.75	0.75	0.25 to 0.33	20	45	75	55 to 60	0	0	0	25 to 30
M5_17	0.11	0.17	0.49	0.49	0.09	0.12	0.15	0.32	0.01	0.02	0.03	0.15	H1	H1	H1	H2	0.67	0.67	0.67	0.25	15	30	40	40 to 45	0	0	0	15 to 20
M5_18	0.14	0.18	0.33	0.33	0.1	0.14	0.16	0.26	0.01	0.02	0.03	0.09	H1	H1	H1	H2	0.58	0.58	0.58	0.17 to 0.33	100	100	110	55 to 60	0	0	0	10 to 20
M5_19	0.12	0.16	0.52	0.52	0.24	0.28	0.32	0.64	0.03	0.05	0.06	0.33	H1	H1	H1	H3	0.58	0.58	0.50	0.17 to 0.25	85	85	90	35 to 45	0	0	0	10 to 20
M5_20	0	0.14	0.44	0.44	0	0.27	0.34	0.61	0	0.04	0.07	0.27	H0	H1	H1	H2	1.00	0.83	0.75	0.25 to 0.33	45	70	85	55 to 60	0	0	0	20 to 30
M5_21	0.18	0.23	0.54	0.54	0.24	0.28	0.33	0.6	0.04	0.06	0.09	0.33	H1	H1	H1	H3	0.92	0.83	0.75	0.33 to 0.42	95	105	110	60	0	0	0	25 to 40
M5_22	0.19	0.22	0.43	0.43	0.25	0.31	0.36	0.63	0.05	0.07	0.09	0.27	H1	H1	H1	H2	0.75	0.75	0.67	0.25 to 0.33	135	140	140	60	0	0	0	25 to 30
M5_23	0	0	0.36	0.36	0	0	0	0.55	0	0	0	0.2	H0	H0	H0	H2	0.00	0.00	0.67	0.25	0	0	10	20 to 35	0	0	0	5 to 10
M5_24	0.19	0.26	0.56	0.56	0.13	0.14	0.14	0.28	0.02	0.03	0.04	0.16	H1	H1	H2	H3	0.58	0.58	0.58	0.17 to 0.25	140	140	140	60	0	0	15	25 to 35
M5_25	0.23	0.27	0.64	0.64	0.18	0.28	0.46	1.35	0.04	0.08	0.16	0.86	H1	H1	H2	H4	0.58	0.67	0.67	0.25 to 0.33	135	135	140	60	0	0	15	30 to 35
M5_26	0.19	0.23	0.49	0.49	0.05	0.05	0.06	0.13	0.01	0.01	0.01	0.06	H1	H1	H1	H2	0.58	0.58	0.58	0.17 to 0.25	135	135	140	60	0	0	0	15 to 25

*A range is provided as the PMF is an envelope of the 15 min and the 30 min durations

Appendix H – Damage assessment stage damage data

Residential Stage-Damage Data

Above Floor Depth (m)	Single Storey High Set Damage	Slab on Ground / Low Set Damage	2 Storey Houses Damage
-5.00	$0	$0	$0
-1.50	$12,443	$0	$0
-1.40	$26,037	$0	$0
-1.30	$27,684	$0	$0
-1.20	$29,331	$0	$0
-1.10	$30,978	$0	$0
-1.00	$32,626	$0	$0
-0.90	$34,273	$0	$0
-0.80	$35,920	$0	$0
-0.70	$37,568	$0	$0
-0.60	$39,215	$0	$0
-0.50	$40,862	$0	$0
-0.40	$42,509	$0	$0
-0.30	$44,157	$0	$0
-0.20	$45,804	$0	$0
-0.10	$47,451	$0	$0
0.00	$85,611	$41,536	$32,808
0.10	$90,044	$81,910	$61,070
0.20	$94,477	$85,772	$63,774
0.30	$98,910	$89,635	$66,477
0.40	$103,343	$93,497	$69,181
0.50	$107,776	$97,359	$71,884
0.60	$112,209	$101,221	$74,588
0.70	$116,642	$105,084	$77,291
0.80	$121,075	$108,946	$79,995
0.90	$125,508	$112,808	$82,699
1.00	$129,941	$116,670	$85,402
1.10	$134,375	$120,533	$88,106
1.20	$138,808	$124,395	$90,809
1.30	$143,241	$128,257	$93,513
1.40	$147,674	$132,119	$96,216
1.50	$152,107	$135,982	$98,920
1.60	$156,540	$139,844	$101,624
1.70	$160,973	$143,706	$104,327
1.80	$165,406	$147,568	$107,031
1.90	$169,839	$151,431	$109,734
2.00	$174,272	$155,293	$112,438
2.10	$175,919	$156,369	$113,191
2.20	$177,567	$157,446	$113,945
2.30	$179,214	$158,522	$114,699
2.40	$180,861	$159,599	$115,452
2.50	$182,508	$160,675	$116,206
2.60	$184,156	$161,752	$116,959
2.70	$185,803	$162,828	$177,867
2.80	$187,450	$163,905	$179,051
2.90	$189,098	$164,981	$180,235
3.00	$190,745	$166,058	$181,419
3.50	$198,981	$171,440	$187,340
4.00	$207,218	$176,822	$193,260
4.50	$215,454	$182,205	$199,181
5.00	$223,691	$187,587	$205,101



Commercial-Industrial Damages

Depth (m)	Commercial Low	Commercial Medium	Commercial High	Industrial Low	Industrial Medium	Industrial High
	WS-C-low	WS-C-med	WS-C-high	WS-I-low	WS-I-med	WS-I-high
-999	0	0	0	0	0	0
0.10	$118	$208	$445	$118	$208	$948
0.20	$118	$208	$445	$118	$208	$948
0.30	$139	$276	$593	$153	$286	$1,047
0.50	$177	$415	$889	$223	$445	$1,245
0.60	$190	$450	$984	$240	$509	$1,328
0.75	$208	$504	$1,127	$267	$608	$1,453
1.00	$238	$548	$1,260	$297	$726	$1,660
1.50	$282	$578	$1,439	$326	$830	$2,016
2.00	$297	$608	$1,601	$356	$919	$2,342

Damage per square metre in Nov 2019 dollars

Appendix I – Damage assessment results

Appendix J – Preliminary modelling results

Appendix K – Detailed management option assessment

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