

8.14. Floodplain Risk Management Study and Plan Public Consultation

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ATTACHMENTS:

1. Community Engagement Strategy - Floodplain Risk Management Study and Plan [8.14.1 - 5 pages]
2. North Sydney Draft FRMSP [8.14.2 - 309 pages]

PURPOSE:

This report is seeking Council's endorsement to undertake community consultation on the Floodplain Risk Management Study & Plan.

EXECUTIVE SUMMARY:

North Sydney Council and the NSW Government, as part of the Floodplain Management grant, completed the North Sydney LGA Wide Flood Study 2016 to begin the process of identifying flood prone land in accordance with the NSW State Government's Floodplain Development Manual.

The next stage of the study is the Floodplain Risk Management Study and Plan (FRMS&P). This study commenced in 2018.

A flood study is a comprehensive technical investigation of flood behavior which defines the nature of flood risk in the LGA by providing information on the extent, level and velocity of floodwaters for a full range of flood magnitudes.

A FRMS&P draws on the results of the flood study to identify, assess and compare various flood risk management options and opportunities aimed at improving the existing flood situation in the LGA. It provides information and tools to allow considered assessment of flood impacts, the management options, plus provides a strategic plan for implementation. Management options are typically categorised as property modification measures, response modification measures, and flood modification measures.

FINANCIAL IMPLICATIONS:

Funds for the Community Consultation have been allocated as part of the original contract project budget. If required, the funds will be rolled over to the following financial year to complete this study and plan

RECOMMENDATION:

1. **THAT** this report on the Floodplain Risk Management Study & Plan be noted.
2. **THAT** the Floodplain Risk Management Study & Plan be placed on public exhibition in accordance with the project-specific Engagement Strategy.
3. **THAT** the tagging of individual lots as being located within the Flood Planning Area be undertaken after the final adoption by Council of the Floodplain Risk Management Study & Plan.
4. **THAT** a report on the outcomes of the community consultation be prepared and brought back to Council for consideration at the end of the exhibition and consultation period.

LINK TO COMMUNITY STRATEGIC PLAN

The relationship with the Community Strategic Plan is as follows:

1. Our Living Environment
 - 1.2 North Sydney is sustainable and resilient
2. Our Built Infrastructure
 - 2.1 Infrastructure and assets meet community needs

BACKGROUND

North Sydney Council and the NSW Government, as part of the Floodplain Management grant, has completed the North Sydney LGA Wide Flood Study 2016 to begin the process of identifying flood prone land in accordance with the NSW State Government's Floodplain Development Manual. The Floodplain Risk Management Study and Plan (FRMS&P) is now ready for public exhibition.

The Flood Study first commenced in 2014 with the LGA wide flood study tender being adopted by Council on 28 April 2014

During this Flood Study, the community were invited to participate through a questionnaire survey asking for flood history of individual properties - these were directly mailed out to 28,000 properties. This mailout was reported to Council on 13 October 2014.

The community consultation on the draft flood study was placed on public exhibition between 28 July 2016 and 8 September 2016. This also included a letter to all properties identified as having flood waters during the Probable Maximum Flood (PMF) anywhere on their property. A total of 5,600 letters were distributed and 6 community meetings were held during the exhibition period.

The LGA Wide Flood Study was adopted by Council on 20 February 2017.

The FRMS&P started in 2018 with the tender being approved by Council on 25 June 2018.

On 8 October 2019, a second questionnaire was directly mailed out to 3,500 properties asking for further information. This questionnaire was undertaken shortly after the November 2018 storm that affected the North Sydney Community.

The Flood Risk Management Study & Plan is now ready for public consultation. A copy of the draft FRMS&P is attached to this report

CONSULTATION REQUIREMENTS

Community engagement will be undertaken in accordance with Council's Community Engagement Protocol.

Around 750 affected properties have been identified to be consulted with in the FPRMS&P compared with 5600 properties consulted in the initial LGA Wide Flood Study.

DETAIL

A flood study is a comprehensive technical investigation of flood behavior which defines the nature of flood risk in the LGA by providing information on the extent, level and velocity of floodwaters for a full range of flood magnitudes.

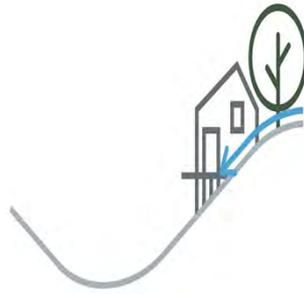
A FRMS&P draws on the results of the flood study to identify, assess and compare various flood risk management options and opportunities aimed at improving the existing flood situation in the LGA. It provides information and tools to allow considered assessment of flood impacts, the management options, plus provides a strategic plan for implementation. Management options are typically categorised as property modification measures, response modification measures, and flood modification measures.



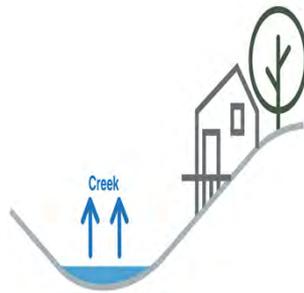
What is Flooding?

Flooding is often associated with inundation from large rivers; however, there are other flood mechanisms that can cause inundation. The North Sydney LGA is primarily affected by two types of flooding: overland flow flooding and mainstream flooding.

Overland flow flooding occurs as rainfall runoff moves toward downstream waterways.



Mainstream flooding occurs when runoff from streets and drains flow into waterways causing them to rise and inundate areas that are usually dry



A FRMS&P provides key information for Council, the SES and the community for effectively managing and mitigating flood risk.

For Council, FRMS&Ps are primarily a planning tool for future development in the LGA and implementing flood mitigation measures for existing development areas. Examples of applications for Council are listed below:

- examination of Council's local flood risk management policies, strategies and planning instruments; and
- identification and assessment of floodplain risk management measures for existing development areas aimed at reducing social, environmental and economic loss of flooding on development and the community.

The FRMS&P allows Council to plan for mitigation works as well as access funding from the State Government's Coast, Estuary and Flood Grants program administered by the Department of Planning, Industry and Environment. The funding for the Grants is currently on a 2:1 basis.

Information from the FRMS&P will assist the SES in its evacuation and logistics planning. The outcomes of the study will provide the SES with:

- a clear description of flood behavior in the study area for a full range of flood events;
- a description of flood warning times for the LGA; and
- identification of critical evacuation issues in the LGA such as locations where road access is cut and the warning time before road access is cut.

If a property is identified as being located within the Flood Planning Area, this means that flood-related development controls may apply for future development applications. Please

note that individual properties have not yet been tagged in the Section 10.7 Planning Certificate.

COMMUNITY ENGAGEMENT STRATEGY

Floodplain Risk Management Study and Plan



Updated March 2022

Councils are required under the *Local Government Act 1993* to inform the community of issues that potentially affect their way of life. North Sydney Council is committed both in principle and in practice, to engaging on matters affecting the North Sydney community.

1. Introduction

This Community Engagement Strategy outlines the steps Council will take to engage stakeholders in the preparation of the *Floodplain Risk Management Study and Plan*. Council is committed to engaging the community to ensure that stakeholders understand the risks associated with flooding and the ways that flooding can be managed throughout the North Sydney local government area (LGA).

1.1 Council's Community Engagement Protocol

This strategy has been prepared in accordance with Council's *Community Engagement Protocol*. The Protocol is used to determine the level of 'level(s) of impact' applicable to this project/decision (proposal). Community engagement opportunities will be provided across a range of 'engagement' levels. This proposal has been determined as:

LEVEL OF IMPACT	LEVEL OF ENGAGEMENT
Low - LGA Wide	Inform/Consult

Council used the framework shown below in Table 1.1 to select the most appropriate 'level(s) of engagement' for this proposal to ensure an appropriate range of engagement 'levels' and methods were offered:

LEVEL	DESCRIPTION
Inform	Providing balanced and objective information to help the community understand problems, alternatives, opportunities and/or solutions
Consult	Obtain public feedback on alternatives and/or decisions
Involve	Work directly with the community throughout the process to ensure that public concerns and aspirations are consistently understood and considered
Collaborate	Partner with the public in each aspect of the decision including the development of alternatives and identification of the preferred solution

Table 1.1 Derived from the IAP2 Public Participation Spectrum

2. Background

In 2013, Council and the NSW Government, as part of a floodplain management grant, undertook the North Sydney LGA Wide Flood Study to begin the process of identifying flood prone land in accordance with the *NSW State Government's Floodplain Development Manual*.

Floodplain Risk Management Study and Plan Community Engagement Strategy

The Flood Study report was adopted by Council on 20 February 2017 (Min. No. 34), resolving in part: *THAT Council note tagging of the Section 149(2) planning certificate for individual properties will only be undertaken at the completion of the Floodplain Risk Management Study and Plan.*

A Flood Study is a comprehensive technical investigation of flood behaviour which defines the nature of flood risk in the LGA by providing information on the extent, level and velocity of floodwaters for a full range of flood magnitudes.

The next stage involves preparation of the *Floodplain Risk Management Study and Plan*. This project is funded by a grant from the NSW Office of Environment and Heritage. In June 2018 Council accepted the tender from GRC Hydro to undertake the *Floodplain Risk Management Study and Plan*.

The *Floodplain Risk Management Study and Plan* draws on the results of the initial Flood Study to identify, assess and compare various flood risk management options and opportunities aimed at improving the existing flood situation in the LGA. It provides information and tools to allow considered assessment of flood impacts, the management options, plus provides a strategic plan for implementation. Management options are typically categorised as property modification measures, response modification measures, and flood modification measures.

3. Community Engagement Strategy

3.1 Who are our community stakeholders?

The Community Engagement Strategy identifies the following groups to engage with in the local community:

- residents/property owners affected by flooding in extreme flood events
- residents/property owners located within the new flood planning area whom will have a tag added to their 10.7 Certificate (formally S149 certificate)
- State Emergency Services and other NSW Government agencies

3.2 Key Communication Messages

- the *Draft Floodplain Risk Management Study and Plan* was developed to help reduce the risk of flooding through different flood mitigation proposals
- Around 750 affected properties have been identified in the flood study.
- Owners of identified properties will be informed of the flood study findings directly in early May as part of this consultation.
- An online forum will also take place in May for owners of affected properties and any other community members who wish to receive more information on the flood study and planfeedback from the community is invited on the flood mitigation proposals

Floodplain Risk Management Study and Plan Community Engagement Strategy

- the consultation outcomes will be reported to Council later in the year and the mitigation plan will be implemented.
- the final *Floodplain Risk Management Study and Plan* will be published on Council's website

3.3 Timetable

Stakeholder engagement will occur prior to adopting the final *Floodplain Risk Management Study and Plan* report. The key phases are outlined in the following table:

Phase	Timing
1. Collect Information	October 2019 - March 2020
2. Finalising Report	April 2020 - February 2022
3. Public Exhibition	May - June 2022

Note: In accordance with Council's Community Engagement Framework described on page 1, the 'level of engagement' per engagement method is indicated.

3.3.1 Stage 1 - Collect Information

This phase involved a questionnaire, directly mailed to a targeted group of residents/owners, requesting feedback regarding flooding history of selected residential properties. The questionnaire results will be summarised and presented as part of the stakeholder engagement to occur in Phase 2.

3.3.2 Stage 2 - Finalising Report

This phase involves preparing the *Draft Floodplain Risk Management Study and Plan*, to be reported to Council, seeking endorsement to publicly exhibit.

3.3.3 Stage 3 - Public Exhibition

This Phase involves finalising the *Draft Floodplain Risk Management Study and Plan* and seeking Council endorsement to public exhibit (for a minimum of 28 days), whereby public feedback is sought. To do this we will undertake the following activities between April and May 2022. Not listed in priority order.

Method	Target Stakeholders	Engagement Level	Purpose
Councillor Bulletin	All Councillors	Inform	Inform stakeholders of the <i>Flood Study</i> findings; and the <i>Draft Floodplain Risk Management Study and Plan</i> ; and direct people to how they can have a say e.g. consultation
Social Media; Facebook, Twitter and Instagram	Existing followers and local groups with social media accounts		
Existing E-newsletters	Subscribers of Council's various newsletters: including Council eNews,		

Floodplain Risk Management Study and Plan Community Engagement Strategy

<i>Method</i>	<i>Target Stakeholders</i>	<i>Engagement Level</i>	<i>Purpose</i>
	Precincts eNews, Business eNews		opportunities.
Direct Letter	All affected properties		
Website (includes Your Say web page)	All	Inform/Consult	Provide information about the project, opportunity to provide online feedback and detail other methods in which feedback can be provided
Precinct System ¹	All active Precinct Committees	Inform/Consult	Encourage Precinct Committees to promote consultation opportunity to their members and/or to make a submission
Online Information Session	All	Inform/Consult	Raise awareness and understanding of the proposed Strategy/Action Plan. Includes Q&A.
Individual site meetings	On request	Inform/Consult	To address individual concerns of affected stakeholders
Submissions	All	Consult	Free form feedback also accepted by email or posted letter ²

Note: In accordance with Council's Community Engagement Framework described on page 1, the 'level of engagement' per engagement method is indicated.

4. Opportunity Cost/Rationale

Engaging the community in this proposal may entail financial costs to Council to achieve a high-quality engagement process. If the process is robust, community ownership of the decisions made will ensure efficient outcomes. Insufficient or poor-quality engagement can result in poor long-term decisions requiring further resources to rectify. The aim of a high-quality community engagement process is to make sustainable decisions. The engagement process will help Council staff and/or Councillors to understand the related recommendations rationale.

5. Further Information

For further information contact Jim Moore, Engineering Project Manager, Engineering & Property Services Division:

¹ North Sydney Community Precinct System was established in the late 1970s, encouraging residents, workers, students and property owners to take an active role in providing input into the operations of Council. Precinct Committees are organised by community members and are advisory. Precinct meetings are one avenue for informing Council of community opinion and maintaining two-way communication between community members and Council staff/Councillors

² For more information about how to make a written submission refer to Council's [Information Sheet: Making a Written Submission to Council](#).

Floodplain Risk Management Study and Plan Community Engagement Strategy

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NORTH SYDNEY LGA-WIDE FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

Draft



February 2022





North Sydney LGA-wide Floodplain Risk Management Study and Plan - Draft

Project North Sydney Local Government Area Wide Floodplain Risk Management Study and Plan
 Project Number 180040
 Client North Sydney Council
 Client Contact Jim Moore
 Report Authors Nathan Cheah, Felix Taaffe, Maren Dingemanse, William Tang-Lu, Feiya He
 Date 11 February 2022
 Verified by Stephen Gray

Date	Version	Description
24-Feb-2020	1	First draft
11-Feb-2022	2	Draft for public exhibition

Filepath: J:\180040\Admin\DraftFRMSP\NorthSydney_Draft_FRMSP_v04.docx

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EXECUTIVE SUMMARY

The Floodplain Risk Management Program

North Sydney Council (Council) has, with the financial support of the NSW Government via the Floodplain Risk Management Program, commissioned GRC Hydro to undertake Floodplain Risk Management Studies and Plans for the North Sydney Local Government Area (LGA).

This study comprises stages 3 to 4 in the five-stage process outlined in the NSW Government's Floodplain Development Manual (FDM, 2005). These works include:

1. Data collection – collection of all applicable data to be used for the ensuing stages of the studies;
2. Flood Study – a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan;
3. Floodplain Risk Management Study (FRMS) – assess the impacts of floods on the existing and future community and allows the identification of management measures to treat flood risk;
4. Floodplain Risk Management Plan (FRMP) – outlines a range of measures, for future implementation, to manage existing, future and residual flood risk effectively and efficiently; and
5. Plan Implementation – once the management plan is adopted, an implementation strategy (devised in Stage 4) is followed to stage components dependent on funding availability.

Following the completion of the Floodplain Risk Management Program, Council will begin implementing its recommended measures and will review the plan periodically.

Report Overview

This report describes the data collection, model update, community consultation undertaken to date, flood risk and mitigation measures assessment of the North Sydney LGA Floodplain Risk Management Studies and Plans (FRMS&P). The study, which has been undertaken by GRC Hydro on behalf of Council, follows on from the North Sydney LGA Flood Study completed in 2017. The FRMS&P investigates flood risk in the North Sydney LGA, and will inform Council's flood planning processes, and recommends flood risk mitigation measures in the Floodplain Risk Management Plan. The Plan is presented as a table in this executive summary. The report contains the following sections:

- Background – description of the study area, overview of existing flood behaviour, relevant policies and legislations;
- Data Collection and Review – description of the available data for use in the current study;
- Flood Model Update – description of the flood model update and results based on methodology prescribed by the Australian Rainfall and Runoff 2019 (ARR2019);
- Flood Risk Assessment – description of the LGA flood risk including flood hazard, flood function, flooding hotspots, economic impacts, flood warning and emergency response;
- Flood Risk Mitigation Measures – description of the approach to flood mitigation and assessment of options proposed for the LGA; and
- Community consultation undertaken during the project.

Mainstream and Overland Flooding

Flooding is often associated with inundation from large rivers; however, there are other ways that flooding can occur. The North Sydney LGA is primarily affected by two types of flooding; overland flow flooding and mainstream flooding. Overland flow flooding occurs when rainfall flows toward creeks and channels, while mainstream flooding occurs when large volumes of water in creeks and channels floods areas that are usually dry. The LGA has a number of steep creeks and stormwater channels that can flood, and around these are areas of overland flooding. With respect to overland flooding, shallow flooding that poses minimal risk to people and property and is drained using small drainage elements is referred to as local drainage and is not the focus of this study. Overland flooding that is drained by larger drainage infrastructure and has greater depths and flow rates is referred to as major drainage, and this is covered by this study. Understanding how flooding occurs and the risks it poses is not straightforward and to this end, this study presents a detailed analysis of how flooding occurs and then quantifies the different types of risk.

Flood Model Update

The current study has updated the modelling approach used in the 2017 Flood Study to be consistent with ARR2019, which has changed the design flood levels. The approach, which involves updates to the design rainfall, losses, temporal patterns and other model parameters, was confirmed with Council and the Department of Planning, Industry and Environment after preliminary modelling results showed issues with the adoption of Bureau of Meteorology (BOM) new design rainfall data. Following further investigation, it was decided that the intensity-frequency-duration (IFD) curves developed using the Sydney Observatory Hill's gauge data would be more appropriate for use in the current study. Description of the model review and update is presented in Section 4.

This report presents the updated flood behaviour for the LGA for a range of design events, which considers both mainstream and overland flow flooding. The peak flood levels are shown to be 0.1-0.2 m lower than those of the 2017 Flood Study for the 1% Annual Exceedance Probability (AEP) flood event. This can be attributed mainly to the use of more recent LiDAR dataset (dated 2013) as well as adopting the ARR2019 methodology in deriving the catchment hydrology for the models. Model verification was also undertaken to provide confidence in the updated modelling results.

Terminology for different sized floods

This report refers to design flood events throughout the document. Design flood events are determined by a computer model and have a specific probability of occurring, described by their Annual Exceedance Probability (AEP). The AEP is the likelihood of a flood of given size or larger occurring in a year. For example, a 20% AEP flood is a relatively small flood that has a 20% chance of occurring in a year, while a 1% AEP flood is a larger flood that has a 1%, or 1 in 100 chance of occurring.

In NSW, this terminology has replaced the language of a '1 in 100 year' or '1 in 5 year' flood, which tended to downplay the frequency of rare floods.

Flood Risk Assessment

An assessment of the North Sydney LGA flood behaviour has been carried out to determine specific areas of flood risk across a range of metrics, including flood hazard, flood function, the economic impacts of flooding and the flood warning available. The flood risk assessment found that:

- The main flooding mechanism for the LGA is overland flow flooding, with flooding hotspots generally found along the major overland flow paths;
- High hazard flows and floodway areas are generally confined to principal flow paths, with flood storage areas typically found upstream of obstructions such as railway or major road embankments;
- Due to the steep terrain and relatively short catchments, flooding in the LGA is best described as flash flooding, with high-intensity short-duration storms tending to cause severe widespread flooding;
- Since flooding in the LGA rises and falls quickly, there is lack of warning time (effectively zero) and preventative action such as evacuation may not be expected prior to a flood;
- Projected rainfall increase due to climate change will exacerbate flooding conditions in the LGA but sea level rise impact is minimal as most of the LGA is elevated well above ocean water level;
- The increased flood risk due to climate change does not require specific flood risk management measures and can be managed via management measures presented in this study, and;
- Several key routes and sensitive infrastructure are impacted by flooding as presented in Section 6.4.

Economic Impacts of Flooding

The economic impacts of flooding in the LGA are substantial, with the combined average annual damages (AAD) calculated to be \$19.5 million covering both residential and non-residential properties in the entire LGA. Table 1 presents the breakdown of the AAD across the range of design flood events as well as the number of properties that would experience flooding in the yard and inundation above the lowest habitable floor level (e.g. garages and storage spaces have been excluded). The AAD has been used to compare the relative economic merits of various proposed flood mitigation measures as presented in Table 2.

Table 1: Combined Flood Damages for North Sydney LGA

Design Event (AEP*)	Number of Properties affected	Number of Properties affected above Floor Level	Flood Damages Total
20%	557	250	\$50,040,000
10%	606	286	\$57,492,600
5%	631	306	\$62,722,800
2%	642	316	\$66,072,900
1%	669	346	\$72,492,400

Probable Maximum Flood	767	551	\$120,634,200
Average Annual Damages (AAD)			\$19,477,500

*'AEP' refers to Annual Exceedance Probability. See 'Terminology for different sized floods' on the previous page

The 767 properties which are flood affected in the PMF event constitute about 7% of the 10,800+ total properties found within the North Sydney LGA.

Flood Risk Mitigation Measures

A range of flood risk mitigation measures have been assessed for the LGA aimed at addressing hotspots, with support for measures also coming via consultation with Council and the community. The types of measures have been categorised as flood modification, property modification or response modification, in accordance with the NSW Floodplain Development Manual (2005). Flood modification measures (Section 6.9) have focused on upgrading the existing trunk drainage systems as well as various complementary measures such as detention basin implementation. Where appropriate, measures have been modelled using one or multiple design flood events. Property modification options (Section 6.7) include flood proofing, development of a Flood Planning Area (FPA) for the LGA, and inclusion of flood related policies in the Local Environment Plan (LEP) and Development Control Plan (DCP). Response modification measures (Section 6.8) include installation of flood signage, development of a local flood plan and requirement for site-specific flood emergency plans. A full list of assessed measures is set out in this report and the recommended measures are summarised in Table 2. The table is a summary of the Draft Floodplain Risk Management Plan and Section 7 of this report constitutes the Plan.

Table 2: Draft Floodplain Risk Management Plan for North Sydney LGA

Option and Report Reference	Description	Responsibility	Priority
PM-01 Inclusion of Flood Related Policy and FPA in the LEP	Install flood-related clauses in the LEP to provide a flood definition for the LGA and objectives for its management. Also provide definition of the FPA.	Council	High
PM-02 Adoption of Matrix-style Controls in DCP	Introduce matrix-style controls on development of flood-prone land considering both the level of flood risk and the type of development.	Council	High
PM-03 Flood Proofing	Consider permanent flood proofing methods for flood-prone lots/properties.	Property Owners	Medium
PM-04 Inclusion of Flood Risk Information on s10.7 Planning Certificates	Include relevant flood risk information on the s10.7 planning certificates to inform property owners of flood risk.	Council	Medium
RM-02 Local Flood Plan	Prepare a Local Flood Plan to detail flood risk within the LGA, responsibilities of relevant agencies, flood response and arrangements.	SES	High

Option and Report Reference	Description	Responsibility	Priority
RM-03 Requirement for Site Specific Flood Emergency Plans	Impose requirement for a site-specific Flood Emergency Plan on new developments in high hazard flooding areas, detailing responsibilities and evacuation planning.	Council	High
FM-S01 Trunk Upgrade in North Sydney CBD	Increase capacity of Sydney Water trunk system through North Sydney CBD to Milson Park and introduce new pits.	Council, Sydney Water and TfNSW	Low
FM-S03 Upgrade Kurraba Road Culvert	Upgrade Sydney Water culvert under the Kurraba Road/Clark Road intersection.	Council and Sydney Water	Medium
FM-S04 Bund at Forsyth Park	Construct bund or levee at Forsyth Park to impede upstream overland flows.	Council	Medium
FM-S05 Trunk Upgrade from Lindsay Street to Kurraba Road	Upgrade Council trunk system from Lindsay Street to the harbour outlet and introduce new pits.	Council	Low
FM-E01 Trunk Upgrade from Yeo Street to Bogota Avenue	Upgrade Council trunk system from Yeo Street to the harbour outlet and introduce new pits.	Council	Low
FM-W01 Trunk Upgrade from Bank Street to Waverton Park	Upgrade Sydney Water trunk system from Bank Street to Woolcott Street and introduce new pits.	Council and Sydney Water	Low
FM-W02 Carlyle Lane Drainage Upgrade	Upgrade Council drainage system from Carlyle Lane to Berrys Creek and enhance capacity of existing pits.	Council	Low
FM-N01 Trunk Upgrade from Albany Street to Flat Rock Creek	Upgrade Sydney Water and Council trunk system from Albany Street to Flat Rock Creek and introduce new pits.	Council and Sydney Water	Low
FM-N02 Bund at St Leonards Park	Construct bund or levee at St Leonards Park to impede upstream overland flows.	Council	High
FM-N03 Anzac Park Basin	Construct basin within Anzac Park to create additional flood storage.	Council and TfNSW	Low
FM-N05+N08 Trunk Upgrade from Anzac Park to Willoughby Creek and Warringa Road Drainage Upgrade	Upgrade Sydney Water trunk system from Anzac Park to Primrose Park, upgrade Warringa Road drainage system and introduce new pits.	Council, Sydney Water and TfNSW	Low

Option and Report Reference	Description	Responsibility	Priority
FM-N06 Reynolds Street Drainage Upgrade	Upgrade Council drainage system from Reynolds Street to the harbour outlet and introduce new pits.	Council	Low
FM-N07 Cooper Lane Drainage Upgrade	Upgrade Council drainage system from Belgrave Street to the harbour outlet and introduce new pits.	Council	Low
FM-N09 Cassins Avenue Drainage Upgrade	Upgrade Council drainage system from Cassins Avenue to St Leonards Park and introduce new pits.	Council	Medium
FM-N11 Cammeray Golf Club Basin	Construct basin adjacent to Warringa Road within Cammeray Golf Course to create additional flood storage.	Council	Medium

Next Steps

The draft FRMS&P will be reviewed by Council and put on public exhibition to gather feedback from the community. The finalised study including the recommended measures will then be put to Council for adoption.

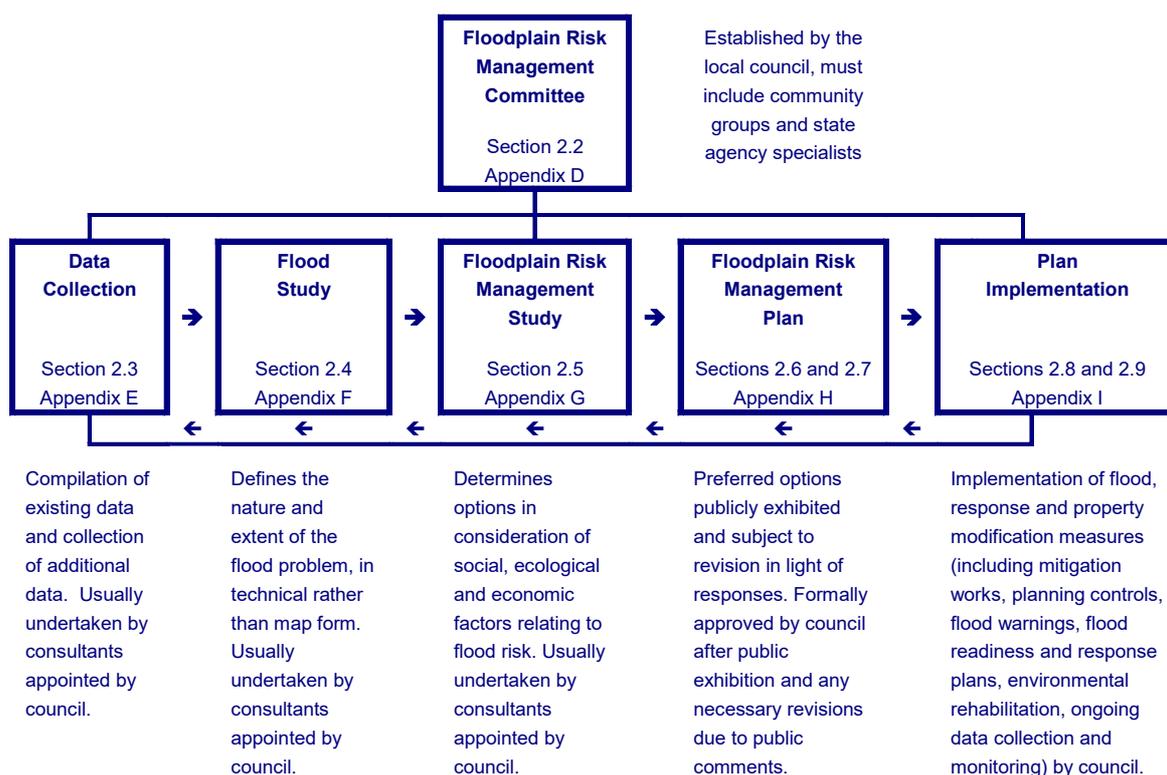
FOREWORD

The New South Wales (NSW) Government’s Flood Prone Land Policy aims to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods.

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

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

Chart 1: The Floodplain Risk Management Process in New South Wales (FDM, 2005)



1. INTRODUCTION

This North Sydney LGA (Local Government Area)-wide Floodplain Risk Management Study and Plan (FRMS&P) has been undertaken by GRC Hydro Pty Ltd (GRC Hydro) on behalf of North Sydney Council (Council), following on from the North Sydney LGA Flood Study completed in February 2017. The FRMS&P updates the 2017 Flood Study considering the recommendations by the recently published Australian Rainfall and Runoff 2019 (ARR2019), re-evaluate flood risks in the LGA, inform Council flood planning processes, and recommend flood risk mitigation measures in the Floodplain Risk Management Plan.

1.1 The Floodplain Risk Management Program

Council has received financial support from the NSW Floodplain Management Program (FMP) managed by the NSW Department of Planning, Industry and Environment (DPIE) to undertake a flood investigation of the North Sydney LGA. To meet this objective, GRC Hydro have been engaged by Council to undertake the FRMS&P.

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

- Floodplain Risk Management Study (FRMS) – which assesses the impacts of floods on the existing and future community and allows the identification of management measures to manage flood risk; and a
- Floodplain Risk Management Plan (FRMP) – that outlines a range of measures, for future implementation, to manage existing, future and residual flood risk effectively and efficiently.

Following the completion of the FRMP, the final stage of the floodplain management process will involve implementing the findings of the FRMP.

Further details of the floodplain risk management stages are outlined below.

Data Collection (completed as part of the 2017 Flood Study)

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

Flood Study (completed as part of the 2017 Flood Study)

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

Floodplain Risk Management Study (current study)

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

Floodplain Risk Management Plan (current study)

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

1.2 Objectives

The objective of this FRMS&P is to improve understanding of flood behaviour and impacts within the North Sydney LGA, and better inform management of flood risk in the study area in consideration of the available information, relevant standards and guidelines. This study also provides a sound technical basis for any further flood risk management investigation in the area as well as allowing an increased understanding of the impacts of floods on existing and future community. It also allows testing and investigation of practical, feasible and economic management measures to treat existing and future risk so as to achieve a tolerable level of residual risk.

The FRMS provides a basis for informing the development of a FRMP which documents and conveys the decisions on the management of flood risk into the future. The FRMP outlines a range of measures to manage existing and future risk so as to achieve a tolerable level of residual risk effectively and efficiently. The FRMP includes a prioritised implementation strategy, proposed measures as well as how they will be implemented.

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

- Relevant government information systems;
- Government and strategic decision makers on flood risk;
- The community and key stakeholders on flood risk;
- Flood risk management planning for existing and future development;
- Emergency management planning for existing and future development, and strategic and development scale land-use planning to manage growth in flood risk;
- Selection of practical, feasible and economic measures for treatment of risk;
- Development of a floodplain risk management plan and prioritised implementation strategy;
- Providing a better understanding of the:
 - variation in flood behaviour, flood function, flood hazard and flood risk in the study area;
 - impacts and costs for a range of flood events or risks on existing and future community;
 - impacts of changes in development and climate on flood risk;

- o emergency response situation and limitations; and
- o effectiveness of current management measures.
- Facilitating information sharing on flood risk across government and with the community.

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

1.3 Project End Users

The key end-user groups that this study aims to support are identified in Table 3.

Table 3: Project End Users

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

2. BACKGROUND

2.1 Study Area

The Study Area is defined by the LGA boundary of North Sydney Council, as shown on Figure 1, with an area of 10.9 km². The study area is completely urbanised, with several commercial centres (broadly, North Sydney Central Business District (CBD), part of the St Leonards commercial centre, and Military Road shops) surrounded by medium to high density residential areas. Suburbs in the LGA include Cammeray, Cremorne, Cremorne Point, Crows Nest, Kirribilli, Kurraba Point, Lavender Bay, McMahons Point, Milsons Point, Neutral Bay, North Sydney, St Leonards, Waverton, and Wollstonecraft.

The LGA's location immediately north of the Sydney CBD and the Harbour Bridge and Tunnel leads it to function as a major thoroughfare for road and rail transport in Sydney. The arterial roads are the M1, bisecting the area north to south, as well as the Pacific Highway and Military Road. The North Shore Line is the main railway line, running generally north-south, while a second, smaller line runs from Waverton to Milsons Point, a remnant of the North Shore Line's terminus at Milsons Point prior to the Harbour Bridge opening.

The LGA's topography consists of a central ridge running east to west, sloping down to Sydney Harbour to the south, and Middle Harbour to the north. Sydney Harbour has several narrow inlets on its northern side, with seven steeply graded peninsulas on the southern side of the LGA, and two inlets on the Middle Harbour side, at Primrose Park and Tunks Park. This topography creates a large number of incised catchments flowing generally north or south, with 18 separate catchments as delineated by the 2017 Flood Study (average size of 0.6 km² or 60 hectares). The area's catchments and topography are shown on Figure 2.

The LGA had a population of 67,658 people in the 2016 census, with a median age of 37 years old (close to the national average). The personal median weekly income is \$1,386, approximately twice the national average. Approximately three quarters of dwellings are apartments, with 14% townhouse/semi-detached and 10% freestanding. The most commonly spoken languages other than English are Mandarin and Cantonese, which approximately 6% of the population speak.

2.2 Historical Floods

Due to the steep terrain and relatively short catchments, flooding in North Sydney is best described as flash flooding. The high intensity short duration storms are the storms that tend to cause severe widespread flooding. This flooding comes on quickly and descends relatively fast after the storm eases.

As part of the 2017 Flood Study, various sources have been examined to gauge the flooding history in the study area, including Council's flood database, Sydney Water's flood database, newspaper articles and community consultation. From this, anecdotal evidence of past flooding was obtained. These sources, whilst described flooding which had occurred, often did not record the depth or level of flooding that is required to calibrate the flood model.

The anecdotal evidence from these flood databases and newspapers reported instances of flooding as having occurred in 1984, 1986, 1991 and 2010. These dates corresponded to high intensity rainfall recorded by rainfall gauges in the vicinity of the study area (WMAwater, 2017).

During the period of the current study, a significant storm occurred in the early morning of 28th November 2018 which resulted in widespread flooding across the North Sydney LGA¹. In addition to reports on the news media, Council received numerous flooding photos and videos of the event provided by local residents. Subsequent community consultation undertaken as part of this study obtained further anecdotal evidence of the event as well as photos from the community confirming the flood impact of the storm on the study area.

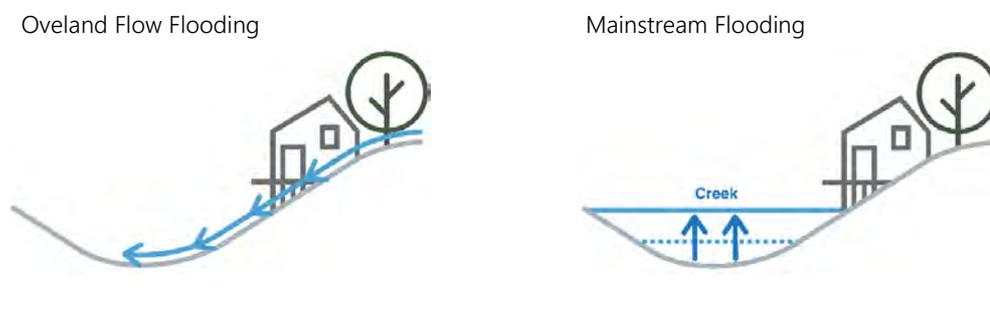
2.3 Flood Mechanisms

The current study assesses two key flood mechanisms that can occur within the North Sydney LGA: overland flow flooding and mainstream flooding. Typically, these two mechanisms occur independently however they can also occur simultaneously.

Overland flow flooding occurs when rainfall in the vicinity of the LGA causes flooding as water flows toward the channels/creeks. This type of flooding is often referred to as “flash flooding” due to short warning times and is the most common within the study area. Typically, this type of flooding rises and recedes over a short period of time and the floodwaters are usually relatively shallow and fast moving. Several major overland flowpaths can be found in the study area which typically follow the natural low point of the local topography. Image 1 (left hand side) depicts this mechanism.

Mainstream flooding occurs from rising water on a defined watercourse causing the watercourse to break its banks, spread over the floodplain and inundate areas that are usually dry. Urban watercourses such as open channels/drains and natural creeks such as Willoughby Creek and Flat Rock Creek (both located north of the LGA) can cause flooding to adjacent low-lying areas. This mechanism typically occurs over a long period of time and typically results in deep, slow moving floodwaters. Image 1 (right hand side) depicts this mechanism. Flooding caused by ocean storm surge can also be categorised as mainstream flooding. Since most of the LGA is elevated well above ocean water level, flood risk due to mainstream ocean flooding is minimal and generally restricted to low-lying areas next to the harbour.

Image 1: Flood Mechanisms affecting North Sydney LGA



¹ Analysis undertaken by GRC Hydro estimated the event to be around 5% to 2% AEP for the 1-hour storm burst at the North Sydney LGA region.

2.4 Policies, Legislation and Guidance

This study made use of several policies, legislation and guidance relevant to management of flood risk in the North Sydney LGA. These are summarised in the following sections.

2.4.1 Implemented Guidelines and References

Table 4 presents the guidelines, manuals and technical reference documents used for this study. These documents detail best practice in regard to management of flood risk. They cover both best practice about the technical assessment of flood behaviour and flood risk, and, more generally, who has responsibility for managing flood risk and how this management is best achieved in the study area.

2.4.2 Summary of Council Planning Policy and Manuals

2.4.2.1 North Sydney Local Environmental Plan (LEP) 2013

The Department of Planning Industry and Environment (DPIE) have developed a set of settled model clauses for use in LEPs, with a specific clause for flood affected land. The LEP does not currently contain the model clause for flood affected land, due to the absence of past LGA-wide flood investigations prepared in accordance with the Floodplain Development Manual 2005. It is noted however, there is reference to the consideration of flooding patterns as a result of climate change for development in a “foreshore area” under Clause 6.9 to the LEP. Otherwise there are no explicit requirements or objective with regards to managing flood risk for development within the LGA. Likewise, no flood planning area (FPA) or flood prone land is defined for the LGA.

2.4.2.2 North Sydney Development Control Plan (DCP) 2013

The DCP contains provisions for stormwater management for residential, commercial and mixed used, non-residential development in the LGA (Sections 1.6.8, 2.6.7 and 3.5.7 respectively) with the following objectives:

- To mimic pre-development or natural drainage systems through the incorporation of WSUD (Water Sensitive Urban Design) on-site;
- To protect watersheds by minimising stormwater discharge and maximising stormwater quality; and
- To minimise off-site localised flooding or stormwater inundation.

Other relevant provisions related to stormwater management include:

- To demonstrate how runoff from the development site will be minimised and the quality of water leaving the site will be improved;
- As a minimum, post-development stormwater discharge rates should be less than pre-development stormwater discharge rates;
- On-site stormwater detention, including the use of grass swales and detention basins, should be pursued where practicable to minimise and filter stormwater runoff; and
- Impervious surfaces should be minimised.

No specific flood-related controls or restrictions were found in the DCP to manage flood risk that could potentially impact on development within the LGA, similar to the reason why there are an absence of flood related provisions within the LEP.

An overview of DCP controls in other Sydney LGAs is given below. City of Sydney and Mosman Council are similar to North Sydney in that they have fully-developed catchments with many separate areas that experience overland flooding.

- City of Sydney has a 'Interim Floodplain Management Policy' that is a standalone document, separate to its DCP. The policy sets minimum floor levels for a variety of development types in the LGA, including residential, commercial and critical facilities. Floor levels for habitable spaces are set at 1% AEP flood level plus 0.5 m freeboard, while basement car parks and critical facilities have a level of either the PMF or 1% AEP + 0.5 m, whichever is higher. The policy does not use a Flood Planning Area and applies to every lot in the LGA. Properties that experience negligible flooding are required to have their floor level 0.3 m above the ground. This means that in some cases properties with no flood liability are subject to flood planning controls, which can be contentious.
- Mosman Council has a 'Policy for Stormwater Management in Mosman'. While it is largely concerned with stormwater and does not contain objectives for floodplain management, the policy requires that "Properties with watercourses or natural flow paths and properties in low points shall provide overland flow paths designed to cope with the 1 in 100 ARI storm event, regardless if there is a pipe of adequate capacity draining the low point or creek or not". It appears to require that such properties have a minimum floor level of 0.3 m above the 1 in 100 ARI storm event.
- Willoughby Council have a Floodplain Management technical standard as part of their DCP. The policy applies to both mainstream and overland flow flooding. It includes description of types of overland flow flooding and states a flood study for a particular site is generally not required for "local drainage" overland flooding, a term also used in the NSW Floodplain Development Manual. This is useful in excluding properties with little to no flood risk, however, types of overland flooding can be difficult to differentiate. Flooding Planning Levels used are 1% AEP + 0.5 m for residential development as well as critical/sensitive uses, and 1% AEP + 0.3 m for non-habitable spaces in commercial developments.
- Lane Cove Council applies some controls related to flooding in their DCP's stormwater section. Controls include varying minimum floor levels based on the degree of risk (0.15 m above ground as a minimum, for nuisance drainage issues, then 1% AEP + 0.3 m for overland flow, but 1% AEP + 0.5 m if high flow rates or depths are present). A flood study is required as part of a development where a known issue is present.
- Other Councils in Sydney tend to cover larger areas and contain creeks or rivers that have relatively large floodplains. In such areas, areas of the floodplain contain widespread high hazard flow unsuited to most types of development, while areas further back from the creek can be safely developed. This has led to the development of a 'flood risk precincts' approach, where 'high', 'moderate' and 'low' precincts are mapped within the LGA and the minimum floor level and other controls vary depending on precinct. Councils that use this approach include Canada Bay, Northern Beaches, Blacktown and Canterbury-Bankstown.

Table 4: Relevant Guidelines and Reference Documents

Reference	Topic
Australian Emergency Management (AEM) Handbook Series, Managing the floodplain: A guide to best practice in flood risk management in Australia – AEM Handbook 7	Best practice
AEM Handbook 7, Technical flood risk management guideline – Flood Hazard	Flood hazard
AEM Handbook 7, Technical flood risk management guideline – Flood Emergency Response Classification of the Floodplain	Emergency response
AEM Handbook 7, Technical flood risk management guideline – Flood risk information to support land-use planning	Land use
AEM Handbook 7, Technical flood risk management guideline – Assessing options and service levels for treating existing risk	Mitigation options and service levels
AEM Handbook 6, National Strategy for Disaster Resilience – community engagement framework	Community engagement
Australian National Committee on Large Dams (ANCOLD) Guidelines	Dam safety
Australian Rainfall & Runoff 2019 (ARR2019) and Specific Project Reports	Best practice
Section 733 of the Local Government Act, 1993	Flood prone land policy
NSW Government’s Floodplain Development Manual (2005)	Flood prone land policy and industry practice
SES requirements from floodplain risk management process	SES requirements
Practical consideration of climate change	Climate change
Coincidence of Coastal Inundation and Catchment Flooding	Coincidence
Floodway Definition	Floodway
Residential flood damage and supporting calculation spreadsheet	Flood damages

2.4.2.3 North Sydney Public Domain Style Manual and Design Codes 2018

This manual sets requirements for the style and design of infrastructure improvements in the LGA, with a focus on visual aesthetics. Recommendations can be found on the use of WSUD solutions to improve general stormwater quality and the use of Council’s stormwater inlet pit with granite lintel to discharge runoff.

2.4.2.4 Infrastructure Specification Manual for Road works, Drainage and Miscellaneous Works 2018

This manual sets requirements for infrastructure works in the LGA with focus on the engineering specifications. In addition to materials that should be used for the drainage structures, standard drawings for different pit types and trench details are included.

2.4.3 Emergency Management Plans

2.4.3.1 Sydney Metropolitan Regional Emergency Management Plan 2017

The Sydney Metropolitan Regional Emergency Management Plan (EMPLAN) was prepared by the Sydney Metropolitan Regional Emergency Management Committee in compliance with the State Emergency & Rescue Management Act 1989. The plan sets out the emergency response arrangements for the Sydney metropolitan region, which encompasses nine LGAs including North Sydney. The plan refers to area-specific response being contained in the various local EMPLANs, including that for Mosman-North Sydney.

2.4.3.2 Mosman and North Sydney Local Emergency Management Plan 2017

The Mosman and North Sydney Local Emergency Management Plan (EMPLAN) was prepared by the Mosman and North Sydney Local Emergency Management Committee in compliance with the State Emergency & Rescue Management Act 1989. The plan sets out the emergency response arrangements for Mosman and North Sydney Council LGAs. The plan identified the NSW SES as the primary agency responsible for dealing with emergencies related to storm and flash flooding.

2.4.4 State and National Plans and Policies

Management of flood risk in the LGA is also guided by various state-wide and national policies related to floodplain management in Australia. These have been listed below, including their relevance to the current study:

- *Australian Rainfall and Runoff 2019* – This national guideline document is used for the estimation of design flood characteristics in Australia. It sets out hydrological data and procedures to be used for hydrological and hydraulic modelling of flooding in Australia.
- *NSW Environmental Planning and Assessment Act 1979* – Is the overarching state legislation for local legislation. The Act provides the framework for regulating and protecting the environment and controlling development. Pursuant to Section 9.1 of the EP&A Act, councils have the responsibility to facilitate the implementation of the NSW Government's Flood Prone Land Policy. It specifies how councils' LEPs manage flooding.
- *NSW Flood Prone Land Policy* - aims to reduce the impact of flooding and flood liability on individual land owners and occupiers of flood prone property and to reduce private and public losses resulting from floods via economically positive methods where possible. The NSW Floodplain Development Manual supports the policy.
- *NSW Government's Floodplain Development Manual (2005)* – Defines the assessment of flood risk in NSW, including flood hazard, hydraulic categories and other variables. More broadly it sets out the objectives for floodplain development in the state, including description of types of mitigation measure. This manual guides councils in the development and implementation of local floodplain risk management plans to produce robust and effective

floodplain risk management outcomes in accordance with the NSW Government's Flood Prone Land Policy.

- *State Environmental Planning Policy (Exempt and Complying Development Codes) (2008)* - are environmental planning tools used to address planning issues within NSW. In a flooding context, the SEPP for Exempt and Complying Development Codes 2008 is key for defining:
 - Exempt developments, where development can occur without the need for development consent; and
 - Complying development, where development must be carried out in accordance with a complying development certificate.

The policy provides further information on where and development of flood-prone land should occur.

3. DATA COLLECTION AND REVIEW

3.1 Previous Studies

Several studies related to flooding in the North Sydney LGA have been undertaken. The most relevant to the current study is the North Sydney LGA Flood Study, prepared by WMAwater on behalf of Council, with the final report published February 2017. Other studies include catchment-level studies undertaken by Council or Sydney Water, or consultants on behalf of Council, and drainage/flooding assessment of the Sydney Metro tunnels and Victoria Cross station (currently under construction) in the LGA. The following sections summarise the previous studies.

3.1.1 North Sydney LGA Flood Study (WMAwater, 2017)

The study was undertaken by WMAwater, on behalf of Council, as part of Council's Floodplain Risk Management Program for the LGA. As per the NSW Floodplain Development Manual, the flood study covers the first and second stages in the program and prepares Council and the community for the current study, which covers the third and fourth stages of the program. The key outputs of the flood study were:

- Design flood information for a range of flood events, including basic information (peak flood depth, level and velocity) and processed outputs (provisional hydraulic hazard and hydraulic classification);
- A set of verified hydrologic and hydraulic models that cover overland and mainstream flooding across the LGA. These models, which used the DRAINS and WBNM software for the hydrologic assessment, and TUFLOW for the hydraulic model, were updated as part of the current study (see Section 4); and
- Establishment of consultation channels with the community and other stakeholders, that have raised awareness of the nature and location of flooding in the LGA, and of the flood study's function and relation to the current study.

Table 5 summarises the approach and results of the flood study.

3.1.2 Sydney Metro Flood Assessments

The Sydney Metro project involves construction of two new stations and twin rail tunnels in the LGA. Specifically, Stage 2 of the project entails a new rail line starting at Chatswood and finishing at Bankstown. The Chatswood to Sydenham section will have 15.5 km twin railway tunnels, of which around 3 km is in the study area. The LGA will have two stations, 'Victoria Cross' in the North Sydney CBD, and 'Crows Nest', approximately 500 m southeast of the existing St Leonards station. As a major infrastructure project, various technical studies have been developed for the project including flooding assessments. The following studies (relating to flooding) are publicly available:

- Sydney Metro City and Southwest, Victoria Cross Over Station Development, Flood assessment and stormwater management report (AECOM, 2018).

The report assessed the flood risk associated with a proposed multi-storey development above the proposed Victoria Cross station and recommended flood risk mitigation measures. The report used the model established in the 2017 flood study, with several adjustments to the modelling of the

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existing case. As an ongoing proposed development, the mitigation measures have not been included in the current study's definition of flood behaviour. Nevertheless, these measures were considered alongside other possible mitigation measures for the North Sydney CBD.

Table 5: Summary of 2017 Flood Study

Feature	Description	Relevance to FRMS&P (current study)
Data collection	<p>The following data was collected for the study:</p> <ul style="list-style-type: none"> • LiDAR data surveyed in 2008, TIN (triangulated irregular network) and DEM (digital elevation model) generated by the consultant. • Council GIS data including aerial photos, LEP layers, cadastral and road data. • Pit and pipe data provided by Sydney Water and Council. Open channel data from Sydney Water reports. • Bureau of Meteorology (BOM) design rainfall data, and rainfall data from 7 pluviometers and 64 daily read stations. <ul style="list-style-type: none"> • Various catchment studies within the LGA. • Questionnaire responses and newspaper description of historical floods. 	<p>More recent data for LiDAR, design rainfall, stormwater assets and aerial photos are available and were assessed for use in the current study (see Section 3.2).</p>
Hydrologic Model	<p>A DRAINS model was established for the study area, with 1231 subcatchments (average 1 ha each) with imperviousness and rainfall losses estimated for different land use types. Each subcatchment generated a hydrograph for each event, that was routed directly into the hydraulic model.</p> <p>A WBNM model was established for the 6.2 km² area outside the study area that discharges into Tunks Park (in the study area).</p>	<p>Hydrologic models were adopted for use in the current study and updated to use ARR2019 methodology (see Section 4.3).</p>
Hydraulic Model	<p>Four 1D/2D TUFLOW models were established, to model the LGA (divided into four sections) with improved model runtime. Inflows were from hydrologic models and downstream boundary was static ocean level. The stormwater network was included as a 1D model embedded in the model grid. Buildings were represented as impermeable barriers, while fences were not explicitly modelled.</p> <p>Due to absence of calibration data, the model was verified against unit flow rates from similar urban catchments, as</p>	<p>The overall hydraulic modelling approach was adopted for use in the current study. Areas of update are described in Section 4.4.</p>

Feature	Description	Relevance to FRMS&P (current study)
	well as comparison to reported flooding locations, and previous stormwater studies.	
Design Flood Information	<p>The following results were produced by the study:</p> <ul style="list-style-type: none"> • Peak flood level, depth and flow for 20%, 10%, 5%, 2% and 1% AEP, and PMF (probable maximum flood). • Duration and depth of road flooding for the same design events. • Provisional hydraulic hazard and hydraulic classification for the 20%, 5% and 1% AEP, and PMF. • Preliminary Flood Emergency Response Classification of Communities. • Sensitivity of 1% AEP flood to climate change scenarios including rainfall increase and sea level rise. • Detailed description of flood behaviour for four flooding hotspots. 	The current study updated the modelling approach using ARR2019 and produced new design flood information, which supersedes that produced by the flood study. The study also produced updated hydraulic hazard and hydraulic classification.
Community Consultation	The study involved distribution of a newsletter and questionnaire to residents and business owners, with 28,000 properties receiving the material and ~1,100 responding to the questionnaire. There were also a series of information sessions during the exhibition phase.	The current study continued the consultation process, albeit using a more targeted approach. See Section 5 for more detail.

3.1.3 Drainage and Catchment-level Studies

Several studies and assessments were undertaken prior to the flood study, for specific drainage or flooding-related issues in North Sydney LGA. These include five studies, all undertaken in 2002 by Sydney Water, for trunk drainage lines, using Rational Method inflows and a hydraulic grade line analysis. There are a further ten studies undertaken by or on behalf of Council, between 1990 and 1998, for various areas within the LGA. These studies are summarised in the flood study, and, having been used by the flood study in verification of the flood risk areas, do not have a direct bearing on the current study.

3.2 Model Build Data

The following sections discuss the availability of up-to-date information provided that was used to update the flood models developed as part of the 2017 Flood Study.

3.2.1 Rainfall Data

With the publication of ARR2019, updated IFD (Intensity-Frequency-Duration) data used to inform design rainfall depths is available from the BOM website (referred herein as the BOM 2016 IFD). Further, the temporal patterns, storm losses and pre-burst depths can be downloaded from the ARR Data Hub. This information was used in the current study and a copy is included in Appendix G.

3.2.2 LiDAR Data

Two sources of LiDAR data were used for the study: that used in the 2017 Flood Study, collected in 2008, and a newer survey from 2013. Both data sets were collected with LiDAR scanning from plane flyovers of the LGA. Details of the two data sets are given below:

- The capture date of the 2008 data is not known, while the 2013 data was captured from 10th to 24th of April 2013;
- Accuracy of the 2008 data is not known, with the 2017 Flood Study estimating it was a typical dataset, with +/- 0.15 m (for 70% of points) vertical accuracy on clear, hard ground, and +/- 0.75 m horizontal accuracy. The 2013 data has vertical accuracy of +/- 0.15 m and horizontal accuracy of 0.8 m; and
- Both datasets consist of a series of point elevations, which was used to develop the DEM. The TIN and DEM were created by WMAwater for the 2008 data, while the surveyor of the 2013 data (Land and Property Information) created the DEM for that data, with resolutions of 1 m, 5 m and 10 m.

In general, the most recent LiDAR is used for a flood investigation, as recent topographic changes in the catchment are not captured in older data. Section 4.4.1 further describes the differences in the two datasets.

3.2.3 Stormwater Network

The stormwater network data collected by the flood study was also utilised for the current study. The data, which consists of pit/pipe and open channel locations and specifications, is contained within the hydraulic model layers of the stormwater network (shown in Figure 3). Further, information on recent stormwater works was made available by Council primarily in the form of CAD drawings, specifically:

1. Work-As-Executed (WAE) stormwater drawings for stormwater rehabilitation works at several locations within the LGA, including:
 - a. Riley Street, North Sydney;
 - b. High/Hipwood Street, North Sydney;
 - c. Aubin Street, Neutral Bay;
 - d. Atchison Street, Crows Nest;
 - e. Carabella Street, Kirribilli (between Peel Street and Holbrook Avenue);
 - f. Carabella Street, Kirribilli (between Fitzroy Street and Parkes Street);

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- g. Holbrook Avenue, Kirribilli;
 - h. Peel Street, Kirribilli; and
 - i. Carlyle Lane, Wollstonecraft.
2. Updated stormwater pits and pipe location in the proximity of the Victoria Cross Station site as well as pipe relocation works resulted from the 177 Pacific Highway redevelopment as incorporated in the AECOM (2018) TUFLOW model.

3.2.4 Council GIS Data

The latest GIS (geographical information system) dataset from Council's database was provided at the commencement of this study. The dataset covers a range of GIS-related information including stormwater assets, building outlines, 2018 aerial photos, cadastre, road names and kerb locations. Whilst most of this information has been used to some degree during the development of the flood study, data such as the building outlines and 2018 aerials were used as a cross-check to verify that the representation of buildings in the flood models is current and accurate. New pits and pipes information from Council GIS database was also used to update the stormwater network represented in the hydraulic model.

3.2.5 Sydney Metro Model

The hydrologic and hydraulic models developed as part of the Sydney Metro study of the Victoria Cross Station (AECOM, 2018) were made available. It is not within the scope of this study to review the reliability of these models. The models provided are for both the pre-development and post-development scenarios. Nevertheless, useful elements from the models which reflect present day conditions such as the building outlines and existing stormwater network were adopted for use in the current study update. These elements have been updated by Sydney Metro as part of the flooding assessment to more accurately represent conditions around the development site.

3.3 Property Floor Level Survey

A property floor level survey was used to estimate buildings' level of exposure to the range of design flood events. The survey typically describes a property's lowest habitable floor level (e.g. excludes garages, ancillary storage spaces and the like), which is then compared to a flood level adjacent to the building, giving an estimate of the depth of flooding in each design event. For a flood study or FRMS, a floor level survey is collected for a subset of properties that are estimated to be affected by flooding. Properties outside of this subset are either not affected, or only affected in very rare floods (e.g. >1% AEP).

Currently, Council does not have detailed floor level data for all properties within the LGA and the 2017 Flood Study did not undertake a floor level survey. Therefore, a property floor level survey was undertaken as part of the current Study in late 2019. The floor level survey data was then used as input to the flood damages assessment (refer Section 6.3), which estimates cost of flooding at a per-property level as well as for the LGA².

² It is important to note that this dataset is not to be used for ascertaining the flood affectation of the individual property.

A subset of properties to be surveyed for floor levels was determined based on the following selection criteria and utilising the design flood results generated as part of the current study:

- Where building does not occupy significant portion of the lot, >10% of cadastral lot inundated by >150 mm flood depth in the 1% AEP event; and
- Where building does occupy significant portion of the lot, >300 mm flood depth found adjacent to the lot in the 1% AEP event.

The locations of the property survey set (894 properties) are shown in Appendix E. Following discussion with Council and DPIE on a suitable approach for the floor level survey, it was agreed that the property floor level is to be manually determined by estimating the floor height relative to the ground of the observable entrance most susceptible to floodwater ingress. Nearby physical features were used to aid the estimation of the ground to floor height, such as the number of bricks/steps to the floor level or the height of a nearby wall. If an entrance is located at the rear of the property and access is not possible to estimate the floor level, it was assumed that the floor level rear of the property is the same as the front. The floor level can be revised, if necessary, when property access is provided by the resident at a later date during the community consultation process. The ground level for each property was then determined using LiDAR data and the absolute floor level was calculated by adding the LiDAR ground level to the estimated height from ground to floor level.

3.4 Site Visit

Numerous site visits were undertaken throughout the study to familiarise staff with the catchment flooding hotspots as well as to conduct ground truthing to confirm overland flow paths. The site visits also allowed the identification of properties to be included in the draft Flood Planning Area (FPA) as presented in Section 6.7.1.1.

4. FLOOD STUDY REVIEW AND UPDATE

The Flood Study (WMAwater, 2017) established a series of hydrologic and hydraulic models, using DRAINS, WBNM and TUFLOW software. The North Sydney LGA was divided into four sections or quadrants, i.e. "North", "South", "East" and "West", with the models developed for each. In the absence of suitable data to calibrate or validate the models, the model results were instead verified using known flow estimates from similar urban catchments in the Sydney Metropolitan area as well as compared against known historical flood behaviour. The models were then used to produce design flood behaviour for the entire LGA. The hydraulic models contained relevant features including the topography, buildings, stormwater pits, pipes and open channels. Both overland flow and mainstream flooding (refer Section 2.3) have been modelled. Further information on the models is given in Table 5.

Following the data collection and review exercise (refer Section 3), the hydraulic and hydrologic models from the 2017 Flood Study were reviewed and updated to use the best available data and methodology prescribed by ARR2019. The changes made and the impact on design flood results are discussed in the following sections.

4.1 ARR2019 Methodology

The hydrologic and hydraulic models were updated to adopt ARR2019 methodology. ARR2019 is based on a series of research projects that aims to provide more accurate techniques for analysis of flood behaviour across Australia. Alongside the updated methods of analysis, it uses a dataset of rainfall and streamflow gauge data that is significantly expanded, spatially and temporally, from ARR87. A summary of the main changes in the ARR2019 methodology, compared to ARR87, is as follows:

- Design rainfall data (i.e. intensity-frequency-duration data) across Australia has been updated due to the availability of three more decades of data;
- Where previously a single temporal pattern was used for a particular design event and duration, now an ensemble of 10 temporal patterns is modelled per storm duration;
- Use of the pre-burst rainfall incorporated prior to the design storm burst;
- Update to the Initial and Continuing Loss values which better reflect local conditions; and
- Update to the calculation of the Aerial Reduction Factor (ARF) based on Australian conditions.

It is important to note that the methodology for determining the Probable Maximum Flood (PMF) has not changed with the release of ARR2019. As such, the approach to estimating the PMF based on the Generalised Short-Duration Method (GSDM) used in the 2017 Flood Study has also been adopted herein.

4.2 Design Rainfall

The updated design rainfall depths for various AEPs and durations were obtained from BOM and compared against those of ARR87. This is presented in Table 6. As shown in the table, BOM's 2016 design rainfall depths are generally lower than ARR87 across the storm durations. For the durations of 15 minute to 2 hours (critical storm duration range for the LGA), the total rainfall depths are

generally lower by 1-20%. The most likely impact of this on the flood modelling is reduced flow volumes and also reduced peak flood levels.

Table 6: Comparison of ARR87, BOM 2016 and At-Site IFD Data

Duration	5% AEP, total rainfall depth (mm)			2% AEP, total rainfall depth (mm)			1% AEP, total rainfall depth (mm)		
	ARR87	BOM 2016	Obs. Hill	ARR87	BOM 2016	Obs. Hill	ARR87	BOM 2016	Obs. Hill
10 min	26.7	27	23.8	31.3	31.7	28.9	34.8	35.3	33.7
15 min	34.3	33.8	30.1	40	39.6	37.6	44.8	44.1	42.8
20 min	40.3	38.8	36.5	48	45.5	45.2	53.0	50.6	51.2
25 min	45.4	42.7	42.4	53.9	50.1	51.8	60.4	55.8	58.8
30 min	50	45.9	47.2	60	53.9	57.2	66.5	60	65.5
45 min	61.1	53.3	60.5	72.5	62.6	72.8	81	69.9	83
1 hour	69.5	58.9	70.4	83.4	69.2	84.8	92.8	77.4	96
1.5 hour	82.4	67.6	83.9	97.9	79.7	103.7	110	89.3	120.3
2 hour	92	74.8	94.1	109.6	88.4	116.6	123	99.2	135.6
3 hour	106.8	87.1	108.1	126.6	103	132.1	142.8	116	151.7
4.5 hour	123.8	103	123.5	147	122	149.3	164.7	138	170.1
6 hour	137.4	116	137	160.2	139	167.2	182.4	157	192.1
9 hour	159.3	140	160	189	168	188.2	211.5	190	208.7
12 hour	177.6	161	175	205.2	193	205.7	236.4	219	228.5

To confirm the accuracy of the IFD data, rainfall frequency analysis of historical pluviometer rain gauge data (also termed "at-site IFD analysis") was undertaken and compared to IFD curves provided by BOM. The analysis was undertaken for the pluviometer rain gauges closest to the North Sydney LGA catchments, i.e. Sydney Observatory Hill (ID: 066062 operated by BOM), Chatswood Bowling Club (ID: 566017 operated by Sydney Water) and Mosman (ID: 566027 operated by Sydney Water). The gauges have approximately 100, 50 and 30 years of continuous rainfall data respectively. Further details of these gauges are provided in Table 7. The gauge records were used to derive an Annual Maximum Series (AMS) of the highest rainfall for each duration in each year of record, and this AMS was then fitted with a Generalised Extreme Value (GEV) probability distribution using FLIKE software. The results of this assessment are presented in

Chart 2 to Chart 4, which provides IFD comparisons for each AEP (note that the Mosman gauge IFD is excluded from Chart 2 due to insufficient length of record to derive a reliable curve for the 1% AEP event).

Table 7: Rainfall Gauges Used in At-site IFD analysis

Gauges	Observatory Hill	Chatswood	Mosman
Station Number	66062	566017	566027
Operator	BOM	Sydney Water	Sydney Water
Years of record (daily)	160	112	115
Years of record (continuous)	102	56	28
Approx. distance to LGA centre	3.1 km	4.4 km	2.8 km

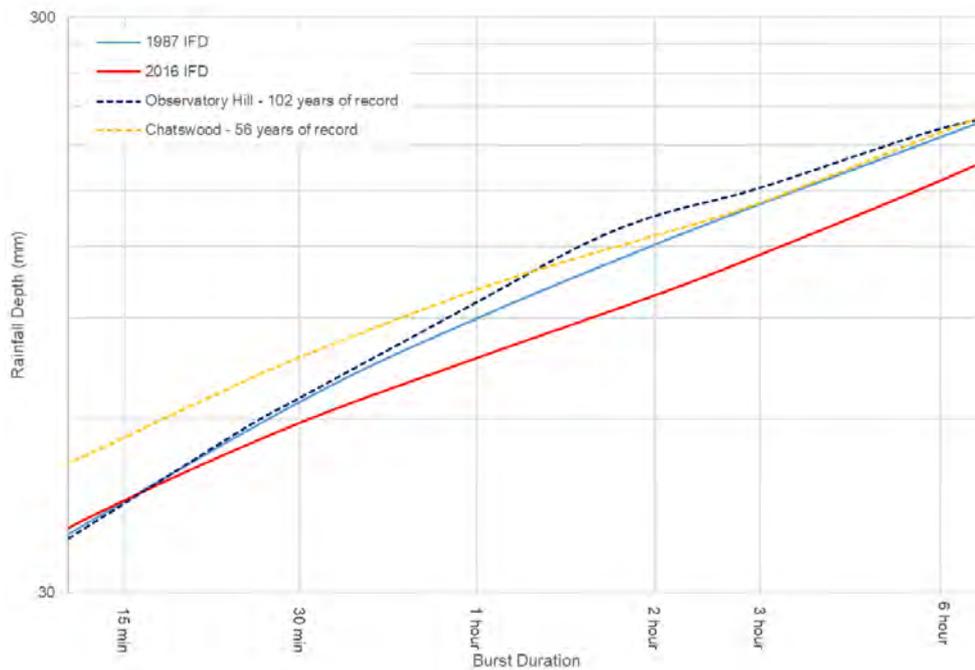


Chart 2: 1% AEP - BoM vs. At-site IFD for durations less than 6 hours

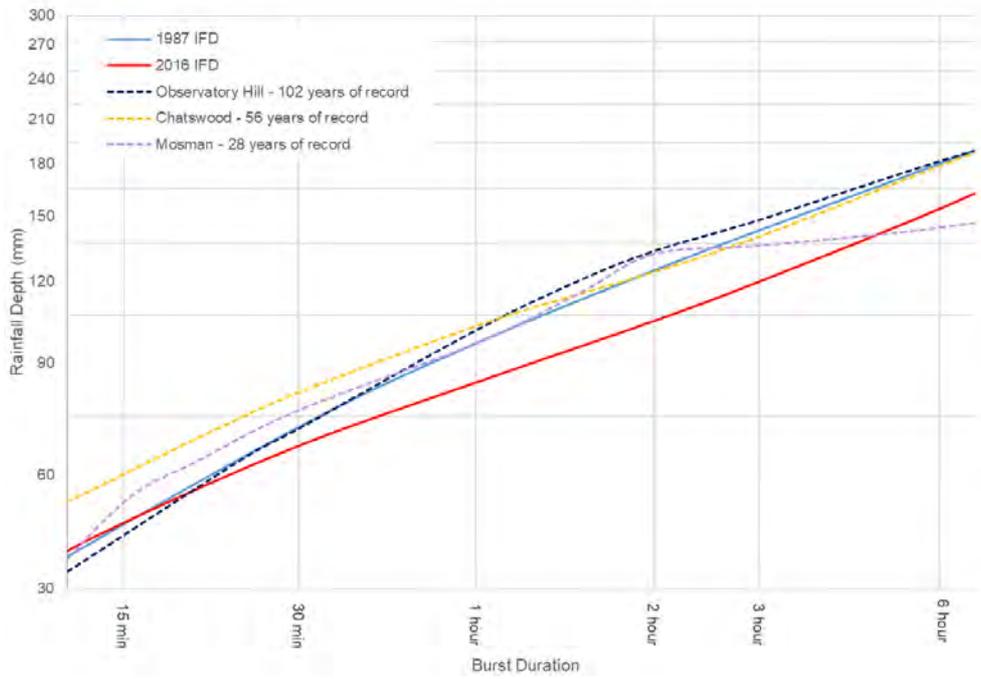


Chart 3: 2% AEP - BoM vs. At-site IFD for durations less than 6 hours

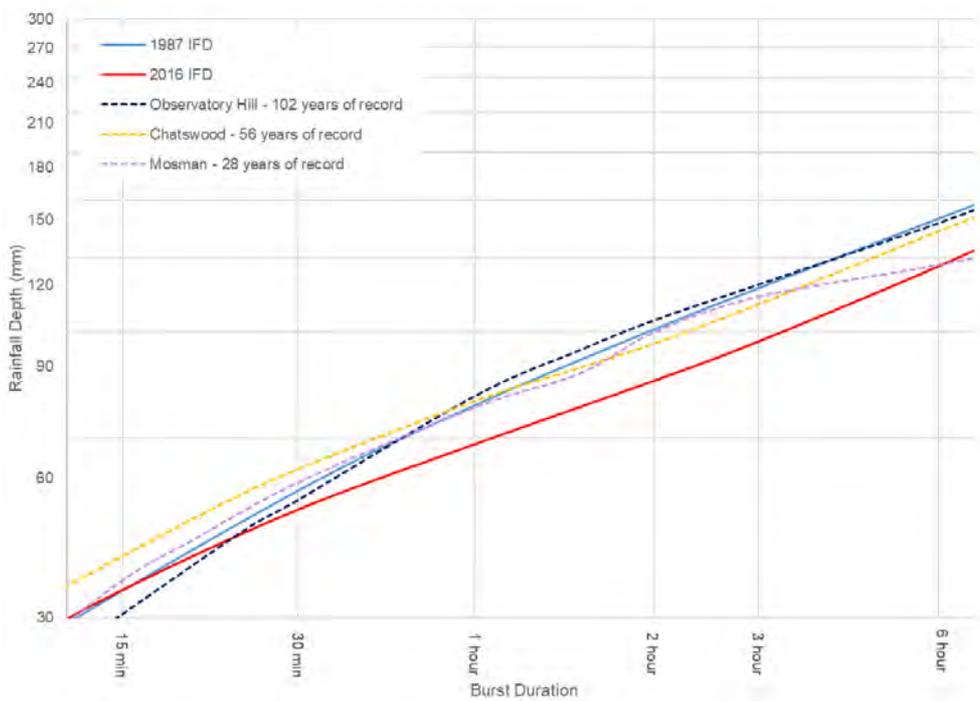


Chart 4: 5% AEP - BoM vs. At-site IFD for durations less than 6 hours

The results show a discrepancy between the at-site IFD data and BOM's 2016 IFD data. The following observations can be made based on the IFD charts:

- For most durations of interest, the three at-site IFDs return similar values to one another, and to the ARR87 IFD, while being markedly different to BOM's 2016 IFD. This indicates that there is not a discrepancy between a single gauge and the 2016 data, but rather, the 2016 data is the outlier;
- For very short durations, the at-site IFDs tend to diverge from one another and show sharper gradient than BOM's 2016 IFD. It is likely these features are caused by a) the gauge data increments, which are 6-minute increments for Observatory Hill and tipping bucket at Chatswood and Mosman, affecting the results; and b) BOM's 2016 IFD use of a scaling formula for sub-hourly durations. Regarding the latter, if the same scaling formula was applied to the at-site IFD, it would produce the same gradient as shown on BOM's 2016 IFD; and
- Of the five IFDs presented on each chart, the results do not indicate that any one IFD is 'correct'. They do, however, indicate that BOM's 2016 IFD is not representative of the three gauges nearest the study area. This is most pronounced for durations of 1-2 hours, which is around the critical duration of the catchments in North Sydney LGA. If one IFD was to be chosen, the Observatory Hill data has the greatest verisimilitude, as it has by far the longest record, and it generally conforms to the two other gauges.

A comparison of the derived at-site IFD for the Observatory Hill gauge with ARR87 and BOM's 2016 IFD is provided in Table 6. The long period of record at the Observatory Hill gauge provides high confidence in the at-site IFD data. In light of the described issues, the at-site IFD data derived from the Observatory Hill gauge were used in the subsequent flood modelling. This method is consistent with recent guidance by NSW OEH (2018) and represents a best practice approach. It also ensures that the design rainfall data is not significantly underestimated, which is likely to occur if BOM's 2016 IFD data is applied.

4.3 Update of Hydrologic Model

The DRAINS and WBNM hydrologic models developed for the LGA as part of the 2017 Flood Study were reviewed and updated. The sub-catchment delineation previously undertaken was retained. DRAINS was used for undertaking the hydrologic modelling for local catchments within the LGA, whilst WBNM was used for undertaking the hydrologic modelling for external catchments outside the LGA, i.e. upstream catchment area located to the north-west of the LGA. The previously used hydrologic model parameters were reviewed and updated as per ARR2019, with the changes outlined in Table 8.

Table 8: Updated Hydrologic Model Parameters

Hydrologic Model Parameters	2017 Flood Study	Current Study
ARR Methodology	ARR87	ARR2019
Model Setup	Catchment node per sub-catchment. No linkage or routing between the nodes. Runoff hydrograph generated for each sub-catchment was used as catchment flow input in the hydraulic model.	Catchment node per sub-catchment. All sub-catchments linked following the overland flow paths so that catchment flow can be routed to the downstream outlet (though without underground pipe routing). This setup allows critical duration analysis to be carried out in DRAINS to identify the most likely storm duration with the highest median peak discharge, thus minimising the number of runs required for the hydraulic modelling. Runoff hydrograph generated for each sub-catchment was also used as catchment flow input in the hydraulic model.
Impervious Surface Area	Division of catchment surface areas as either paved, supplementary or grassed areas. Estimation of impervious percentage was undertaken for each land-use category.	Use of the concept of Effective Impervious Area (EIA) as per ARR2019. The impervious percentage determined from the previous study was adopted as the Total Impervious Area (TIA) and a ratio of 60% was applied for EIA/TIA, in line with published values in ARR2019 and DRAINS User Manual (2018).
Rainfall Loss Model and Values	<p>Paved/Impervious area (DRAINS and WBNM): Initial loss – 1.0 mm</p> <p>Grassed area (DRAINS): Initial loss – 5.0 mm and continuing loss based on Horton’s infiltration equation which considers representative soil type (Type 3) and antecedent moisture condition (Type 3)</p> <p>Pervious area (WBNM): Initial loss – 10 mm and continuing loss of 2.5 mm/hr as per ARR87 recommendation for NSW catchments east of the dividing range</p>	<p>Effective Impervious Area (EIA) (DRAINS and WBNM): Initial loss – 1.0 mm</p> <p>Remaining Area which include both indirectly connected area and grassed/pervious area (DRAINS and WBNM): Initial loss – 19.6 mm, which is 70% of the rural initial loss obtained from ARR Data Hub and continuing loss of 1.6 mm/hr, in line with ARR2019 and DRAINS User Manual (2018)</p> <p>Application of pre-burst rainfall obtained from ARR Data Hub to derive initial loss for storm bursts</p>

Hydrologic Model Parameters	2017 Flood Study	Current Study
Design Rainfall	ARR87 IFD	At-site IFD based on Observatory Hill gauge
	Use of single temporal pattern for each duration	Use of ensemble of 10 temporal patterns for each duration
	Areal reduction factor not applied	Areal reduction factor of 1 applied as per ARR2019 recommendation as majority of the catchments has area less than or equal to 1 km ²

Based on the ARR2019 methodology, the temporal pattern that is closest to generating the average in terms of peak flow was determined for each storm duration. An example of this is shown in Chart 5. A preliminary critical duration analysis was then undertaken for each of the hydrologic model, i.e. "North", "South", "East" and "West", to identify possible storm durations which would yield the highest peak discharge for the catchment. This helped narrow down the number of simulation runs required for the hydraulic modelling (which has much longer run times) whilst acknowledging that the hydrologic models do not account for flood storage areas which can attenuate flows. A more detailed analysis of the critical storm duration was still required when undertaking the subsequent hydraulic modelling.

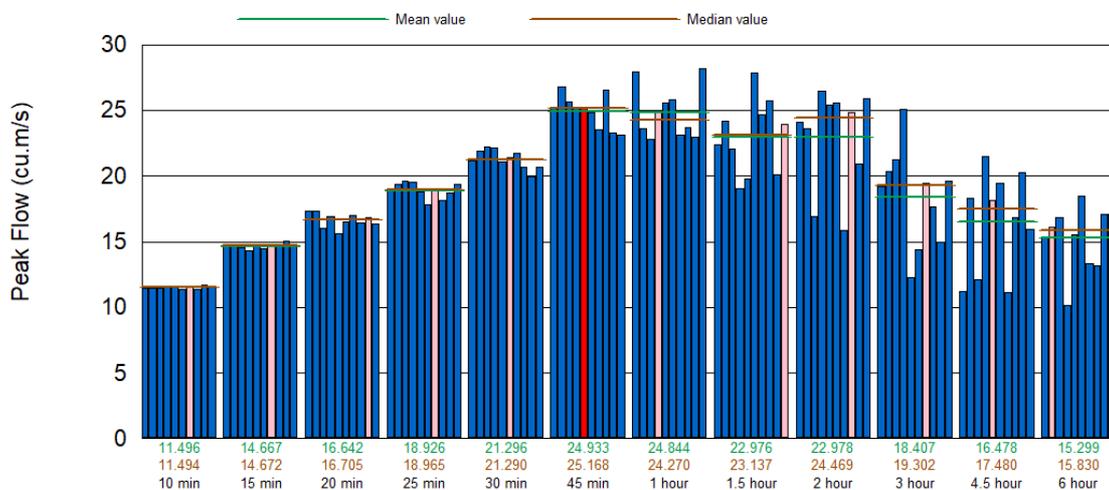


Chart 5: Plot of Anderson Park Outlet Peak Flows

4.4 Update of Hydraulic Model

The TUFLOW hydraulic models developed for the LGA as part of the 2017 Flood Study were reviewed and updated. Since the Flood Study was completed, various changes have occurred in the catchment that are relevant and necessitate an update of the flood models. Updated catchment data was also made available by Council and other stakeholders (refer Section 3.2). Hence the models were refined using this information and where gaps were present these have been filled. These changes were schematised in the hydraulic models, and their effect on flood behaviour was determined. Comparison of the updated model results with those from the 2017 Flood Study is presented in Section 4.5.

The following updates were introduced to the models and discussed in the following sections:

- Adopting hydrology developed based on the ARR2019 approach (refer Section 4.1) and using updated inflow hydrographs generated from the DRAINS model (refer Section 4.3);
- Incorporating the 2013 LiDAR data covering the North Sydney LGA as the new DEM;
- Updating stormwater pits and pipes network in the hydraulic model based on WAE drawings, information obtained from the Metro model and new pits and pipes information from Council GIS database;
- Adjusting the building outlines layer based on the latest Council GIS information and aerial photos;
- Introduction of blockage factors for hydraulic structures as per ARR2019; and
- Minor refinements to model schematisation following findings from site visits and ground truthing exercise.

Several model assumptions or parameters adopted in the 2017 Flood Study were retained such as the Manning's 'n' values, details relating to the stormwater pits, pipes and open channels (unless updated stormwater information is available), location of boundary conditions, omission of fencing and coincident flooding assumptions (i.e. local catchment vs ocean flood).

4.4.1 2013 LiDAR

LiDAR surveyed in 2013 is available for use (refer Section 3.2.2) and is likely to better represent recent topographical changes in the study area than the old LiDAR data used in the 2017 Flood Study. To assess the suitability of the 2013 LiDAR, the following steps were undertaken. Firstly, the two 1 m DEMs (2008 and 2013 LiDAR data) were compared for their representation of features across the LGA. Secondly, the hydraulic model was updated to use the new LiDAR, including adjusting stormwater pits and pipes where necessary. Thirdly, the results of the model with updated DEM were compared against those from the 2017 Flood Study (refer Section 4.5).

The two LiDAR datasets were compared via the 1 m DEM produced from each. The comparison gave the following results:

- Across hard surfaces, free of obstructions such as trees and buildings, the 2013 data is typically between 0.05 and 0.15 m lower than the 2008 data;
- In park areas, away from tree cover, the 2013 data is typically between 0.02 and 0.09 m lower than the 2008 data;

- For road sections with tree cover, the 2013 data is typically between 0.1 and 0.25 m lower than the 2008 data; and
- For the North Sydney CBD area, where tall buildings can obstruct the coverage, the 2013 data is typically 0.05 to 0.15 m lower than the 2008 data.

Image 2 presents topographic profiles from three typical areas in the LGA, with the chart showing the elevation data from the two datasets, and aerial photos showing the location of the profile.

The TUFLOW models were updated to incorporate the DEM based on the 2013 LiDAR. To facilitate the new terrain surface, the inverts of a few pits and pipes had to be adjusted, to avoid them being 'above' ground. This was achieved by setting the invert of the affected pit/pipes to the DEM ground level minus 600 mm (assumed cover depth) minus the pipe size, and then checking this lay between the upstream and downstream inverts. Where this was not achieved, the invert was calculated by assuming a grade of 0.5% or 1% to the downstream invert. Where neither method was possible, a reduced cover depth was used.

4.4.2 Stormwater Rehabilitation Works

WAE drawings were supplied for stormwater rehabilitation works recently undertaken in the LGA (refer Section 3.2.3). These drawings were used to schematise the stormwater pits and pipes network in the hydraulic models to reflect present day conditions.

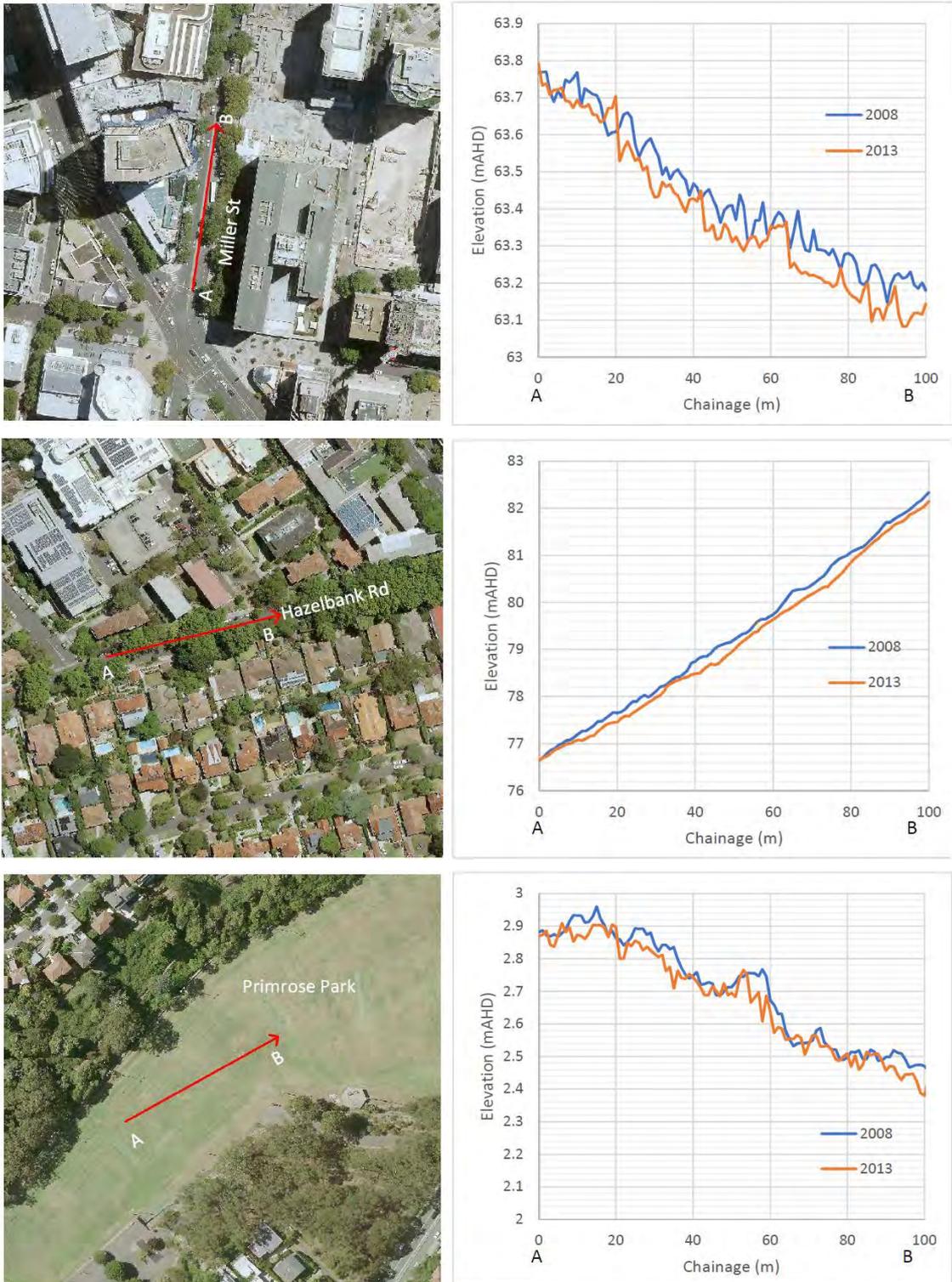
4.4.3 Sydney Metro Model

The Sydney Metro project has involved assessment of flooding in the North Sydney CBD, using the 2017 Flood Study hydrologic and hydraulic models. The modelling involved updating the 'existing' or base case in the vicinity of the proposed Victoria Cross station. The updated model was made available for the current study (refer Section 3.2.5), and the modelled elements incorporated in the current model updates are changes to the building outlines and existing stormwater network around the Sydney Metro site.

4.4.4 Building Outlines

Polygons of building outlines were used to define impermeable barriers in the hydraulic models. Building polygons were updated primarily in the North Sydney CBD area following the 2017 Flood Study and based on the Sydney Metro model updates, to improve the accuracy of overland flow paths through the area. In addition to this, a Council-supplied buildings polygon layer and the latest aerials were used to confirm buildings were correctly represented throughout the rest of the catchments (refer Section 3.2.4).

Image 2: Comparison of 2008 and 2013 LiDAR



4.4.5 Blockage Factors

The blockage assumptions adopted in the 2017 Flood Study were largely retained for the current study except for the blockage factors adopted for hydraulic structures such as road culverts. The hydraulic modelling undertaken for the Flood Study assumed no blockage of pipes, culverts and bridges greater than 450 mm in diameter. Like the Flood Study, stormwater pipes less than 450 mm in diameter were conservatively assumed to be completely blocked as part of the hydraulic modelling undertaken herein. The sensitivity of the model results to changes in blockage factors for pipes larger than 450mm is examined further in Section 4.9.

As per recommendations found in Book 6 Chapter 6 of ARR2019 on 'Blockage of Hydraulic Structures', the blockage factors for all road culverts within the LGA were revised. Assessment was carried out following the procedure outlined in ARR2019 to quantify the most likely blockage level and mechanism for a small bridge or culvert when impacted by sediment or debris laden floodwater, for a range of design flood events. Details of the assessment are provided in Appendix H and the blockage factors derived for the culverts affected are incorporated into the TUFLOW models.

4.4.6 Additional Model Refinements

Several other changes were introduced to the hydraulic models and the major ones are listed as follows. Some of the changes were prompted following site visits.

- Inclusion of pedestrian tunnel under Wollstonecraft train station (see Image 3);
- Inclusion of noise wall and concrete blocks adjacent to the Brook St/Warringah Freeway ramp intersection, installed by the RMS in 2013 (see Image 4);
- Conversion of pipe into an open drain for section between 75 and 77 Reynolds St, Cremorne;
- Incorporate footpath adjacent to 21 Burroway St, Neutral Bay; and
- Activate non-active pipes greater than 450 mm in diameter.

Image 3: Pedestrian Tunnel under Wollstonecraft Train Station



Image 4: Noise Wall Structure and Concrete Blocks adjacent to Warringah Freeway Ramp



4.5 Comparison to 2017 Flood Study Results

The design flood behaviour corresponding to the adopted modelling approach based on ARR2019 methodology and model changes was compared to the results from the 2017 Flood Study. The comparison was undertaken for the 1% AEP event, given its importance in Council's planning policy. Comparison is based on the peak flood levels taken at various locations in each of the four hydraulic models as shown in Figure 4. The results are presented in Table 9 to Table 12. A comparison of the flood extents is also provided in Figure 5 to Figure 8.

Table 9: Comparison of 1% AEP Peak Flood Levels – East Model

ID	Location (refer Figure 4)	2017 Flood Study Peak Flood Level (mAHD)	Current Study Peak Flood Level (mAHD)	Difference (m)
1	Yeo St	81.49	81.33	-0.17
2	Harrison St	76.60	76.42	-0.18
3	Bennett St	68.23	68.15	-0.09
4	Bertha St	58.83	58.61	-0.22
5	Burroway St	54.43	54.26	-0.18
6	Powell St	48.99	48.77	-0.22
7	Bannerman St	34.84	34.64	-0.20
8	Guthrie Ave	38.91	38.81	-0.09
9	Honda Rd	22.08	21.90	-0.18
10	Bogota Ave	18.12	18.03	-0.09
11	Hunts Lookout	15.54	14.56	-0.98*
12	Spofforth St	57.64	57.53	-0.11
Average				-0.23
Median				-0.18

* Significant decrease in peak flood level is a result of improved LiDAR definition for this heavily vegetated area

Table 10: Comparison of 1% AEP Peak Flood Levels – North Model

ID	Location (refer Figure 4)	2017 Flood Study Peak Flood Level (mAHD)	Current Study Peak Flood Level (mAHD)	Difference (m)
13	Military Rd	81.67	81.51	-0.16
14	Belgrave St	69.07	68.90	-0.17
15	Sutherland St	62.96	62.87	-0.09
16	Grasmere La	60.13	60.00	-0.13
17	Grasmere Rd	55.80	55.68	-0.12
18	Little Young St	32.06	31.99	-0.06
19	Brightmore St	45.56	45.47	-0.09
20	Brightmore Res	9.69	9.60	-0.09
21	Young St	9.43	9.37	-0.05
22	Primrose Pk	2.95	2.95	0.00
23	Ryries Pde	32.03	32.19	+0.17
24	Grafton St	41.98	41.76	-0.22
25	Park Av	45.05	44.96	-0.09
26	Cammeray Rd	52.13	51.99	-0.15
27	Warringa Rd	54.29	54.32	+0.02
28	Cammeray Av	67.50	67.40	-0.09
29	Anzac Pk	67.49	67.40	-0.09
30	Ernest St	67.49	67.40	-0.10
31	Miller St	75.84	75.46	-0.38
32	Rodborough Ave	77.83	77.30	-0.53
33	Carlow St	81.09	80.95	-0.14
34	West St	86.93	86.82	-0.11
35	Hamilton La	44.66	44.23	-0.43

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ID	Location (refer Figure 4)	2017 Flood Study			Current Study			Difference (m)
		Peak (mAHD)	Flood Level	Level	Peak (mAHD)	Flood Level	Level	
36	Palmer St	59.27			59.20			-0.08
37	Brooke St	65.80			65.75			-0.05
38	Wheatlegh St	73.57			73.35			-0.22
39	Chandos St	74.24			74.09			-0.15
40	Willoughby Rd	77.46			77.32			-0.14
41	Hume La	78.35			78.16			-0.19
42	Atchison St	78.43			78.24			-0.20
43	Albany La	79.90			79.52			-0.38
44	Albany St	81.18			81.16			-0.02
Average								-0.14
Median								-0.12

Table 11: Comparison of 1% AEP Peak Flood Levels – West Model

ID	Location (refer Figure 4)	2017 Flood Study Peak Flood Level (mAHD)	Current Study Peak Flood Level (mAHD)	Difference (m)
45	Christie St	71.23	71.24	+0.01
46	Lithgow St	65.72	65.50	-0.22
47	Russell St	41.96	41.78	-0.18
48	Carlyle La	54.83	54.13	-0.70*
49	Belmont Av	46.98	47.35	+0.37
50	Newlands La	42.26	42.02	-0.25
51	Newlands St	67.05	66.79	-0.25
52	Hazelbank Rd	60.91	60.72	-0.19
53	Waverton Oval	4.11	4.06	-0.05
54	Woolcott St	27.62	27.47	-0.15
55	Euroka_St	30.49	30.22	-0.27
56	Ancrum_St	38.16	38.05	-0.11
57	Bank St	45.53	45.46	-0.07
Average				-0.16
Median				-0.18

* Significant decrease in peak flood level is a result of stormwater rehabilitation works undertaken along Carlyle Lane

Table 12: Comparison of 1% AEP Peak Flood Levels – South Model

ID	Location (refer Figure 4)	2017 Flood Study Peak Flood Level (mAHD)	Current Study Peak Flood Level (mAHD)	Difference (m)
58	Lavender St	36.74	36.60	-0.14
59	Miller St	63.45	63.26	-0.20
60	Pacific Hwy/Miller St Intersection	64.25	64.18	-0.07
61	Mount St	45.86	45.69	-0.17
62	Little Walker St	43.39	44.86	+1.47*
63	Pacific Hwy/Walker St Intersection	49.62	49.58	-0.05
64	Warringah Freeway/Tunnel Entrance	31.13	30.95	-0.17
65	Clark Rd	13.61	13.59	-0.02
66	Hipwood St	4.78	4.81	+0.02
67	Anderson Park Outlet	2.16	1.91	-0.24
68	Clark Rd/Kurraba Rd Intersection	3.35	3.25	-0.10
69	Warringah Freeway	45.03	44.92	-0.11
70	McLaren St	69.77	69.68	-0.09
71	Rawson St Channel	6.20	6.13	-0.06
72	Forsyth Park	26.22	26.15	-0.08
73	Kurraba Rd	20.96	21.05	+0.10
74	Aubin St	31.24	31.33	+0.09
75	Phillips St	41.56	41.23	-0.33
76	Kurraba Rd/Wycombe Rd Intersection	28.16	28.06	-0.11
77	Carabella St/Peel St Intersection	21.74	21.56	-0.18

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ID	Location (refer Figure 4)	2017 Flood Study		Current Study		Difference (m)
		Peak Flood Level (mAHD)	Level	Peak Flood Level (mAHD)	Level	
78	Holbrook Ave	12.41		12.25		-0.16
Average						-0.03
Median						-0.10

* Significant increase in peak flood level is a result of revision made to the overland flow path/building obstruction as advised by Council

In summary, the revision of the flood models produced 1% AEP peak flood levels which are about 0.1-0.2m lower than those of the 2017 flood study. This can be attributed mainly to the use of the new LiDAR dataset as well as adopting the ARR2019 methodology in deriving the catchment hydrology for the models. For areas where there is significant increase or decrease in peak flood levels as a result of the model revision, this was further investigated and the causes were identified as follows (in addition to the aforementioned reasons):

- Improved terrain definition in the more recent LiDAR dataset particularly for heavily vegetated areas;
- Revision of overland flow paths following updates to the existing building footprints; and
- Flood improvements as a result of Council's stormwater rehabilitation works.

The comparison of the revised design flood results corresponding to the adopted modelling approach based on ARR2019 methodology and at-site IFD, against those of the 2017 Flood Study, also serves as a verification of the modelling work undertaken herein.

4.6 Further Verification

As part of the model verification process, the design flow estimates from the revised models were compared against those from the 2017 Flood Study as well as other similar urban catchments in the Sydney Metropolitan region. Typically, the unit flow rates calculated for the 1% AEP event range from 0.4 to 0.6 m³/s/ha (WMAwater, 2017). For each model, a representative catchment was selected which should be located upstream of the flow path with minimal flow attenuation and the unit flow rates were determined. The results are provided in Table 13 for the locations shown in Image 5. Overall, the results show that the unit flow rates for the flood models herein are within the quoted range, hence providing confidence in model accuracy.

Table 13: Unit Flow Rates for the 1% AEP Event

Flood Model	Selected Catchment Area (ha)	2017 Flood Model (ARR87)		Current Flood Model (ARR2019)	
		Peak Discharge (m3/s)	Unit Flow Rate (m3/s/ha)	Peak Discharge (m3/s)	Unit Flow Rate (m3/s/ha)
East	4.8	2.2	0.5	1.8	0.4
North	3.2	1.4	0.4	1.2	0.4
West	6.3	3.1	0.5	2.5	0.4
South	4.2	2.1	0.5	2.1	0.5

Image 5: Location for Deriving Unit Flow Rates



4.7 Design Flood Results

The flood models revised herein were used to re-estimate the full range of design flood behaviour for the study area. The design flood results define the area's flood liability and are one of the key inputs in describing the area's flood risk. The 1% AEP event in particular will be used to guide residential and commercial development as per Council's and NSW Government's policies. The PMF was also modelled which describes the largest possible flood event and its spatial extent defines the area's floodplain.

Based on the ARR2019 methodology, each design event consists of consideration of multiple storm durations and an ensemble of temporal patterns per storm duration. The critical storm for each duration was selected based on the temporal pattern that produced the median peak flood level in the hydraulic model. This is calculated using a grid analysis of the peak flood level grids and the grid that is closest, across all grid cells, to the median flood level grid. Critical duration assessment was then undertaken by generating a maximum envelope grid using the median peak flood level grid for each duration modelled for each AEP event and the storm duration which yields the highest peak flood levels for majority of the catchment was deemed the critical event. A summary of the critical durations for each model is outlined in Table 14.

Table 14: Critical duration assessment

Flood Model	Event	2017 Flood Study (ARR87)	Current Study (ARR2019 using at-site IFD) * TP = temporal pattern no
East	PMF	15 minute	
	1% AEP	25 minute	45 minute (TP09)
	2% AEP	25 minute	45 minute (TP09)
	5% AEP	25 minute	1 hour (TP10)
	10% AEP	25 minute	1 hour (TP10)
	20% AEP	25 minute	45 minute (TP03)
North	PMF	15 minute, 1 hour, 2hour (envelope)	
	1% AEP	1 hour	45 minute (TP02), 1.5 hour (TP08) (envelope)
	2% AEP	1 hour	1.5 hour (TP01)
	5% AEP	1 hour	1 hour (TP10)
	10% AEP	1 hour	1 hour (TP10)
	20% AEP	1 hour	1 hour (TP08)

Flood Model	Event	2017 Flood Study (ARR87)	Current Study (ARR2019 using at-site IFD) * TP = temporal pattern no
West	PMF	15 minute, 30 minute, 2 hour (envelope)	
	1% AEP	1 hour	45 minute (TP03), 2 hour (TP02) (envelope)
	2% AEP	1 hour	1 hour (TP08)
	5% AEP	1 hour	1 hour (TP10)
	10% AEP	1 hour	1 hour (TP03)
	20% AEP	1 hour	45 minute (TP08)
South	PMF	15 minute, 1 hour (envelope)	
	1% AEP	2 hour	45 minute (TP02), 1 hour (TP05) (envelope)
	2% AEP	2 hour	45 minute (TP09), 1 hour (TP05) (envelope)
	5% AEP	2 hour	1 hour (TP10)
	10% AEP	2 hour	1 hour (TP10)
	20% AEP	2 hour	45 minute (TP03)

The revised design flood results are presented in the output formats tabulated in Table 15. These results will supersede the 2017 Flood Study results upon adoption of the FRMS. The 5% and 1% AEP peak flood levels and depths for the locations shown in Figure 4 are provided in Table 16 to Table 19, with the results for the remainder events provided in Appendix B.

Table 15: Design Flood Results Output

Outputs	Design Events	Figures/Tables
Peak Flood Depths	20%, 10%, 5%, 2%, 1% AEP and PMF	Figure 9 to Figure 14 Table 16 to Table 19 (5% and 1% AEP only) Table B 5 to Table B 8
Peak Flood Levels	20%, 10%, 5%, 2%, 1% AEP and PMF	Figure 9 to Figure 14 Table 16 to Table 19 (5% and 1% AEP only) Table B 1 to Table B 4

Outputs	Design Events	Figures/Tables
Peak Flood Extents	20%, 10%, 5%, 2%, 1% AEP and PMF	Figure 9 to Figure 14
Peak Flood Velocities	20%, 10%, 5%, 2%, 1% AEP and PMF	Figure 15 to Figure 20
Peak Flows	20%, 10%, 5%, 2%, 1% AEP and PMF	Table B 9 to Table B 12
Flood Hazard	20%, 5%, 1% AEP and PMF	Figure 21 to Figure 24
Flood Function (Hydraulic Categories)	20%, 5%, 1% AEP and PMF	Figure 25 to Figure 28

Table 16: 5% and 1% AEP Design Flood Levels and Depths – East Model

ID	Location (refer Figure 4)	Suburb	5% AEP Peak Flood Level (mAHD)	5% AEP Peak Flood Depth (m)	1% AEP Peak Flood Level (mAHD)	1% AEP Peak Flood Depth (m)
1	Yeo St	Cremorne	81.32	0.02	81.33	0.03
2	Harrison St	Cremorne	76.40	0.17	76.42	0.19
3	Bennett St	Neutral Bay	68.11	0.16	68.15	0.19
4	Bertha St	Cremorne	58.58	0.12	58.61	0.14
5	Burroway St	Neutral Bay	54.23	0.11	54.26	0.13
6	Powell St	Neutral Bay	48.75	0.26	48.77	0.28
7	Bannerman St	Cremorne	34.60	0.46	34.64	0.50
8	Guthrie Ave	Cremorne	38.80	0.08	38.81	0.09
9	Honda Rd	Kurraba Point	21.75	0.40	21.90	0.54
10	Bogota Ave	Kurraba Point	17.94	0.46	18.03	0.54
11	Hunts Lookout	Cremorne Point	14.56	0.08	14.56	0.08
12	Spofforth St	Cremorne	57.47	0.34	57.53	0.40

Table 17: 5% and 1% AEP Design Flood Levels and Depths – North Model

ID	Location (refer Figure 4)	Suburb	5% AEP Peak Flood Level (mAHD)	5% AEP Peak Flood Depth (m)	1% AEP Peak Flood Level (mAHD)	1% AEP Peak Flood Depth (m)
13	Military Rd	Neutral Bay	81.48	0.40	81.51	0.44
14	Belgrave St	Cremorne	68.84	0.56	68.90	0.62
15	Sutherland St	Cremorne	62.75	0.50	62.87	0.62
16	Grasmere La	Cremorne	59.91	0.60	60.00	0.68
17	Grasmere Rd	Cremorne	55.63	0.48	55.68	0.52
18	Little Young St	Cremorne	31.91	0.56	31.99	0.64
19	Brightmore St	Cremorne	45.38	0.53	45.47	0.62
20	Brightmore Res	Cremorne	9.39	2.93	9.60	3.14
21	Young St	Cremorne	9.14	0.38	9.37	0.62
22	Primrose Pk	Cremorne	2.89	0.55	2.95	0.61
23	Ryries Pde	Cremorne	32.11	0.26	32.19	0.34
24	Grafton St	Cremorne	41.70	0.48	41.76	0.55
25	Park Av	Cremorne	44.87	0.43	44.96	0.52
26	Cammeray Rd	Cammeray	51.92	0.47	51.99	0.53

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ID	Location (refer Figure 4)	Suburb	5% AEP Peak Flood Level (mAHD)	5% AEP Peak Flood Depth (m)	1% AEP Peak Flood Level (mAHD)	1% AEP Peak Flood Depth (m)
27	Warringa Rd	Cammeray	54.27	0.75	54.32	0.80
28	Cammeray Av	Cammeray	66.11	1.59	67.40	2.88
29	Anzac Pk	Cammeray	66.11	2.35	67.40	3.64
30	Ernest St	Cammeray	66.96	0.35	67.40	0.78
31	Miller St	Cammeray	75.38	0.25	75.46	0.33
32	Rodborough Ave	Crows Nest	77.05	0.59	77.30	0.84
33	Carlow St	North Sydney	80.91	0.21	80.95	0.26
34	West St	North Sydney	86.79	0.34	86.82	0.38
35	Hamilton La	Cammeray	44.13	0.41	44.23	0.51
36	Palmer St	Cammeray	59.08	0.48	59.20	0.59
37	Brooke St	Crows Nest	65.71	0.17	65.75	0.21
38	Wheatlegh St	Crows Nest	73.25	0.80	73.35	0.89
39	Chandos St	Naremburn	74.04	0.31	74.09	0.36
40	Willoughby Rd	Crows Nest	77.25	0.40	77.32	0.47
41	Hume La	Crows Nest	78.05	1.76	78.16	1.87

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ID	Location (refer Figure 4)	Suburb	5% AEP Peak Flood Level (mAHD)	5% AEP Peak Flood Depth (m)	1% AEP Peak Flood Level (mAHD)	1% AEP Peak Flood Depth (m)
42	Atchison St	Crows Nest	78.09	0.95	78.24	1.09
43	Albany La	Crows Nest	79.43	0.20	79.52	0.29
44	Albany St	Crows Nest	81.02	0.57	81.16	0.71

Table 18: 5% and 1% AEP Design Flood Levels and Depths – West Model

ID	Location (refer Figure 4)	Suburb	5% AEP Peak Flood Level (mAHD)	5% AEP Peak Flood Depth (m)	1% AEP Peak Flood Level (mAHD)	1% AEP Peak Flood Depth (m)
45	Christie St	Wollstonecraft	71.20	0.07	71.24	0.11
46	Lithgow St	Wollstonecraft	65.44	0.53	65.50	0.58
47	Russell St	Wollstonecraft	41.74	0.63	41.78	0.68
48	Carlyle La	Wollstonecraft	53.30	0.95	54.13	1.77
49	Belmont Av	Wollstonecraft	46.63	2.57	47.35	3.30
50	Newlands La	Wollstonecraft	41.33	0.82	42.02	1.51
51	Newlands St	Wollstonecraft	66.72	0.59	66.79	0.67
52	Hazelbank Rd	Wollstonecraft	60.68	0.28	60.72	0.31
53	Waverton Oval	Waverton	4.02	0.10	4.06	0.14
54	Woolcott St	Waverton	27.30	1.36	27.47	1.53
55	Euroka_St	Waverton	30.14	0.49	30.22	0.57
56	Ancrum_St	Waverton	37.95	0.39	38.05	0.49
57	Bank St	North Sydney	45.38	0.45	45.46	0.53

Table 19: 5% and 1% AEP Design Flood Levels and Depths – South Model

ID	Location (refer Figure 4)	Suburb	5% AEP Peak Flood Level (mAHD)	5% AEP Peak Flood Depth (m)	1% AEP Peak Flood Level (mAHD)	1% AEP Peak Flood Depth (m)
58	Lavender St	North Sydney	36.59	0.01	36.60	0.03
59	Miller St	North Sydney	63.20	0.30	63.26	0.36
60	Pacific Hwy/Miller St Intersection	North Sydney	64.17	0.07	64.18	0.08
61	Mount St	North Sydney	45.65	0.05	45.69	0.08
62	Little Walker St	North Sydney	44.25	1.43	44.86	2.03
63	Pacific Hwy/Walker St Intersection	North Sydney	49.57	0.00	49.58	0.00
64	Warringah Freeway/Tunnel Entrance	North Sydney	30.36	0.44	30.95	1.04
65	Clark Rd	North Sydney	13.55	0.15	13.59	0.19
66	Hipwood St	Kirribilli	4.76	0.23	4.81	0.28
67	Anderson Park Outlet	Neutral Bay	1.53	0.41	1.91	0.79
68	Clark Rd/Kurraba Rd Intersection	Neutral Bay	3.11	0.32	3.25	0.46
69	Warringah Freeway	North Sydney	44.91	0.10	44.92	0.11

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ID	Location (refer Figure 4)	Suburb	5% AEP Peak Flood Level (mAHD)	5% AEP Peak Flood Depth (m)	1% AEP Peak Flood Level (mAHD)	1% AEP Peak Flood Depth (m)
70	McLaren St	North Sydney	69.67	0.06	69.68	0.07
71	Rawson St Channel	Neutral Bay	5.89	1.01	6.13	1.23
72	Forsyth Park	Neutral Bay	26.12	0.11	26.15	0.13
73	Kurraba Rd	Neutral Bay	21.02	0.14	21.05	0.17
74	Aubin St	Neutral Bay	31.30	0.45	31.33	0.48
75	Phillips St	Neutral Bay	41.21	0.30	41.23	0.32
76	Kurraba Rd/Wycombe Rd Intersection	Kurraba Point	28.05	0.01	28.06	0.02
77	Carabella St/Peel St Intersection	Kirribilli	21.55	0.06	21.56	0.07
78	Holbrook Ave	Kirribilli	12.23	0.02	12.25	0.03

4.8 Climate Change

The design flood results were used to assess the impact of climate change on flood producing rainfall, and by extension, flooding itself. The assessment used the IPCC (Intergovernmental Panel on Climate Change) greenhouse gas concentration scenarios and subsequent modelling estimating each scenario's effect on rare rainfall events. There are four IPCC greenhouse gas concentration projections named RCP 2.5, 4.5, 6.0 and 8.5, with the RCP 2.5 being the most optimistic and 8.5 the least optimistic. The ARR2019 methodology recommends the use of RCP 4.5 and 8.5 scenarios, and their projected increase in precipitation intensity were obtained from the ARR Data Hub and shown in Table 20 for the 2090 estimate.

Table 20: Climate Change Factors – Percentage Increase in Rainfall Intensity in 2090

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

This indicates that, for example, under a relatively low emissions scenario (RCP 4.5), rainfall intensity will increase by 9.1% in North Sydney by 2090. The significance of this percentage is measured by comparing it to the range of design flood events. The results of this assessment are shown in Table 21, which lists the total rainfall depth for the 5%, 2% and 1% AEP events (for the typical critical duration of the LGA, i.e. 45 minutes) and then compares those events with the increased rainfall caused by two emissions scenarios – RCP 4.5 and RCP 8.5.

Table 21: Comparison between Design Rainfall and Projected Climate Change Rainfall Intensity

AEP	Total Rainfall Depth (mm)		
	At-site IFD 45 minutes	2090 RCP 4.5 +9.10%	2090 RCP 8.5 +18.60%
5%	60.5	66.0	71.8
2%	72.8	79.4	86.3
1%	83	90.6	98.4

The table shows that, overall, the 2% AEP floods will increase to a magnitude close to the 1% AEP event, under both emissions scenarios. Likewise, the 5% AEP floods will increase to a magnitude close to the 2% AEP event. In other words, a 1% AEP flood, which previously occurred every 100 years on average, will happen twice as often, or once every 50 years on average, under a RCP 4.5 or 8.5 greenhouse gas scenario.

The impact of these changes on peak flood levels was determined by comparing the 2% and 1% AEP events with details provided in Appendix C. A summary of the results is provided in Table 22. It was found that for some locations, the increase in the 2% AEP peak flood levels based on the RCP 8.5 emission scenario in particular would result in flood levels matching the present day 1% AEP event. Two example locations are shown below to further explain how climate change will affect

flooding. Note that increased rainfall will worsen flooding at all locations in the LGA that currently experience flooding, and the examples below could be taken at any such area.

Image 6: Carlyle Lane/Russell Street – 1% AEP existing flooding with climate change explanation

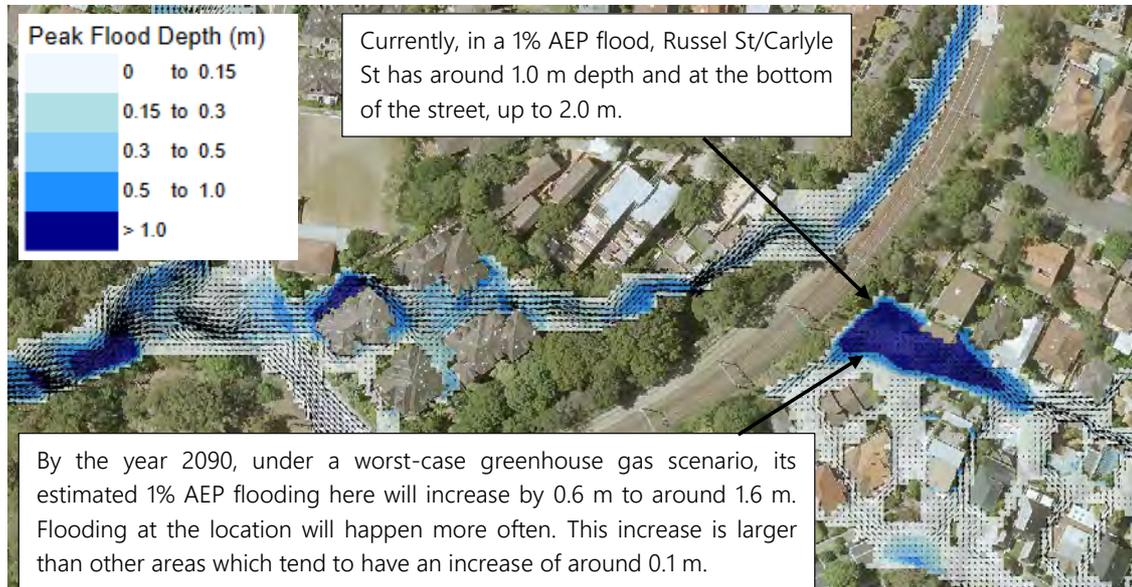
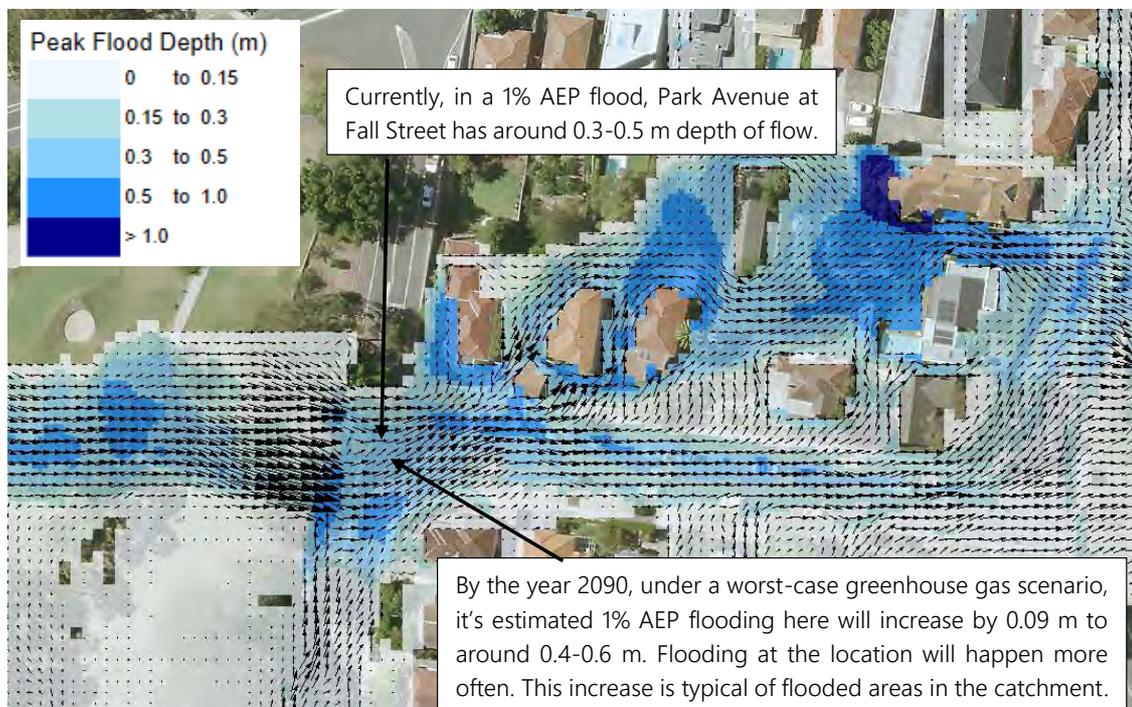


Image 7: Park Avenue, Cammeray - 1% AEP existing flooding with climate change explanation



With regards to sea level rise, DPIE (formerly Office of Environment and Heritage (OEH) and prior to that, Department of Environment, Climate Change and Water (DECCW)) provided guidelines which set the benchmarks for a projected rise in sea level of 0.4 m by 2050 and 0.9 m by 2100 as derived by IPCC and CSIRO (DECCW, 2010). The sensitivity of the design flood results to sea level rise was also assessed herein for the 2100 scenario. A summary of the results is provided in Table 22 with details provided in Appendix C.

Table 22: Average Changes to Peak Flood Levels (m) under Projected Climate Change Scenarios

Model	1% AEP				2% AEP			
	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
East	+0.01	+0.03	+0.01	+0.03	+0.01	+0.03	+0.01	+0.03
North	+0.06	+0.13	+0.06	+0.13	+0.05	+0.10	+0.05	+0.10
West	+0.08	+0.16	+0.08	+0.16	+0.07	+0.15	+0.07	+0.15
South	+0.05	+0.09	+0.06	+0.10	+0.04	+0.08	+0.06	+0.10

From Table 22, the peak flood level increase for both the 2% and 1% AEP events under the RCP 4.5 scenario is in the order of 0.1 m, and up to 0.2 m under the RCP 8.5 scenario. There is minimal difference for the results when sea level rise is considered, and this is to be expected since most of the LGA is elevated well above ocean water level. Thus, increased flood risk due to sea level rise is generally restricted to low-lying areas next to the harbour such as Anderson Park in Neutral Bay.

4.8.1 Managing Increased Flood Risk due to Climate Change

As described in the previous section and presented in detail in Appendix C, climate change will increase the frequency and severity of flooding in the LGA, due to the expected increases in the intensity of rainfall events that cause flooding. There are also some locations where sea level rise will slightly increase flood risk. The analysis shows that in the large majority of locations, depths of flooding will increase by around 0.1 m, under a long term planning horizon of 2090, with a worst-case greenhouse gas concentration.

The relatively small magnitude of this 0.1 m increase means that increased flood risk due to climate change, while significant, does not require specific risk management measures. Naturally, climate change is a result of greenhouse gas emissions in Australia and abroad and climate risk can certainly be mitigated by reducing these emissions to zero, in accordance with IPCC recommendations. However, it remains that measures that will manage and reduce existing flood risk in the LGA, as detailed in Section 6.6 of this report, are sufficient to also manage flood risk associated with climate change.

4.9 Sensitivity Analysis

This section describes the sensitivity of the model results to changes in model parameters. In hydraulic modelling, each model parameter is estimated based on the available data, guidance and knowledge of the catchment. Sensitivity analysis quantifies assumptions made, by measuring their effect on model flood behaviour. Large changes in flood behaviour indicate parameters that the model is sensitive to. For the current study, sensitivity analysis was undertaken for the rainfall losses, hydraulic roughness (Manning's 'n') and pipe blockage factors.

The model sensitivity is tested by varying each parameter within a reasonable estimate range, and then assessing the output from the hydraulic model to determine the change in peak flood level results for each scenario. This analysis has been undertaken for the 1% AEP event. Table 23 presents the results of the sensitivity analysis with further details provided in Appendix D.

Table 23: Average Changes to 1% AEP Peak Flood Levels (m) for Sensitivity Analysis Scenarios

Model	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
East	0.00	0.00	0.00	0.00	+0.01	+0.02
North	+0.01	-0.01	-0.01	+0.01	+0.06	+0.16
West	+0.02	-0.01	-0.02	+0.03	+0.07	+0.23
South	+0.01	-0.02	0.00	0.00	+0.01	+0.02

The sensitivity analysis results show that the model results are generally insensitive to the rainfall losses and hydraulic roughness, whilst more sensitive to the pipe blockage factors whereby the 1% AEP peak flood levels increase is in the order of 0.1 m based on a blockage factor of 20% and 0.2 m for a blockage factor of 50%. It is important to note that stormwater pipes less than 450 mm in diameter were fully blocked as part of the hydraulic modelling undertaken herein (see Section 4.4.5).

4.10 Flood Function

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

- Flow Conveyance/Floodway – the areas where a significant proportion of the floodwaters flow and typically align with defined channels. If these areas are blocked or developed, there will be significant redistribution of flow and increased flood levels across the floodplain. Generally, flow conveyance areas have deep and/or fast-moving floodwaters;

- Flood Storage – areas where, during a flood, a significant proportion of floodwaters extend into, water is stored and then recedes after a flood. Significant filling or development in these areas may increase flood levels nearby; and
- Flood Fringe – areas that make up the remainder of the flood extent. Development in these areas are unlikely to alter flood behaviour in the surrounding area.

There is no prescribed methodology for deriving each category and as such categorisation is typically determined based on experience and knowledge of the study area.

For the current study, the flood function classifications have been undertaken in accordance with the findings of Howells et al (2003), who defined these categories based on the depth and velocity of flood waters. This is also in line with the approach previously adopted by the 2017 Flood Study. For the technical calculation of these classifications in the North Sydney LGA the following was adopted:

- Flow Conveyance/Floodway – areas where:
 - the velocity-depth product $> 0.25 \text{ m}^2/\text{s}$ and peak velocity $> 0.25 \text{ m/s}$
 - or
 - peak velocity $> 1 \text{ m/s}$ and peak depth $> 0.15 \text{ m}$
- Flood Storage - areas outside the Flow Conveyance where depths exceed 0.5 m
- Flood Fringe – areas outside of Flow Conveyance where depths are less than 0.5 m

Figure 25 to Figure 28 present the Flood Function for the 20%, 5%, 1% AEP and PMF events.

Following review of the design flood behaviour of the study area, it was found that since the majority of the areas are dominated by shallow overland flow, the difference in peak flood level across the design storms modelled is not significant and generally in the order of 0.1 m. Further, high hazard flows and floodway areas are generally confined to principal flow paths within the study area. Limited areas of flood storage were found, and these areas are localised and typically found upstream of obstructions to flow path such as upstream of railway or major road embankments. The flow conveyance/floodway areas were critical in identifying properties to be included in the draft Flood Planning Area.

4.11 Flood Hazard

Flood hazard is defined as the threat that flooding will pose to human activity. For the 2017 Flood Study, the hazard categories were determined in accordance with Appendix L of the NSW Floodplain Development Manual (2005). As part of the current study, the hazard categories were revised based on the Australian Emergency Management Handbook 7 guideline as per OEH's recommendation, which considers the threat to types of people (children, adult) and activity (pedestrian, vehicle and within a building). The flood hazard categories from this guideline are presented in Image 8.

The chart divides a flood event into six categories of hazard, specifically:

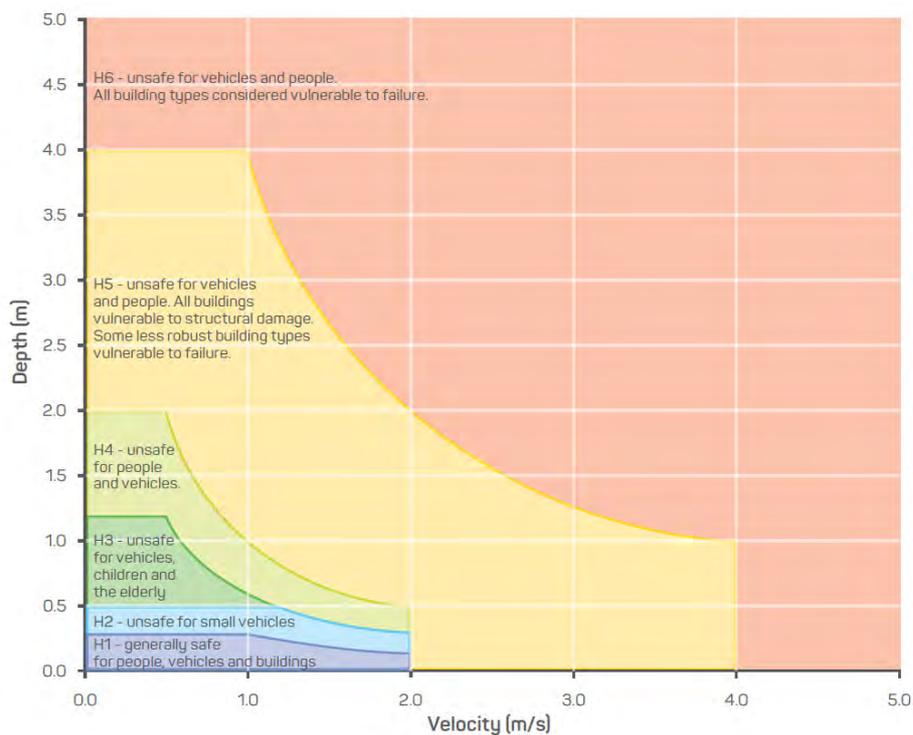
- H1 – Generally safe for people, vehicles and buildings (corresponding to very shallow and slow flow);
- H2 – Unsafe for small vehicles;
- H3 – Unsafe for vehicles, children and the elderly;
- H4 – Unsafe for people and vehicles;

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- H5 – Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure; and
- H6 – Unsafe for vehicles and people. All building types considered vulnerable to failure (corresponding to very deep and fast flow).

Figure 21 to Figure 24 present the Flood Hazard for the 20%, 5%, 1% AEP and PMF events.

Image 8: Flood Hazard Curves based on AEM Handbook 7



Generally, it was found that high hazard areas (above H3 hazard) correspond to the flow conveyance/floodway areas with fast flowing floodwaters as well as flood storage areas with significant depths of floodwaters. For the latter, these are usually areas upstream of railway or major road embankments which include (and not limited to) Anzac Park and Harry Howard Reserve, as well as topographic low points such as Brightmore Reserve, Tunks Park, and Primrose Park.

In addition to utilising the flood hazard curves, the following factors were also considered herein that would influence the vulnerability of communities to flood hazard:

- Effective warning time available to respond to a flood event;
- Rate of rise of floodwaters; and
- Isolation from safety during flood.

These are discussed further in Section 6.4.

5. COMMUNITY CONSULTATION

Community consultation formed an integral part in completing Stages 1 and 2 to the North Sydney Wide Flood Study project. Following on from this approach, community consultation was undertaken during the Study to inform residents about the current Study, gather further information on flooding as well as potential flood mitigation measures, identify community concerns, and, most importantly, develop and maintain community confidence and collaboration in the Study results.

Following the inception of the Study, Council provided information on the floodplain risk management process on their website. A newsletter and questionnaire were then distributed to selected residents in October 2019 to inform residents of the Study and request feedback on potential mitigation measures. The results of the survey are documented in the following section.

This community consultation section will also be updated to describe the consultation processes undertaken during public exhibition of this draft FRMS&P, once carried out.

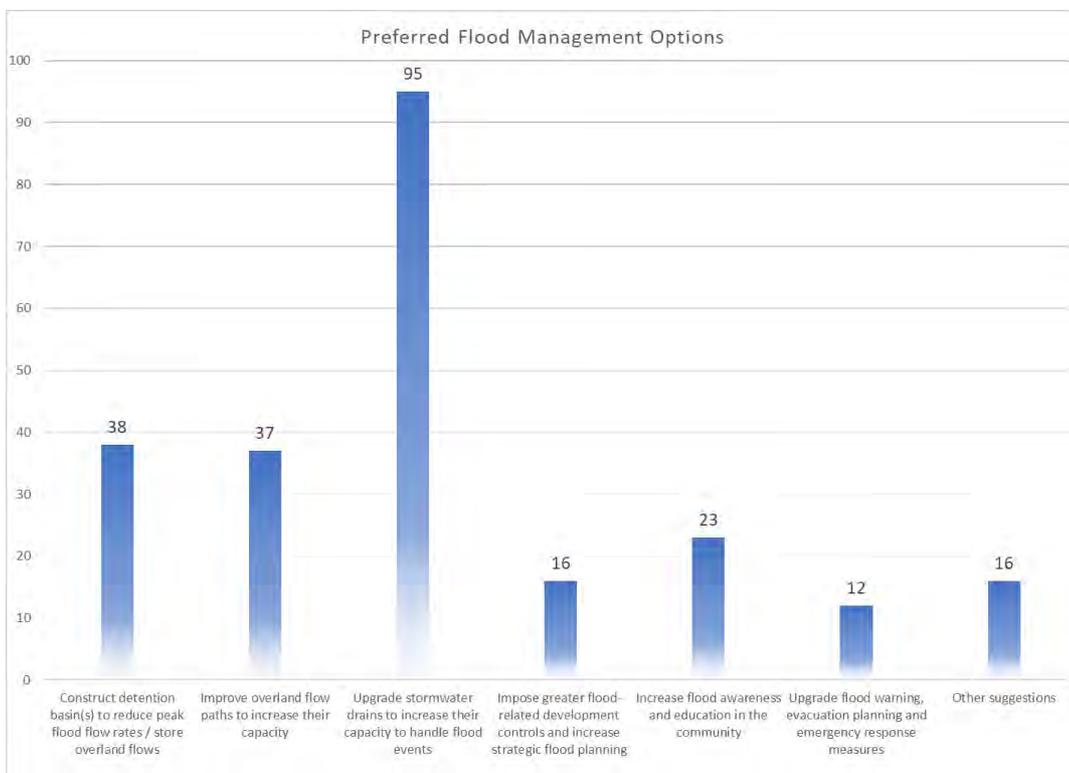
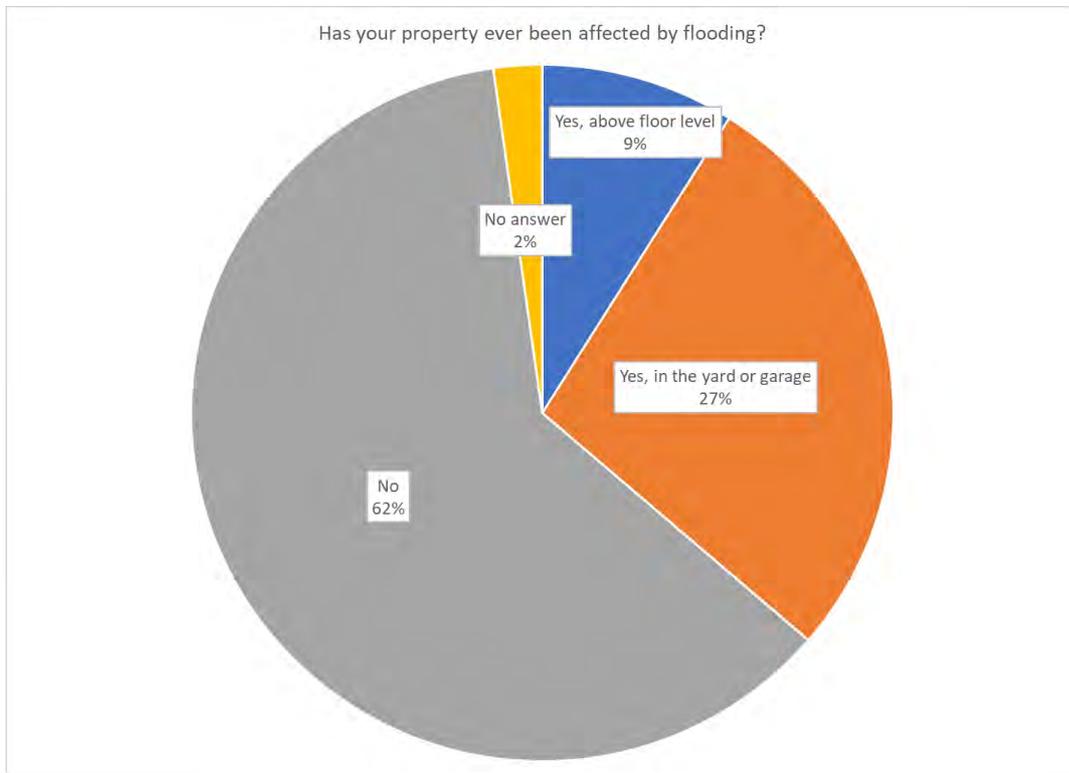
5.1 Newsletter and Questionnaire

A newsletter and questionnaire were sent out in October 2019 to inform residents of the study and request feedback on potential mitigation measures. The mailout consisted of a 2-page newsletter and 2-page questionnaire, a copy of which is provided in Appendix F. The newsletter and questionnaire were distributed to residents located in areas identified as in the general vicinity of flood affectation (approximately 3,000+ properties). Community members who did not receive a questionnaire were still able to participate in the questionnaire via Council's website, which contained the same newsletter information and a link to an online version of the questionnaire.

A total of 179 responses were received from the selected residents, which amount to about 5% response rate. A summary of the survey results is shown in Chart 6. Approximately 27% of respondents indicated that they had experienced flooding in their yard or garage, while 9% of respondents had experienced over floor flooding of habitable floor levels. These results highlight that there is a general awareness of flooding within the LGA and the potential for flooding to impact on properties.

The questionnaire outlined a range of flood mitigation measures to manage flood risk and asked community members to select their preferred measures. A large majority of the respondents favoured upgrade of existing stormwater drains to alleviate flood risk within the study area (95 respondents). Other popular measures include construction of detention basin(s) which can help with reducing peak discharge as well as enhancing conveyance capacity of existing overland flow paths (38 and 37 respondents respectively). Support for non-structural measures was comparatively low. Consideration of these community preferences has been taken into account when deriving and assessing potential flood mitigation measures herein (see Section 6.10.2).

Chart 6: Questionnaire Results



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5.2 Public Exhibition

To be completed after the public exhibition of the draft Floodplain Risk Management Study and Plan.

5.3 Future Consultation

To be completed once further community consultation is undertaken.

6. FLOODPLAIN RISK MANAGEMENT STUDY

6.1 Overview

The following Floodplain Risk Management Study (FRMS) draws on the revised design flood results (see Section 4.7) to identify, assess and compare various flood risk management mitigation options and opportunities aimed at improving the existing flood situation in the North Sydney LGA. An approach has been undertaken which assesses the flood impacts and economic impacts of management options. Based on this work an implementation Plan has then been devised. This FRMS provides key information for Council, the SES and the community for effectively managing and mitigating flood risk within the LGA.

The following sections utilise information on existing flood conditions at the LGA to:

- Identify flooding hotspots (see Section 6.2);
- Ascertain the economic impact of existing flooding in the LGA (see Section 6.3);
- Determine the existing flood warning times along key evacuation routes (see Section 6.4);
- Assess the vulnerability of sensitive land use and public infrastructure (see Section 6.4);
- Develop the flood emergency response classifications (see Section 6.5); and
- Assess feasibility of mitigation options in reducing flood risk at hotspots (see Section 6.9).

6.2 Flooding Hotspots

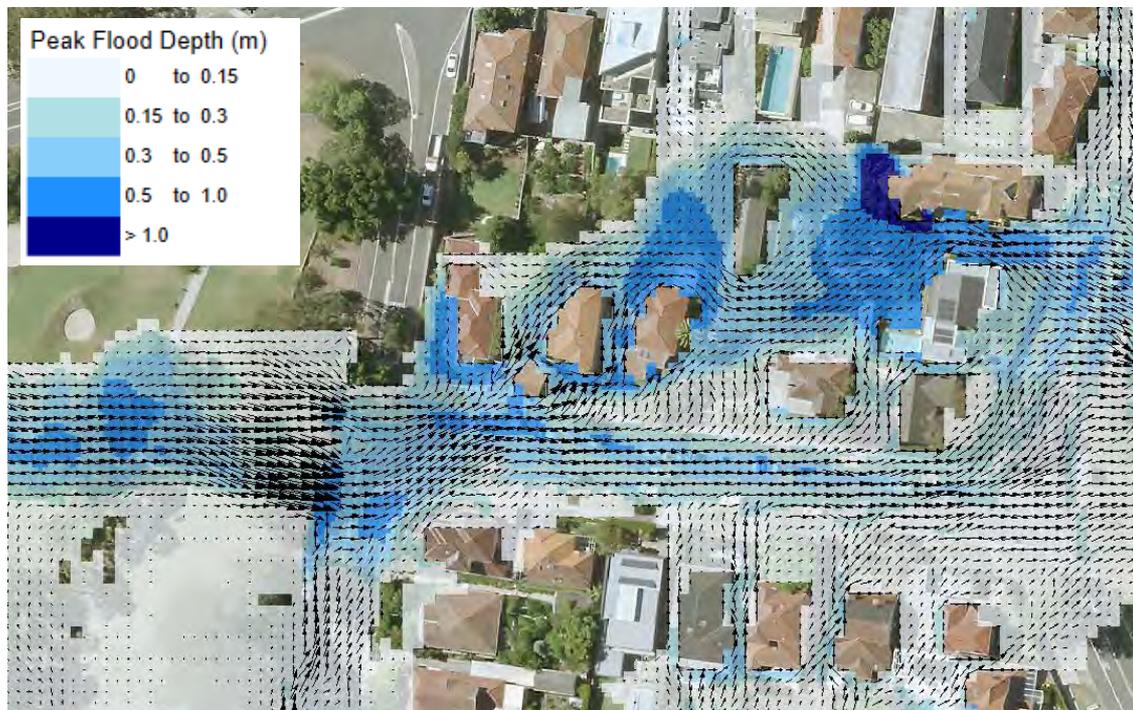
Flooding hotspots refer to areas that are particularly flood affected and/or affected by hazardous flooding. Several hotspot areas were identified during the 2017 Flood Study and have been reassessed in the current study using the updated flood modelling results. The following sections discuss the flood mechanisms affecting key hotspots which were identified based on the modelling work undertaken herein.

6.2.1 Creek Lane, Cammeray

Creek Lane is located at what was the former Willoughby Creek flow path and is subject to significant flood affectation as shown in Image 9. The flow path originates as far upstream as North Sydney and flows in excess of the underground trunk capacity traverse overland from the Cammeray Golf Club through Creek Lane and discharge to the harbour via Primrose Park. The 1% AEP flows through the area are shown to be of 'H4' hazard category (refer Figure 23), thus unsafe for people and vehicles.

Mitigation measures, i.e. FM-N05+N08 and FM-N11 (see Section 6.9), consider upgrading the trunk capacity under Creek Lane and storing some of the upstream catchment runoff.

Image 9: Hot Spot – Creek Lane – 1% AEP Design Flood Behaviour

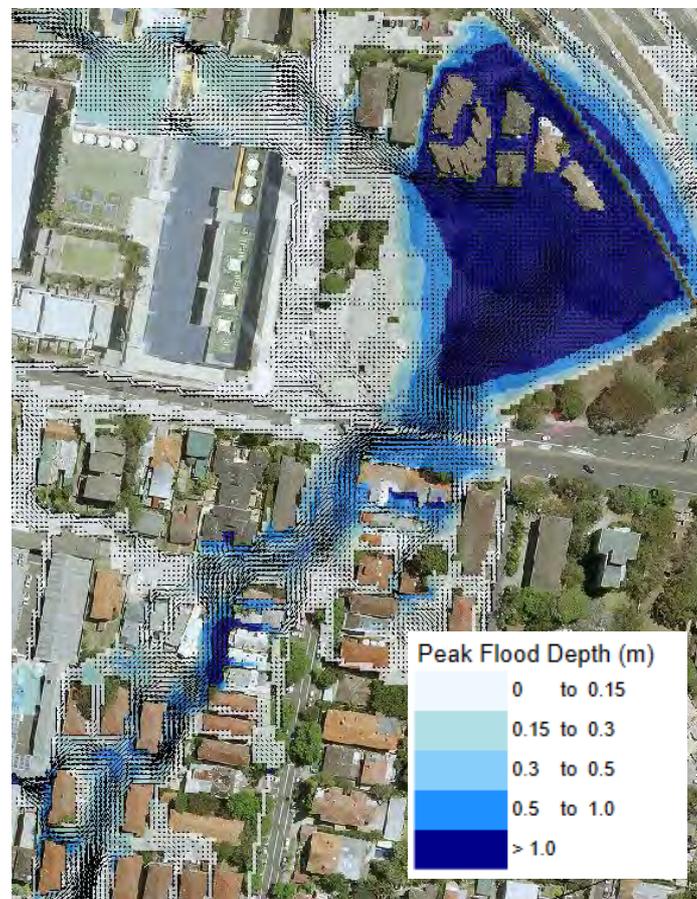


6.2.2 Lytton Street/Anzac Park, Cammeray

Properties adjacent to Lytton Street and Anzac Park were subjected to historical floods. Whilst the issue affecting the Lytton Street properties mainly pertains to conveyance of high hazard flows, flooding at Anzac Park is mainly caused by the obstruction to overland flows posed by the Warringah Freeway, with the underground trunk system providing the only relief to discharge floodwaters. Significant flood depths in excess of 1 m can be expected for the properties adjacent to Anzac Park for the 1% AEP event as shown in Image 10.

Mitigation measures, i.e. FM-N02, FM-N03, and FM-N05+N08 (see Section 6.9), consider storing some of the upstream catchment runoff, augmenting the storage available in Anzac Park and upgrading the trunk capacity under Warringah Freeway.

Image 10: Hot Spot – Lytton Street/Anzac Park – 1% AEP Design Flood Behaviour

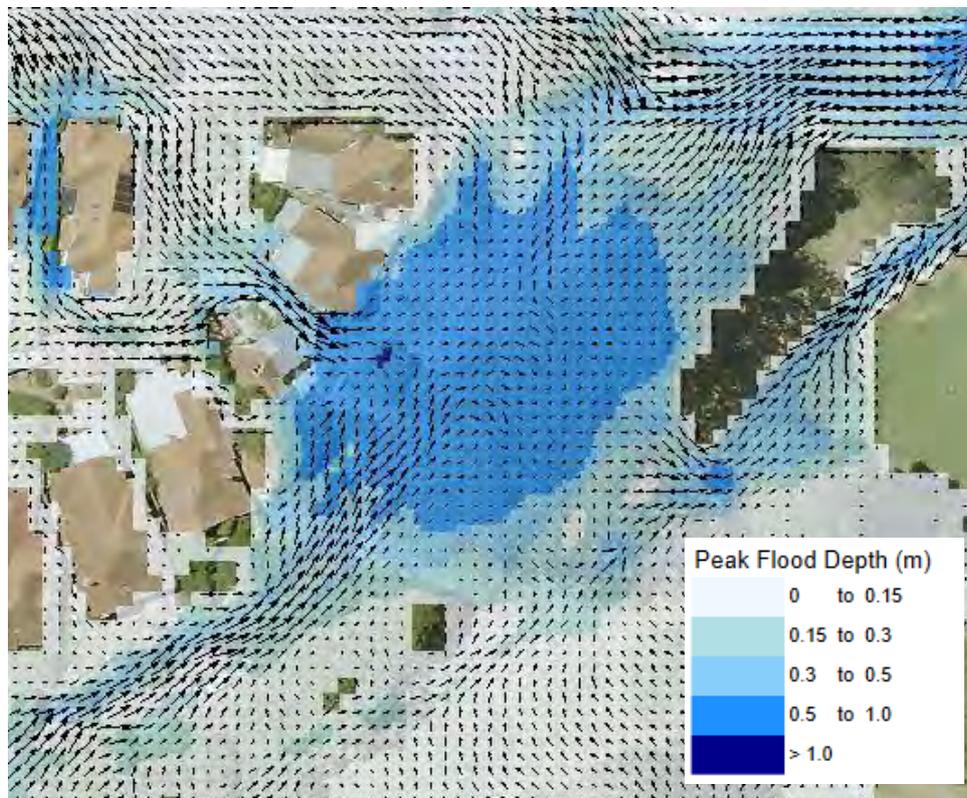


6.2.3 Warringa Road, Cammeray

Located between the two hotspots as described in Sections 6.2.1 and 6.2.2, the Warringa Road low point collects runoff from the western part of Cammeray Golf Course as well as Amherst Street. Referring to Image 11, significant flood depths of up to 1 m can be expected at this location for the 1% AEP event. Flows in excess of the local drainage capacity and storage offered by the low point subsequently overtop into Cammeray Golf Course before flowing eastward towards Creek Lane.

Mitigation measures, i.e. FM-N05+N08 and FM-N11 (see Section 6.9), consider augmenting the existing stormwater pits and pipes at this location and providing a basin within the Cammeray Golf Course.

Image 11: Hot Spot – Warringa Road – 1% AEP Design Flood Behaviour



6.2.4 Benelong Lane, Cremorne

Benelong Lane serves as a major overland flow path for the catchment which extends upstream to Military Road. Overland flows from upstream catchments enter this laneway from Grasmere Road before eventually discharging to Brightmore Reserve on the downstream end as shown in Image 12. The 1% AEP flow is shown to be of 'H5' category (refer Figure 23), thus unsafe for vehicles and people as well as may cause structural damage to buildings.

Mitigation measure, i.e. FM-N07 (see Section 6.9), considers upgrading the trunk drainage through this location to alleviate some of the existing flood risk.

Image 12: Hot Spot – Benelong Lane – 1% AEP Design Flood Behaviour



6.2.5 Cooper Lane, Cremorne

Cooper Lane is located upstream of Benelong Lane (refer Section 6.2.4) and also serves as a major overland flow path for the same catchment which extends upstream to Military Road. The topographic lowest point for this area is located between Cooper Lane and Young Street as shown in Image 13. The existing stormwater system along Cooper Lane serves to capture some of the runoff prior to it reaching the low point located at the rear of existing properties.

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Mitigation measure, i.e. FM-N07 (see Section 6.9), considers introducing additional pits along Cooper Lane and upgrading the drainage system located at the low point.

Image 13: Hot Spot – Cooper Lane – 1% AEP Design Flood Behaviour

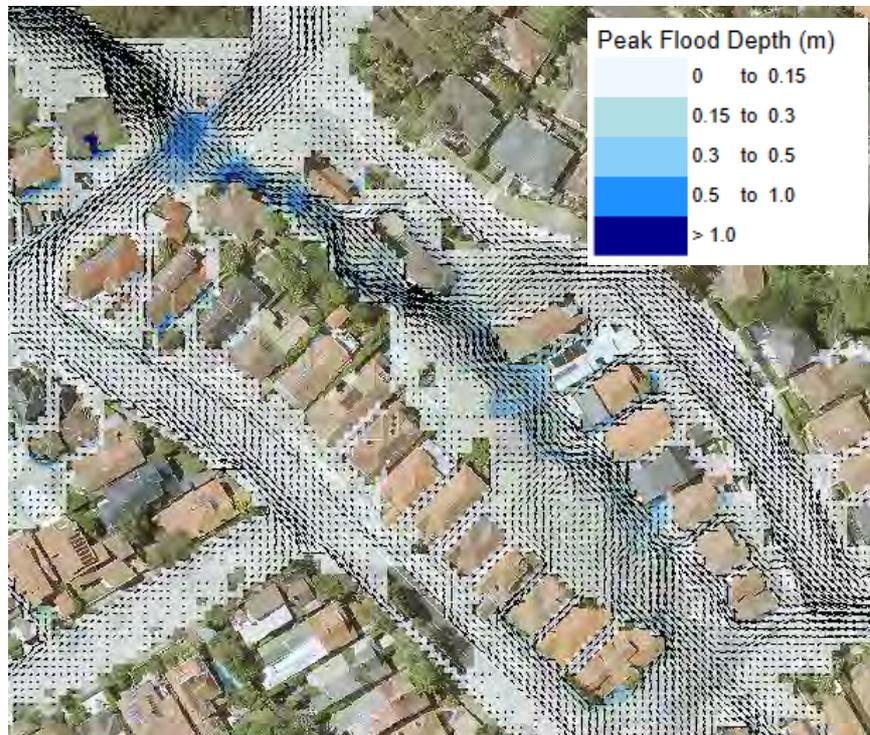


6.2.6 Reynolds Street, Cremorne

An overland flow path is found traversing Reynolds Street via the low point between Benelong Road and Levick Street before discharging towards the direction of Brightmore Reserve, as shown in Image 14. Historically, overland flows have been observed to overtop the Reynolds Street footpath and enter the rear of the properties downstream of Reynolds Street. Peak flood velocity in excess of 2 m/s can be found at this location in the 1% AEP event (refer Figure 19).

Mitigation measure, i.e. FM-N06 (see Section 6.9), considers introducing additional pits on Reynolds Street as well as augmenting the existing drainage capacity at this location.

Image 14: Hot Spot – Reynolds Street – 1% AEP Design Flood Behaviour

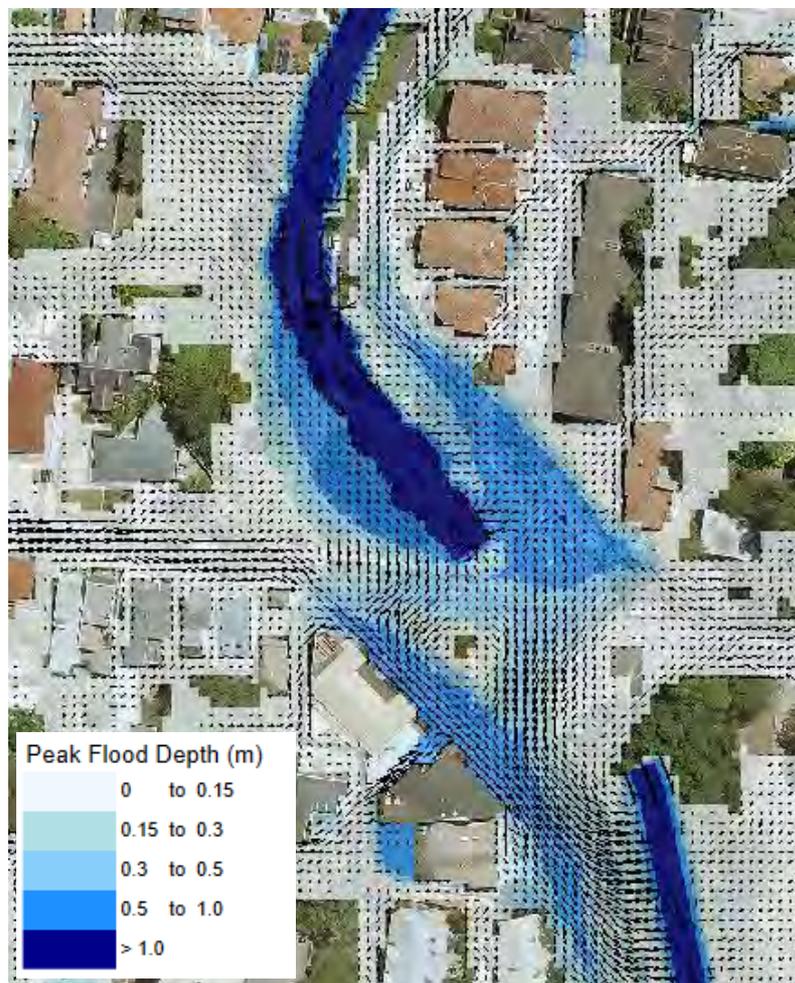


6.2.7 Kurraba Road/Clark Road, Neutral Bay

The Kurraba Road and Clark Road intersection has been subject to flooding in the past. It serves as a choke point for the open channel which conveys flows from the upstream catchment. Downstream of the road culvert, channel flows eventually discharge to the harbour approximately 400m south of the intersection. Once the culvert under the road intersection reaches capacity, floodwaters start to overtop the channel into the adjacent park to the west as well as Rawson Street to the east before subsequently inundating the row of shops fronting the intersection, as shown in Image 15. Peak flood depths up to 1 m can be found on the surrounding roads in the 1% AEP event. Further, due to the proximity of this location to the harbour, the open channel and road culvert are subject to tidal influence which can limit the effectiveness of proposed future structure upgrades.

A range of mitigation measures were considered to alleviate flooding at this hotspot including FM-S02, FM-S03, and FM-S04 (see Section 6.9), which consider storing some of the upstream catchment runoff and upgrading the road culvert under the intersection.

Image 15: Hot Spot – Kurraba Road/Clark Road – 1% AEP Design Flood Behaviour



6.2.8 Bank Street/Ancrum Street, North Sydney

A major overland flow path traverses through this hotspot following the topographic low point located between existing buildings as shown in Image 16. There is a Sydney Water trunk with capacity limited to frequent storm events which alignment roughly follows the overland flow path. High hazard flows can be expected for the 1% AEP event which are driven by high flow velocities in excess of 2 m/s (refer Figure 19). The downstream discharge point of the flow path is at the rail underpass on Euroka Street.

Limited mitigation measures can be considered for this hotspot other than augmenting the existing trunk capacity, i.e. FM-W01 (see Section 6.9).

Image 16: Hot Spot – Bank Street/Ancrum Street – 1% AEP Design Flood Behaviour



6.2.9 Cassins Lane, North Sydney

An overland flow path exists which flows in the westward direction from West Street entering into Cassins Lane and Cassins Avenue, impacting on Marist College as shown in Image 17. An inlet is installed in front of the college, though for rare events such as the 1% AEP floodwaters would overwhelm the drainage system and enter the college compound, resulting in peak flood depths up to 0.5 m.

Mitigation measure, i.e. FM-N09 (see Section 6.9), considers introducing additional pits as well as augmenting the existing drainage capacity located under the college and its surrounds.

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Image 17: Hot Spot – Cassins Lane – 1% AEP Design Flood Behaviour



6.2.10 Miller Street, North Sydney

A trapped depression is found on Miller Street for the area shown in Image 18 with floodwaters found to overtop the kerb and footpath for storm events including the 1% AEP. Historically, flooding is known to impact on commercial property located downstream (east of Miller Street) when the existing drainage system reaches capacity. Significant drainage works are currently being undertaken for the Sydney Metro site located to the north which should alleviate the existing flood conditions to some degree.

Mitigation measure, FM-S01 (see Section 6.9), considers a large-scale Sydney Water trunk upgrade through the North Sydney CBD which would also alleviate flood risk for this hotspot.

Image 18: Hot Spot – Miller Street – 1% AEP Design Flood Behaviour



6.2.11 Carlyle Lane/Russell Street, Wollstonecraft

The railway embankment presents a major obstruction to the overland flow path discharging westward along Carlyle Lane, as shown in Image 19. Peak flood depths in excess of 1 m can be expected at the lowest point of Carlyle Lane for the 1% AEP event. Council has undertaken drainage improvement works along Carlyle Lane to help alleviate stormwater/flooding issues though the existing drainage system downstream is a constraint in allowing more floodwaters to be discharged to Berrys Creek. Downstream of the railway embankment, another overland flow path originating

from north of River Road also discharges to Berrys Creek after traversing through some residential properties. There is a depression on Russell Street which can trap floodwaters in excess of 0.5 m in the 1% AEP event.

Mitigation measure, i.e. FM-W02 (see Section 6.9), considers introducing additional pits as well as augmenting the existing drainage capacity from Carlyle Lane to Berrys Creek under the railway embankment.

Image 19: Hot Spot – Carlyle Lane/Russell Street – 1% AEP Design Flood Behaviour



6.3 Economic Impact of Flooding

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

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

The flood damages assessment for the current study utilised guidance for estimating residential flood damages from DPIE (formerly OEH/DECC). This guideline (DECC, 2007) uses the depth of flooding above ground and floor level to estimate the variation of damage to structures and yards. There is, however, no prescribed methodology for calculating commercial flood damages provided by the OEH guideline. Thus, the damage curves developed by the Flood Hazard Research Centre (FHRC, 2013) were adopted herein and this is discussed further in Section 6.3.2.

The flood damages assessment described herein was carried out for the 894 surveyed properties (refer Section 3.3), 819 of which are residential, 7 are public facilities and the remaining 68 properties are commercial/retail. Floor levels and ground levels for each property were compared to the design flood levels at the same location. Based on this comparison, a site-specific level of flood affectation was derived. This informs the flood damages calculation whereby a monetary value was applied to each property based on the depth of flooding over a range of design flood events.

For the purposes of the assessment herein, the public facilities were grouped with the residential property set as they generally have lodging facilities and are also located adjacent to the residential areas.

6.3.1 Residential Properties

6.3.1.1 Residential Property Inundation

The level of flood affectation for the residential properties and public facilities was derived by comparing design flood levels to ground and floor level estimates. The dataset consisted of 826 properties (819 residential properties and 7 public facilities). This process identified the flood event, with respect to probability, that first inundates each property over ground and floor level respectively.

Table 24 quantifies the number of residential properties affected in each design flood event. The results show that many of the surveyed properties, despite being subject to inundation of the yard, are not necessarily flooded above floor level.

Table 24: Residential Property Flood Affection

Design Event (AEP)	Number of Properties affected	Number of Properties affected above Floor Level
20%	501	216
10%	546	247
5%	569	266
2%	579	272
1%	604	299
PMF	701	491

6.3.1.1 Residential Flood Damages

The residential flood damage estimates provide a monetary value of flood damages for each residential property for a range of design flood events. A key outcome of this assessment is the Average Annual Damage (AAD). The AAD is equal to the total damage caused by all floods over a long period of time divided by the number of years in that period (FDM, 2005). The AAD is primarily used during a Floodplain Risk Management Study and Plan (FRMS&P) to compare the relative economic merits of various proposed flood mitigation measures, which is discussed further in Section 6.10.2.

A residential AAD of \$11.5 million was calculated for the North Sydney LGA, based on the damages curves provided in the spreadsheet developed by OEH (DECC, 2007) and shown in Chart 7. Table 25 presents the AAD and the total residential flood damages per design event.

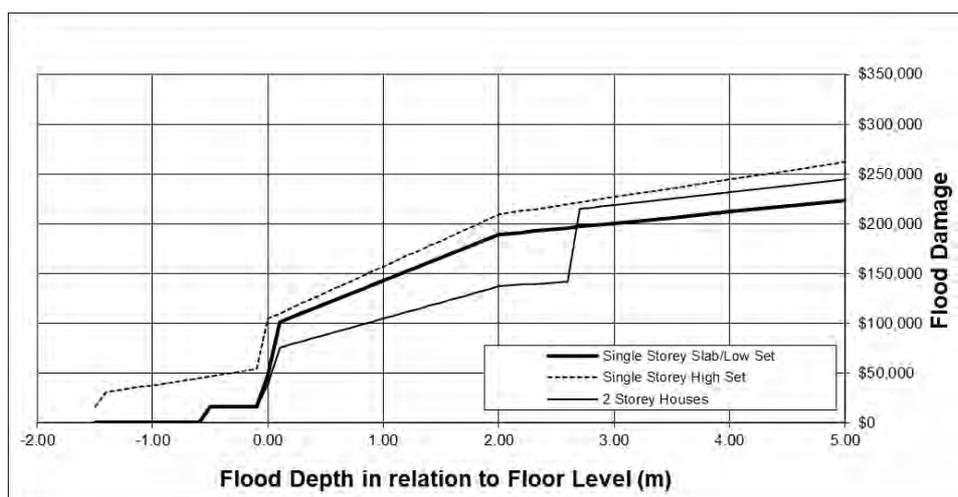


Chart 7: Residential Flood Damages Curves

Table 25: Residential Flood Damages

Design Event (AEP)	Flood Damages Total	Flood Damage per property
20%	\$29,597,400	\$59,100
10%	\$34,249,100	\$62,800
5%	\$37,301,500	\$65,600
2%	\$38,271,500	\$66,100
1%	\$41,507,500	\$68,800
PMF	\$71,529,500	\$102,100
Average Annual Damages (AAD)		\$11,517,900

6.3.2 Commercial Properties

The calculation of tangible commercial flood damages on a large scale can be highly varied. Commercial flood damages are dependent on factors such as:

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

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

There is no prescribed methodology for calculating commercial flood damages provided by the OEH guideline (DECC, 2007). Thus, the damage curves developed by the FHRC (2013) were adapted for the commercial flood damages assessment herein.

The Flood and Coastal Erosion Risk Management – A Manual for Economic Appraisal (FHRC, 2013) produced by the FHRC at Middlesex University in the United Kingdom developed non-residential flood damages curves based on observed flood damages from the early 2000's. These curves provide a contemporary evaluation of the damage to non-residential building and contents. The current study has adopted a typical non-residential flood damage relationship between depth of inundation

and damage per square metre of floor space from this Manual and applied it for commercial properties in the North Sydney LGA. This flood damages curve was adjusted to account for the exchange rate from British pound sterling to Australian dollars and inflation from 2013 to present. The curve is shown in Chart 8 with the 'Indicative' curve adopted for all commercial properties without basement. For commercial properties with basement, the 'Indicative' curve was adopted for over floor flooding and the 'High' curve was applied for inundation depth below floor level to account for the substantial damages to basement and its contents generally observed for this LGA. The floor space of each commercial property in the LGA was individually calculated and the flood damages curve was adjusted accordingly.

While the methodology described above provides only an indicative commercial AAD estimate, this estimate is considered fit for purpose in the comparative assessment of flood mitigation measures and the relative cost benefit presented in Section 6.9.

6.3.2.1 Commercial Property Inundation

The level of flood affectation for the commercial properties was derived by comparing design flood levels to ground and floor level estimates. The dataset consisted of 68 commercial properties. This process identified the flood event, with respect to probability, that first inundates each property over ground and floor level respectively.

Table 26 quantifies the number of commercial properties affected in each design flood event.

Table 26: Commercial Property Flood Affection

Design Event (AEP)	Number of Properties affected	Number of Properties affected above Floor Level
20%	56	34
10%	60	39
5%	62	40
2%	63	44
1%	65	47
PMF	66	60

6.3.2.2 Commercial Flood Damages

The commercial flood damage estimates provide a monetary value of flood damages for each commercial property for a range of design flood events. The AAD derived was used to compare the relative economic merits of various proposed flood mitigation measures, which is discussed further in Section 6.10.2.

A commercial AAD close to \$8 million was calculated for the North Sydney LGA, based on the damage curves developed by FHRC (2013) and shown in Chart 8. Table 27 presents the AAD and the total commercial flood damages per design event.

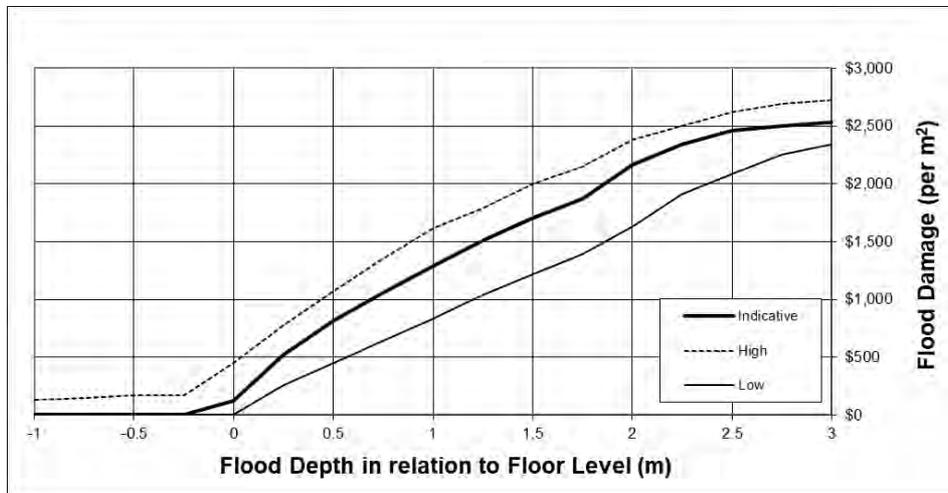


Chart 8: Commercial Flood Damages Curves

Table 27: Commercial Flood Damages

Design Event (AEP)	Flood Damages Total	Flood Damage per property
20%	\$20,442,700	\$365,100
10%	\$23,243,500	\$387,400
5%	\$25,421,400	\$410,100
2%	\$27,801,500	\$441,300
1%	\$30,984,900	\$476,700
PMF	\$49,104,700	\$744,100
Average Annual Damages (AAD)		\$7,959,700

6.3.3 Combined Flood Damages

Following the derivation of the residential and commercial AAD as described in Sections 6.3.1.1 and 6.3.2.2, the combined AAD for the North Sydney LGA was determined for the various design flood events and tabulated in Table 28. The number of properties that would experience flooding on the yard as well as inundation above floor level was also provided. A combined AAD of \$19.5 million was calculated and this value was used to compare the relative economic merits of various proposed flood mitigation measures, which is discussed further in Section 6.10.2.

Table 28: Combined Flood Damages

Design Event (AEP)	Number of Properties affected	Number of Properties affected above Floor Level	Flood Damages Total
20%	557	250	\$50,040,000
10%	606	286	\$57,492,600
5%	631	306	\$62,722,800
2%	642	316	\$66,072,900
1%	669	346	\$72,492,400
PMF	767	551	\$120,634,200
Average Annual Damages (AAD)			\$19,477,500

6.4 Community Flood Risk

The safety of the community during flood events is a key concern for floodplain management. An assessment of the existing flood risk to the community has been undertaken to identify critical locations and access routes that are vulnerable to flooding and would benefit from consideration when assessing floodplain risk management measures (see Section 6.8).

The following sections have identified flooded locations such as key evacuation routes (see Section 6.4.1), sensitive land use areas (see Section 6.4.2) and critical infrastructure/public facilities (see Section 6.4.3).

6.4.1 Risk to Evacuation Routes

The availability of safe vehicular evacuation routes from flood prone areas can have a significant influence on the safety of the community. ARR2019 advises that small vehicles can withstand flood depths of up to 0.3 m before beginning to float in still water and will float in much shallower water as flood velocities increase. Given these figures, an analysis of key evacuation routes has been undertaken for the North Sydney LGA. This analysis has assessed the existing flood liability of these routes for consideration in the assessment of floodplain risk management measures.

Analysis of the flood emergency response classifications (see Section 6.5) indicated key locations in the study area that are isolated or severely impacted in various flood magnitudes. These areas are located primarily along the major overland flow paths. A detailed analysis of the evacuation routes for these areas was undertaken based on the hazard category defined in Section 4.11. This analysis assessed a range of flood magnitudes using the design flood results to determine the flood liability of each route. Based on the hazard classification as per the Australian Emergency Management

Handbook 7, road with 'H2' category flooding is considered unsafe for small vehicles but remains trafficable for large vehicles like 4WD and trucks. Road with 'H3' category flooding and above is not trafficable as vehicles will become unstable. The analysis results are presented in Table 29 to Table 32.

Table 29: Flood Affection of Key Routes based on Hazard – East Model

ID	Location (refer Figure 29)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
E01	Bannerman St - Between Murdoch St and Shellcove Rd	H1	H1	H1	H2	H3	H5
E02	Bennett St - Between Murdoch St and Wycombe Rd	H1	H1	H1	H1	H1	H5
E03	Bertha Rd - Between Murdoch St and Burroway St	H1	H1	H1	H1	H2	H5
E04	Bogota Av - Between Murdoch St and Honda Rd	H3	H5	H5	H6	H6	H6
E05	Harrison St - Between Rangers Rd and Wycombe Rd	H1	H1	H1	H1	H1	H2
E06	Honda Rd - Between Bogota Av and Shellcove Rd	H1	H2	H5	H5	H5	H6
E07	Yeo St - Between Rangers Rd and Barry La	H1	H1	H1	H1	H1	H1
E08	Rangers Rd - Between Spofforth St and Murdoch St	H1	H1	H1	H1	H1	H5
E09	Spofforth St - Between Military Rd and Florence St	H1	H1	H1	H3	H5	H5
E10	Spofforth St - Between Boyle St and Kareela La	H2	H5	H5	H5	H5	H6

Table 30: Flood Affection of Key Routes based on Hazard – North Model

ID	Location (refer Figure 29)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
N01	Falcon St - Between Rodborough Ave and Lytton St	H1	H1	H1	H1	H2	H5

ID	Location (refer Figure 29)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
N02	Atchison St – between Oxley St and Willoughby Rd	H2	H3	H3	H3	H3	H5
N03	Belgrave St - Between Young St and Cooper La	H1	H1	H1	H1	H1	H5
N04	Brightmore St	H2	H3	H3	H3	H3	H6
N05	Brook St	H1	H1	H1	H1	H1	H5
N06	Cammeray Rd / Amherst St - Between Bellevue St and Grafton St	H1	H3	H5	H5	H5	H6
N07	Chandos St near Willoughby Rd	H1	H5	H5	H5	H5	H6
N08	Cooper La - Between Grosvenor La and Belgrave St	H1	H1	H1	H1	H5	H6
N09	Ernest St - Between Warringah Fwy and Miller St	H3	H3	H5	H5	H5	H6
N10	Grafton St - Between Cammeray Rd and Fall St	H1	H2	H3	H3	H5	H6
N11	Grasmere Rd - Between Young St and Benelong Rd	H1	H4	H5	H5	H5	H6
N12	Miller St - Between Ernest St and Falcon St	H1	H1	H1	H1	H2	H5
N13	Palmer St near Armstrong St	H1	H5	H5	H5	H5	H6
N14	Park Ave - Between Cammeray Rd and Sutherland St	H3	H4	H4	H4	H5	H6
N15	Reynolds St - Between Benelong Rd and Levick St	H1	H5	H5	H5	H5	H6
N16	Waters Rd - Between Belgrave St and Winnie St	H1	H1	H1	H1	H1	H5
N17	West St - Between Hayberry St and Holtermann St	H1	H1	H2	H2	H5	H5
N18	Young St - Between Little Young St and Wonga Rd	H1	H1	H1	H4	H4	H5

Table 31: Flood Affection of Key Routes based on Hazard – West Model

ID	Location (refer Figure 29)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
W01	Bay Rd near Crows Nest Rd	H1	H5	H5	H5	H5	H6
W02	Crows Nest Rd	H1	H3	H5	H5	H5	H6
W03	Euroka St / Union St - Between Bank St and Euroka La	H1	H2	H4	H5	H5	H6
W04	Hazelbank Rd - Between Pacific Hwy and Ivy St	H5	H5	H5	H5	H5	H6
W05	Lithgow St - Between River Rd and Oxley St	H2	H2	H2	H2	H3	H5
W06	Meadow La - Between Shirley Rd and Rocklands Rd	H2	H3	H3	H4	H5	H6
W07	River Rd - Between Eastview St and Russell St	H3	H3	H3	H3	H3	H5
W08	Rocklands Rd near Gillies St	H1	H1	H1	H1	H3	H6
W09	Woolcott St - Between Euroka St and Larkin St	H3	H5	H5	H5	H5	H6

Table 32: Flood Affection of Key Routes based on Hazard – South Model

ID	Location (refer Figure 29)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
S01	Angelo St - Between Berry St and McLaren St	H1	H1	H1	H1	H5	H6
S02	Aubin St	H1	H1	H1	H1	H1	H6
S03	Clark Rd - Between McDougall St and High St	H1	H1	H1	H1	H1	H6

ID	Location (refer Figure 29)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
S04	Clark Rd - Between Margaret St and Kurraba Rd	H2	H2	H3	H4	H5	H6
S05	Eaton St - Between Nook La and Montpellier St	H1	H1	H5	H5	H5	H6
S06	Falcon St - Between Military Rd and Merlin St	H1	H1	H1	H1	H1	H2
S07	High St - Between Little Alfred St and Hipwood St	H1	H1	H1	H1	H1	H5
S08	Hipwood St - Between McDougall St and High St	H1	H1	H1	H1	H1	H6
S09	Kurraba Rd - Between Neutral St and Holdsworth St	H1	H1	H2	H2	H3	H5
S10	Kurraba Rd	H1	H1	H1	H1	H5	H5
S11	Lower Wycombe Rd	H1	H5	H5	H5	H5	H6
S12	Manns Avenue	H1	H5	H5	H5	H5	H6
S13	Military Rd - Between Falcon St and Park Av	H1	H1	H1	H1	H1	H1
S14	Miller St - Between Pacific Hwy and McLaren St	H1	H1	H1	H1	H1	H5
S15	Mount St - Between Pacific Hwy and Arthur St	H1	H1	H5	H5	H5	H6
S16	Pacific Hwy - Between McLaren St and High St	H1	H1	H1	H1	H3	H5
S17	Phillips St	H1	H1	H1	H1	H1	H5
S18	Rawson St - Between Kurraba Rd and Darley St	H1	H2	H3	H3	H3	H6
S19	Walker St - Between Pacific Hwy and Berry St	H1	H1	H1	H1	H1	H6

The results show that several routes become impassable for the rarer events such as the 1% AEP and PMF, hence evacuation is not possible and a 'shelter-in-place' policy would be more appropriate for

the affected properties. Key routes located at the upstream catchment divide, i.e. Military Road and Falcon Street, are generally trafficable and not flood-affected during major flood events.

Analysis of the rate of rise of flood level was also undertaken and the results are presented in Chart 9 and Chart 10 for selected key routes which experience flooding representative of the LGA, i.e. Kurraba Rd/Clark Rd Intersection (ID: S04) and Miller St (ID: S14). The charts show a relatively short time to peak flood level for the various critical storm events, i.e. generally less than 1 hour, which confirms the dominating catchment flood behaviour is flash flooding. This indicates the lack of warning time available for residents in the LGA to evacuate on the road during a flood event.

Chart 9: Rate of Rise of Flood Level on Kurraba Rd/Clark Rd Intersection based on Critical Events

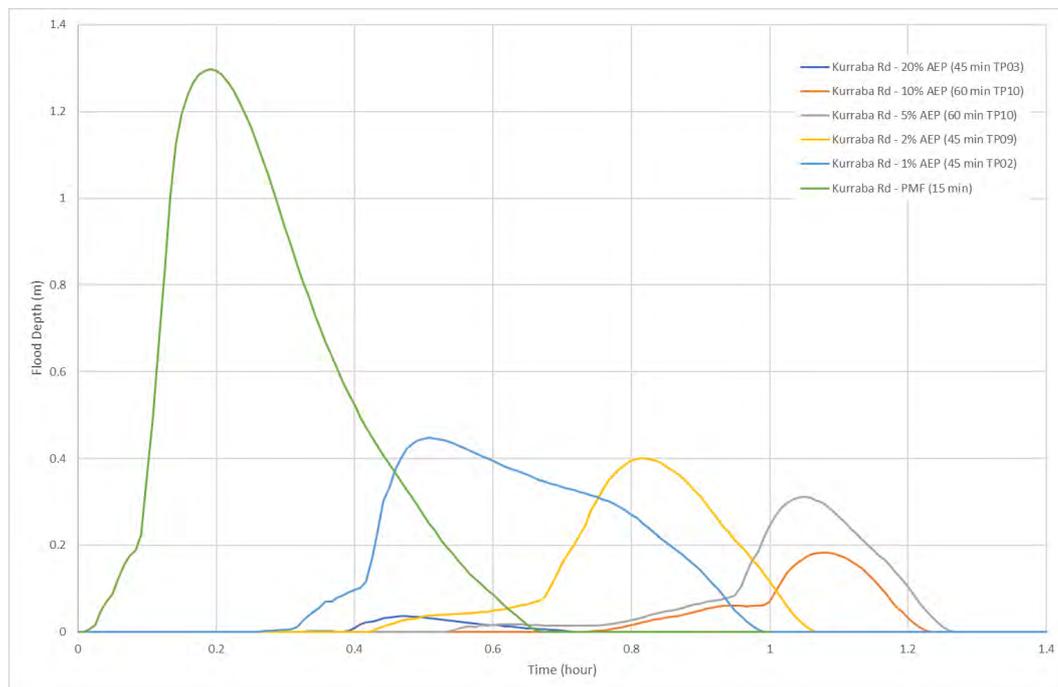
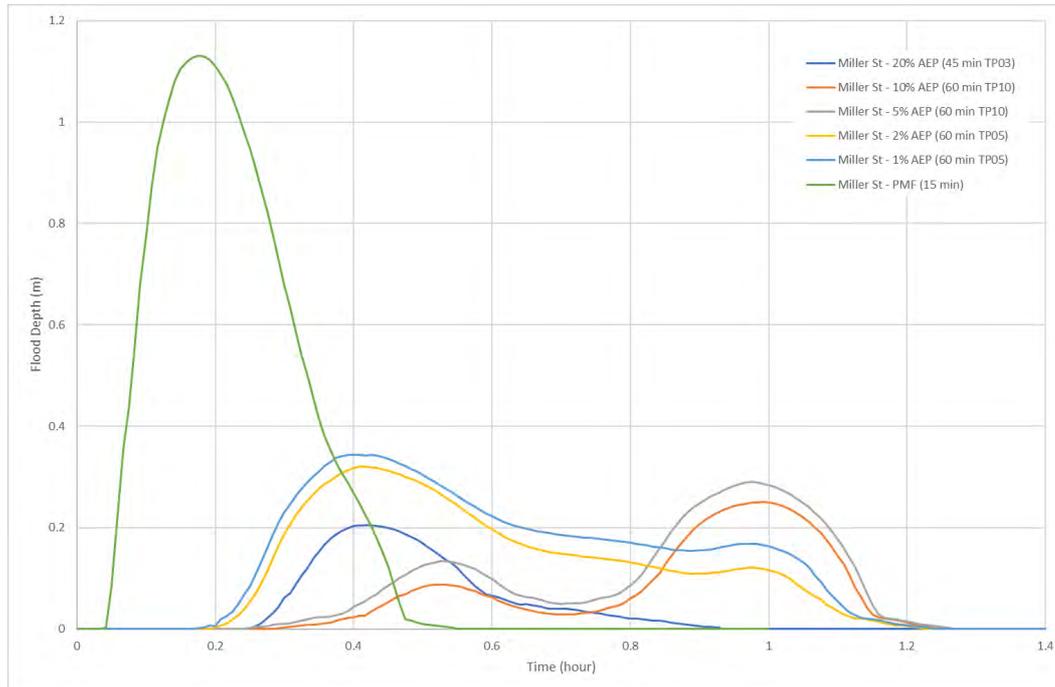


Chart 10: Rate of Rise of Flood Level on Miller St Depression based on Critical Events



6.4.2 Risk to Sensitive Land Use

The current study has assessed the flood liability of sensitive infrastructure such as hospitals, education facilities and aged care facilities.

An assessment of the flood affection of medical facilities found that these are located outside of the PMF flood extent (see Table 33).

Table 33: Flood Affection at Medical Facilities

Medical Facility	Location	Flooded
Mater Hospital	25 Rocklands Road, North Sydney	Not flooded
Crows Nest Day Hospital	1/22 Clarke Street, Crows Nest	Not flooded

Table 34 presents the flood affection of the aged care facilities within the LGA. Some are flooded in the PMF event and it is important that these facilities have an effective flood plan in place.

Table 34: Flood Affection at Aged Care Facilities

Aged Care Facility	Location	Flooded
Lansdowne Gardens	11 Manns Avenue, Neutral Bay	Flooded and access issues in PMF
Lansdowne Gardens	58 Wycombe Road, Neutral Bay	Not flooded
James Milson Village	4 Clark Road, North Sydney	Flooded and access issues in PMF

Aged Care Facility	Location	Flooded
Bougainvillea Strata Retirement Village	7-17 Waters Road, Neutral Bay	Not flooded

Table 35 and Table 36 present the flood affectation at early learning facilities and educational facilities respectively within the North Sydney LGA. Typically, these locations are not flooded or first experience flooding in the PMF event. Of note are the SDN North Sydney Children’s Education and Care Centre and North Sydney Family Day Care which can experience significant flood depths and high hazard flows in rare events and an effective flood plan is necessary at those locations.

Table 35: Flood Affection at Early Learning Facilities

Early Learning Facility	Location	Flooded
KU Greenwood Children's Centre	Corner Blue Street & Pacific Highway, North Sydney	Not flooded
Greenwood Childcare Centre	36 Blue Street, North Sydney	Not flooded
Guthrie Child Care Centre	25 Shirley Road, Wollstonecraft	Not flooded
Guardian Childcare & Education Walker Street	141 Walker Street, North Sydney	Not flooded
Goodstart Early Learning North Sydney – Berry Street	3/20 Berry Street, North Sydney	Affected by PMF overland flow
Crows Nest Kindergarten	82 Hayberry Street, Crows Nest	Not flooded
Active Kids Group Cremorne	37 Murdoch Street, Cremorne	Not flooded
SDN North Sydney Children's Education and Care Centre	8 Rodborough Avenue, Crows Nest	Flooded and access issues in PMF
Only About Children Cremorne	15-19 Parraween Street, Cremorne	Not flooded
North Sydney Family Day Care	96 Bank Street, North Sydney	Flooded and access issues in PMF
Toybox Early Learning	1/75 Miller Street, North Sydney	Not flooded
Only About Children North Sydney	65 Berry Street, North Sydney	Affected by PMF overland flow
Neutral Bay Kindergarten	29A Waters Road, Cremorne	Not flooded
Goodstart Early Learning North Sydney - West Street	8 West Street, North Sydney	Not flooded
Neutral Bay Pre-School	77 Shellcove Road, Neutral Bay	Affected by PMF overland flow
St Thomas North Sydney Preschool	McLaren St, North Sydney	Not flooded
Happy Kids Family Day Care (Camberay)	6 Massey St, Cammeray	Partially flooded in PMF
KU Cammeray Preschool	22 Warwick Avenue, Cammeray	Not flooded

Table 36: Flood Affection at Educational Facilities

Education Facility	Location	Flooded
Cammeraygal High School	192 Pacific Highway, Wollstonecraft	Not flooded
Anzac Park Public School	2 Anzac Avenue, Cammeray	Partially flooded in PMF
Cameragal Montessori School	Corner Walker & Lavender Street, Lavender Bay	Not flooded
Cameragal Montessori School	12 Miller Street, North Sydney	Affected by PMF overland flow
Cameragal Montessori School	1/181 Blues Point Road, North Sydney	Affected by PMF overland flow
Shore School	Blue Street, North Sydney	Partially affected by PMF overland flow
Shore Preparatory School	22 Edward Street, North Sydney	Affected by PMF overland flow
North Sydney Public School	Bay Road, Waverton	Not flooded
Neutral Bay Public School	Ben Boyd Road, Neutral Bay	Not flooded
Cammeray Public School	Palmer Street, Cammeray	Not flooded
St Mary's Catholic Primary School	40 Ridge Street, North Sydney	Not flooded
Marist College North Shore	270 Miller Street, North Sydney	Flooded and access issues in PMF
Wenona School	176 Walker Street, North Sydney	Affected by PMF overland flow
Loreto Kirribilli	85 Carabella Street, Kirribilli	Partially affected by PMF overland flow
Redlands Junior Campus	2 Allister Street, Cremorne	Affected by PMF overland flow
The Margaret Roberts Preparatory School	2 Allister Street, Cremorne	Affected by PMF overland flow
St Aloysius' College	47 Upper Pitt Street, Kirribilli	Affected by PMF overland flow
St Aloysius' College Junior School	29 Burton Street, Kirribilli	Not flooded

Education Facility	Location	Flooded
Redlands	272 Military Road, Cremorne	Not flooded
Cammeraygal High School, West Street Campus	149 West Street, Crows Nest	Affected by PMF overland flow
Monte Sant' Angelo Mercy College	128 Miller Street, North Sydney	Not flooded

6.4.3 Risk to Critical Infrastructure/Public Facilities

Flood damage to critical infrastructure and public facilities can significantly contribute to the total costs of a flood event as well as disturbing the day-to-day operations of the community. Given this, Table 37 presents the flood affectation of critical infrastructure and public facilities within the LGA. Of note are the Forsyth Park Community Centre and Ausgrid Crows Nest Zone Substation, both of which are subject to inundation in the PMF flood event. The majority of the other community centres are not flood affected in the PMF and would serve as suitable locations for evacuation centres during a major flood event.

Table 37: Flood Affectation to Critical Infrastructure/Public Facilities

Infrastructure	Location	Flooded
Forsyth Park Community Centre	2B Montpelier Street, Neutral Bay	Flooded in PMF
McMahons Point Community Centre	165 Blues Point Road, McMahons Point	Affected by PMF overland flow
North Sydney Community Centre	220 Miller Street, North Sydney	Partially affected by PMF overland flow
Crows Nest Centre	2 Ernest Place, Crows Nest	Not flooded
Fred Hutley Hall	200 Miller Street, North Sydney	Not flooded
Neutral Bay Community Centre	190-192 Military Road, Neutral Bay	Not flooded
Kirribilli Neighbourhood Centre	16-18 Fitzroy Street, Kirribilli	Not flooded
SES – North Sydney Unit	10 Balls Head Drive, Waverton	Not flooded
Electrical Substations		
Ausgrid Crows Nest Zone Substation	23 Albany Street, Crows Nest	Flooded in PMF
North Sydney Zone Substation	3 Ward Street, North Sydney	Affected by PMF overland flow

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6.5 Flood Emergency Response

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

In the current study, Flood Emergency Response classifications have been undertaken in accordance with the Australian Emergency Management Handbook 7 and detailed in Table 38.

Table 38: Flood Emergency Response Classifications

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

Emergency response classifications typically pertain to areas impeded by mainstream flooding where there are significant warning times allowing for preventative action to be taken. In areas predominantly affected by overland and flash flooding, such as the North Sydney LGA, preventative

action cannot be undertaken due to a lack of flood warning time (effectively zero). In the event of flooding, generally, residents are safest indoors and should avoid walking or driving in flood waters. Therefore, in the North Sydney LGA, emergency response classifications will be most useful for agencies, such as the SES, as a response to the aftermath of a flood.

Figure 29 presents the emergency response classifications based on Table 38 for the North Sydney LGA. Much of the LGA was found to be Flood Free, Indirect Consequence (NIC) or Flooded with a Rising Road Exit Route (FER). Along the main overland flow paths, there are generally areas of Flooded, Isolated and Submerged (FIS) or areas with an Overland Escape Exit Route (FEO).

In areas of FEO, road access would not be possible for the duration of the flood event however access can be achieved overland (i.e. on foot). Due to the short duration of these events (for much of the catchment – peak duration will be measured in minutes), residents in these areas would generally be safest waiting for floodwaters to recede before exiting their properties.

In areas of FIS, road access would be cut prior to properties being inundated by floodwaters. The flooding hotspots discussed in Section 6.2 are located within areas classified as FIS.

The Flood Emergency Response classifications herein are derived for the PMF flood event only. Due to the flash flood nature of the catchment the event magnitude is unknown at the time of the event. If those responding to a flood used Emergency Response classifications derived for a smaller event than that which is occurring, these classifications may be incorrect. A key example of this is the classification of Flooded, Isolated, Elevated (FIE) and Flooded, Isolated, Submerged (FIS). The classifications derived for a smaller event may define areas as FIE meaning that they lose flood access however they are not inundated. In larger events however, these FIE areas may become inundated meaning that their classification changes to FIS and as such their affectation is more severe. Thus, given the flash flood nature of the catchment and the unknown event magnitude, it is precautionary to only use the PMF emergency response classifications.

6.6 Floodplain Risk Management Measures

6.6.1 Overview

Assessment of flood risk mitigation measures is one of the key outputs of the current study, along with assessment of the LGA flood risk. Flood risk mitigation measures are broadly defined as interventions that Council and other stakeholders can implement that will reduce, or otherwise manage, the risk of flooding in the study area. There is a wide range of measures that can be used to manage flood risk, from large-scale drainage works to non-structural interventions (e.g. planning control for new development). To determine which are best suited to a particular area, the range of measures is considered and evaluated against the nature of the flood risk. Measures that are considered to have potential to reduce flood risk are then investigated further, including hydraulic and/or hydrologic modelling if appropriate. The investigation then determines whether a measure is feasible and ranks the feasible measures for implementation priority. The recommended measures are summarised in the Floodplain Risk Management Plan (FRMP), including timing, responsibility and indicative costing.

Mitigation measures are chosen from three categories set out in the NSW Floodplain Development Manual (2005), as follows:

1. Property Modification Measures are those that modify existing properties to manage their flood risk. This includes planning-related measures such as setting minimum floor levels and zoning based on a locality's flood risk. They also include raising of floor levels, and in cases of high flood risk, voluntary purchase schemes.
2. Response Modification Measures are those that improve the ability of people to plan for and react to flood events. They often involve emergency services and can be targeted at different phases of a flood, e.g. preparation, response and recovery.
3. Flood Modification Measures are those that change the depth, level, flow or velocity of floodwaters, via structural measures. They are often used to exclude flow from an area (e.g. a levee bank) or to reduce the peak flow (e.g. detention basin).

All measures will have different effects for different sizes of flood. For example, measures that give benefit in the 10% AEP flood may have negligible benefit in the 1% AEP event.

Table 39 gives an overview of typical measures in each category and their advantages and disadvantages, based on the NSW Floodplain Development Manual (2005).

Table 39: Overview of typical mitigation measure types

	Measure	Areas of Application	Advantages	Disadvantages
Property Modification	Land-use Planning	Can be used in any area of development on flood-prone land but is particularly effective where new areas of development are planned.	In areas of new development, can avoid large-scale flood risk by incorporating flood risk mitigation into the development process.	Limited use when development is not planned as controls or zoning are not enforced. In such cases the measure will only be effective in the long term. Stringent controls on development may not be accepted by community.
	Voluntary Purchase	Where residential properties are exposed to high hazard flow that poses risk to life or high financial cost.	Can significantly reduce flood risk by removing people from high risk flooding.	Expensive relative to other options and requires consent of each residence.
	Voluntary Floor Raising	Where properties are exposed to low hazard and localised flow that can be avoided with higher floor levels.	Can significantly reduce cost of flooding in an area by reducing above-floor flooding. Avoids relocation of people.	Generally only suitable for low hazard flow. Not all construction types are suitable for raising, and state government funding is only available for residential properties that meet certain criteria.
	Flood Access	Where isolation during a flood event is considered hazardous.	Can reduce risk to life by provision of access routes out of a flooded area.	Does not reduce damage to built assets. Limited to areas with isolation and access issues.
Response Modification	Flood Education, community readiness	Where a community's knowledge of flooding can be improved in order to reduce their flood risk.	Can equip community with best response/recovery plan for flooding, often cost-effective.	Hard to ensure 100% of community is reached, limited benefit in particularly high hazard areas.
	Flood Prediction and Warning	Where rainfall and flooding in a catchment can be forecast or	Can be used to initiate complete evacuation or other preparation measures.	Limited use in small catchments, warnings may be misinterpreted, does not reduce risk to fixed assets (e.g. houses).

	Measure	Areas of Application	Advantages	Disadvantages
		measured and warning sent to downstream areas.		
	Recovery Planning	Where recovery from a flood can be significantly improved.	Designate responsibilities between agencies involved including Council, SES, community and insurers.	Focuses on the aftermath of a flood event so generally used in conjunction with other measures.
Flood Modification	Flood Mitigation Dams	Where a larger creek or river has available land to detain flood flow.	Can completely remove instance of common floods.	Often severe environmental impacts, requires large areas of land.
	Retarding Basins	Where an overland flowpath or small creek can be detained before it enters an urban area.	Reduces the flood peak and therefore flood levels in urban areas.	Requires large area of land, can be hazardous during a flood if a multi-use space.
	Levees	Where a creek or river can be blocked from a developed area.	Can protect against a range of floods, can be straightforward design and construction.	Level of protection often overestimated, can be overtopped and fail. Often impacts properties outside the levee.
	Bypass Floodways	Where there is land available with suitable topography to create a bypass channel for a creek or river.	Can reduce flooding in an urban area by diverting flow during a flood.	Requires large area of land and only suited to some floodplain topographies. May impact areas downstream.
	Channel Modifications	Where a creek or river is particularly constricted or otherwise inefficient in conveying floodwaters.	Can reduce peak flood level by improving conveyance along a section of channel.	Often significant impacts on environment and natural amenity. May impact areas downstream.

As described previously, all measures have the common disadvantage of having limited benefit in extreme floods, or in floods larger than their design event. Similarly, all measures must be maintained, either physically in the case of built measures, or renewed and updated in the case of flood education, planning controls and other interventions.

Property modification measures are presented in Section 6.7, response modification measures are presented in Sections 6.8 whilst flood modification options are presented in Section 6.9.

6.7 Property Modification Measures

Property Modification (PM) measures are those that modify existing properties, or future development in the area, to manage the area's flood risk. These measures tend to be either interventions for specific properties with high flood risk, such as house raising or voluntary purchase (few if any suitable examples in the LGA), or broader policy changes that gradually reduce flood risk as development occurs (more applicable to this LGA).

6.7.1 Inclusion of Flood Related Policy in the LEP (PM-01)

Having identified that a significant number of properties are affected by flooding, it is recommended that the DPIE's settled model clause for flood affected land be incorporated into the LEP via a planning proposal process. This will assist in establishing those properties which are at risk of flooding to consider additional matters when they are to be redeveloped and ensure that risks to future habitans are prevented or minimised. Optionally this could also include more specific controls for sensitive and/or critical uses that occur anywhere within the PMF extent. The LEP would therefore set the tone and the inclusion of standard language defining the lots/properties flood related development controls may apply to is of great benefit to Council as they seek to manage flood risk moving forward. Typically included with the LEP is the definition of the Flood Planning Area (FPA) and Flood Planning Level (FPL) which are discussed further in the following sections.

6.7.1.1 Draft Flood Planning Area

The Flood Planning Area (FPA) identifies those properties that are subject to flood related development controls. The FPA is a key planning tool for managing and mitigating flood risk in an LGA.

The process of deriving the FPA varies depending on the dominant flood mechanism in a study area, with a different approach generally used for areas of mainstream flooding compared to areas of overland flow flooding. The Floodplain Development Manual (2005) recommends the FPA be derived from the 1% AEP flood level plus 0.5 m freeboard level, whereby the area of land below this level is subject to flood related development controls. For the North Sydney LGA, which is affected primarily by overland flow flooding, the 1% AEP flood level plus 0.5 m freeboard is generally much higher than the PMF level. Hence, adopting this level criterion for defining the FPA will result in an extent much larger than the PMF, and risk imposing flood-related planning controls on properties which are not subject to flood risk. Therefore, an alternative method to establish the FPA is proposed.

The initial criteria adopted for the FPA for the North Sydney LGA were based on what was typically used in other Sydney Metropolitan LGAs:

- Property lots with inundation depth greater than or equal to 0.15 m covering more than 10% of the cadastral lot; and
- Where the building extent covers most/all of the cadastral lot, property lots with inundation depth greater than or equal to 0.3 m adjacent to the cadastral lot.

Using the aforementioned criteria, a preliminary set of properties were identified using the 1% AEP design flood results and their flood affectation was verified during a ground truthing exercise carried out in late 2019. Following the site visit, further understanding was gained on the different flood mechanisms which can affect the individual properties within the LGA and the FPA criteria were refined accordingly. The refined criteria, which utilise the floodways/flow conveyance areas identified in Section 4.10, were discussed with Council and DPIE prior to adoption for the current study. The draft FPA was then developed based on two refined criteria, which replace the original two criteria described above. The refined criteria are:

- Category A (520 properties): Located on/in the proximity of an identified/designated floodway; and
- Category B (225 properties): Located on/adjacent to a localised flood with significant flood depth or flow (that is not part of the identified/designated floodway).

The properties which form the draft FPA are shown in Figure 31.

6.7.1.2 Flood Planning Level

The Flood Planning Level (FPL) is generally used to set minimum building floor levels for new developments, in addition to defining the FPA extent. As discussed in Section 6.7.1.1, whilst an FPL based on the 1% AEP flood level plus 0.5 m freeboard is suitable for mainstream flooding, its application to the North Sydney LGA would be onerous particularly for areas affected solely by overland flow flooding.

While the 1% AEP flood level could be adopted as the baseline for setting the FPL, the freeboard for areas affected by overland flow flooding can be reduced based on the land use type, e.g. lower freeboard for commercial properties could be applied due to lesser flood risk to life when compared to habitable residential properties. The FPL should therefore be defined according to the different land use type within the LGA and incorporated as part of Council's controls including the LEP and DCP. For properties not included as part of the FPA, it may be necessary to enforce a nominal level above surrounding ground for new developments especially those with underground basements. This is done to reduce exposure of the new developments to potential local drainage or stormwater issues which are not the subject of the study herein.

Recommendation: The inclusion of flood related policy in the LEP as well as the adoption of the FPA and FPL are recommended as actions in the draft Floodplain Risk Management Plan.

6.7.2 Adoption of Matrix-style Development Control Plan (PM-02)

Council's Development Control Plan (DCP) is designed to support the implementation of Council's LEP and typically contains more detailed controls. It is recommended that the DCP be amended to incorporate controls relating to the development of flood-prone land that consider both the level of flood risk and the type of development. A planning matrix consisting of controls for the different

development types and flood risk precincts is commonly adopted by numerous NSW councils. The flood-related controls in such DCPs typically address the following matters:

- Floor level or FPL;
- Building components and materials;
- Structural soundness;
- Flood affectation (this includes controls that ensure development does not direct flow to neighbouring lots, or worsen flooding for others in any other way);
- Evacuation or property access; and
- Management and design.

Recommendation: The adoption of a matrix-style planning controls in Council's DCP is recommended as an action in the draft Floodplain Risk Management Plan.

6.7.3 Voluntary Purchase

In a situation where it is impractical or uneconomical to mitigate high hazard flooding from properties, it may be necessary to acquire the affected properties and undertake demolition to remove them from the floodplain. This would remove residents from the high-risk areas and restore the hydraulic capacity of the floodplain. The purchase of such properties should be at an equitable price and only where voluntarily offered. Generally, voluntary purchase has minimal impacts on the environment though this scheme can have significant economic and social costs.

Recommendation: This option is not supported in the draft Floodplain Risk Management Plan as there is no existing property within the LGA which is subject to extreme risk of flooding or loss of life. Further, such a scheme would be costly for this LGA and is not warranted given that more cost-effective flood mitigation options are available.

6.7.4 Voluntary Floor Raising

This measure can be undertaken to raise habitable floor levels and eliminate above floor flooding for affected properties. It is suitable mainly for timber or non-brick single storey buildings and for properties generally located in low hazard areas. The building structure must be able to withstand loadings from floodwaters and debris. Even though the raised building provides safe refuge to residents during a flood event, the risk to life remains present should residents choose to exit the building or a medical emergency occurring during the flood event. For properties located in high hazard areas, rare floods could still cause inundation of the building should the floor levels not be sufficiently raised.

Recommendation: The option is not considered in the draft Floodplain Risk Management Plan as most properties within the LGA are of slab-on-ground construction and the shallow nature of overland flow flooding means comparatively cost-effective measures such as flood proofing are available.

6.7.5 Flood Proofing (PM-03)

Flood proofing can be undertaken to seal all building entry points such as doors and windows from floodwaters. Both temporary and permanent flood proofing methods are available with the temporary ones being sandbags, portable flood barriers, whilst permanent ones being flood gates,

sealing of gaps between brick works and electrical wiring insulation. This measure is generally less expensive compared to other property modification measures and causes less disruption. The effective deployment of temporary flood proofing measures would rely on the experience and knowledge of the user as well as sufficient warning time before the onset of flooding. As the LGA experiences mainly flash flooding, this is generally not possible.

Recommendation: Permanent flood proofing measures are considered as an option in the draft Floodplain Risk Management Plan.

6.7.6 Property Modifications

Modifications can be made to flood-affected properties either to manage overland flows through the property or strengthening the building to provide shelter and reduce flood risk to the residents. For the former, this can be in the form of adjustment to walls and fences within the property or provision of an easement to maintain continuity of overland flow paths. This, however, may have knock on effects on neighbouring properties which may prompt adjustment on neighbouring properties as well. In terms of building strengthening, this is undertaken to provide a structurally stable refuge for residents. Both measures, nevertheless, cannot be mandated by Council nor can Council or the State Government provide funding for these modifications. As such, any decision to employ these measures would be up to the individual property owners.

Recommendation: The option is not considered in the draft Floodplain Risk Management Plan as the benefits are generally localised and as such implementation of the scheme is problematic.

6.7.7 Inclusion of Flood Risk Information on s10.7 (2) & (5) Planning Certificates (PM-04)

Planning Certificates outline the relevant planning information that applies to a particular parcel of land on the date that the Certificate was issued. These Certificates are required to accompany any contract of sale of any registered parcel of land pursuant to the provisions of the Conveyancing Act, 1919 and the Conveyancing (Sale of Land) Regulation 2010.

If requested, councils are required to prepare a Planning Certificate under s.10.7 of the Environmental Planning and Assessment (EP&A) Act, 1979. There are two types of Planning Certificates:

Section 10.7(2) Planning Certificate (Basic):

Contains basic information to satisfy the requirements identified under Schedule 4 to the Environmental Planning and Assessment Regulation 2000. In particular, clause 7A to Schedule 4 prescribes the following flooding information to be provided:

- 7A *Flood related development controls information*
- (1) *Whether or not development on that land or part of the land for the purposes of dwelling houses, dual occupancies, multi dwelling housing or residential flat buildings (not including development for the purposes of group homes or seniors housing) is subject to flood related development controls.*
 - (2) *Whether or not development on that land or part of the land for any other purpose is subject to flood related development controls.*

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- (3) *Words and expressions in this clause have the same meanings as in the Standard Instrument.*

Section 10.7(2)&(5) Planning Certificate (Full):

Contains all information provided within a Basic Planning Certificate and any additional information that a council is of the opinion that should be provide in relation to the property.

For instance, a Full Planning Certificate may include information pertaining to the specific flood related controls that apply to the land to which the Certificate relates. The following types of information could be included:

- Design flood levels/depths specific to the property for the 5% AEP, 1% AEP and PMF events;
- Flood hazard;
- Hydraulic categorisation (e.g. floodway); and
- Associated flood mapping for the above items.

It is noted that some councils may upon request provide a "Flood Information Certificate", which only identifies flood related information applying to a particular property. This Flood Information Certificate is separate to a Planning Certificate. Where a Flood information Certificate is issued, the Council generally does not include any additional flood information on a full Planning Certificate. Due to the evolving nature of flooding impacts, resulting from changes to the built form, it is preferable to provide detailed flood information in a separate standalone Certificate, as the information presented is of a very technical nature and specific responses are required for each individual property. It also enables council to better recoup fees for services

It is recommended that to better inform stakeholders of a property's flood risk, that Council incorporate the required flooding information on both types of Planning Certificates based on the final outcomes of this Study and Plan as required under Section 10.7(2) of the EP&A Act. This could include an additional statement directing the applicant of the Planning Certificate to obtain a Flood Information Certificate for detailed information pertaining to flooding.

Alternatively, where a Full Planning Certificate under s.10.7 of the EP&A Act is requested, some or all of the previously addressed matters above could be provided within the Planning Certificate.

Once Council has a final adopted version of the Floodplain Risk Management Study and Plan, the prescribed questions under s.10.7(2) of the EP&A Act will be answered on the Planning Certificate.

These matters will only be incorporated on a Planning Certificate once this Study and Plan have been adopted in final form by Council. Despite this, Council will include an advisory note on its Full Planning Certificate information advising of the public exhibition of this draft version of the Study and Plan.

Recommendation: Inclusion of relevant flood risk information on the Planning Certificates once the final version of the Floodplain Risk Management Plan is adopted by Council. In addition, that once publicly exhibited for comment, that a notation be included on all Planning Certificates that a draft Study and Plan are available for comment.

6.8 Response Modification Measures

Owing to the flash flood nature of flooding within the LGA, Response Modification (RM) measures have limited use in flood risk management for this study area. Simply put, flooding happens irregularly, and without any effective warning. For most if not all impacted properties the idea that a response can be planned and implemented is not realistic. The exception may be for road crossings throughout the LGA impacted by overland flow, buildings in lower catchment areas frequented by the public that are subject to high levels of flood hazard and basements (e.g. car parks) that have persistent and hazardous flooding problems.

6.8.1 Flood Prediction and Warning

BOM provides flood forecasting and warning services suited mainly for mainstream riverine flooding rather than flash flooding which is more common in the North Sydney LGA. The services may be of some benefit in alerting residents of potential flooding though there is little time to develop reliable flood warnings and also limited time for effective dissemination and response to the flood warnings. The BOM services include:

- Weather forecast – which may indicate the likelihood of heavy rain with often more than 24 hours' notice;
- Flood Watch – will typically provide +24 hours' notice of potential flooding;
- Severe Weather Warning – typically issued when heavy rain and/or flash flooding are forecast; and
- Severe Thunderstorm Warning – generally provide between 0.5 to 2 hours' notice of impending severe storms.

Recommendation: The difficulty in predicting flash flooding and lack of warning time available for the catchment means that the provision of an effective flood warning service is not possible, hence this option is not considered in the draft Floodplain Risk Management Plan.

6.8.2 Education and Flood Awareness

The community readiness in responding to a flood event is correlated to awareness of flood occurrence and issues within their neighbourhood. The residents in the North Sydney LGA have a certain level of flood awareness due to recent experience with the November 2018 storm event that caused widespread flooding, as evident from the questionnaire responses (see Section 5.1). Nevertheless, community awareness will generally decline over time and this is usually addressed by implementing a community awareness programme that runs over a period.

Given the lack of frequency of flooding, its transitory nature and the overall lack of consequence associated with it for the community in this LGA (whilst acknowledging there will be private losses), keeping flooding at the forefront of community awareness is unrealistic and perhaps also unwarranted given the level of flood risk in the catchment.

Recommendation: Community education and raising flood awareness among the residents are deemed unrealistic and unwarranted, hence this option is not considered in the draft Floodplain Risk Management Plan.

6.8.3 Flood Signage (RM-01)

For areas with flood liability issues especially road crossings, specific actions such as the installation of flood signage may prove of use in reminding people of existing flood issues and how best to respond to them. On flood-prone roads and locations, a warning sign and a depth marker is often used to warn vehicles and pedestrians of dangerous flooding. They are used particularly in regional areas where a creek may completely submerge a section of road when the cross-drainage is exceeded. Recent research has found that while such signage is important given the high number of fatalities due to vehicles crossing flooded roads, signage is often ineffective at persuading motorists to turn around, especially if it is static signage that does not change the warning when a flood is occurring.

In North Sydney there are a number of flood-affected roads where vehicles are likely to enter hazardous floodwaters during a flood. Overall, upgraded cross-drainage and general awareness is recommended for such locations, over warning signage. Signage in the LGA would have to be static, as there is robust advance warning of flooding occurring in the area, and as such vehicles are likely to ignore the signage as in virtually all instances it will be perceived as warning against a non-existent risk. In addition, the primary risk that signage would be aimed at, which is risk to life, is largely not present in North Sydney and is more applicable to larger creeks and rivers in other areas of Sydney and NSW.

Recommendation: Proposal for the installation of flood signage at the appropriate locations is not included in the draft Floodplain Risk Management Plan.

6.8.4 Local Flood Plan (RM-02)

As discussed in Section 2.4.3, the Mosman and North Sydney Local Emergency Management Plan (EMPLAN) sets out the emergency response arrangements for the North Sydney LGA. The plan identified the NSW SES as the primary agency responsible for dealing with emergencies related to storm and flash flooding. The characteristics of the LGA flood behaviour, however, do not lend themselves to a managed flood response as there is lack of effective warning time and flooding would be distributed across the LGA. Hence, the SES response would be ad-hoc or demand based.

No local Flood Plan is currently available for the North Sydney LGA and the development of such a plan in conjunction with the SES to complement the EMPLAN would be useful. The Plan should include the following as a minimum:

- Purposes and authority of the plan;
- Responsibilities of the SES Local Controller, other officers, agencies and local organisations;
- Description of the local catchment flood behaviour, hotspots of flooding and its consequences (as per Section 6.2);
- List of key emergency egress routes and their trafficability during a flood event (as per Section 6.4.1);
- List of vulnerable facilities and sensitive infrastructure (as per Sections 6.4.2 and 6.4.3); and
- List of suitable evacuation centres which are flood free and accessible by road (as per Section 6.4.3).

Recommendation: Preparation of a local Flood Plan to complement the EMPLAN is considered in the draft Floodplain Risk Management Plan. The Plan will include description of the responsibilities of SES and other local agencies as well as provide details of flood-related arrangements.

6.8.5 Requirement for Site Specific Flood Emergency Plans (RM-03)

This measure involves requiring a Flood Emergency Plan to form part of a development application for any lot in a high hazard area. The Plan will ensure that development in these areas includes planning for evacuation if required (including access routes) and other preparation (e.g. responsibilities and warning systems).

Such a plan should only be required as a risk mitigation measure where the lot has significant areas of high hazard (e.g. H3 to H6 flow) or evacuation constraints (e.g. not flooded but isolated).

Recommendation: Requirement for a site-specific Flood Emergency Plan imposed on new developments in high hazard flooding areas is considered in the draft Floodplain Risk Management Plan. The Plan will include description of responsibilities of individuals or building management as well as planning for evacuation if required.

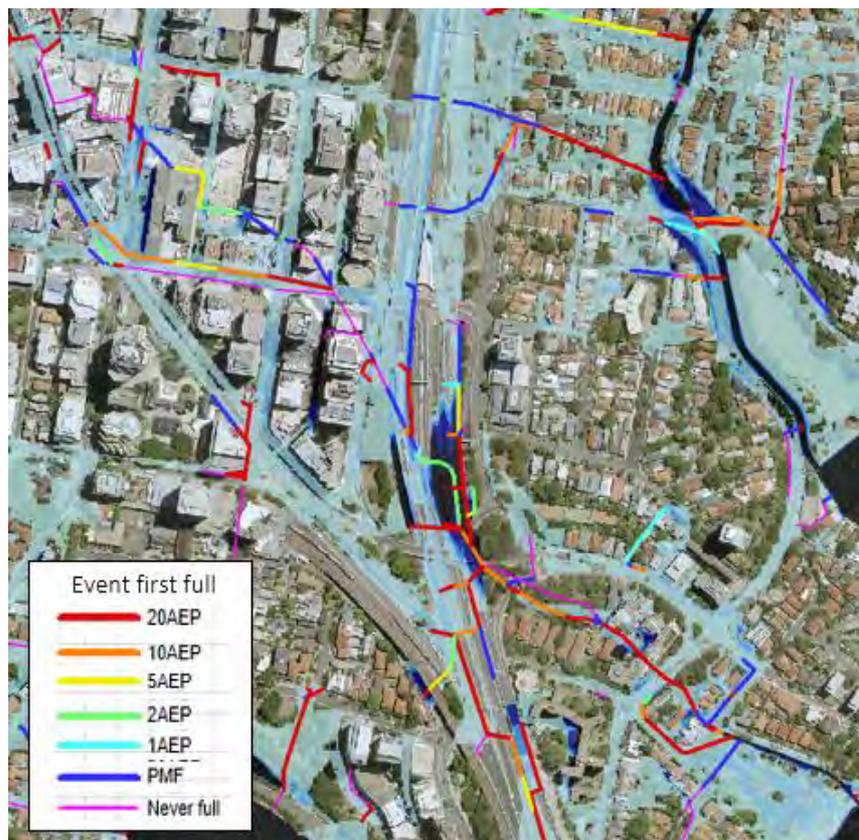
6.9 Flood Modification Measures

Flood Modification (FM) measures were developed based on assessment of the LGA flood risk and flooding hotspots, with support for measures also coming via consultation with Council and the community. As the catchment is highly urbanised and fully developed, suitable measures are limited to costly and disruptive drainage upgrades or repurposing of park lands for flood storage or attenuation of overland flows. The measures proposed herein are categorised into different implementation time horizons: short term (within the next 10 years), medium term (within the next 20 years) and long term (over 20 years).

6.9.1 Trunk Upgrade in North Sydney CBD (FM-S01)

This mitigation measure consists of increasing the capacity of the Sydney Water trunk from North Sydney CBD, through the M1 freeway, all the way to the Milson Park open channel. Model analysis of these systems found that the existing trunk has capacity as shown in Image 20. When the underground trunk reaches capacity, upstream catchment flows are conveyed above ground contributing to flood affectation around the North Sydney CBD area. The proposed upgrade introduces new pits and an additional 1.2 to 1.5 m diameter trunk line to convey more flows and the sensitivity of the surface flood behaviour to these changes was assessed.

Image 20: North Sydney CBD Sydney Water Trunk Capacity



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The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed upgrade works and the impact on the 1% AEP flood level is shown in Image 21.

Image 21: North Sydney CBD Sydney Water Trunk Upgrade (FM-S01) - 1% AEP Impact

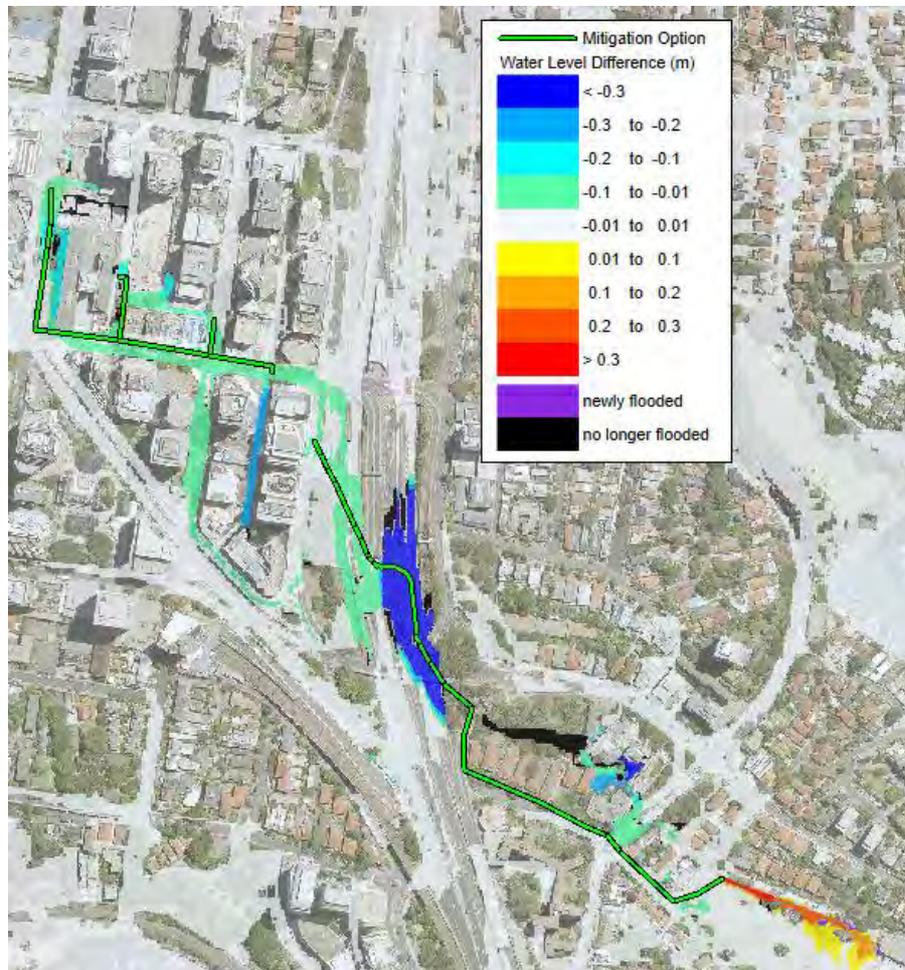


Image 21 shows that upgrading the trunk capacity has a beneficial effect on flood affectation, with areas in proximity to the trunk upgrade experiencing the most reduction in peak flood level. Peak flow in the trunk increases from 8.5 m³/s under existing conditions to 13.5 m³/s at the discharge point at Milson Park. The increased trunk flow results in a decrease in flood level of up to 0.27 m at Little Walker Street and up to 0.12 m at Miller Street, and an increase of up to 0.32 m in the open channel at Milson Park. The increase does not affect any properties adjacent to the park.

The option would be beneficial to road access since the inundation depth of key routes would be reduced. Several flood-affected properties would also benefit from the reduction in flood levels. If this option is adopted, further refinements can be made to the alignment of the proposed trunk upgrade and pits locations. The option has technical and administrative constraints that would need to be addressed in the planning stages. The drainage system has multiple owners (primarily Council and Sydney Water) and an agreement would need to be reached with all stakeholders, for funding,

design and construction of the works. Technically, there would be significant difficulty in crossing the freeway and micro-tunnelling may be required, which is significantly more expensive than more conventional techniques. Furthermore, design and construction of sections of pipe in the CBD area would likely encounter significant issues relating to the high density of underground utilities in the area.

Recommendation: This option is recommended as a long-term measure in the draft Floodplain Risk Management Plan due to the significant benefit in flood level reduction achieved along the trunk alignment.

6.9.2 Bund at Warringa Park (FM-S02)

This mitigation measure consists of constructing a bund or wall structure adjacent to the open channel next to Rawson Street to prevent floodwaters from overtopping onto the Kurraba Road/Clark Road Intersection once the culvert underneath reaches capacity. There would be increased floodwaters retained within the open channel as well as on Warringa Park. This option is designed to alleviate flooding at the intersection as well as reduce flood-affectation for the commercial properties fronting the intersection. Care was taken in the hydraulic modelling to prevent floodwaters from either spilling onto Rawson Street further upstream or inundating properties located on the unprotected side of the channel.

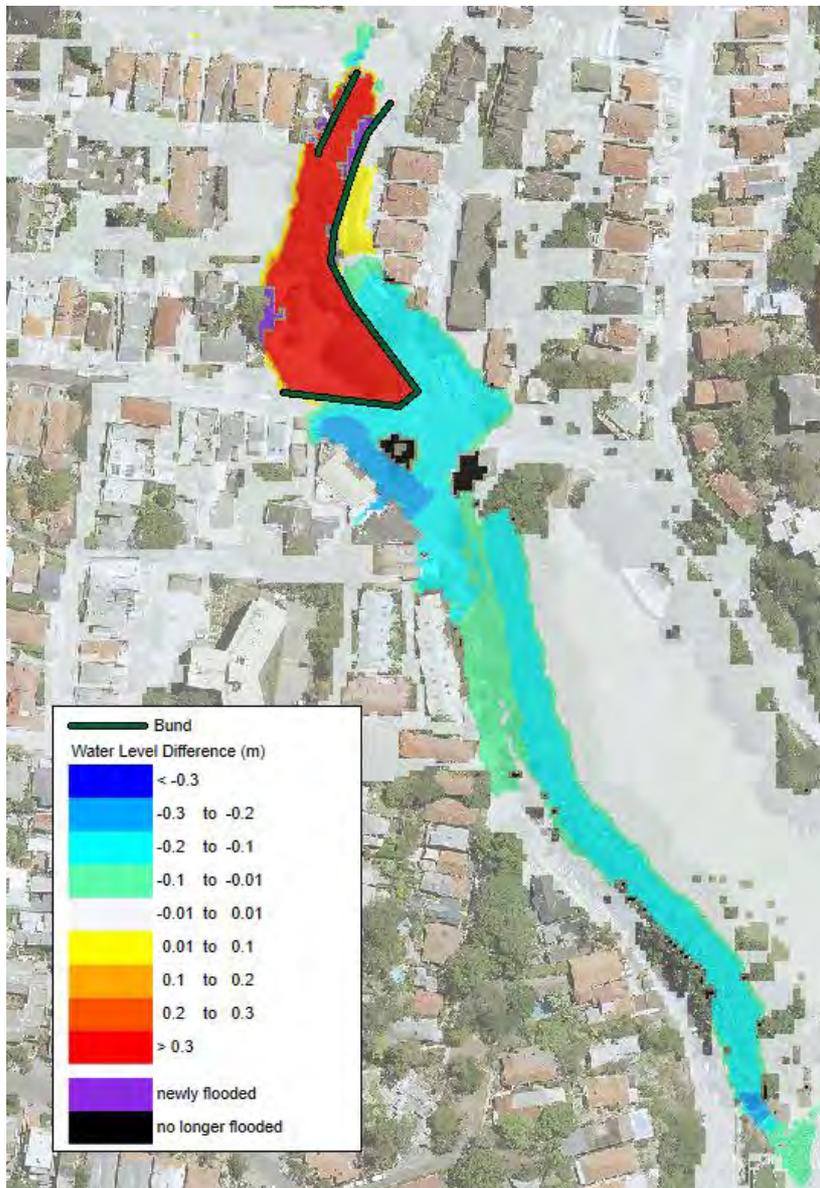
Constructing the bund or wall is technically feasible since the available land is Council owned and disruption to public should be minimal. The bund would have to be well maintained to ensure structural integrity and stability.

The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the bund/wall alignment and the impact on the 1% AEP flood level are shown in Image 22. Initial model runs had the bund/wall extended to 40 Kurraba Road on one end and mid-way between the Kurraba Road/Clark Road Intersection and the Rawson Street/Darley Street Intersection on the other end. The model results show that floodwaters would spill further upstream onto Rawson Street where the bund/wall terminates due to the increased peak flood levels on the channel. This causes adverse flood impacts on Rawson Street residential properties. Subsequent modelling runs had the bund/wall extending to the Rawson Street/Darley Street Intersection as shown in Image 22 with the top of bund/wall roughly matching the road elevation. Bunding is also required for the other side of the channel adjacent to 39 Darley Street as the increased peak flood levels resulted in floodwaters encroaching onto that property.

The aforementioned bund/wall design would improve flood-affectation downstream in the 1% AEP event with a peak flood level decrease of up to 0.25 m (see Image 22). However, adverse flood impacts can be found for residential properties on Rawson Street due to floodwaters spilling over the bund as well as for 39 Darley Street where the new bund/wall prevents overland flow from entering the channel. The increase in the 1% AEP peak flood levels at these locations is 0.05 m and 0.39 m respectively. It can be seen that this measure would benefit some properties at the expense of other properties and therefore this option was not pursued further.

Recommendation: This option is not recommended as a measure in the draft Floodplain Risk Management Plan due to the adverse impacts caused on surrounding properties despite benefits for the Kurraba Road retail shops.

Image 22: Bund at Warringa Park (FM-S02) - 1% AEP Impact

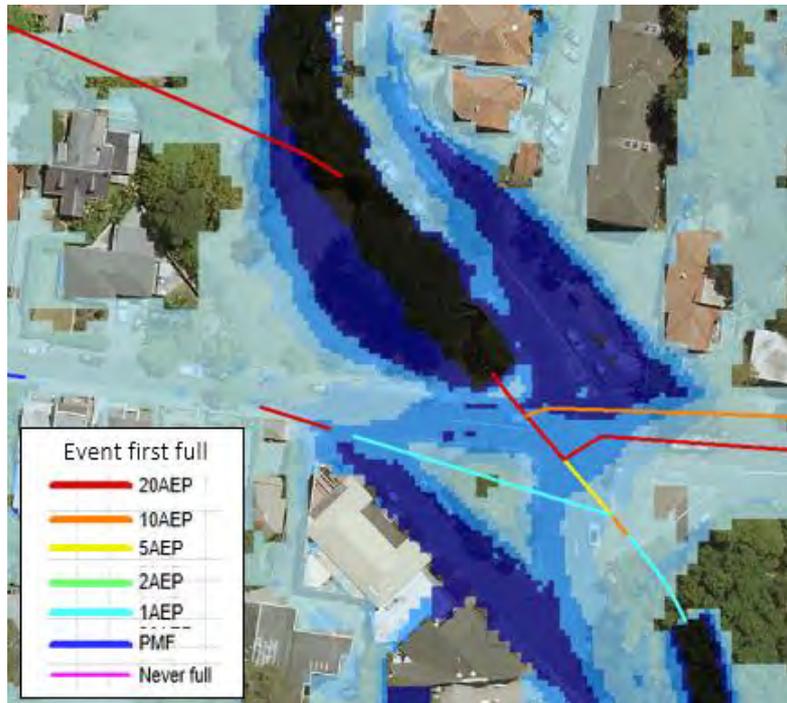


6.9.3 Upgrade Kurraba Road Culvert (FM-S03)

This mitigation measure consists of upgrading the Sydney Water culvert under the Kurraba Road/Clark Road Intersection to alleviate the backwater effect caused by this 'choke point' as shown in Image 23. Further investigation found that the upstream section of 35 m length has a cross-sectional area smaller than the remaining section of the culvert. Hence the proposed culvert upgrade

involves upsizing the smaller culvert section to provide extra conveyance capacity under the intersection.

Image 23: Kurraba Road Culvert Capacity



The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed culvert upgrade and the impact on the 1% AEP flood level is shown in Image 24. The results show that increasing the culvert capacity has a beneficial effect on flood affectation for the Kurraba Road/Clark Road Intersection and its surrounds, with the retail shops fronting the intersection experiencing the most reduction in peak flood level. The culvert peak flow increases from 12.8 m³/s under existing conditions to 16.2 m³/s as it discharges to the open channel adjacent to Anderson Park. The increased culvert flow results in a flood level decrease of up to 0.07 m at the Kurraba Road/Clark Road Intersection and 0.13 m for the road in front of the retail shops. This improves the flood affectation for these properties.

The option would be beneficial to road access since the inundation depth of the intersection and the Kurraba Road thoroughfare would be reduced. If this option is adopted, there is potential for disruption to local traffic since the road would need to be closed to install the new culvert.

Recommendation: This option is recommended as a medium-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction for the Kurraba Road/Clark Road Intersection and adjacent properties.

Image 24: Kurraba Road Culvert Upgrade (FM-S03) - 1% AEP Impact



6.9.4 Bund at Forsyth Park (FM-S04)

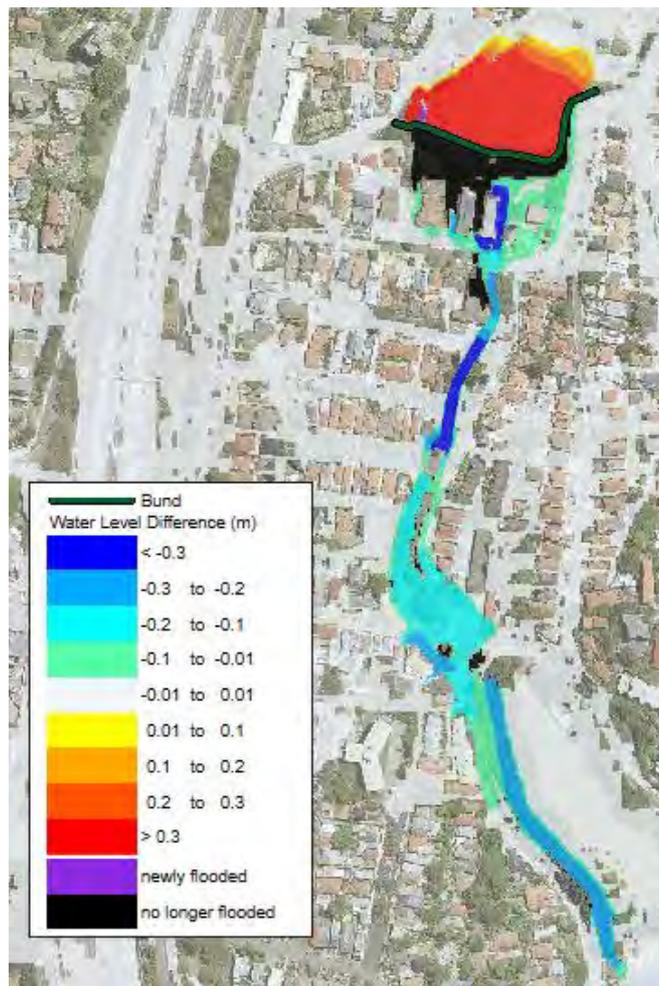
This mitigation measure consists of constructing a bund or levee along the southern edge of Forsyth Park to stop upstream overland flows from spilling and impacting on residential properties downstream. As part of this option, Forsyth Park is converted effectively into a retarding basin to maximise floodwater retention, though an outlet can be installed to permit gradual discharge of flows once the main flood event has passed. The proposed basin volume is about 8,000 m³ with the bund/levee averaging 1.4 m in height and up to 2.5 m height at the highest point (without freeboard) to withhold flood volume up to the 1% AEP event. Constructing the bund/levee is technically feasible since the available land is Council owned and disruption to public should be minimal. The bund/levee would have to be well maintained to ensure structural integrity and stability.

The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the bund/levee alignment and the impact on the 1% AEP flood level are shown in Image 25. The

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bund/levee would improve flood-affectation downstream in the 1% AEP event with a peak flood level decrease of up to 0.40 m along the open channel adjacent to Rawson Street and up to 0.14 m for the Kurraba Road/Clark Road Intersection as shown in Image 25. Increase in peak flood levels occurs within the Forsyth Park basin for the 1% AEP event as a result of attenuation of overland flows but does not adversely impact on any existing properties. If this option is pursued, it would be necessary to install signs within Forsyth Park to inform the community about the dual usage of the park as a flood mitigation basin during a storm event.

Image 25: Bund at Forsyth Park (FM-S04) – 1% AEP Impact

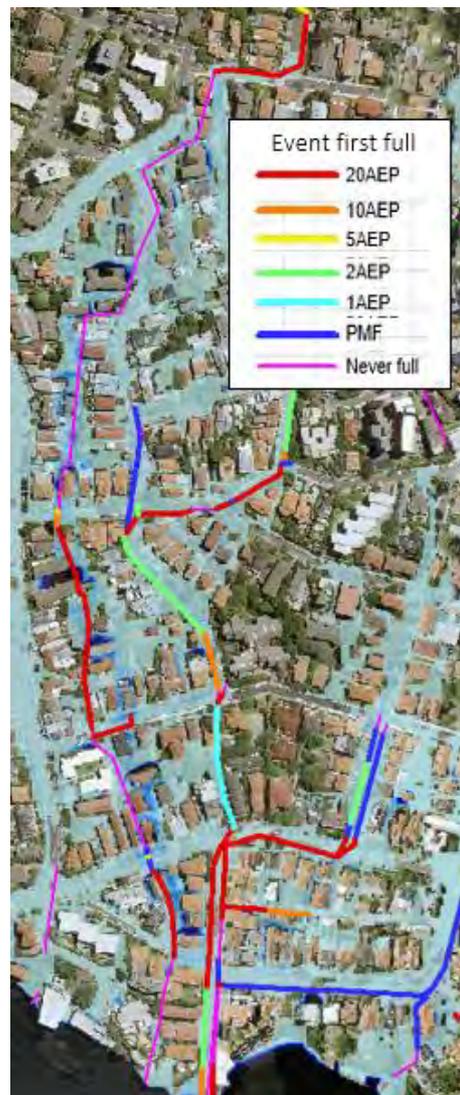


Recommendation: The option is recommended as a short-term measure in the draft Floodplain Risk Management Plan due to the significant reduction in peak flood levels for downstream properties and roads.

6.9.5 Trunk Upgrade from Lindsay Street to Kurraba Road (FM-S05)

This mitigation measure consists of increasing the capacity of Council's trunk system from Lindsay Street, through Kurraba Road, all the way to the harbour. Model analysis of these systems found that the existing trunk has capacity as shown in Image 26. When the underground trunk reaches capacity, upstream catchment flows are conveyed above ground forming a major overland flow path and inundating residential properties. The sensitivity of the surface flood behaviour to the capacity of the trunk was assessed by doubling its capacity from Lindsay Street to the harbour as well as introducing additional pits to capture more overland flows.

Image 26: Trunk Capacity from Lindsay Street to Kurraba Road



The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed trunk upgrade works and the impact on the 1% AEP flood level is shown in Image 27.

Image 27: Trunk Upgrade from Lindsay Street to Kurraba Road (FM-S05) – 1% AEP Impact



Image 27 shows that upgrading the trunk capacity has limited benefit for properties located upstream of the catchment due to the steep gradient and trunk system not running at full capacity. The reduction in the 1% AEP peak flood levels only become more pronounced as the trunk approaches the harbour, with areas in proximity to the trunk upgrade experiencing the most reduction in peak flood level. Peak flow in the trunk increases from 1.7 m³/s under existing conditions to 2.8 m³/s at the harbour outlet. The increased trunk flow results in a decrease in flood level of up to 0.10 m on Phillips Street, 0.12 m on Aubin Street and 0.15 m on Kurraba Road.

The option would be beneficial to road access since the inundation depth of key routes would be reduced. Several flood-affected properties would also benefit from the reduction in flood levels. If this option is adopted, further refinements can be made to the alignment of the proposed trunk upgrade and pits locations.

Recommendation: The option is recommended as a long-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction achieved along the trunk alignment.

6.9.6 Trunk Upgrade from Yeo Street to Bogota Avenue (FM-E01)

This mitigation measure consists of increasing the capacity of Council's trunk system from Yeo Street, through Bogota Avenue to the harbour. Model analysis of these systems found that the existing trunk has capacity as shown in Image 28. When the underground trunk reaches capacity, upstream catchment flows are conveyed above ground forming a major overland flow path and inundating residential properties. The sensitivity of the surface flood behaviour to the capacity of the trunk was assessed by doubling its capacity from Yeo Street to Bannerman Street, tripling its capacity from Bannerman Street to harbour, and introducing additional pits to capture more overland flows.

Image 28: Trunk Capacity from Yeo Street to Bogota Avenue



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The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed trunk upgrade works and the impact on the 1% AEP flood level is shown in Image 29.

Image 29: Trunk Upgrade from Yeo Street to Bogota Avenue (FM-E01) – 1% AEP Impact

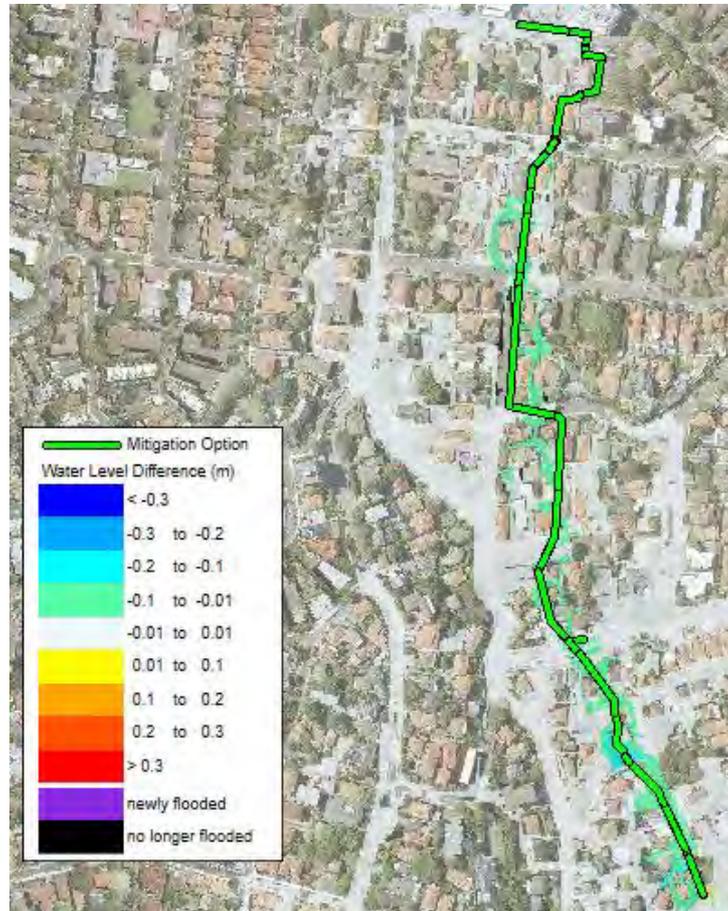


Image 29 shows that upgrading the trunk capacity has limited benefit for properties located upstream of the catchment due to the steep gradient and trunk system not running at full capacity. The reduction in the 1% AEP peak flood levels only become more pronounced as the trunk approaches the harbour, with areas in proximity to the trunk upgrade experiencing the most reduction in peak flood level. Peak flow in the trunk increases from 6.9 m³/s under existing conditions to 9.7 m³/s at the harbour outlet. The increased trunk flow results in a decrease in flood level of up to 0.1 m on Bennett Street, 0.07 m on Bannerman Street and 0.1 m on Bogota Avenue.

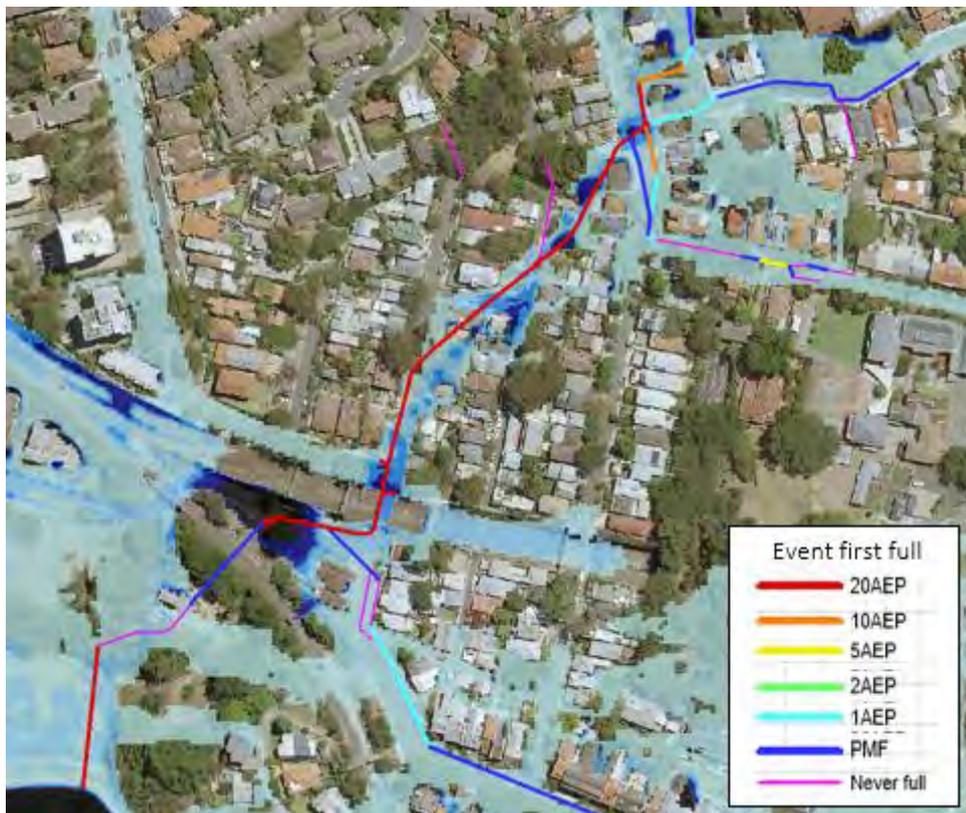
The option would be beneficial to road access since the inundation depth of key routes would be reduced. Several flood-affected properties would also benefit from the reduction in flood levels. If this option is adopted, further refinements can be made to the alignment of the proposed trunk upgrade and pits locations. In sections where the upgrade passes through private property, this would present a significant technical constraint for the design and construction of the pipe system. Wherever possible the upgrade would be placed along the roadways, parallel to the existing system.

Recommendation: The option is recommended as a long-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction achieved along the trunk alignment.

6.9.7 Trunk Upgrade from Bank Street to Waverton Park (FM-W01)

This mitigation measure consists of increasing the capacity of Sydney Water trunk system from Bank Street, through Euroka Street to Woolcott Street. Model analysis of these systems found that the existing trunk has capacity as shown in Image 30. As the trunk system reaches capacity between Bank Street and Euroka Street in particular, floodwaters are conveyed above ground forming a major overland flow path and inundating residential properties. The proposed upgrade introduces new pits and an additional 1.0 m diameter trunk line to convey more flows for the section between Bank Street and Euroka Street, as well as doubling the existing trunk capacity from Euroka Street to Woolcott Street. Downstream of Woolcott Street the trunk system has capacity in excess of the 1% AEP (except for the outlet), thus an upgrade is not required for that section. The sensitivity of the surface flood behaviour to these changes was assessed herein.

Image 30: Trunk Capacity from Bank Street to Waverton Park



The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed trunk upgrade works and the impact on the 1% AEP flood level is shown in Image 31.

Image 31: Trunk Upgrade from Bank Street to Waverton Park (FM-W01) – 1% AEP Impact



The results show that upgrading the trunk capacity is most beneficial for properties located in proximity to the trunk alignment. With peak flow in the trunk increases from 4.0 m³/s under existing conditions to 6.9 m³/s at the end of the upgraded section, the peak flood levels decrease by up to 0.23 m on Bank Street, 0.33 m on Ancrum Street and 0.18 m on Euroka Street. Some localised adverse impacts are found downstream whereby the increased trunk conveyance attenuated local runoff entering the system. This is to be expected and can be addressed at a later stage either by enhancing the trunk system further or introducing separate pit inlets to capture local runoff that feeds into the trunk.

The option proposed herein would be beneficial to road access since the inundation depth of key routes would be reduced. Several flood-affected properties would also benefit from the reduction in flood levels. If this option is adopted, further refinements can be made to the alignment of the proposed trunk upgrade and pits locations. In sections where the upgrade passes through private property, this would present a significant technical constraint for the design and construction of the pipe system. Wherever possible the upgrade would be placed along the roadways, parallel to the existing system.

Recommendation: The option is recommended as a long-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction achieved along the trunk alignment.

6.9.8 Carlyle Lane Drainage Upgrade (FM-W02)

This mitigation measure consists of upgrading the drainage system servicing Carlyle Lane which subsequently traverses under the railway embankment and Russell Street before discharging to Berrys Creek to the west. The proposed option would alleviate the flooding issue occurring on Carlyle Lane caused by the railway embankment obstructing overland flows, as well as reducing flood levels on Russell Street. The proposed drainage upgrade involves upsizing the 0.75 and 0.9 m diameter pipes from Carlyle Lane to Russell Street to a rectangular box culvert of 1.8 m x 0.9 m while leaving the railway culvert intact, as well as introducing additional pits to capture more overland flows.

The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed drainage upgrade and the impact on the 1% AEP flood level is shown in Image 32.

Image 32: Carlyle Lane Drainage Upgrade (FM-W02) – 1% AEP Impact



The results show that enhancing the proposed drainage line capacity has a beneficial effect on flood affectation for the Carlyle Lane properties as well as properties downstream of the railway embankment. Peak flow in the drainage pipe increases from 1.6 m³/s under existing conditions to 7.0 m³/s as it discharges to Berrys Creek. The increased pipe flow results in a decrease in flood level of up to 1.31 m at Carlyle Lane and 0.19 m for Russell Street. This improves the flood affectation for adjacent residential properties. Slight increase in the peak flood levels of generally 0.1 m is

experienced downstream at Berrys Creek for the 1% AEP event though this does not adversely impact on any properties.

The option would be beneficial to road access since the inundation depth of the Russell Street thoroughfare would be reduced. If this option is adopted, there is potential for disruption to local traffic since the road would need to be closed to install the new box culverts. In sections where the upgrade passes through private property, this would present a significant technical constraint for the design and construction of the pipe system. Wherever possible the upgrade would be placed along the roadways, parallel to the existing system.

Recommendation: The option is recommended as a medium-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction achieved along the upgraded drainage alignment.

6.9.9 Trunk Upgrade from Albany Street to Flat Rock Creek (FM-N01)

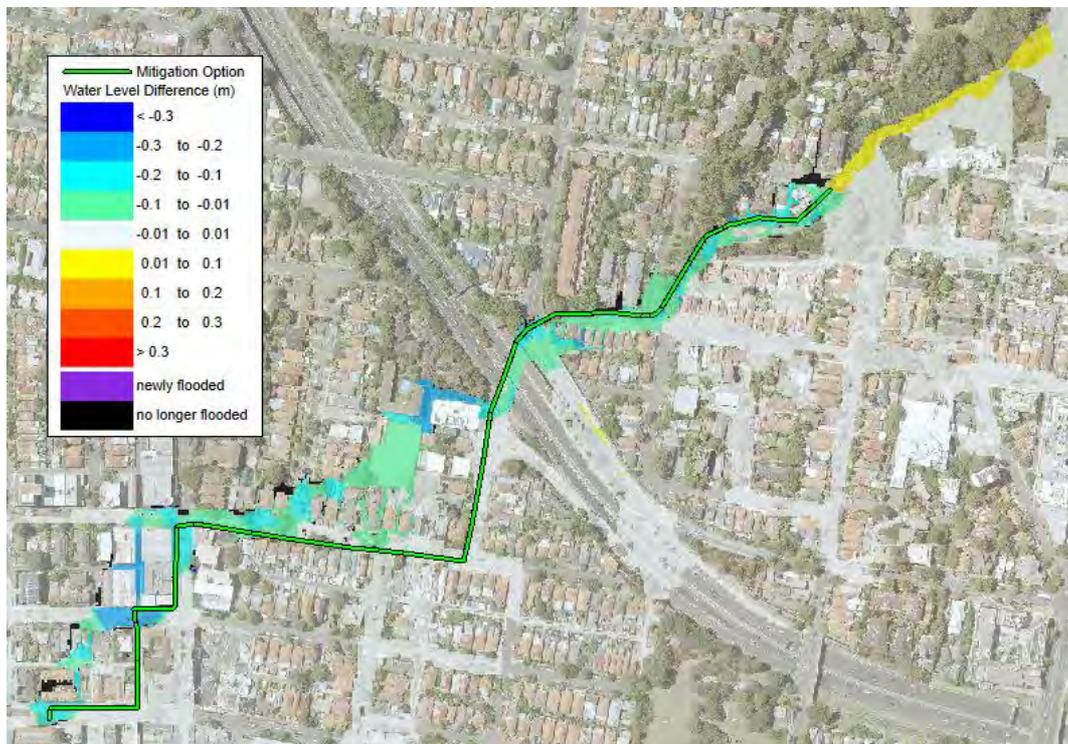
This mitigation measure consists of increasing the capacity of Council and Sydney Water trunk system from Albany Street, through Chandos Street, Brook Street, all the way to the discharge point at Flat Rock Creek. Model analysis of these systems found that the existing trunk has capacity as shown in Image 33. When the underground trunk reaches capacity, upstream catchment flows are conveyed above ground forming a major overland flow path and inundating residential properties. The sensitivity of the surface flood behaviour to the capacity of the trunk was assessed by introducing new 1.35 m diameter pipes from Albany Street to Palmer Street, doubling the capacity of existing pipes from Palmer Street to Hamilton Reserve, and introducing additional pits to capture more overland flows.

Image 33: Trunk Capacity from Albany Street to Flat Rock Creek



The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed trunk upgrade works and the impact on the 1% AEP flood level is shown in Image 34.

Image 34: Trunk Upgrade from Albany Street to Flat Rock Creek (FM-N01) – 1% AEP Impact



The results show that upgrading the trunk capacity is most beneficial for properties located in proximity to the trunk alignment. With peak flow in the trunk increases from 7.1 m³/s under existing conditions to 13.5 m³/s at the Flat Rock Creek discharge point, the 1% AEP peak flood levels decrease by up to 0.28 m on Atchison Street, 0.15 m on Chandos Street and 0.16 m on Palmer Street. Slight increase in the 1% AEP peak flood levels of up to 0.24 m is experienced downstream though this does not adversely impact on any properties.

The option would be beneficial to road access since the inundation depth of key routes would be reduced. Several flood-affected properties would also benefit from the reduction in flood levels. If this option is adopted, further refinements can be made to the alignment of the proposed trunk upgrade and pits locations.

Recommendation: The option is recommended as a long-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction achieved along the trunk alignment.

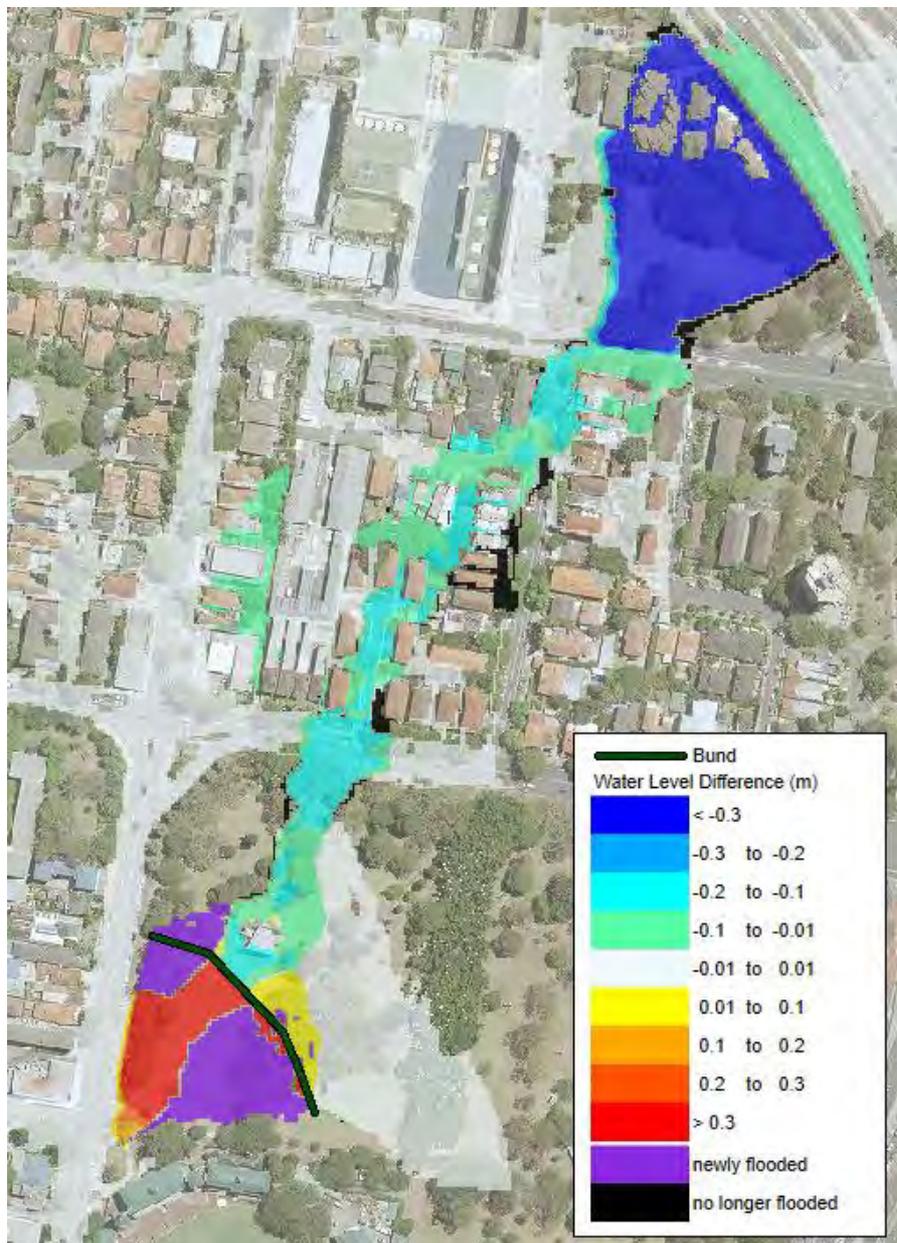
6.9.10 Bund at St Leonards Park (FM-N02)

This mitigation measure consists of constructing a bund or levee within St Leonards Park to stop upstream overland flows originating west of Miller Street from impacting on residential properties further downstream. As part of this option, the south-western portion of St Leonards Park is converted effectively into a retarding basin to maximise floodwater retention, though an outlet can be installed to permit gradual discharge of flows once the main flood event has passed. The proposed basin volume is approximately 9,100 m³, with the bund/levee height averaging 1.8 m with a maximum height of 3.0 m (without freeboard). Constructing the bund/levee is technically feasible since the available land is Council owned and disruption to public should be minimal. The bund/levee would have to be well maintained to ensure structural integrity and stability.

The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the bund/levee alignment and the impact on the 1% AEP flood level are shown in Image 35. The bund/levee would improve flood-affectation downstream in the 1% AEP event with a peak flood level decrease of up to 0.18 m on Falcon Street, 0.15 m on Lytton Street, 0.16 m on Ernest Street and substantial drop in the Anzac Park peak flood levels by up to 0.42 m. Increase in peak flood levels occurs within the St Leonards Park basin as a result of attenuation of overland flows but does not adversely impact on Miller Street or any existing properties. If this option is pursued, it would be necessary to install signs within St Leonards Park to inform the community about the dual usage of the park as a flood mitigation basin during a storm event.

Recommendation: The option is recommended as a short-term measure in the draft Floodplain Risk Management Plan due to the significant reduction in peak flood levels for downstream properties and roads.

Image 35: Bund at St Leonards Park (FM-N02) – 1% AEP Impact

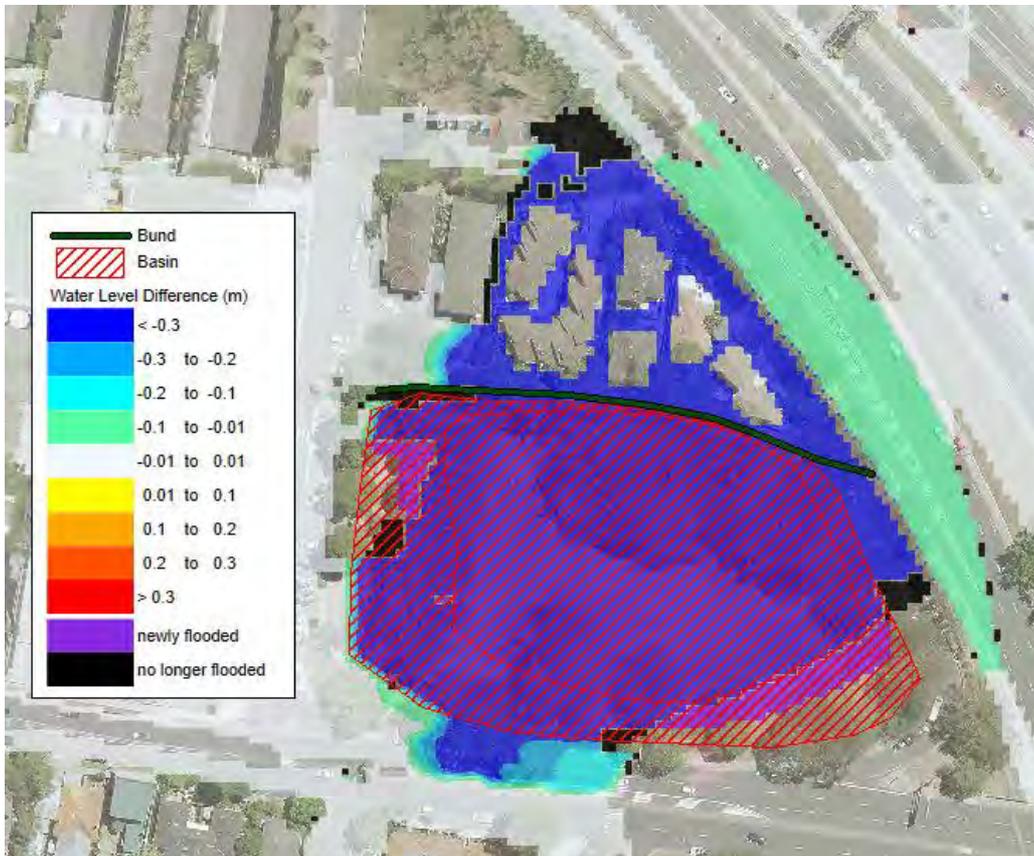


6.9.11 Anzac Park Basin (FM-N03)

This mitigation measure consists of excavating a retarding basin within Anzac Park to create additional storage for floodwaters obstructed behind the noise walls of Warringah Freeway. The basin, with a proposed volume of 22,600 m³, would provide ample storage to accommodate floodwaters and alleviate impacts of flooding on the Cammeray Avenue properties. An outlet can be installed at the basin to permit gradual discharge of flows once the main flood event has passed.

Constructing the basin may be difficult due to the large volume of earthworks involved as well as the presence of trees and utilities that need to be relocated.

Image 36: Anzac Park Basin (FM-N03) – 1% AEP Impact



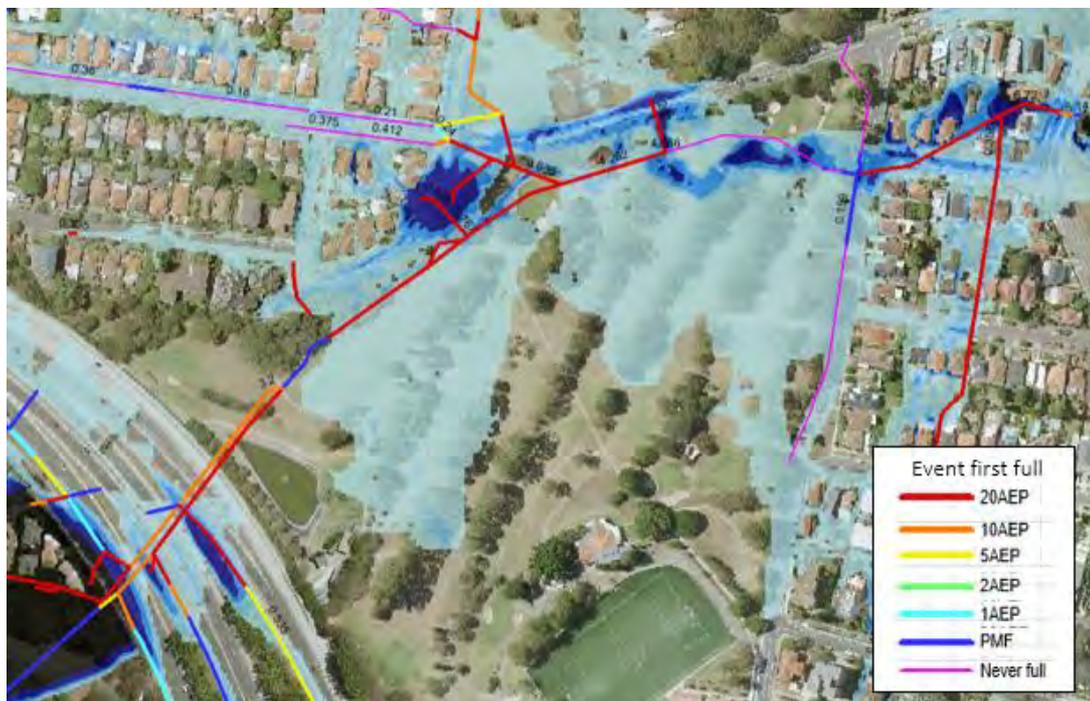
The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The basin extent and the impact on the 1% AEP flood level are shown in Image 36. The basin would improve flood-affectation for adjacent properties in the 1% AEP event with a peak flood level decrease of up to 1.0 m on Cammeray Avenue and 0.75 m within Anzac Park itself. No adverse flood impact can be found elsewhere. If this option is pursued, it would be necessary to install signs within Anzac Park to inform the community about the dual usage of the park as a flood mitigation basin during a storm event.

Recommendation: The option is recommended as a medium-term measure in the draft Floodplain Risk Management Plan due to the significant reduction in peak flood levels for properties and roads adjacent to the park.

6.9.12 Trunk Upgrade from Anzac Park to Willoughby Creek and Warringa Road Drainage Upgrade (FM-N05+N08)

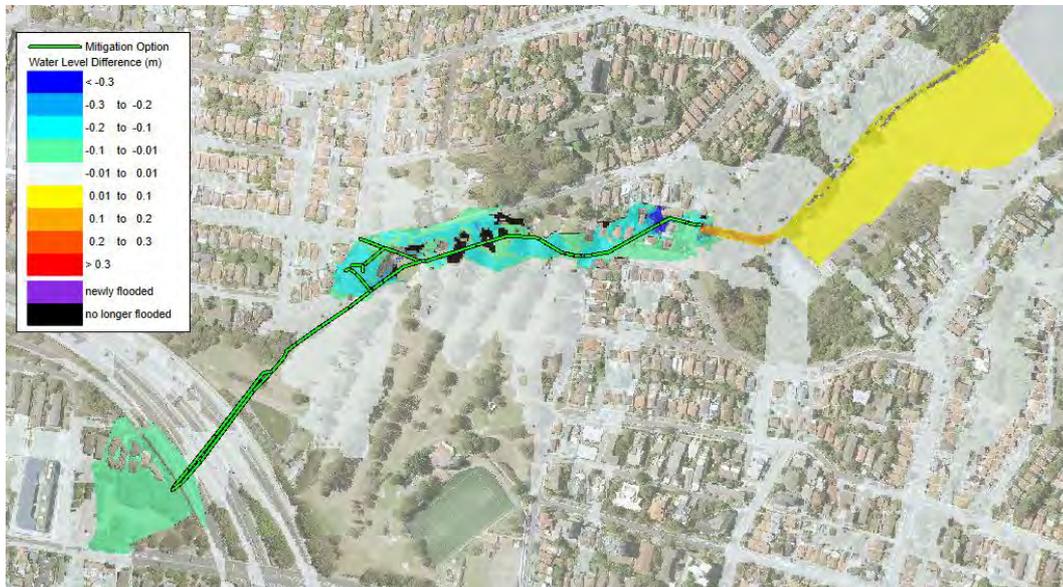
This mitigation measure consists of increasing the capacity of Sydney Water trunk system from Anzac Park, through Warringah Freeway all the way to the Willoughby Creek discharge point at Primrose Park. The Warringa Road drainage system servicing the trapped low point is also proposed to be upgraded and integrated with this option. Model analysis of these systems found that the existing trunk has capacity as shown in Image 37. When the underground trunk reaches capacity, flows in excess of the trunk capacity are conveyed above ground forming a major overland flow path and inundating residential properties downstream. The sensitivity of the surface flood behaviour to the capacity of the trunk was assessed by further enhancing its capacity using 3.6 m x 1.6 m and 4.2 m x 1.6 m box culverts, as well as upgrading the Warringa Road drainage by doubling the pipe capacity to accommodate more flows.

Image 37: Trunk Capacity from Anzac Park to Willoughby Creek



The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed trunk/drainage upgrade works and the impact on the 1% AEP flood level is shown in Image 38.

Image 38: Trunk Upgrade from Anzac Park to Willoughby Creek and Warringa Road Drainage Upgrade (FM-N05+N08) – 1% AEP Impact



The results show that upgrading the trunk capacity is most beneficial for properties located in proximity to the trunk alignment. With peak flow in the trunk increases from 19.1 m³/s under existing conditions to 27.9 m³/s at the Primrose Park discharge point, the 1% AEP peak flood levels decrease by up to 0.04 m on Anzac Park, 0.11 m on Warringa Road and 0.33 m on Creek Lane. Slight increase in the 1% AEP peak flood levels of around 0.1 m is experienced downstream at Primrose Park though this does not adversely impact on any properties.

The option would be beneficial to road access since the inundation depth of key routes would be reduced. Several flood-affected properties would also benefit from the reduction in flood levels. If this option is adopted, further refinements can be made to the alignment of the proposed trunk upgrade and pits locations. In sections where the upgrade passes through private property, this would present a significant technical constraint for the design and construction of the pipe system. Wherever possible the upgrade would be placed along the roadways, parallel to the existing system.

Recommendation: The option is recommended as a long-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction achieved along the upgraded trunk alignment.

6.9.13 Reynolds Street Drainage Upgrade (FM-N06)

This mitigation measure consists of increasing the capacity of the Council trunk system from Reynolds Street, through Brightmore Reserve to the harbour outlet at Primrose Park. Model analysis of these systems found that the existing trunk has capacity as shown Image 39. When the underground trunk reaches capacity, upstream catchment flows are conveyed above ground forming a major overland flow path and inundating residential properties. The proposed drainage upgrade involves doubling the trunk capacity up to Brightmore Reserve and removing any 'choke points' (i.e. reduced pipe size compared to upstream), as well as introducing new pits to capture more overland flows. The sensitivity of the surface flood behaviour to these changes was assessed.

Image 39: Reynolds Street Drainage Capacity



The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed trunk upgrade works and the impact on the 1% AEP flood level is shown Image 40.

Image 40: Reynolds Street Drainage Upgrade (FM-N06) – 1% AEP Impact



Image 40 shows that upgrading the trunk capacity is most beneficial for properties located in proximity to the trunk alignment. With peak flow in the trunk increases from 12.1 m³/s under existing conditions to 15.8 m³/s at the Primrose Park outlet, the 1% AEP peak flood levels decrease by up to 0.13 m on Brightmore Street, and 0.15 m on Wonga Road.

The option would be beneficial to road access since the inundation depth of key routes would be reduced. Several flood-affected properties would also benefit from the reduction in flood levels. If this option is adopted, further refinements can be made to the alignment of the proposed trunk upgrade and pits locations. In sections where the upgrade passes through private property, this would present a significant technical constraint for the design and construction of the pipe system. Wherever possible the upgrade would be placed along the roadways, parallel to the existing system.

Council's Bushcare group has provided initial feedback on the option and its benefits and constraints. These include:

- The option will likely benefit the remnant bushland in the area that currently experiences periodic severe erosion due to overland flow, and damage to the bushland infrastructure.

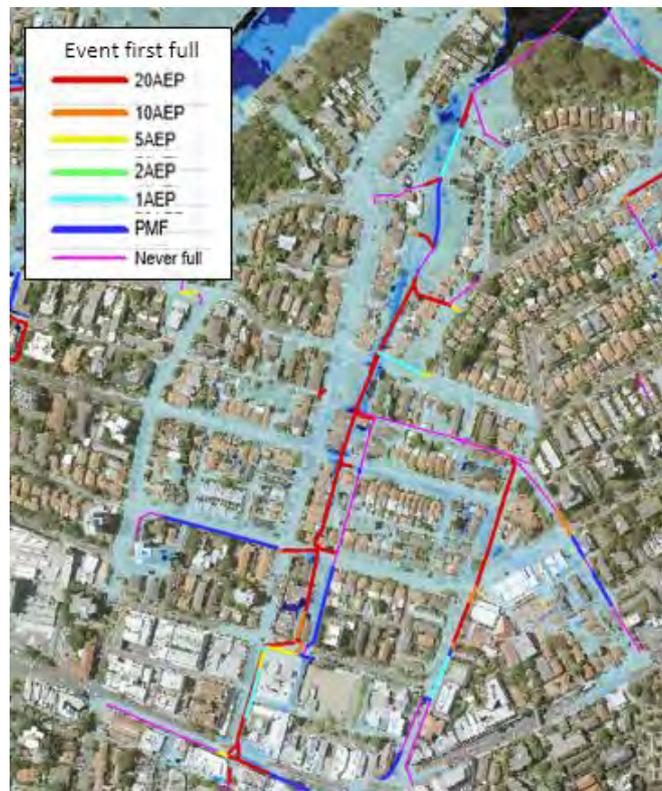
- The option would require comprehensive environmental impact assessment to determine the range of potential environmental impacts and suitable mitigation measures for each. This includes potential impacts on flora and fauna in the area, including any threatened species. One area of particular concern is the microbat population that uses parts of the existing drainage as a permanent habitat and breeding area.

Recommendation: The option is recommended as a long-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction achieved along the trunk alignment.

6.9.14 Cooper Lane Drainage Upgrade (FM-N07)

This mitigation measure consists of increasing the capacity of the Council trunk system from Belgrave Street, through Benelong Lane, Brightmore Reserve, all the way to the discharge point at Primrose Park. Model analysis of these systems found that the existing trunk has capacity as shown in Image 41. When the underground trunk reaches capacity, upstream catchment flows are conveyed above ground forming a major overland flow path and inundating residential properties. The proposed drainage upgrade involves doubling the trunk capacity, upsizing pipes at Grasmere Reserve to maintain a consistent pipe diameter, as well as introducing additional pits to capture more overland flows. The sensitivity of the surface flood behaviour to these changes was assessed.

Image 41: Cooper Lane Drainage Capacity



The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed trunk upgrade works and the impact on the 1% AEP flood level is shown in Image 42.

Image 42: Cooper Lane Drainage Upgrade (FM-N07) – 1% AEP Impact



The results show that upgrading the trunk capacity is most beneficial for properties located in proximity to the trunk alignment. With peak flow in the trunk increases from 12.3 m³/s under existing conditions to 17.3m³/s at the Primrose Park harbour outlet, the 1% AEP peak flood levels decrease by up to 0.05 m on Sutherland Street, 0.22 m on Grasmere Road and 0.21 m on Wonga Road.

The option would be beneficial to road access since the inundation depth of key routes would be reduced. Several flood-affected properties would also benefit from the reduction in flood levels. If this option is adopted, further refinements can be made to the alignment of the proposed trunk upgrade and pits locations. In sections where the upgrade passes through private property or bushland, this would present a significant technical constraint for the design and construction of the pipe system. Wherever possible the upgrade would be placed along the roadways, parallel to the existing system. For this option, it may also be possible to utilise recent pipe upgrades undertaken by Council from Cooper Lane.

Recommendation: The option is recommended as a long-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction achieved along the upgraded trunk alignment.

6.9.15 Cassins Avenue Drainage Upgrade (FM-N09)

This mitigation measure consists of upgrading the drainage system at Cassins Avenue and Carlow Street up to Miller Street. The proposed option would alleviate the flooding issue occurring in the immediate surrounds of the North Shore Marist College. The proposed drainage upgrade involves doubling the pipe capacity to provide extra conveyance capacity as well as introducing additional pits to capture more overland flows.

The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The location of the proposed drainage upgrade and the impact on the 1% AEP flood level is shown in Image 43.

Image 43: Cassins Avenue Drainage Upgrade (FM-N09) – 1% AEP Impact



Image 43 shows that enhancing the proposed drainage line capacity has a beneficial effect on flood affectation for the Cassins Avenue properties as well as Marist College. The peak flow increases from 0.3 m³/s under existing conditions to 0.6 m³/s at the Miller Street drainage pipeline, which is relatively minimal as the extra pipe capacity is mainly used as storage for the additional flows. Peak flood level decrease of up to 0.09 m at Cassins Avenue and 0.10 m at Carlow Street occurs as a result of the upgrade for the 1% AEP event. This improves the flood affectation for adjacent residential properties.

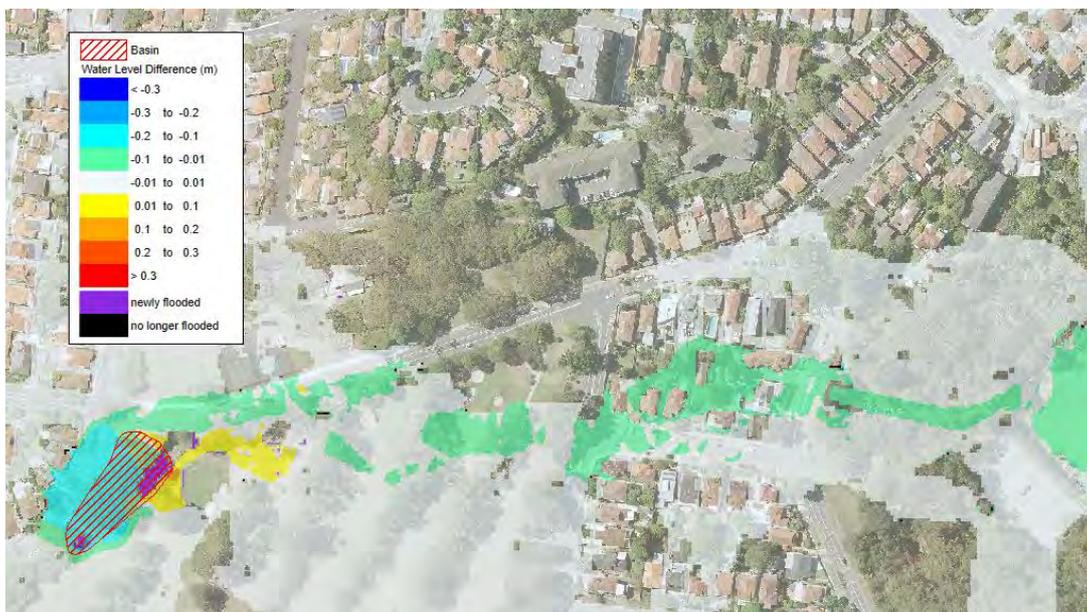
The option would help alleviate flood risk for Marist College and the surrounding properties. If this option is adopted, there is potential for disruption to local traffic since the road would need to be closed to install the new pipes. Sections of the upgrade beneath the school would be technically difficult, and may only be feasible as part of redevelopment of the school grounds (if that occurs).

Recommendation: The option is recommended as a medium-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction for Marist College and the surrounding properties.

6.9.16 Cammeray Golf Club Basin (FM-N11)

This mitigation measure consists of excavating a retarding basin adjacent to Warringa Road within Cammeray Golf Club to create additional storage for floodwaters and to reduce overland flows discharging downstream. The basin, with a proposed volume of 2,500m³, would provide storage to maximise floodwater retention and alleviate impacts of flooding primarily for the Warringa Road properties. Reduced overland flows would also reduce peak flood levels further downstream at Creek Lane, east of the golf course. An outlet can be installed at the basin to permit gradual discharge of flows once the main flood event has passed. Constructing the basin may be difficult due to the presence of trees and utilities that need to be relocated.

Image 44: Cammeray Golf Club Basin (FM-N11) – 1% AEP Impact



The option was assessed using the TUFLOW model for the 1% and 5% AEP events. The basin extent and the impact on the 1% AEP flood level are shown in Image 44. The basin would improve flood-affectation for the Warringa Road properties in the 1% AEP event with a peak flood level decrease of up to 0.12 m on Warringa Road. Reduction in peak flood levels is also experienced downstream on Creek Lane of up to 0.05 m. If this option is pursued, it would be necessary to install signs near the basin to inform the public about the dual usage of this land as a flood mitigation basin during a storm event.

Recommendation: The option is recommended as a medium-term measure in the draft Floodplain Risk Management Plan due to the benefit in flood level reduction for properties on Warringa Road and Creek Lane.

6.10 Assessment of Flood Risk Management Measures

This section assesses the various flood modification, property modification and response modification measures with the view to identifying those measures that are both feasible and will significantly reduce flood risk.

For the flood modification measures, the cost effectiveness of each measure was determined based on the benefit/cost (B/C) approach, whereby the reduction in the flood damages as a result of implementing the measure was compared against the cost of implementation.

6.10.1 Benefit/Cost Ratio of Measures

Preliminary cost estimates of each measure were calculated using Rawlinsons' Australian Construction Handbook (2020), with the details provided in Appendix J. Some costs were not factored in the calculation including the ongoing costs of maintaining the proposed works (assumed to form part of Council's annual budget) and costs associated with land and property acquisition. More accurate estimates should be obtained during subsequent design phase once a particular option is adopted for implementation. A summary of the costing of the recommended flood mitigation measures is presented in Table 40, along with the reduction of flood damages based on a net present worth calculated over a design structure life of 50 years with a 7% discount factor applied. The performance of each option was ascertained by comparing against the base case (i.e. existing conditions).

The results show that most of the trunk/drainage upgrade options have b/c ratio of less than 1, thus the cost of implementation outweighs the economic benefit gained from the reduction in flood damages. Both options that involve construction of a bund/levee, i.e. FM-S04 and FM-N02, have a b/c ratio of greater than 1. This can be attributed to the comparatively low cost owing to the lack of excavation work required unlike the trunk/drainage upgrade options.

Table 40: Cost/Benefit Ratio of Recommended Flood Mitigation Measures

Ref	Measures	Implementation Time Horizon	AAD	NPV of Damage	Option Cost	Option Benefit Relative to Base	Benefit/Cost Ratio
-	Base Case	-	\$19,477,440	\$287,619,429	-	-	-
FM-S01	Trunk Upgrade in North Sydney CBD	Long-term	\$19,055,166	\$281,383,800	\$10,083,000	\$6,235,629	0.62
FM-S03	Upgrade Kurraba Road Culvert	Medium-term	\$19,470,378	\$287,515,147	\$371,000	\$104,282	0.28
FM-S04	Bund at Forsyth Park	Short-term	\$19,449,604	\$287,208,384	\$292,000	\$411,045	1.41
FM-S05	Trunk Upgrade from Lindsay Street to Kurraba Road	Long-term	\$19,460,483	\$287,369,034	\$2,452,000	\$250,395	0.10
FM-E01	Trunk Upgrade from Yeo Street to Bogota Avenue	Long-term	\$19,372,139	\$286,064,477	\$3,803,000	\$1,554,952	0.41
FM-W01	Trunk Upgrade from Bank Street to Waverton Park	Long-term	\$19,383,120	\$286,226,629	\$2,247,000	\$1,392,800	0.62
FM-W02	Carlyle Lane Drainage Upgrade	Medium-term	\$19,460,195	\$287,364,775	\$3,482,000	\$254,654	0.07
FM-N01	Trunk Upgrade from Albany Street to Flat Rock Creek	Long-term	\$18,857,510	\$278,465,044	\$8,866,000	\$9,154,385	1.03
FM-N02	Bund at St Leonards Park	Short-term	\$19,198,140	\$283,495,072	\$418,000	\$4,124,357	9.87
FM-N03	Anzac Park Basin	Medium-term	\$19,275,338	\$284,635,030	\$9,988,000	\$2,984,399	0.30

Ref	Measures	Implementation Time Horizon	AAD	NPV of Damage	Option Cost	Option Benefit Relative to Base	Benefit/Cost Ratio
FM-N05+N08	Trunk Upgrade from Anzac Park to Willoughby Creek and Warringa Road Drainage Upgrade	Long-term	\$19,265,423	\$284,488,617	\$16,359,000	\$3,130,812	0.19
FM-N06	Reynolds Street Drainage Upgrade	Long-term	\$19,347,622	\$285,702,435	\$4,041,000	\$1,916,994	0.47
FM-N07	Cooper Lane Drainage Upgrade	Long-term	\$19,282,088	\$284,734,707	\$6,068,000	\$2,884,722	0.48
FM-N09	Cassins Avenue Drainage Upgrade	Medium-term	\$19,346,861	\$285,691,199	\$2,021,000	\$1,928,230	0.95
FM-N11	Cammeray Golf Club Basin	Medium-term	\$19,301,714	\$285,024,516	\$1,351,000	\$2,594,913	1.92

6.10.2 Multi-criteria Matrix Assessment

To compare the relative advantages and disadvantages of each recommended option, the measures were scored based on a multi-criteria matrix assessment. This enables options to be prioritised and is a useful tool for decision-makers and other stakeholders. It should be noted that scoring and ranking is only used for an indicative comparison and is not intended to act as a final verdict on the options. Also note that the scoring and ranking may be updated following the public exhibition period, especially in regard to community acceptance.

The results of the analysis are presented in Table 41. Each criterion corresponds to a column and has been scored between -3 (lowest score), 0 (neutral) and 3 (highest score).

The table shows that the highest ranked measures are the inclusion of flood-related policy provisions within Council's LEP (PM-01) and installation of flood signage (RM-01). These measures have widespread benefit to property flooding and generally straightforward to implement, while having no significant drawbacks. Other high scoring measures are adoption of matrix-style planning controls in the DCP (PM-02), requirement for site-specific Flood Emergency Plans for new developments (RM-03) and provision of a bund or levee at St Leonards Park to attenuate overland flows (FM-N02). With the FM-N02 option, there is significant benefit to be gained from reducing flows and peak flood levels for flood-affected properties located downstream of the bund.

The results of the assessment were used to inform the draft Plan outlined in the executive summary of this document, including the priority of each recommended measure.

Table 41: Multi-criteria Assessment of Measures

Reference	Report Section	Mitigation Measure	Impact on Road Flooding	Impact on Property Flooding	Impact on Risk to Life	Technical Feasibility	Community Acceptance	Economic Value	Cost and Available Funding	Environmental Impact	Impact on SES	Political Feasibility	Total Score	Rank
Property Modification Measures (Section 6.7)														
PM-01	6.7.1	Inclusion of Flood Related Policy and FPA in the LEP	0	3	1	3	2	3	0	0	2	2	16	1=
PM-02	6.7.2	Adoption of Matrix-style Controls in DCP	0	3	1	2	2	2	0	0	1	2	13	3=
PM-03	6.7.5	Flood Proofing	0	2	1	1	2	1	-1	0	1	1	8	7=
PM-04	6.7.7	Inclusion of Flood Risk Information on s10.7 Planning Certificates	0	1	1	2	0	2	0	0	1	1	8	7=
Response Modification Measures (Section 6.8)														
RM-01	6.8.3	Flood Signage	0	0	2	3	3	1	1	0	3	3	16	1=
RM-02	6.8.4	Local Flood Plan	0	0	1	2	2	0	2	0	1	2	10	6
RM-03	6.8.5	Requirement for Site Specific Flood Emergency Plans	0	0	2	2	2	1	2	0	2	2	13	3=

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Reference	Report Section	Mitigation Measure	Impact on Road Flooding	Impact on Property Flooding	Impact on Risk to Life	Technical Feasibility	Community Acceptance	Economic Value	Cost and Available Funding	Environmental Impact	Impact on SES	Political Feasibility	Total Score	Rank
Flood Modification Measures (Section 6.9)														
FM-S01	6.9.1	Trunk Upgrade in North Sydney CBD	2	3	2	-3	2	0	-3	-1	0	-2	0	15
FM-S03	6.9.3	Upgrade Kurraba Road Culvert	1	1	1	-1	2	-1	0	0	0	2	5	10
FM-S04	6.9.4	Bund at Forsyth Park	1	1	1	1	1	1	0	-1	0	1	6	9
FM-S05	6.9.5	Trunk Upgrade from Lindsay Street to Kurraba Road	1	1	1	-3	2	-2	-2	0	0	-2	-4	20=
FM-E01	6.9.6	Trunk Upgrade from Yeo Street to Bogota Avenue	1	2	1	-3	2	-1	-2	0	0	-2	-2	17=
FM-W01	6.9.7	Trunk Upgrade from Bank Street to Waverton Park	2	2	2	-3	2	0	-2	0	0	-2	1	12=
FM-W02	6.9.8	Carlyle Lane Drainage Upgrade	2	1	1	-2	2	-3	-2	-1	0	-2	-4	20=
FM-N01	6.9.9	Trunk Upgrade from Albany Street to Flat Rock Creek	2	3	2	-3	2	1	-3	-1	0	-2	1	12=
FM-N02	6.9.10	Bund at St Leonards Park	2	2	2	1	1	3	0	-1	0	1	11	5
FM-N03	6.9.11	Anzac Park Basin	2	2	2	-1	-1	-1	-3	-2	0	-2	-4	20=

Reference	Report Section	Mitigation Measure	Impact on Road Flooding	Impact on Property Flooding	Impact on Risk to Life	Technical Feasibility	Community Acceptance	Economic Value	Cost and Available Funding	Environmental Impact	Impact on SES	Political Feasibility	Total Score	Rank
FM-N05+N08	6.9.12	Trunk Upgrade from Anzac Park to Willoughby Creek and Warringa Road Drainage Upgrade	2	2	2	-3	2	-2	-3	-1	0	-2	-3	19
FM-N06	6.9.13	Reynolds Street Drainage Upgrade	2	2	2	-3	2	-1	-2	-1	0	-2	-1	16
FM-N07	6.9.14	Cooper Lane Drainage Upgrade	2	2	2	-3	2	-1	-3	-1	0	-2	-2	17=
FM-N09	6.9.15	Cassins Avenue Drainage Upgrade	1	2	1	-1	2	0	-2	0	0	-1	2	11
FM-N11	6.9.16	Cammeray Golf Club Basin	2	2	2	-1	-1	2	-2	-2	0	-1	1	12=

7. DRAFT FLOODPLAIN RISK MANAGEMENT PLAN

This Draft Floodplain Risk Management Plan is the final output of the analysis presented in Sections 6.6 to 6.10 of this report, which assessed a range of flood mitigation options for North Sydney LGA. The Draft Plan contains the measures that have significant benefit to the area and are recommended to be implemented. Each measure has an assigned responsibility (either Council, property owners, or the SES) and a priority. The Plan is presented as a separate section to provide Council and other stakeholders with a summary of the recommendations put forward. The same table is presented in the executive summary of this report.

In the table below, high priority measures are those that should be implemented in the short term, while low priority measures are recommended for implementation in the long term. The distinction has been made because several structural measures involve large-scale construction activities, that are very expensive and are likely to be highly disruptive to the community. These measures are therefore recorded in the Plan for when other activities may make them relatively feasible, for example, Sydney Water replacing or repairing their stormwater assets.

Table 42: Draft Floodplain Risk Management Plan for North Sydney LGA

Option and Report Reference	Description	Responsibility	Priority
PM-01 Inclusion of Flood Related Policy and FPA in the LEP	Install flood-related clauses in the LEP to provide a flood definition for the LGA and objectives for its management. Also provide definition of the FPA.	Council	High
PM-02 Adoption of Matrix-style Controls in DCP	Introduce matrix-style controls on development of flood-prone land considering both the level of flood risk and the type of development.	Council	High
PM-03 Flood Proofing	Consider permanent flood proofing methods for flood-prone lots/properties.	Property Owners	Medium
PM-04 Inclusion of Flood Risk Information on s10.7 Planning Certificates	Include relevant flood risk information on the s10.7 planning certificates to inform property owners of flood risk.	Council	Medium
RM-02 Local Flood Plan	Prepare a Local Flood Plan to detail flood risk within the LGA, responsibilities of relevant agencies, flood response and arrangements.	SES	High
RM-03 Requirement for Site Specific Flood Emergency Plans	Impose requirement for a site-specific Flood Emergency Plan on new developments in high hazard flooding	Council	High

Option and Report Reference	Description	Responsibility	Priority
	areas, detailing responsibilities and evacuation planning.		
FM-S01 Trunk Upgrade in North Sydney CBD	Increase capacity of Sydney Water trunk system through North Sydney CBD to Milson Park and introduce new pits.	Council, Sydney Water and TfNSW	Low
FM-S03 Upgrade Kurraba Road Culvert	Upgrade Sydney Water culvert under the Kurraba Road/Clark Road intersection.	Council, Sydney Water	Medium
FM-S04 Bund at Forsyth Park	Construct bund or levee at Forsyth Park to impede upstream overland flows.	Council	Medium
FM-S05 Trunk Upgrade from Lindsay Street to Kurraba Road	Upgrade Council trunk system from Lindsay Street to the harbour outlet and introduce new pits.	Council	Low
FM-E01 Trunk Upgrade from Yeo Street to Bogota Avenue	Upgrade Council trunk system from Yeo Street to the harbour outlet and introduce new pits.	Council	Low
FM-W01 Trunk Upgrade from Bank Street to Waverton Park	Upgrade Sydney Water trunk system from Bank Street to Woolcott Street and introduce new pits.	Council, Sydney Water	Low
FM-W02 Carlyle Lane Drainage Upgrade	Upgrade Council drainage system from Carlyle Lane to Berrys Creek and enhance capacity of existing pits.	Council	Low
FM-N01 Trunk Upgrade from Albany Street to Flat Rock Creek	Upgrade Sydney Water and Council trunk system from Albany Street to Flat Rock Creek and introduce new pits.	Council, Sydney Water	Low
FM-N02 Bund at St Leonards Park	Construct bund or levee at St Leonards Park to impede upstream overland flows.	Council	High
FM-N03 Anzac Park Basin	Construct basin within Anzac Park to create additional flood storage.	Council, TfNSW	Low
FM-N05+N08 Trunk Upgrade from Anzac Park to Willoughby Creek and Warringa Road Drainage Upgrade	Upgrade Sydney Water trunk system from Anzac Park to Primrose Park, upgrade Warringa Road drainage system and introduce new pits.	Council, Sydney Water and TfNSW	Low
FM-N06 Reynolds Street Drainage Upgrade	Upgrade Council drainage system from Reynolds Street to the harbour outlet and introduce new pits.	Council	Low

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Option and Report Reference	Description	Responsibility	Priority
FM-N07 Cooper Lane Drainage Upgrade	Upgrade Council drainage system from Belgrave Street to the harbour outlet and introduce new pits.	Council	Low
FM-N09 Cassins Avenue Drainage Upgrade	Upgrade Council drainage system from Cassins Avenue to St Leonards Park and introduce new pits.	Council	Medium
FM-N11 Cammeray Golf Club Basin	Construct basin adjacent to Warringa Road within Cammeray Golf Course to create additional flood storage.	Council	Medium

8. REFERENCES

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17. Sydney Metropolitan Regional Emergency Management Plan, 2017, Mosman North Sydney Local Emergency Management Committee.

9. FIGURES

Figure 1: Study Area

Figure 2: DEM based on 2013 LiDAR

Figure 3: Stormwater Network

Figure 4: Results Reporting Location

Figure 5: Flood Study and FRMS Updates Results Comparison – South Model - 1% AEP Design Event

Figure 6: Flood Study and FRMS Updates Results Comparison – East Model - 1% AEP Design Event

Figure 7: Flood Study and FRMS Updates Results Comparison – West Model - 1% AEP Design Event

Figure 8: Flood Study and FRMS Updates Results Comparison – North Model - 1% AEP Design Event

Figure 9: Peak Flood Depths and Levels – 20% AEP Design Event

Figure 10: Peak Flood Depths and Levels - 10% AEP Design Event

Figure 11: Peak Flood Depths and Levels - 5% AEP Design Event

Figure 12: Peak Flood Depths and Levels - 2% AEP Design Event

Figure 13: Peak Flood Depths and Levels - 1% AEP Design Event

Figure 14: Peak Flood Depths and Levels - PMF Design Event

Figure 15: Peak Flood Velocities – 20% AEP Design Event

Figure 16: Peak Flood Velocities - 10% AEP Design Event

Figure 17: Peak Flood Velocities - 5% AEP Design Event

Figure 18: Peak Flood Velocities - 2% AEP Design Event

Figure 19: Peak Flood Velocities - 1% AEP Design Event

Figure 20: Peak Flood Velocities - PMF Design Event

Figure 21: Flood Hazard - 20% AEP Design Event

Figure 22: Flood Hazard - 5% AEP Design Event

Figure 23: Flood Hazard - 1% AEP Design Event

Figure 24: Flood Hazard - PMF Design Event

Figure 25: Flood Function - 20% AEP Design Event

Figure 26: Flood Function - 5% AEP Design Event

Figure 27: Flood Function - 1% AEP Design Event

Figure 28: Flood Function - PMF Design Event

Figure 29: Flood Emergency Response – PMF Design Event

Figure 30: Location of Questionnaire Respondents

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Figure 31: Draft Flood Planning Area

Figure 32: 1% AEP Flood Impact Map - Trunk Upgrade in North Sydney CBD (FM-S01)

Figure 33: 1% AEP Flood Impact Map - Bund at Warringa Park (FM-S02)

Figure 34: 1% AEP Flood Impact Map - Upgrade Kurraba Road Culvert (FM-S03)

Figure 35: 1% AEP Flood Impact Map - Bund at Forsyth Park (FM-S04)

Figure 36: 1% AEP Flood Impact Map - Trunk Upgrade from Lindsay St to Kurraba Rd (FM-S05)

Figure 37: 1% AEP Flood Impact Map - Trunk Upgrade from Yeo St to Bogota Ave (FM-E01)

Figure 38: 1% AEP Flood Impact Map - Trunk Upgrade from Bank St to Waverton Park (FM-W01)

Figure 39: 1% AEP Flood Impact Map - Carlyle Lane Drainage Upgrade (FM-W02)

Figure 40: 1% AEP Flood Impact Map - Trunk Upgrade from Pacific Highway to Flat Rock Creek (FM-N01)

Figure 41: 1% AEP Flood Impact Map - Bund at St Leonards Park (FM-N02)

Figure 42: 1% AEP Flood Impact Map - Anzac Park Basin (FM-N03)

Figure 43: 1% AEP Flood Impact Map - Trunk Upgrade from Anzac Park to Willoughby Ck and Warringa Rd Drainage Upgrade (FM-N05+N08)

Figure 44: 1% AEP Flood Impact Map - Reynolds Street Drainage Upgrade (FM-N06)

Figure 45: 1% AEP Flood Impact Map - Cooper Lane Drainage Upgrade (FM-N07)

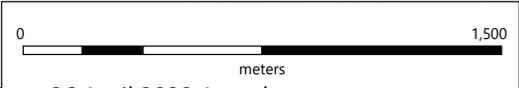
Figure 46: 1% AEP Flood Impact Map - Cassins Avenue Drainage Upgrade (FM-N09)

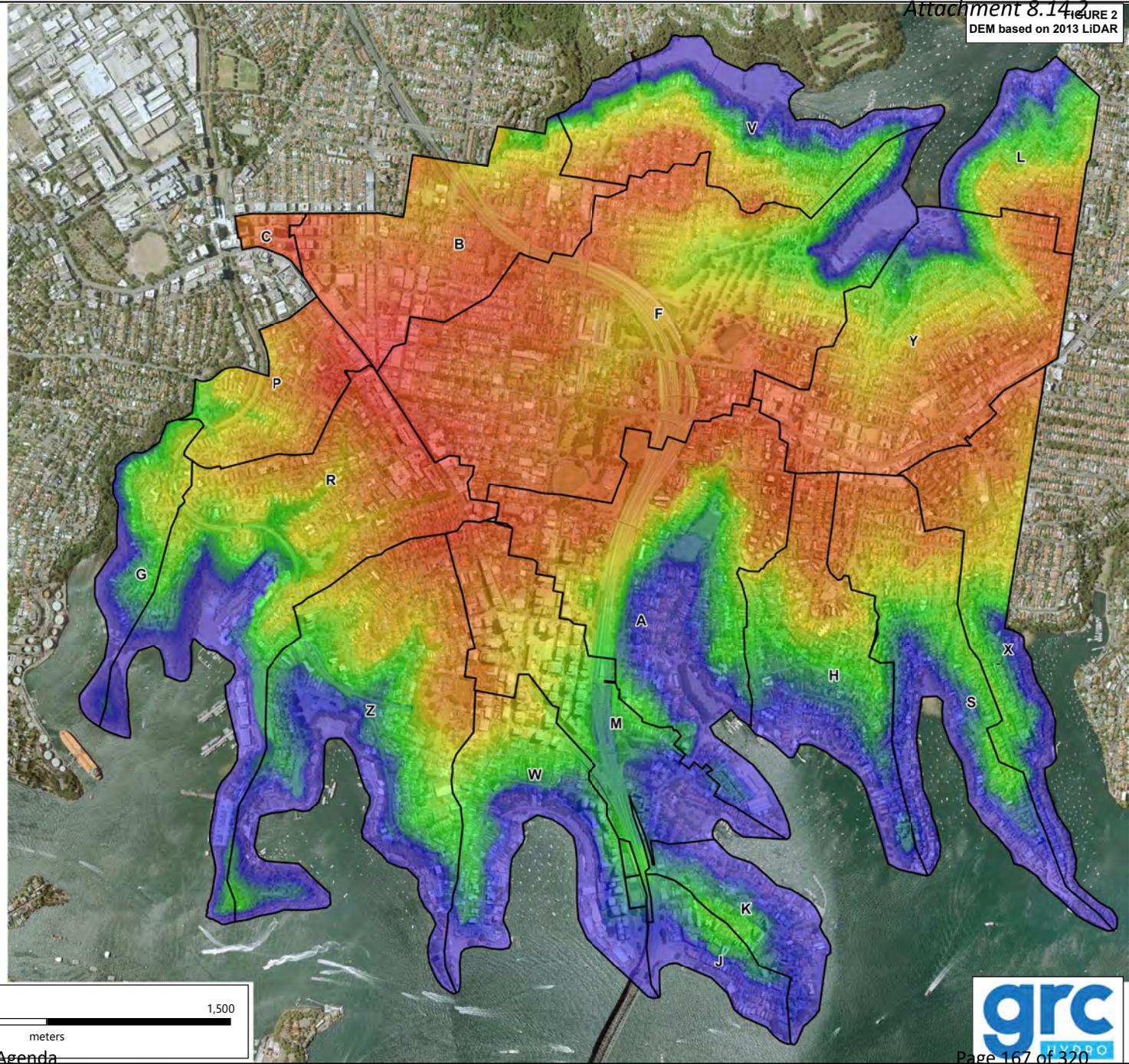
Figure 47: 1% AEP Flood Impact Map - Cammeray Golf Club Basin (FM-N11)

Figure E 1: Property Floor Level Survey

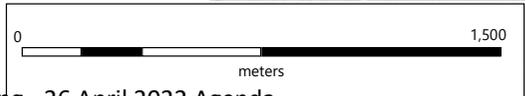
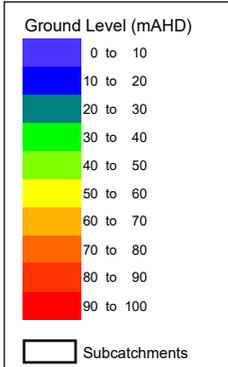


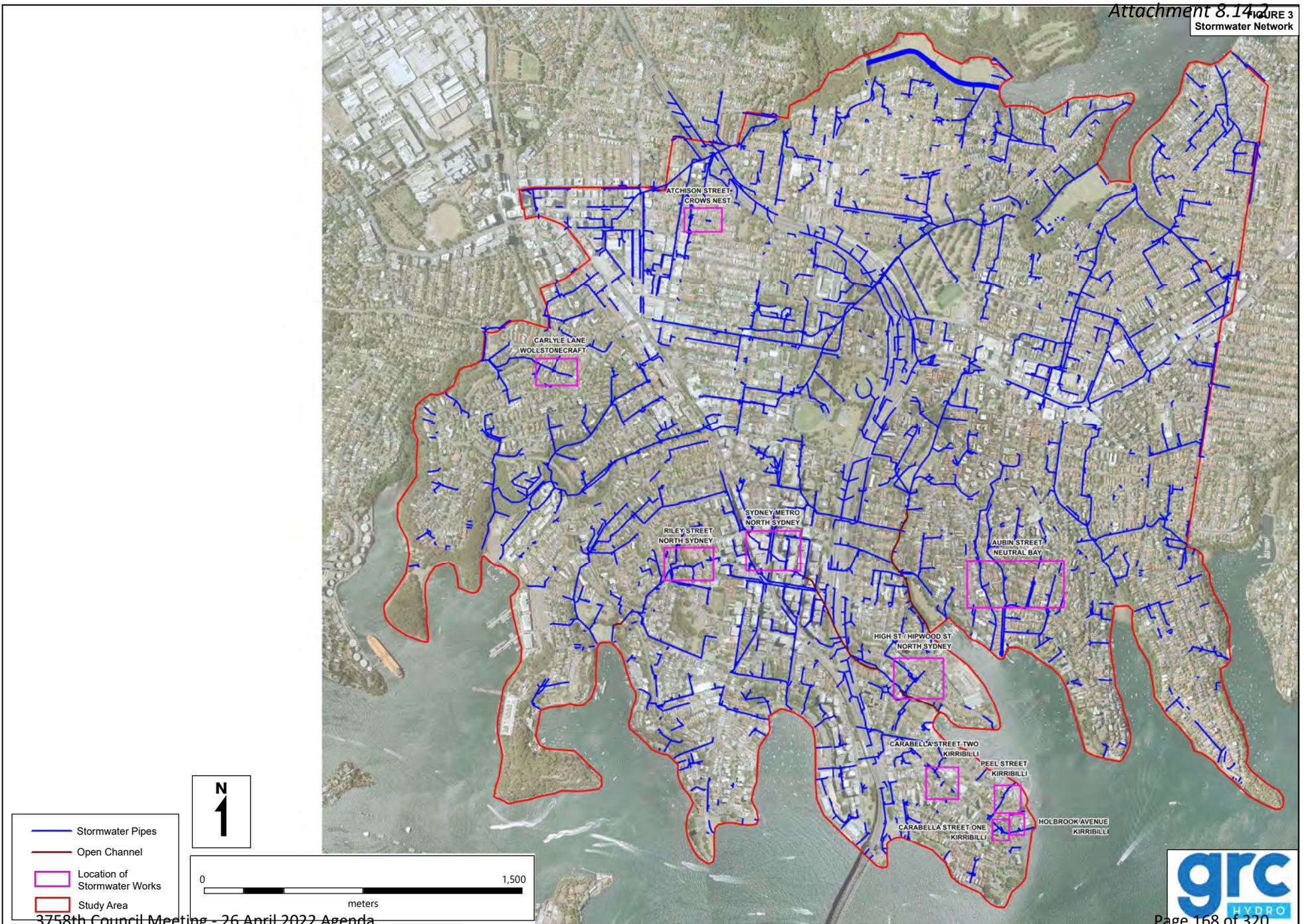
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-  Hydraulic Model Quadrants





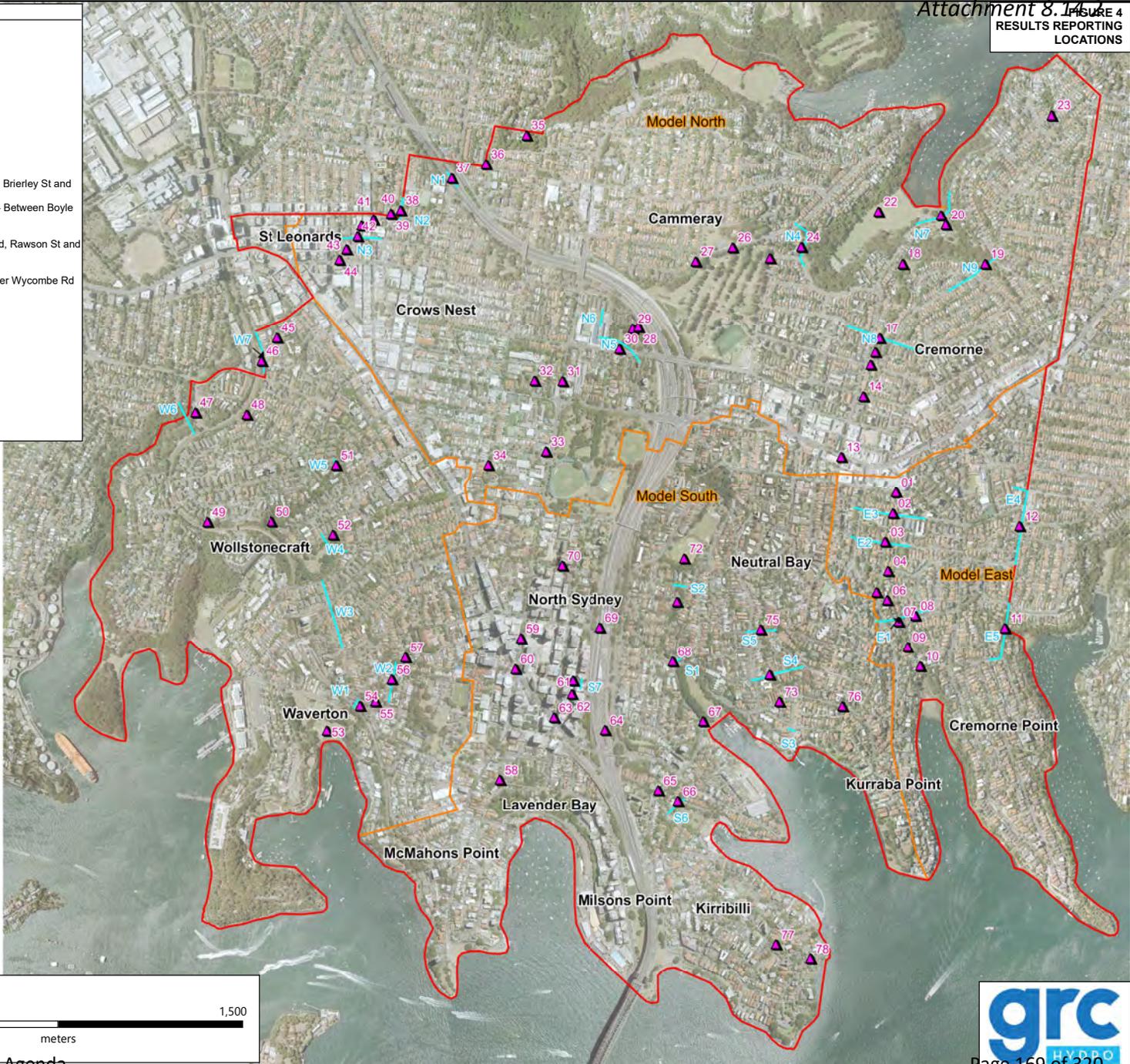
Label	Catchment Name
F	FALL STREET
Z	BERRYS BAY
R	ROCKLANDS ROAD
M	MILSON PARK
H	HAYES STREET
A	ANDERSON PARK
Y	YOUNG STREET
W	WALKER STREET
B	BROOK STREET
G	GORE COVE
C	CHRISTIE STREET
X	MOSMAN BAY
S	SHELL COVE
J	JEFFREYS STREET WHARF
K	KIRRIBILLI
L	LONG BAY
V	VERNON STREET
P	SMOOTHEY PARK





ID	Location
1	Yeo St
2	Harrison St
3	Bennett St
4	Bertha St
5	Burroway Cnr
6	Powell St
7	Bannerman St
8	Guthrie Ave
9	Honda Rd
10	Bogota Ave
11	Hunts Lookout
12	Spofforth St
13	Military Rd
14	Belgrave St
15	Sutherland St
16	Grasmere La
17	Grasmere Rd
18	Little Young St
19	Brightmore St
20	Brightmore Res
21	Young St
22	Primrose Pk
23	Ryries Pde
24	Grafton St
25	Park Ave
26	Cammeray Rd
27	Warringah Rd
28	Cammeray Ave
29	Aznac Pk
30	Ernest St
31	Miller St
32	Rodborough Ave
33	Carlow St
34	West St
35	Hamilton La
36	Palmer St
37	Brooke St
38	Wheatleigh St
39	Chandos St
40	Willoughby Rd
41	Hume La
42	Atchison St
43	Albany La
44	Albany St
45	Christie St
46	Lithgow St
47	Russell St
48	Carlyle La
49	Belmont Av
50	Newlands La
51	Newlands St
52	Hazelbank Rd
53	Waverton Oval
54	Woolcott St
55	Euroka St
56	Ancrum St
57	Bank St
58	Lavender St
59	Miller St
60	Pacific Hwy / Miller St Intersection
61	Mount St
62	Little Walker St
63	Pacific Hwy / Walker St Intersection
64	Warringah Freeway / Tunnel Entrance
65	Clark Rd
66	Hipwood St
67	Anderson Park Outlet
68	Clark Rd / Kurraba Rd Intersection
69	Warringah Freeway
70	McLaren St
71	Rawson St Channel
72	Forsyth Park
73	Kurraba Rd
74	Aubin St
75	Phillips St
76	Kurraba Rd / Wycombe Rd Intersection
77	Carabella St / Peel St Intersection
78	Holbrook Ave

ID	Location
N1	Brooke St
N2	Wheatleigh St
N3	Atchison St
N4	Grafton St
N5	Ernest St
N6	Anzac Ave
N7	Young St
N8	Grasmere Rd
N9	Brightmore St
E1	Bannerman St
E2	Bennet St
E3	Harrison St
E4	Spofforth St - Between Brierley St and Florence St
E5	Lower Spofforth Walk - Between Boyle St and Hodgson Ave
S1	Intersection of Clark Rd, Rawson St and Kurraba Rd
S2	Eaton St
S3	Cnr Hayes St and Lower Wycombe Rd
S4	Aubin St
S5	Phillips St
S6	Hipwood St
S7	Mount St
W1	Woolcott St
W2	Ancrum St
W3	Carr St
W4	Brennan Park
W5	Newlands St
W6	Russel St
W7	Lithgow St



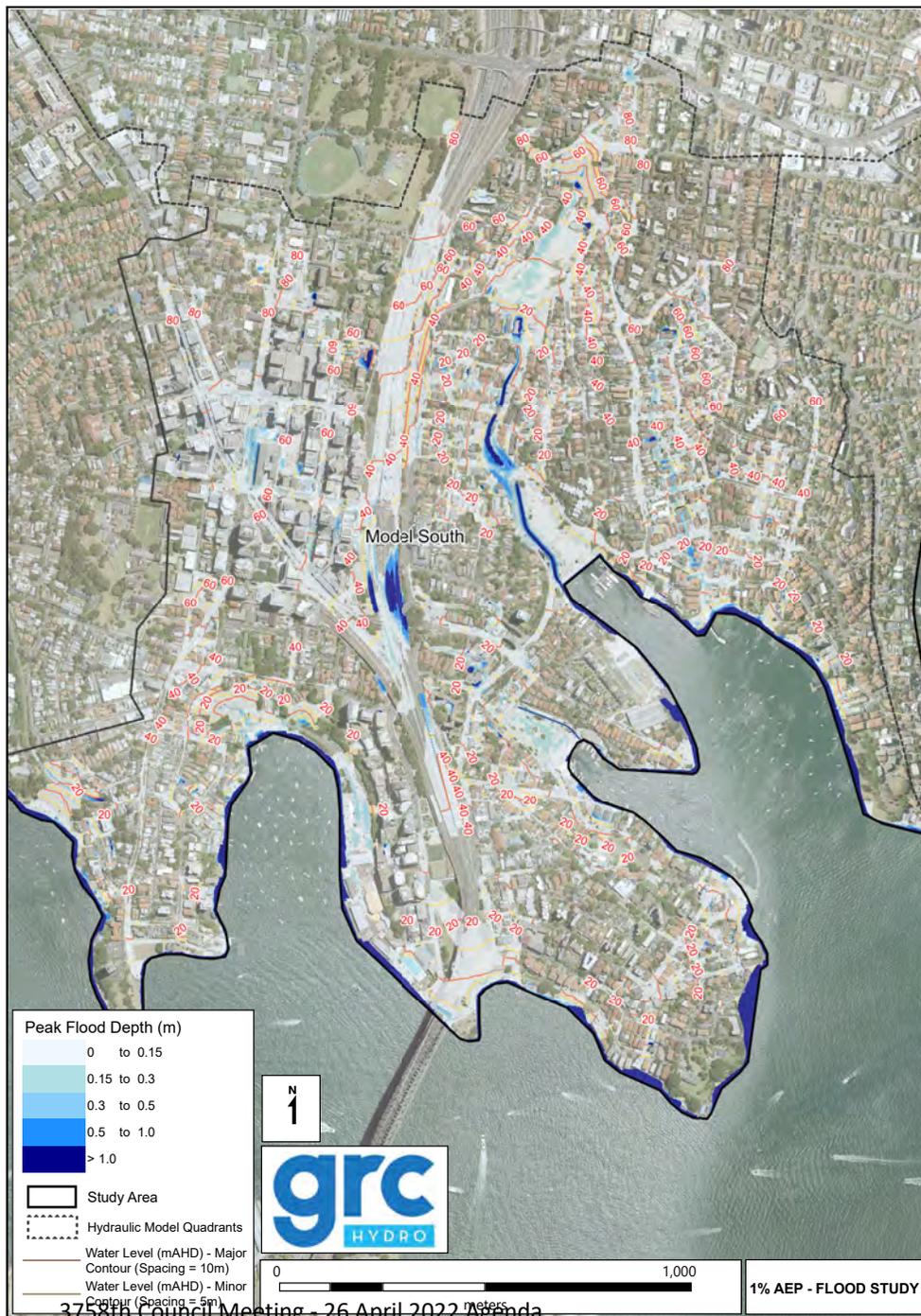
— flow reporting locations
 Study Area
 Hydraulic Model Quadrants
▲ Comparison Points

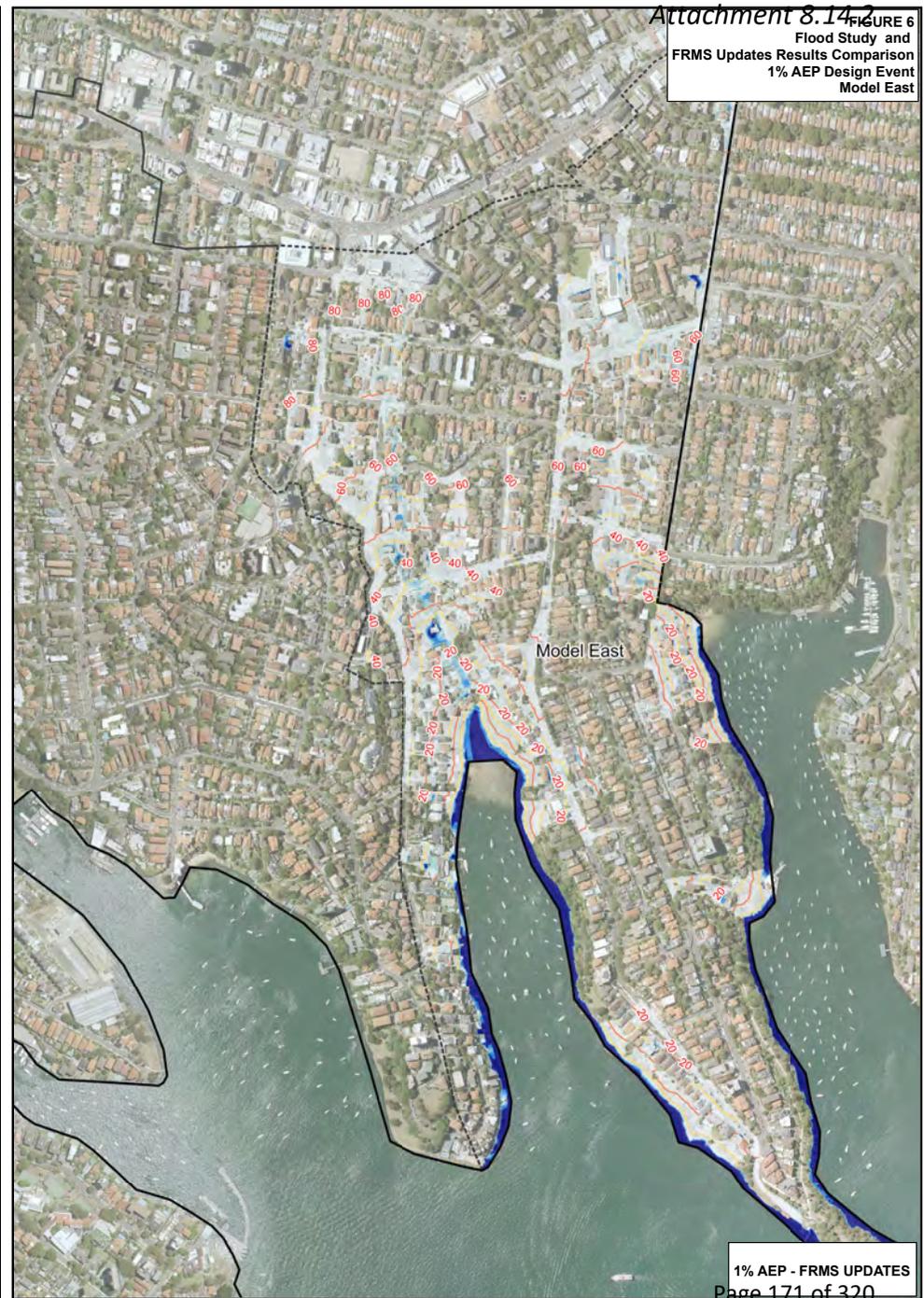
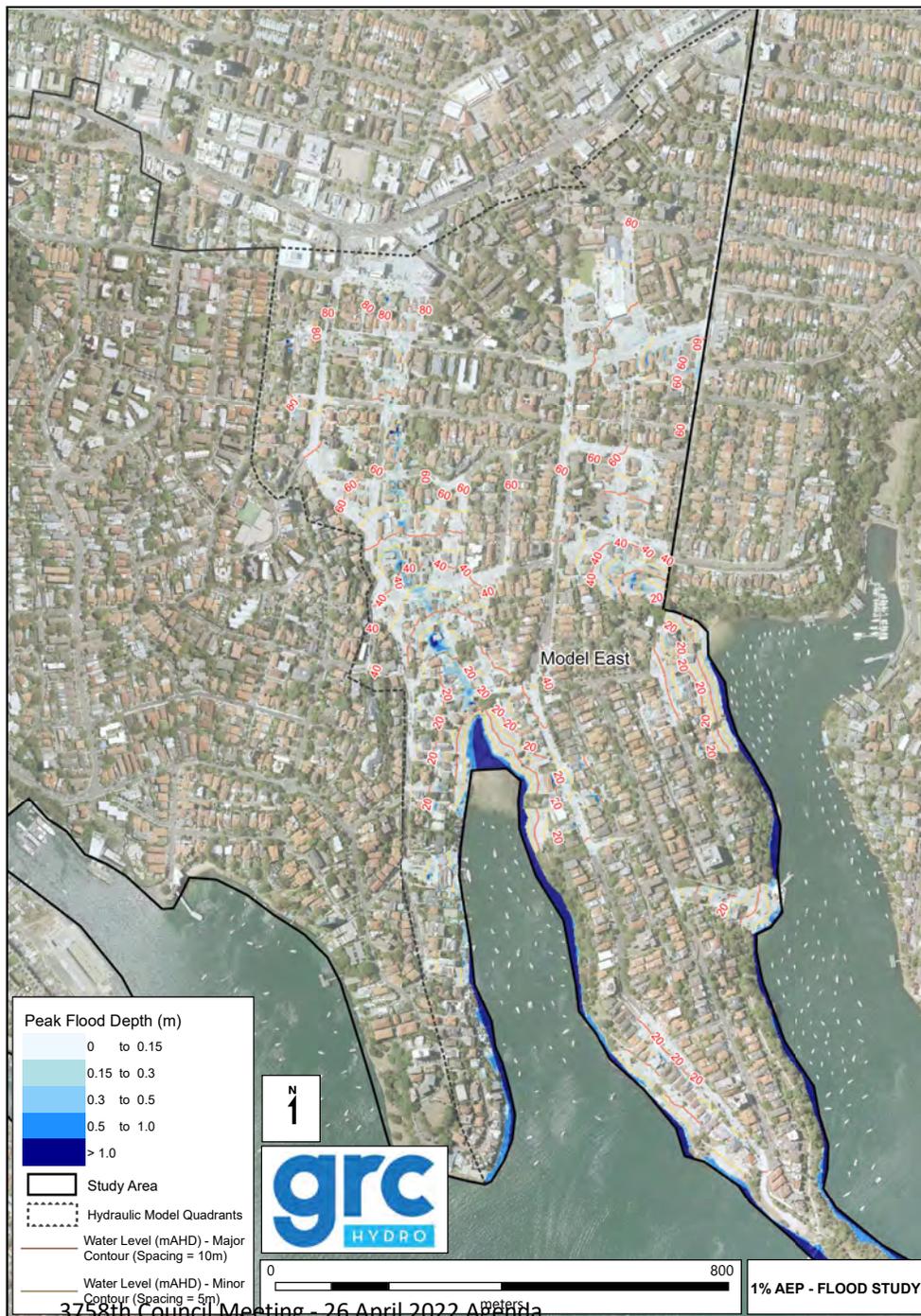
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1

0 ————— 1,500
 meters



Attachment 8.14.2
FIGURE 5
 Flood Study and
 FRMS Updates Results Comparison
 1% AEP Design Event
 Model South





Attachment 8.14.2
FIGURE 7
 Flood Study and
 FRMS Updates Results Comparison
 1% AEP Design Event
 Model West

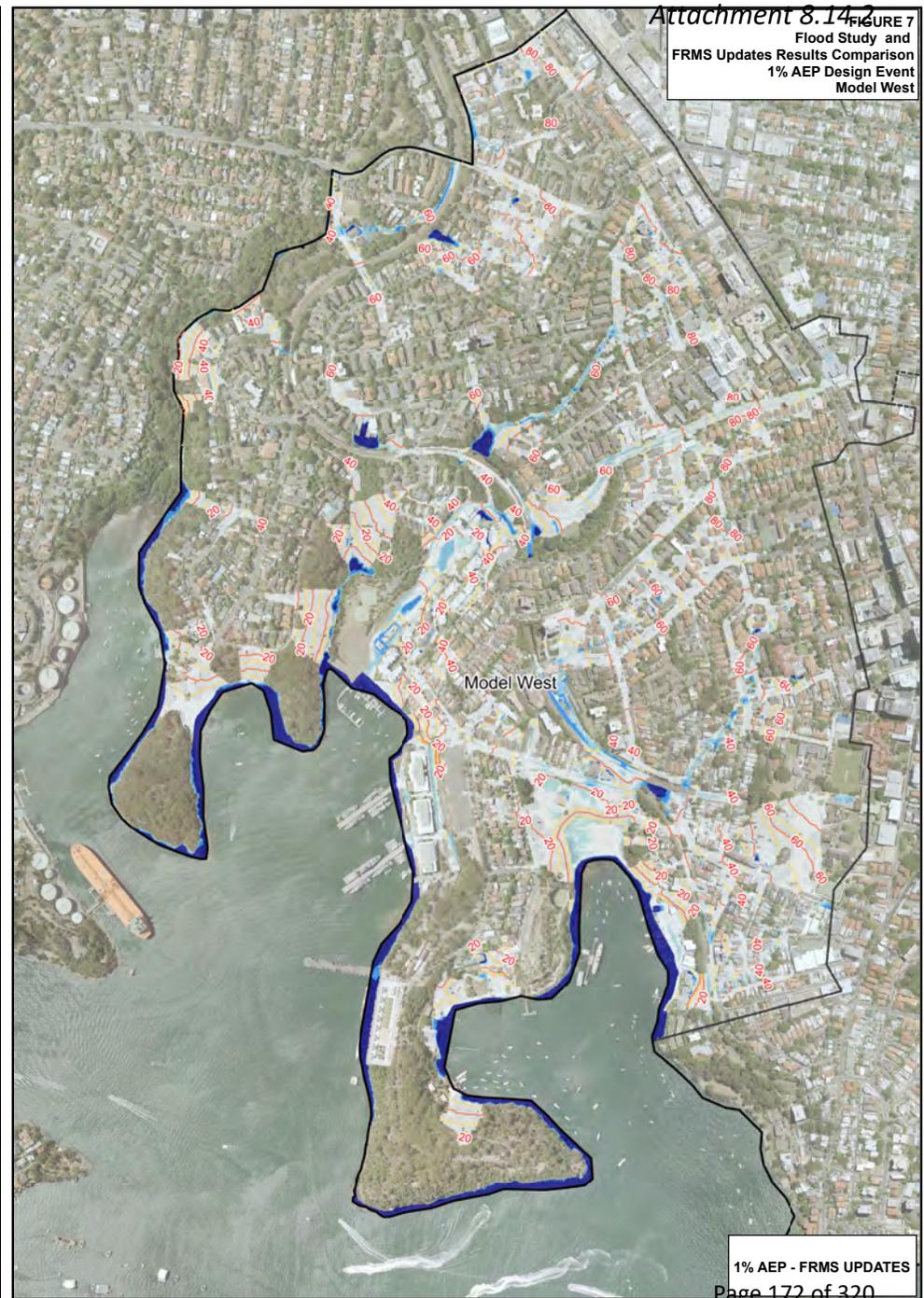
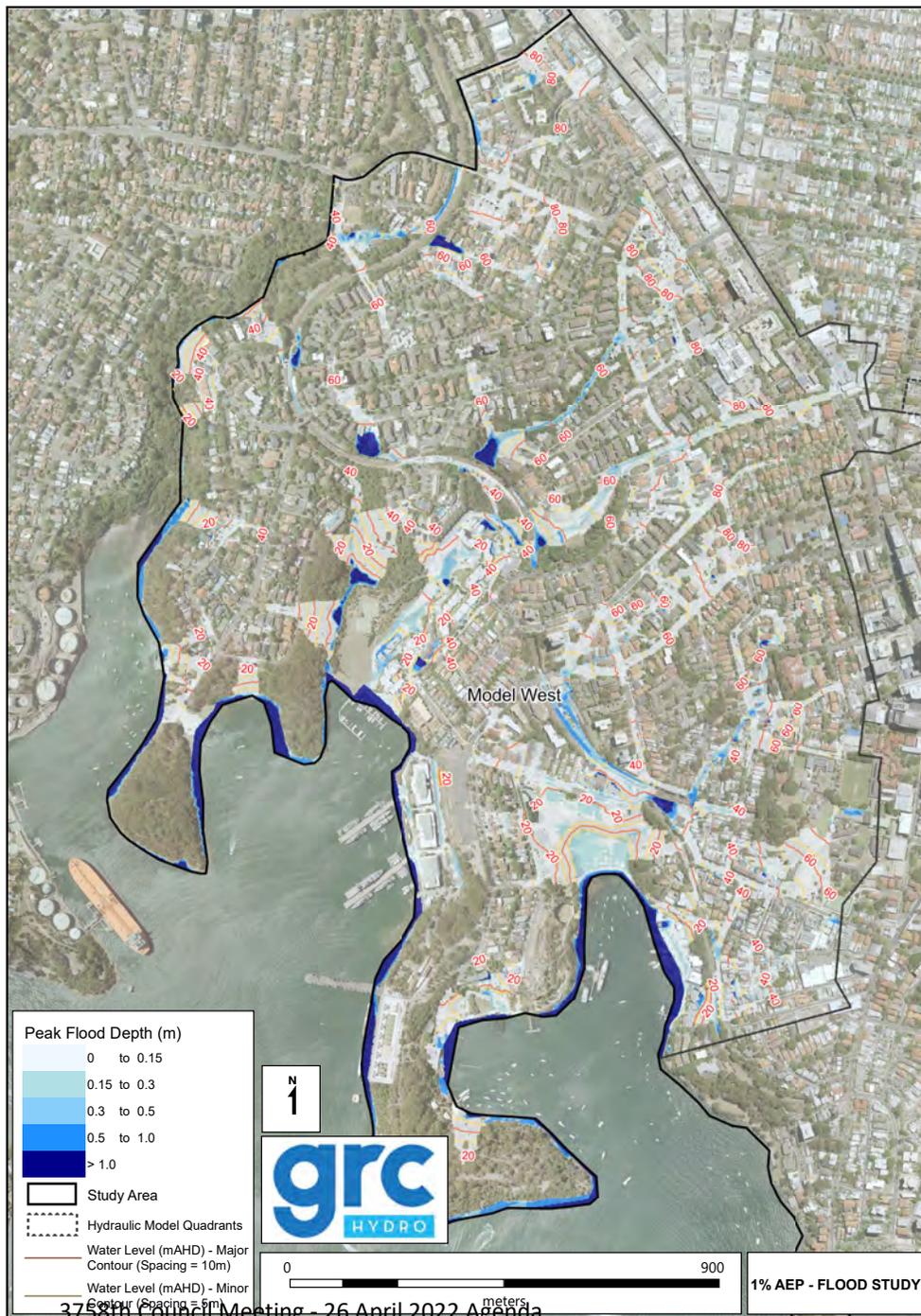
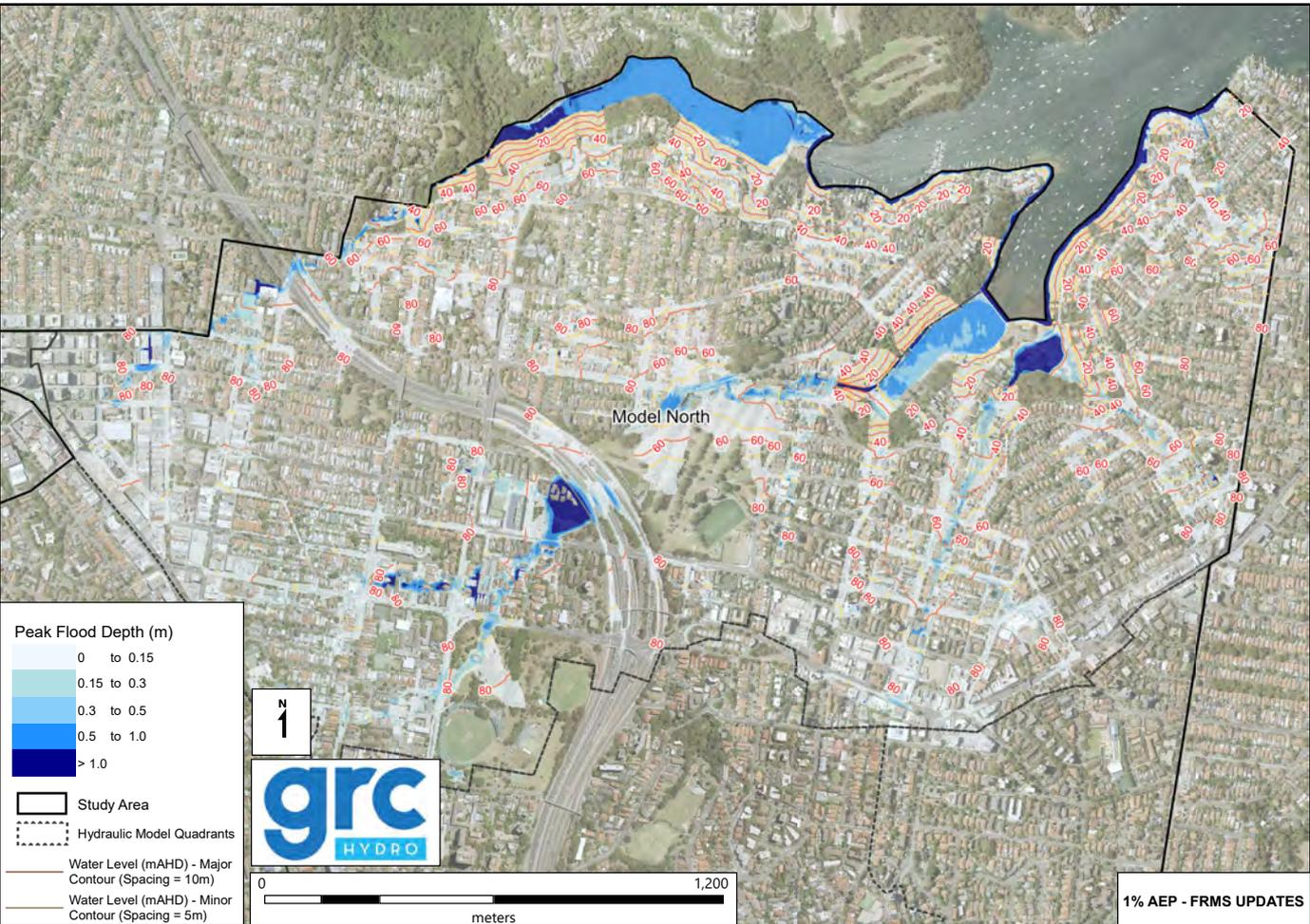
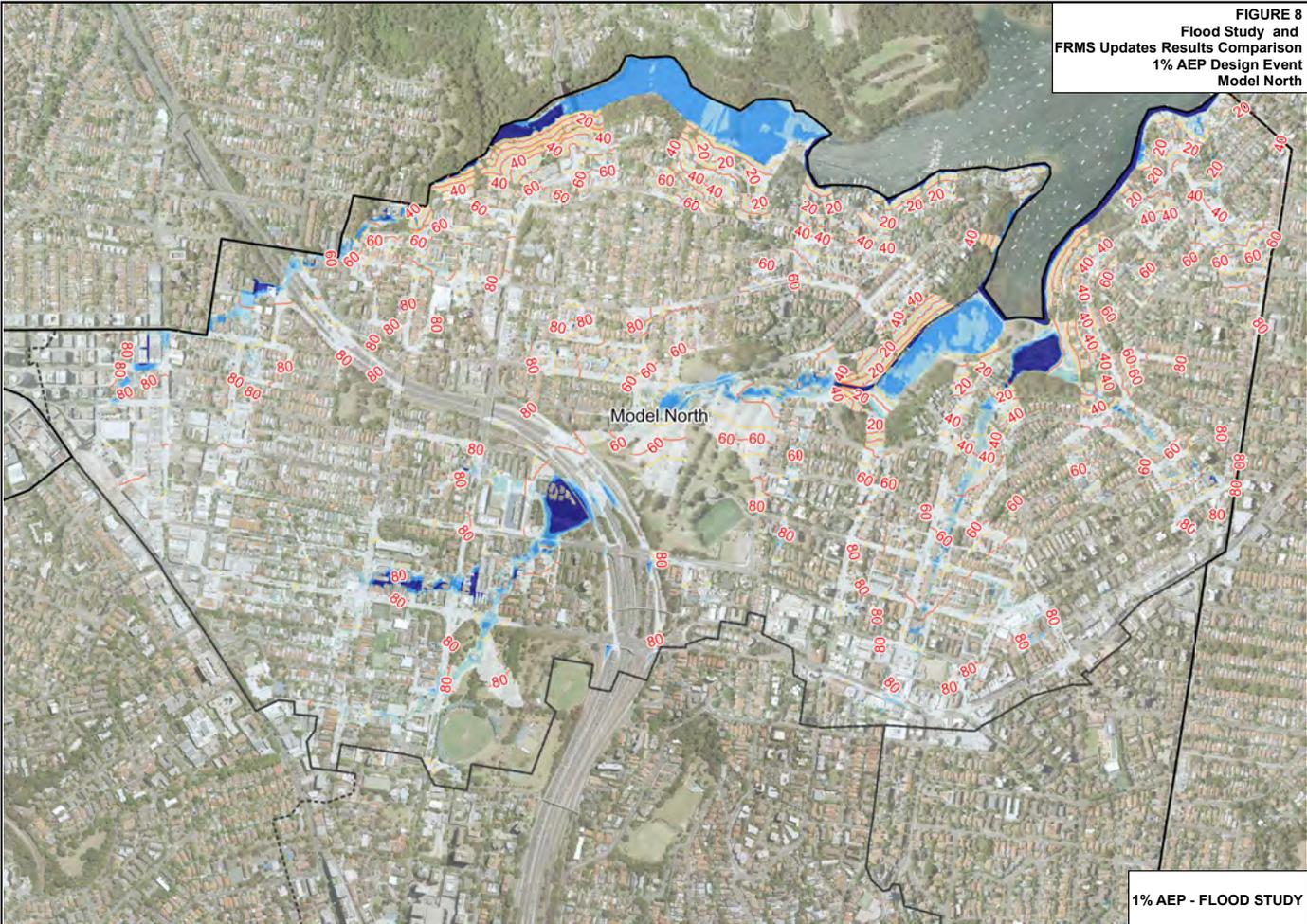
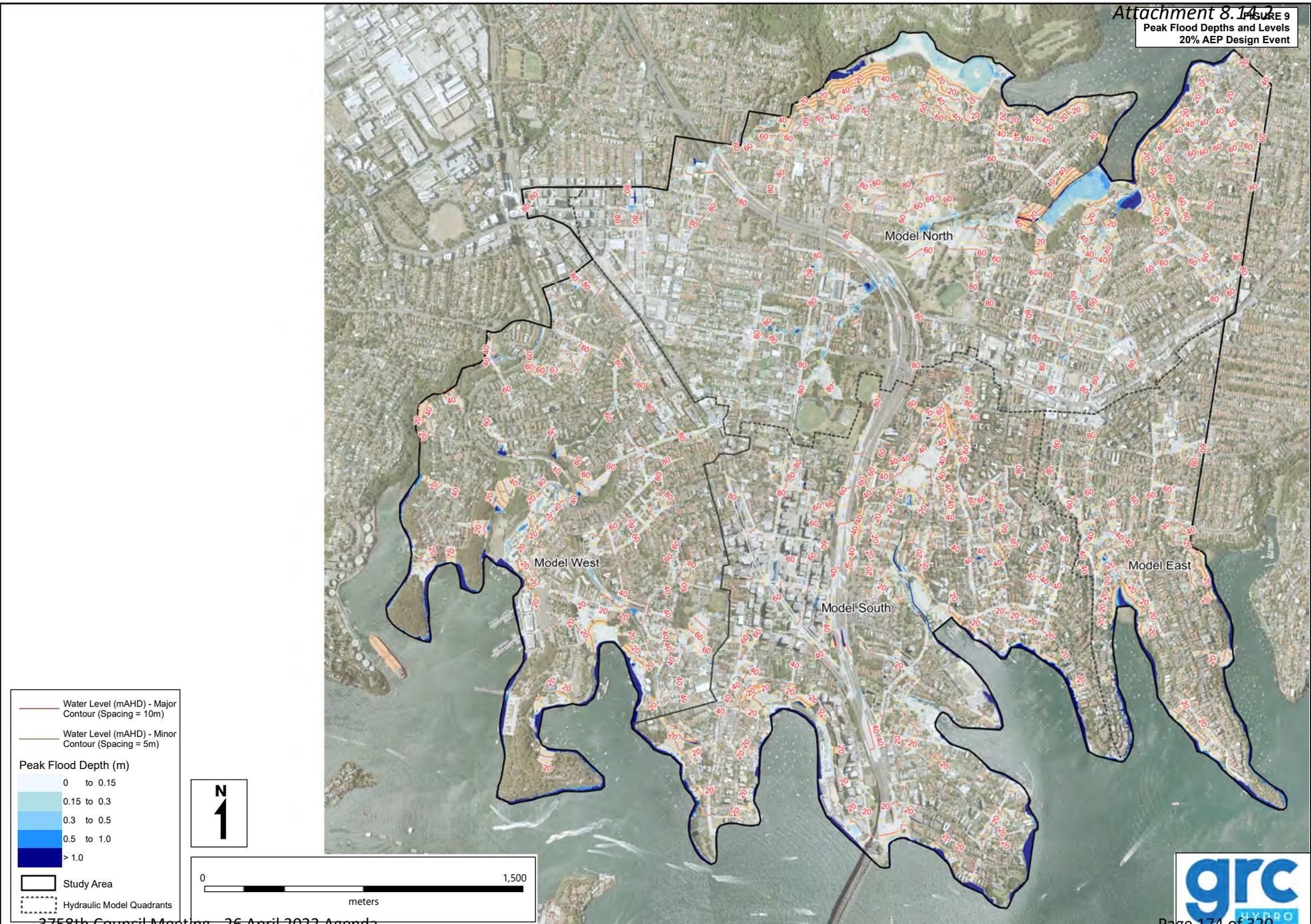
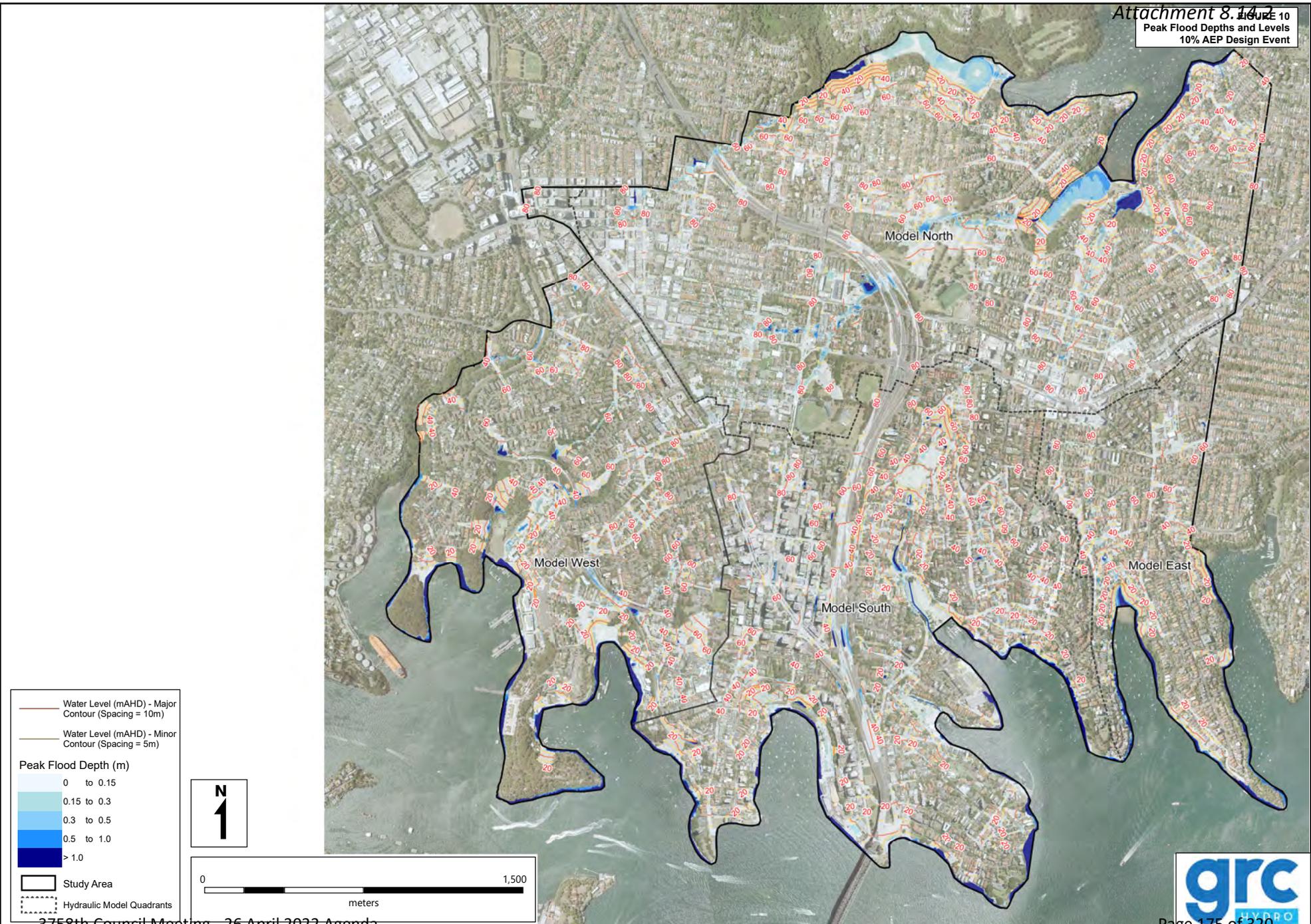


FIGURE 8
Flood Study and
FRMS Updates Results Comparison
1% AEP Design Event
Model North



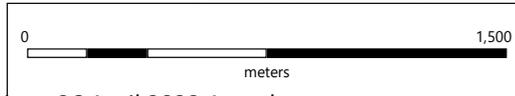


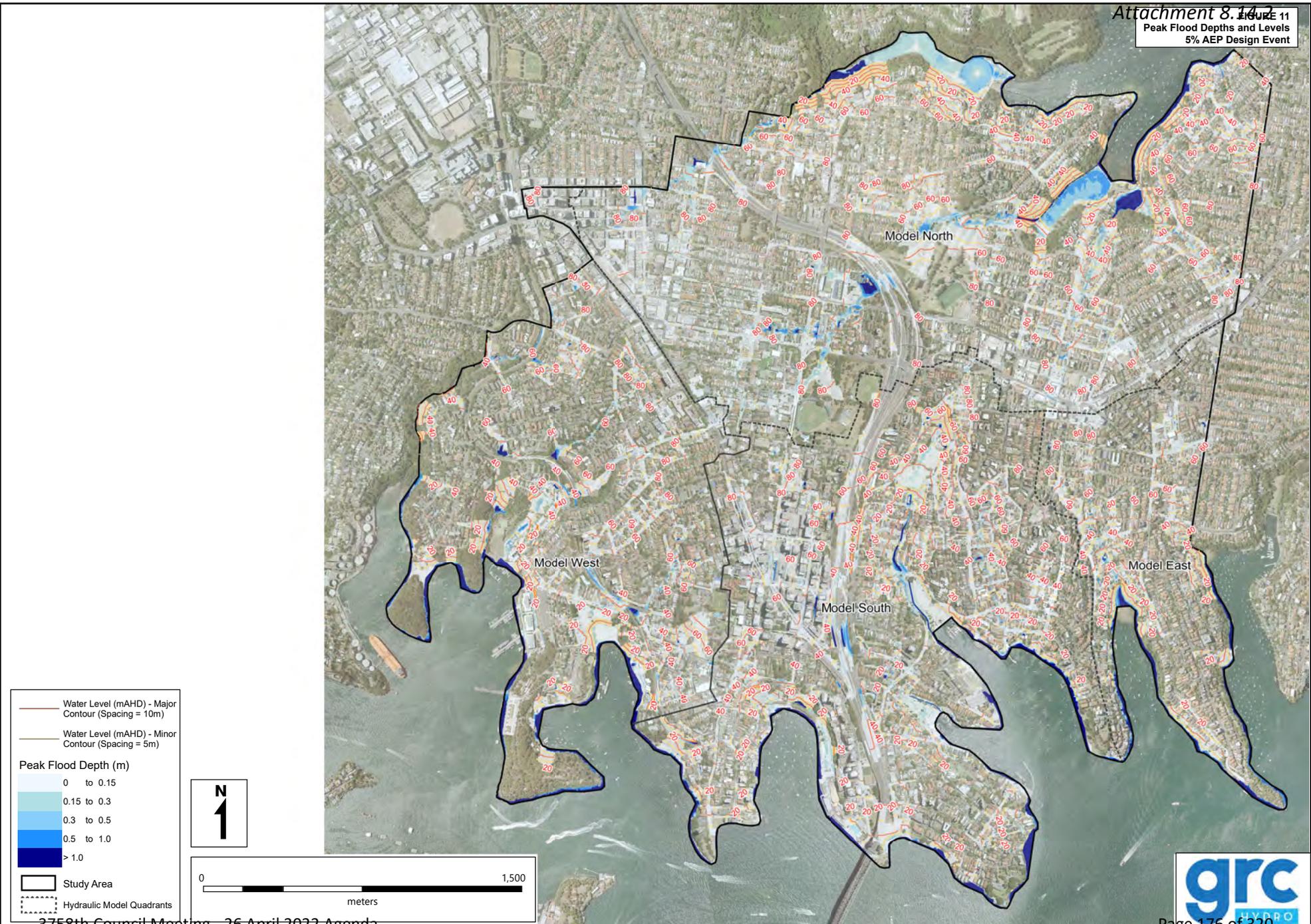


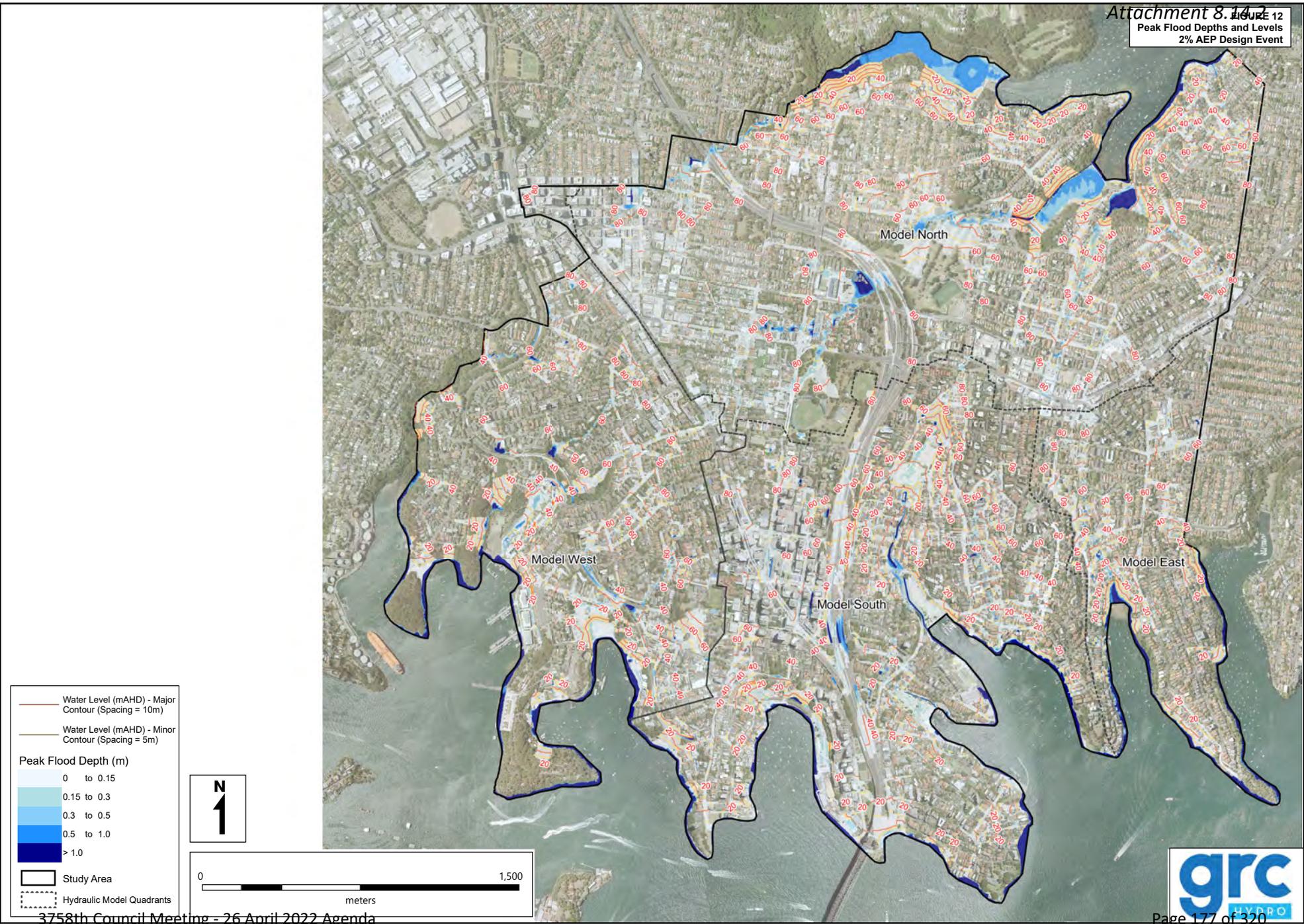
— Water Level (mAHD) - Major Contour (Spacing = 10m)
— Water Level (mAHD) - Minor Contour (Spacing = 5m)

Peak Flood Depth (m)
 0 to 0.15
 0.15 to 0.3
 0.3 to 0.5
 0.5 to 1.0
 > 1.0

Study Area
 Hydraulic Model Quadrants



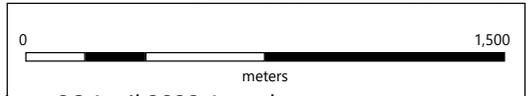


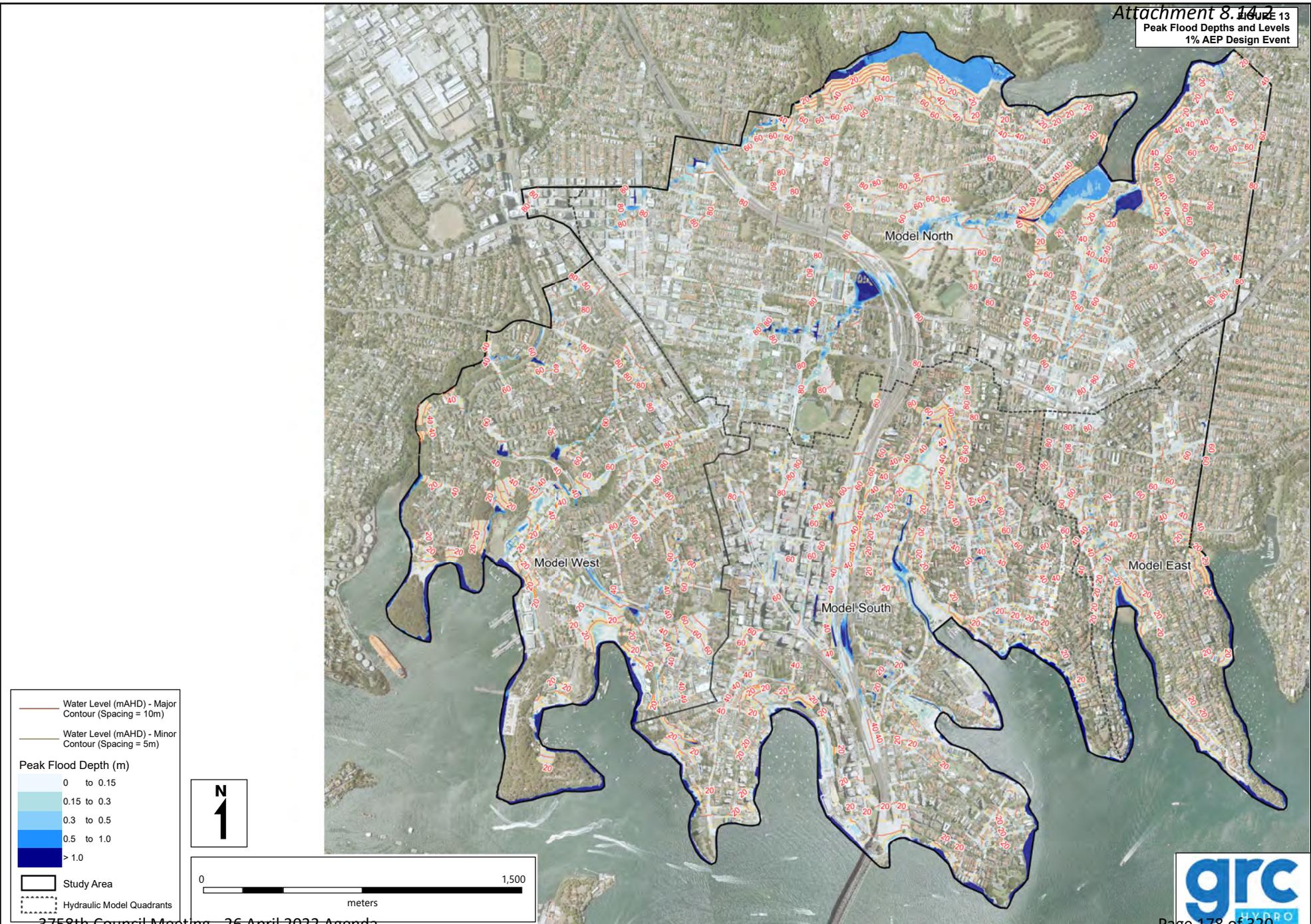


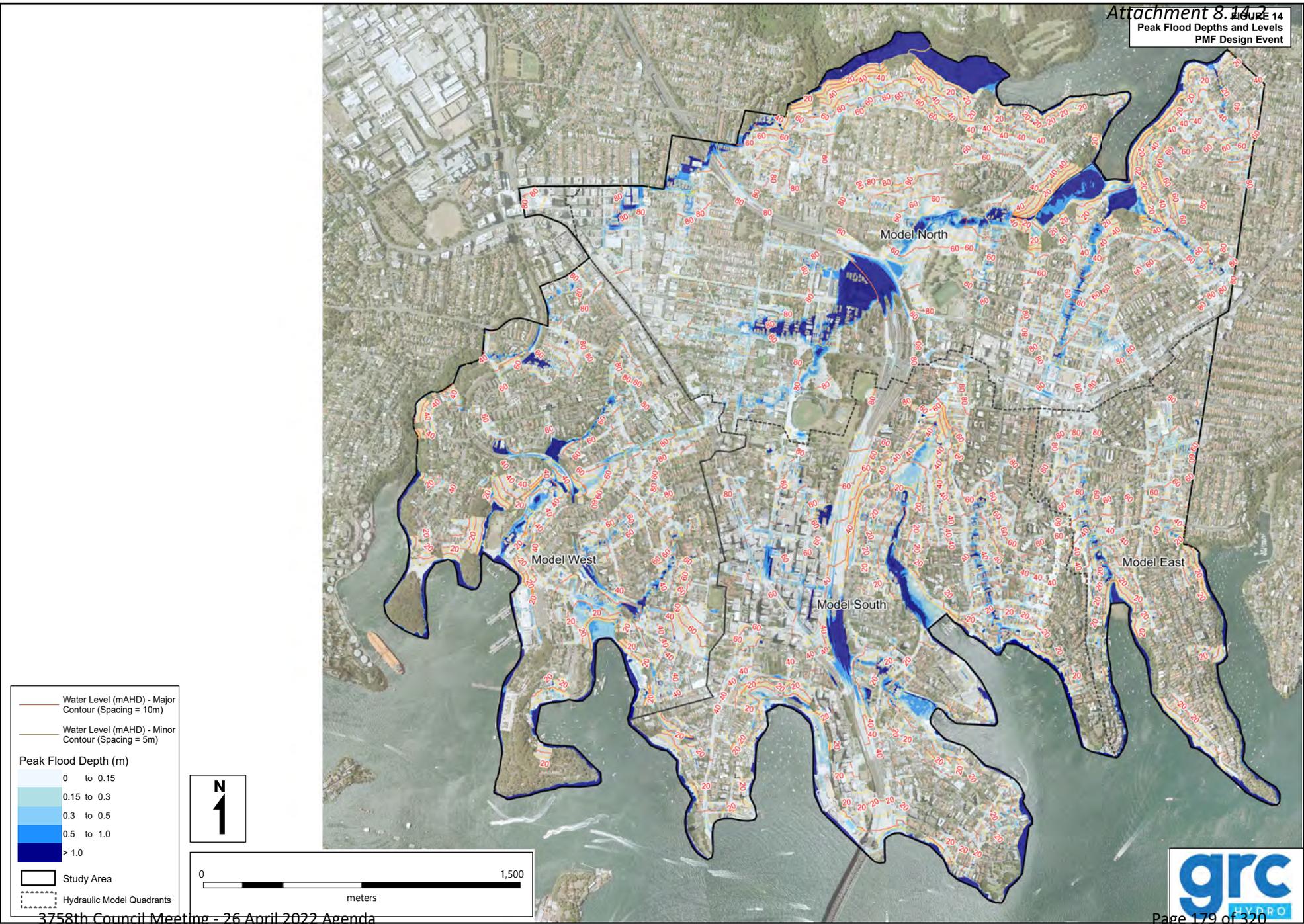
— Water Level (mAHd) - Major Contour (Spacing = 10m)
— Water Level (mAHd) - Minor Contour (Spacing = 5m)

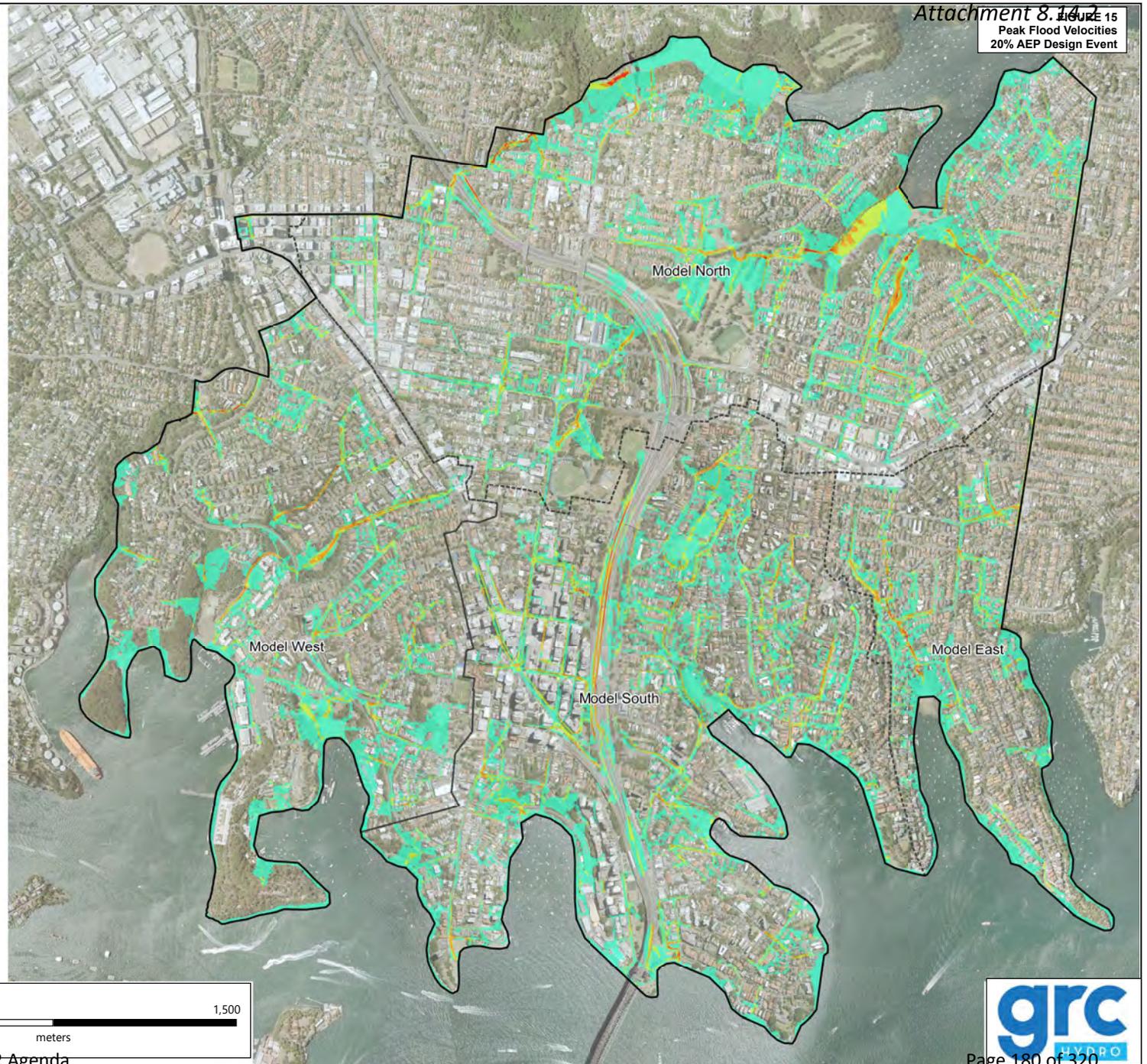
Peak Flood Depth (m)
■ 0 to 0.15
■ 0.15 to 0.3
■ 0.3 to 0.5
■ 0.5 to 1.0
■ > 1.0

Study Area
 Hydraulic Model Quadrants

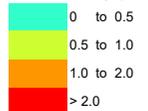






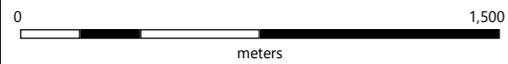


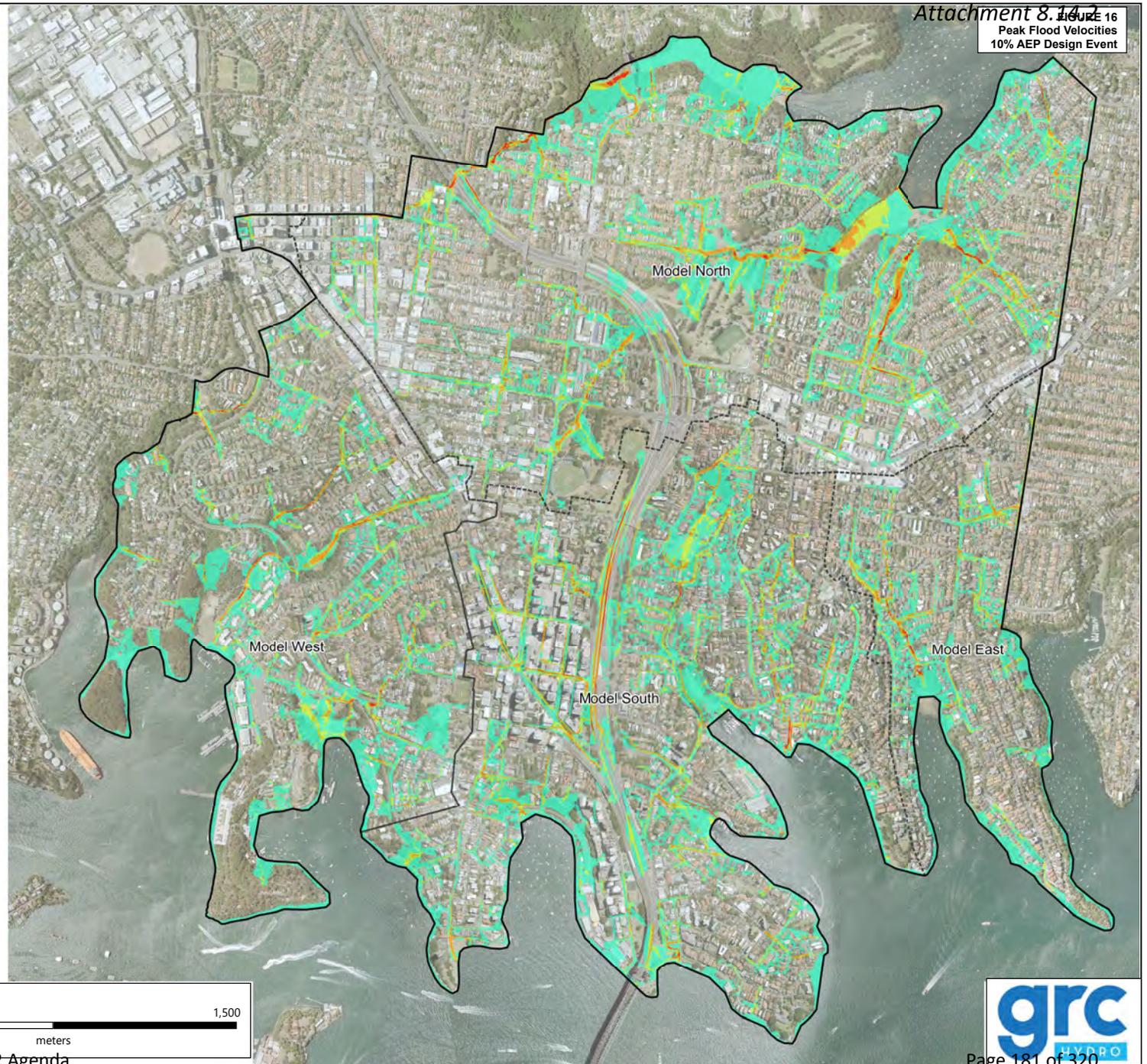
Peak Velocity (m/s)



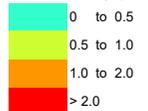
Study Area

Hydraulic Model Quadrants





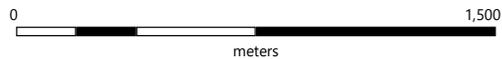
Peak Velocity (m/s)

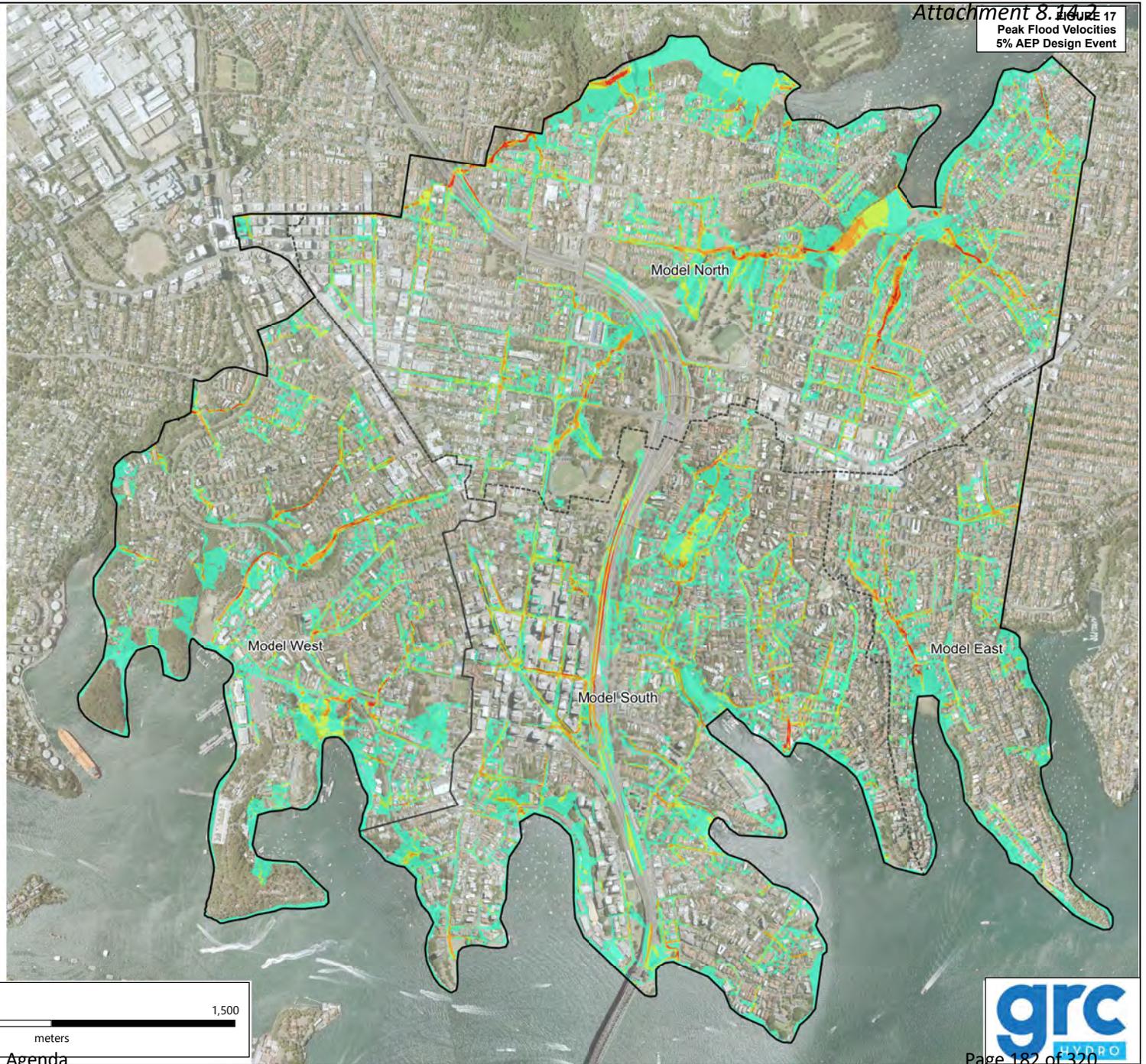


N
1

Study Area

Hydraulic Model Quadrants





Peak Velocity (m/s)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- > 2.0

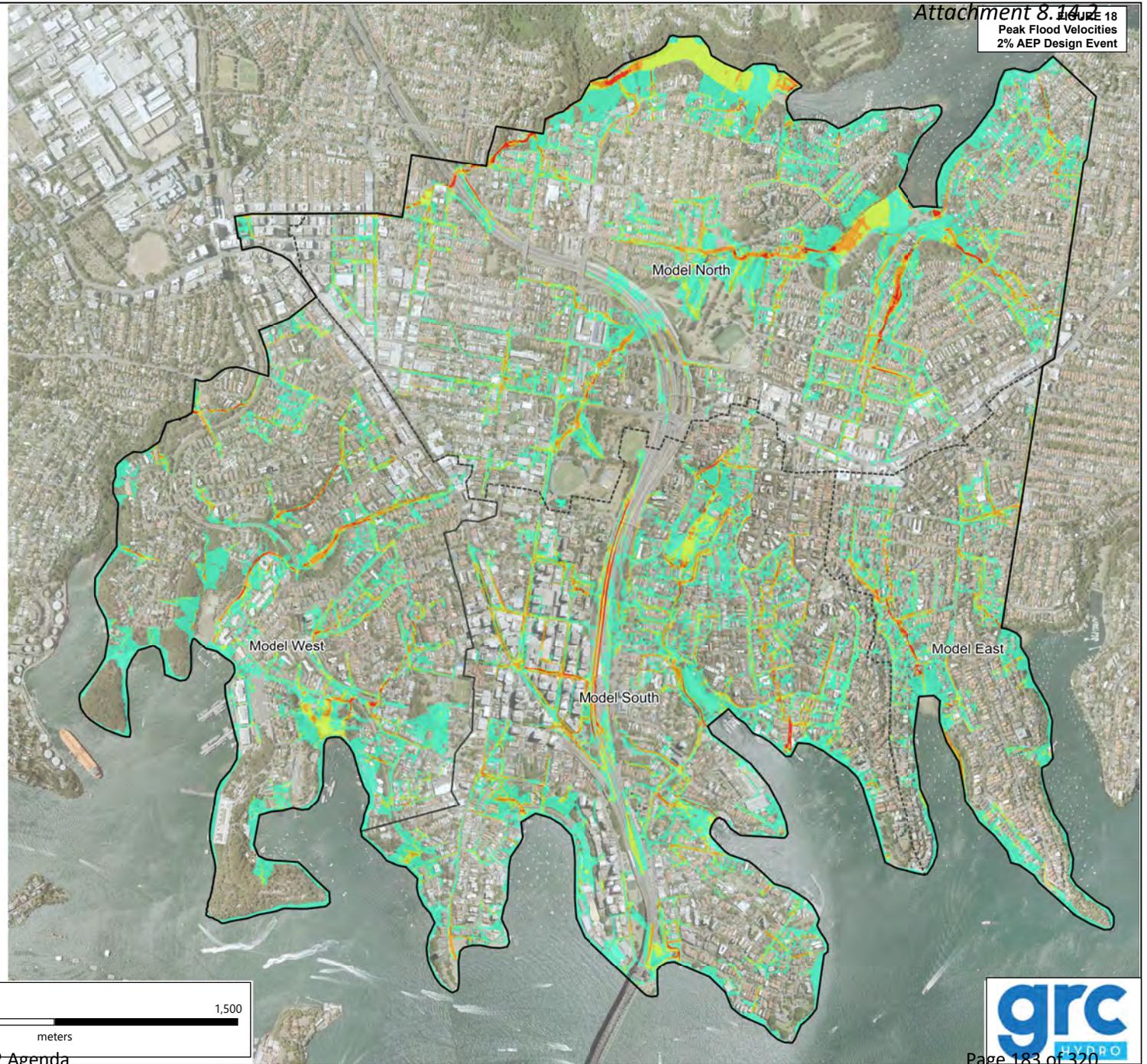
Study Area

Hydraulic Model Quadrants

N
1

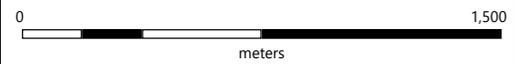
0 1,500
meters

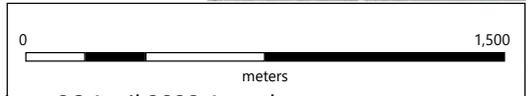
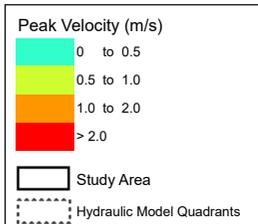
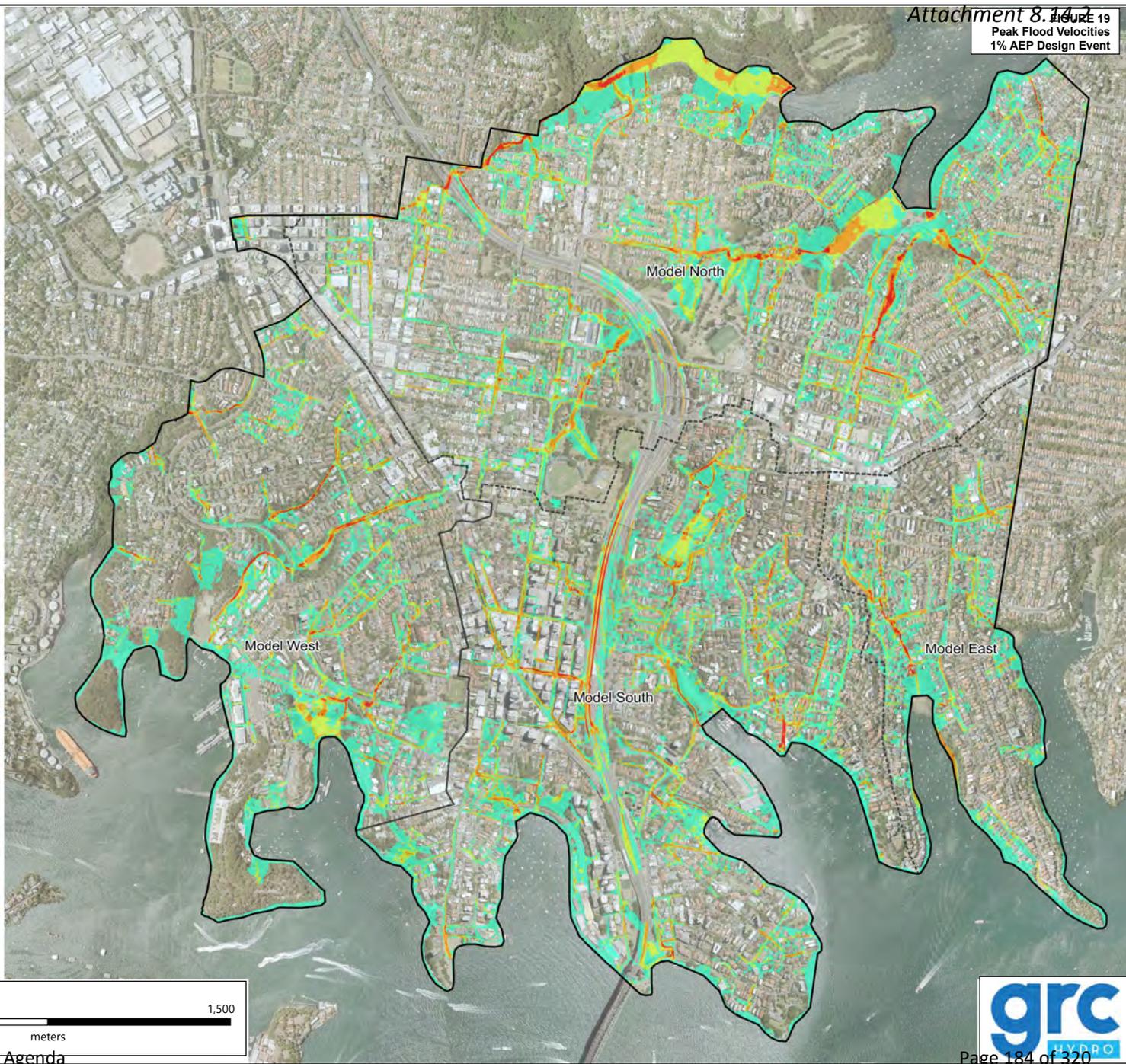


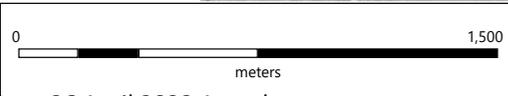
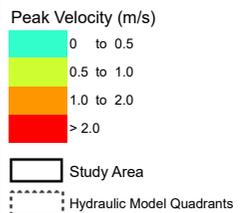
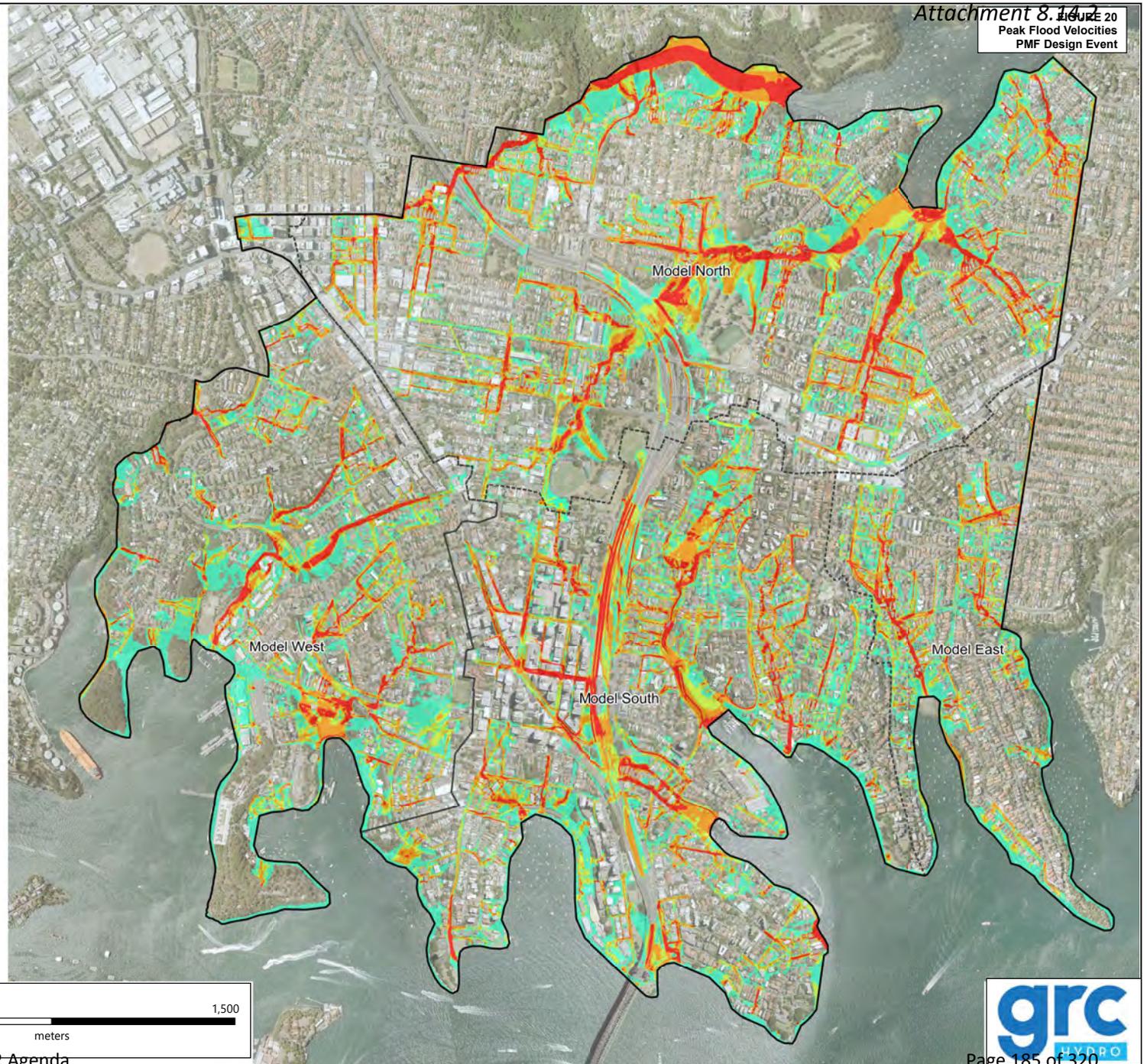


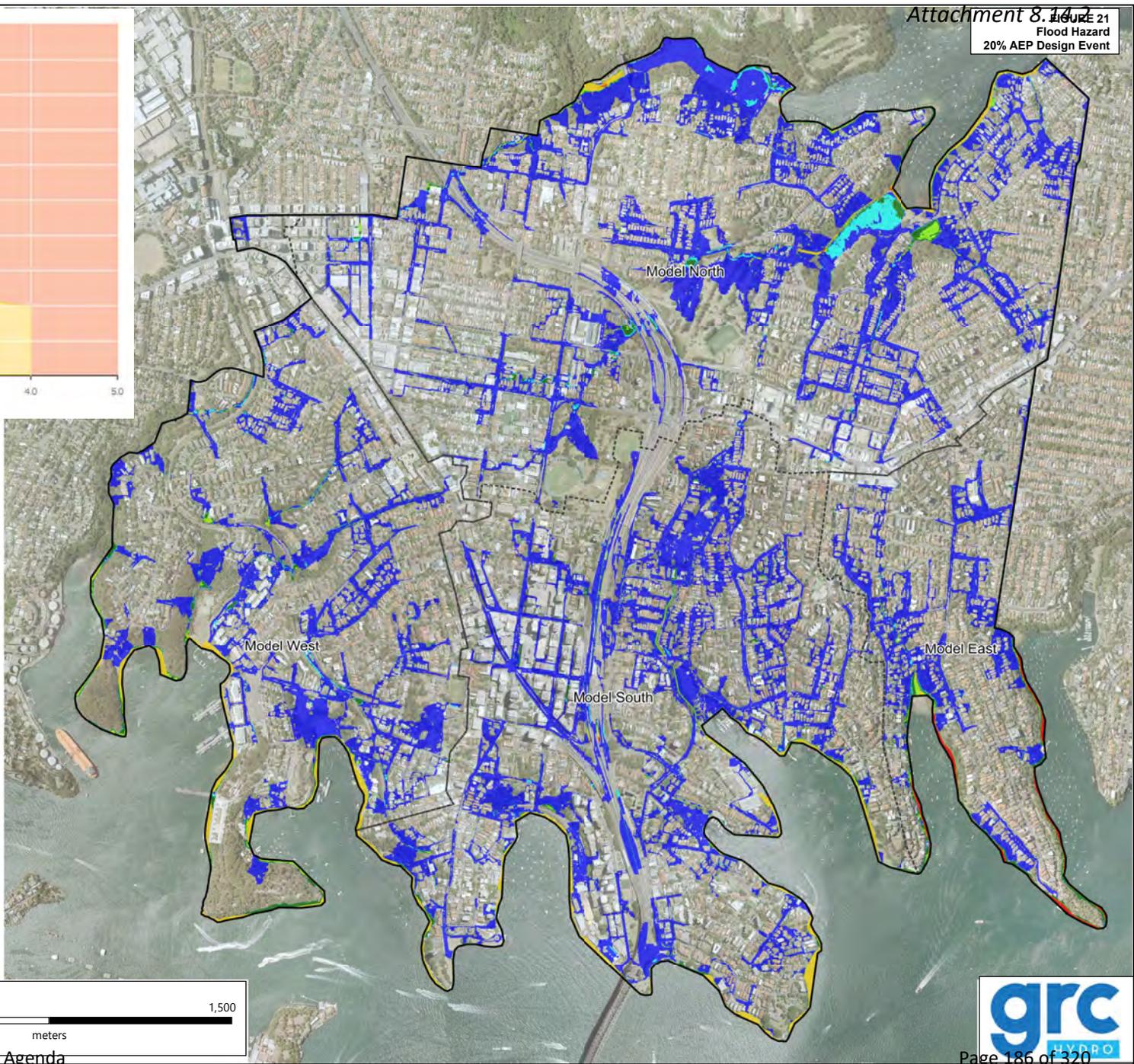
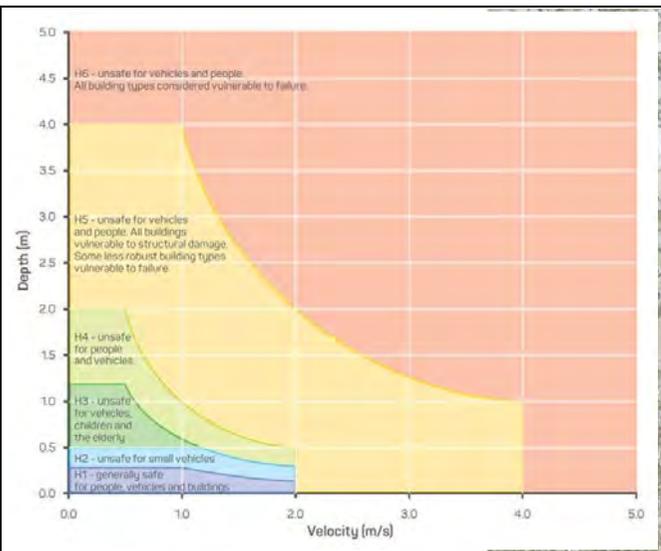
Peak Velocity (m/s)

- 0 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- > 2.0





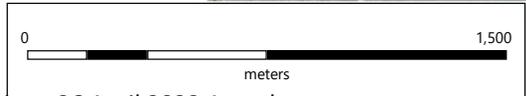


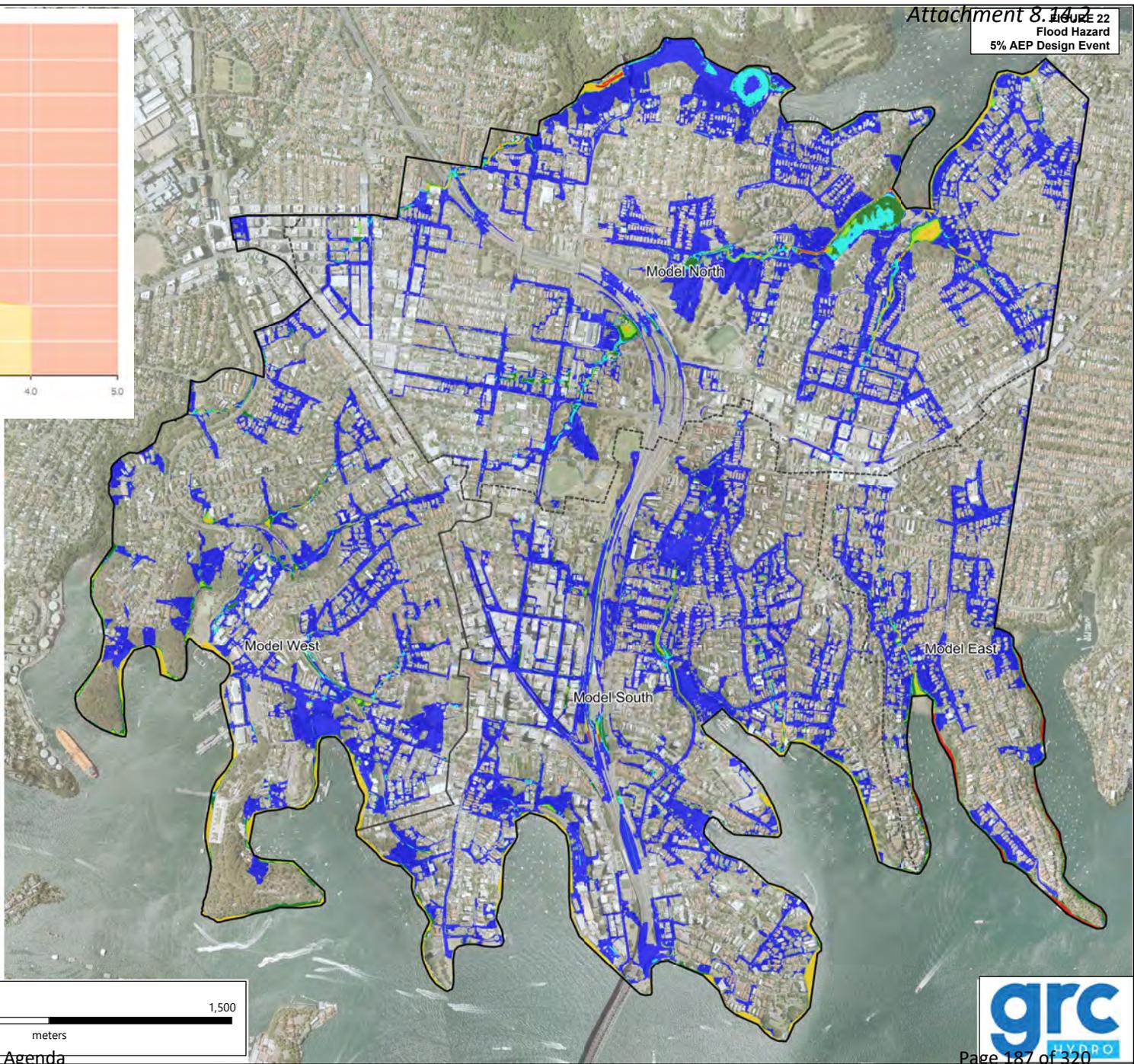
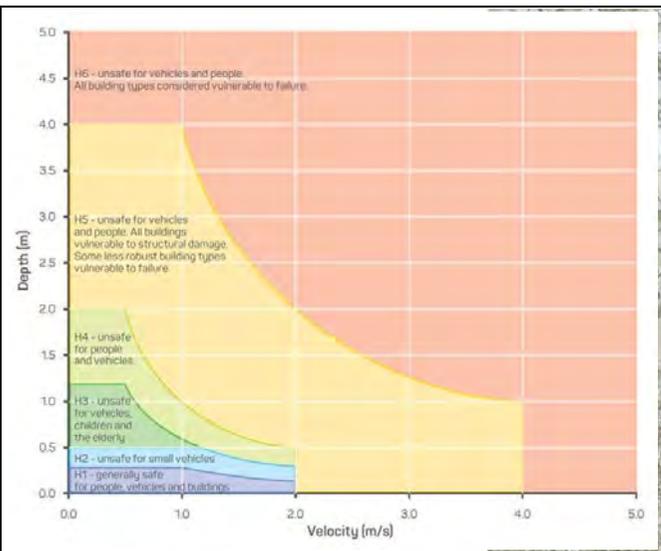


Hazard Classification

- H1
- H2
- H3
- H4
- H5
- H6

Study Area
 Hydraulic Model Quadrants

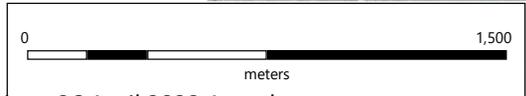


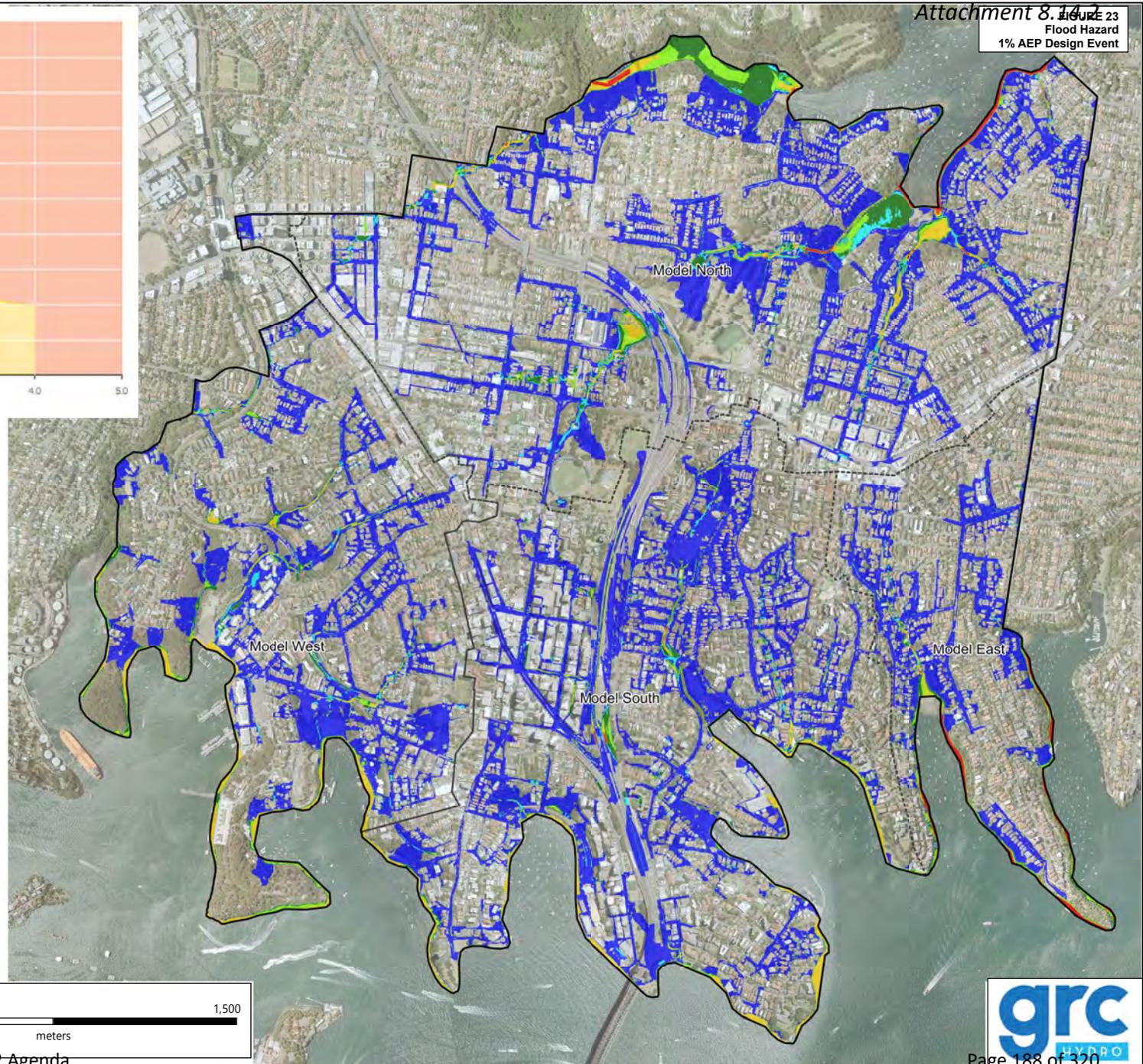
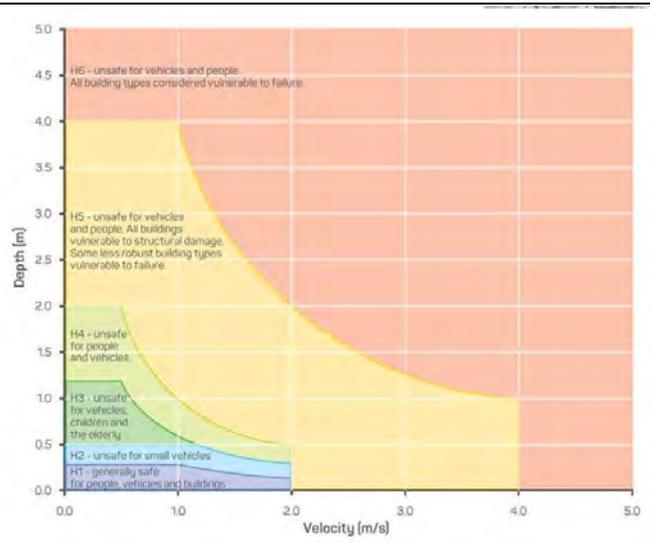


Hazard Classification

- H1
- H2
- H3
- H4
- H5
- H6

Study Area
 Hydraulic Model Quadrants

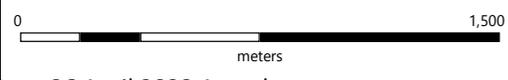


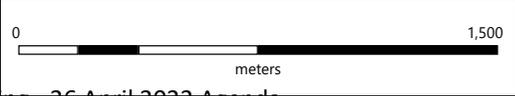
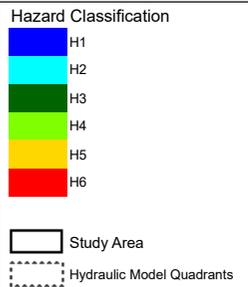
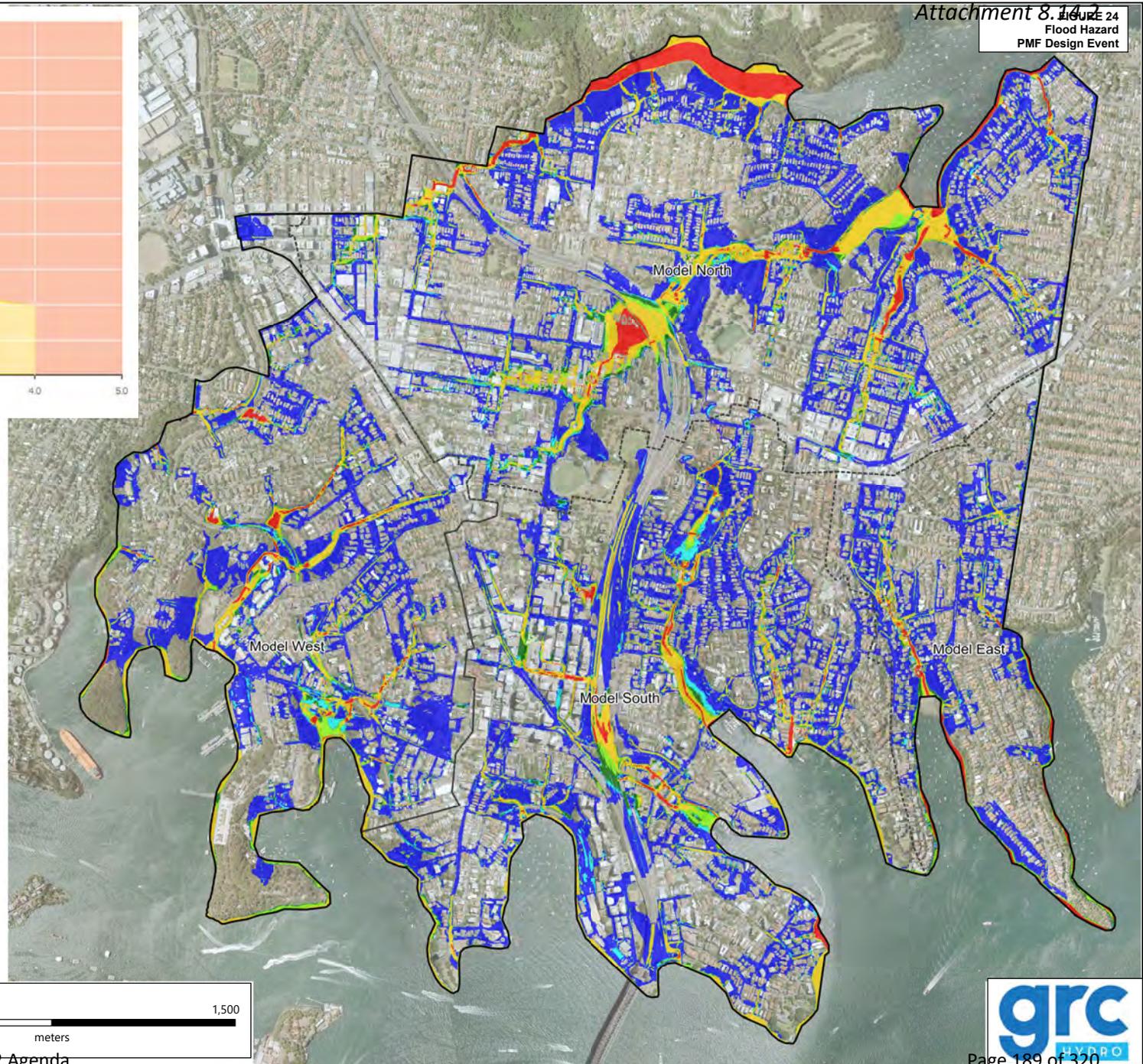
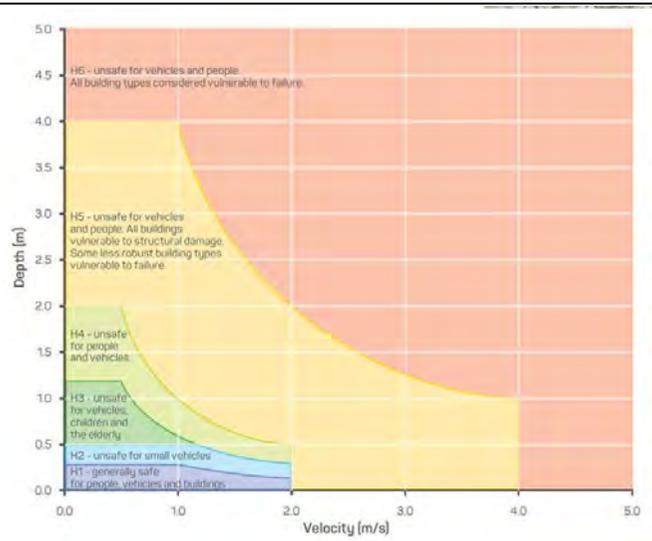


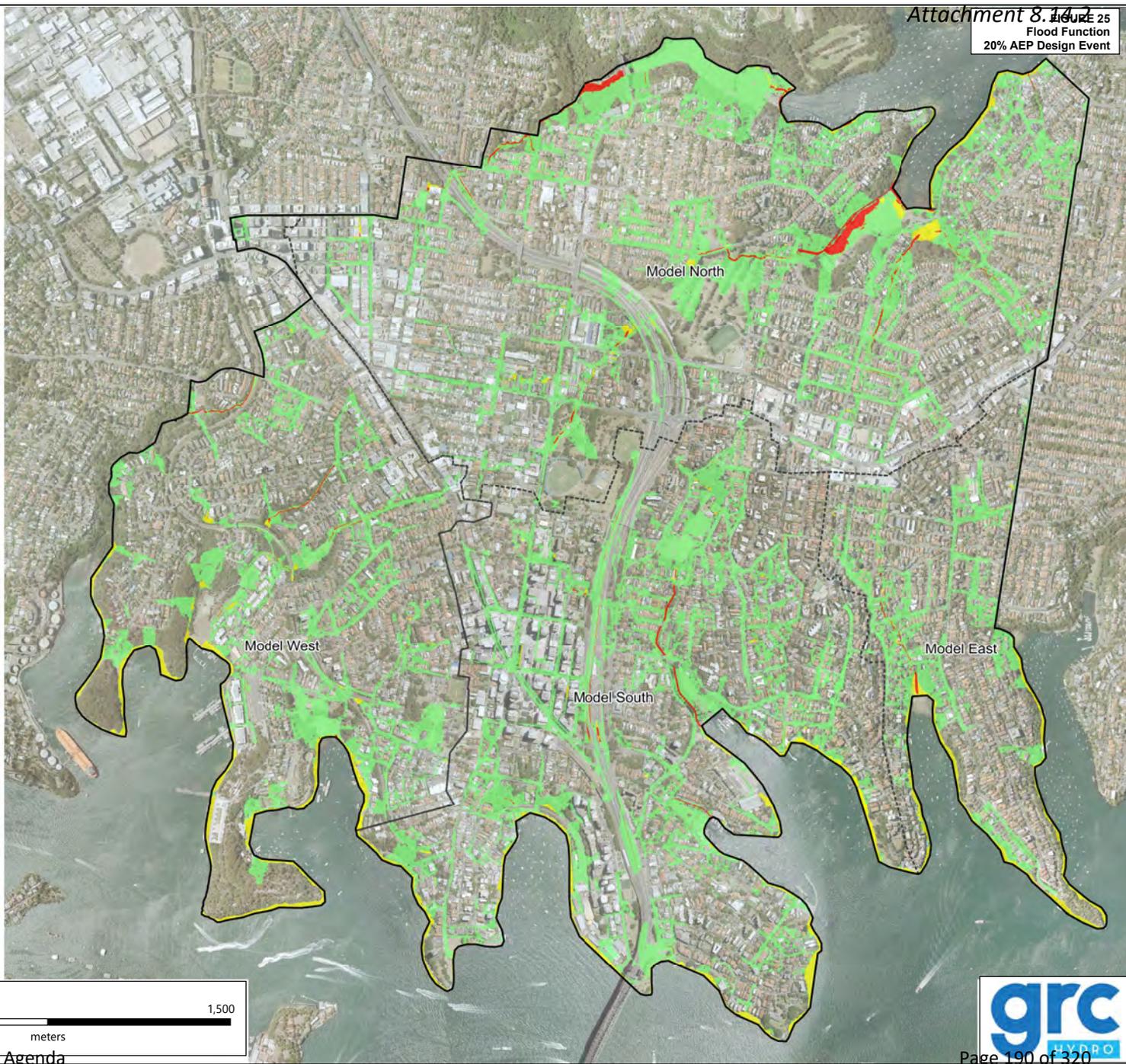
Hazard Classification

- H1
- H2
- H3
- H4
- H5
- H6

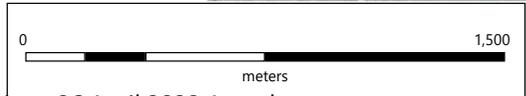
Study Area
 Hydraulic Model Quadrants

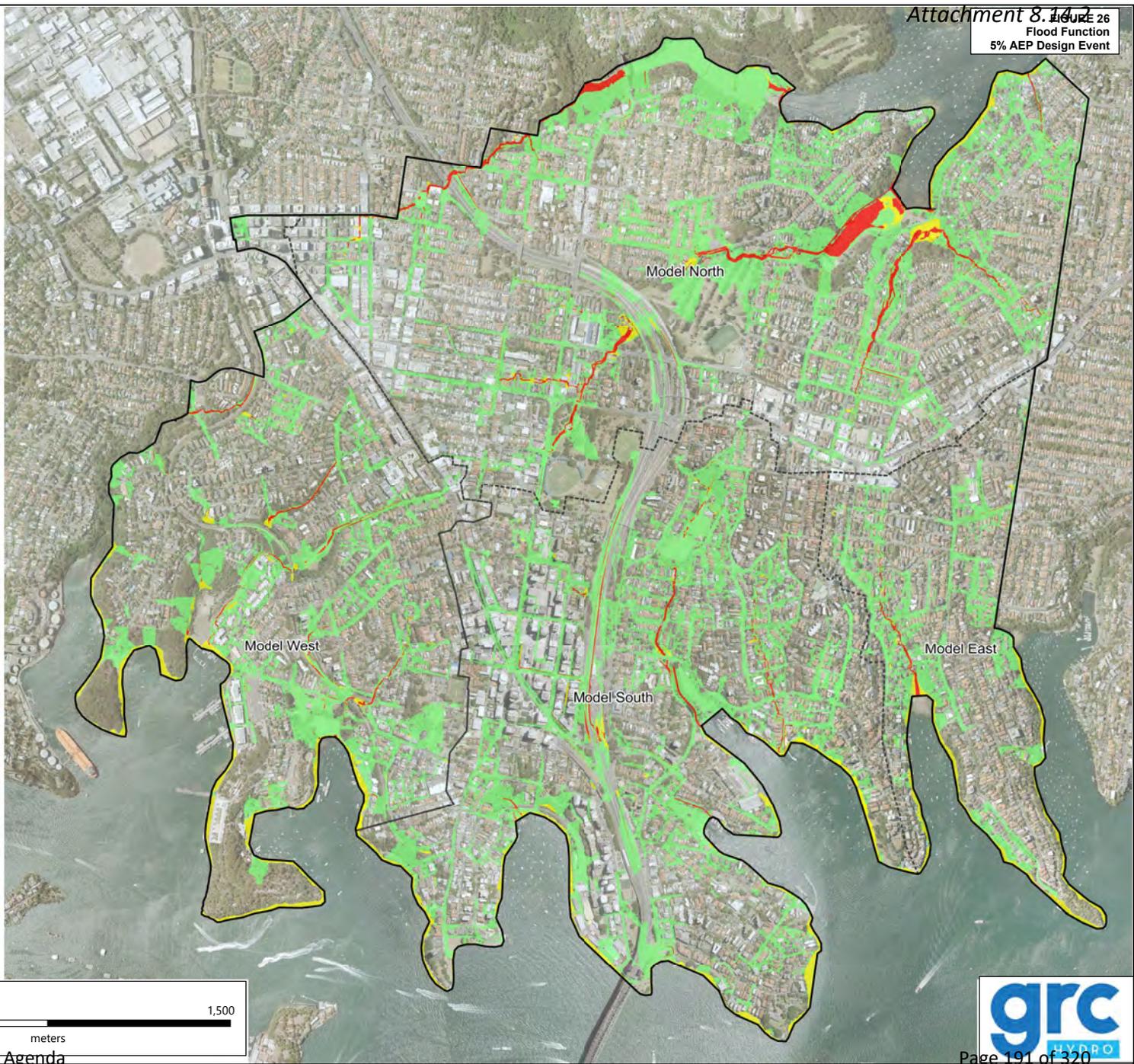






- Flood Function
- Floodway
 - Flood Storage
 - Flood Fringe
- Study Area
- Hydraulic Model Quadrants



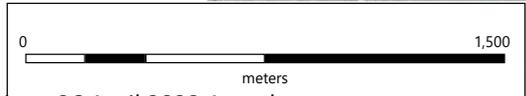


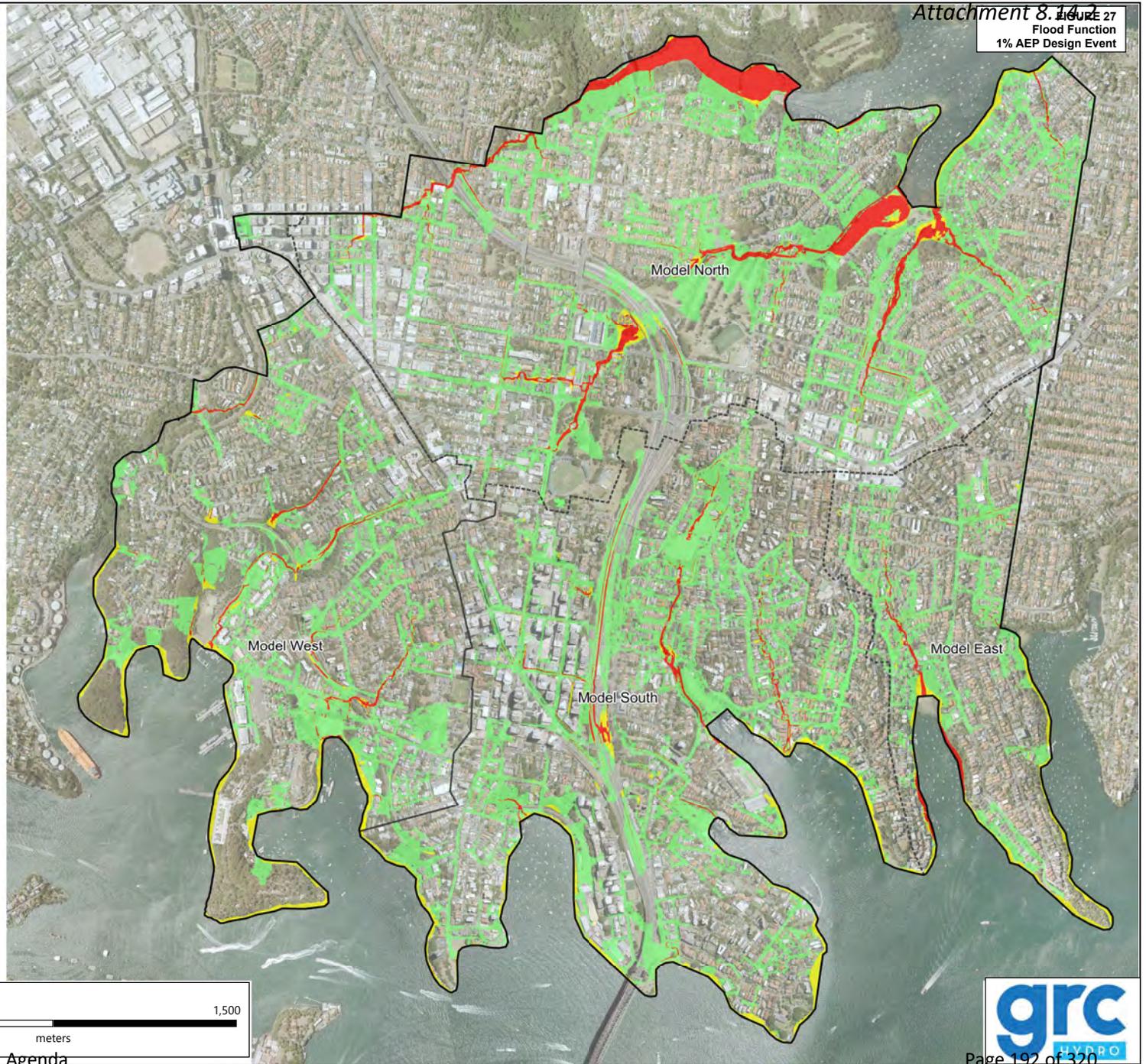
Flood Function

- Floodway
- Flood Storage
- Flood Fringe

Study Area

Hydraulic Model Quadrants



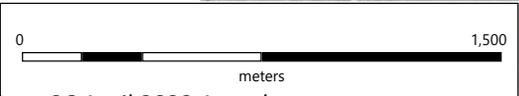


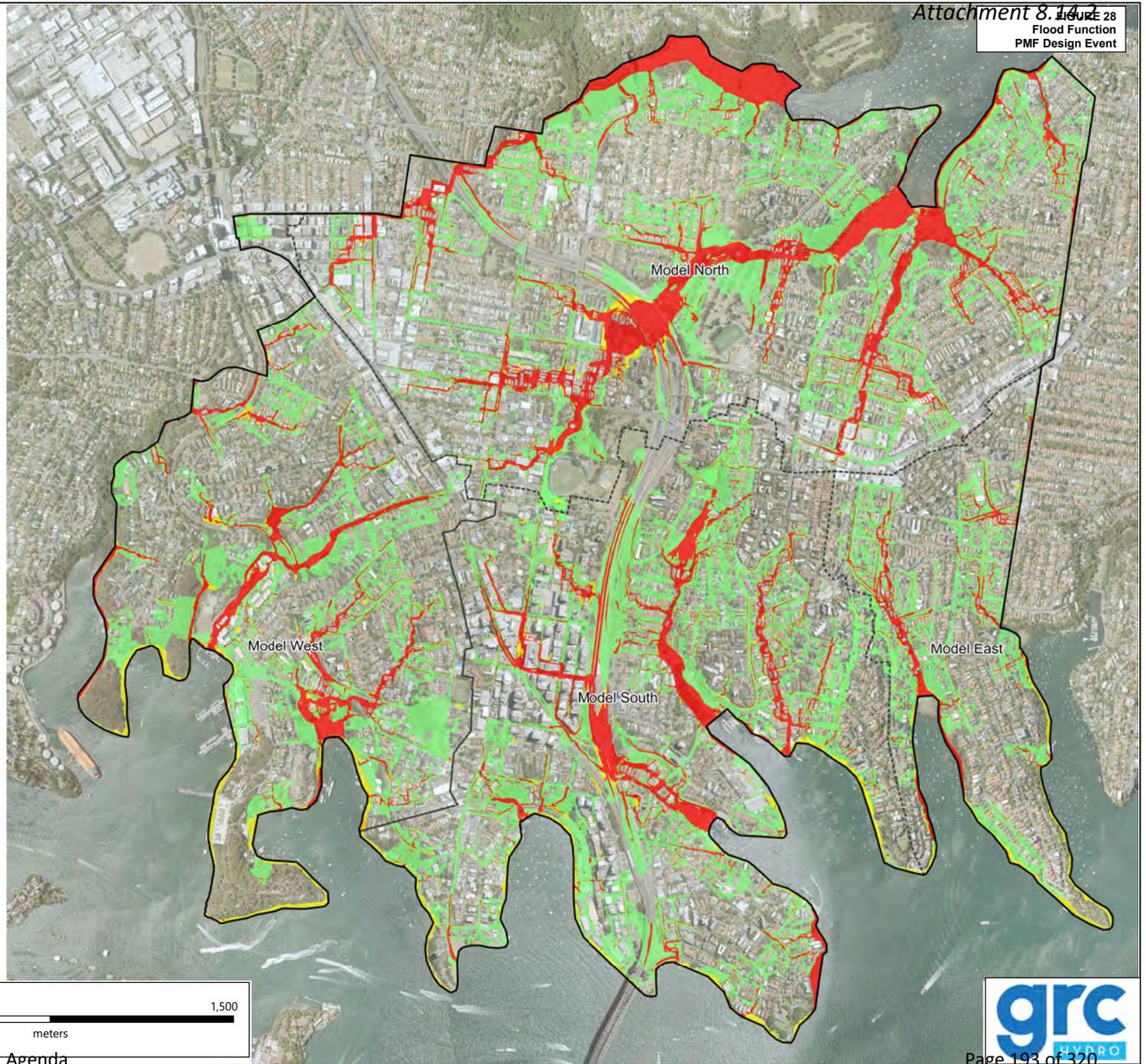
Flood Function

- Floodway
- Flood Storage
- Flood Fringe

Study Area

Hydraulic Model Quadrants



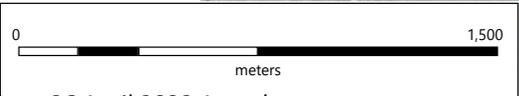


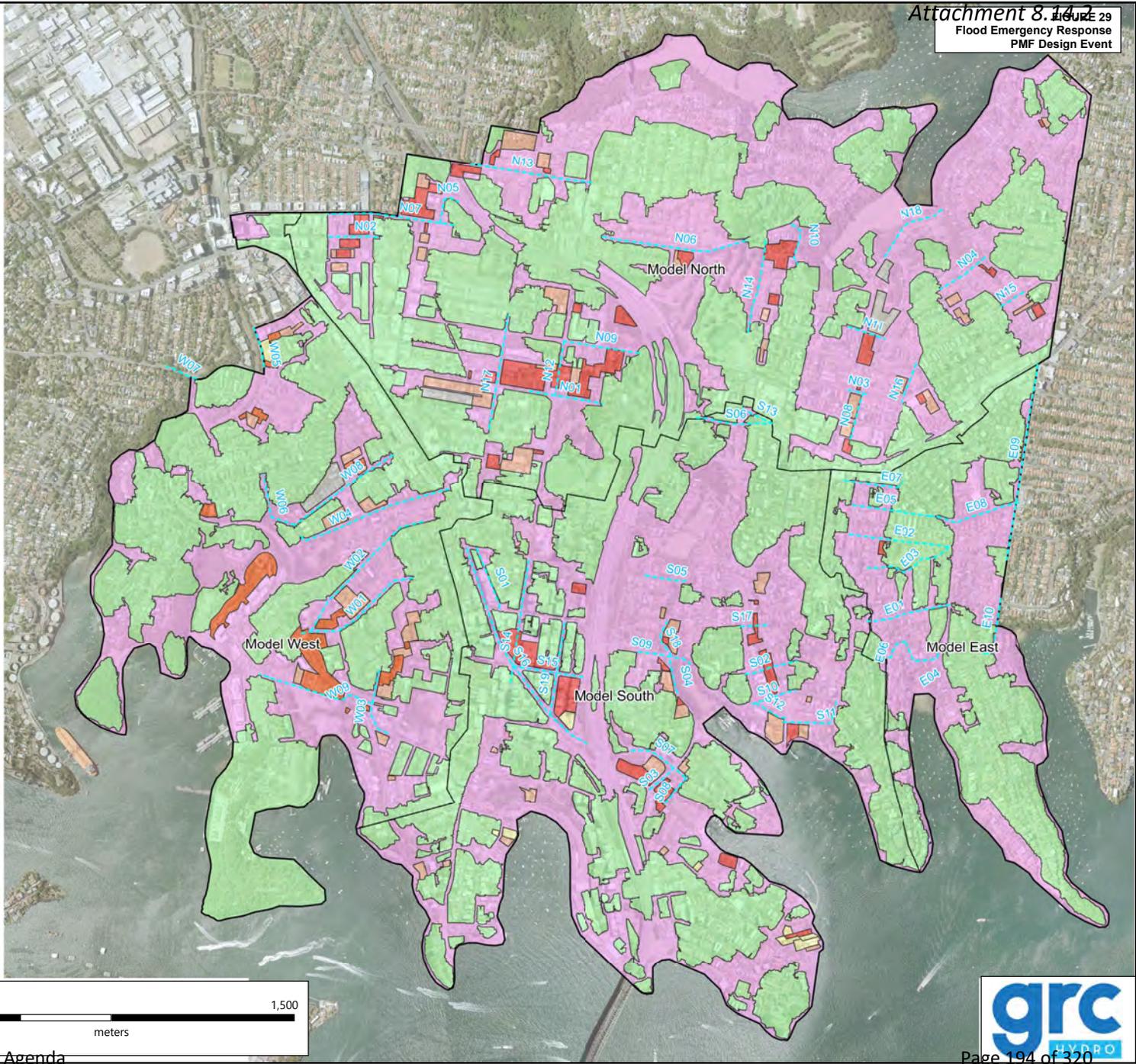
Flood Function

- Floodway
- Flood Storage
- Flood Fringe

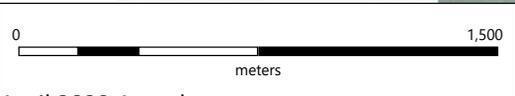
Study Area

Hydraulic Model Quadrants





- Flood Emergency Response Classifications**
- Flood Free
 - Indirect Consequence (NIC)
 - Rising Road (FER)
 - Elevated (FIE)
 - Overland Escape (FEO)
 - Submerged (FIS)
- Key Routes
- ▭ Study Area
- ▭ Hydraulic Model Quadrants



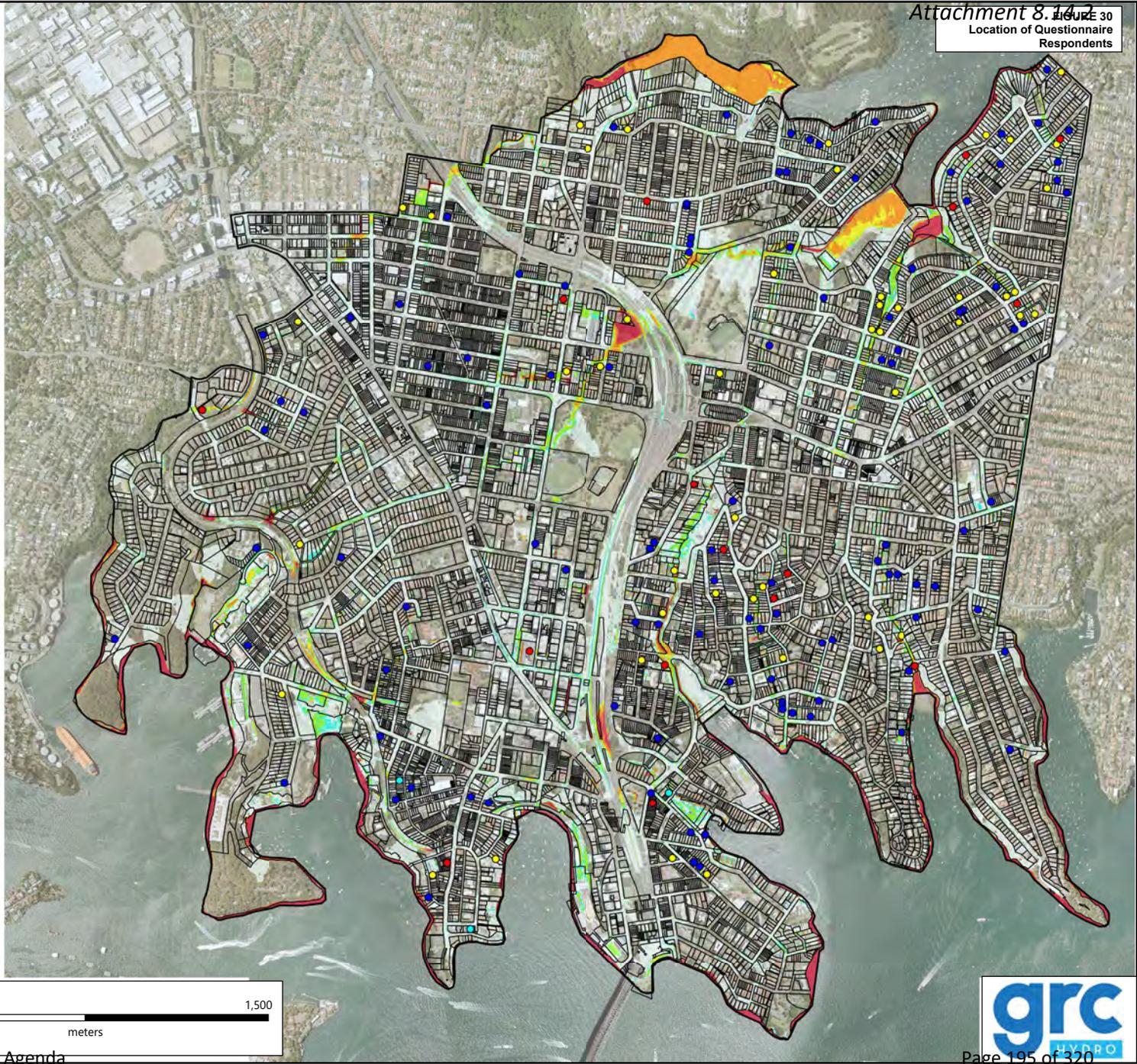
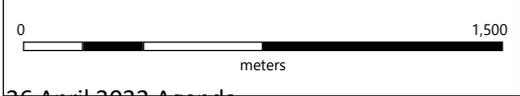
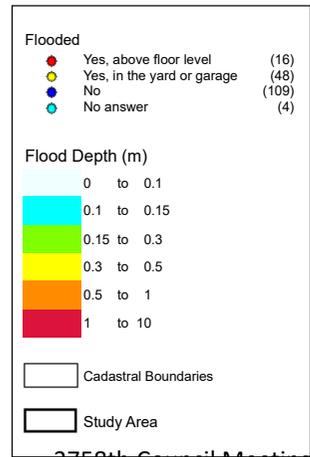




Figure 31 - B
Draft Flood Planning Area



Figure 31 - C
Draft Flood Planning Area



Figure 31 - D
Draft Flood Planning Area



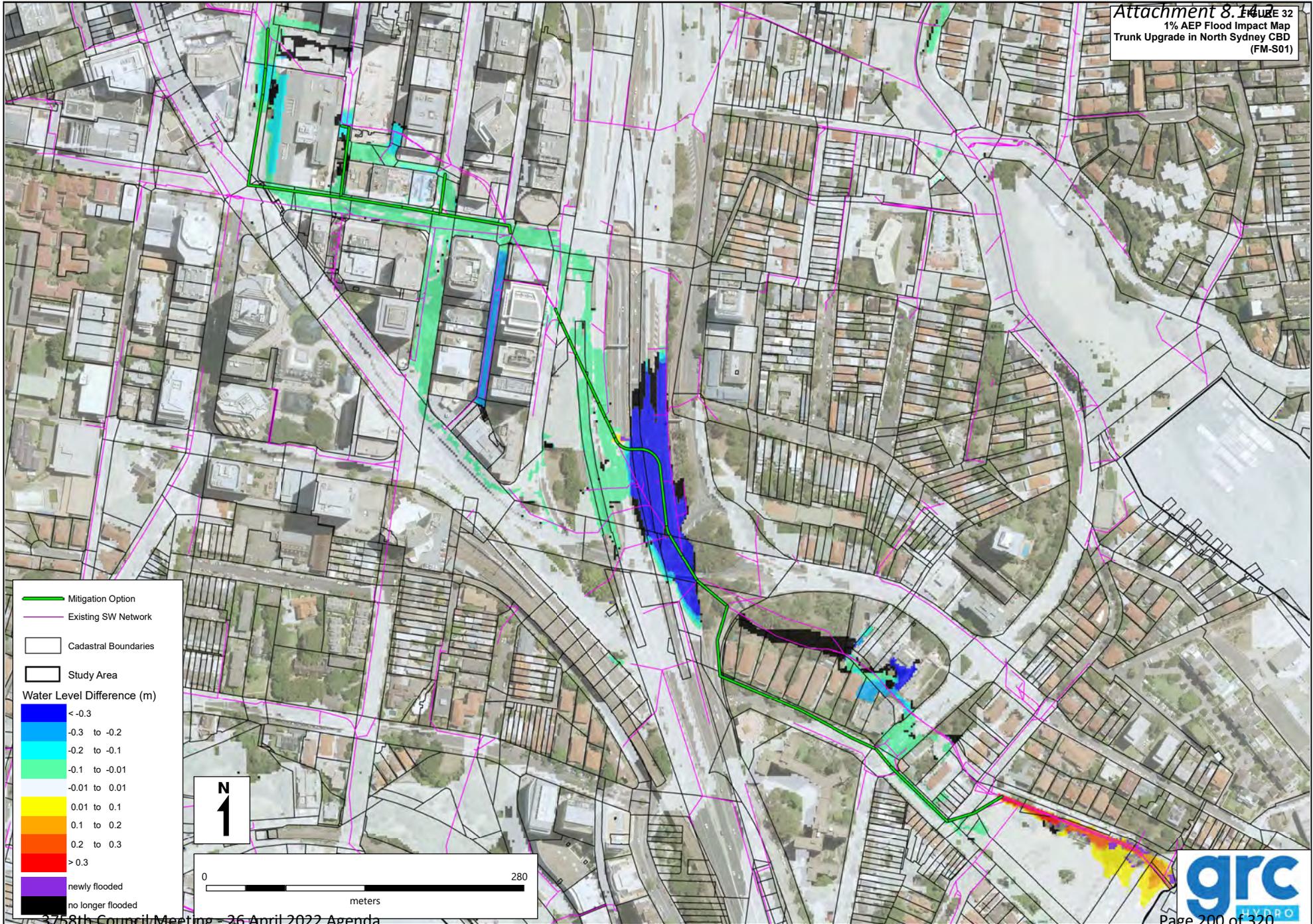


FIGURE 33
1% AEP Flood Impact Map
Bund at Warringa Park
(FM-S02)

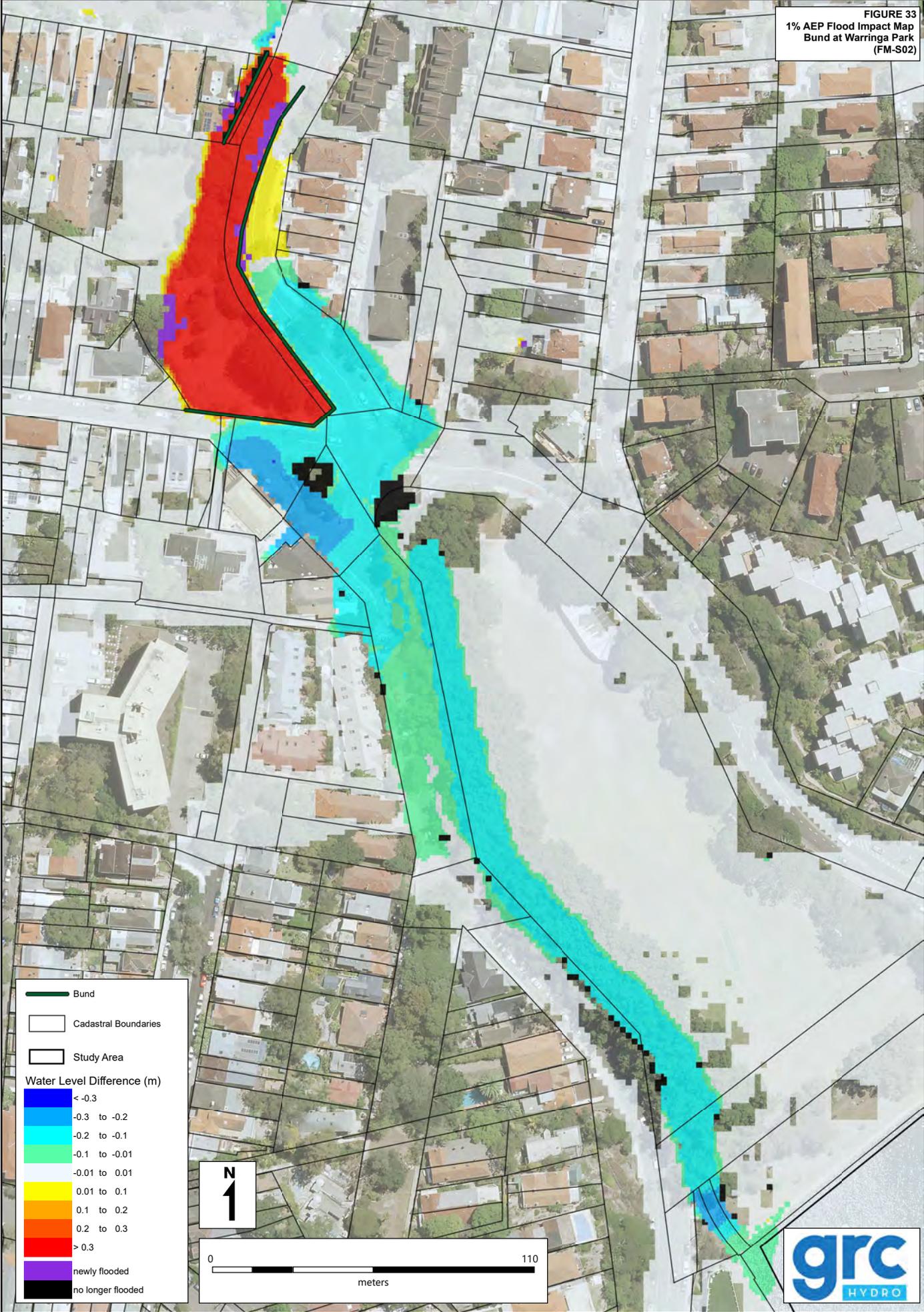


FIGURE 34
1% AEP Flood Impact Map
Upgrade Kurraba Road Culvert
(FM-S03)

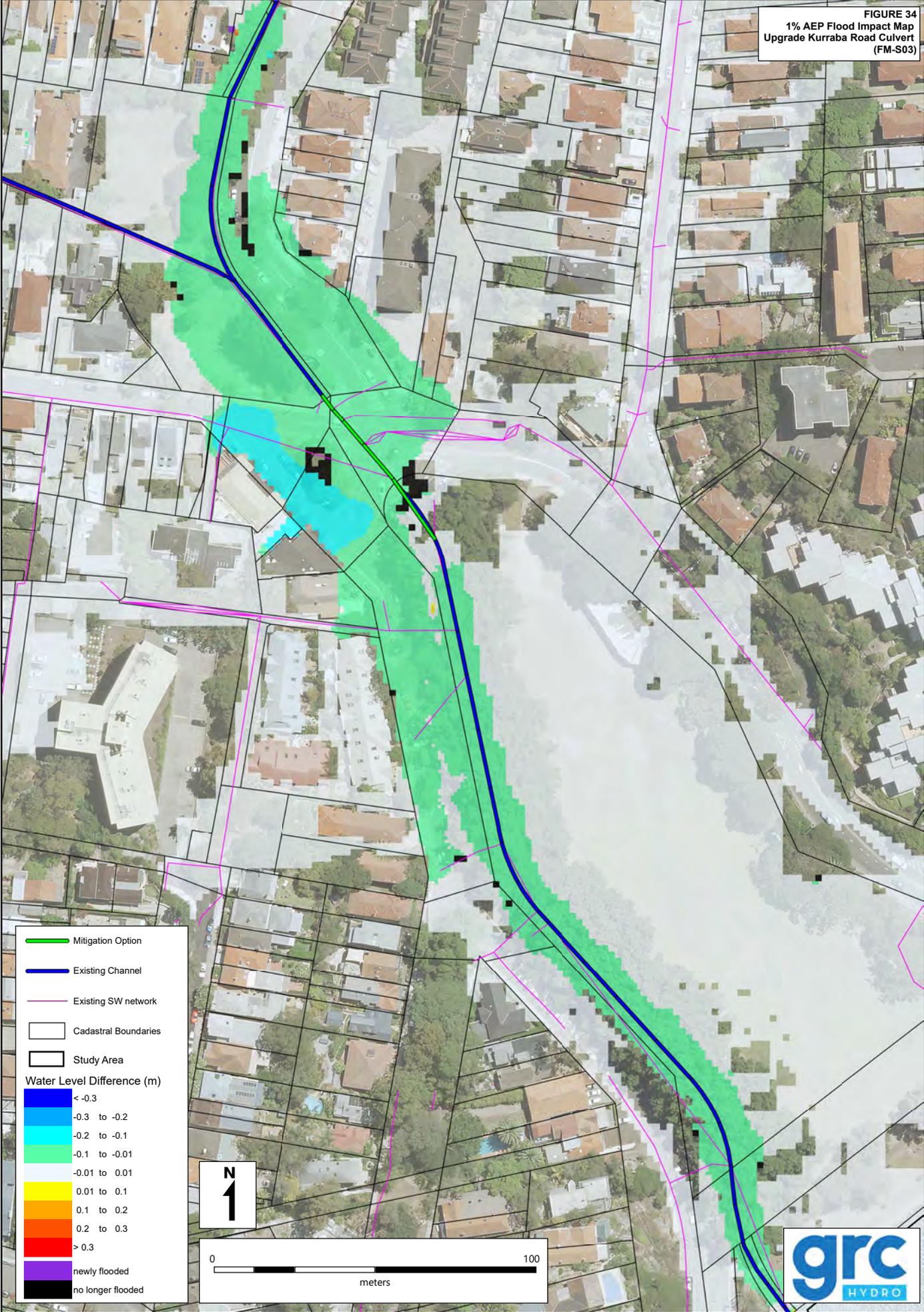


FIGURE 35
1% AEP Flood Impact Map
Bund at Forsyth Park
(FM-S04)

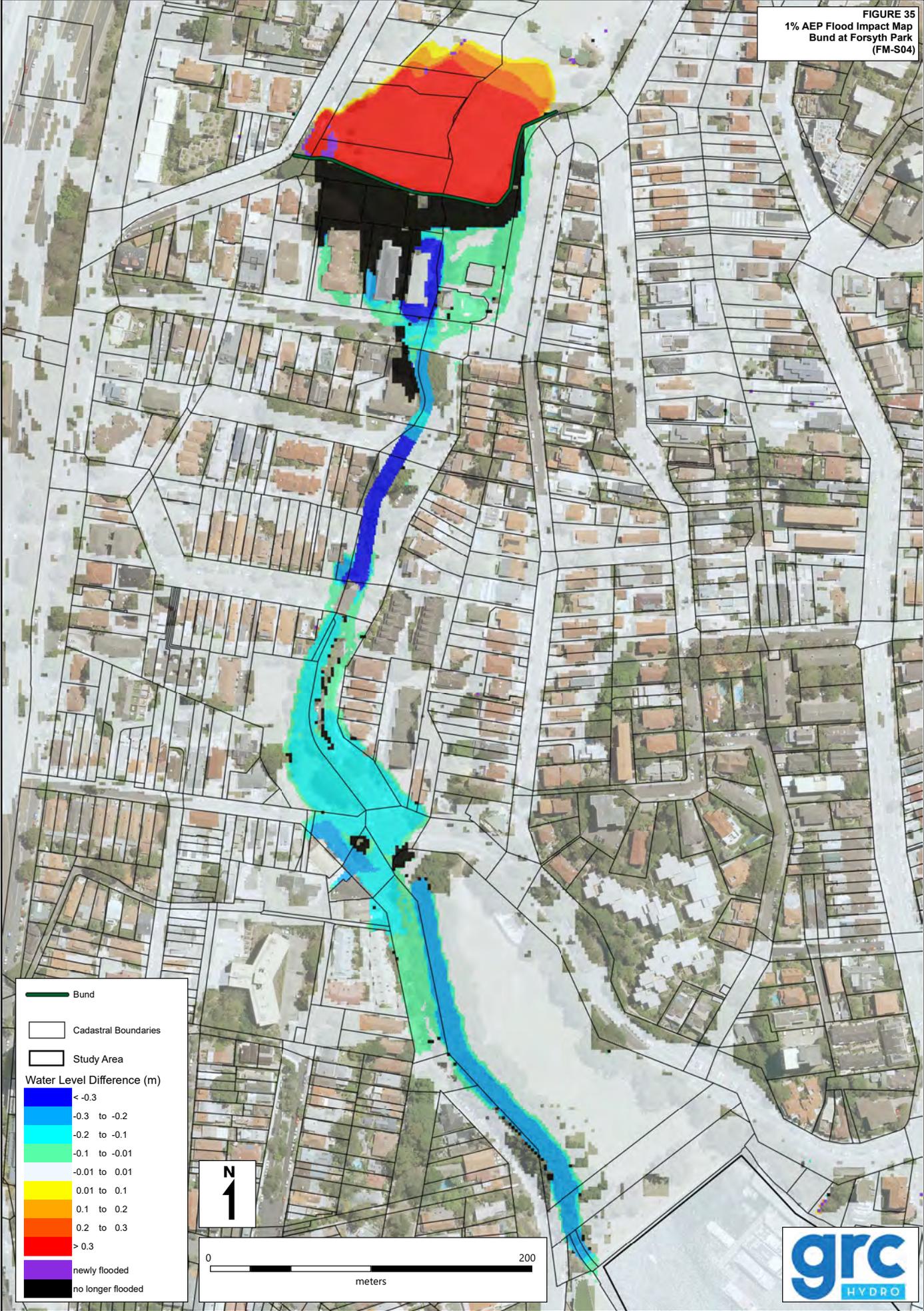


FIGURE 36
1% AEP Flood Impact Map
Trunk upgrade from Lindsay St to Kurraba Rd
(FM-S05)

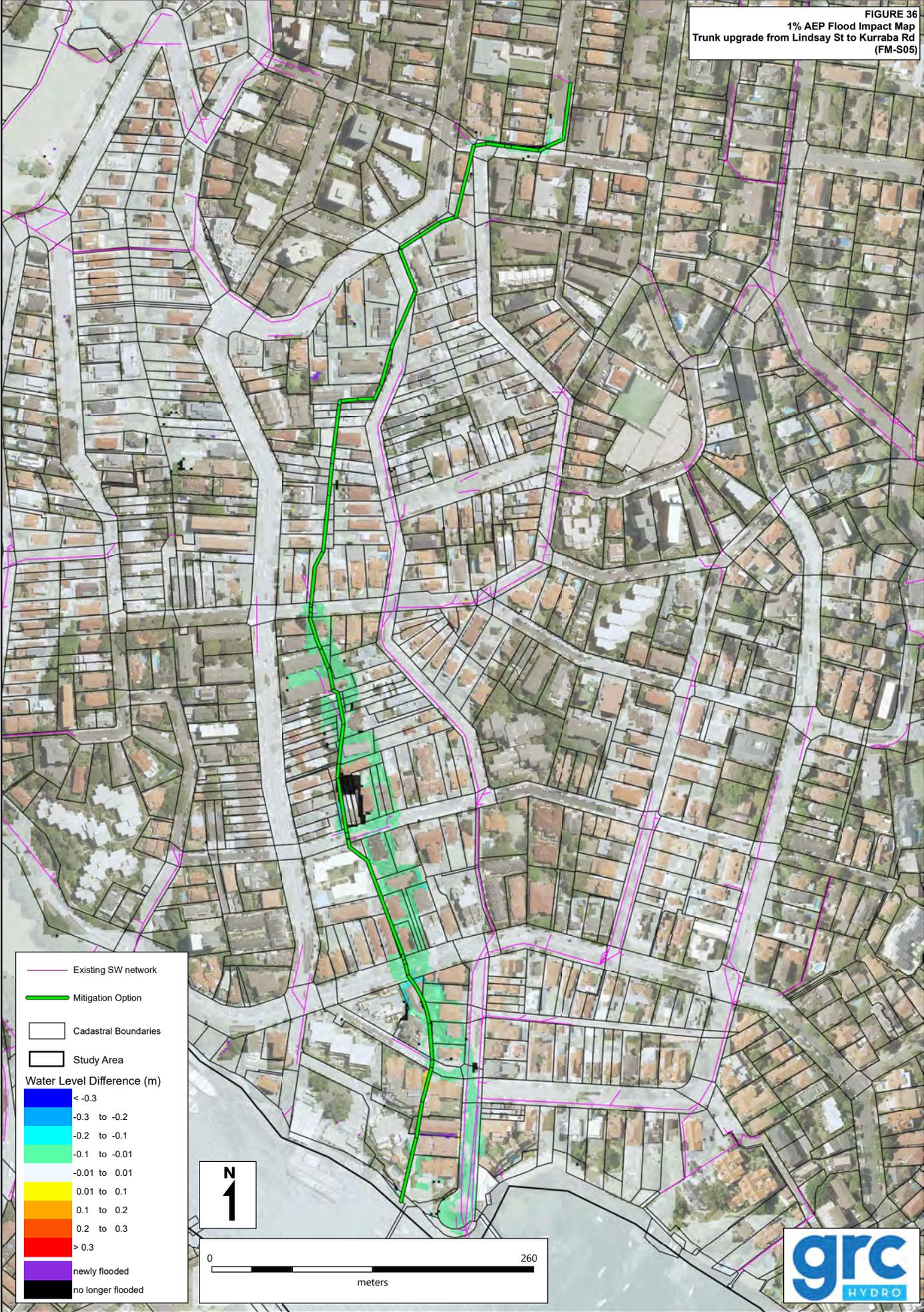
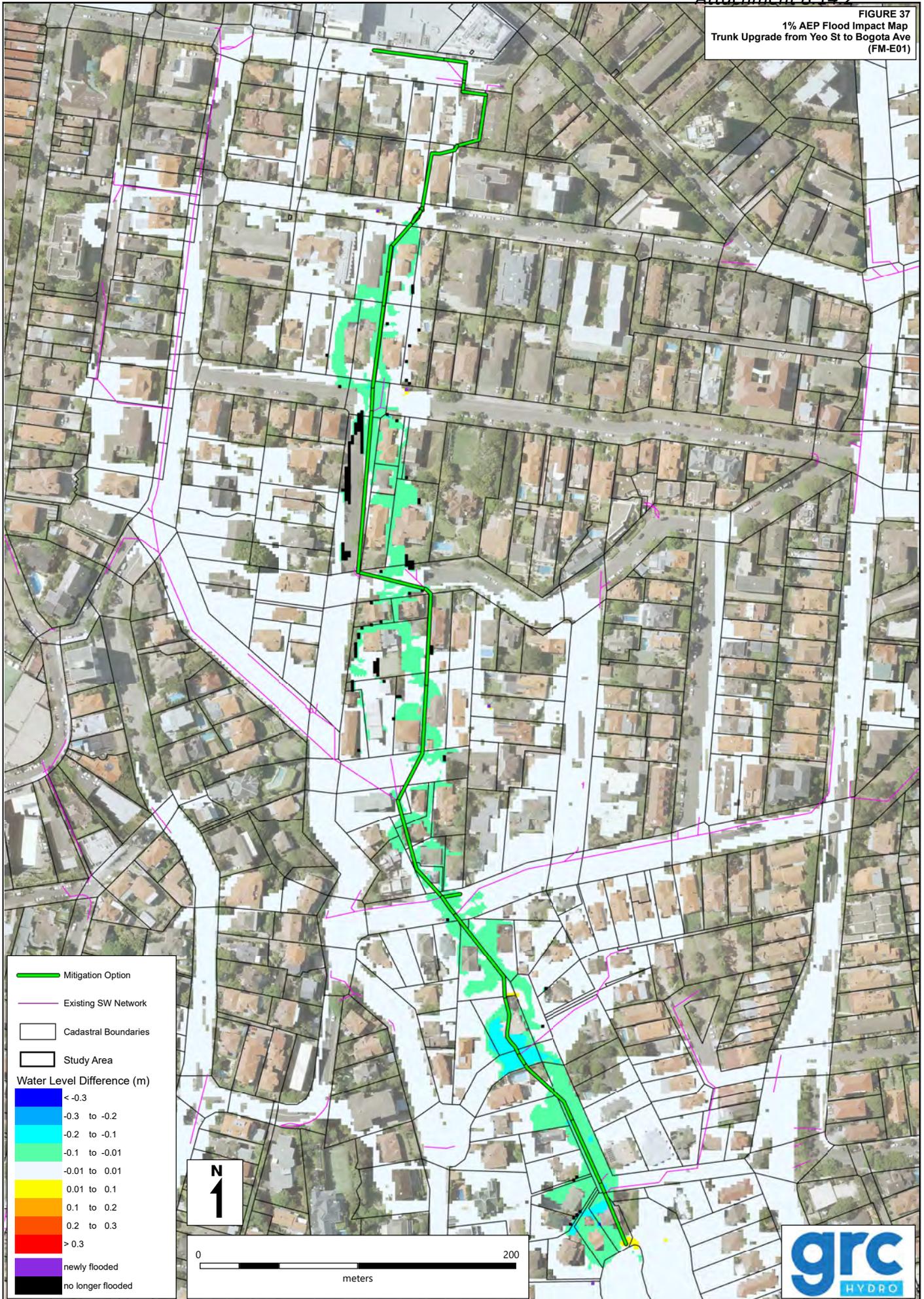


FIGURE 37
1% AEP Flood Impact Map
Trunk Upgrade from Yeo St to Bogota Ave
(FM-E01)

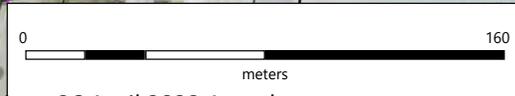


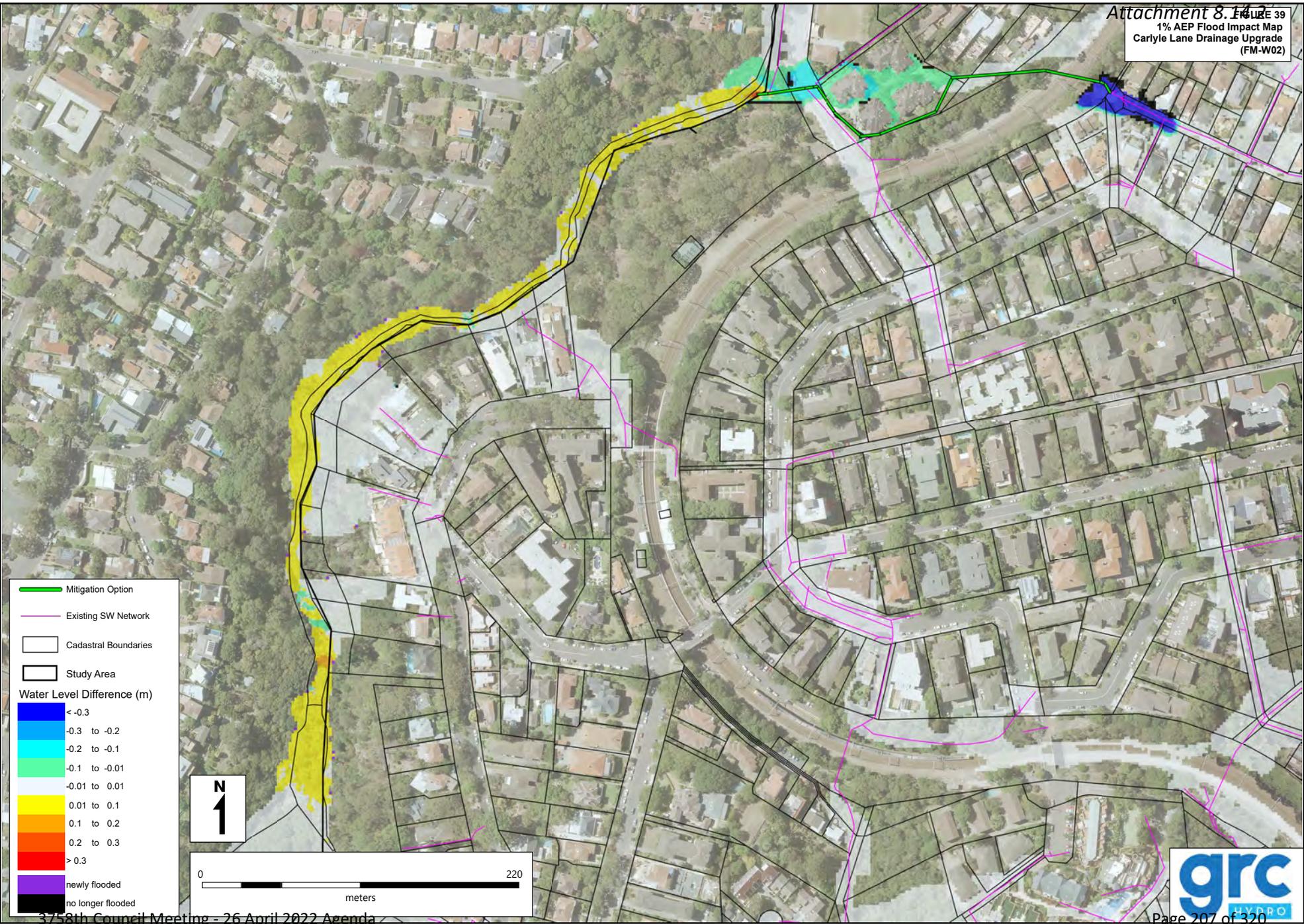


— Mitigation Option
— Existing SW Network
 Cadastral Boundaries
 Study Area

Water Level Difference (m)

■	< -0.3
■	-0.3 to -0.2
■	-0.2 to -0.1
■	-0.1 to -0.01
■	-0.01 to 0.01
■	0.01 to 0.1
■	0.1 to 0.2
■	0.2 to 0.3
■	> 0.3
■	newly flooded
■	no longer flooded

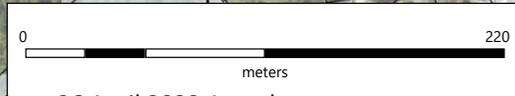




— Mitigation Option
— Existing SW Network
 Cadastral Boundaries
 Study Area

Water Level Difference (m)

■	< -0.3
■	-0.3 to -0.2
■	-0.2 to -0.1
■	-0.1 to -0.01
■	0.01 to 0.1
■	0.1 to 0.2
■	0.2 to 0.3
■	> 0.3
■	newly flooded
■	no longer flooded



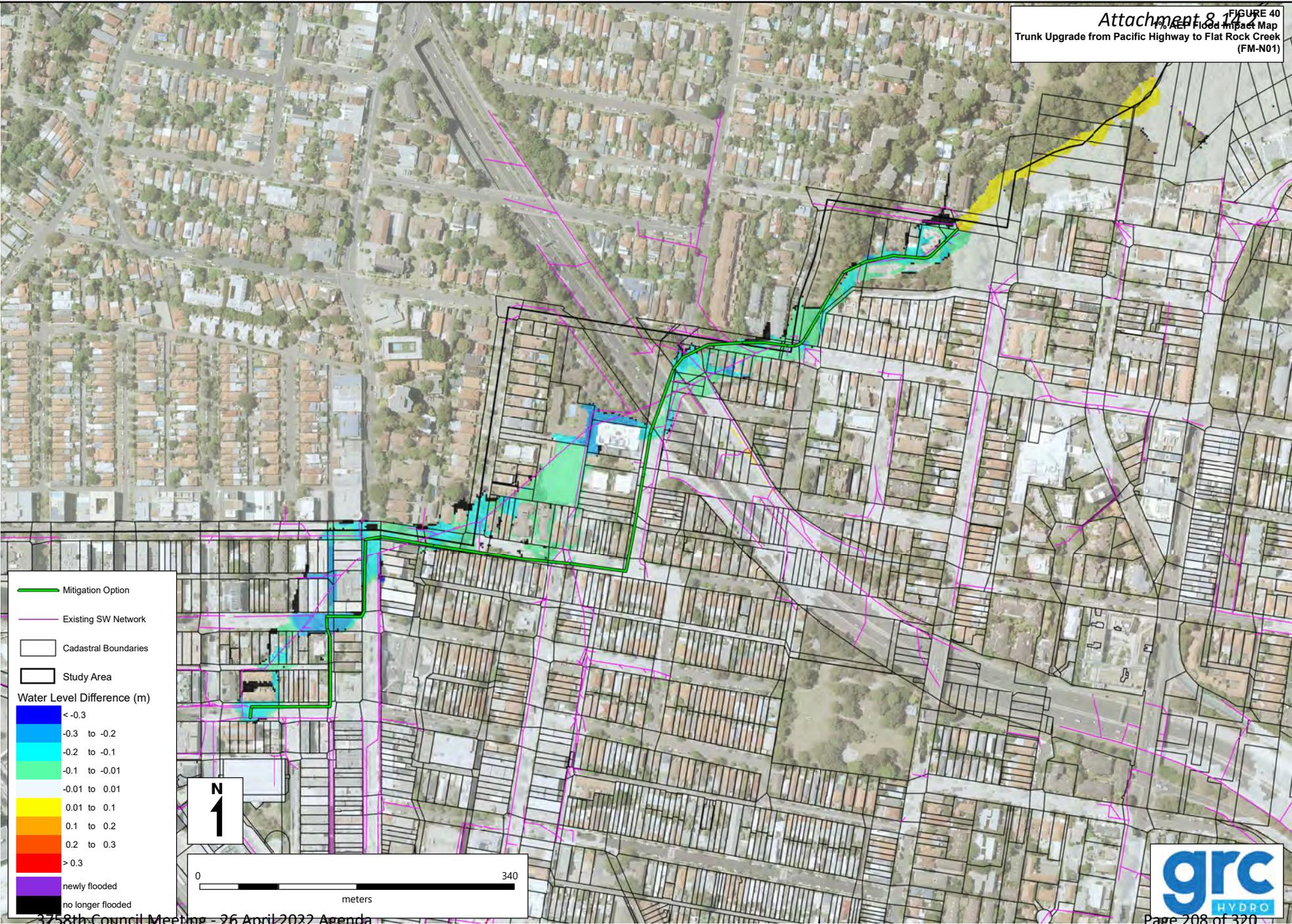


FIGURE 41
1% AEP Flood Impact Map
Bund at St Leonards Park
(FM-N02)

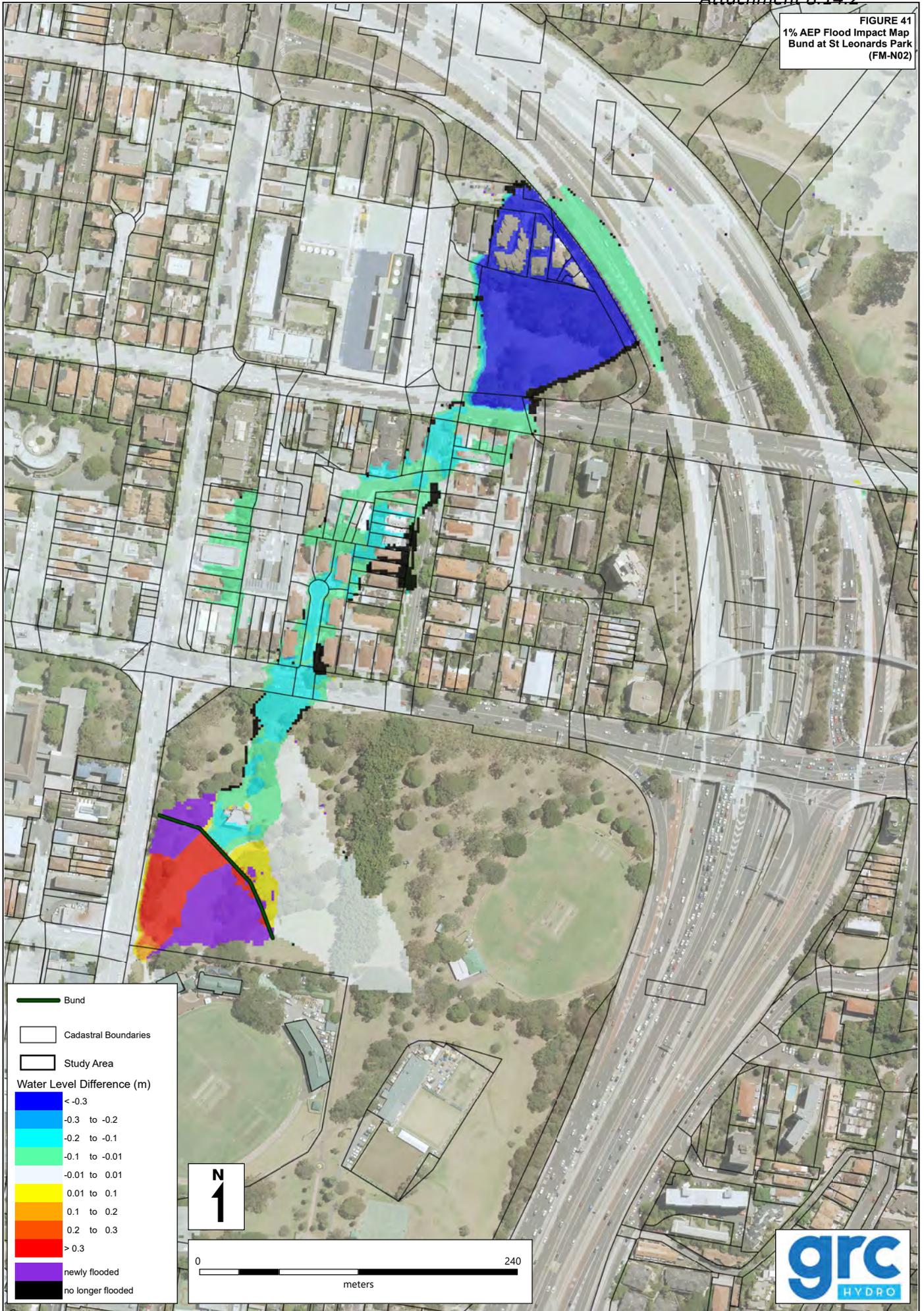
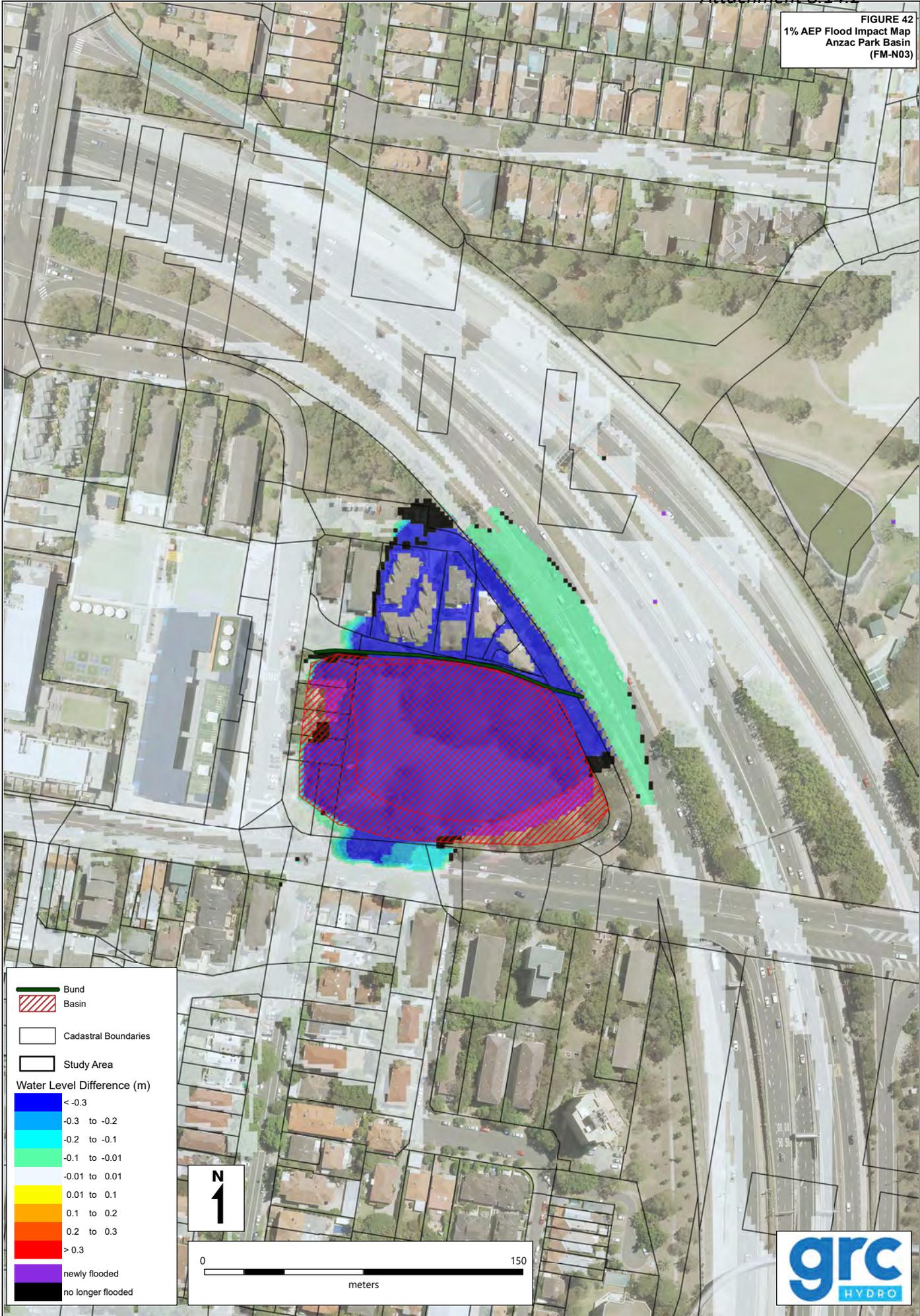
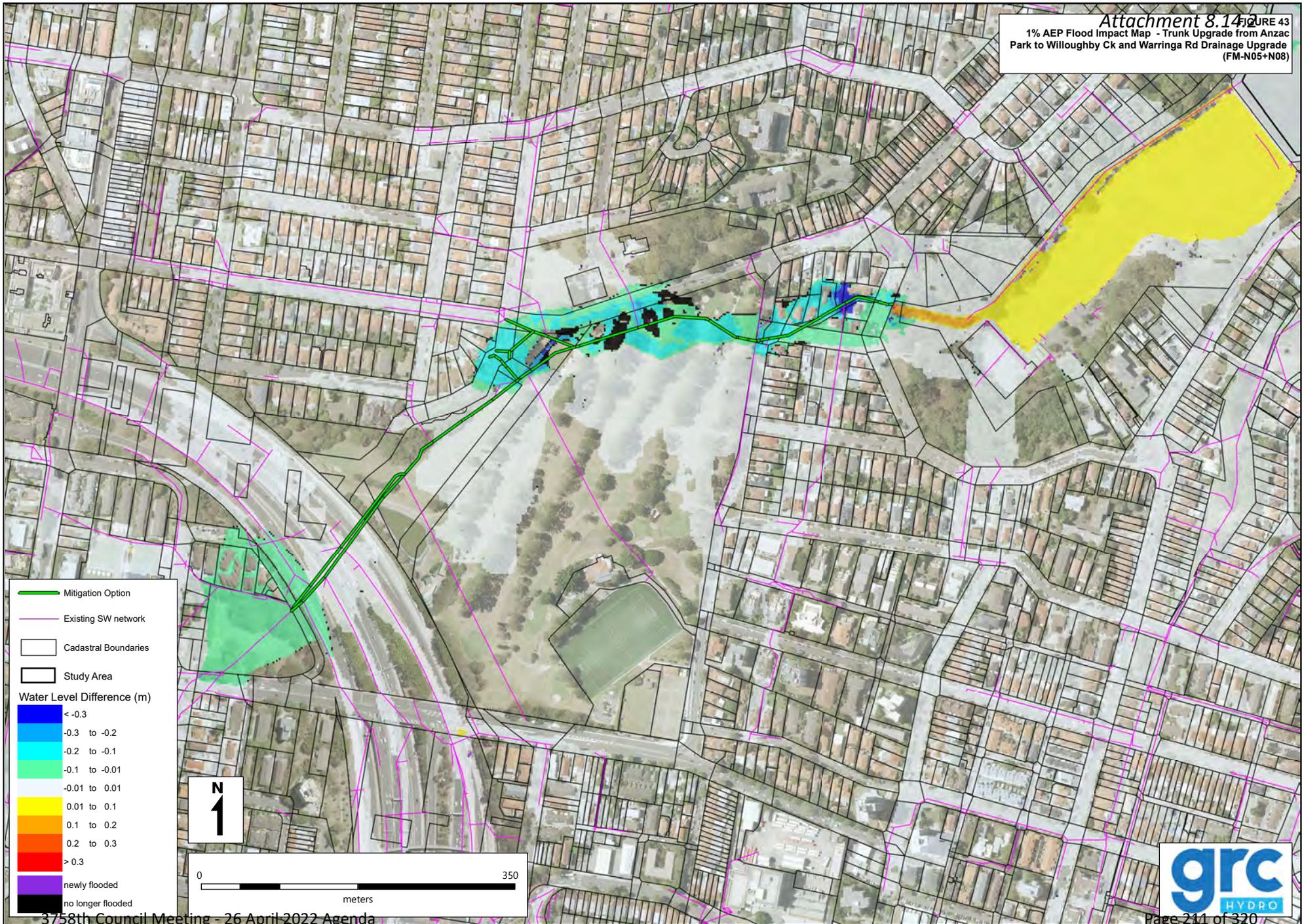


FIGURE 42
1% AEP Flood Impact Map
Anzac Park Basin
(FM-N03)



Attachment 8.14
 FIGURE 43
 1% AEP Flood Impact Map - Trunk Upgrade from Anzac
 Park to Willoughby Ck and Warringa Rd Drainage Upgrade
 (FM-N05+N08)





— Mitigation Option
— Existing SW network
 Cadastral Boundaries
 Study Area
Water Level Difference (m)
 <math>< -0.3</math>
 $-0.3 \text{ to } -0.2$
 $-0.2 \text{ to } -0.1$
 $-0.1 \text{ to } -0.01$
 $-0.01 \text{ to } 0.01$
 $0.01 \text{ to } 0.1$
 $0.1 \text{ to } 0.2$
 $0.2 \text{ to } 0.3$
 > 0.3
 newly flooded
 no longer flooded

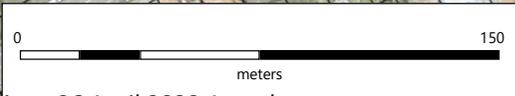
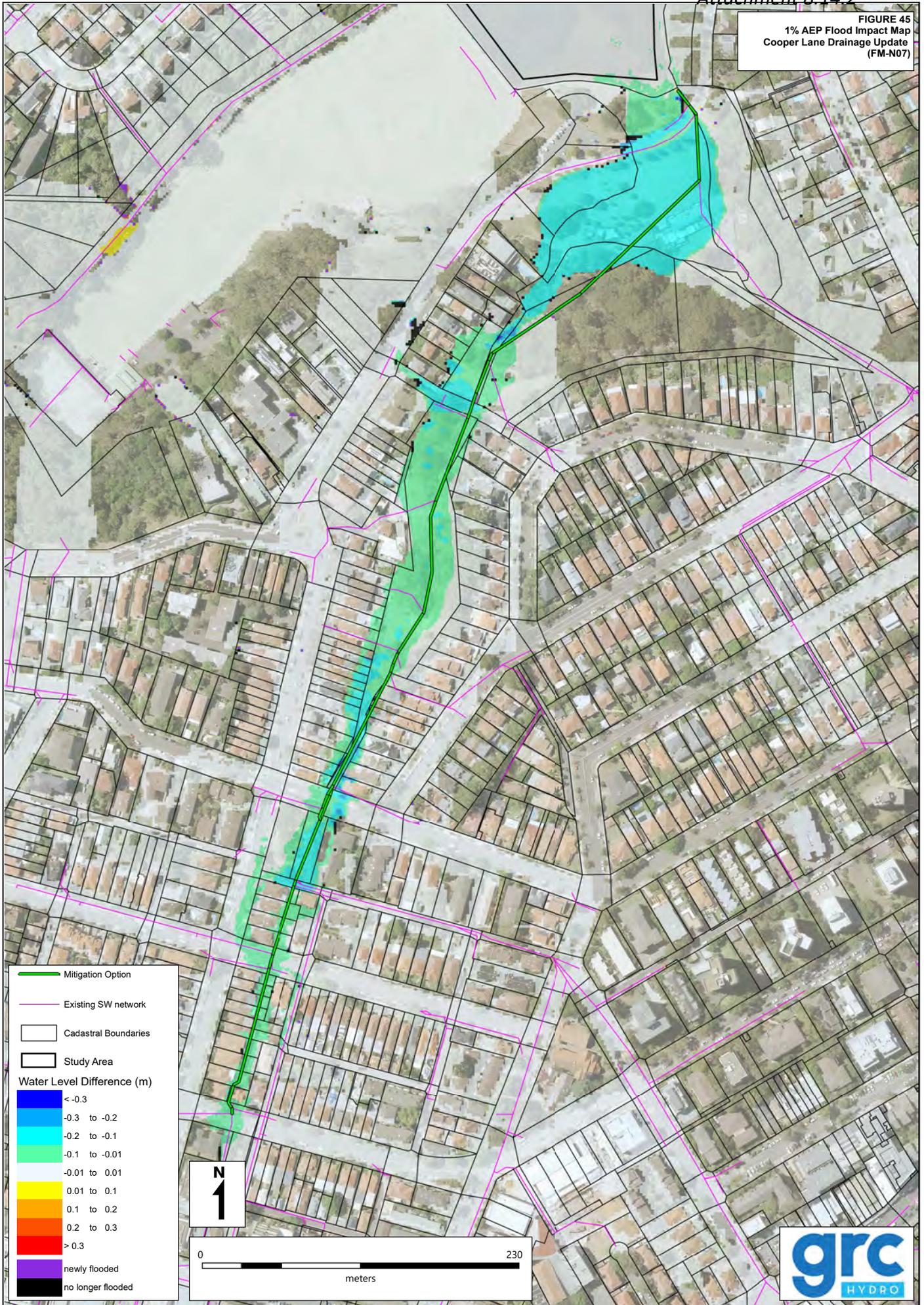


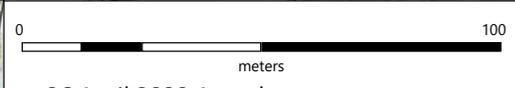
FIGURE 45
1% AEP Flood Impact Map
Cooper Lane Drainage Update
(FM-N07)





— Mitigation Option
— Existing SW network
 Cadastral Boundaries
 Study Area

Water Level Difference (m)
 <math>< -0.3</math>
 $-0.3 \text{ to } -0.2$
 $-0.2 \text{ to } -0.1$
 $-0.1 \text{ to } -0.01$
 $-0.01 \text{ to } 0.01$
 $0.01 \text{ to } 0.1$
 $0.1 \text{ to } 0.2$
 $0.2 \text{ to } 0.3$
 > 0.3
 newly flooded
 no longer flooded





APPENDIX A – GLOSSARY

Glossary of Key Terminology (From NSW Floodplain Development Manual, 2005)

annual exceedance probability (AEP)	the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. E.g., if a peak flood discharge of 500 m ³ /s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m ³ /s or larger events occurring in any one year (see ARI). (see Table A 1, Appendix A)
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
average annual damage (AAD)	depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
average recurrence interval (ARI)	the long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
catchment	the land area draining through the mainstream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	the council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the council, however legislation or an EPI may specify a Minister or public authority (other than a council), or the Director General of DIPNR, as having the function to determine an application.
development	is defined in Part 4 of the EP&A Act <u>infill development</u> : refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development <u>new development</u> : refers to development of a completely different nature to that associated with the former land use. E.g., the urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. <u>redevelopment</u> : refers to rebuilding in an area. E.g., as urban areas age, it may become necessary to demolish and reconstruct buildings on a

relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.

disaster plan (DISPLAN)	a step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
discharge	the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m ³ /s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
effective warning time	the time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	a range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage (refer Section C6) before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunamis.
flood awareness	Awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	the remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	is synonymous with flood prone land (i.e.) land susceptible to flooding by the PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (see flood planning area).

flood mitigation standard	the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	a management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.
flood planning area	the area of land below the FPL and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
flood planning levels (FPLs)	are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	a combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.
flood readiness	Readiness is an ability to react within the effective warning time.
flood risk	<p>potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below:</p> <p><u>existing flood risk</u>: the risk a community is exposed to as a result of its location on the floodplain.</p> <p><u>future flood risk</u>: the risk a community may be exposed to as a result of new development on the floodplain.</p> <p><u>continuing flood risk</u>: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town</p>

protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

flood storage areas	those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
freeboard	provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. (See Section K5). Freeboard is included in the flood planning level.
habitable room	in a residential situation: a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. in an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	a source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community.
hydraulics	term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	a graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

mainstream flooding	inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	<p>councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of this manual major drainage involves:</p> <ul style="list-style-type: none"> • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flowpaths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	the mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	the merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into council plans, policy, and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local flood risk management policy and EPIs.
minor, moderate and major flooding	<p>both the SES and the BoM use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:</p> <p><u>minor flooding</u>: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.</p> <p><u>moderate flooding</u>: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.</p>

	<u>major flooding</u> : appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	measures that modify either the flood, the property or the response to flooding.
peak discharge	the maximum discharge occurring during a flood event.
probable maximum flood (PMF)	the PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
probable maximum precipitation (PMP)	the PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	a statistical measure of the expected chance of flooding (see AEP).
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	the amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	equivalent to water level (both measured with reference to a specified datum).
stage hydrograph	a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	a plan prepared by a registered surveyor.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.

Table A 1: ARR 2019 Preferred Terminology

Frequency Descriptor	EY	AEP (%)	AEP	ARI
			(1 in x)	
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	20
	0.02	2	50	50
	0.01	1	100	100
Very Rare	0.005	0.5	200	200
	0.002	0.2	500	500
	0.001	0.1	1000	1000
	0.0005	0.05	2000	2000
Extreme	0.0002	0.02	5000	5000
			↓	
			PMP/ PMPDF	

APPENDIX B – UPDATED DESIGN FLOOD RESULTS

Table B 1: Design Peak Flood Levels (mAHD) – East Model

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
1	Yeo St	Cremorne	81.3	81.3	81.3	81.3	81.3	81.4
2	Harrison St	Cremorne	76.4	76.4	76.4	76.4	76.4	76.6
3	Bennett St	Neutral Bay	68.1	68.1	68.1	68.1	68.1	68.4
4	Bertha St	Cremorne	58.6	58.6	58.6	58.6	58.6	58.8
5	Burroway St	Neutral Bay	54.2	54.2	54.2	54.2	54.3	54.4
6	Powell St	Neutral Bay	48.7	48.7	48.8	48.8	48.8	49.0
7	Bannerman St	Cremorne	34.5	34.6	34.6	34.6	34.6	35.0
8	Guthrie Ave	Cremorne	38.8	38.8	38.8	38.8	38.8	39.0
9	Honda Rd	Kurraba Point	21.6	21.7	21.8	21.8	21.9	23.0
10	Bogota Ave	Kurraba Point	17.8	17.9	17.9	18.0	18.0	18.8
11	Hunts Lookout	Cremorne Point	14.6	14.6	14.6	14.6	14.6	14.7
12	Spofforth St	Cremorne	57.4	57.4	57.5	57.5	57.5	57.9

Table B 2: Design Peak Flood Levels (mAHD) – North Model

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
13	Military Rd	Neutral Bay	81.4	81.5	81.5	81.5	81.5	81.7
14	Belgrave St	Cremorne	68.7	68.8	68.8	68.9	68.9	69.2
15	Sutherland St	Cremorne	62.5	62.7	62.8	62.8	62.9	63.7
16	Grasmere La	Cremorne	59.8	59.9	59.9	59.9	60.0	60.7
17	Grasmere Rd	Cremorne	55.5	55.6	55.6	55.6	55.7	56.2
18	Little Young St	Cremorne	31.8	31.9	31.9	31.9	32.0	32.5
19	Brightmore St	Cremorne	45.2	45.3	45.4	45.4	45.5	46.1
20	Brightmore Res	Cremorne	8.4	9.0	9.4	9.6	9.6	10.4
21	Young St	Cremorne	9.0	9.0	9.1	9.4	9.4	10.1
22	Primrose Pk	Cremorne	2.8	2.8	2.9	2.9	2.9	3.5
23	Ryries Pde	Cremorne	32.0	32.1	32.1	32.1	32.2	32.5
24	Grafton St	Cremorne	41.5	41.6	41.7	41.7	41.8	42.4
25	Park Av	Cremorne	44.6	44.8	44.9	44.9	45.0	45.7
26	Cammeray Rd	Cammeray	51.7	51.8	51.9	51.9	52.0	52.4

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
27	Warringa Rd	Cammeray	54.1	54.2	54.3	54.3	54.3	54.9
28	Cammeray Av	Cammeray	65.1	65.6	66.1	66.5	67.4	71.3
29	Anzac Pk	Cammeray	65.1	65.6	66.1	66.5	67.4	71.3
30	Ernest St	Cammeray	66.9	66.9	67.0	67.0	67.4	71.3
31	Miller St	Cammeray	75.3	75.3	75.4	75.4	75.5	76.8
32	Rodborough Ave	Crows Nest	76.7	76.9	77.0	77.1	77.3	79.0
33	Carlow St	North Sydney	80.8	80.9	80.9	80.9	81.0	81.3
34	West St	North Sydney	86.7	86.8	86.8	86.8	86.8	87.1
35	Hamilton La	Cammeray	43.9	44.0	44.1	44.2	44.2	44.7
36	Palmer St	Cammeray	58.6	58.9	59.1	59.1	59.2	59.7
37	Brooke St	Crows Nest	65.6	65.7	65.7	65.7	65.8	66.2
38	Wheatlegh St	Crows Nest	73.1	73.2	73.3	73.3	73.3	74.2
39	Chandos St	Naremburn	73.9	74.0	74.0	74.0	74.1	74.5
40	Willoughby Rd	Crows Nest	77.1	77.2	77.3	77.3	77.3	77.8
41	Hume La	Crows Nest	77.9	78.0	78.0	78.1	78.2	78.9

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ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
42	Atchison St	Crows Nest	77.9	78.0	78.1	78.1	78.2	79.0
43	Albany La	Crows Nest	79.3	79.4	79.4	79.4	79.5	80.2
44	Albany St	Crows Nest	80.6	80.8	81.0	81.0	81.2	81.8

Table B 3: Design Peak Flood Levels (mAHD) – West Model

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
45	Christie St	Wollstonecraft	71.2	71.2	71.2	71.2	71.2	71.8
46	Lithgow St	Wollstonecraft	65.4	65.4	65.4	65.4	65.5	65.9
47	Russell St	Wollstonecraft	41.7	41.7	41.7	41.7	41.8	42.1
48	Carlyle La	Wollstonecraft	52.7	52.9	53.3	53.5	54.1	60.2
49	Belmont Av	Wollstonecraft	46.0	46.3	46.6	46.8	47.4	49.5
50	Newlands La	Wollstonecraft	40.6	41.0	41.3	41.6	42.0	45.7
51	Newlands St	Wollstonecraft	66.6	66.7	66.7	66.7	66.8	67.6
52	Hazelbank Rd	Wollstonecraft	60.6	60.6	60.7	60.7	60.7	61.0
53	Waverton Oval	Waverton	4.0	4.0	4.0	4.0	4.1	4.4
54	Woolcott St	Waverton	26.7	27.2	27.3	27.4	27.5	28.6
55	Euroka_St	Waverton	29.8	30.0	30.1	30.2	30.2	31.8
56	Ancrum_St	Waverton	37.7	37.9	37.9	38.0	38.1	38.7
57	Bank St	North Sydney	45.2	45.3	45.4	45.4	45.5	46.1

Table B 4: Design Peak Flood Levels (mAHD) – South Model

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
58	Lavender St	North Sydney	36.6	36.6	36.6	36.6	36.6	36.7
59	Miller St	North Sydney	63.1	63.2	63.2	63.2	63.3	64.0
60	Pacific Hwy/Miller St Intersection	North Sydney	64.1	64.2	64.2	64.2	64.2	64.3
61	Mount St	North Sydney	45.6	45.6	45.6	45.7	45.7	46.0
62	Little Walker St	North Sydney	43.7	44.0	44.3	44.6	44.9	46.0
63	Pacific Hwy/Walker St Intersection	North Sydney	49.6	49.6	49.6	49.6	49.6	49.6
64	Warringah Freeway/Tunnel Entrance	North Sydney	29.9	30.1	30.4	30.6	31.0	33.2
65	Clark Rd	North Sydney	13.5	13.5	13.6	13.6	13.6	14.2
66	Hipwood St	Kirribilli	4.7	4.7	4.8	4.8	4.8	5.3
67	Anderson Park Outlet	Neutral Bay	1.3	1.3	1.5	1.8	1.9	3.3
68	Clark Rd/Kurraba Rd Intersection	Neutral Bay	2.8	3.0	3.1	3.2	3.3	4.1
69	Warringah Freeway	North Sydney	44.9	44.9	44.9	44.9	44.9	45.0

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ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
70	McLaren St	North Sydney	69.7	69.7	69.7	69.7	69.7	69.7
71	Rawson St Channel	Neutral Bay	5.3	5.4	5.9	6.0	6.1	8.0
72	Forsyth Park	Neutral Bay	26.1	26.1	26.1	26.1	26.1	26.3
73	Kurraba Rd	Neutral Bay	20.9	21.0	21.0	21.0	21.1	21.3
74	Aubin St	Neutral Bay	31.2	31.3	31.3	31.3	31.3	31.6
75	Phillips St	Neutral Bay	41.1	41.2	41.2	41.2	41.2	41.7
76	Kurraba Rd/Wycombe Rd Intersection	Kurraba Point	28.0	28.0	28.1	28.1	28.1	28.1
77	Carabella St/Peel St Intersection	Kirribilli	21.5	21.5	21.5	21.6	21.6	21.7
78	Holbrook Ave	Kirribilli	12.2	12.2	12.2	12.2	12.2	12.4

Table B 5: Design Peak Flood Depths (m) – East Model

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
1	Yeo St	Cremorne	0.0	0.0	0.0	0.0	0.0	0.1
2	Harrison St	Cremorne	0.1	0.2	0.2	0.2	0.2	0.4
3	Bennett St	Neutral Bay	0.1	0.1	0.2	0.2	0.2	0.5
4	Bertha St	Cremorne	0.1	0.1	0.1	0.1	0.1	0.4
5	Burroway St	Neutral Bay	0.1	0.1	0.1	0.1	0.1	0.2
6	Powell St	Neutral Bay	0.2	0.2	0.3	0.3	0.3	0.5
7	Bannerman St	Cremorne	0.4	0.4	0.5	0.5	0.5	0.8
8	Guthrie Ave	Cremorne	0.1	0.1	0.1	0.1	0.1	0.3
9	Honda Rd	Kurraba Point	0.2	0.3	0.4	0.5	0.5	1.6
10	Bogota Ave	Kurraba Point	0.4	0.4	0.5	0.5	0.5	1.3
11	Hunts Lookout	Cremorne Point	0.1	0.1	0.1	0.1	0.1	0.2
12	Spofforth St	Cremorne	0.3	0.3	0.3	0.4	0.4	0.8

Table B 6: Design Peak Flood Depths (m) – North Model

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
13	Military Rd	Neutral Bay	0.3	0.4	0.4	0.4	0.4	0.6
14	Belgrave St	Cremorne	0.4	0.5	0.6	0.6	0.6	0.9
15	Sutherland St	Cremorne	0.2	0.4	0.5	0.5	0.6	1.4
16	Grasmere La	Cremorne	0.5	0.5	0.6	0.6	0.7	1.3
17	Grasmere Rd	Cremorne	0.4	0.5	0.5	0.5	0.5	1.1
18	Little Young St	Cremorne	0.4	0.5	0.6	0.6	0.6	1.2
19	Brightmore St	Cremorne	0.4	0.5	0.5	0.5	0.6	1.3
20	Brightmore Res	Cremorne	2.0	2.5	2.9	3.1	3.1	3.9
21	Young St	Cremorne	0.2	0.2	0.4	0.6	0.6	1.3
22	Primrose Pk	Cremorne	0.5	0.5	0.6	0.6	0.6	1.2
23	Ryries Pde	Cremorne	0.1	0.2	0.3	0.3	0.3	0.6
24	Grafton St	Cremorne	0.3	0.4	0.5	0.5	0.5	1.2
25	Park Av	Cremorne	0.2	0.3	0.4	0.4	0.5	1.3
26	Cammeray Rd	Cammeray	0.3	0.4	0.5	0.5	0.5	1.0

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
27	Warringa Rd	Cammeray	0.6	0.7	0.7	0.8	0.8	1.4
28	Cammeray Av	Cammeray	0.5	1.1	1.6	2.0	2.9	6.8
29	Anzac Pk	Cammeray	1.3	1.8	2.4	2.8	3.6	7.6
30	Ernest St	Cammeray	0.2	0.3	0.3	0.4	0.8	4.7
31	Miller St	Cammeray	0.2	0.2	0.3	0.3	0.3	1.6
32	Rodborough Ave	Crows Nest	0.3	0.4	0.6	0.6	0.8	2.5
33	Carlow St	North Sydney	0.1	0.2	0.2	0.2	0.3	0.6
34	West St	North Sydney	0.3	0.3	0.3	0.3	0.4	0.7
35	Hamilton La	Cammeray	0.2	0.3	0.4	0.4	0.5	1.0
36	Palmer St	Cammeray	0.1	0.3	0.5	0.5	0.6	1.1
37	Brooke St	Crows Nest	0.1	0.1	0.2	0.2	0.2	0.7
38	Wheatlegh St	Crows Nest	0.6	0.7	0.8	0.8	0.9	1.7
39	Chandos St	Naremburn	0.2	0.3	0.3	0.3	0.4	0.8
40	Willoughby Rd	Crows Nest	0.2	0.3	0.4	0.4	0.5	1.0
41	Hume La	Crows Nest	1.6	1.7	1.8	1.8	1.9	2.6

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ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
42	Atchison St	Crows Nest	0.7	0.9	1.0	1.0	1.1	1.9
43	Albany La	Crows Nest	0.0	0.2	0.2	0.2	0.3	1.0
44	Albany St	Crows Nest	0.2	0.4	0.6	0.6	0.7	1.3

Table B 7: Design Peak Flood Depths (m) – West Model

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
45	Christie St	Wollstonecraft	0.0	0.1	0.1	0.1	0.1	0.7
46	Lithgow St	Wollstonecraft	0.4	0.5	0.5	0.5	0.6	1.0
47	Russell St	Wollstonecraft	0.6	0.6	0.6	0.6	0.7	1.0
48	Carlyle La	Wollstonecraft	0.3	0.5	0.9	1.2	1.8	7.9
49	Belmont Av	Wollstonecraft	1.9	2.2	2.6	2.8	3.3	5.5
50	Newlands La	Wollstonecraft	0.1	0.5	0.8	1.1	1.5	5.2
51	Newlands St	Wollstonecraft	0.5	0.5	0.6	0.6	0.7	1.4
52	Hazelbank Rd	Wollstonecraft	0.2	0.2	0.3	0.3	0.3	0.6
53	Waverton Oval	Waverton	0.1	0.1	0.1	0.1	0.1	0.5
54	Woolcott St	Waverton	0.8	1.2	1.4	1.4	1.5	2.7
55	Euroka_St	Waverton	0.2	0.4	0.5	0.5	0.6	2.2
56	Ancrum_St	Waverton	0.2	0.3	0.4	0.4	0.5	1.1
57	Bank St	North Sydney	0.3	0.4	0.4	0.4	0.5	1.2

Table B 8: Design Peak Flood Depths (m) – South Model

ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
58	Lavender St	North Sydney	0.0	0.0	0.0	0.0	0.0	0.1
59	Miller St	North Sydney	0.2	0.3	0.3	0.3	0.4	1.1
60	Pacific Hwy/Miller St Intersection	North Sydney	0.0	0.1	0.1	0.1	0.1	0.2
61	Mount St	North Sydney	0.0	0.0	0.1	0.1	0.1	0.3
62	Little Walker St	North Sydney	0.9	1.2	1.4	1.7	2.0	3.2
63	Pacific Hwy/Walker St Intersection	North Sydney	0.0	0.0	0.0	0.0	0.0	0.0
64	Warringah Freeway/Tunnel Entrance	North Sydney	0.0	0.2	0.4	0.7	1.0	3.3
65	Clark Rd	North Sydney	0.1	0.1	0.1	0.2	0.2	0.8
66	Hipwood St	Kirribilli	0.2	0.2	0.2	0.3	0.3	0.8
67	Anderson Park Outlet	Neutral Bay	0.3	0.3	0.4	0.6	0.8	2.2
68	Clark Rd/Kurraba Rd Intersection	Neutral Bay	0.0	0.2	0.3	0.4	0.5	1.3
69	Warringah Freeway	North Sydney	0.1	0.1	0.1	0.1	0.1	0.2

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ID	Location (refer Figure 4)	Suburb	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
70	McLaren St	North Sydney	0.0	0.1	0.1	0.1	0.1	0.1
71	Rawson St Channel	Neutral Bay	0.4	0.6	1.0	1.1	1.2	2.9
72	Forsyth Park	Neutral Bay	0.1	0.1	0.1	0.1	0.1	0.3
73	Kurraba Rd	Neutral Bay	0.1	0.1	0.1	0.2	0.2	0.4
74	Aubin St	Neutral Bay	0.3	0.4	0.4	0.5	0.5	0.8
75	Phillips St	Neutral Bay	0.2	0.3	0.3	0.3	0.3	0.8
76	Kurraba Rd/Wycombe Rd Intersection	Kurraba Point	0.0	0.0	0.0	0.0	0.0	0.1
77	Carabella St/Peel St Intersection	Kirribilli	0.1	0.1	0.1	0.1	0.1	0.2
78	Holbrook Ave	Kirribilli	0.0	0.0	0.0	0.0	0.0	0.1

Table B 9: Design Peak Flows (m³/s) – East Model

ID	Location (refer Figure 4)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
E1	Bannerman St	2.6	3.3	4.0	4.6	5.6	33.2
E2	Bennet St	1.1	1.4	1.8	2.1	2.5	18.0
E3	Harrison St	0.8	1.1	1.4	1.6	1.8	10.4
E4	Spofforth St - Between Brierley St and Florence St	2.0	2.6	3.2	3.7	4.5	23.6
E5	Lower Spofforth Walk - Between Boyle St and Hodgson Ave	1.5	1.9	2.3	2.7	3.2	22.4

Table B 10: Design Peak Flows (m³/s) – North Model

ID	Location (refer Figure 4)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
N1	Brooke Street	1.8	4.7	7.2	7.9	10.5	73.0
N2	Wheatleigh Street	0.3	0.2	0.2	0.2	0.2	0.2
N3	Atchison Street	1.2	2.4	3.2	3.2	4.8	29.6
N4	Grafton Street	3.3	7.8	12.0	13.2	17.3	100.8
N5	Ernest Street	2.4	4.9	7.7	8.6	12.4	57.4
N6	Anzac Avenue	0.9	1.6	2.0	2.0	3.0	18.9
N7	Young Street	0.3	0.5	2.8	13.7	14.5	145.9
N8	Grasmere Road	3.1	5.9	8.0	8.5	11.9	74.4
N9	Brightmore Street	2.4	4.1	5.3	5.2	7.9	49.5

Table B 11: Design Peak Flows (m³/s) – West Model

ID	Location (refer Figure 4)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
W1	Woolcott St	0.1	1.4	2.7	3.4	4.9	36.6
W2	Ancrum St	0.6	1.7	2.9	3.0	4.5	29.3
W3	Carr St	1.2	1.9	2.4	2.7	3.4	20.4
W4	Brennan Park	2.0	2.5	3.6	3.6	4.9	26.7
W5	Newlands St	1.5	2.0	2.9	3.0	4.2	24.5
W6	Russel St	9.9	13.3	14.6	17.3	20.3	94.2
W7	Lithgow St	1.5	2.0	2.7	2.8	3.7	19.6

Table B 12: Design Peak Flows (m³/s) – South Model

ID	Location (refer Figure 4)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	PMF
S1	Intersection of Clark Rd, Rawson St and Kurraba Rd	0.0	1.0	2.8	4.8	6.3	72.0
S2	Eaton St	1.3	3.2	4.9	6.2	7.8	54.5
S3	Cnr Hayes St and Lower Wycombe Rd	1.8	3.4	5.0	6.4	6.7	37.4
S4	Aubin St	1.0	2.8	3.8	4.8	5.3	35.8
S5	Phillips St	1.3	2.2	2.8	3.4	3.7	24.4
S6	Hipwood Street	0.9	1.4	1.7	2.1	2.6	52.9
S7	Mount St	0.7	1.2	1.8	2.3	3.0	32.2

APPENDIX C – CLIMATE CHANGE RESULTS

Table C 1: Difference in Peak Flood Levels for Climate Change Scenarios (m) – East Model

ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
1	Yeo St	81.33	0.00	0.00	0.00	0.00	81.32	0.00	0.00	0.00	0.00
2	Harrison St	76.42	0.01	0.02	0.01	0.02	76.41	0.01	0.01	0.01	0.01
3	Bennett St	68.15	0.01	0.03	0.01	0.03	68.13	0.01	0.02	0.01	0.02
4	Bertha St	58.61	0.01	0.01	0.01	0.01	58.60	0.01	0.01	0.01	0.01
5	Burroway St	54.26	0.01	0.01	0.01	0.01	54.25	0.01	0.01	0.01	0.01
6	Powell St	48.77	0.01	0.02	0.01	0.02	48.76	0.01	0.01	0.01	0.01
7	Bannerman St	34.64	0.02	0.03	0.02	0.03	34.62	0.01	0.03	0.01	0.03
8	Guthrie Ave	38.81	0.00	0.01	0.00	0.01	38.81	0.01	0.01	0.01	0.01
9	Honda Rd	21.90	0.05	0.10	0.05	0.10	21.82	0.05	0.10	0.05	0.10
10	Bogota Ave	18.03	0.03	0.07	0.03	0.07	17.98	0.03	0.06	0.03	0.06

ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
11	Hunts Lookout	14.56	0.00	0.00	0.00	0.00	14.56	0.00	0.00	0.00	0.00
12	Spofforth St	57.53	0.02	0.04	0.02	0.04	57.50	0.02	0.04	0.02	0.04
	Average		+0.01	+0.03	+0.01	+0.03		+0.01	+0.03	+0.01	+0.03

Table C 2: Difference in Peak Flood Levels for Climate Change Scenarios (m) – North Model

ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
13	Military Rd	81.51	0.01	0.02	0.01	0.02	81.48	0.01	0.02	0.01	0.02
14	Belgrave St	68.90	0.02	0.04	0.02	0.04	68.85	0.02	0.03	0.02	0.03
15	Sutherland St	62.87	0.05	0.10	0.05	0.10	62.76	0.04	0.07	0.04	0.07
16	Grasmere La	60.00	0.03	0.07	0.03	0.07	59.92	0.02	0.05	0.02	0.05
17	Grasmere Rd	55.68	0.02	0.05	0.02	0.05	55.64	0.01	0.03	0.01	0.03
18	Little Young St	31.99	0.04	0.08	0.04	0.08	31.92	0.03	0.05	0.03	0.05
19	Brightmore St	45.47	0.04	0.07	0.04	0.07	45.38	0.03	0.05	0.03	0.05
20	Brightmore Res	9.60	0.06	0.11	0.06	0.11	9.59	0.03	0.06	0.03	0.06
21	Young St	9.37	0.07	0.14	0.07	0.14	9.37	0.04	0.07	0.04	0.07
22	Primrose Pk	2.95	0.03	0.06	0.03	0.06	2.91	0.02	0.05	0.02	0.04
23	Ryries Pde	32.19	0.02	0.04	0.02	0.04	32.11	0.02	0.04	0.02	0.04
24	Grafton St	41.76	0.03	0.06	0.03	0.06	41.71	0.03	0.05	0.03	0.05

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ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
25	Park Av	44.96	0.05	0.09	0.05	0.09	44.89	0.04	0.08	0.04	0.08
26	Cammeray Rd	51.99	0.01	0.02	0.01	0.02	51.94	0.03	0.05	0.03	0.05
27	Warringa Rd	54.32	0.03	0.06	0.03	0.06	54.27	0.02	0.04	0.02	0.04
28	Cammeray Av	67.40	0.33	0.68	0.33	0.68	66.53	0.37	0.72	0.37	0.72
29	Anzac Pk	67.40	0.33	0.68	0.33	0.68	66.53	0.37	0.72	0.37	0.72
30	Ernest St	67.40	0.33	0.68	0.33	0.68	66.98	0.02	0.27	0.02	0.27
31	Miller St	75.46	0.02	0.04	0.02	0.04	75.39	0.02	0.04	0.02	0.04
32	Rodborough Ave	77.30	0.08	0.16	0.08	0.16	77.06	0.07	0.13	0.07	0.13
33	Carlow St	80.95	0.02	0.04	0.02	0.04	80.91	0.01	0.03	0.01	0.03
34	West St	86.82	0.01	0.03	0.01	0.03	86.78	0.01	0.02	0.01	0.02
35	Hamilton La	44.23	0.03	0.08	0.03	0.08	44.17	0.04	0.07	0.04	0.07
36	Palmer St	59.20	0.04	0.08	0.04	0.08	59.12	0.05	0.08	0.05	0.08

ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
37	Brooke St	65.75	0.02	0.04	0.02	0.04	65.72	0.01	0.03	0.01	0.03
38	Wheatlegh St	73.35	0.05	0.10	0.05	0.10	73.28	0.03	0.06	0.03	0.06
39	Chandos St	74.09	0.03	0.05	0.03	0.05	74.04	0.01	0.03	0.01	0.03
40	Willoughby Rd	77.32	0.03	0.06	0.03	0.06	77.26	0.02	0.04	0.02	0.04
41	Hume La	78.16	0.04	0.08	0.04	0.08	78.05	0.03	0.07	0.03	0.07
42	Atchison St	78.24	0.06	0.10	0.06	0.10	78.10	0.04	0.08	0.04	0.08
43	Albany La	79.52	0.04	0.08	0.04	0.08	79.43	0.02	0.04	0.02	0.04
44	Albany St	81.16	0.04	0.07	0.04	0.07	81.01	0.05	0.09	0.05	0.09
	Average		+0.06	+0.13	+0.06	+0.13		+0.05	+0.10	+0.05	+0.10

Table C 3: Difference in Peak Flood Levels for Climate Change Scenarios (m) – West Model

ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
45	Christie St	71.24	0.02	0.05	0.02	0.05	71.20	0.01	0.02	0.01	0.02
46	Lithgow St	65.50	0.02	0.04	0.02	0.04	65.45	0.02	0.03	0.02	0.03
47	Russell St	41.78	0.01	0.03	0.01	0.03	41.75	0.01	0.03	0.01	0.03
48	Carlyle La	54.13	0.31	0.63	0.31	0.63	53.53	0.29	0.61	0.29	0.61
49	Belmont Av	47.35	0.16	0.33	0.16	0.33	46.81	0.17	0.34	0.17	0.34
50	Newlands La	42.02	0.26	0.53	0.26	0.53	41.60	0.26	0.51	0.26	0.51
51	Newlands St	66.79	0.04	0.07	0.04	0.07	66.72	0.02	0.04	0.02	0.04
52	Hazelbank Rd	60.72	0.01	0.02	0.01	0.02	60.68	0.01	0.02	0.01	0.02
53	Waverton Oval	4.06	0.01	0.03	0.01	0.03	4.04	0.01	0.03	0.01	0.03
54	Woolcott St	27.47	0.06	0.13	0.06	0.13	27.36	0.06	0.11	0.06	0.11
55	Euroka_St	30.22	0.06	0.13	0.06	0.13	30.17	0.02	0.04	0.02	0.04
56	Ancrum_St	38.05	0.04	0.08	0.04	0.08	37.95	0.03	0.06	0.03	0.06

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ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
57	Bank St	45.46	0.03	0.06	0.03	0.06	45.38	0.03	0.05	0.03	0.05
	Average		+0.08	+0.16	+0.08	+0.16		+0.07	+0.15	+0.07	+0.15

Table C 4: Difference in Peak Flood Levels for Climate Change Scenarios (m) – South Model

ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
58	Lavender St	36.60	0.00	0.01	0.00	0.01	36.60	0.00	0.00	0.00	0.00
59	Miller St	63.26	0.02	0.05	0.02	0.05	63.23	0.02	0.04	0.02	0.04
60	Pacific Hwy/Miller St Intersection	64.18	0.00	0.01	0.00	0.01	64.18	0.00	0.01	0.00	0.01
61	Mount St	45.69	0.01	0.02	0.01	0.02	45.67	0.01	0.03	0.01	0.03
62	Little Walker St	44.86	0.23	0.45	0.23	0.45	44.55	0.22	0.45	0.22	0.45
63	Pacific Hwy/Walker St Intersection	49.58	0.00	0.00	0.00	0.00	49.57	0.00	0.00	0.00	0.00
64	Warringah Freeway/Tunnel Entrance	30.95	0.27	0.52	0.27	0.52	30.58	0.25	0.49	0.25	0.49
65	Clark Rd	13.59	0.01	0.02	0.01	0.02	13.57	0.01	0.02	0.01	0.02
66	Hipwood St	4.81	0.02	0.03	0.02	0.03	4.78	0.02	0.04	0.02	0.04

ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
67	Anderson Park Outlet	1.91	0.15	0.27	0.45	0.47	1.75	0.13	0.25	0.59	0.60
68	Clark Rd/Kurraba Rd Intersection	3.25	0.05	0.10	0.08	0.13	3.20	0.04	0.08	0.06	0.10
69	Warringah Freeway	44.92	0.00	0.01	0.00	0.01	44.92	0.01	0.01	0.01	0.01
70	McLaren St	69.68	0.01	0.01	0.01	0.01	69.68	0.00	0.01	0.00	0.01
71	Rawson St Channel	6.13	0.09	0.17	0.09	0.17	6.01	0.00	0.10	0.00	0.10
72	Forsyth Park	26.15	0.01	0.02	0.01	0.02	26.13	0.01	0.02	0.01	0.02
73	Kurraba Rd	21.05	0.01	0.03	0.01	0.03	21.04	0.01	0.02	0.01	0.02
74	Aubin St	31.33	0.02	0.04	0.02	0.04	31.32	0.02	0.03	0.02	0.03
75	Phillips St	41.23	0.02	0.02	0.02	0.02	41.23	0.01	0.02	0.01	0.02
76	Kurraba Rd/Wycombe Rd Intersection	28.06	0.00	0.00	0.00	0.00	28.06	0.00	0.00	0.00	0.00

ID	Location (refer Figure 4)	1% AEP					2% AEP				
		Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)	Base Case (mAHD)	RCP 4.5 Scenario	RCP 8.5 Scenario	RCP 4.5 Scenario with Sea Level Rise (2100)	RCP 8.5 Scenario with Sea Level Rise (2100)
77	Carabella St/Peel St Intersection	21.56	0.00	0.01	0.00	0.01	21.55	0.00	0.01	0.00	0.01
78	Holbrook Ave	12.25	0.01	0.01	0.01	0.01	12.24	0.01	0.01	0.01	0.01
	Average		+0.05	+0.09	+0.06	+0.10		+0.04	+0.08	+0.06	+0.10

APPENDIX D – SENSITIVITY ANALYSIS RESULTS

Table D 1: Difference in Peak Flood Levels for Sensitivity Analysis Scenarios (m) – East Model

ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
1	Yeo St	81.33	0.00	0.00	0.00	0.00	0.00	0.00
2	Harrison St	76.42	0.00	0.00	0.00	0.00	0.00	0.01
3	Bennett St	68.15	0.00	0.00	0.00	0.00	0.01	0.03
4	Bertha St	58.61	0.00	0.00	-0.01	0.01	0.00	0.01
5	Burroway St	54.26	0.00	0.00	0.00	0.00	0.00	0.00
6	Powell St	48.77	0.00	0.00	0.00	0.00	0.00	0.01
7	Bannerman St	34.64	0.00	0.00	-0.01	0.00	0.01	0.03
8	Guthrie Ave	38.81	0.00	0.00	-0.01	0.01	0.00	0.00
9	Honda Rd	21.90	0.00	0.00	0.02	-0.01	0.03	0.10
10	Bogota Ave	18.03	0.00	0.00	-0.01	0.00	0.03	0.08
11	Hunts Lookout	14.56	0.00	0.00	0.00	0.01	0.00	0.00

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ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
12	Spofforth St	57.53	0.00	0.00	-0.01	0.00	0.01	0.02
	Average		0.00	0.00	0.00	0.00	+0.01	+0.02

Table D 2: Difference in Peak Flood Levels for Sensitivity Analysis Scenarios (m) – North Model

ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
13	Military Rd	81.51	0.00	0.00	-0.01	0.00	0.00	0.01
14	Belgrave St	68.90	0.01	-0.01	0.00	0.00	0.01	0.03
15	Sutherland St	62.87	0.01	-0.02	0.01	0.00	0.04	0.10
16	Grasmere La	60.00	0.01	-0.01	-0.01	0.01	0.02	0.04
17	Grasmere Rd	55.68	0.01	0.00	-0.02	0.02	0.01	0.02
18	Little Young St	31.99	0.01	-0.01	-0.03	0.02	0.01	0.04
19	Brightmore St	45.47	0.01	-0.01	0.00	0.01	0.02	0.06
20	Brightmore Res	9.60	0.02	-0.01	0.01	0.00	0.03	0.08
21	Young St	9.37	0.02	-0.01	0.00	0.00	0.04	0.09
22	Primrose Pk	2.95	0.01	-0.01	-0.04	0.03	-0.02	-0.05
23	Ryries Pde	32.19	0.00	-0.01	-0.01	0.00	0.01	0.04
24	Grafton St	41.76	0.01	-0.01	0.01	0.00	0.01	0.03
25	Park Av	44.96	0.02	-0.01	0.02	0.00	0.01	0.03

North Sydney LGA-wide Floodplain Risk Management Study and Plan – Draft

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ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
26	Cammeray Rd	51.99	0.00	0.00	-0.01	0.01	0.00	0.01
27	Warringa Rd	54.32	0.01	-0.01	-0.02	0.02	0.01	0.01
28	Cammeray Av	67.40	0.02	-0.01	0.01	0.01	0.46	1.25
29	Anzac Pk	67.40	0.02	-0.02	0.01	0.01	0.46	1.25
30	Ernest St	67.40	0.02	-0.01	0.01	0.01	0.46	1.26
31	Miller St	75.46	0.00	-0.01	-0.01	-0.01	0.02	0.04
32	Rodborough Ave	77.30	0.03	-0.03	-0.03	0.00	0.05	0.12
33	Carlow St	80.95	0.01	-0.01	-0.01	0.01	0.00	0.00
34	West St	86.82	0.00	0.00	0.00	0.01	0.01	0.03
35	Hamilton La	44.23	0.00	0.00	0.01	-0.01	0.02	0.05
36	Palmer St	59.20	0.00	0.00	-0.03	0.01	0.02	0.06
37	Brooke St	65.75	0.00	0.00	-0.01	0.05	0.01	0.02
38	Wheatlegh St	73.35	0.01	0.00	-0.01	0.01	0.02	0.05

ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
39	Chandos St	74.09	0.01	-0.01	-0.02	0.02	0.01	0.03
40	Willoughby Rd	77.32	0.01	-0.01	0.01	0.00	0.01	0.04
41	Hume La	78.16	0.01	-0.01	-0.01	0.01	0.02	0.05
42	Atchison St	78.24	0.02	-0.02	-0.01	0.01	0.03	0.07
43	Albany La	79.52	0.01	-0.01	-0.04	0.03	0.03	0.08
44	Albany St	81.16	0.01	-0.01	-0.03	0.02	0.04	0.12
	Average		+0.01	-0.01	-0.01	+0.01	+0.06	+0.16

Table D 3: Difference in Peak Flood Levels for Sensitivity Analysis Scenarios (m) – West Model

ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
45	Christie St	71.24	0.01	-0.01	-0.01	0.01	0.01	0.07
46	Lithgow St	65.50	0.00	-0.01	-0.02	0.02	0.00	0.00
47	Russell St	41.78	0.00	0.00	0.00	-0.01	0.00	-0.02
48	Carlyle La	54.13	0.11	-0.06	-0.10	0.22	0.53	1.51
49	Belmont Av	47.35	0.01	-0.01	0.01	0.00	0.00	0.00
50	Newlands La	42.02	0.06	-0.01	0.01	0.01	0.23	1.08
51	Newlands St	66.79	0.01	-0.01	-0.01	0.01	0.02	0.04
52	Hazelbank Rd	60.72	0.00	0.00	-0.01	0.00	0.00	0.01
53	Waverton Oval	4.06	0.00	0.00	-0.02	0.01	0.01	0.01
54	Woolcott St	27.47	0.02	0.00	-0.01	0.01	0.03	0.08
55	Euroka_St	30.22	0.02	-0.02	-0.03	0.02	0.03	0.07
56	Ancrum_St	38.05	0.02	-0.02	-0.04	0.02	0.03	0.06
57	Bank St	45.46	0.01	-0.01	-0.01	0.00	0.02	0.05

North Sydney LGA-wide Floodplain Risk Management Study and Plan – Draft

ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
	Average		+0.02	-0.01	-0.02	+0.03	+0.07	+0.23

Table D 4: Difference in Peak Flood Levels for Sensitivity Analysis Scenarios (m) – South Model

ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
58	Lavender St	36.60	0.00	0.00	0.00	0.00	0.00	0.00
59	Miller St	63.26	0.01	-0.01	0.00	0.00	0.01	0.04
60	Pacific Hwy/Miller St Intersection	64.18	0.00	0.00	0.00	0.00	0.00	0.00
61	Mount St	45.69	0.00	-0.01	0.00	0.01	0.01	0.02
62	Little Walker St	44.86	0.07	-0.07	-0.01	0.00	0.08	0.29
63	Pacific Hwy/Walker St Intersection	49.58	0.00	0.00	0.00	0.00	0.00	0.00
64	Warringah Freeway/Tunnel Entrance	30.95	0.07	-0.07	-0.08	0.06	0.01	0.07
65	Clark Rd	13.59	0.00	0.00	0.02	-0.02	0.03	0.05
66	Hipwood St	4.81	0.00	-0.01	0.00	0.00	0.00	0.05
67	Anderson Park Outlet	1.91	0.04	-0.05	0.07	-0.22	-0.03	-0.10

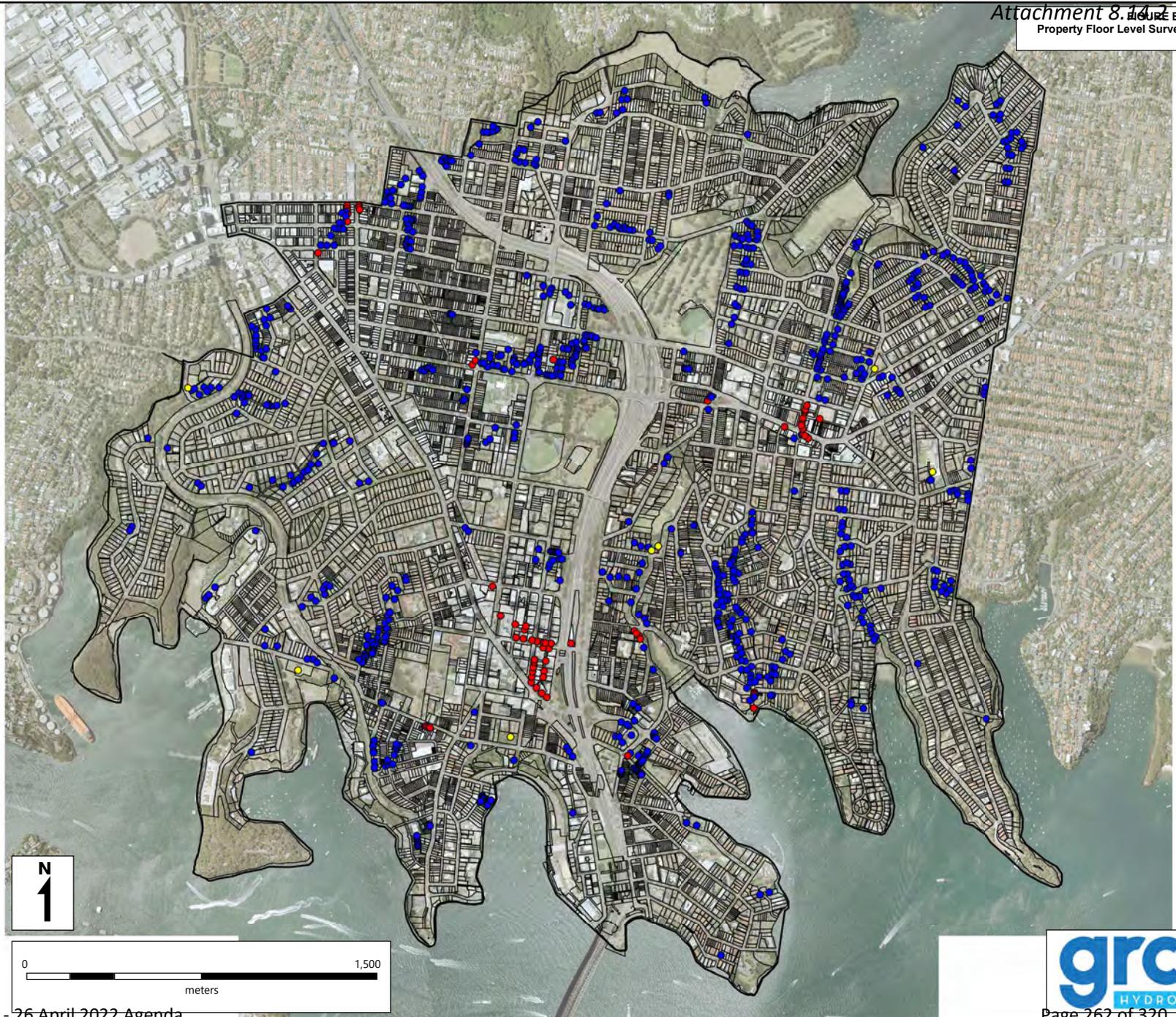
North Sydney LGA-wide Floodplain Risk Management Study and Plan – Draft

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ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
68	Clark Rd/Kurraba Rd Intersection	3.25	0.01	-0.02	-0.01	0.01	-0.01	-0.04
69	Warringah Freeway	44.92	0.00	0.00	0.02	-0.01	0.00	0.01
70	McLaren St	69.68	0.00	0.00	0.00	0.00	0.00	0.01
71	Rawson St Channel	6.13	-0.05	-0.13	-0.02	0.02	-0.02	-0.08
72	Forsyth Park	26.15	0.00	0.00	-0.01	0.01	0.00	0.00
73	Kurraba Rd	21.05	0.00	-0.01	0.01	0.00	0.00	0.02
74	Aubin St	31.33	0.01	-0.01	0.01	0.00	0.01	0.03
75	Phillips St	41.23	0.00	-0.01	0.00	0.01	0.00	0.01
76	Kurraba Rd/Wycombe Rd Intersection	28.06	0.00	0.00	0.00	0.00	0.00	0.00
77	Carabella St/Peel St Intersection	21.56	0.00	0.00	-0.01	0.01	0.00	0.00
78	Holbrook Ave	12.25	0.00	0.00	-0.01	0.00	0.01	0.01

ID	Location (refer Figure 4)	1% AEP						
		Base Case (mAHD)	Rainfall Loss -20%	Rainfall Loss +20%	Manning's 'n' -20%	Manning's 'n' +20%	Pipe Blockage +20%	Pipe Blockage +50%
	Average		+0.01	-0.02	0.00	0.00	+0.01	+0.02

APPENDIX E – PROPERTY FLOOD LEVEL SURVEY

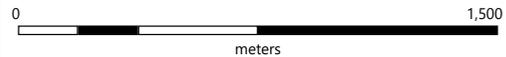


Floor Level Survey

- Residential (819)
- Commercial (68)
- Public (7)

□ Cadastral Boundaries

□ Study Area



APPENDIX F – NEWSLETTER AND QUESTIONNAIRE

Have Your Say on Flooding in Your Area North Sydney LGA Floodplain Risk Management Study and Plan



North Sydney LGA Floodplain Risk Management Study & Plan

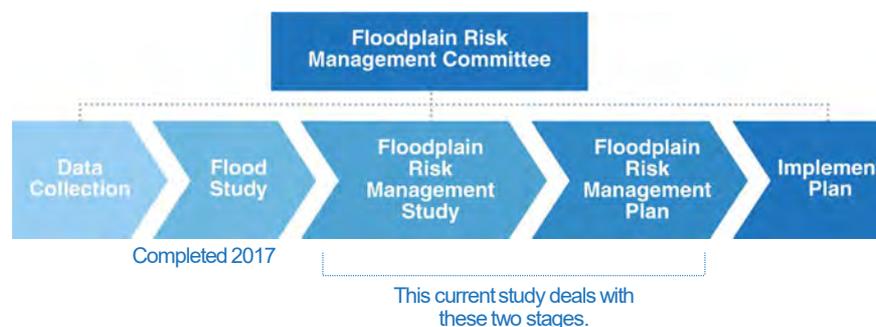
On behalf of North Sydney Council, GRC Hydro are undertaking the North Sydney Local Government Area (LGA) Floodplain Risk Management Study & Plan. We would like to hear your experiences of flooding to better understand how flooding occurs in your area and what measures may improve the current flood situation.

This study and plan will identify and recommend appropriate actions to manage flooding in your LGA. This study will be used by Council to manage flood risks in your area.

What is the Floodplain Risk Management Program?

The Floodplain Risk Management Program, managed by the NSW Government, helps Councils make informed decisions about managing flood risk, implementing management plans to reduce flood risk and to provide essential information to the SES to deal with flood emergencies.

This program consists of five stages and the current study will undertake the third and fourth stages of this process; Floodplain Risk Management Study and Floodplain Risk Management Plan. This follows on from the flood study completed by Council in 2017.



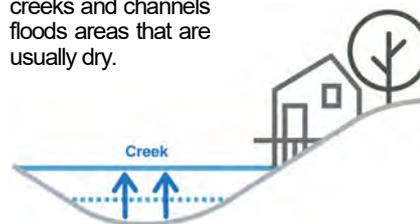
What is Flooding?

Flooding is often associated with inundation from large rivers; however, there are other ways that flooding can occur. The North Sydney LGA is primarily affected by two types of flooding; overland flow flooding and mainstream flooding.

Overland flow flooding occurs when rainfall flows toward creeks and channels.



Mainstream flooding occurs when large volumes of water in creeks and channels floods areas that are usually dry.



What is a floodplain risk management study and plan?

A Floodplain Risk Management Study and Plan draws on the results of a Flood Study to identify, assess and compare various flood risk management options. It provides information and tools to assess the flood impacts of different management options and provides a plan for the implementation of the preferred options.

A FRMS&P draws on the results of the flood study to identify, assess and compare various flood risk management options. These options are aimed at improving the existing flood situation in the LGA. The FRMS&P provides information and tools to allow considered assessment of flood impacts of management options and provides a strategic plan for their implementation. Management options are typically categorised as property modification measures, response modification measures and flood modification measures.

Have Your Say on Flooding in Your Area North Sydney LGA Floodplain Risk Management Study and Plan



What is a FRMS&P used for?

A Floodplain Risk Management Study and Plan provides key information for Council, the SES and the community for effectively managing and mitigating flood risk.

For Council, FRMS&P's are a planning tool for future development in the LGA and implementing flood mitigation measures for existing development areas. Examples of applications for Council include:

- Identification and assessment of floodplain risk management measures for existing development areas aimed at reducing social, environmental and economic loss of flooding on development and the community; and
- Examination of Council's local flood risk management policies, strategies and planning instruments.

Information from the FRMS&P will assist the SES in its evacuation and logistics planning. The outcomes of the study will provide the SES with:

- a clear description of flood behaviour in the study area for a full range of flood events;
- a description of flood warning times for the LGA; and
- identification of critical evacuation issues in the LGA such as locations where road access is cut and the warning time before road access is cut.

The Study Area

The North Sydney Local Government Area covers an 11 square kilometre area with a topographic ridge running east to west sloping down toward Sydney Harbour to the south and Middle Harbour in the north. The topography creates a large number of steep catchments flowing generally north or south. The study area is shown in the map below, which shows the LGA boundary in purple along with suburbs and major roads.



Why your feedback is important

GRC Hydro will be identifying areas that are significantly flood affected and assessing flood modification measures to relieve the flood risk at these locations. This involves using computer models developed in the North Sydney LGA Flood Study to assess flood mitigation measures. Community input and knowledge of measures that might mitigate flooding in the LGA is invaluable to this study.

How can you help us?

Your feedback is important in helping us get a complete picture of the community's knowledge of flood behaviour and mitigation in your LGA. There are a variety of ways you can share your experiences and knowledge with us.

01. Fill out the questionnaire included with this letter and email it to northsydney@grchydro.com.au.

02. Fill out the questionnaire online by going to the website listed below or using your smartphone to navigate to the questionnaire using the QR code below.

QRCode:



Website:

grchydro.com.au/northsydney

For more information, please do not hesitate to contact the representatives nominated at the bottom of this page.

What happens next?

GRC Hydro will assess flood modification measures and produce a draft FRMS&P report for Council. It will be on Public Exhibition in early 2020.

Who can we contact?

If you have any further questions regarding the study or any further flood information/photos please attach them to your questionnaire or contact the following representatives.

grc HYDRO
Nathan Cheah
Associate, GRC Hydro
northsydney@grchydro.com.au
02 9030 0342



Jim Moore
Engineering Project Manager, North Sydney Council
Floodstudy@northsydney.nsw.gov.au
02 9936 8100

**Please return your questionnaire by 25th
October 2019 to ensure that it is counted.**

Have Your Say on Flooding in Your Area

North Sydney LGA Floodplain Risk Management Study and Plan Questionnaire



Flood Management Options

The current study is assessing a range of measures aimed at managing the current flood risk. The study is looking for input from residents to better understand local preferences for floodplain management.

Which of the following options do you prefer for managing flood risk? (tick one or multiple boxes based on preference)

- Construct detention basin(s) to reduce peak flood flow rates / store overland flows
- Increase flood awareness and education in the community
- Improve overland flow paths to increase their capacity
- Upgrade flood warning, evacuation planning and emergency response measures
- Upgrade stormwater drains to increase their capacity to handle flood events
- Other suggestions (describe below)
- Impose greater flood-related development controls and increase strategic flood planning

Other Comments

If you have other comments which could assist us in the development of the North Sydney LGA Floodplain Risk Management Study & Plan, please write them in the space below.

Please return your questionnaire by 25th October 2019 to ensure that it is counted. If your information does not fit in the space provided, please email it to northsydney@grchydro.com.au

APPENDIX G – ARR DATAHUB

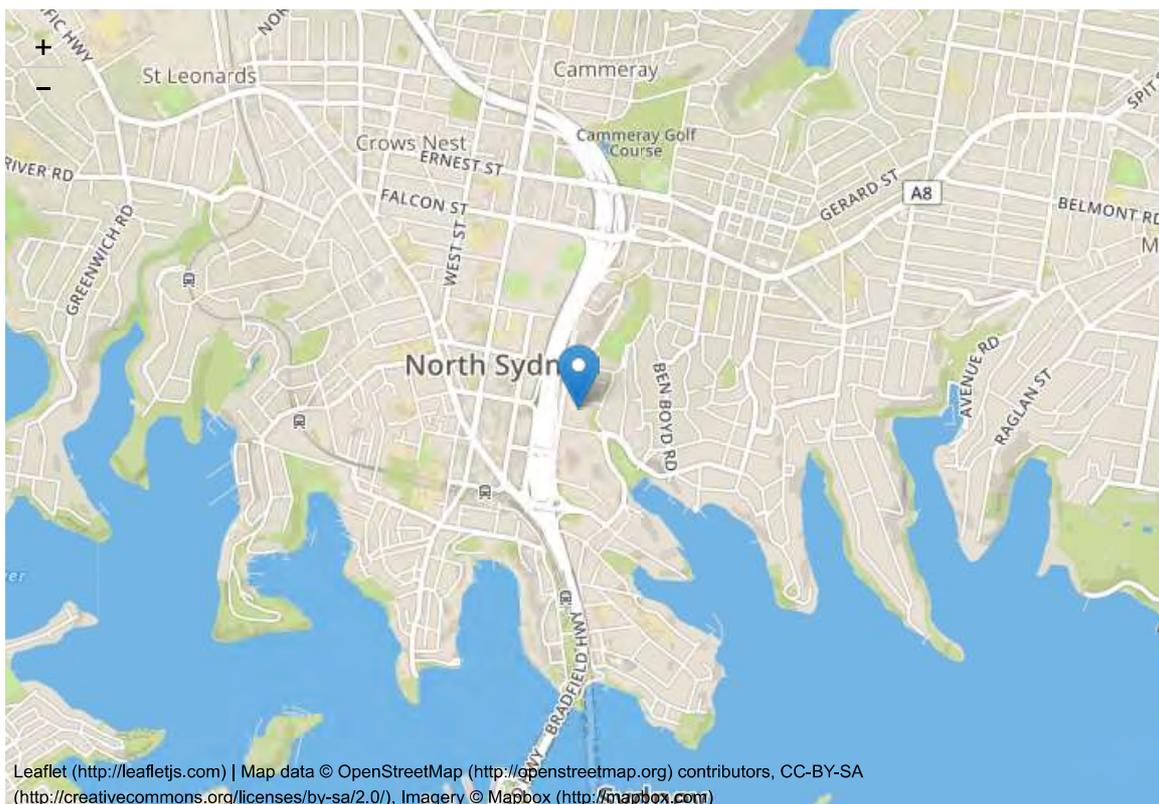
07/09/2018

Results | ARR Data Hub

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	151.213
Latitude	-33.837
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
Interim Climate Change Factors	show



Region Information

Data Category	Region
---------------	--------

<http://data.arr-software.org/>

1/10

07/09/2018

Results | ARR Data Hub

Data Category	Region
River Region	Sydney Coast-Georges River
ARF Parameters	SE Coast
Temporal Patterns	East Coast South

Data

River Region

division	South East Coast (NSW)
rivregnum	13
River Region	Sydney Coast-Georges River

Layer Info

Time Accessed	07 September 2018 03:26PM
Version	2016_v1

07/09/2018

Results | ARR Data Hub

ARF Parameters

Long Duration ARF

$$ARF = Min \left\{ 1, \left[1 - a (Area^b - c \log_{10} Duration) Duration^{-d} + e Area^f Duration^g (0.3 + \log_{10} AEP) + h 10^{i Area \frac{Duration}{1440}} (0.3 + \log_{10} AEP) \right] \right\}$$

Zone	a	b	c	d	e	f	g	h	i
SE Coast	0.06	0.361	0.0	0.317	8.11e-05	0.651	0.0	0.0	0.0

Short Duration ARF

$$ARF = Min \left[1, 1 - 0.287 (Area^{0.265} - 0.439 \log_{10}(Duration)) \cdot Duration^{-0.36} + 2.26 \times 10^{-3} \times Area^{0.226} \cdot Duration^{0.125} (0.3 + \log_{10}(AEP)) + 0.0141 \times Area^{0.213} \times 10^{-0.021 \frac{(Duration-180)^2}{1440}} (0.3 + \log_{10}(AEP)) \right]$$

Layer Info

Time Accessed	07 September 2018 03:26PM
Version	2016_v1

Storm Losses

Note: Burst Loss = Storm Loss - Preburst

Note: These losses are only for rural use and are **NOT FOR USE** in urban areas

id	17135.0
Storm Initial Losses (mm)	28.0
Storm Continuing Losses (mm/h)	1.6

Layer Info

07/09/2018

Results | ARR Data Hub

Time Accessed	07 September 2018 03:26PM
Version	2016_v1

Temporal Patterns | Download (.zip) (./temporal_patterns/tp/ECsouth.zip)

code	ECsouth
Label	East Coast South

Layer Info

Time Accessed	07 September 2018 03:26PM
Version	2016_v2

Areal Temporal Patterns | Download (.zip) (./temporal_patterns/areal/Areal_ECsouth.zip)

code	ECsouth
arealabel	East Coast South

Layer Info

Time Accessed	07 September 2018 03:26PM
Version	2016_v2

BOM IFD Depths

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-33.8375&longitude=151.2125&sdmin=true&sdhr=true&sdday=true&user_label=) to obtain the IFD depths for catchment centroid from the BoM website

No data	No data found at this location!
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Layer Info

<http://data.arr-software.org/>

4/10

07/09/2018

Results | ARR Data Hub

Time Accessed

07 September 2018 03:26PM

Median Preburst Depths and Ratios

Values are of the format depth (ratio) with depth in mm

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	11.0 (0.335)	7.7 (0.177)	5.6 (0.109)	3.5 (0.060)	2.1 (0.030)	1.0 (0.013)
90 (1.5)	14.0 (0.372)	9.5 (0.189)	6.5 (0.110)	3.6 (0.053)	2.1 (0.027)	1.0 (0.011)
120 (2.0)	9.3 (0.223)	7.7 (0.139)	6.6 (0.102)	5.6 (0.075)	4.2 (0.048)	3.2 (0.032)
180 (3.0)	6.8 (0.140)	6.5 (0.101)	6.3 (0.084)	6.2 (0.071)	6.9 (0.067)	7.4 (0.064)
360 (6.0)	11.1 (0.175)	17.9 (0.211)	22.3 (0.223)	26.6 (0.229)	18.9 (0.136)	13.0 (0.083)
720 (12.0)	4.8 (0.056)	11.6 (0.101)	16.2 (0.117)	20.5 (0.127)	26.1 (0.135)	30.3 (0.139)
1080 (18.0)	3.7 (0.036)	8.2 (0.059)	11.2 (0.067)	14.1 (0.072)	22.2 (0.094)	28.3 (0.106)
1440 (24.0)	0.8 (0.007)	6.3 (0.039)	9.9 (0.052)	13.3 (0.060)	21.1 (0.078)	26.9 (0.088)
2160 (36.0)	0.0 (0.000)	2.9 (0.016)	4.9 (0.021)	6.7 (0.025)	9.4 (0.029)	11.5 (0.032)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	2.0 (0.006)	3.5 (0.009)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	1.2 (0.003)	2.2 (0.005)

Layer Info

Time Accessed 07 September 2018 03:26PM

Version 2018_v1

<http://data.arr-software.org/>

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07/09/2018

Results | ARR Data Hub

Note Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

10% Preburst Depths

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time 07 September 2018 03:26PM

Accessed

Version 2018_v1

Note Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

<http://data.arr-software.org/>

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07/09/2018

Results | ARR Data Hub

25% Preburst Depths

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.4 (0.011)	0.2 (0.005)	0.1 (0.002)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
90 (1.5)	0.9 (0.023)	0.5 (0.010)	0.2 (0.004)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
120 (2.0)	0.1 (0.003)	0.1 (0.001)	0.0 (0.001)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
180 (3.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
360 (6.0)	0.1 (0.002)	0.5 (0.006)	0.8 (0.008)	1.0 (0.009)	0.4 (0.003)	0.0 (0.000)
720 (12.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
1080 (18.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	1.2 (0.005)	2.2 (0.008)
1440 (24.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.4 (0.002)	0.7 (0.002)
2160 (36.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
2880 (48.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)
4320 (72.0)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)	0.0 (0.000)

Layer Info

Time Accessed	07 September 2018 03:26PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

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Results | ARR Data Hub

75% Preburst Depths

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	40.2 (1.232)	37.9 (0.869)	36.4 (0.710)	34.9 (0.593)	28.4 (0.410)	23.5 (0.303)
90 (1.5)	46.8 (1.244)	39.7 (0.793)	35.1 (0.596)	30.6 (0.453)	27.8 (0.349)	25.7 (0.288)
120 (2.0)	42.0 (1.011)	37.7 (0.680)	34.8 (0.534)	32.0 (0.428)	35.9 (0.406)	38.7 (0.391)
180 (3.0)	48.1 (0.999)	45.5 (0.710)	43.8 (0.581)	42.2 (0.485)	57.0 (0.553)	68.1 (0.587)
360 (6.0)	44.0 (0.696)	60.5 (0.714)	71.4 (0.712)	81.9 (0.703)	86.5 (0.623)	90.0 (0.574)
720 (12.0)	24.6 (0.289)	37.3 (0.324)	45.8 (0.333)	53.9 (0.335)	67.0 (0.347)	76.8 (0.351)
1080 (18.0)	23.8 (0.235)	38.2 (0.275)	47.7 (0.286)	56.9 (0.290)	71.4 (0.304)	82.2 (0.309)
1440 (24.0)	12.3 (0.107)	31.6 (0.200)	44.4 (0.233)	56.7 (0.253)	67.1 (0.249)	74.8 (0.245)
2160 (36.0)	7.1 (0.052)	21.4 (0.113)	30.9 (0.136)	40.0 (0.150)	51.5 (0.160)	60.1 (0.165)
2880 (48.0)	2.8 (0.018)	7.6 (0.036)	10.7 (0.042)	13.8 (0.046)	25.1 (0.070)	33.7 (0.083)
4320 (72.0)	0.0 (0.000)	1.6 (0.007)	2.6 (0.009)	3.6 (0.011)	20.9 (0.051)	33.8 (0.074)

Layer Info

Time Accessed	07 September 2018 03:26PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

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07/09/2018

Results | ARR Data Hub

90% Preburst Depths

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	91.6 (2.805)	94.8 (2.172)	96.9 (1.890)	98.9 (1.680)	103.6 (1.496)	107.1 (1.383)
90 (1.5)	108.2 (2.877)	105.2 (2.100)	103.3 (1.754)	101.4 (1.499)	113.6 (1.425)	122.8 (1.375)
120 (2.0)	89.3 (2.146)	94.6 (1.709)	98.1 (1.508)	101.5 (1.356)	108.2 (1.224)	113.2 (1.142)
180 (3.0)	92.3 (1.916)	102.2 (1.594)	108.8 (1.441)	115.1 (1.322)	126.6 (1.227)	135.2 (1.165)
360 (6.0)	84.9 (1.344)	106.8 (1.261)	121.3 (1.209)	135.2 (1.161)	158.1 (1.139)	175.3 (1.118)
720 (12.0)	50.6 (0.596)	78.2 (0.678)	96.5 (0.700)	114.0 (0.707)	133.6 (0.692)	148.3 (0.678)
1080 (18.0)	53.6 (0.528)	81.4 (0.585)	99.9 (0.599)	117.5 (0.600)	138.3 (0.588)	153.9 (0.577)
1440 (24.0)	40.6 (0.354)	67.3 (0.425)	84.9 (0.446)	101.9 (0.455)	118.4 (0.440)	130.7 (0.428)
2160 (36.0)	31.4 (0.232)	52.3 (0.277)	66.1 (0.291)	79.3 (0.297)	100.0 (0.312)	115.6 (0.318)
2880 (48.0)	19.9 (0.132)	43.6 (0.207)	59.3 (0.234)	74.4 (0.250)	91.0 (0.254)	103.5 (0.256)
4320 (72.0)	9.5 (0.055)	21.4 (0.089)	29.3 (0.101)	36.9 (0.109)	62.7 (0.155)	82.0 (0.180)

Layer Info

Time Accessed	07 September 2018 03:26PM
Version	2018_v1
Note	Preburst interpolation methods for catchment wide preburst has been slightly altered. Point values remain unchanged.

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Results | ARR Data Hub

Interim Climate Change Factors

Values are of the format temperature increase in degrees Celcius (% increase in rainfall)

	RCP 4.5	RCP6	RCP 8.5
2030	0.892 (4.5%)	0.775 (3.9%)	0.979 (4.9%)
2040	1.121 (5.6%)	1.002 (5.0%)	1.351 (6.8%)
2050	1.334 (6.7%)	1.28 (6.4%)	1.765 (8.8%)
2060	1.522 (7.6%)	1.527 (7.6%)	2.23 (11.2%)
2070	1.659 (8.3%)	1.745 (8.7%)	2.741 (13.7%)
2080	1.78 (8.9%)	1.999 (10.0%)	3.249 (16.2%)
2090	1.825 (9.1%)	2.271 (11.4%)	3.727 (18.6%)

Layer Info

Time Accessed	07 September 2018 03:26PM
Version	2016_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values

[Download TXT \(downloads/1536298004.txt\)](downloads/1536298004.txt)
[Generating PDF... \(downloads/1536298004.pdf\)](downloads/1536298004.pdf)

APPENDIX H – HYDRAULIC STRUCTURE BLOCKAGES

BLOCKAGE ASSESSMENT FORM ARR2016

STRUCTURE: Anderson Park Channel Outlet – Culvert at Darley St

OPENING WIDTH: 1.829m (W) x 1.829m (H)

DEBRIS TYPE / MATERIAL / L₁₀ / SOURCE AREA

Debris Type/Material	L ₁₀	Source Area	How Assessed
Urban	1.5 m	Urban debris that could fit through gaps of fence	Aerial/Google Maps & Street View
Floating	1.5 m	Tree branches and sticks falling into channel from trees adjacent – fenced and thick growth	Aerial/Google Maps & Street View
Non-floating	Silt and Gravel	From Willow Tree Park and road surface	Aerial/Google Maps & Street View

DEBRIS AVAILABILITY (HML) – for the selected debris type/size and its source area

Availability	Typical Source Area Characteristics	Notes
High	<ul style="list-style-type: none"> Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter. Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements. Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse. Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course. 	
Medium	<ul style="list-style-type: none"> State forest areas with clear understory, grazing land with stands of trees Source areas generally falling between the High and Low categories. 	Floating: Potential for tree logs to fall in
Low	<ul style="list-style-type: none"> Well maintained rural lands and paddocks, with minimal outbuildings Streams with moderate to flat slopes and stable beds and banks. Arid areas where vegetation is deep rooted and soils resistant to scour Urban areas that are well maintained with limited debris present in the source area. 	Urban: Limited debris from surrounding (well maintained) Non-floating: Relatively stable channel

DEBRIS MOBILITY (HML) - for the selected debris type/size and its source area

Mobility	Typical Source Area Characteristics	Notes
High	<ul style="list-style-type: none"> Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover. Receiving streams that frequently overtop their banks. Main debris source areas close to streams 	
Medium	<ul style="list-style-type: none"> Source areas generally falling between the High and Low categories. 	Urban: fast urban catchment response, good vegetation cover Floating: fast urban catchment response, good vegetation cover

		Non-floating: fast urban catchment response, good vegetation cover
Low	<ul style="list-style-type: none"> • Low rainfall intensities and large, flat source areas. • Receiving streams that Infrequently overtop their banks. • Main source areas well away from streams 	

DEBRIS TRANSPORTABILITY (HML) - for the selected debris type/size and stream characteristics

Transportability	Typical Transporting Stream Characteristics	Notes
High	<ul style="list-style-type: none"> • Steep bed slopes (> 3%).and/or high stream velocity (V>2.5m/sec) • Deep stream relative to vertical debris dimension (D>0.5L₁₀) • Wide streams relative to horizontal debris dimension. (W>L₁₀) • Streams relatively straight and free of constrictions/snag points. • High temporal variability in maximum stream flows 	Urban: Relative deep and wide channel and velocity >2.5m/s
		Floating: Relative deep and wide channel and velocity >2.5m/s
		Non-floating: Relative deep and wide channel and velocity >2.5m/s
Medium	<ul style="list-style-type: none"> • Streams generally falling between High and Low categories 	
Low	<ul style="list-style-type: none"> • Flat bed slopes (< 1%).and/or low stream velocity (V<1m/sec) • Shallow stream relative to vertical debris dimension (D<0.5L₁₀) • Narrow streams relative to horizontal debris dimension. (W<L₁₀) • Streams meander with frequent constrictions/snag points. • Low temporal variability in maximum stream flows 	

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - for the selected debris type/size arriving at the site

Debris Potential	Combinations of the Above (any order)	Notes
High	HHH or HHM	
Medium	MMM or HML or HMM or HLL	LMH
		MMH
		LMH
Low	LLL or MML or MLL	

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - for the selected debris type/size

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted at Site Debris Potential		
	High	Medium	Low			
AEP > 5% (frequent)	Medium	Low	Low	Low	Low	Low
AEP 5% - AEP 0.5%	High	Medium	Low	Medium	Medium	Medium
AEP < 0.5%	High	High	Medium	High	High	High

MOST LIKELY DESIGN INLET BLOCKAGE LEVEL (B_{DES}%) for the selected debris type/size

Control Dimension Inlet Width W (m)	At Site 1% AEP Debris Potential			Event AEP	Bdes% Floating
	High	Medium	Low		
W < L ₁₀	100%	50%	25%	AEP > 5% (frequent)	0%
W ≥ L ₁₀ ≤ 3L ₁₀	20%	10%	0%	AEP 5% - AEP 0.5%	10%
W > 3L ₁₀	10%	0%	0%	AEP < 0.5%	20%

Note: W=1.83m ≥ L₁₀ ≤ 3L₁₀

LIKELIHOOD OF SEDIMENT BEING DEPOSITED IN WATERWAY (HML)

Peak Velocity through Structure (m/s)	Particle Type				
	Clay/Silt	Sand	Gravel	Cobbles	Boulders
>= 3	L	L	L	L	M
1.0 to 3	L	L	L	M	M
0.5 to 1	L	L	L	M	H
0.1 to 0.5	L	L	M	H	H
< 0.1	L	M	H	H	H

Note: V>3m/s

MOST LIKELY DEPOSITIONAL BLOCKAGE LEVELS – B_{DES}%

Likelihood that deposition will occur	AEP Adjusted Debris Potential			Event AEP	Bdes% Non-Floating
	High	Medium	Low		
High	100%	60%	25%	AEP > 5% (frequent)	0%
Medium	60%	40%	15%	AEP 5% - AEP 0.5%	15%
Low	25%	15%	0%	AEP < 0.5%	25%

ESTIMATED BLOCKAGE LEVELS – B_{DES}%

Event AEP	Bdes% Floating	Bdes% Non-Floating	Bdes% Final
AEP > 5% (frequent)	0%	0%	0%
AEP 5% - AEP 0.5%	10%	15%	15%
AEP < 0.5%	20%	25%	25%

BLOCKAGE ASSESSMENT FORM ARR2016

STRUCTURE: Anderson Park Channel Outlet – Culvert at Kurraba Rd

OPENING WIDTH: 3.048m (W) x 1.676m (H)

DEBRIS TYPE / MATERIAL / L₁₀ / SOURCE AREA

Debris Type/Material	L ₁₀	Source Area	How Assessed
Urban	1.5 m	Urban debris that could fit through gaps of fence	Aerial/Google Maps & Street View
Floating	0.5 m	Tree branches and sticks falling into channel from trees adjacent – well fenced	Aerial/Google Maps & Street View
Non-floating	Silt and Sand	From Warringa Park and road surface	Aerial/Google Maps & Street View

DEBRIS AVAILABILITY (HML) – for the selected debris type/size and its source area

Availability	Typical Source Area Characteristics	Notes
High	<ul style="list-style-type: none"> Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter. Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements. Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse. Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course. 	
Medium	<ul style="list-style-type: none"> State forest areas with clear understory, grazing land with stands of trees Source areas generally falling between the High and Low categories. 	
Low	<ul style="list-style-type: none"> Well maintained rural lands and paddocks, with minimal outbuildings Streams with moderate to flat slopes and stable beds and banks. Arid areas where vegetation is deep rooted and soils resistant to scour Urban areas that are well maintained with limited debris present in the source area. 	<p>Urban: Limited debris from surrounding (well maintained)</p> <p>Floating: Well fenced to stop tree logs from falling in</p> <p>Non-floating: Formalised concrete channel</p>

DEBRIS MOBILITY (HML) - for the selected debris type/size and its source area

Mobility	Typical Source Area Characteristics	Notes
High	<ul style="list-style-type: none"> Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover. Receiving streams that frequently overtop their banks. Main debris source areas close to streams 	
Medium	<ul style="list-style-type: none"> Source areas generally falling between the High and Low categories. 	<p>Urban: fast urban catchment response, good vegetation cover</p> <p>Floating: fast urban catchment response, good vegetation cover</p>

		Non-floating: fast urban catchment response, good vegetation cover
Low	<ul style="list-style-type: none"> • Low rainfall intensities and large, flat source areas. • Receiving streams that Infrequently overtop their banks. • Main source areas well away from streams 	

DEBRIS TRANSPORTABILITY (HML) - for the selected debris type/size and stream characteristics

Transportability	Typical Transporting Stream Characteristics	Notes
High	<ul style="list-style-type: none"> • Steep bed slopes (> 3%).and/or high stream velocity ($V > 2.5m/sec$) • Deep stream relative to vertical debris dimension ($D > 0.5L_{10}$) • Wide streams relative to horizontal debris dimension. ($W > L_{10}$) • Streams relatively straight and free of constrictions/snag points. • High temporal variability in maximum stream flows 	
Medium	<ul style="list-style-type: none"> • Streams generally falling between High and Low categories 	Urban: Relative deep and wide channel but velocity between 1-2m/s
		Floating: Relative deep and wide channel but velocity between 1-2m/s
		Non-floating: Relative deep and wide channel but velocity between 1-2m/s
Low	<ul style="list-style-type: none"> • Flat bed slopes (< 1%).and/or low stream velocity ($V < 1m/sec$) • Shallow stream relative to vertical debris dimension ($D < 0.5L_{10}$) • Narrow streams relative to horizontal debris dimension. ($W < L_{10}$) • Streams meander with frequent constrictions/snag points. • Low temporal variability in maximum stream flows 	

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - for the selected debris type/size arriving at the site

Debris Potential	Combinations of the Above (any order)	Notes
High	HHH or HHM	
Medium	MMM or HML or HMM or HLL	
Low	LLL or MML or MLL	LMM
		LMM
		LMM

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - for the selected debris type/size

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted at Site Debris Potential		
	High	Medium	Low			
AEP > 5% (frequent)	Medium	Low	Low	Low	Low	Low
AEP 5% - AEP 0.5%	High	Medium	Low	Low	Low	Low
AEP < 0.5%	High	High	Medium	Medium	Medium	Medium

MOST LIKELY DESIGN INLET BLOCKAGE LEVEL (B_{DES}%) for the selected debris type/size

Control Dimension Inlet Width W (m)	At Site 1% AEP Debris Potential			Event AEP	Bdes% Floating
	High	Medium	Low		
$W < L_{10}$	100%	50%	25%	AEP > 5% (frequent)	0%

$W \geq L_{10} \leq 3L_{10}$	20%	10%	0%	AEP 5% - AEP 0.5%	0%
$W > 3L_{10}$	10%	0%	0%	AEP < 0.5%	10%

Note: W (Urban - Conservative) = $3.05m \geq L_{10} \leq 3L_{10}$

LIKELIHOOD OF SEDIMENT BEING DEPOSITED IN WATERWAY (HML)

Peak Velocity through Structure (m/s)	Particle Type				
	Clay/Silt	Sand	Gravel	Cobbles	Boulders
≥ 3	L	L	L	L	M
1.0 to 3	L	L	L	M	M
0.5 to 1	L	L	L	M	H
0.1 to 0.5	L	L	M	H	H
< 0.1	L	M	H	H	H

Note: $V > 3m/s$

MOST LIKELY DEPOSITIONAL BLOCKAGE LEVELS – B_{DES}%

Likelihood that deposition will occur	AEP Adjusted Debris Potential			Event AEP	Bdes% Non-Floating
	High	Medium	Low		
High	100%	60%	25%	AEP > 5% (frequent)	0%
Medium	60%	40%	15%	AEP 5% - AEP 0.5%	0%
Low	25%	15%	0%	AEP < 0.5%	15%

ESTIMATED BLOCKAGE LEVELS – B_{DES}%

Event AEP	Bdes% Floating	Bdes% Non-Floating	Bdes% Final
AEP > 5% (frequent)	0%	0%	0%
AEP 5% - AEP 0.5%	0%	0%	0%
AEP < 0.5%	10%	15%	15%

BLOCKAGE ASSESSMENT FORM ARR2016

STRUCTURE: Reynolds St Drain Outlet

OPENING WIDTH: 0.55m (W) x 1.05m (H)

DEBRIS TYPE / MATERIAL / L₁₀ / SOURCE AREA

Debris Type/Material	L ₁₀	Source Area	How Assessed
Urban	0.5 m	Urban debris that could fit through gaps of fence	Aerial/Google Maps & Street View
Floating	0.5 m	Tree branches and sticks falling into drain from trees adjacent – fenced and lawn	Aerial/Google Maps & Street View
Non-floating	Silt and Gravel	From road surface	Aerial/Google Maps & Street View

DEBRIS AVAILABILITY (HML) – for the selected debris type/size and its source area

Availability	Typical Source Area Characteristics	Notes
High	<ul style="list-style-type: none"> Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter. Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements. Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse. Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course. 	
Medium	<ul style="list-style-type: none"> State forest areas with clear understory, grazing land with stands of trees Source areas generally falling between the High and Low categories. 	
Low	<ul style="list-style-type: none"> Well maintained rural lands and paddocks, with minimal outbuildings Streams with moderate to flat slopes and stable beds and banks. Arid areas where vegetation is deep rooted and soils resistant to scour Urban areas that are well maintained with limited debris present in the source area. 	Urban: Limited debris from surrounding (well maintained) Floating: Potential for tree branches to fall in Non-floating: Relatively stable drain

DEBRIS MOBILITY (HML) - for the selected debris type/size and its source area

Mobility	Typical Source Area Characteristics	Notes
High	<ul style="list-style-type: none"> Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover. Receiving streams that frequently overtop their banks. Main debris source areas close to streams 	
Medium	<ul style="list-style-type: none"> Source areas generally falling between the High and Low categories. 	Urban: fast urban catchment response, good vegetation cover Floating: fast urban catchment response, good vegetation cover

		Non-floating: fast urban catchment response, good vegetation cover
Low	<ul style="list-style-type: none"> Low rainfall intensities and large, flat source areas. Receiving streams that Infrequently overtop their banks. Main source areas well away from streams 	

DEBRIS TRANSPORTABILITY (HML) - for the selected debris type/size and stream characteristics

Transportability	Typical Transporting Stream Characteristics	Notes
High	<ul style="list-style-type: none"> Steep bed slopes (> 3%).and/or high stream velocity ($V > 2.5\text{m/sec}$) Deep stream relative to vertical debris dimension ($D > 0.5L_{10}$) Wide streams relative to horizontal debris dimension. ($W > L_{10}$) Streams relatively straight and free of constrictions/snag points. High temporal variability in maximum stream flows 	
Medium	<ul style="list-style-type: none"> Streams generally falling between High and Low categories 	Urban: Shallow and narrow drain. Velocity close to 2.5m/s Floating: Shallow and narrow drain. Velocity close to 2.5m/s Non-floating: Shallow and narrow drain. Velocity close to 2.5m/s
Low	<ul style="list-style-type: none"> Flat bed slopes (< 1%).and/or low stream velocity ($V < 1\text{m/sec}$) Shallow stream relative to vertical debris dimension ($D < 0.5L_{10}$) Narrow streams relative to horizontal debris dimension. ($W < L_{10}$) Streams meander with frequent constrictions/snag points. Low temporal variability in maximum stream flows 	

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - for the selected debris type/size arriving at the site

Debris Potential	Combinations of the Above (any order)	Notes
High	HHH or HHM	
Medium	MMM or HML or HMM or HLL	
Low	LLL or MML or MLL	LMM LMM LMM

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - for the selected debris type/size

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted at Site Debris Potential		
	High	Medium	Low			
AEP > 5% (frequent)	Medium	Low	Low	Low	Low	Low
AEP 5% - AEP 0.5%	High	Medium	Low	Low	Low	Low
AEP < 0.5%	High	High	Medium	Medium	Medium	Medium

MOST LIKELY DESIGN INLET BLOCKAGE LEVEL (B_{DES}%) for the selected debris type/size

Control Dimension Inlet Width W (m)	At Site 1% AEP Debris Potential			Event AEP	Bdes% Floating
	High	Medium	Low		
$W < L_{10}$	100%	50%	25%	AEP > 5% (frequent)	0%
$W \geq L_{10} \leq 3L_{10}$	20%	10%	0%	AEP 5% - AEP 0.5%	0%
$W > 3L_{10}$	10%	0%	0%	AEP < 0.5%	10%

Note: $W = 0.55\text{m} \geq L_{10} \leq 3L_{10}$

LIKELIHOOD OF SEDIMENT BEING DEPOSITED IN WATERWAY (HML)

Peak Velocity through Structure (m/s)	Particle Type				
	Clay/Silt	Sand	Gravel	Cobbles	Boulders
>= 3	L	L	L	L	M
1.0 to 3	L	L	L	M	M
0.5 to 1	L	L	L	M	H
0.1 to 0.5	L	L	M	H	H
< 0.1	L	M	H	H	H

Note: V~2.4m/s

MOST LIKELY DEPOSITIONAL BLOCKAGE LEVELS – B_{DES}%

Likelihood that deposition will occur	AEP Adjusted Debris Potential			Event AEP	Bdes% Non-Floating
	High	Medium	Low		
High	100%	60%	25%	AEP > 5% (frequent)	0%
Medium	60%	40%	15%	AEP 5% - AEP 0.5%	0%
Low	25%	15%	0%	AEP < 0.5%	15%

ESTIMATED BLOCKAGE LEVELS – B_{DES}%

Event AEP	Bdes% Floating	Bdes% Non-Floating	Bdes% Final
AEP > 5% (frequent)	0%	0%	0%
AEP 5% - AEP 0.5%	0%	0%	0%
AEP < 0.5%	10%	15%	15%

BLOCKAGE ASSESSMENT FORM ARR2016

STRUCTURE: Tunks Park Box Culverts

OPENING WIDTH: 3.07m (W) x 2.15m (H) x 6

DEBRIS TYPE / MATERIAL / L₁₀ / SOURCE AREA

Debris Type/Material	L ₁₀	Source Area	How Assessed
Urban	-	Significant distance away from nearest urban area	Aerial
Floating	3-4 m	Tree logs from forest reserve	Aerial/Google Maps & Street View
Non-floating	Gravel and silt	Upstream creek bed	Aerial/Google Maps & Street View

DEBRIS AVAILABILITY (HML) – for the selected debris type/size and its source area

Availability	Typical Source Area Characteristics	Notes
High	<ul style="list-style-type: none"> Dense forest, thick vegetation, extensive canopy, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter. Streams with boulder/cobble beds and steep bed slopes and banks showing signs of substantial past bed/bank movements. Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse. Urban areas that are not well maintained and/or old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course. 	Floating: forest reserve upstream
Medium	<ul style="list-style-type: none"> State forest areas with clear understory, grazing land with stands of trees Source areas generally falling between the High and Low categories. 	
Low	<ul style="list-style-type: none"> Well maintained rural lands and paddocks, with minimal outbuildings Streams with moderate to flat slopes and stable beds and banks. Arid areas where vegetation is deep rooted and soils resistant to scour Urban areas that are well maintained with limited debris present in the source area. 	Non-floating: relatively stable creek bed

DEBRIS MOBILITY (HML) - for the selected debris type/size and its source area

Mobility	Typical Source Area Characteristics	Notes
High	<ul style="list-style-type: none"> Steep source area with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover. Receiving streams that frequently overtop their banks. Main debris source areas close to streams 	
Medium	<ul style="list-style-type: none"> Source areas generally falling between the High and Low categories. 	Floating: relatively steep slope and fast urban catchment response, dense vegetation cover Non-floating: gravels found along creek, dense vegetation cover

Low	<ul style="list-style-type: none"> • Low rainfall intensities and large, flat source areas. • Receiving streams that infrequently overtop their banks. • Main source areas well away from streams 	
-----	--	--

DEBRIS TRANSPORTABILITY (HML) - for the selected debris type/size and stream characteristics

Transportability	Typical Transporting Stream Characteristics	Notes
High	<ul style="list-style-type: none"> • Steep bed slopes (> 3%).and/or high stream velocity ($V > 2.5m/sec$) • Deep stream relative to vertical debris dimension ($D > 0.5L_{10}$) • Wide streams relative to horizontal debris dimension. ($W > L_{10}$) • Streams relatively straight and free of constrictions/snag points. • High temporal variability in maximum stream flows 	Floating: steep slopes and high stream velocity, deep and wide stream
		Non-floating: steep slopes and high stream velocity, deep and wide stream
Medium	<ul style="list-style-type: none"> • Streams generally falling between High and Low categories 	
Low	<ul style="list-style-type: none"> • Flat bed slopes (< 1%).and/or low stream velocity ($V < 1m/sec$) • Shallow stream relative to vertical debris dimension ($D < 0.5L_{10}$) • Narrow streams relative to horizontal debris dimension. ($W < L_{10}$) • Streams meander with frequent constrictions/snag points. • Low temporal variability in maximum stream flows 	

SITE BASED DEBRIS POTENTIAL 1%AEP (HML) - for the selected debris type/size arriving at the site

Debris Potential	Combinations of the Above (any order)	Notes
High	HHH or HHM	HMH
Medium	MMM or HML or HMM or HLL	LMH
Low	LLL or MML or MLL	

AEP ADJUSTED SITE DEBRIS POTENTIAL (HML) - for the selected debris type/size

Event AEP	At Site 1% AEP Debris Potential			AEP Adjusted at Site Debris Potential	
	High	Medium	Low		
AEP > 5% (frequent)	Medium	Low	Low	Medium	Low
AEP 5% - AEP 0.5%	High	Medium	Low	High	Medium
AEP < 0.5%	High	High	Medium	High	High

MOST LIKELY DESIGN INLET BLOCKAGE LEVEL (B_{DES}%) for the selected debris type/size

Control Dimension Inlet Width W (m)	At Site 1% AEP Debris Potential			Event AEP	B _{des} % Floating
	High	Medium	Low		
$W < L_{10}$	100%	50%	25%	AEP > 5% (frequent)	10%
$W \geq L_{10} \leq 3L_{10}$	20%	10%	0%	AEP 5% - AEP 0.5%	20%
$W > 3L_{10}$	10%	0%	0%	AEP < 0.5%	20%

Note: $W = 3.07m \geq L_{10} \leq 3L_{10}$

LIKELIHOOD OF SEDIMENT BEING DEPOSITED IN WATERWAY (HML)

Peak Velocity through Structure (m/s)	Particle Type				
	Clay/Silt	Sand	Gravel	Cobbles	Boulders
≥ 3	L	L	L	L	M
1.0 to 3	L	L	L	M	M
0.5 to 1	L	L	L	M	H

0.1 to 0.5	L	L	M	H	H
< 0.1	L	M	H	H	H

Note: V>3.5m/s

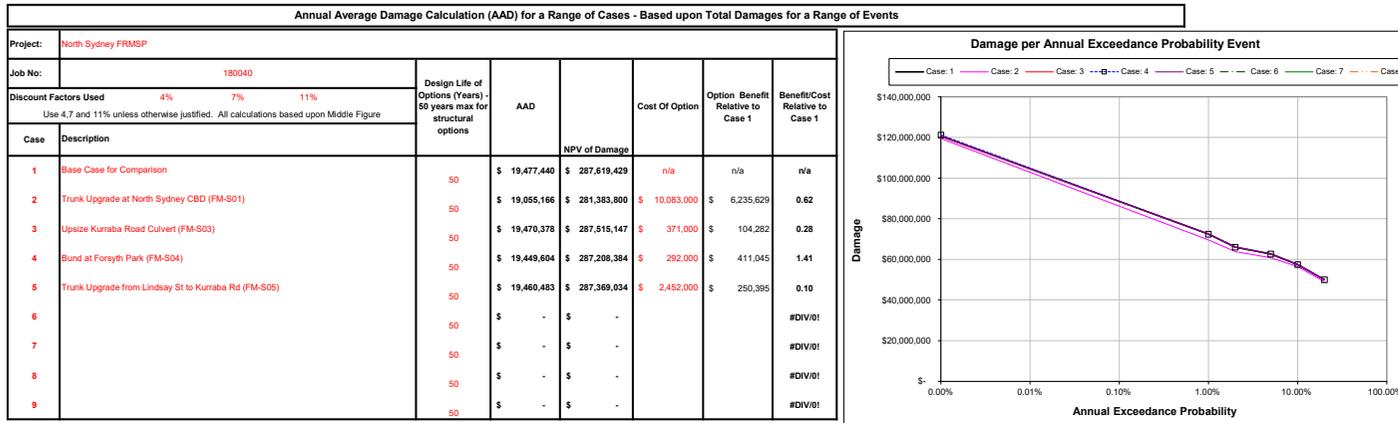
MOST LIKELY DEPOSITIONAL BLOCKAGE LEVELS – B_{DES}%

Likelihood that deposition will occur	AEP Adjusted Debris Potential			Event AEP	Bdes% Non-Floating
	High	Medium	Low		
High	100%	60%	25%	AEP > 5% (frequent)	0%
Medium	60%	40%	15%	AEP 5% - AEP 0.5%	15%
Low	25%	15%	0%	AEP < 0.5%	25%

ESTIMATED BLOCKAGE LEVELS – B_{DES}%

Event AEP	Bdes% Floating	Bdes% Non-Floating	Bdes% Final
AEP > 5% (frequent)	10%	0%	10%
AEP 5% - AEP 0.5%	20%	15%	20%
AEP < 0.5%	20%	25%	25%

APPENDIX I – FLOOD DAMAGES CALCULATION



AAD Calculation for Various Cases

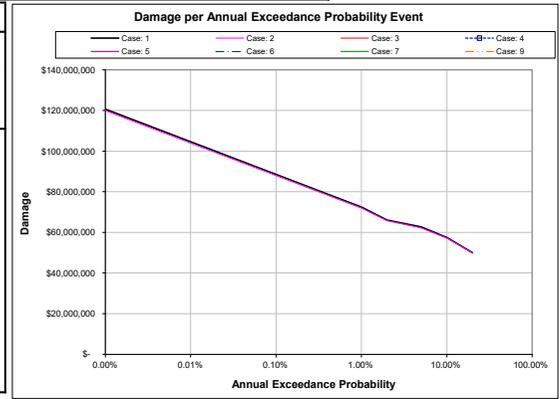
AEP	Case: 1		Case: 2		Case: 3		Case: 4		Case: 5		Case: 6		Case: 7		Case: 8		Case: 9	
	AEP Event Damage	Contribution to AAD																
0.001%	\$ 120,634,127	\$ 954,687	\$ 119,537,682	\$ 944,449	\$ 120,599,570	\$ 954,332	\$ 121,214,487	\$ 967,014	\$ 120,739,723	\$ 954,715	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
1.0%	\$ 72,492,355	\$ 692,826	\$ 69,541,193	\$ 666,506	\$ 72,459,927	\$ 692,307	\$ 72,381,894	\$ 691,833	\$ 72,396,448	\$ 691,807	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
2.0%	\$ 66,072,694	\$ 1,931,935	\$ 63,760,037	\$ 1,869,361	\$ 66,001,571	\$ 1,929,094	\$ 65,944,607	\$ 1,928,054	\$ 65,964,920	\$ 1,929,554	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
5.0%	\$ 62,722,790	\$ 3,005,384	\$ 60,864,051	\$ 2,934,851	\$ 62,604,674	\$ 3,002,293	\$ 62,592,356	\$ 3,000,299	\$ 62,672,022	\$ 3,002,857	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
10.0%	\$ 57,492,561	\$ 5,376,628	\$ 56,529,979	\$ 5,279,874	\$ 57,487,040	\$ 5,376,352	\$ 57,419,591	\$ 5,368,886	\$ 57,442,262	\$ 5,371,972	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
20.0%	\$ 50,039,998	\$ 7,506,000	\$ 49,067,500	\$ 7,360,125	\$ 50,039,998	\$ 7,506,000	\$ 49,958,125	\$ 7,493,719	\$ 49,997,184	\$ 7,499,578	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
50.0%	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
100.0%	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
TOTAL AAD		\$ 19,477,440	TOTAL AAD	\$ 19,055,166	TOTAL AAD	\$ 19,470,378	TOTAL AAD	\$ 19,449,604	TOTAL AAD	\$ 19,460,483	TOTAL AAD	\$ -						

Summary of NPV of Damages for Options

Discount Factor	Case								
	1	2	3	4	5	6	7	8	9
Applicable Timeframe For Option yrs (Max 50)	50	50	50	50	50	50	50	50	50
4%	\$ 435,154,675	\$ 425,720,462	\$ 434,996,901	\$ 434,532,783	\$ 434,775,840	\$ -	\$ -	\$ -	\$ -
7%	\$ 287,619,429	\$ 281,383,800	\$ 287,615,147	\$ 287,208,384	\$ 287,369,034	\$ -	\$ -	\$ -	\$ -
11%	\$ 195,480,163	\$ 191,242,126	\$ 195,409,288	\$ 195,200,797	\$ 195,309,983	\$ -	\$ -	\$ -	\$ -

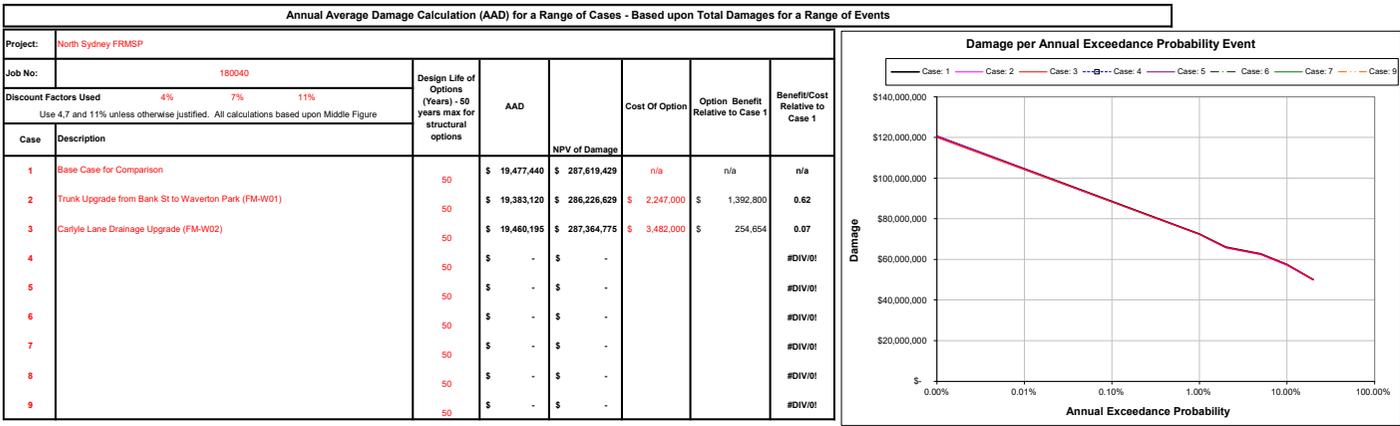
Annual Average Damage Calculation (AAD) for a Range of Cases - Based upon Total Damages for a Range of Events

Project:	North Sydney FRMSP							
Job No:	180040							
Discount Factors Used	4%	7%	11%	Design Life of Options (Years) - 50 years max for structural options	AAD	NPV of Damage	Option Benefit Relative to Case 1	Benefit/Cost Relative to Case 1
Use 4.7 and 11% unless otherwise justified. All calculations based upon Middle Figure								
Case	Description							
1	Base Case for Comparison		50	\$ 19,477,440	\$ 237,619,429	n/a	n/a	n/a
2	Trunk Upgrade from Yeo St to Bogota Ave (FM-E01)		50	\$ 19,372,139	\$ 286,064,477	\$ 3,803,000	1,554,952	0.41
3			50	\$ -	\$ -			#DIV/0!
4			50	\$ -	\$ -			#DIV/0!
5			50	\$ -	\$ -			#DIV/0!
6			50	\$ -	\$ -			#DIV/0!
7			50	\$ -	\$ -			#DIV/0!
8			50	\$ -	\$ -			#DIV/0!
9			50	\$ -	\$ -			#DIV/0!



AAD Calculation for Various Cases																		
AEP	Case: 1 AEP Event Damage	Contribution to AAD	Case: 2 AEP Event Damage	Contribution to AAD	Case: 3 AEP Event Damage	Contribution to AAD	Case: 4 AEP Event Damage	Contribution to AAD	Case: 5 AEP Event Damage	Contribution to AAD	Case: 6 AEP Event Damage	Contribution to AAD	Case: 7 AEP Event Damage	Contribution to AAD	Case: 8 AEP Event Damage	Contribution to AAD	Case: 9 AEP Event Damage	Contribution to AAD
0.001%	\$ 120,634,127	\$ 964,667	\$ 119,881,354	\$ 958,516	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
1.0%	\$ 72,492,355	\$ 692,826	\$ 72,013,610	\$ 688,949	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
2.0%	\$ 66,072,894	\$ 1,931,935	\$ 65,776,284	\$ 1,920,174	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
5.0%	\$ 62,722,790	\$ 3,005,384	\$ 62,235,346	\$ 2,984,850	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
10.0%	\$ 57,492,561	\$ 5,376,628	\$ 57,158,660	\$ 5,348,362	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
20.0%	\$ 50,039,998	\$ 7,506,000	\$ 49,808,584	\$ 7,471,288	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
50.0%																		
	TOTAL AAD	\$ 19,477,440	TOTAL AAD	\$ 19,372,139	TOTAL AAD	\$ -												

Summary of NPV of Damages for Options									
Discount Factor	Case								
	1	2	3	4	5	6	7	8	9
Applicable Timeframe For Option yrs (Max 50)	50	50	50	50	50	50	50	50	50
4%	\$ 436,154,675	\$ 432,802,106	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
7%	\$ 287,619,429	\$ 286,064,477	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
11%	\$ 195,480,163	\$ 194,423,342	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -



AAD Calculation for Various Cases

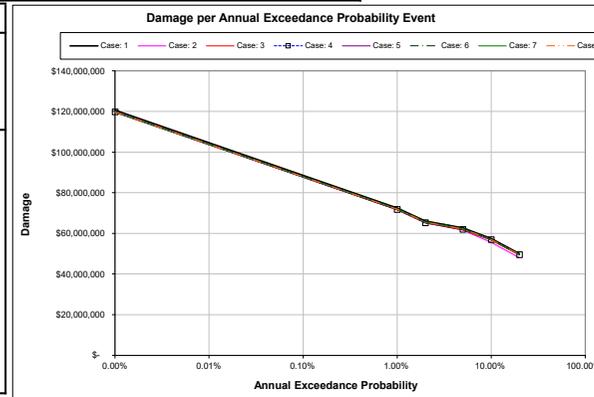
AEP	Case: 1		Case: 2		Case: 3		Case: 4		Case: 5		Case: 6		Case: 7		Case: 8		Case: 9	
	AEP Event Damage	Contribution to AAD	AEP Event Damage	Contribution to AAD	AEP Event Damage	Contribution to AAD	AEP Event Damage	Contribution to AAD	AEP Event Damage	Contribution to AAD	AEP Event Damage	Contribution to AAD	AEP Event Damage	Contribution to AAD	AEP Event Damage	Contribution to AAD	AEP Event Damage	Contribution to AAD
0.001%	\$ 120,634,127	\$ 964,667	\$ 120,515,411	\$ 962,944	\$ 119,985,401	\$ 960,896	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
1.0%	\$ 72,492,355	\$ 692,826	\$ 72,266,091	\$ 689,852	\$ 72,386,198	\$ 691,794	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
2.0%	\$ 66,072,894	\$ 1,931,935	\$ 65,704,380	\$ 1,620,966	\$ 65,972,629	\$ 1,929,414	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
5.0%	\$ 62,722,790	\$ 3,005,384	\$ 62,360,001	\$ 2,985,496	\$ 62,654,990	\$ 3,003,327	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
10.0%	\$ 57,492,561	\$ 5,376,628	\$ 57,059,845	\$ 5,345,710	\$ 57,478,085	\$ 5,374,119	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
20.0%	\$ 50,039,998	\$ 7,506,000	\$ 49,854,350	\$ 7,478,152	\$ 50,004,295	\$ 7,500,644	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
50.0%	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
100.0%	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
	TOTAL AAD	\$ 19,477,440	TOTAL AAD	\$ 19,383,120	TOTAL AAD	\$ 19,460,195	TOTAL AAD	\$ -										

Summary of NPV of Damages for Options

Discount Factor	Case								
	1	2	3	4	5	6	7	8	9
Applicable Timeframe For Option yrs (Max 50)	50	50	50	50	50	50	50	50	50
4%	\$ 435,154,675	\$ 433,047,434	\$ 434,769,395	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
7%	\$ 287,619,429	\$ 286,226,629	\$ 287,364,775	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
11%	\$ 195,460,163	\$ 194,533,548	\$ 195,307,088	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -

Annual Average Damage Calculation (AAD) for a Range of Cases - Based upon Total Damages for a Range of Events

Project:	North Sydney FRMSP								
Job No:	180040								
Discount Factors Used	4%	7%	11%	Design Life of Options (Years) - 50 years max for structural options	AAD	NPV of Damage	Cost Of Option	Option Benefit Relative to Case 1	Benefit/Cost Relative to Case 1
Use 4.7 and 11% unless otherwise justified. All calculations based upon Middle Figure									
Case	Description								
1	Base Case for Comparison	50	\$ 19,477,440	\$ 287,619,429	n/a	n/a	n/a		
2	Pacific Highway to Flat Rock Creek Trunk (FM-N01)	50	\$ 18,857,510	\$ 278,465,044	\$ 8,866,000	\$ 9,154,385	1.03		
3	Bund at St Leonards Park (FM-N02)	50	\$ 19,198,140	\$ 283,495,072	\$ 418,000	\$ 4,124,357	9.87		
4	Anzac Park Basin (FM-N03)	50	\$ 19,275,338	\$ 284,635,030	\$ 9,988,000	\$ 2,984,399	0.30		
5	Trunk Upgrade from Anzac Park to Willoughby Creek and Warringa Rd Drainage Upgrade (FM-N05+N08)	50	\$ 19,265,423	\$ 284,488,517	\$ 16,359,000	\$ 3,130,812	0.19		
6	Reynolds Street Drainage Upgrade (FM-N06)	50	\$ 19,347,822	\$ 285,702,435	\$ 4,041,000	\$ 1,916,994	0.47		
7	Cooper Lane Drainage Upgrade (FM-N07)	50	\$ 19,282,088	\$ 284,734,707	\$ 6,068,000	\$ 2,884,722	0.48		
8	Cassins Avenue Drainage Upgrade (FM-N09)	50	\$ 19,346,861	\$ 285,691,199	\$ 2,021,000	\$ 1,928,230	0.95		
9	Cammeray Golf Club Basin (FM-N11)	50	\$ 19,301,714	\$ 285,024,516	\$ 1,351,000	\$ 2,594,913	1.92		



AAD Calculation for Various Cases																		
AEP	Case: 1		Case: 2		Case: 3		Case: 4		Case: 5		Case: 6		Case: 7		Case: 8		Case: 9	
	AEP Event Damage	Contribution to AAD																
0.001%	\$ 120,634,127	\$ 954,667	\$ 119,594,991	\$ 954,892	\$ 119,780,755	\$ 955,843	\$ 119,776,743	\$ 956,871	\$ 119,727,376	\$ 956,141	\$ 119,826,338	\$ 960,126	\$ 119,599,049	\$ 956,596	\$ 119,786,013	\$ 960,430	\$ 119,804,432	\$ 957,672
1.0%	\$ 72,492,355	\$ 692,826	\$ 71,684,544	\$ 684,734	\$ 71,579,226	\$ 683,336	\$ 71,789,048	\$ 685,182	\$ 71,692,244	\$ 685,022	\$ 72,391,158	\$ 692,320	\$ 71,911,752	\$ 686,848	\$ 72,492,355	\$ 692,872	\$ 71,921,652	\$ 687,205
2.0%	\$ 66,072,894	\$ 1,931,935	\$ 65,282,247	\$ 1,903,163	\$ 65,088,032	\$ 1,901,421	\$ 65,247,335	\$ 1,907,702	\$ 65,312,140	\$ 1,909,070	\$ 66,072,894	\$ 1,931,935	\$ 65,457,945	\$ 1,913,513	\$ 66,082,139	\$ 1,931,545	\$ 65,519,257	\$ 1,915,326
5.0%	\$ 62,722,790	\$ 3,005,384	\$ 61,595,299	\$ 2,929,607	\$ 61,673,339	\$ 2,958,890	\$ 61,932,809	\$ 2,971,275	\$ 61,959,173	\$ 2,970,430	\$ 62,722,790	\$ 2,992,802	\$ 62,109,600	\$ 2,972,513	\$ 62,687,561	\$ 2,991,806	\$ 62,169,153	\$ 2,978,873
10.0%	\$ 57,492,561	\$ 5,376,628	\$ 55,588,978	\$ 5,180,865	\$ 56,682,251	\$ 5,300,247	\$ 56,918,199	\$ 5,323,009	\$ 56,858,017	\$ 5,318,366	\$ 56,989,293	\$ 5,329,708	\$ 56,790,900	\$ 5,317,813	\$ 56,984,670	\$ 5,329,477	\$ 56,985,773	\$ 5,327,626
20.0%	\$ 50,039,998	\$ 7,506,000	\$ 48,028,324	\$ 7,204,249	\$ 49,322,691	\$ 7,398,404	\$ 49,541,987	\$ 7,431,298	\$ 49,509,298	\$ 7,426,395	\$ 49,604,866	\$ 7,440,730	\$ 49,565,361	\$ 7,434,804	\$ 49,604,866	\$ 7,440,730	\$ 49,566,746	\$ 7,435,012
50.0%	TOTAL AAD	\$ 19,477,440	TOTAL AAD	\$ 18,857,510	TOTAL AAD	\$ 19,198,140	TOTAL AAD	\$ 19,275,338	TOTAL AAD	\$ 19,265,423	TOTAL AAD	\$ 19,347,822	TOTAL AAD	\$ 19,282,088	TOTAL AAD	\$ 19,346,861	TOTAL AAD	\$ 19,301,714

Summary of NPV of Damages for Options									
Discount Factor	Case								
	1	2	3	4	5	6	7	8	9
Applicable Timeframe For Option yrs (Max 50)	50	50	50	50	50	50	50	50	50
4%	\$ 435,154,675	\$ 421,304,521	\$ 428,914,716	\$ 430,639,420	\$ 430,417,804	\$ 432,254,353	\$ 430,790,227	\$ 432,237,354	\$ 431,228,693
7%	\$ 287,819,429	\$ 278,465,044	\$ 283,495,072	\$ 284,635,030	\$ 284,488,517	\$ 285,702,435	\$ 284,734,707	\$ 285,691,199	\$ 285,024,516
11%	\$ 195,480,163	\$ 189,258,398	\$ 192,677,049	\$ 193,451,820	\$ 193,352,311	\$ 194,177,281	\$ 193,519,566	\$ 194,169,644	\$ 193,716,534

APPENDIX J – PRELIMINARY COSTINGS

Cost Estimate - S01 Trunk Upgrade at North Sydney CBD					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 1,309,392.10
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	3813	m2	\$ 13,344.96
2.2	Excavation of fill (soft rock)	221	16796	m3	\$ 3,711,966.29
2.3	Supply and install of 1.2 m diameter pipe	1050	480	m	\$ 503,791.77
	Supply and install of 1.5 m diameter pipe	1680	356	m	\$ 597,742.99
	Supply and install of 1.2 x 1.6 m culvert	1790	64	m	\$ 114,723.03
	Supply and install of 1.2 x 1.9 m culvert	1981	158	m	\$ 313,117.63
2.4	Disposal of displaced pipe volume fill	300	1655	m3	\$ 496,481.26
2.5	Drainage pit, assume 1 per 50 m	2000	21	each	\$ 42,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	3813	m2	\$ 158,614.33
2.6	Adjustment of existing services (assume 10% works cost)				\$ 595,178.23
3	Contingency (assume 20% works cost)				\$ 1,309,392.10
				Subtotal	\$ 9,165,744.69
				GST	\$ 916,574.47
				Total	\$ 10,082,319.16

Cost Estimate - S03 Upsize Kurraba Road Culvert					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
				Assume 20% of works cost	\$ 48,071.71
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	194	m2	\$ 680.05
2.2	Excavation of fill (soft rock)	221	544	m3	\$ 120,232.84
2.3	Supply and install of 3.8 m x 1.8 m culvert	620	34	m	\$ 20,770.00
2.4	Disposal of displaced pipe volume fill	300	229	m3	\$ 68,742.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	194	m2	\$ 8,082.88
2.6	Adjustment of existing services (assume 10% works cost)				\$ 21,850.78
3	Contingency (assume 20% works cost)				\$ 48,071.71
				Subtotal	\$ 336,501.97
				GST	\$ 33,650.20
				Total	\$ 370,152.16

Cost Estimate - S04 Bund at Forsyth Park					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
				Assume 20% of works cost	\$ 37,824.61
2	Construction				
2.1	Excavation of fill	\$22.00	1397.3	m3	\$ 30,739.72
2.2	Haulage of fill (assumed <10 km)	\$13.80	1397.3	m3	\$ 19,282.19
2.3	Placement, compaction and shaping	\$6.50	838.3	m2	\$ 5,448.88
2.4	Top soil placement	\$10.60	838.3	m2	\$ 8,885.86
2.5	Hydro mulch, sprayed grass seed compound	\$3,250.00	0.1	ha	\$ 272.44
2.6	Geotextile layer for embankment	64	1677		\$ 107,300.93
2.7	Adjustment of existing services (assume 10% works cost)				\$ 17,193.00
3	Contingency (assume 20% works cost)				\$ 37,824.61
				Subtotal	\$ 264,772.24
				GST	\$ 26,477.22
				Total	\$ 291,249.46

Cost Estimate - S05 Trunk Upgrade from Lindsay St to Kurraba Rd					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 318,347.91
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	3102	m2	\$ 10,858.68
2.2	Excavation of fill (soft rock)	221	3405	m3	\$ 752,415.92
2.3	Supply and install of 0.375 m diameter pipe	202	32	m	\$ 6,378.69
	Supply and install of 0.45 m diameter pipe	246	744	m	\$ 182,933.91
	Supply and install of 0.6 m diameter pipe	323	28	m	\$ 9,021.00
	Supply and install of 0.675 m diameter pipe	429	19	m	\$ 8,108.16
	Supply and install of 0.75 m diameter pipe	534	47	m	\$ 25,352.66
	Supply and install of 0.9 m diameter pipe	706	73	m	\$ 51,502.14
	Supply and install of 0.75 x 0.75 m culvert	701	117	m	\$ 81,831.72
	Supply and install of 0.9 x 0.9 m culvert	1009	13	m	\$ 13,114.84
	Supply and install of 1.3 x 1.3 m culvert	1668	25	m	\$ 41,749.03
2.4	Disposal of displaced pipe volume fill	300	322	m3	\$ 96,706.05
2.5	Drainage pit, assume 1 per 50 m	2000	19	each	\$ 38,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	3102	m2	\$ 129,063.17
2.6	Adjustment of existing services (assume 10% works cost)				\$ 144,703.60
3	Contingency (assume 20% works cost)				\$ 318,347.91
				Subtotal	\$ 2,228,435.39
				GST	\$ 222,843.54
				Total	\$ 2,451,278.93

Cost Estimate - E01 Trunk Upgrade from Yeo St to Bogota Ave					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 493,777.44
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	2855	m2	\$ 9,993.51
2.2	Excavation of fill (soft rock)	221	5751	m3	\$ 1,270,908.03
2.3	Supply and install of 0.3 m diameter pipe	158.5	24	m	\$ 3,783.82
	Supply and install of 0.675 m diameter pipe	429	273	m	\$ 117,152.50
	Supply and install of 0.825 m diameter pipe	620	62	m	\$ 38,634.93
	Supply and install of 1.5 m diameter pipe	1680	268	m	\$ 450,240.00
	Supply and install of 2.1 m diameter pipe	3293	6	m	\$ 20,539.76
2.4	Disposal of displaced pipe volume fill	300	628	m3	\$ 188,410.36
2.5	Drainage pit, assume 1 per 50 m	2000	13	each	\$ 26,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	2855	m2	\$ 118,780.00
2.6	Adjustment of existing services (assume 10% works cost)				\$ 224,444.29
3	Contingency (assume 20% works cost)				\$ 493,777.44
				Subtotal	\$ 3,456,442.09
				GST	\$ 345,644.21
				Total	\$ 3,802,086.30

Cost Estimate - W01 Trunk Upgrade from Bank St to Waverton Park					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 291,706.40
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	1118	m2	\$ 3,912.23
2.2	Excavation of fill (soft rock)	221	3832	m3	\$ 846,791.32
2.3	Supply and install of 0.825 m diameter pipe	620	283	m	\$ 175,208.40
	Supply and install of 1.05 m diameter pipe	667	203	m	\$ 135,453.49
2.4	Disposal of displaced pipe volume fill	300	327	m3	\$ 98,073.05
2.5	Drainage pit, assume 1 per 50 m	2000	10	each	\$ 20,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	1118	m2	\$ 46,499.68
2.6	Adjustment of existing services (assume 10% works cost)				\$ 132,593.82
3	Contingency (assume 20% works cost)				\$ 291,706.40
				Subtotal	\$ 2,041,944.79
				GST	\$ 204,194.48
				Total	\$ 2,246,139.27

Cost Estimate - W02 Carlyle Lane Drainage Upgrade					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 452,090.85
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	1715	m2	\$ 6,001.42
2.2	Excavation of fill (soft rock)	221	4870	m3	\$ 1,076,185.07
2.3	Supply and install of 1.8 m diameter pipe	2419	12	m	\$ 27,867.08
	Supply and install of 1.8 m x 0.9 m culvert	1630	401	m	\$ 653,876.71
2.4	Disposal of displaced pipe volume fill	300	679	m3	\$ 203,696.92
2.5	Drainage pit, assume 1 per 50 m	2000	8	each	\$ 16,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	1715	m2	\$ 71,331.21
2.6	Adjustment of existing services (assume 10% works cost)				\$ 205,495.84
3	Contingency (assume 20% works cost)				\$ 452,090.85
				Subtotal	\$ 3,164,635.96
				GST	\$ 316,463.60
				Total	\$ 3,481,099.56

Cost Estimate - N01 Pacific Highway to Flat Rock Creek Trunk					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
			Assume 20% of works cost		\$ 1,151,421.22
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	4011	m2	\$ 14,038.09
2.2	Excavation of fill (soft rock)	221	12925	m3	\$ 2,856,426.05
2.3	Supply and install of 1.35 m diameter pipe	1365	1197	m	\$ 1,634,284.96
2.4	Disposal of displaced pipe volume fill	300	1714	m3	\$ 514,131.02
2.5	Drainage pit, assume 1 per 50 m	2000	24	each	\$ 48,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	4011	m2	\$ 166,852.71
2.6	Adjustment of existing services (assume 10% works cost)				\$ 523,373.28
3	Contingency (assume 20% works cost)				\$ 1,151,421.22
				Subtotal	\$ 8,059,948.55
				GST	\$ 805,994.86
				Total	\$ 8,865,943.41

Cost Estimate - N02 Bund at St Leonards Park					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
				Assume 20% of works cost	\$ 54,163.18
2	Construction				
2.1	Excavation of fill	\$22.00	1620.5	m3	\$ 35,652.04
2.2	Haulage of fill (assumed <50 km)	\$69.00	1620.5	m3	\$ 111,817.77
2.3	Placement, compaction and shaping	\$6.50	678.9	m2	\$ 4,412.74
2.4	Top soil placement	\$10.60	678.9	m2	\$ 7,196.15
2.5	Hydro mulch, sprayed grass seed compound	\$3,250.00	0.1	ha	\$ 220.64
2.5	Geotextile layer for embankment	64	1358		\$ 86,896.95
2.6	Adjustment of existing services (assume 10% works cost)				\$ 24,619.63
3	Contingency (assume 20% works cost)				\$ 54,163.18
				Subtotal	\$ 379,142.28
				GST	\$ 37,914.23
				Total	\$ 417,056.51

Cost Estimate - N03 Anzac Park Basin					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 1,297,062.80
2	Construction				
2.1	Disposal of excess fill	\$300.00	17684.9	m3	\$ 5,305,468.60
2.2	Excavation of lowered basin area (soil)	\$30.00	18395.0	m3	\$ 551,850.23
2.3	Placement, compaction and shaping	\$6.50	471.9	m2	\$ 3,067.09
2.4	Top soil placement	\$10.60	471.9	m2	\$ 5,001.72
2.5	Hydro mulch, sprayed grass seed compound	\$3,250.00	0.0	ha	\$ 153.35
2.5	Geotextile layer for embankment	64	472		\$ 30,199.04
2.6	Adjustment of existing services (assume 10% works cost)				\$ 589,574.00
3	Contingency (assume 20% works cost)				\$ 1,297,062.80
				Subtotal	\$ 9,079,439.63
				GST	\$ 907,943.96
				Total	\$ 9,987,383.60

Cost Estimate - N05 Trunk Upgrade from Anzac Park to Willoughby Creek					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 2,028,922.76
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	5902	m2	\$ 20,658.21
2.2	Excavation of fill (soft rock)	221	31102	m3	\$ 6,873,492.76
2.3	Supply and install of 2.4 x 3.05 m culvert	4654	18	m	\$ 84,298.41
	Supply and install of 3.6 x 1.6 m culvert	3826	166	m	\$ 635,169.93
	Supply and install of 4.2 x 1.6 m culvert	4336	161	m	\$ 698,016.81
2.4	Disposal of displaced pipe volume fill	300	2171	m3	\$ 651,202.54
2.5	Drainage pit, assume 1 per 50 m	2000	7	each	\$ 14,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	5902	m2	\$ 245,537.55
2.6	Adjustment of existing services (assume 10% works cost)				\$ 922,237.62
3	Contingency (assume 20% works cost)				\$ 2,028,922.76
				Subtotal	\$ 14,202,459.35
				GST	\$ 1,420,245.94
				Total	\$ 15,622,705.29

Cost Estimate - N08 Warringa Road Drainage Upgrade					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs	0	0	0	0
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
0	Assume 20% works cost				\$ 95,552.46
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	481	m2	\$ 1,682
2.2	Excavation of fill (soft rock)	221	1167	m3	\$ 257,849
2.3	Supply and install of 0.6 m diameter pipe	323	34	m	\$ 11,096
	Supply and install of 0.675 m diameter pipe	428.5	38	m	\$ 16,212
	Supply and install of 0.75 m diameter pipe	534	16	m	\$ 8,655
	Supply and install of 0.9 m diameter pipe	706	34	m	\$ 23,727
	Supply and install of 1.05 m diameter pipe	878	25	m	\$ 22,194
	Supply and install of 1.5 m diameter pipe	1680	20	m	\$ 34,066
2.4	Disposal of displaced pipe volume fill	300	110	m3	\$ 32,854
2.5	Drainage pit, assume 1 per 50 m	2000	3	each	\$ 6,000
2.5	Backfilling, compaction and reinstate disturbed road pavement	41.6	481	m2	\$ 19,994
2.6	Adjustment of existing services (assume 10% works cost)				\$ 43,433
3	Contingency (assume 20% works cost)				\$ 95,552
				Subtotal	\$ 668,867
				GST	\$ 66,887
				Total	\$ 735,754

Cost Estimate - N06 Reynolds Street Drainage Upgrade					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 524,758.09
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	2044	m2	\$ 7,154.00
2.2	Excavation of fill (soft rock)	221	5630	m3	\$ 1,244,318.81
2.3	Supply and install of 0.45 m diameter pipe	246	51	m	\$ 12,587.95
	Supply and install of 0.6 m diameter pipe	323	68	m	\$ 22,078.51
	Supply and install of 1.05 m diameter pipe	878	135	m	\$ 118,806.46
	Supply and install of 0.55 x 1.05 m culvert	719	38	m	\$ 27,051.90
	Supply and install of 1.1 x 1.1 m culvert	1413	54	m	\$ 76,302.44
	Supply and install of 2 x 1.5 m culvert	2362	127	m	\$ 299,284.46
	Supply and install of 2 x 2 m culvert	2893	70	m	\$ 202,939.86
2.4	Disposal of displaced pipe volume fill	300	892	m3	\$ 267,709.26
2.5	Drainage pit, assume 1 per 50 m	2000	11	each	\$ 22,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	2044	m2	\$ 85,030.39
2.6	Adjustment of existing services (assume 10% works cost)				\$ 238,526.40
3	Contingency (assume 20% works cost)				\$ 524,758.09
				Subtotal	\$ 3,673,306.63
				GST	\$ 367,330.66
				Total	\$ 4,040,637.29

Cost Estimate - N07 Cooper Lane Drainage Upgrade					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
					Assume 20% of works cost
					\$ 788,024.29
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	3273	m2	\$ 11,456.77
2.2	Excavation of fill (soft rock)	221	7879	m3	\$ 1,741,264.45
2.3	Supply and install of 0.9 m diameter pipe	706	311	m	\$ 219,566.00
	Supply and install of 1.2 m diameter pipe	1050	68	m	\$ 70,934.64
	Supply and install of 1.5 m diameter pipe	1680	175	m	\$ 293,341.98
	Supply and install of 2.25 m diameter pipe	3780	24	m	\$ 90,711.68
	Supply and install of 1.6 x 1.1 m culvert	2893	229	m	\$ 662,155.16
2.4	Disposal of displaced pipe volume fill	300	1081	m3	\$ 324,326.07
2.5	Drainage pit, assume 1 per 50 m	2000	16	each	\$ 32,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	3273	m2	\$ 136,171.85
2.6	Adjustment of existing services (assume 10% works cost)				\$ 358,192.86
3	Contingency (assume 20% works cost)				\$ 788,024.29
				Subtotal	\$ 5,516,170.03
				GST	\$ 551,617.00
				Total	\$ 6,067,787.04

Cost Estimate - N09 Cassins Avenue Drainage Upgrade					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
				Assume 20% of works cost	\$ 262,392.84
2	Construction				
2.1	Pull up and dispose existing road surface	3.5	1980	m2	\$ 6,928.87
2.2	Excavation of fill (soft rock)	221	2921	m3	\$ 645,546.32
2.3	Supply and install of 0.375 m diameter pipe	202	56	m	\$ 11,326.00
	Supply and install of 0.45 m diameter pipe	246	253	m	\$ 62,311.25
	Supply and install of 0.525 m diameter pipe	285	238	m	\$ 67,682.15
	Supply and install of 0.675 m diameter pipe	429	60	m	\$ 25,645.73
	Supply and install of 0.75 m diameter pipe	534	6	m	\$ 3,329.98
	Supply and install of 0.9 m diameter pipe	706	78	m	\$ 54,950.95
	Supply and install of 0.5 x 0.6 m culvert	374	12	m	\$ 4,483.33
	Supply and install of 0.75 x 0.5 m culvert	467	31	m	\$ 14,701.18
	Supply and install of 0.9 x 0.94 m culvert	1054	15	m	\$ 15,740.85
	Supply and install of 1.2 x 0.8 m culvert	1196	74	m	\$ 88,471.11
2.4	Disposal of displaced pipe volume fill	300	271	m3	\$ 81,222.51
2.5	Drainage pit, assume 1 per 50 m	2000	14	each	\$ 28,000.00
2.5	Backfilling, compaction and reinstate disturbed road pavement with bitumin surface	41.6	1980	m2	\$ 82,354.52
2.6	Adjustment of existing services (assume 10% works cost)				\$ 119,269.47
3	Contingency (assume 20% works cost)				\$ 262,392.84
				Subtotal	\$ 1,836,749.89
				GST	\$ 183,674.99
				Total	\$ 2,020,424.88

Cost Estimate - N11 Cammeray Golf Club Basin					
No.	Item	Unit rate (\$)	Amount	Units	Cost
1	Pre-construction Costs				
1.1	Site establishment			1	\$ -
1.2	Provision of sediment and erosion control, geotechnical supervision			1	\$ -
1.3	Detailed Design and Survey (Construction and WAE)			1	\$ -
			Assume 20% of works cost		\$ 175,441.69
2	Construction				
2.1	Excavation of fill (soil)	\$22.00	1910.3	m3	\$ 42,026.27
2.2	Disposal of fill	\$300.00	1910.3	m3	\$ 573,085.49
2.3	Placement, compaction and shaping	\$6.50	2239.5	m2	\$ 14,556.69
2.4	Top soil placement	\$10.60	2239.5	m2	\$ 23,738.59
2.5	Hydro mulch, sprayed grass seed compound	\$3,250.00	0.2	ha	\$ 727.83
2.5	Geotextile layer for embankment	64	2239		\$ 143,327.36
2.6	Adjustment of existing services (assume 10% works cost)				\$ 79,746.22
3	Contingency (assume 20% works cost)				\$ 175,441.69
				Subtotal	\$ 1,228,091.84
				GST	\$ 122,809.18
				Total	\$ 1,350,901.02