BAYSIDE COUNCIL

BAYSIDE WEST FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

FINAL

MAY 2023

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FINAL

MAY 2023

Project Bayside West Floodplain Risk Management Study and Plan	**Project Number** 120061
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Cover Image: Arncliffe Street, Wolli Creek during the February 2022 storm event. Source: SES https://www.theleader.com.au/story/7631930/latest-rainfall-figures/

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BAYSIDE WEST FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

TABLE OF CONTENTS

PAGE

APPENDICES

LIST OF TABLES

LIST OF PHOTOGRAPHS

LIST OF DIAGRAMS

LIST OF FIGURES

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F

APPENDIX G

APPENDIX H

LIST OF ACRONYMS

1D	One-dimensional
2D	Two-dimensional
AAD	Average Annual Damage
ABS	Australian Bureau of Statistics
AEP	Annual Exceedance Probability
AMC	Antecedent Moisture Condition
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff (1987, 2016 and 2019 versions)
AVM	Average Variability Method
AWE	Average Weekly Earnings
BCA	Building Code of Australia
BoM	Bureau of Meteorology
CBA	Cost-Benefit Analysis
CBR	Cost-Benefit Ratio
CCTV	Closed Circuit Television
CPI	Consumer Price Index
CPU	Central Processing Unit
DCP	Development Control Plan
DFE	Defined Flood Event
DPE	Department of Planning and Environment
DPIE	Department of Planning, Industry and Environment (now DPE)
DRAINS	Hydrologic and 1D hydraulic model for simulating urban stormwater
ELVIS	Elevation Information System
EY	Exceedances per Year
FDM	Floodplain Development Manual
FPA	Flood Planning Area
FPL	Flood Planning Level
FRMC	Floodplain Risk Management Committee
FRMS&P	Floodplain Risk Management Study and Plan
GIS	Geographic Information System
GPT	Gross Pollutant Trap
GPU	Graphics Processing Unit
HHWSS	High High Water Solstice Springs
HPC	Heavily Parallelised Compute
IFD	Intensity, Frequency and Duration (Rainfall)
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
LiDAR	Light Detection and Ranging (airborne survey method)
m	metres
m^3/s	cubic metres per second
mAHD	meters above Australian Height Datum

MCMA	Multi-Criteria Matrix Assessment
NGRS	North Georges River Submain
NPV	Net Present Value
OEH	Office of Environment and Heritage (now DPE)
PMF	Probable Maximum Flood
PMP	Probably Maximum Precipitation
RCP	Representative Concentration Pathway
SES	State Emergency Service
SSP	Shared Socio-economic Pathway
SWC	Sydney Water Corporation
SWSOOS	Southern and Western Suburbs Ocean Outfall Sewer
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model)
VHR	Voluntary House Raising
VP	Voluntary Purchase
WAE	Work As Executed
WBNM	Watershed Bounded Network Model (hydrologic model)
WSUD	Water Sensitive Urban Design
XP-RAFTS	Runoff Analysis and Flow Training Simulation (hydrologic model) released by XP Solutions

ADOPTED TERMINOLOGY

Australian Rainfall and Runoff (ARR, ed Ball et al, 2019) recommends terminology that is not misleading to the public and stakeholders. Therefore the use of terms such as “recurrence interval” and “return period” are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals such as every 100 years. However, rare events may occur in clusters. For example there are several instances of an event with a 1% chance of occurring within a short period, for example the 1949 and 1950 events at Kempsey. Historically the term Average Recurrence Interval (ARI) has been used.

ARR 2019 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. The table below describes how they are subtly different.

For events more frequent than 50% AEP, expressing frequency in terms of Annual Exceedance Probability is not meaningful and misleading particularly in areas with strong seasonality. Therefore the term Exceedances per Year (EY) is recommended. Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6 month Average Recurrence Interval where there is no seasonality, or an event that is likely to occur twice in one year.

The Probable Maximum Flood (PMF) is the largest flood that could possibly occur on a catchment. It is related to the Probable Maximum Precipitation (PMP). The PMP has an approximate probability. Due to the conservativeness applied to other factors influencing flooding a PMP does not translate to a PMF of the same AEP. Therefore an AEP is not assigned to the PMF.

This report has adopted the approach recommended by ARR and uses % AEP for all events rarer than the 50 % AEP and EY for all events more frequent than this.

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
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	19.5
	0.02	2	50	49.5
	0.01	1	100	99.5
Very Rare	0.005	0.5	200	199.5
	0.002	0.2	500	499.5
	0.001	0.1	1000	999.5
	0.0005	0.05	2000	1999.5
Extreme	0.0002	0.02	5000	4999.5
			↓	
			PMP/ PMP Flood	

FOREWORD

The NSW State Government's Flood Prone Land Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

1. ***Flood Study***
   - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management***
   - Evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan***
   - Involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan***
   - Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

This study constitutes the second and third stages of the management process.

ACKNOWLEDGEMENTS

This study was undertaken by WMAwater Pty Ltd, on behalf of Bayside Council. Bayside Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. The document does not necessarily represent the opinions of the NSW Government or the Department of Planning and Environment (DPE).

A number of organisations and individuals have contributed both time and valuable information to this study. The assistance of the following in providing data and/or guidance to the study is gratefully acknowledged:

- Bayside Floodplain Risk Management Committee
- Residents of the study area
- Bayside Council
- Department of Planning and Environment (DPE)
- State Emergency Service (SES)

EXECUTIVE SUMMARY

The Bayside West Floodplain Risk Management Study involves the updating of the existing Flood Studies (completed in 2015 to 2019) to better define the existing flood behaviour and current flood risk. The study expands upon this information to further understand and plan for the nature and extent of flood risk throughout the study area. It seeks to investigate methods by which to manage existing, future and residual flood risk in the study area and to develop a Floodplain Risk Management Plan which documents the decisions for the management of flood risk into the future. This study provides an opportunity to revisit the existing Floodplain Risk Management Study and Plans (completed in 1998 to 2005), providing a consolidated flood risk management plan based on the latest information available. It has been undertaken in accordance with the NSW Government's Flood Prone Land Policy.

Study Area

The study area consists of the Bayside Local Government Area (LGA) to the west of the Cooks River. This area covers the former City of Rockdale LGA, an area of approximately 31.3 km^2. Historically, these areas have been divided into catchment areas for the purpose of flood investigations. These areas are:

- Bardwell Creek: the area within the Bayside LGA draining to Wolli Creek (including Bardwell Creek), which discharges into the Cooks River near the railway bridge.
- Bonnie Doon: the catchment draining to the Bonnie Doon channel, the Eve Street catchment and the Cahill Park catchment comprise this area, which drain to the Cooks River between Wolli Creek and Muddy Creek.
- Muddy Creek: the catchment area draining to Muddy Creek (including Spring Street Drain), which discharges into the Cooks River upstream of the General Holmes Drive crossing. This area also consists of the catchment for Scarborough Ponds, which is a trapped low point drained via culverts into Botany Bay.
- Sans Souci: the southern peninsula of the Bayside LGA, consisting of the catchment areas of Goomun Creek, Bado-Berong Creek and Waradiel Creek, which drain to Botany Bay.

Available Data

This study aims to update the existing Floodplain Risk Management Studies and Plans for this area, including:

- Wolli Creek, Bardwell Creek, Bonnie Doon Channel and Eve Street/Cahill Park Catchments Floodplain Management Study and Plan (Webb, McKeown & Associates, Match 1998)
- Spring Street Drain, Muddy Creek and Scarborough Ponds Floodplain Management Study and Plan (Willing & Partners, January 2000)
- Sans Souci Drainage Catchments Floodplain Risk Management Study and Plan (Cardno Willing, February 2005)

These studies provide a database of flood risk management options that have been investigated in the past. The current study was based on modelling produced in the latest flood studies, including:

- Bardwell Creek 2D Flood Study Review (WMAwater, March 2019)
- Bonnie Doon, Eve Street / Cahill Park Pipe and Overland 2D Flood Study (WMAwater, February 2017)
- Spring Street Drain, Muddy Creek and Scarborough Ponds Catchments Flood Study Review (BMT WBM, February 2017)
- Sans Souci Flood Study Review (Cardno, September 2015)

These studies contain a technical description of the flood models and the calibration process undertaken. These flood models form the basis of the current study.

Model Updates

The flood models were updated as part of the current study. Model updates primarily consisted of:

1. Minor updates due to recent developments, drainage updates and correcting the representation of certain hydraulic features
2. Update hydrology to consider Australian Rainfall and Runoff (ARR) 2019 guidelines

Minor model updates generally resulted in some changes to peak flood levels, although these were generally localised to areas where changes were made. The updates to ARR 2019 guidelines generally resulted in lower flood levels across the study area, primarily driven by lower design rainfall intensities.

Design Flood Behaviour

Design flood behaviour was simulated with the updated models and is defined in this study. Results for peak flood depth, level, velocity, hydraulic hazard, hydraulic categories and flood emergency response classifications are mapped in this report. Additional flood assessments and comparisons were also undertaken, including tidal inundation, pipe capacity assessment, climate change sensitivity (both rainfall intensity and sea level rise considerations), blockage sensitivity, levee failure assessment and assessment of floodplain works.

Economic Impacts of Flooding

A flood damages assessment was carried out for the inundation of residential and commercial properties in the study area. A property database was compiled from surveyed and estimated floor levels, with over 8,000 properties identified. In each model area, there was typically a gradual increase in the number of properties affected with increasing flood magnitude, except for the PMF event in which the number of properties affected is substantially higher. Commercial and industrial properties account for approximately 5% to 40% of the affected properties, and up to 60% of the total flood damage cost, depending on the area and flood affectation of the commercial and industrial zones. The total damage cost is approximately between $10M and $30M for the 1% AEP event, with the average annual damages between $1.7M and $3.8M across the various model areas. The total average annual damage for the entire Bayside West study area was estimated to be approximately $10.6M. This represents the average cost of flooding each year.

Floodplain Risk Management Measures

A variety of flood risk management measures were investigated as part of this study. These measures can be separated into three broad categories:

- Flood modification measures, which modify the physical behaviour of a flood including depth, velocity and direction of flow paths.
- Property modification measures, which modify the existing land use and development controls for future development.
- Response modification measures, which modify the response of the community to flood hazard by educating flood affected residents about the nature of flooding so that they can make better informed decisions.

Options were identified from the existing Floodplain Risk Management Studies and Plans as well as additional measures identified by Bayside Council and WMAwater. This resulted in over 150 options to be investigated. A large number of these were considered not to be feasible based on a high-level assessment, hydraulic assessment or detailed assessment. The options that were considered viable were then assessed using a multicriteria analysis, which considered not only flood impacts, but also construction feasibility, economic merits and the alleviation or exacerbation of property damages, risk to life and pressure on emergency responders among others. The outcomes of the analysis undertaken in this Floodplain Risk Management Study are presented in this report. The recommended options for implementation in the Floodplain Risk Management Plan are presented below.

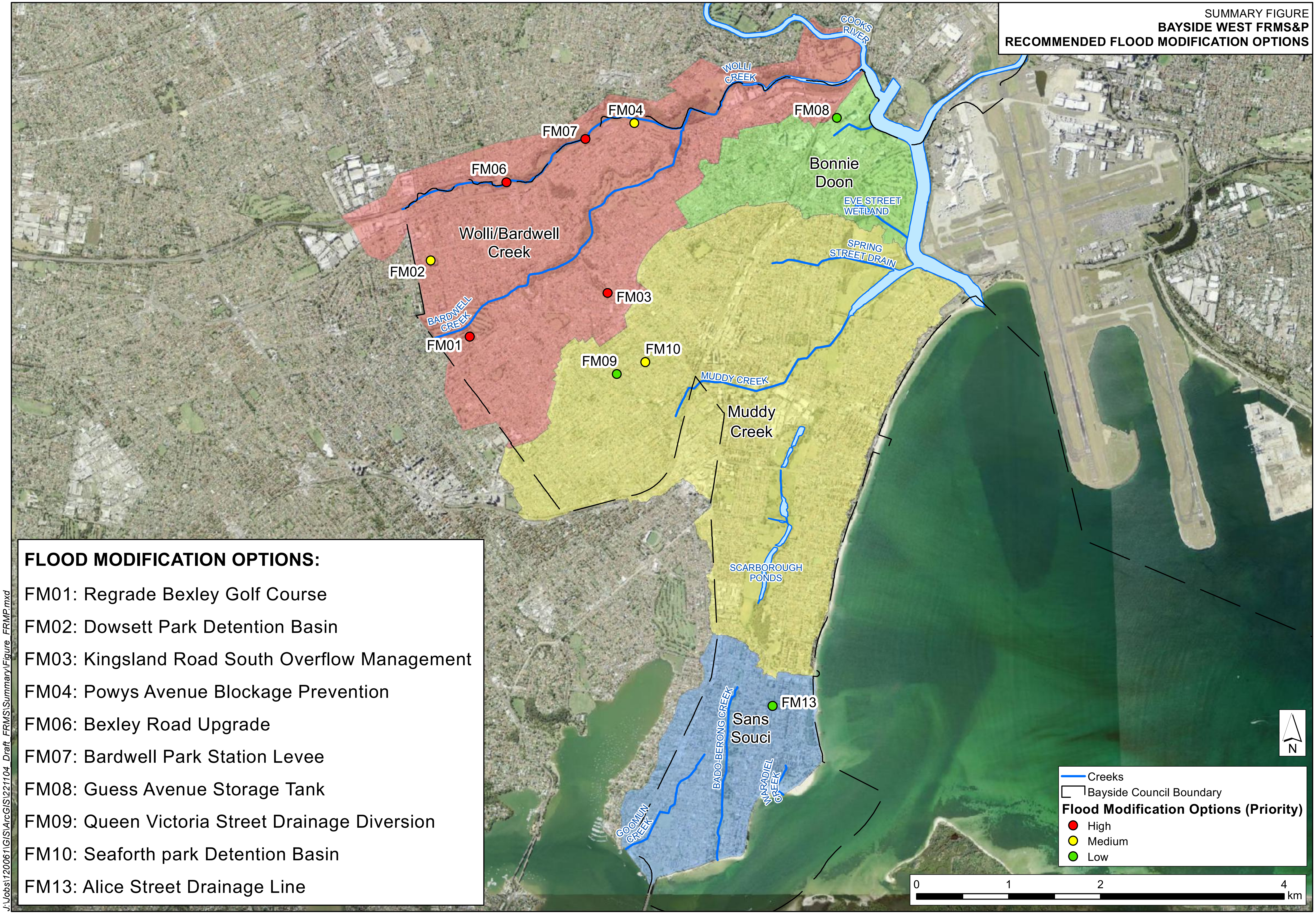
	Option ID Report Section	Option	Description	Responsibility	Funding	Cost	CBR	Priority
Flood Modification Options	FM01 10.2.4.4	Regrade Bexley Golf Course	Regrade land from Bridge Street into Bexley Golf Course to allow overland flows to Bardwell Creek.	Council, in liaison with Bexley Golf Course	May be eligible for NSW Government funding	$200,000	1.2	High
	FM06 10.2.4.9	Bexley Road Upgrade	Upgrade Bexley Road crossing Wolli Creek.	Transport for NSW	Transport for NSW / State Government	$20M - $100M	N/A	High
	FM07 10.2.4.10	Bardwell Park Station Levee	Construct levee to protect Bardwell Park Station from Wolli Creek flooding.	Transport for NSW	Transport for NSW / State Government	$300,000	N/A	High
	FM14 10.2.5.1	Channel and Drainage Maintenance	Maintenance involves regularly removing unwanted vegetation and other debris from the drainage network, It is recommended to continue its drainage maintenance program.	Council	Internal (Existing Drainage Maintenance Program)	N/A	N/A	High

	Option ID Report Section	Option	Description	Responsibility	Funding	Cost	CBR	Priority
Flood Modification Options	FM03 10.2.4.6	Kingsland Road South Overflow Management	Management of drainage on Kingsland Road South via overland flow path to Highgate Street and/or barrier on Kingsland Road South to prevent overflow.	Council	Likely Council funded	$75,000	N/A	High
	FM04 10.2.4.7	Powys Avenue Blockage Prevention	Implement blockage prevention on openings under noise wall. This may include structural options (screens with wider openings, sloped screens, debris deflectors) and regular maintenance.	Transport for NSW	Transport for NSW / Council	$35,000 capital costs $2,000 annual mainten-ance cost	6.8	Medium
	FM10 10.2.4.13	Seaforth Park Detention Basin	Excavate Seaforth Park to form two detention basins. Construct pit outlets in the basin that connect to the existing 600 mm pipe under the park.	Council	May be eligible for NSW Government funding	$3.9M	0.3	Medium
	FM15 10.2.5.2	Levee Inspection and Maintenance Program	Regularly inspect levees for signs of weakness and maintain them, including drainage systems and filling of gaps.	Council	Internal	$10,000 per annum	N/A	Medium
	FM02 10.2.4.5	Dowsett Park Detention Basin	Excavate Dowsett Park to form a detention basin. Remove a section of 900 mm pipe such that is discharges into the basin and also forms the low flow outlet of the basin.	Council	May be eligible for NSW Government funding	$4.4M	0.3	Medium
	FM18 10.2.5.5	Filling of Low - Lying Land	Filling of low lying land to achieve protection from rising sea levels.	Council and private land owners	Council and private land owners	Not Estimated	N/A	Low
	FM08 10.2.4.11	Guess Avenue Storage Tank	Construct an underground flood storage tank under No. 2 or No. 4 Guess Avenue or future Gertrude St extension.	Council / Future Developer	Council / future developer	$1M - $8M	0.1	Low
	FM13 10.2.4.16	Alice Street Drainage Line	Construct a new box culvert from the corner of Chuter Avenue and Alice Street to Botany Bay.	Council	May be eligible for NSW Government funding	$7.9M	0.2	Low

	Option ID Report Section	Option	Description	Responsibility	Funding	Cost	CBR	Priority
	FM09 10.2.4.12	Queen Victoria Street Drainage Diversion	Construct a new 900 mm diameter pipe along Queen Victoria Street, from Caledonian Street to the sag point just downstream of Connemarra Street.	Council	May be eligible for NSW Government funding	$2.3M	0.3	Low
Property Modification Measures	PM09 10.3.9	Climate Change Policy	A climate change policy guides Council's operations and policies at a high level. Climate change adaptation should also be considered at an LGA-wide scale.	Council	Internal	N/A	N/A	High
	PM05 10.3.5	Flood Planning Levels	Bayside Council's current adopted Flood Planning Level is considered appropriate. It is recommended to update flood levels based on the updated modelling developed as part of this FRMS&P and consider incorporating climate change projections into FPLs..	Council	Internal	N/A	N/A	High
	PM07 10.3.7	Flood Planning Policy	Flood planning policy is typically governed by the LEP and DCP. Consideration should be given to the following: • Inclusion of climate change in the full range of flood related development controls. • Implementation of the draft DCP. • Provision of special flood considerations clause in the LEP.	Council	Internal	N/A	N/A	High
	PM03 10.3.3	Flood Proofing	Flood proofing of non-residential buildings with temporary flood barriers (both existing and new structures, where floor levels are allowed to be lower).	Council (policy) and property owners (cost of flood proofing)	Internal (policy) Private (flood proofing)	Varies	N/A	High

	Option ID Report Section	Option	Description	Responsibility	Funding	Cost	CBR	Priority
Property Modification Measures	PM06 10.3.6	Flood Planning Area	It is recommended to retain the current lot-based tagging approach, and update the tagging status based on the updated modelling undertaken as part of this FRMS&P.	Council	Internal	N/A	N/A	High
	PM08 10.3.8	Section 10.7 Certificates	Section 10.7 Certificates are required to show flood notation. This informs the land owner of flood risk and applicable development controls.	Council	Internal	N/A	N/A	High
Response Modification Measures	RM01 10.4.1	Flood Emergency Management Planning and Coordination	It is recommended that the SES: • Use the information and modelling developed as part of this FRMS to update their local flood plan for Bayside. • Consider providing an updated FloodSafe brochure or information on their website specific for the flood risk in Bayside. It is recommended that Bayside Council and SES: • Hold regular meetings of all responders and training exercises between flood events to identify roles and responsibilities in practice and build relationships between agencies and/or community groups.	Council and SES	Internal	N/A	N/A	High

	Option ID Report Section	Option	Description	Responsibility	Funding	Cost	CBR	Priority
Response Modification Measures	RM03 10.4.3	Community Flood Awareness and Education	It is recommended to design and implement and ongoing community flood education program to maintain a high level of flood awareness and understanding of the risk and appropriate response to flooding in the Bayside West study catchments.	Council	Internal with opportunities for State Government assistance.	Varies	N/A	High
	RM04 10.4.4	Improvements to Drive Safety	Installation of flood signs and flood depth indicators can improve driver safety, in conjunction with community education about the risks of driving through floodwaters. It is recommended that a detailed study is undertaken to confirm the preferred locations, residual flood risk (i.e. need for road closure) and safe alternative routes and how traffic can be diverted in flood events. Following the detailed study, installation can proceed in accordance with the outcomes of that study.	Council and Transport for NSW where applicable.	Council and Transport for NSW, with opportunities for State Government funding.	Not Estimated	N/A	High
	RM02 10.4.2	Flood Warning System	It is recommended that the severe weather and severe thunderstorm warnings issued by the BoM be used to prepare for potential flash flooding events. Community awareness campaigns may assist residents in interpreting warnings from the BoM, anticipating the impacts and preparing accordingly.	Bureau of Meteorology, Council, SES.	Internal	N/A	N/A	Medium



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1. INTRODUCTION

1.1. Overview

Bayside Council (Council) has engaged WMAwater to undertake the Bayside West Floodplain Risk Management Study and Plan (FRMS&P). This study is jointly funded by the NSW Department of Planning and Environment (DPE) and the Council. The FRMS&P has been undertaken in accordance with the NSW Government's Flood Prone Land Policy and the "Floodplain Development Manual: the management of flood liable land", New South Wales Government, April 2005 (FDM) (Reference 1).

The primary aim of this FRMS&P is to provide a more informed understanding of flood risks and impacts across the study area and develop a long-term strategy to manage this risk. The study involves updating the existing Flood Studies (completed in 2015 to 2019) to better define the existing flood behaviour and current flood risk. The FRMS&P expands upon this information to further understand and plan for the nature and extent of flood risk throughout the study area. This FRMS&P seeks to investigate methods by which to manage existing, future and residual flood risk in the study area and to develop a Floodplain Risk Management Plan which documents the decisions for the management of flood risk into the future. This study provides an opportunity to revisit the existing FRMS&P's (completed in 1998 to 2005) and re-evaluate flood risk mitigation measures with up-to-date modelling. This study provides a consolidated flood risk management plan based on the latest information available.

1.2. Study Area

The study area consists of the Bayside Local Government Area (LGA) to the west of the Cooks River (see Figure 1). This area covers the former City of Rockdale LGA, an area of approximately 31.3 km^2. It comprises the suburbs of Kingsgrove (part), Bexley, Bexley North, Bardwell Park, Bardwell Valley, Turrella, Arncliffe, Wolli Creek, Carlton (part), Kogarah (part), Rockdale, Banksia, Kyeemagh, Brighton-La-Sands, Monterey, Ramsgate (part), Ramsgate Beach, Dolls Point, Sandringham and Sans Souci (part). The study area is bound by the Cooks River and Botany Bay to the east and south, Wolli Creek to the north and the Bayside LGA boundary to the west, which generally follows (north to south) Kingsgrove Road, Croydon Road, Botany Street, the Illawarra railway line, Harrow Road, Princes Highway and Rocky Point Road.

Historically, these areas have been divided into catchment areas for the purpose of flood investigations. These areas are (shown in Figure 1):

- Bardwell Creek: the area within the Bayside LGA draining to Wolli Creek (including Bardwell Creek), which discharges into the Cooks River near the railway bridge.
- Bonnie Doon: the catchment draining to the Bonnie Doon channel, the Eve Street catchment and the Cahill Park catchment comprise this area, which drain to the Cooks River between Wolli Creek and Muddy Creek.
- Muddy Creek: the catchment area draining to Muddy Creek (including Spring Street Drain), which discharges into the Cooks River upstream of the General Holmes Drive crossing. This area also consists of the catchment for Scarborough Ponds, which is a trapped low

point drained via culverts into Botany Bay.
- Sans Souci: the southern peninsula of the Bayside LGA, consisting of the catchment areas of Goomun Creek, Bado-Berong Creek and Waradiel Creek, which drain to Botany Bay.

While this study considers the entire Bayside West region as the study area, often the model domain areas, which are delineated based on catchments, are useful divisions for discussing sub-areas within the larger study area. Where this is appropriate, the discussion proceeds in the sequence in which the model areas are listed above.

1.3. Catchment Description

Each of the four catchment areas that comprise the Bayside West study area are described below. These are summaries of the information contained in the relevant Flood Studies. For further, more detailed information regarding each catchment and specific hydraulic features, refer to the relevant Flood Study as outlined in Section 2.1.2. The topography across the study area is shown in Figure 2, based on the latest available LiDAR data (Sydney dataset dated April/May 2020 from NSW Spatial Services, obtained from the Elevation Information System, ELVIS, https://elevation.fsdf.org.au/)

Bardwell Creek

This study area consists of both Wolli Creek and Bardwell Creek catchment areas. It is located north of the Bonnie Doon catchment and drains to the Cooks River, which flows into Botany Bay. This study area covers approximately 7.1 km^2, with the total catchment area of Bardwell Creek and Wolli Creek comprising some 20.9 km^2.

The catchment generally flows from west to east, with Bardwell Creek running north-east through the middle of the urban area, and Wolli Creek running along the northern boundary. The two creeks are in relatively well-defined valleys. Elevations in the upper part of the catchment (to the south) reach approximately 70 mAHD. The topography within the study area has moderately steep terrain, where grades of approximately 5% in the suburban areas are common.

The land use within the catchment consists primarily of medium density urban residential development and commercial developments (including some light industrial areas), together with areas of open space such Bexley Golf Club, Bardwell Golf Club and several parks. High density urban residential developments and shopping complexes are a notable feature of the lower catchment in the suburbs of Wolli Creek and Turrella. Piped drainage systems which flow into a series of culverts and concrete lined open channels are prevalent in the upper catchment of both Wolli Creek and Bardwell Creek.

Drainage elements in the catchment include natural creek channels, kerbs and gutters, pits and pipes, and a network of trunk drainage elements including culverts and concrete-lined or otherwise modified open channels. These trunk drainage assets are primarily owned by Sydney Water Corporation (SWC) and Bayside Council, with drainage assets in the catchment to the west and north of the study area owned by Georges River Council and Canterbury-Bankstown Council, respectively.

In Bardwell Creek the urban drainage network collects surface runoff and discharges into two small concrete lined open channels downstream of Croydon Road. These channels combine at Bexley Golf Club, near the upstream extent of the study area and flow through a series of culverts before discharging into a semi-natural creek downstream of Ellerslie Road. Bardwell Creek then passes under the Bexley Road bridge and is piped under a portion of the Bardwell Valley Golf Course via twin 2.5 m diameter culverts. Bardwell Creek then passes under Bardwell Road and the railway bridge at the end of Hannam Street before joining Wolli Creek.

In the upstream portion of the study area, Wolli Creek consists of a concrete lined open-channel which extends for approximately 1.2 km between Kingsgrove Road and Bexley Road. This section was widened and realigned as part of the M5 Motorway East construction works between 1998 and 2002. The channel is crossed by a series of pedestrian bridges and a gross pollutant trap near Nairn Street. Wolli Creek passes through a series of culverts under Bexley Road and continues downstream through a densely vegetated, meandering natural creek corridor. This natural creek follows the East Hills railway line, passing under Harthill Law Avenue bridge. Noise walls constructed along substantial stretches on the northern and southern sides of the railway corridor, as part of rail duplication works in 2000 and 2001, act as a barrier to overland flows for areas south of the railway line. Wolli Creek is joined by Bardwell Creek near Hannam Street.

Turrella Weir, located at Henderson Street, defines the tidal and non-tidal portions of Wolli Creek. Immediately downstream, Wolli Creek passes under the Turrella footbridge and continues around an industrial area at Turrella. Wolli Creek is crossed by the historic SWC Wolli Creek Sewage Aqueduct, which is part of the Southern and Western Suburbs Ocean Outfall Sewer (SWSOOS), before the confluence with the Cooks River near the Tempe railway bridge.

Bonnie Doon

The Bonnie Doon catchment area comprises an area of approximately 1.8 km^2 that drains in a north-easterly direction to Cooks River. This area is traditionally split into the Upper and Lower Bonnie Doon catchment areas, bisected by the Illawarra railway line. This study area also consists of a further 0.7 km^2 comprising the Kogarah Golf course and a small catchment draining to the Eve Street wetlands, which drain in an easterly direction to the Cooks River.

The flows within the pipe network from the north-west part of the catchment drain in a northerly direction to the adjoining Wolli and Bardwell Creeks catchment. However, flows in excess of the pipe system capacity remain in the Bonnie Doon catchment. The Illawarra railway line is raised above natural ground level and restricts surface flows from west to east apart from the road opening at Allen Street and recently constructed pedestrian tunnel adjacent to Allen Street.

Downstream of the Illawarra railway line, there is an open concrete lined channel which discharges into the Cooks River through Cahill Park. The SWSOOS provides a major obstacle to overland flow downstream of the Illawarra railway line, as does the Princes Highway where flows in excess of the culvert capacity must cross the highway.

The land use upstream of the Illawarra railway line comprises a mix of residential, industrial and commercial developments together with areas of open space (such as Arncliffe Park). Upstream of Bonar Street the development is mainly residential while downstream includes light/medium industrial and commercial sites. Significant re-development for residential units has been occurring in the region from Bonar Street to the Illawarra railway line since the mid 2000's.

Downstream of the Illawarra railway line and upstream of the Princes Highway, the developments were principally large commercial usage (car yards) with some light industrial usage. However, in the last 15+ years the area has changed with significant redevelopment for high rise residential developments, particularly around Wolli Creek railway station and along Arncliffe Street. Downstream of the Princes Highway there are smaller commercial developments combined with detached residential developments. There are extensive areas of open space at Cahill Park, Eve Street wetlands and at Kogarah Golf course. It is likely that significant re-development of this area will occur over the next few years, as has occurred in recent years in the vicinity of Gertrude Street.

Three stormwater conduits drain water to the downstream side of the Illawarra railway line. They are located at the Allen Street underpass, the north-eastern extremity of Wollongong Road and Firth Street, comprising:

- a 1370 mm x 1210 mm box culvert within the railway underpass between Wollongong Road and Allen Street.
- a 1500 mm diameter pipe from the intersection of Wollongong Road and Martin Avenue draining to Arncliffe Street.
- a 750 mm diameter pipe from Firth Street to the car park at Arncliffe railway station.

The existing storm drainage system is typical of older areas of the Sydney metropolitan area and consists mainly of kerb and gutter drainage to pipes, with some box culverts in the lower reaches of the catchment. The Bonnie Doon channel is an open rectangular concrete lined channel extending from the SWSOOS to the Cooks River.

Muddy Creek

This study area comprises three separate stormwater catchments, namely Spring Street Drain, Muddy Creek and Scarborough ponds. The total catchment area is approximately 13.1 km^2 and is fully developed, consisting primarily of medium to high-density housing and commercial developments. There are some large open spaces within the study area including the reserves and parks along Scarborough Ponds, Barton Park, McCarthy Reserve and Gardiners Park. The Spring Street Drain and Muddy Creek catchments drain to Cooks River, with the Scarborough Ponds catchment draining to Botany Bay. To the west of the Illawarra railway line, the topography slopes gradually to the catchment boundaries, with a maximum elevation of approximately 68 mAHD to the south west of the Muddy Creek catchment. The Spring Street Drain catchment has a maximum elevation of approximately 55 mAHD, with the catchment generally draining eastwards. To the east of the Illawarra railway line, the terrain is generally quite flat in both the Muddy Creek and Spring Street Drain catchments. The Scarborough Ponds catchment has a maximum elevation of approximately 31 mAHD, with the catchment draining towards the ponds.

The Spring Street Drain catchment area is approximately 2.7 km^2 and drained by an extensive stormwater network of pits, pipes and covered box sections. The Spring Street Drain itself is a brick and concrete lined stormwater channel which runs for approximately 2 km from near Short Street, Banksia, to join the tidal reach of Muddy Creek just upstream from its confluence with the Cooks River. The open channel of Spring Street Drain is crossed by several bridges, including West Botany Street in Banksia. The North Georges River Submain (NGRS) sewer also crosses the channel.

The Muddy Creek catchment area is approximately 6.2 km^2, with portions of the catchment extending into the Georges River Council LGA. The catchment is drained by an extensive stormwater network which collects flows and diverts it to the Muddy Creek stormwater channel. The channel is a brick and concrete lined stormwater channel which runs for approximately 4.3 km through the catchment. The channel forms the main drainage system in the catchment and is owned by SWC. Downstream of Bestic Street in Rockdale, the channel has been dredged and widened to form a tidal basin, which discharges to the Cooks River. Significant hydraulic features in the Muddy Creek catchment include several road bridges, footbridges and a culvert under the Illawarra railway line. The NGRS sewer also crosses the channel upstream of the Princes Highway in Rockdale, where it can obstruct flows in large floods.

The Scarborough Ponds catchment has a total area of approximately 4.2 km^2. Scarborough Ponds consists of a series of a linked dredged ponds and semi-natural wetlands which have formed behind the low beach ridge fronting Botany Bay. Scarborough Ponds discharges to Botany Bay via an artificial outlet (3 x 1350 mm diameter pipes) at the southern end of the ponds. These pipes were constructed in the 1970's at Florence Street, Ramsgate Beach, to improve drainage. There are two roads that cross the ponds, President Avenue in Brighton-Le-Sands and Barton Street in Monterey. These crossings and the surrounding land are all relatively low-lying. Several pipes and drainage ditches convey stormwater into the ponds from the surrounding catchment.

Sans Souci

The Sans Souci study area is bounded by Rocky Point Road to the west, which is a localised high point and the Bayside LGA boundary. The northern extent of the study area adjoins the Scarborough Ponds catchment boundary in the vicinity of Ramsgate Road. The catchment is drained by three distinct channels, namely Waradiel Creek, Bado-Berong Creek and Goomun Creek. These creeks flow in a southerly direction and discharge into Botany Bay. This study area covers approximately 3.1 km^2.

Land use within the catchment is dominated by low and medium density residential properties, with commercial areas along Rocky Point Road and Russell Avenue. Several parks and reserves are located within the catchment and are generally adjacent to the three creeks.

Waradiel Creek, also known as Sans Souci Drain No. 1, conveys flows from Ramsgate Road in a south-east direction via a pipe network to Alfred Street, where it discharges into Botany Bay adjacent to Georges River Sailing Club. The overall length of the combined pipe and channel network is approximately 1.5 km.

Bado-Berong Creek, also known as Sans Souci Drain No. 2, commences south of Park Road and conveys flow in a well-defined channel to Botany Bay. A relatively wide vegetated floodplain exists along the creek alignment and is used as public recreation space. Culverts convey flow beneath road crossings at Alice Street, Ritchie Street, Sandringham Street, Russell Avenue, Ida Street and Riverside Drive where the creek discharges into Botany Bay. Several pedestrian bridges traverse the channel providing connectivity to residents on each side of the creek. The overall length of Bado-Berong Creek is approximately 1.9 km.

Goomun Creek, also known as Sans Souci Drain No. 3, comprises a rectangular concrete lined open channel from Russell Avenue to Kendall Street Reserve, with a length of approximately 1.2 km. The channel is bordered by residential properties along its alignment to Kendall Street Reserve. At Kendall Street Reserve, it is diverted along the western boundary of the reserve and then continues as an enclosed channel and culvert network to its outfall to Botany Bay, west of Rocky Point Road.

Drain No. 3A is located between Bado-Berong Creek and Goomun Creek and comprises a piped stormwater network located beneath Brantwood Street and discharges into Botany Bay. It is approximately 9 ha in area.

1.4. Historical Flooding

Flood problems have been experienced across the study area when intense local rainfall generates runoff exceeding the capacity of both the stormwater system producing overland flooding, and the channels and creeks resulting in overbank flow. Flooding in some areas may be exacerbated by the blockage of hydraulic structures and the presence of obstructions to overland flow paths.

The catchment has experienced several floods of note in the last 50 years including floods in 1975, 1984, 1986, 1988, 1991, 1992, 1993, 1996, 1998, 2005, 2014, 2015, 2018, 2020 and most recently 2022. Prior events have occurred but there are limited records. Flood events in the study area frequently result in inundation causing damage to both residential and commercial properties. Inundation of roads is also a frequent occurrence, resulting in flood risk to vehicles and passengers.

Some of the key areas identified in the previous Flood Studies (see Section 2.1.2) include the following:

Bardwell Creek

- Bexley Road crossing Wolli Creek is frequently closed due to flooding. Most recently this occurred in March 2022 (Photo 1).
- Flooding of the East Hills railway line occurs in the vicinity of Bardwell Park station, resulting in closure of the railway line. This occurred most recently in February 2020 (Photo 2).
- Flooding has occurred behind the levee at Hillcrest Avenue, such as October 2014.
- Flooding has occurred along the concrete lined channel section of Barwell Creek between

Laycock Street and Preddys Road, such as October 2014 when blockage of the Coveney Street culverts was caused by a water tank and car.

Photo 1: Flooding across Bexley Road in the March 2022 storm event. *Source: Live Traffic Sydney*

Photo 2: Flooding at Bardwell Park railway station in the February 2020 storm event. *Source: Sydney Trains*

Bonnie Doon

- Flooding has been reported on Hirst Street near the Dowling Street roundabout. Overland flow can affect residential properties on the flow path from this location to Arncliffe Park (Kembla Street, Walters Street and Mitchell Avenue). This was the case in February 1993.
- Kelsey Street, Bonar Street, Station Street, Wollongong Road and the Allen Street railway underpass have experienced flooding in the past, such as the February 1993 event.
- In the lower catchment, flooding is frequently experienced on Arncliffe Street adjacent to the Bonnie Doon open channel. This water can extend into Willis Street and Guess Avenue. This most recently occurred in February 2022 (Photo 3).

Photo 3: Flooding on Arncliffe Street in the February 2022 storm event. *Source: SES*

Muddy Creek

Reports of flooding are limited to the flood marks that were recorded for the February 1993, April 1998 and October 2014 events:

- Flooding has been reported in overland flow areas upstream of the Illawarra railway line.
- Flooding adjacent to the railway line, including Frys Reserve (Muddy Creek) and on the Subway Road underpass (Spring Street Drain).
- Flooding has been observed adjacent to Muddy Creek downstream of the Illawarra railway line, particularly on the northern bank between Harrow Road and Bestic Street.
- Flooding has been observed along the Spring Street Drain open channel, between Short Street and West Botany Street.

Sans Souci

There are limited reports of flooding in the Sans Souci area, however, flood marks were recorded for the March 1975 event at:

- Properties along Goomun Creek overbank areas, including Bonanza Parade, Russell Avenue, Evans Street, Griffiths Street, Toyer Avenue, Ida Street, Kendall Street, Fontainebleau Street and Meriel Street.
- Limited properties along the Bado-Berong Creek overbank area, including Sandringham Street, Horbury Street and Napoleon Street.

During the heavy rainfall events of March 2022, Bayside Council set up an interactive mapping tool to obtain information about flood prone hot spots in the Bayside LGA (https://haveyoursay.bayside.nsw.gov.au/floodpronehotspots2022). Residents were able to drop a pin onto a digital map and add text and photos of flooding. The following flood-prone hot spots were identified by the community:

- Bexley Rad, Bexley North
- Bardwell Park railway station, Bardwell Park
- Turrella Street, Turrella
- Wollongong Road, Arncliffe
- Bonar Street, Wolli Creek
- Arncliffe Street, Wolli Creek
- Gertrude Street and Cahill Park, Wolli Creek
- Forest Road, Bexley
- Gardiner Park, Banksia
- Spring Street Drain, between Short Street and West Botany Street (including Spring Street and Lynwen Crescent), Arncliffe
- Barton Park, Arncliffe
- White Oak Reserve, Brighton-Le-Sands
- West Botany Street, Rockdale
- Toomevara Street, Kogarah
- Corner of President Avenue and O'Connell Street, Monterey
- Chuter Avenue, Monterey
- Grand Parade, Monterey and Ramsgate Beach
- Ramsgate Road, Ramsgate Beach
- Pemberton Reserve, Sans Souci
- Alfred Street, Sans Souci
- Bado-Berong Creek, between Park Road and Russell Avenue (including Horbury Street and Alice Street), Sans Souci
- Griffiths Street, Sans Souci
- Peter Depena Reserve, Sandringham

While some of these locations were local stormwater drainage issues (such as blocked drains), the observations from the community confirm the key flood hot spot areas across the Bayside West study area.

1.5. Demographics

Understanding the social characteristics of the study area can help in ensuring appropriate risk management practices are adopted, and shape the methods used for community engagement. Census data regarding house tenure and age distribution can also provide an indication of the community's lived experience with recent flood events, and hence an indication of their flood awareness. Information for the Bayside West study area was obtained from the latest 2021 census data from the Australian Bureau of Statistics (ABS).

The Bayside West study area is covered by the Kogarah – Rockdale Level 3 statistical area. A portion of this statistical area lies just to the west of the Bayside LGA (covering suburbs such as Kogarah Bay, Beverley Park, Carlton, Allawah and Kingsgrove). A summary of the relevant information is contained in Table 1.

Table 1: Demographic Overview of the Bayside West study area (*Source: Reference* 2)

Census Category	Census Statistic	Bayside West	NSW
Population	Total Population	145,918	8,072,163
	Male	49.6 %	49.4 %
	Female	50.4 %	50.6 %
Age	0-14 years	15.3 %	18.2 %
	15-64 years	68.5 %	64.1 %
	65-84 years	13.6 %	15.4 %
	> 85 years	2.6 %	2.3 %
Dwellings	Occupied dwellings	91.4 %	90.6 %
	Unoccupied dwellings	8.6 %	9.4 %
	Separate house	39.7 %	65.6 %
	Semi-detached	11.9 %	11.7 %
	Flat/Apartment	47.4 %	21.7 %
	Average people per dwelling	2.6	2.6
	No car at dwelling	13.7 %	9.0 %
Households	Family households (%)	69.7 %	71.2 %
	Lone person households (%)	24.8 %	25.0 %
	Group households (%)	5.6 %	3.8 %
Tenure	Owned (%)	58.7 %	64.0 %
	Rented (%)	38.3 %	32.6 %
Median Weekly Income	Personal	$834	$813
	Family	$2,187	$2,185
	Household	$1,923	$1,829
Cultural Diversity	Country of birth	Australia (47.0 %)	Australia (65.4%)
	Top Non-Australian countries of birth	China (7.3 %)	-
		Nepal (4.3 %)	-
		Greece (2.8 %)	-
		Lebanon (2.4 %)	-
	English only used at home	38.7 %	67.6 %
	Non-English language used at home	62.5 %	29.5 %
	Top Non-English languages	Greek, Mandarin, Arabic, Cantonese, Nepali.	-

The characteristics noted above are considered in the community engagement strategy and when considering response modification options, such as flood education, warning or evacuation systems. Key characteristics include:

- Approximately 15% of the population are under the age of 15 and 16% are over the age of 65. These groups of people are more likely to be vulnerable and require assistance during flood events to evacuate and more likely to require assistance with recovery following a flood. The study area, however, typically has a slightly higher proportion of adults who are less likely to be vulnerable (in the 15 to 64 age bracket) than the state average.
- There is a high proportion (almost 50%, more than double the state average) of dwellings that are flats or apartments. This means that they are more likely to not be affected by above floor flooding and be safe during 'flash flooding' events that result in overland flow flooding. It may, however, contribute to evacuation difficulties if required, with many people trying to exit from a single building at once.
- Almost 14% of households do not have a car (50% higher than the state average), which may hinder the possibility of evacuation.
- Approximately a quarter of people live alone. These people may be at a greater risk of being unaware of flood warnings or evacuation orders.
- There is a higher proportion of people renting in the Bayside West area than the state average. These households may be more likely to move around and be less aware of local flooding issues. Home ownership may also affect the willingness to participate in property modification measures.
- There is a higher proportion of people not born in Australia (over half) than the state average. There is also a very high proportion of households that speak a language other than English at home (over 60%, double the state average). This diversity of culture in the Bayside West study area means that flood signs, warnings, messages, brochures, etc. may need to cater for multiple languages. Interpretation services may also be required during emergencies and for effective public education strategies.
- The median weekly income for individuals, families and households is similar to or higher than the state average. This suggests that the value of house contents may be average or above average (for flood damages), and the ability to recover from flooding events may also be average or above average.

Information on work status and education was not yet available from the 2021 census, however, the 2016 census indicates that:

- People are generally well educated (68% attaining year 12 or above). This suggests that there is a high capacity to understand technical information through education.
- A high proportion of people in the labour force were engaged in full-time or part-time work (89%). This means a large proportion of the population are in the workforce and may not be at their property during a flood event. This may limit their ability to minimise property damage.

1.6. Natural Environment

The Bayside West study area is highly urbanised with limited (less than 3% of the study area) natural areas (Reference 3). The natural areas that do remain, however, are of ecological significance and have high conservation value as they provide habitat for internationally significant migratory birds, threatened plants and animals and fish spawning grounds for Botany Bay. There are seven endangered ecological communities that cover almost a third of the Bayside West study area's vegetation, with over half of this vegetation in a disturbed condition (Reference 3). Within these communities there are also threatened species, with three species observed in the study area and a further eleven that could potentially occur in the area. There are also twenty-eight threatened and significant fauna within the Bayside West study area (Reference 3). Priority areas that were identified in Reference 3 as key natural habitat areas include:

- Bardwell Creek corridor (including Coolibah Reserve, Bardwell Valley Golf Club and Bardwell Park)
- Stotts Reserve
- Wolli Creek corridor (including Girrahween Park and Waterworth Park)
- Marsh Street and Eve Street Wetlands
- Spring Street and Landing Lights Wetlands
- Frys Reserve
- Scarborough Ponds
- Bado-berong Creek
- Lady Robinsons Beach (Botany Bay Foreshore)

These areas typically align with natural or semi-natural waterways and wetlands, and hence these ecological communities should be considered when developing flood mitigation measures.

1.7. Heritage

In NSW, there are different types of statutory lists for local, state and national heritage items. Local heritage items are listed in the heritage schedule of a local council's Local Environmental Plan (LEP) or regional environmental plan. State heritage items are places and items of particular importance to the people of NSW, and are listed on the State Heritage Register. National heritage items are listed on the National Heritage List, established by the Australian Government to list places of outstanding heritage significance to Australia. In addition to these, there are other statutory listings such as the Aboriginal sites register. It is important in floodplain management and in the development of flood mitigation measures to be aware of these heritage items and where an additional heritage assessment may be required to ensure heritage items are preserved.

The State Heritage Inventory (Reference 4) is an online database containing heritage items in NSW including Aboriginal Places, State Heritage Register, Interim Heritage Orders, State Agency Heritage Registers and Local Environmental Plans. In Bayside West there is approximately 280 local heritage items and 12 state heritage items. The state heritage items within the study area include:

- Wolli Creek Aqueduct
- Wilsons Farm House
- Kyeemagh Market Gardens
- Rockdale Railway Station
- Arncliffe Railway Station
- Cairnsfoot Special School
- Arncliffe Market Gardens
- Western Outfall Main Sewer (part of the SWSOOS)

- Toomevara Lane Chinese Market Garden
- Dappeto
- Lydham Hall
- Tempe House and St Magdalenes Chapel

While there were no identified Aboriginal Heritage items within the Bayside West study area from the search with the State Heritage Inventory, an Aboriginal Heritage study conducted by Bayside Council identified 13 Aboriginal Heritage sites.

2. AVAILABLE DATA

2.1. Previous Studies

There are several previous studies that have been carried out within the study area that need to be considered in this FRMS&P. It is noted that only the most recent studies pertaining to this FRMS&P are reviewed here. The relevant Flood Studies often contain a more comprehensive overview of previous flood investigations undertaken in each of the catchment areas.

2.1.1. Floodplain Risk Management Studies and Plans

Wolli Creek, Bardwell Creek, Bonnie Doon Channel and Eve Street/Cahill Park Catchments Floodplain Management Study and Plan (Webb, McKeown & Associates, March 1998, Reference 5)

This FRMS&P was undertaken by Webb, McKeown and Associates (now WMAwater) and completed in 1998. It was based upon the modelling and findings of the Wolli Creek, Bardwell Creek and Bonnie Doon Flood Study (Webb, McKeown & Associates, 1996), the Eve Street/Cahill Park Flood and Drainage Study (Webb, McKeown & Associates, 1996) and the Bonnie Doon Drainage Catchment Flood Study (Lawson and Treloar, 1997). The FRMS&P analysed the existing flood problem areas, and investigated floodplain management strategies that would address existing flood problems or mitigate the impact of possible future development within the catchments. The study considered the social, economic, environmental and hydraulic factors. A comprehensive community consultation program was also undertaken and incorporated into the assessment of options. A priority list of options was developed. These options have been re-assessed as part of the current study.

Spring Street Drain, Muddy Creek and Scarborough Ponds Floodplain Management Study and Plan (Willing & Partners, January 2000, Reference 6)

The study was based upon the modelling and findings of the Muddy Creek and Scarborough Ponds Flood Study (AWACS, 1997) and the Spring Street Drain Flood Study (Lawson and Treloar, 1997). The FRMS&P analysed the existing flood behaviour and drainage system, including an assessment of flood damages. The study investigated floodplain management measures to reduce flood damages and flood risk and undertook a socio-economic appraisal of the options. A draft floodplain management plan was presented which prioritised the options for implementation. These options have been re-assessed as part of the current study.

Sans Souci Drainage Catchments Floodplain Risk Management Study and Plan (Cardno Willing, February 2005, Reference 7)

The study was based upon the modelling and findings of the Scarborough Ponds, Muddy Creek & Sans Souci Drain No 1 Flood Study (AWACS, 1997) and the Sans Souci Drain No. 2 and 3 Flood Study (Webb, McKeown & Associates, 1994). The FRMS&P assessed the existing flood behaviour and undertook a flood damages assessment. The study investigated floodplain management options to reduce flood risk and evaluated these options based on constructability and technical viability, capital and operational costs, effectiveness, environmental impacts and social acceptance. It also undertook a socio-economic appraisal of the options. A draft floodplain risk management plan was presented which prioritised the options for implementation. These options have been re-assessed as part of the current study.

2.1.2. Flood Studies

Bardwell Creek 2D Flood Study Review (WMAwater, March 2019, Reference 8)

The study area comprised the catchments of Bardwell Creek and Wolli Creek within the Bayside LGA. A WBNM hydrologic model was developed for the entire Wolli and Bardwell Creek catchment to the Cooks River, and a 1D/2D TUFLOW hydraulic model covering the catchment area within the Bayside LGA. The WBNM model simulated rainfall runoff that was used as inflows into the TUFLOW model. A 2 m grid covering an area of 9.55 km^2 was used to simulate overland flows within the study area, with 1D elements for stormwater pits, pipes, culverts and concrete channel sections of Wolli Creek and Bardwell Creek. Blockage of hydraulic structures was considered. Surface roughness (Manning's “n”) was assigned based on land use and buildings were represented as solid obstructions. The downstream tailwater boundary considered coincident Cooks River flooding. The model was calibrated using the November 1984, December 1992, February 1993 and January 1996 flood events, with the October 2014 event being used as a validation. The 20%, 10%, 5%, 1% and 0.5% Annual Exceedance Probability (AEP) design flood events were simulated using ARR 2016 guidelines (now ARR 2019, Reference 9). The Probable Maximum Flood (PMF) event was also simulated. The critical duration was found to be 45 minutes for the 20% AEP event and 60 minutes for all other events, and a representative temporal pattern was selected for each event. Design flood results were produced including peak flood depths, levels, velocities, hydraulic hazard, hydraulic categories and flood emergency response classification of communities. Peak flood levels and flows were also tabulated at key locations. A sensitivity analysis was undertaken considering the catchment lag factor, Manning's “n”, culvert and bridge blockage, pit inlet blockage, increase in rainfall intensity due to climate change and sea level rise due to climate change. Eleven flood ‘hot spots’ were also identified and analysed.

Bonnie Doon, Eve Street / Cahill Park Pipe and Overland 2D Flood Study (WMAwater, February 2017, Reference 10)

This study built upon the modelling undertaken for the Bonnie Doon Pipe and Overland 2D Flood Study (WMAwater, 2011), which was undertaken for the upper Bonnie Doon catchment. The study area focussed on the lower Bonnie Doon, Eve Street and Cahill Park catchments, although flood results were also presented for the upper Bonnie Doon catchment, and hence superseded the 2011 study. The study developed a DRAINS hydrologic model and a 1D/2D TUFLOW hydraulic model for the study area. The DRAINS model simulated rainfall runoff that was used as inflows into the TUFLOW model. A 2 m grid covering an area of 2.46 km^2 was used to simulate overland flows within the study area, with 1D elements for stormwater pits, pipes, culverts and concrete channel sections of the Bonnie Doon channel. Blockage of hydraulic structures was only considered in a sensitivity analysis. Surface roughness (Manning's “n”) was assigned based on land use and buildings were represented as solid obstructions. The downstream tailwater boundary considered coincident Cooks River flooding. The model was calibrated using the

February 1993 flood event. The 20%, 10%, 5% and 1% AEP design flood events were simulated using ARR 1987 guidelines (Reference 11). The PMF event was also simulated. The critical duration was found to be 60 minutes for all events for most of the study area and was adopted for the design flood events. Design flood results were produced including peak flood depths, levels, velocities, hydraulic hazard and hydraulic categories. Peak flood depths were also tabulated at key locations. A sensitivity analysis was undertaken considering rainfall losses, Manning's "n", blockage of pipes and bridges, blockage of all small pipes and increase in rainfall intensity due to climate change.

Spring Street Drain, Muddy Creek and Scarborough Ponds Catchments Flood Study Review (BMT WBM, February 2017, Reference 12)

This Flood Study covered the three major catchments of Spring Street Drain, Muddy Creek and Scarborough Ponds. The study developed an XP-RAFTS hydrologic model and a 1D/2D TUFLOW hydraulic model for the study area. The XP-RAFTS model simulated rainfall runoff for 190 sub-catchments that were used as inflows into the TUFLOW model. A 2 m grid covering an area of approximately 13.1 km^2 was used to simulate overland flows within the study area, with 1D elements for stormwater pits, pipes, culverts and concrete channel sections of Muddy Creek and Spring Street Drain. Blockage of hydraulic structures was only considered in a sensitivity analysis. Surface roughness (Manning's "n") was assigned based on land use and buildings were represented with a high Manning's "n" and slightly raised walls on the upstream side (where a building is located on a major flow path, to divert shallow flows around the building). Some major obstructions such as solid walls were also included as raised walls within the terrain. The downstream tailwater boundary considered coincident ocean water levels. The model was calibrated using the April 1998 flood event, and validated using the February 1993 and October 2014 events. The 50%, 20%, 10%, 5%, 2%, 1% and 0.5% AEP design flood events were simulated using ARR 1987 guidelines (Reference 11). The critical duration was found to be the 2 hour and 9 hour durations. The PMF event was also simulated, with critical durations of 15 minutes, 45 minutes and 90 minutes. Design flood results were produced including peak flood depths, levels, velocities, hydraulic hazard, hydraulic categories and flood emergency response classifications. Peak flood levels and flows were also tabulated at key locations. Flood problem areas were highlighted in the report. A sensitivity analysis was undertaken considering Manning's "n", blockage of the stormwater drainage network, blockage of culverts and bridges on Spring Street Drain and Muddy Creek, rainfall losses, downstream boundary conditions, the behaviour of Scarborough Ponds, increase in rainfall intensity due to climate change and tidal inundation scenarios considering climate change.

Sans Souci Flood Study Review (Cardno, September 2015, Reference 13)

This Flood Study covered the catchments south of Scarborough Ponds, namely Waradiel Creek, Bado-Berong Creek and Goomun Creek. The study utilised the direct rainfall approach within a 1D/2D TUFLOW hydraulic model developed for the study area. Flows generated by the direct rainfall method were verified using an XP-RAFTS model. A 2 m grid covering an area of approximately 3.1 km^2 was used to simulate overland flows within the study area, with 1D elements for stormwater pits, pipes, culverts and channel sections of the three main creeks. Blockage of hydraulic structures was not considered. Surface roughness (Manning's "n") was assigned based on land use and buildings were represented with a high Manning's "n" value. The downstream tailwater boundary considered coincident ocean water levels. The model was calibrated using the March 1975 flood event. The 20%, 10%, 5%, 1% AEP design flood events were simulated using ARR 1987 guidelines (Reference 11). The critical duration was found to be the 1 hour and 9 hour durations. The PMF event was also simulated. Due to the direct rainfall approach, the results were filtered for shallow depths less than 0.15 m, and removal of isolated areas of ponding less than 200 m^2.

Design flood results were produced including peak flood depths, levels, velocities, hydraulic hazard, hydraulic categories and flood risk precincts. A sensitivity analysis was undertaken considering catchment rainfall, Manning's "n", rainfall losses, increase in rainfall intensity due to climate change and sea level rise due to climate change.

2.1.3. Other Relevant Studies

Bonnie Doon Catchment Upper Catchment Diversion Preliminary Assessment (Webb, McKeown & Associates, June 2001, Reference 14)

Webb, McKeown and Associates (now WMAwater) were commissioned by Rockdale City Council to undertake an investigation of the feasibility and potential flood benefits of diverting surface flows from the upper portion of the Bonnie Doon catchment (upstream of Fripp Street) to the Bardwell Creek catchment. This report encompassed the results of Stage 1, involving modelling using ILSAX, development of peak flow rates at critical locations in the catchment (both with and without diversion), assessment of potential impacts in Bardwell Creek and a preliminary cost estimate. There was estimated to be a reduction in 1% AEP flows by between 40% and 50% upstream of Arncliffe Park, with a negligible effect on peak flood levels in Bardwell Creek. The study simply assessed the hydrologic benefit of a diversion system, and recognised that the ultimate success of such a system could only be assessed through further studies into the hydraulic operation of the system, the technical feasibility of capturing and diverting the water, interaction with buried services, detailed design and final project costs.

Cooks River Flood Study (MWH + PB, February 2009, Reference 15)

This 2009 study by MWH and Parsons Brinckerhoff Joint Venture (Reference 15) used a WBNM hydrologic model and a TUFLOW hydraulic model to determine design flood levels in the Cooks River, up to Bexley Road on Wolli Creek and Bardwell Creek, and in the lower Muddy Creek catchment including Spring Street Drain to the Illawarra railway line. The models were calibrated to the November 1961 and March 1983 recorded flood data on the Cooks River but no calibration was undertaken on Wolli Creek, Bardwell Creek, Spring Street Drain or Muddy Creek. The 2 year average recurrence interval (ARI), 20 year ARI, 100 year ARI and PMF events were simulated.

This study provides the most current design flood levels in the Cooks River, however it should be noted that the results are based on the ARR 1987 design flood methodology and may change if the ARR 2019 methodology was undertaken.

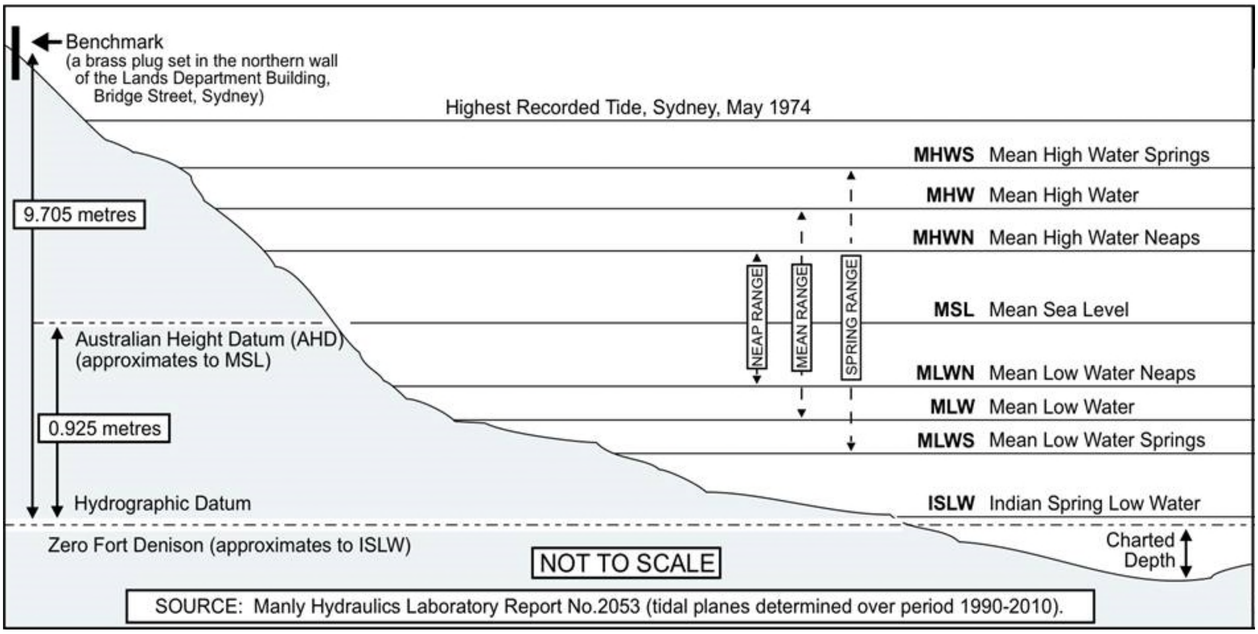
OEH NSW Tidal Planes Analysis: 1990-2010 Harmonic Analysis (Manly Hydraulics Laboratory, October 2012, Reference 16)

Manly Hydraulics Laboratory prepared the *NSW Tidal Planes Analysis: 1990-2010 Harmonic Analysis* report on behalf of the Office of Environment and Heritage (OEH, now DPE). It was released in October 2012 and was based on data from 188 tidal monitoring stations from 1st July 1990 to the 30th June 2010. Data from the relevant stations are shown in Table 2, with a tidal plane diagram shown as Diagram 1.

Table 2: Tidal Planes Analysis Results (Reference 16)

Tidal Planes	Annual Average Amplitude (mAHD)		
	Ocean Tide Gauge Port Jackson (213470)	**Ocean Tide Gauge Port Hacking (213473)**	**Cooks River at Tempe Bridge (213415)**
High High Water Solstices Springs (HHWSS)	1.00	1.04	1.06
Mean High Water Springs (MHWS)	0.65	0.68	0.70
Mean High Water (MHW)	0.52	0.56	0.57
Mean High Water Neaps (MHWN)	0.40	0.44	0.45
Mean Sea Level (MSL)	0.02	0.07	0.06
Mean Low Water Neaps (MLWN)	-0.36	-0.31	-0.33
Mean Low Water (MLW)	-0.48	-0.43	-0.46
Mean Low Water Springs (MLWS)	-0.61	-0.55	-0.58
Indian Spring Low Water (ISLW)	-0.86	-0.81	-0.84

Diagram 1: Tidal Planes Diagram



Bonnie Doon Catchment Flood Risk Management Concept Design Report (WMAwater, October 2017, Reference 15)

In order to progress a number of potential flood risk mitigation options in the upper Bonnie Doon catchment, WMAwater was engaged by Bayside Council to prepare a concept design report. Wollongong Road pipe upgrades and various Arncliffe Park upgrades involving swales, detention basins and storage tanks were investigated. The study found that the Wollongong Road pipe upgrade offered the greatest reduction in flood damages, while a non-synthetic field at the base of a detention basin provided the greatest reduction in flood damages of the Arncliffe Park sports field upgrade options.

Arncliffe Park Synthetic Turf project – Flood Assessment (WMAwater, February 2019, Reference 15)

Bayside Council, in their investigation of the construction of a synthetic turf playing field in Arncliffe Park, engaged WMAwater to undertake a flood modelling of the detailed design. This flood assessment determined finished levels of the playing surface to ensure that it would be flood free in the 1% AEP design flood event. A flood impact assessment was also undertaken to demonstrate that the field would not adversely affect properties and roads outside the site boundary. The proposed field included 18 x 600 mm diameter pipes beneath the field to convey overland flows under the field. The results indicated shallow flows over the field in both the 5% AEP and 1% AEP events, with increases in flood levels of up to 0.02 m downstream of the field.

Dominey Reserve Detention Basin Investigation (BMT, June 2018, Reference 19)

One of the proposed mitigation measures of the Spring Street Drain, Muddy Creek and Scarborough Ponds FRMS&P (Reference 6) was a detention basin in Dominey Reserve, Bexley. This report documents an investigation into the basin's effectiveness in reducing flood risk and undertaking a cost-benefit analysis. The assessment utilised flood modelling from the most recent Flood Study (Reference 12) to assess the basin. The basin was modelled with an embankment and spillway in the 2D domain, and outlet pits in the 1D domain. The greatest impacts (typically up to 0.2 m) were estimated in events more frequent than the 5% AEP event, since the basin capacity was estimated to be below the 5% AEP event. Considering downstream flood damages and basin construction costs, a cost-benefit ratio of 1.3 was determined.

Gardiner Park Synthetic Field – Flood Assessment (WMAwater, September 2020, Reference 20)

WMAwater was engaged by Bayside Council to undertake a flood assessment for proposed upgrades to sporting facilities in Gardiner Park, Banksia. The design included field upgrades as well as stormwater upgrades and flood mitigation infrastructure within the park to improve drainage system performance and meet the flood-related development requirements. Detailed designs were provided to WMAwater and by utilising flood modelling, the design was adjusted to ensure no adverse downstream impacts. A subsequent memo was also issued in February 2021 outlining a supplementary flood assessment undertaken to assess minor changes to the proposed design at the construction stage, as well as assessing the impacts of climate change (increased rainfall intensity) on the design. It demonstrated the design revisions would not adversely affect the flood behaviour outside of the site, under current and future climate scenarios.

Bayside Catchments Flood Tagging (WMAwater, November 2019, Reference 21)

WMAwater was engaged by Bayside Council to review the available flood studies (see Section 2.1.2) and to produce a consistent approach to flood tagging across the entire LGA. A lot-based property tagging exercise was undertaken to define flood affected lots within the Bayside LGA. Flood affectation for the 1% AEP and PMF design flood events was produced. Additional property tagging was produced for the 1% AEP event under 0.4 m and 0.9 m sea level rise scenarios. The methodology consisted of an initial automated GIS tagging analysis followed by a comprehensive process of desktop review and ground truthing. The methodology was developed to provide a consistent approach to identifying flood liable lots which considered the range of modelling approaches employed in the catchment wide flood studies within the LGA. Properties were classified as tagged or not tagged based on their risk of flood affectation in the modelled design events and the reason for this classification was added to the property tagging database.

Sydney Water Stormwater Renewals – Investigation and Design Services Package B – Muddy Creek Hydraulic Modelling Report (ENSure, January 2020, Reference 21)

This report, prepared by the ENSure Joint Venture (Jacobs and GHD) for Sydney Water outlined the hydrology and hydraulic assessment that was undertaken for the detailed concept design for the proposed renewal and channel naturalisation of Muddy Creek (in the vicinity of West Botany Street and Bestic Street). The report presented the design flood level and flow velocity information required for the design of the replacement channel, as well as determined and assessed the impact of the channel modification on existing flood behaviour. The flood modelling (based on the existing Muddy Creek Flood Study model of Reference 12) was also provided.

Sydney Water Capacity Assessments and Design Drawings

Sydney Water Corporation (SWC) was contacted to obtain information on SWC assets within the study area. These included the following:

- Muddy Creek SWC 70 Capacity Assessment (Sydney Water, July 2000).
- Bardwell Creek SWC 21 Capacity Assessment (Sydney Water, August 2000).
- Flynn’s Reserve, Bexley GPT details, including WAE drawings and Operation and Maintenance Manual.

2.2. DRAINS Models

Council provided ten existing DRAINS models that cover a large proportion of the Bayside West study area. The DRAINS models are used by Council for assessment of the stormwater network and design of minor drainage upgrades. Council requested, as part of this FRMS&P that the existing DRAINS models be updated and extended. This was undertaken, with the outcomes documented in Appendix B. The upper Bonnie Doon DRAINS model is the only model that provides inflow hydrographs into any of the Flood Study TUFLOW models.

2.3. Planning Documents

Council provided draft versions of the updated Local Environmental Plan (LEP) and Development Control Plan (DCP) documents. These are still in the process of being formulated by Council and contain updated draft flood-related development controls to be reviewed as part of this FRMS&P.

2.4. GIS

The following GIS datasets were provided by Council:

- Cadastre boundaries were provided including lot/DP information.
- Flood Mitigation: this layer identifies the location and basic information about nine public and private flood mitigation assets in the study area.
- Stormwater Pipes: Council's database of stormwater pipes in the study area, containing the location and geometry for most assets, although invert data are missing for most of these.
- Stormwater Pits: Council's database of stormwater pits in the study area, containing the location and geometry for most assets, although invert data are missing for most of these.
- Pipe information updates: This layer contains corrections to Council's pit and pipe database, assumed to be from various sources (survey, development applications, designs, etc) where the current pipe asset layer contains incorrect or outdated information.

2.5. Recent Developments and Upgrades

Council provided information relating to recent developments and upgrades in the catchment (in addition to the GIS files provided, as outlined in Section 2.4). These are as follows:

- Discovery Point, Wolli Creek – Work-As-Executed (WAE) survey, including the stormwater network.
- 15-23 Lusty Street, Wolli Creek – detention tank drawings.
- Arncliffe Street, Wolli Creek – maps and plans of potential land acquisitions with street and drainage upgrades.
- Bonar Street Precinct, Arncliffe – WAE drawings of stormwater and detention tank with CCTV and inspection reports.
- Valda Avenue, Arncliffe – details of recent rectification and pit connection works to resolve frequent ponding at the end of Valda Avenue.
- Wickham Street and Charles Street, Arncliffe – drainage upgrade drawings.
- Gibbes Street, Rockdale – photographs and WAE drawings of drainage upgrades.
- 9 Banksia Avenue, Banksia – WAE stormwater plans
- The Strand, Rockdale – levee extent and photographs.
- 344 West Botany St, Brighton-Le-Sands (Brighton Terraces) – WAE drawings of development at this address including stormwater upgrades.
- Bona Park, Sans Souci and Depena Reserve, Dolls Point – Plans of Water Sensitive Urban Design (WSUD) and Gross Pollutant Trap (GPT) infrastructure.
- Alfred Street, Sans Souci – additional pipe outlet from channel.

2.6. Additional Drainage and Flooding Information

Council provided the following additional miscellaneous data to be considered for the current study:

- 20 The Glen Road, Bardwell Valley – photos of the February 2020 flood event.
- 17 Kingsland Road South, Bexley – photos and videos of the March 2021 flood event.
- Arncliffe Street, Wolli Creek – photos and videos of flooding from residents of the March 2021 flood event.
- Cahill Park Masterplan Report (McGregor Coxall, March 2018) – flood modelling was undertaken by GRC Hydro which considered a potential levee in the park and its impacts.
- 61-63 Mutch Avenue Kyeemagh – observations and queries from resident about previous design flood modelling and mapping. Responses from BMT WBM were also provided, addressing the comments raised by the residents.
- 49 Horbury Street, Sans Souci – pictures of flooding from a resident.
- Toyer Avenue, Sans Souci – details from a consultant which may indicate TUFLOW model instability issues.
- LEP Acquisitions Strategy – maps and plans of past and potential land acquisitions for flood considerations.
- Consideration of an overland flow policy, with the example of fencing obstructions on Ida Street, Sans Souci provided.
- Council CCTV and drainage details for various underground pipes, primarily in the Spring Street Drain catchment upstream of the open channel

2.7. Site Visits

A site visit was conducted on 11th September 2020, attended by WMAwater staff and Council staff at the project inception. Key locations for flood problems and potential mitigation measures were visited. A second site visit was conducted by WMAwater staff on 3rd March 2021 to re-visit some of these sites plus additional locations after flood model results were reviewed.

3. COMMUNITY CONSULTATION

One of the central objectives of the FRMS process is to actively liaise with the community throughout the process, keeping them informed about the current study, identify community concerns and gather information from the community on potential management options. Each of the previous FRMS&P's and flood studies undertook extensive community consultation including obtaining flood information for the calibration of flood models and identification of flood hot spots, as well as input into development of flood mitigation options. Community consultation undertaken as part of this study is outlined in the following sections.

3.1. Provision of Information

Information on the study was provided on Council's Floodplain Management webpage (https://www.bayside.nsw.gov.au/area/environment/floodplain-management) under 'Current Work'.

3.2. Floodplain Risk Management Committee

This FRMS&P was overseen by a Floodplain Risk Management Committee (FRMC), consisting of councillors, Council staff and representatives from the community, Sydney Water, SES and DPE. Regular meetings were held in which the FRMC was provided an update on the progress of the project as well as draft reports. Input from the FRMC, including community members, was sought at each stage.

3.3. Public Exhibition

A draft version of this report was placed on public exhibition from 30th November 2022 to 31st January 2023 to invite comment from the community. A copy of the report was available for inspection at Council's Service Centres at Eastgardens and Rockdale and via download from Council's 'Have Your Say' website (https://haveyoursay.bayside.nsw.gov.au/bayside-west-floodplain-risk-management-study). General information was provided on the website along with the draft FRMS&P (including all figures and appendices). A public exhibition summary of the report was also provided. Instructions for making formal written submissions were also provided for those wishing to comment on the study.

Four written submissions were received via the online portal and one submission via email. A submission was also received from the SES. The 'Have Your Say' consultation report containing a summary of the engagement with the community through the website is provided in Appendix J. A compilation of the submissions is also included in Appendix J, with a summary below.

- Three community submissions related to FM08 – Guess Avenue Storage Tank. The community in general wanted this item to be a higher priority. The priority of this action was retained. The complications of solving the Arncliffe Street flooding issue are outlined in Section 10.2.4.11. The solution of a storage tank is limited due to the low-lying nature of the street, proximity to the Bonnie Doon channel and the catchment that drains to this location.
- One submission was concerned about the ecological and geomorphological impacts of

FM06 – Bexley Road Upgrade, FM07 – Bardwell Park Station Levee and FM12 – Mutch Avenue Drainage Line. In general the impacts are considered to be minor, but a recommendation was added that these issues be considered in subsequent more detailed studies.

- One submission was received from Bexley Golf Course, which requested that new dams be considered on the golf course to mitigate flooding and for re-use on site. There are several constraints to the formation of a basin and the downstream benefit would be limited. However, it is recommended that this be considered further in conjunction with FM01 – Regrade Bexley Golf Course.
- The SES had a number of requests that were included in the final report, including:
    - Identification of rainfall gauges aligned to appropriate IFD tables
    - Time range to overtop or fill behind levees
    - Provision of information related to the study
    - Spatial mapping of inundated floor levels
    - Recognition of SES's 'shelter-in-place' position

  These requests were included in the report where practical and addressed in the relevant sections.

The multi-criteria matrix assessment (Section 11) was also updated to consider the community and stakeholder support.

4. MODEL UPDATES

4.1. Overview

The relevant Flood Study models (hydrologic and hydraulic models), as described in Section 2.1.2, were adopted for the current study. It was not within the scope of this FRMS&P to undertake a comprehensive review and update of the models. The relevant Flood Study models were developed within the last ten years using detailed 2D modelling and are considered to be largely valid. Model updates within the scope of this project primarily consist of:

1. Minor updates due to recent developments, drainage upgrades and correcting the representation of certain hydraulic features
2. Update hydrology to consider ARR 2019 guidelines (Reference 9)

The model updates undertaken are outlined in the sections below. Due to the nature of the updates, it was not considered necessary to re-calibrate the flood models and no historic flood events were simulated with the updated models. The ARR 2019 updates are outlined in Section 5.

4.2. Hydrologic Model Updates

No changes were made to the hydrologic models for the study area, including the sub-catchment parameters and model configuration. These models were run with updated rainfall data, in accordance with ARR 2019 (Reference 9), as described in Section 5.

4.3. Hydraulic Model Updates

The updates made to the TUFLOW hydraulic models consisted of the following:

- Updates based on WMAwater's review of the models.
- Updates based on Council's request to investigate flood behaviour or representation of certain features within the study area.
- Updates based on Council's provision of recent developments and drainage upgrades.

The checks and updates that were made to the TUFLOW models are outlined in Table 3 and shown in Figure 3 to Figure 6 for the various model areas. The updates made to the models were in accordance with best practice techniques (Reference 24).

Table 3: TUFLOW Model Checks and Updates

Map ID	Model	Name	Review Outcome	Details
1	Wolli/Bardwell Creek	Kingsgrove RSL Flow path	Not updated	The model represents the terrain and features seen on site. In the model, flow comes around both sides of RSL, ponds in the park and then flows downstream, primarily on west near Kingsgrove Hotel, but also near the church too. The site visit confirmed these flow paths.
2	Wolli/Bardwell Creek	SWSOOS Flow path	Updated	There are openings adjacent to the SWSOOS in the model that carry 0.6 m^3/s in the 1% AEP event, which is reasonable given observations on site. Improved the schematisation using 1D pipes (replicating observations on site) and connectivity on either side of the SWSOOS upstream of this (large arch openings now represented as open 2D cells rather than 1D culverts).
3	Bonnie Doon	Bidjigal Road Stormwater	Updated	Pits and pipes refined based on WAE drawings, particularly on Bonar Street; tank is represented in model in 1D. Refined buildings, terrain and materials in this area to represent recent development (e.g. Bonar Street park) based on recent aerial imagery and the 2020 LiDAR dataset.
4	Wolli/Bardwell Creek	Bridge Street Channel	Updated	Updated channel cross sections and culvert crossings upstream of Bexley Golf Course based on SWC capacity report, retaining inverts. Sizes of culverts and channels changed slightly in accordance with drawings provided in the SWC capacity report.
5	Wolli/Bardwell Creek	Hillcrest Avenue Stormwater	Not updated	Incomplete stormwater data from the Council GIS layer. Currently no stormwater network from the street is modelled. 3 x 375 mm diameter pipes are modelled to drain Hillcrest Avenue runoff under the levee. The stormwater network in the street itself is not a critical feature and at this location the focus is on the levee performance.
6	Muddy Creek	Seaforth Park Flows	Updated	Model extended upstream of Seaforth Park to model flows through the park (for potential basin options). Stormwater network extended based on Council GIS layer, boundary inflows updated and RAFTS catchment MC29 flows distributed upstream/downstream of Seaforth Park based on proportional area draining to these locations.
7	Muddy Creek	Frys Reserve Detention	Not updated	There is a high flow culvert with equivalent size as that provided by Council (9 m x 1.2 m in the model to represent 4 x 2 m x 1 m approximated by Council); levee included as a breakline with a height of 8.1 mAHD.
8	Muddy Creek	The Strand Levee	Updated	There is a levee breakline in the model with similar heights to those observed on site. Extended

Map ID	Model	Name	Review Outcome	Details
				downstream one building to location observed on site, but this should not affect results.
9	Muddy Creek	Rockdale Tennis Club Footbridge	Not updated	Footbridge not represented in the flood study model. Flood levels checked against LiDAR for the 1% AEP and should be flood free so not included. Note that bridge details were not provided.
10	Muddy Creek	Brighton Terrace Development	Updated	Existing 900 mm diameter pipe updated to 1.5 m x 0.6 m box through Brighton Terrace development only, as indicated on WAE drawings.
11	Muddy Creek	Bay St Reserve	Not updated	Pipes working correctly, there is a channel breakline through the Reserve; same invert levels in the pipe. Ponding appears reasonable.
12	Muddy Creek	Bruce Street	Not updated	Inflows placed at pits with limited capacity. Local water ponds in cul-de-sac up to the 5% AEP. Contributions from Hinkler Street in 2% AEP event and greater. Flows from Muddy Creek contribute in the 1% AEP and greater.
13	Muddy Creek	Banksia Avenue Development	Updated	Block wall included in model, assumed to enclose development and cut off overland flow path. There was no evidence of an overland flow path under the wall on site.
14	Muddy Creek	Short Street Trunk Drain	Not updated	Spring Street Drain is not a SWC asset – thus not in capacity assessment report so details could not be updated.
15	Muddy Creek	Subway Road	Not updated	Subway Road represented in model and appears to be replicating flood behaviour well (based on site visit observations). Water ponds upstream of Banksia Station and then flows into Subway Road at approximately RL 14 mAHD.
16	Muddy Creek	French Street Stormwater	Not updated	Results appear reasonable - peak flow of 2.7 m^3/s in twin 1.2 m pipes (1% AEP) out of peak 4.1 m^3/s in total system outlet. Very few inlets on French Street (verified on Street View).
17	Muddy Creek	Scarborough Ponds Outlet	Not updated	3 x 1.35 m diameter outlet pipes in the model. Appears reasonable though no data available to check against apart from sizes indicated in Flood Study report (Reference 12). Modelled invert levels of pipes result in a ‘hump’ in the culverts from the pond to the ocean. Assumed to be correct.
18	Sans Souci	Pemberton Reserve Basin	Updated	Flood Study report (Reference 13) says the basin is in, there is a maximum of 0.7 m water ponding in the model. Terrain looks reasonable, although pipes look suspect – 450 mm diameter pipe under park but no pits to drain water. Pits added based on aerial imagery. Note there is a

Map ID	Model	Name	Review Outcome	Details
				1.35 m pipe under Park Road which turns into a 900 mm diameter under the houses on the downstream side. Retained as there was no data to indicate a different configuration.
19	Muddy Creek	Subway Road Stormwater	Not updated	Network from Council GIS data is already in the model, appears to be accurate based on provided data and Street View.
20	Sans Souci	Alfred Street Culvert	Updated	Double the existing 1.05 m pipe (assumed the new pipe was a duplicate of the existing - no size provided) - into existing twin 1.2 m pipes appears reasonable.
21	Bonnie Doon	Wickham Street Pipe Upgrade	Updated	525 mm pipe along Charles Street and Wickham Street is in the model. Only updated invert levels from long section design plots.
22	Sans Souci	Sanoni Avenue Pipe Upgrade	Updated	Existing model had a channel directly to the ocean and culverts on the side. Removed channel to the ocean, insert culverts as per Council data. Completely revised this outlet as it did not represent the actual channel and culvert configuration.
23	Sans Souci	Kendall Street Reserve Channel	Not updated	Channel widening and stabilisation works undertaken. Observed on site and over time through Street View and does not appear to be significant changes to channel capacity. In the absence of surveyed cross sections, the existing cross sections were retained.
24	Muddy Creek	Margaret Street Stormwater	Updated	750 mm pipe used instead of 600 mm pipe as the starting pipe in the street. The rest of the drainage line was correct.
25	Bonnie Doon	Upper Bonnie Doon Stormwater	Updated	Representation of pipes were checked and updated within the Bonnie Doon upper model area. There were some inconsistencies in the Reference 18 model.
26	Sans Souci	Sans Souci Model Boundary	Updated	Model ocean boundary set up was not considered best practice and was updated. While it should not affect model results within Sans Souci, it may help with model mass errors (TUFLOW Classic).
27	Sans Souci	Sans Souci Culvert Connections	Updated	Updated culvert connections to the ocean to connect to more cells – previously this was limiting the amount of water that could discharge to the ocean and artificially raising water levels in the channels upstream of the outlets.
28	Muddy Creek	Muddy Creek Model Updates by	Updated	Included in the model (modifications around West Botany Street) from the Jacobs base case only (Reference 22). No proposed channel naturalisation was included.

Map ID	Model	Name	Review Outcome	Details
		Jacobs		
29	Muddy Creek	Gardiner Park Updates	Updated	Included in the model (modifications for Gardiner Park) from the WMAwater proposed case model (Reference 20).
30	Bonnie Doon	Arncliffe Park Updates	Updated	Included in the model (modifications for Arncliffe Park) from the WMAwater proposed case model (Reference 18).
31	Bonnie Doon	Gertrude Street Stormwater	Updated	Pipe along Gertrude Street now included, pit invert levels estimated based on the existing pits upstream and downstream.
32	Bonnie Doon	Valda Avenue Outlet	Updated	Pipe extended to actual outlet, as observed in aerial imagery and LiDAR.
33	Bonnie Doon	Eden Street Pipes	Updated	Pipes updated under M5, but outside modelled flood extent.
34	Muddy Creek	Kent Street Pipes	Not updated	Pipes not updated - were not included in the model and are upstream of the modelled start of the flow path (two streets away). Hydrology/inflows not modified to account for this.
35	Muddy Creek	Bryant Street Inlet	Updated	Pipes updated, but outside modelled flood extent.
36	Muddy Creek	Market Street Pipe Alignment	Updated	Pipe alignment and pits updated, invert levels estimated.
37	Muddy Creek	Hegerty Street Stormwater	Updated	New drainage line added. Outlet estimated based on StreetView pit location and connected to channel.
38	Muddy Creek	Queen Victoria Street Stormwater	Updated	Pipes added, although outside 1% AEP flood extent.
39	Muddy Creek	Glenfarne Street Stormwater	Not updated	Pipes not updated - were not included in the model and are upstream of the modelled start of the flow path (two streets away). Hydrology/inflows not modified to account for this.
40	Muddy Creek	Ador Avenue Reserve Stormwater	Updated	Added pipes to drain field and pits (inlets and inverts estimated); connected outlet to the channel.
41	Muddy Creek	O'Connell Street Stormwater	Updated	New pipes along O'Connell Street, assume 4 x 450 mm pipes connect to 900 mm in centre of road.

Map ID	Model	Name	Review Outcome	Details
42	Muddy Creek	Scarborough Park Open Channel	Not updated	There is an existing thick breakline to represent the open channel, which is considered adequate. The channel is drowned out in any case from Scarborough Ponds flooding.
43	Muddy Creek	Garrigarrang Avenue Stormwater	Updated	New road near Ramsgate Park apartments – added new stormwater line, updated materials layer for buildings, parklands and roads, new terrain to represent road and development from 2020 LiDAR information.
44	Sans Souci	Ramsgate Road Stormwater	Updated	Updated the pipes (minor changes) based on Council's GIS layer.
45	Sans Souci	Ramsgate Shopping Centre Stormwater	Updated	Updated from Council's GIS layer. Pit inlets and invert levels estimated. Included line along Ramsgate Road to the ocean.
46	Sans Souci	Bona Park WSUD	Not updated	Small water quality device. Will have minimal storage that will not affect flooding. Site is inundated 0.2-0.3 m in 1% AEP - minimal infiltration that is not modelled as part.
47	Sans Souci	Peter Depena Reserve WSUD	Not updated	Small water quality device designed for infiltration. Will have minimal storage and only takes flow from a 375 mm pipe. Will have minimal effect on flooding and infiltration is not modelled.
48	Wolli/Bardwell Creek	20 The Glen Road	Checked	Reported flooding was due to a pipe burst rather than flooding, however, modelling overland flows down side of house where observations were made.
49	Bonnie Doon	Discovery Point Stormwater	Updated	Updated stormwater with invert levels estimated based on the upstream and downstream inverts, LiDAR and approximate cover. Also updated terrain (based on 2020 LiDAR), buildings (based on aerial imagery) and inflow locations due to development not previously modelled.
50	Wolli/Bardwell Creek	Lusty Street Detention Tank	Updated	This was included in a previous scenario modelled as part of the Flood Study (Reference 10). Adopted the modelled detention tank and adjusted with a more accurate storage representation based on drawings provided. Set initial water level to be the same as Wolli Creek (i.e. tank almost full in 1% AEP event), given the tank cannot freely drain unassisted.
51	Bonnie Doon	Wollongong Road Detention Tank	Not updated	Already in model and appears to be reasonable compared to information provided.
52	Muddy Creek	Gibbes Street	Not	Well outside modelled flood extent (too far upstream). Also do not have pipe sizes from Gibbes

Map ID	Model	Name	Review Outcome	Details
		Stormwater	updated	Street to Farr Street and this entire branch is not currently modelled.
53	Muddy Creek	Cooks River Outlets	Updated	Revised Cooks River boundary to include boat ramp. Included pipe network at the end of Mutch, Owen and Jacobson Avenues – assumed invert levels and obtained size of pipes from Council's GIS (where not specified – assumed to be 300 mm diameter). Added 1D downstream boundaries on the pipes.
54	Sans Souci	49 Horbury Street	Checked	Model represents observations well. Low lying area in front of the house results in maximum ponding of ~0.2 m depth in 1% AEP with pipes flowing full.
55	Sans Souci	Toyer Street and Ida Street	Checked	Some minor variations in water level which do not appear to be instabilities. Seemed to be solved with model updates and HPC - more stable at Ida Street, not flooded on Toyer Street. A pit on northern side of Ida Street was modelled as a node (assumed due to 1.2 m diameter pipe in Council's GIS layer that feeds into a 450 mm pipe – this pipe at the upstream end of the network does not convey flows).
56	Bonnie Doon	Bonar Street Stormwater	Updated	Updated (see item 3 for details).
57	Bonnie Doon	Wollongong Road Culvert	Not updated	Existing pipes appear to be correct. 1.5 m diameter pipe changes to 1.5 m x 1.5 m box (representing the arch section seen in CCTV - appears to be OK without having actual dimensions and given upstream 1.5 m diameter pipe will be the control).
58	All (in Muddy Creek map)	Demolished Buildings	Updated	Removed buildings currently demolished (2020 aerial/StreetView) in Muddy Creek, Bonnie Doon and Bardwell Creek. Other parcels of land marked were not changed (assumed to be future demolitions e.g. highway corridor).
59	Muddy Creek	Subway Road Rail Culvert	Updated	Updated pipe size from 1.2 m to 0.9 m diameter – assumed the whole line (2 sections have CCTV), although retained 1.2 m diameter under the railway (representing the arch culvert). Added open channel upstream of railway, allowing exchange of water with overland flows.
60	Muddy Creek	Cnr Tabrett and Princes Culvert	Not updated	Same size as existing layer.
61	Muddy Creek	286 Princes Highway Culvert	Updated	Updated pipe size from 1.2 m to 0.9 m diameter – assumed whole line (2 sections have CCTV).

Map ID	Model	Name	Review Outcome	Details
62	Muddy Creek	Tabrett St Culvert	Not updated	CCTV report has diameter/height of 1.2 m. This could be height? Retained existing dimensions as 1.9 m x 1.37 m box - the whole line has these dimensions - seems reasonable based on CCTV images.
63	Muddy Creek	Princes Highway Culvert	Updated	Update height from 1.5 m to 1.2 m based on CCTV report. Retain width as 1.9 m - fits dimensions in CCTV image and downstream dimensions.
64	Muddy Creek	Princes Highway Culvert	Updated	Updated from 1.9 m x 1.3 m box to 1.8 m diameter pipe - CCTV shows box to pipe transition at this location. Matches downstream pipe size.
65	Muddy Creek	Albert Street Culvert	Not updated	No height in the CCTV report. 1.21 m x 1.21 m appears to be reasonable.
66	Muddy Creek	Albert Street Culvert	Not updated	No height in the CCTV report. 1.21 m x 1.21 m appears to be reasonable.
67	Muddy Creek	Albert Street Culvert	Not updated	CCTV has 1.8 m diameter pipe - retained in model. This includes blind pit with direction change as well.
68	Muddy Creek	Banksia Avenue Culvert	Not updated	Same size as existing pipe - no change.
69	Muddy Creek	Banksia Avenue Culvert	Not updated	Same size as existing pipe - no change.
70	Muddy Creek	Tabrett Street Culvert	Not updated	CCTV has 1.2 m diameter/height, but no images of box to compare dimensions. Retain existing box (1.9 m x 1.37 m) consistent with upstream and downstream sections.
71	Muddy Creek	Princes Highway Culvert	Not updated	Same size as existing pipe - no change.
72	Muddy Creek	Short Street Culvert	Updated	No height found in CCTV report. Retained existing 2.36 m x 1.37 m box as per existing model - looks reasonable given CCTV image. But double capacity – site visit observations showed 2 box culverts exiting, so assume upstream 1.9 m x 1.37 m and 1.21 m x 1.21 m join into this twin box line. Also continued upstream 1.8 m diameter pipe to downstream of Short Street (large pipe observed to discharge at this location). There is a large 8 m wide headwall at Short Street –

Map ID	Model	Name	Review Outcome	Details
				assume that Short Street crossing is not a constraint on upstream pipes.
73	Muddy Creek	Subway Road Rail Culvert	Updated	Pipes updated based on CCTV data, including twin lines where indicated.
74	Bonnie Doon	Arncliffe Pedestrian Tunnel	Updated	Included new pedestrian tunnel as an arch culvert, with dimensions estimated/scaled from image of design (https://www.bamser.com.au/projects/Arncliffe%20Pedestrian%20Link%20-%20Construction%20Phase%20Services).
75	Bonnie Doon	Arncliffe St Flooding	Updated	0.7 m deep in 10% AEP, photos show 0.3-0.4 m in recent event - water ponds here. Aco drains not in model, but main pits and pipes are that should represent this. Revised representation of buildings including where water can flow from Arncliffe Street into channel. Appears to be reasonable.
76	Muddy Creek	Muddy Creek Water Level Lines	Updated	Straightened 1D mapping lines (perpendicular to flow now), removed mapping of culvert flows and fixed up junctions - 1D channel mapping will be cleaner.
77	Wolli/Bardwell Creek	Wolli/Bardwell 1D Water level Lines	Updated	Adjusted 1D mapping lines on Wolli and Bardwell Creeks. 1D channel mapping will be cleaner.
78	Bonnie Doon	Eve Street Wetland	Updated	Eve Street Wetland had no outlet connection to the Cooks River. Applied terrain modifications to represent the wetland (0.6 mAHD) and channel under and adjacent to M5. Culvert details to Cooks River unknown, so applied the Cooks River tailwater boundary to the end of the downstream end of the channel.

The TUFLOW models were run in the same version of TUFLOW that they were developed for, except for Sans Souci. This model was updated to TUFLOW version 2020-10-AA_iSP, using the HPC engine and utilising a GPU. This was due to the long run times of the model in TUFLOW version 2011-09-AF using the Classic engine (as run for the Flood Study). The 9 hour event had a run time of approximately 5 days, which was not considered feasible, particularly for running the ARR 2019 critical duration assessment and iterations of flood mitigation measures. Using the most recent version of TUFLOW and the HPC engine on a GPU card resulted in reduced runtimes by a factor of approximately 150 (the 9 hour event took just 45 minutes to run).

4.4. Comparison of Results with Hydraulic Model Updates

The TUFLOW models were re-run for the 1% AEP event as per the existing flood studies to determine how peak flood levels change after implementation of these updates. These maps are shown on Figure 7 to Figure 10 for the various models with the results summarised below.

Bardwell Creek

In the Bardwell Creek model, the flood levels are similar, with some minor decreases in the vicinity of Bexley Golf Club (-0.03 m to -0.07 m), and conversely minor increases in the vicinity of Bardwell Valley Golf Club (up to 0.05 m), as shown in Figure 7.

Bonnie Doon

In the Bonnie Doon model, there are changes in the vicinity of Arncliffe Park, due to the park upgrades (Figure 8). The updates to the Bonar Street stormwater result in a more stable model, with a mass error now less than 0.1%. There are increases in flood level in the area around Bidjigal Road of approximately 0.2 m, although the increase can be above 0.5 m where there have been significant terrain changes. There is a decrease upstream of the railway line on Wollongong Road, and increase downstream (up to 0.1 m), with increases downstream of the SWSOOS up to 0.15 m. Levels in Eve Street wetlands reduces by 0.6 m, due to the connection to Cooks River.

Muddy Creek

In the Muddy Creek model, there appears to be a change in flood extent, since some filtering of shallow flood depths appears to have been undertaken in the original Flood Study grids, although this is not documented. In terms of peak flood levels, there are some changes in flood levels on the branches and flow paths upstream of the railway. This is most prominent on the branch running parallel to the Illawarra railway line, in the vicinity of Union Street (within ±0.2 m), upstream of Frys Reserve detention basin, in the vicinity of Wolseley Street (typically within ±0.1 m, with some larger localised reductions), and increases on the flow path between Gardiner Park and the Illawarra railway line (up to 0.06 m). Between the Illawarra railway line and the Spring Street Drain channel, there are changes typically within ±0.3 m due to development changes. Changes in the area downstream of Muddy Creek and Spring Street Drain are generally less than ±0.05 m. There are minimal changes to peak flood levels in the Scarborough Ponds catchment.

Sans Souci

In the Sans Souci catchment, there are generally decreases in the lower reaches of the channels due to refinement of the outlet structure schematisation. These decreases are up to 0.25 m on Goomun Creek, 0.5 m on Bado-berong Creek, 0.4 m on Waradiel Creek (although there are increases up to 0.3 m at the outlet).

5. DESIGN FLOOD EVENT MODELLING

5.1. Updates to Australian Rainfall and Runoff

Design flood modelling for this study was undertaken in accordance with the guidance for rainfall-runoff flood estimation techniques in the updated edition of ARR (ARR 2019, Reference 9). The new guidelines were first published in 2016 and finalised in 2019, producing a significant update on the last major edition of ARR published in 1987 (ARR 1987, Reference 11). Numerous technological developments and a larger set of recorded rainfall data has been available for updating the guidelines on design rainfall depths and temporal patterns. This set of data includes a larger number of rainfall gauges which continuously record rainfall (pluviometers) and a longer record of storms (inclusion of events from approximately 1985 to 2015). Prior to this, the sub-daily rainfall records in many locations apart from capital city centres covered only a ten to fifteen year period from the 1970s. This additional data allows for Australia-specific techniques and regionalised information to be used across the country.

Compared to ARR 1987, there are three major updates to the rainfall-runoff design flood method as follows:

1. The Intensity-Frequency-Duration (IFD) design rainfall data and the initial and continuing loss values across Australia have been updated using the additional 30 years of data;
2. There is information about the amount of rainfall likely to occur before the main storm burst and how to incorporate this into model estimates;
3. The approach for assuming design temporal patterns and determining the critical duration has been significantly revised. ARR 2019 recommends that 10 temporal patterns should be analysed for each storm duration in order to determine the critical storm event. The critical storm event is not the event producing the maximum peak value for all the durations but the temporal pattern of the duration which produces the maximum average peak value from the 10 storms.

ARR 2019 also contains guidelines for the consideration of blockage in design flood events, with a new methodology proposed for determining blockage of conduits.

The design event modelling inputs adopting ARR 2019 are described in the following sections. It is noted that the Bardwell Creek 2D Flood Study Review (Reference 8) adopted ARR 2016 procedures (the same as ARR 2019 procedures for the purpose of its implementation in this study), while the remaining studies adopted ARR 1987. The updates outlined below primarily relate to the remaining study areas. The ARR 2019 datahub (Reference 23), contains information for each model area. A sample of the datahub data for the study area centroid is provided in Attachment A.

5.2. IFD Design Rainfall Data

A significant factor with the implementation of ARR 2019 is the updated IFD data (updated in 2016 and referred to as ARR 2016 IFD). The IFD data for the study area centroid is provided in Table 4, noting that there is some variation between each of the catchment areas (typically within ±5%).

The change in design rainfall depths between ARR 1987 and ARR 2016 for the centroid of the Bayside West study area is outlined in Table 5 and shown visually in Diagram 2. The 1% AEP rainfall is intensity is almost 30% lower for the 1 hour and 2 hour durations, as shown in Table 5. The 1% AEP rainfall intensity for these durations is now slightly less than the ARR 1987 5% AEP rainfall depth, as shown in Diagram 2. These design rainfalls would therefore be expected to produce significantly lower design flood levels across the study area.

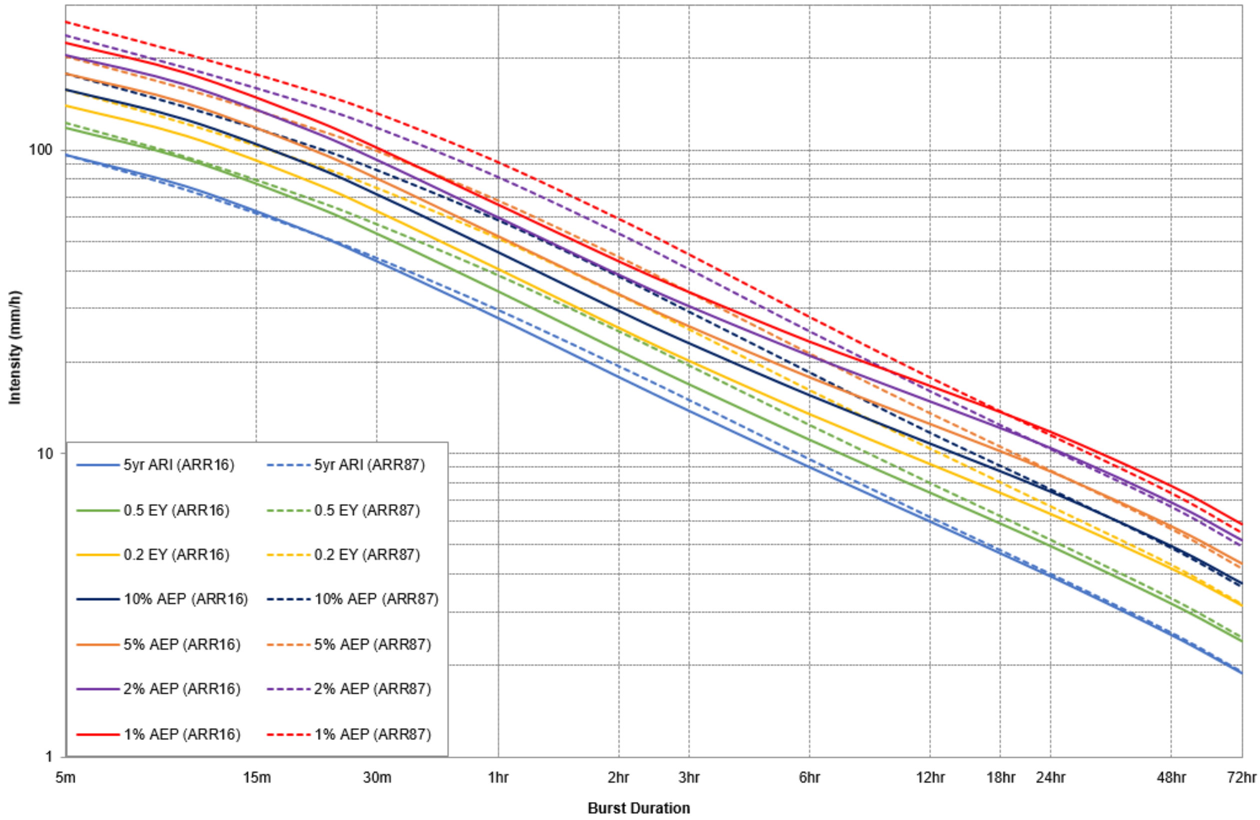
Table 4: Design rainfall depths (mm) at the centroid of the Bayside West study area

Duration	Frequency							
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
5 min	8.84	11.5	13.2	14.9	17.1	18.8	20.6	23.4
10 min	13.9	18.2	21	23.8	27.3	29.9	32.7	37
15 min	17.4	22.7	26.3	29.6	34	37.3	40.8	46.2
30 min	23.7	30.9	35.7	40.3	46.3	50.8	55.7	63.1
45 min	27.8	36	41.6	47	54	59.4	65.2	73.8
1 hr	30.8	39.9	46.1	52.1	60	66.1	72.5	82.1
1.5 hr	35.5	46.1	53.2	60.3	69.6	76.9	84.4	95.5
2 hr	39.4	51.1	59.1	67.1	77.7	86	94.3	107
3 hr	45.7	59.6	69.2	78.8	91.7	102	111	126
4.5 hr	53.5	70.2	82	93.8	110	122	133	151
6 hr	60	79.5	93.2	107	126	140	153	173
9 hr	71.1	95.4	113	130	154	172	187	212
12 hr	80.3	109	129	150	178	200	217	246
18 hr	95.4	131	157	182	218	245	268	303
24 hr	107	149	179	209	250	282	308	349
30 hr	117	164	197	230	276	311	350	402
36 hr	125	177	212	248	298	336	381	440
48 hr	139	197	237	276	331	374	424	489

Table 5: Percentage change in design rainfall depths for ARR 2016 compared to ARR 1987 for the Bayside West study area

Duration	Frequency						
	1 EY	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
5 min	0%	-4%	-11%	-11%	-12%	-14%	-15%
10 min	3%	-2%	-9%	-9%	-10%	-12%	-13%
20 min	0%	-5%	-12%	-13%	-15%	-18%	-19%
30 min	-3%	-7%	-16%	-17%	-19%	-22%	-23%
1 hr	-6%	-12%	-21%	-21%	-24%	-26%	-28%
2 hr	-8%	-14%	-22%	-23%	-25%	-27%	-28%
3 hr	-8%	-13%	-21%	-21%	-23%	-24%	-25%
6 hr	-6%	-10%	-17%	-16%	-17%	-17%	-17%
12 hr	-3%	-7%	-11%	-8%	-8%	-7%	-6%
24 hr	-2%	-4%	-6%	-2%	-1%	1%	2%
48 hr	-2%	-3%	-3%	1%	2%	4%	5%
72 hr	-1%	-2%	-1%	2%	3%	5%	6%

Diagram 2: Comparison of ARR 1987 and ARR 2016 IFD Data for Bayside West study area



5.3. Rainfall Losses

The term “rainfall loss” refers to rain that falls but does not end up flowing across the catchment, either in pipes or as overland flow. The primary mechanism by which rainfall is “lost” and does not form runoff in urban catchments is through infiltration into the ground. A small amount of rainfall is also intercepted by trees, buildings and other catchment features and eventually evaporates rather than contributing to runoff volumes.

Methods for modelling the proportion of rainfall that is “lost” to infiltration are outlined in ARR 2019 (Reference 9). The methods are of varying degrees of complexity, with the more complex options only suitable if sufficient data are available. The method most typically used for design flood estimation is to apply an initial and continuing loss to the rainfall. The initial loss represents the wetting of the catchment prior to runoff starting to occur and the continuing loss represents the ongoing infiltration of water into the saturated soils while rainfall continues.

Rainfall losses from a paved or other impervious areas are considered to consist of only an initial loss (an amount sufficient to wet the pavement and fill minor surface depressions, typically 1 mm to 2 mm). Losses from grassed areas are comprised of an initial loss and a continuing loss.

ARR 2019 also recommends the consideration of pre-burst rainfall. The typical approach for flood modelling is to simulate the rainfall burst only, recognising that this often occurs within a larger storm event, with rainfall occurring before and after this main burst. ARR 2019 recommends adopting the median pre-burst depth, such that this rainfall depth is subtracted from the storm initial loss to calculate a burst initial loss. The burst initial loss is then applied to the hydrological model. The formula for deriving the burst initial loss is as follows (with negative losses assumed to be zero):

Burst Initial Loss = Storm Initial Loss – Pre-Burst Depth

The storm initial loss, pre-burst depth (varies with AEP and duration, provided for a range of percentiles) and continuing loss is available through the ARR Datahub (Reference 23). It is noted that the Bardwell Creek 2D Flood Study Review (Reference 8) adopted this approach, although the 75th percentile pre-burst rainfall depths were adopted rather than the median (50th percentile) pre-burst depths. A review into the rainfall losses and methodology for NSW was undertaken (Reference 25) and found that there was an under-estimation bias being experienced when using the standard ARR 2019 method (i.e. losses were generally too high). The results indicated a significant overestimation of burst initial loss due to the skew nature of the pre-burst distribution and adopting the median pre-burst value. It is now recommended to adopt the probability neutral burst initial losses that have been derived and provided on the ARR Datahub (Reference 23). These burst initial losses are applied directly to the storm burst in the hydrologic model and vary with AEP and duration. The probability neutral burst initial losses for the study area centroid are provided in Table 6.

Table 6: ARR datahub probability neutral burst initial losses (mm) for the Bayside West study area centroid

Duration (min)	**AEP**					
	50%	**20%**	**10%**	**5%**	**2%**	**1%**
60	15.5	8.9	9	9.9	8.6	5.9
90	15.2	8.8	8.9	8.8	8.5	7.3
120	15	9	9.7	9.1	8.6	6.3
180	16.1	10.1	10.8	9.9	10	6.3
360	16.5	10.7	11.2	10.1	9.8	5
720	20.7	14.9	14.3	13.4	12	5.5
1080	20.2	15.6	15	13.2	14	3.5
1440	23.5	18.2	17.5	15.5	15.6	6.6
2160	27.2	22	21.3	19.6	18.8	7.9
2880	32	27.1	25.6	27.4	20.7	8.7

Note 1: For AEPs rarer than 1% (i.e. 0.5% and 0.2%), the 1% AEP losses have been adopted

Note 2: For durations not listed in this table, losses were interpolated, or for durations less than 60 minutes, the 60 minute losses were applied

For continuing losses, the ARR datahub (Reference 23) provides a continuing loss value to be used where a value cannot be calibrated with certainty and regional values may not be available or appropriate. This continuing loss value was adopted for the Bardwell Creek 2D Flood Study Review (Reference 8). Since then, the review into the rainfall losses and methodology for NSW (Reference 25) has recommended that these continuing loss values be factored by 0.4.

The application of initial loss and continuing loss for each of the modelled catchment areas is outlined in Table 7.

Table 7: Adopted initial and continuing loss approach for pervious areas for each model area

Model Area	Initial Loss	Continuing Loss	Comment
Bardwell Creek	Storm initial loss from ARR datahub with 75th percentile pre-burst rainfall. Typically 0 mm to 15 mm.	ARR datahub. Varies between 2.1 mm/h and 2.5 mm/h.	Retained from Flood Study.
Bonnie Doon	Depression storage values retained from Flood Study, of 5 mm for grassed areas. Antecedent moisture condition (AMC) of 3.	AMC of 3 and soil type of 3.	Application of ILSAX hydrology in DRAINS model (rather than initial and continuing loss).
Muddy Creek	Probability neutral burst initial loss from ARR datahub.	Datahub continuing loss (2.1 mm/h), factored by 0.4.	Adopt the current recommendations in XP-RAFTS model.
Sans Souci	Probability neutral burst initial loss from ARR datahub for pervious areas, for residential areas this was reduced by 50% to account the impervious fraction.	Datahub continuing loss (2.1 mm/h)	Adopt the current recommendations in TUFLOW direct rainfall model, although continuing losses were not factored due to the sandy soils present in Sans Souci (noting that the Flood Study adopted 2.5 mm/h) The application of losses to different land uses is as per the Flood Study.

5.4. Areal Reduction Factor

The design rainfall estimates are based on point rainfalls and the catchment-average rainfall depth will be less. Areal reduction factors (ARFs) allow for the fact that larger catchments are less likely than smaller catchments to experience high intensity storms simultaneously over the whole catchment area. It is noted that the Bardwell Creek 2D Flood Study Review (Reference 8) adopted ARFs and these were retained for the current study. With the ARR 2019 updates to the remaining model areas, ARFs were only applied to the Muddy Creek catchment. An area of 3.15 km^2 was adopted for the calculation of ARFs, which is representative of the Muddy Creek catchment to the Illawarra railway line. This is similar to the approach in the Flood Study (Reference 12), and results in a factor of 0.95 to 1.0.

5.5. Critical Duration Assessment

The adoption of ARR 2019 has made a significant difference in critical duration analysis (the storm duration which produces the highest flood level at a given catchment location). Each AEP event may have a unique critical duration and critical storm for each particular area. The critical duration may vary throughout the catchment, with longer durations generally causing more severe flooding lower down in the catchment compared to the upper, as the total contributing catchment area size increases. The details of the critical analysis are provided below.

5.5.1. Temporal Patterns

Temporal patterns are a hydrologic tool that describe how rain falls over time and are used in hydrograph estimation. There are significant updates in the application of temporal patterns for design events in ARR 2019. Previously, with ARR 1987 guidelines, a single temporal pattern was adopted for each rainfall event duration (Reference 11). The ARR 1987 temporal patterns were developed using the Average Variability Method (AVM). The AVM divides Australia into 8 zones and provides two temporal patterns for 20 storm durations for ARI ≤ 30 years and ARI > 30years. The AVM provides a pattern that describes the rainfall pattern of the most intense burst within a storm event and should not be considered representative of a typical rainfall pattern. A limitation with the AVM, as discussed in ARR 2019 (Reference 9), is that it assumes that the variability of the pattern is of less importance than the central tendency, that is the central value of the probability distribution of rainfall volume. In reality, the runoff response can be very catchment-specific and therefore it is recognised that a representative pattern will not necessarily produce the median response from an ensemble of patterns. The AVM temporal patterns should only be used in conjunction with the ARR 1987 IFD tables.

The single synthetic temporal patterns of ARR 1987 had known problems whereby for some durations (most notably the 25 minute, 2 hour and 9 hour storms) the patterns contained internal bursts that were more intense than the AEP of interest. This led to these durations frequently being found to be “critical,” since they produced modelled flood levels that were higher than a probability neutral approach would generate.

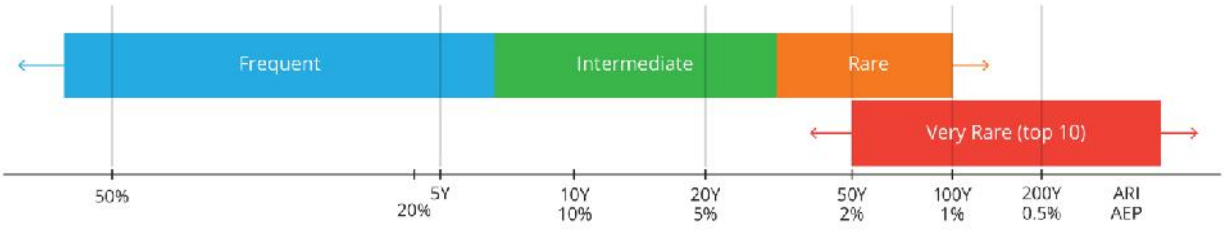
ARR 2019 recommends an approach where an ensemble of different temporal patterns is investigated. It is widely accepted that there are a large variety of temporal patterns possible for rainfall events of similar magnitude. This variation in temporal pattern can result in significant effects on the estimated peak flow. As such, the revised temporal patterns have adopted an ensemble of ten different temporal patterns for a particular design rainfall event. The rainfall-runoff response can be quite catchment specific, and using an ensemble of temporal patterns attempts to produce the probability-neutral catchment response so that the AEP of the estimated peak flood levels is consistent with the AEP of the rainfall. This results in critical durations that are more commensurate with the catchment size.

As hydrologic modelling has advanced, it is becoming increasingly important to use realistic temporal patterns. The ARR 1987 temporal patterns only provided a pattern of the most intense burst within a storm, whereas the ARR 2019 temporal patterns look at the entirety of the storm including pre-burst rainfall, the burst and post-burst rainfall. There can be significant variability in the burst loading distribution (i.e. depending on where 50% of the burst rainfall occurs an event can be defined as front, middle or back loaded). The ARR 2019 method divides Australia into 12 temporal pattern regions, with the Bayside West study area falling within the East Coast South region. The temporal patterns for this region were obtained from the ARR datahub (Reference 23).

ARR 2019 provides 30 patterns for each duration and are sub-divided into three temporal pattern bins based on the frequency of the events. Diagram 3 shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. There are ten temporal patterns for each

AEP/duration in ARR 2019 that have been utilised in this study for the 20% AEP to 0.2% AEP events.

Diagram 3: Temporal Pattern Bins



The representative temporal pattern out of the 10 is the pattern which produces the peak flow (or peak flood level) just greater than the average of the 10 peak flows (or levels). Thus, the temporal pattern adopted does not produce the largest peak flow (or level) for that storm duration. The critical storm duration is that which produces the maximum average peak flow (or level).

5.5.2. Representative Storm Burst Selection

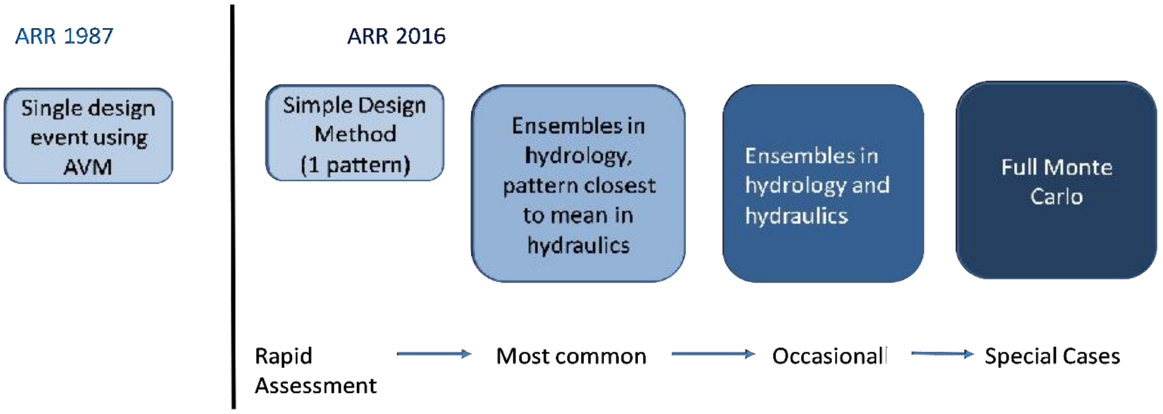
The representative storm is the temporal pattern and duration that best represents the flood behaviour (e.g. flow or level) for a specific design magnitude. It is generally related to the catchment size, as flow takes longer to concentrate at the outlet from a larger catchment, as well as other considerations like land use, shape, stream characteristics, etc.

With ARR 2019 methodology, the critical storm duration for a location is the design storm duration that produces the highest average flow (or level) across the full range of durations at that location of interest. Where there are multiple locations of interest with different contributing catchment sizes, there can be multiple critical durations that need to be considered.

Once the critical duration is established, it is usually desirable to select a representative design storm temporal pattern that reproduces this behaviour for all points of interest. This representative storm can then be used for determining design flood behaviour and for future modelling to inform floodplain management decisions.

The potential methods for the ensemble modelling approach are outlined in Reference 9 and reproduced in Diagram 4.

Diagram 4: Ensemble Hydrology Approaches in ARR 2019



The "Most common" approach is to rely on a hydrologic model to determine the representative storm before proceeding with hydraulic modelling. The "Occasional" approach simulates the full ensemble of temporal patterns and durations in both the hydrologic and hydraulic model to determine the representative storm. For this study, the "Occasional" approach was adopted for both Bonnie Doon (due to the limitations of DRAINS modelling to accurately simulate downstream routed flows) and Sans Souci (due to the direct rainfall approach). The "Most common" approach was adopted for the Muddy Creek model area, where flows simulated in the XP-RAFTS model were used to select the representative storm. The storms previously selected in the Bardwell Creek 2D Flood Study Review (Reference 8) were adopted for the Bardwell Creek model area.

Adopting a range of critical duration events across a catchment complicates future analysis and use of the modelling tools, as this may mean adopting different critical durations to represent the peak level, velocity or hazard. It also means that when undertaking sensitivity analysis or the modelling of options a multitude of durations must be run, increasing costs and time to use the modelling. Thus, it is preferable to adopt a single representative storm that is similar to the critical duration behaviour for each AEP where possible. This critical duration analysis process and selection of representative temporal patterns is described below and in Section 5.5.3 (Scarborough Ponds).

Bardwell Creek

The storms previously selected in the Bardwell Creek 2D Flood Study Review (Reference 8) were adopted for the Bardwell Creek model area. These are summarised in Table 8.

Table 8: Adopted representative design storms for Bardwell Creek

Temporal Pattern Bin	Adopted representative durations and temporal patterns
Frequent (20% AEP)	45 minute TP4548 (No. 4)
Intermediate (10% AEP and 5% AEP)	60 minute TP4568 (No. 6)
Rare (2% AEP to 0.2% AEP	60 minute TP4561 (No. 10)

Bonnie Doon

For Bonnie Doon, both the upper and lower Bonnie Doon DRAINS models were run for durations from 15 minutes to 24 hours, with the ensemble of temporal patterns for the 20% AEP, 5% AEP and 1% AEP events (representative of each temporal pattern bin). Each of these storms was then simulated in the TUFLOW model. For each duration, a grid of the mean peak level at each grid cell was calculated, and then a maximum envelope grid was calculated taking the highest mean peak level for each grid cell. This shows the “true” critical duration peak mean level at all cells across the catchment. The source of the peak mean level for each grid cell was mapped to show the variation in critical duration across the catchment. This critical duration map is shown in Figure 11 for the 1% AEP event.

The process above indicated that the 30 minute, 60 minute and 90 minute durations are critical for the majority of the catchments in the study area, with the primary exception being the storage area within the Kogarah Golf Club, where the critical duration was 1440 minutes (24 hours). Through a comparison of the peak flood level grid for each storm with the “true” critical duration peak mean level across the catchment, representative storms were selected. The envelope of the selected storms generally resulted in minimal variation in peak level from the “true” critical duration peak mean level (within ±0.05 m). Figure 12 shows this difference for the 1% AEP event. The adopted representative storms are shown in Table 9.

Table 9: Adopted representative design storms for Bonnie Doon

Temporal Pattern Bin	Adopted representative durations and temporal patterns
Frequent (20% AEP)	30 minute TP4519 (No. 5) 720 minute TP4802 (No. 1)
Intermediate (10% AEP and 5% AEP)	30 minute TP4511 (No. 6) 720 minute TP4791 (No. 5)
Rare (2% AEP to 0.2% AEP	30 minute TP4498 (No. 5) 90 minute TP4588 (No. 10) 540 minute TP4746 (No. 8)

Muddy Creek

For Muddy Creek, the existing XP-RAFTS model was used to simulate sub-catchment flows, and the transporting of these flows to downstream areas. The XP-RAFTS model has adopted a simple lag time, rather than true routing and hence the downstream flows are expected to be larger than what would be simulated in the TUFLOW model. Nevertheless, this approach was considered appropriate for the purpose of representative storm selection. The XP-RAFTS model was run for durations from 15 minutes to 12 hours, with the ensemble of temporal patterns for the 20% AEP, 5% AEP and 1% AEP events (representative of each temporal pattern bin). A total of 23 locations across the catchment were used to assess the critical duration and adoption of representative storms.

For each AEP and duration, the mean peak flow was computed at these locations for the ensemble of temporal patterns. For each AEP, the maximum of the mean peak flows was adopted as the representative “true” flow at each location. Each individual storm could then be compared to this flow to select storms that adequately replicate this peak flow at each location. A single storm was adopted for each AEP bin, as shown in Table 10. The results of the assessment are also shown in Table 11 for the 1% AEP event, indicating that the adopted storms are typically within 5% of the mean peak flow. For those where the adopted peak was more than 5% lower than the critical mean peak, a 15 minute storm was identified as being representative of these upstream areas. This storm was tested in the TUFLOW model, and the peak flood levels were typically within 0.02 m of the 60 minute storm. Given these results, the 60 minute storm was considered representative across the catchment.

Table 10: Adopted representative design storms for Muddy Creek

Temporal Pattern Bin	Adopted representative duration and temporal pattern
Frequent (20% AEP)	60 minute TP4583 (No. 10)
Intermediate (10% AEP and 5% AEP)	60 minute TP4565 (No. 3)
Rare (2% AEP to 0.2% AEP)	60 minute TP4557 (No. 6)

Table 11: Critical duration analysis results for Muddy Creek (1% AEP)

Catchment ID	Location[1]	Ensemble Results		Adopted Representative Results	
		Critical Duration (mins)	Mean (critical) Flow (m^3/s)	Peak Flow (m^3/s)	% Difference (Peak Flow minus Mean Flow)
MC72	Main Muddy Creek flowpath start	15	3.15	2.50	-21%
MC68	Main Muddy Creek flowpath mid	30	21.14	21.28	1%
MC60	Kogarah train station	45	24.16	23.92	-1%
MC62	Queen Vic St flowpath start	15	3.52	2.66	-24%
MC59	Queen Vic St flowpath end	15	9.46	9.09	-4%
MC32	Wolseley St flowpath start	15	4.99	3.82	-23%
MC57	Wolseley St flowpath end	30	20.85	20.37	-2%
MC53	Muddy Creek @ Frys Reserve	45	49.14	51.19	4%
SP12	Scarborough Ponds industrial flowpath	30	13.23	13.35	1%
MC47	Muddy Creek @ Princes Hwy	60	57.50	60.52	5%
MC35	Muddy Creek @ Bay St	60	63.54	66.44	5%
MC18	Muddy Creek @ Sheralee Caravan Park	90	68.64	68.86	0%
MC1	Muddy Creek outlet to Cooks River	60	106.34	110.29	4%
MC25	Rockdale train station	30	8.82	8.66	-2%
SS48	Railway Street flowpath	30	10.05	9.91	-1%
ADD27	Gardiner Park flowpath	15	9.24	8.67	-6%
SS24	Spring St Drain @ Short St	30	33.21	34.46	4%
SS39	Spring St Drain local flowpath	15	5.87	5.19	-12%
SS26	Spring St Drain @ W Botany St	45	43.37	43.75	1%
SS28	Spring St Drain Outlet	60	47.36	48.27	2%
SP42	Scarborough Ponds local flowpath	15	2.42	1.72	-29%
SP40	Scarborough Ponds Upstream	45	28.41	29.65	4%
SP55	Scarborough Ponds Downstream	15	12.69	12.51	-1%

1 The sub-catchment GIS layer was not provided, however, sub-catchment locations were inferred based on TUFLOW inflow locations. The actual location of these points is less of a concern than it is to have a variety of points that represent both small upstream catchments and the downstream reaches of the main creeks.

Sans Souci

For Sans Souci, the direct rainfall method was employed, whereby rainfall is applied directly to the TUFLOW 2D domain. In this case, the TUFLOW model was run with ARR 2019 storms for durations from 30 minutes to 18 hours with the ensemble of temporal patterns for the 20% AEP, 5% AEP and 1% AEP events (representative of each temporal pattern bin). For each duration, a grid of the mean peak level at each grid cell was calculated, and then a maximum envelope grid was calculated taking the highest mean peak level for each grid cell. This shows the "true" critical duration peak mean level at all cells across the catchment. The source of the peak mean level for each grid cell was mapped to show the variation in critical duration across the catchment. This critical duration map is shown in Figure 13 for the 1% AEP event.

The process above indicated that the critical duration is typically 60 minutes on Goomun Creek, approximately 6 hours (360 minute) on Bado-berong Creek and Waradiel Creek, with some areas of ponding being up to 12 hours (720 minute). Through a comparison of the peak flood level grid for each storm with the "true" critical duration peak mean level across the catchment, representative storms were selected. The envelope of the selected storms generally resulted in minimal variation from the "true" critical duration peak mean level (within ±0.05 m). Figure 14 shows this difference for the 1% AEP event. The adopted representative storms are shown in Table 9.

Table 12: Adopted representative design storms for Sans Souci

Temporal Pattern Bin	Adopted representative durations and temporal patterns
Frequent (20% AEP)	60 minute TP4579 (No. 6) 270 minute TP2749 (No. 1)
Intermediate (10% AEP and 5% AEP)	60 minute TP4569 (No. 7) 360 minute TP4730 (No. 9)
Rare (2% AEP to 0.2% AEP)	60 minute TP4559 (No. 8) 360 minute TP4406 (No. 1)

5.5.3. Scarborough Ponds Critical Duration

It was recognised in the Spring Street Drain, Muddy Creek and Scarborough Ponds Catchments Flood Study Review that "the flood conditions of the Scarborough Ponds system are driven by total catchment runoff volume rather than peak flows and as such display a significantly different critical storm duration to the rest of the study area. The critical storm duration for this peak storage volume is typically 30-hours and 48-hours, depending on the adopted design conditions. The peak flood levels attained within Scarborough Ponds can be readily estimated using XP-RAFTS, through the representation of the stage-storage relationship and piped drainage discharge within the retarding basin module." (Reference 12, p.65). It is noted, however, that this assessment was not undertaken for the Flood Study, and the XP-RAFTS model was not set up as such.

The critical duration for Scarborough Ponds was found by applying the following methodology:

1. Include Scarborough Ponds as a basin in the existing XP-RAFTS model. A stage-storage curve was extracted from the TUFLOW model terrain in addition to a stage-discharge curve based on TUFLOW water level and culvert flow results.

2. For each AEP event, run the full suite of durations and temporal patterns in the XP-RAFTS model with an initial water level in the ponds based on the adopted tailwater level (see Section 5.8). Analysing these results, the mean peak water level could be determined for each duration, and the maximum mean peak water level across the range of durations simulated could be determined. This is the “true” peak water level for the ponds for a particular AEP event. The critical duration was typically found to be 36 hours.
3. It was not considered feasible to run the TUFLOW model for these long duration events, and hence the XP-RAFTS model was run for the adopted 60 minute representative storm event (see Section 5.5.2) with a high initial water level in order to match the “true” peak water level from the critical duration for the ponds. This was an iterative approach to determine an initial water level that would give the correct peak level in the ponds with the shorter duration storm event.
4. These initial water levels were adopted in the TUFLOW model for the short duration event to simulate the correct peak water level in the basin.

The critical duration and peak water levels for Scarborough Ponds and the raised initial water levels for simulation with the shorter duration (60 minute) storms and the results from the TUFLOW model are shown in Table 13.

Table 13: Critical duration, peak water level and adopted initial water level for the 60 minute storm events for Scarborough Ponds

Event	XP-RAFTS Results		TUFLOW Results	
	Critical duration (hours)	**Mean Peak Water Level (mAHD)**	**Adopted Initial Water Level (mAHD) for 60 minute storm**	**Simulated Peak Water Level (mAHD) with 60 minute storm**
20% AEP	36	2.09	1.98	2.11
10% AEP	36	2.22	2.07	2.22
5% AEP	36	2.34	2.19	2.34
2% AEP	36	2.52	2.36	2.53
1% AEP	36	2.65	2.47	2.65
0.5% AEP	36	2.82	2.64	2.82
0.2% AEP	36	2.98	2.78	2.98

The following checks were undertaken to assess the suitability of using the RAFTS model to simulate the Scarborough Ponds storage:

- Stage-discharge curve sensitivity to the tailwater level in Botany Bay was tested and it was found that the discharge did not vary significantly with varying tailwater levels (as long as the water level in the ponds is higher than the water level in Botany Bay). This was tested with both static and dynamic tailwater conditions.
- The results for the adopted basin configuration in XP-RAFTS was compared with the results from the TUFLOW model for several storm events. It was found that the peak water level simulated in both models was within 0.01 m.
- For the 1% AEP event, the storm producing the closest pond water level to the mean peak water level for the critical duration (36 hour, TP4861) was run in TUFLOW to verify that if the longer critical duration storms were simulated in the TUFLOW model, a similar peak water level would be achieved. This resulted in a water level within 0.04 m of the mean peak water level from XP-RAFTS.

- The TUFLOW results for the peak water level in Scarborough Ponds, with the 60 minute storm duration and raised initial water level were almost identical to the mean peak water level from XP-RAFTS for the critical 36 hour storm duration (within 0.01 m).

5.6. Probable Maximum Precipitation

The design storms for the probable maximum precipitation (PMP) were derived using the Bureau of Meteorology's (BoM) Generalised Short Duration Method (Reference 26) and were not modified from those adopted for the relevant Flood Studies (including the adopted rainfall depths, spatial and temporal patterns). The simulated durations are summarised in Table 14. These events were used to estimate the PMF event.

Table 14: Adopted PMP Storm Events

Model Area	Simulated Duration(s)
Bardwell Creek	60 minute
Bonnie Doon	60 minute
Muddy Creek	15 minute, 45 minute, 90 minute, 300 minute
Sans Souci	60 minute, 150 minute

The only exception is the 300 minute storm duration for Muddy Creek. Noting the revised critical duration assessment for Scarborough Ponds (see Section 5.5.3), it was determined that the XP-RAFTS model was not suitable for determining the critical duration of the PMP event, as there are significant overflows from the ponds to the south (over Ramsgate Road into Sans Souci) and to the north (over Bay Street into Muddy Creek). These overflows are not represented in the XP-RAFTS model. A range of PMP durations up to 9 hours were run in TUFLOW and it was found that the 300 minute duration (5 hour) storm produced the critical level in Scarborough Ponds. This storm was simulated in TUFLOW with the adopted tailwater level as the initial water level (no raised initial water level as per other design events) to simulate the critical duration in Scarborough Ponds for the PMF event.

5.7. Debris Blockage

Design blockage for hydraulic structures was adopted in accordance with ARR 2019 (Reference 9). ARR 2019 recommends applying blockage to hydraulic structures and outlines a methodology to determine inlet blockage factors by considering debris availability, debris mobility, debris transportability and waterway opening of the structure. The availability of debris is dependent on factors such as the potential for soil erosion, local geology, the source area, the amount and type of vegetative cover, the degree of urbanisation, land clearing and preceding wind and rainfall. However, the type of materials that can be mobilised can vary greatly between catchments and individual flood events.

Observations of debris conveyed in streams strongly suggest a correlation between event magnitude and debris potential at a site. Rarer events produce deeper and faster floodwater able to transport large quantities and larger sizes of debris, smaller events may not be able to transport larger blockage material at all. Debris potential is adjusted as required for greater or lesser probabilities to establish the most likely blockage conditions for that event.

The likelihood of blockage at a particular structure depends on whether or not debris is able to reach across the structure inlet or become trapped within the structure. The most likely blockage to occur at a structure is determined by considering the potential quantity and type of debris and the structure opening size as shown in Table 15.

Table 15: Most Likely Inlet Blockage Levels (Reference 9)

Control Dimension	At-Site Debris Potential		
	High	**Medium**	**Low**
$W < L_{10}$	100%	50%	25%
$L_{10} \leq W \leq 3 \times L_{10}$	20%	10%	0%
$W > 3 \times L_{10}$	10%	0%	0%

Notes: W refers to the opening diameter / width
L_{10} refers to the 10% percentile length of debris that could arrive at the site

While it is impractical to undertake a blockage assessment for every structure within the Bayside West study area, structures were grouped and simplified blockage factors applied. Blockage values were selected based on past experience and ARR 2019 guidance for blockage with consideration of the control inlet dimensions and AEP adjusted debris potential. Blockage was implemented for the Bonnie Doon, Muddy Creek and Sans Souci models. The Bardwell Creek 2D Flood Study Review (Reference 8) generally adopted no blockage of pit inlets, no blockage of culverts for frequent events, up to 10% blockage of culverts for rare events and up to 20% blockage of culverts in the PMF event. These blockages were updated and simplified for the current study, with the high blockage factors (up to 90%) being retained from the Flood Study for culverts and gaps under the noise walls.

Blockage was applied to structures with open inlets (such as kerb inlets and culverts with headwalls). A summary of the adopted blockage factors are:

- Pit inlets blocked 50%
- Small culverts (width or diameter <= 1.2 m) blocked 50%
- Large culverts (width or diameter > 1.2 m) blocked 20%
- Bridges (with piers) blocked 5%
- Bridges (clear spanning) not blocked

5.8. Tailwater Conditions

Coincident tailwater conditions were updated to ensure consistency across the Bayside West study area. Wolli Creek, Bonnie Doon and Muddy Creek rely on levels in the Cooks River to set a tailwater boundary, while Scarborough Ponds and Sans Souci rely on levels in Botany Bay.

The tailwater levels for Botany Bay were informed by the current Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways (Reference 27). The 'simplistic approach' was adopted for type A waterway entrances (open ocean embayments and estuaries), whereby a static tailwater level was assumed. The tailwater levels for Botany Bay are based on the tidal planes analysis (see Table 2) and design ocean water levels for Fort Denison (Table 16).

Table 16: Design still water levels for Fort Denison (Reference 27, which rounds up levels to the nearest 0.05m, sourced from Table 5.1 and Table 5.2)

AEP	Design Still Water Level (mAHD)
1% AEP	1.45
2% AEP	1.40
5% AEP	1.40
10% AEP	1.35
1EY	1.25

Coincident tailwater levels for the Cooks River were obtained from the Cooks River Flood Study (Reference 15). The study simulated the 2 year ARI, 20 year ARI, 100 year ARI and PMF event, and adopted the High High Water Solstice Springs (HHWSS) tailwater level of 1.1 mAHD for all design flood events (Reference 15). This value aligns with the HHWSS in Reference 16 and Reference 27. The 100 year ARI flood level, however, was derived by enveloping (taking the maximum) of the 100 year ARI catchment flood (with coincident HHWSS tailwater level) and 100 year ARI tide (1.7 mAHD, consisting of a 1% AEP tide level of 1.45 mAHD plus 0.25 m for wave setup and simulated with coincident 2 year ARI catchment rainfall). The tidal event dominates up to approximately the Bonnie Doon and Muddy Creek catchment boundary, with the fluvial event dominating upstream of this. The Cooks River Flood Study adopted ARR 1987, and simulating Cooks River flooding with ARR 2019 guidelines would result in different flood levels.

In accordance with the Floodplain Risk Management Guide (Reference 27), the recommended coincident ocean boundaries are outlined in Table 17.

Table 17: Coincident catchment flooding and oceanic inundation scenarios (Reference 27)

Design AEP	Catchment Flood Scenario	Ocean Water Level Boundary Scenario
20% AEP	20% AEP	HHWSS
10% AEP	10% AEP	HHWSS
5% AEP	5% AEP	HHWSS
2% AEP	2% AEP	5% AEP
1% AEP	1% AEP	5% AEP
	5% AEP	1% AEP
0.5% AEP	0.5% AEP	1% AEP
0.2% AEP	0.2% AEP	1% AEP
PMF	PMF	1% AEP

The coincident tailwater levels adopted for the current study are shown in Table 18. These levels were selected considering the Floodplain Risk Management Guide (Reference 27), the previous Flood Studies and past experience in similar catchments.

Table 18: Adopted coincident tailwater conditions (mAHD)

Design Flood Events	Wolli Creek[1]	Bonnie Doon[2]	Muddy Creek[1]	Scarborough Ponds and Sans Souci[3]	Comment
20% AEP to 5% AEP	1.6	1.6 – 1.35	1.35	1.30	Adopt 2 year ARI Cooks River level and 1EY ocean level (Table 16) plus 0.05 m wave setup for Botany Bay.
2% AEP and 1% AEP	2.0	2.0 – 1.60	1.60	1.50	Adopt 5% AEP Cooks River level and 5% AEP ocean level (Table 16) plus 0.1 m wave setup for Botany Bay.
0.5% AEP to PMF	2.3	2.3 – 1.85	1.85	1.70	Adopt 1% AEP Cooks River level and 1% AEP ocean level (Table 16) plus 0.25 m wave setup for Botany Bay (as per Reference 15).
Previous Flood Study comparison	Same as flood study, although the 0.5% AEP event adopted a tailwater level of 2.0 mAHD.	Flood Study adopted 5% AEP Cooks River levels for all events (2.0 - 1.6 mAHD).	Flood Study adopted 1.1 mAHD (HHWSS) for 20% - 5% AEP; 1.4 mAHD (5% AEP ocean) for 2% - 1% AEP; 1.45 mAHD (1% AEP ocean) for 0.5% AEP – PMF). Note this was also for Scarborough Ponds outlet.	Flood Study adopted 1 mAHD for 20% - 1% AEP, 2 mAHD for PMF. Separate ocean scenarios run: 20% AEP = 1.35 mAHD with 50% AEP rainfall; 10% AEP = 1.42 mAHD with 20% AEP rainfall; 5% AEP = 1.5 mAHD with 20% AEP rainfall; 1% AEP = 1.7 mAHD with 20% AEP rainfall.	

1 Based on Cooks River design levels at the creek outlet
2 Based on Cooks River design levels which vary across the boundary
3 Based on Botany Bay tide or design levels

The initial water level for each TUFLOW model was set to the adopted tailwater level, with the exception of Scarborough Ponds (see Section 5.5.3).

The Floodplain Risk Management Guide (Reference 27) recommends that for the 1% AEP event, an envelope approach be adopted, considering both the 1% AEP catchment flood and 1% AEP ocean inundation to define the true flood risk at a location. The 1% AEP ocean inundation scenario has not been applied to the models, but rather, the 1% AEP ocean extent and 1% AEP Cooks River extent is provided on the 1% AEP flood depth and level maps. At any given location, the 1% AEP flood risk should consider both local catchment flooding (simulated as part of this FRMS&P) and Cooks River or Botany Bay flooding. This approach was adopted as it:

- Clearly differentiates between catchment flooding and ocean inundation.
- Allows mapping of the Botany Bay foreshore outside of the Sans Souci model domain (i.e. Ramsgate, Monterey, Brighton-Le-Sands and Kyeemagh) as these areas are not included in any model domain.
- Allows the inundation to be continuous and to be extended up the Cooks River to provide 1% AEP Cooks River levels for Bardwell Creek, Bonnie Doon and Muddy Creek. This study does not attempt to redefine the Cooks River Flood Study levels, but rather maps the levels determined in that study (Reference 15).
- Is relatively simple to determine the flood level within this extent:
  - It is 1.7 mAHD for areas on Botany Bay. This is the 1% AEP ocean level (Table 16) plus 0.25 m wave setup for Botany Bay (as per Reference 15).
  - The extent along the Cooks River indicates where the Cooks River Flood Study should be considered, with levels obtained from that study (Reference 15).
- Is considered appropriate due to the minimal interaction of catchment flooding with ocean levels.

The same methodology applied for the Sans Souci Flood Study Review (Reference 13) was also tested for determining the 1% AEP flood extent considering the envelope of the 1% AEP design flood and the 1% AEP ocean level (with coincident 20% AEP rainfall). It was found that the 1% AEP ocean event was only dominant for the coastline bordering Botany Bay, and not for any of the internal creeks (except for a small portion of Depena Reserve, where the ocean dominated levels were 0.1 m higher than the catchment flood levels), providing further justification for this approach.

5.9. Comparison of Results with ARR 2019 Updates

The hydrologic and hydraulic models were run for the 5% AEP and 1% AEP design flood events utilising ARR 2019 guidelines and the updated tailwater conditions. The results were compared with the ARR 1987 results to understand the change in flood behaviour. Both ARR 1987 and ARR 2019 simulations included the model updates outlined in Section 4. The change in peak flood levels are shown in Figure 15 to Figure 22, for the 5% AEP and 1% AEP events for the various model areas.

The peak flood levels typically decrease with the adoption of ARR 2019 guidelines. This is due to the following:

- Updated IFD information, which is up to 30% lower than the ARR 1987 IFD (see Section 5.2), in which the ARR 2019 1% AEP rainfall intensity is similar to the ARR 1987 5% AEP rainfall intensity. This applies to Bonnie Doon, Muddy Creek and Sans Souci.
- Updated temporal patterns, which typically produce a lower peak flow that the AVM

temporal patterns of ARR 1987 (see Section 5.5.1). This applies to Bonnie Doon, Muddy Creek and Sans Souci.

- Minor changes are expected to occur due to updated areal reduction factors (Muddy Creek only) and rainfall losses (Muddy Creek and Sans Souci).
- Localised changes are expected to occur due to updated tailwater conditions (primarily Muddy Creek and Sans Souci) and updated structure blockage factors (all models).

Each of the model areas are discussed in more detail below.

Bardwell Creek

The previous model adopted ARR 2019 hydrology, and as such, this map indicates the change in peak flood level due to the blockage updates only. The changes in peak flood level for the 5% AEP and 1% AEP events is shown in Figure 15 and Figure 16, respectively. The change in flood level is typically within ±0.05 m across the catchment. This is due to the adoption of 50% pit inlet blockage. There are some areas where this is greater, and these are as follows (locations marked on figures):

1. A flood storage area near the intersection of Stoney Creek Road and Preddys Road, where flood levels increase by approximately 0.7 m in the 5% AEP event and 0.3 m in the 1% AEP event.
2. Within the Bardwell Valley Golf Club, where flood levels increase by up to 0.25 m upstream of the major culverts and decrease by approximately 0.1 m downstream of the culverts, in both the 5% AEP and 1% AEP events.
3. At several locations upstream of the East Hills railway line, where flood levels increase by between 0.2 m and 0.5 m in both the 5% AEP and 1% AEP events.

These changes in flood level are due to the new blockage factors adopted.

Bonnie Doon

The changes in 5% AEP and 1% AEP peak flood levels in Bonnie Doon are shown in Figure 17 and Figure 18, respectively. These figures indicate there is generally a reduction in flood levels. There are minor reductions (up to 0.05 m) on shallow overland flow paths, with reductions up to 0.2 m across the catchment. There are several key areas where the change in flood level is greater than this, and these are as follows (locations marked on figures):

4. Upstream of Arncliffe Park, the flood level decreases by up to 0.3 m in the 5% AEP and 1% AEP events.
5. Between Arncliffe Park and the Illawarra railway line, there are flood level decreases up to 0.2 m in the 5% AEP event and 0.3 m in the 1% AEP event on Kelsey Street and Wollongong Road, and up to 1 m in the 5% AEP and 0.6 m in the 1% AEP event on Bonar Street.
6. Upstream of the SWSOOS, the flood level decreases by up to 0.3 m in the 5% AEP event and 0.5 m in the 1% AEP event.
7. In the vicinity of Arncliffe Street, the flood level decreases by up to 0.4 m in the 5% AEP and 1% AEP events.

8. Within Kogarah Golf Club, the flood level decreases by up to 0.25 m in the 5% AEP event and increases by up to 0.1 m in the 1% AEP event.

At locations 4, 5 and 7, the flood level typically decreases by up to 0.4 m. These areas are flood storage areas, and peak levels in these volume-driven areas are generally more sensitive to the changes in rainfall intensity and design temporal patterns.

At location 6, the flood level decreases by up to 0.5 m. This location is within a temporary flood storage area upstream of the SWSOOS. The storage area and volume are relatively small and the outlet under the SWSOOS is constrained, and hence a small change to the inflows result in large changes to the flood level at this location. The difference between the 5% and 1% AEP results (ARR 1987) is approximately 0.7 m. The changes with ARR 2019 produce similar sensitivity for the 1% AEP event.

At location 8, there is a decrease in the 5% AEP event, primarily due to the lower tailwater level and coincidently a lower initial water level within the golf course. In the 1% AEP event, there is a slight increase in flood level. This is due to a longer duration storm being modelled that is more representative of the critical duration at this location (up to 9 hours with ARR 2019, compared with the 1 hour ARR 1987 being adopted previously). A longer duration storm fills this area which has no defined outlet except when it overtops into the Cooks River.

There are some minor changes at the Cooks River boundary due to a redefinition of tailwater conditions.

Muddy Creek

In the Muddy Creek model, the changes in the 5% AEP and 1% AEP peak flood levels are shown in Figure 19 and Figure 20, respectively. There is generally a reduction in peak flood levels of up to 0.2 m, with some storage areas indicating reductions up to 0.5 m. There are several key areas where the change in flood level has been investigated, and these are as follows (shown in the figures):

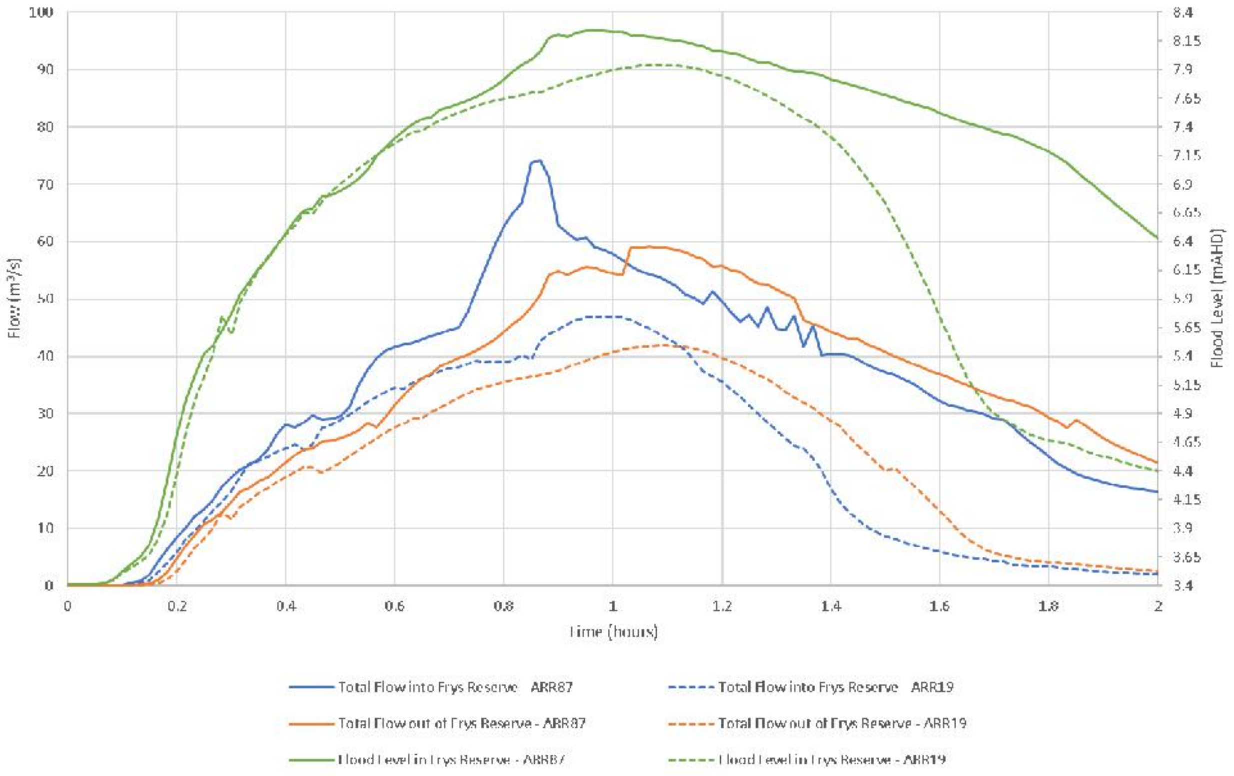
9. Frys Reserve, upstream of the railway line on Muddy Creek, the flood level decreases by up to 0.3 m in both the 5% AEP and 1% AEP events.
10. Harrow Road, downstream of the railway line on Muddy Creek, the flood level decreases by up to 0.6 m in the 5% AEP event and by up to 1.3 m in the 1% AEP event.
11. Bruce Street and Reading Street trapped sag points, the flood level decreases by approximately 0.3 m in both the 5% AEP and 1% AEP events.
12. Railway Street, upstream of Rockdale railway station, the flood level decreases by up to 1.0 m in both the 5% AEP and 1% AEP events.
13. Subway Road, under the railway line, the flood level decreases by approximately 1.4 m in the 5% AEP event and approximately 0.3 m in the 1% AEP event.
14. Princes Highway, downstream of the railway line on Spring Street Drain, the flood level decreases by up to 0.6 m in both the 5% AEP and 1% AEP events.

15. Spring Street Drain open channel, the flood level decreases by up to 2 m in the 1% AEP event, although this is highly localised and the decrease is typically in the order of 0.3 m to 1 m. Decreases in the 5% AEP event are up to 0.3 m.
16. Scarborough Ponds, increase in flood level of approximately 0.2 m in the 5% AEP event and 0.3 m in the 1% AEP event.

For the Muddy Creek model, there are changes in rainfall intensity, temporal patterns, areal reduction factors and rainfall losses with ARR 2019. Blockage has also been included and the tailwater conditions have been modified. The changes in peak flood levels are primarily driven by the change in rainfall intensity and temporal pattern, with localised changes due to blockage and tailwater conditions. As with the Bonnie Doon catchment, the largest changes occur at temporary flood storage locations. At location 9 for example, Frys Reserve detention basin stores water upstream of the railway line. At this location, the change in rainfall depth, and hence volume arriving at the basin (particularly at the peak) is reduced and flood levels within the basin reduce by approximately 0.3 m using ARR 2019.

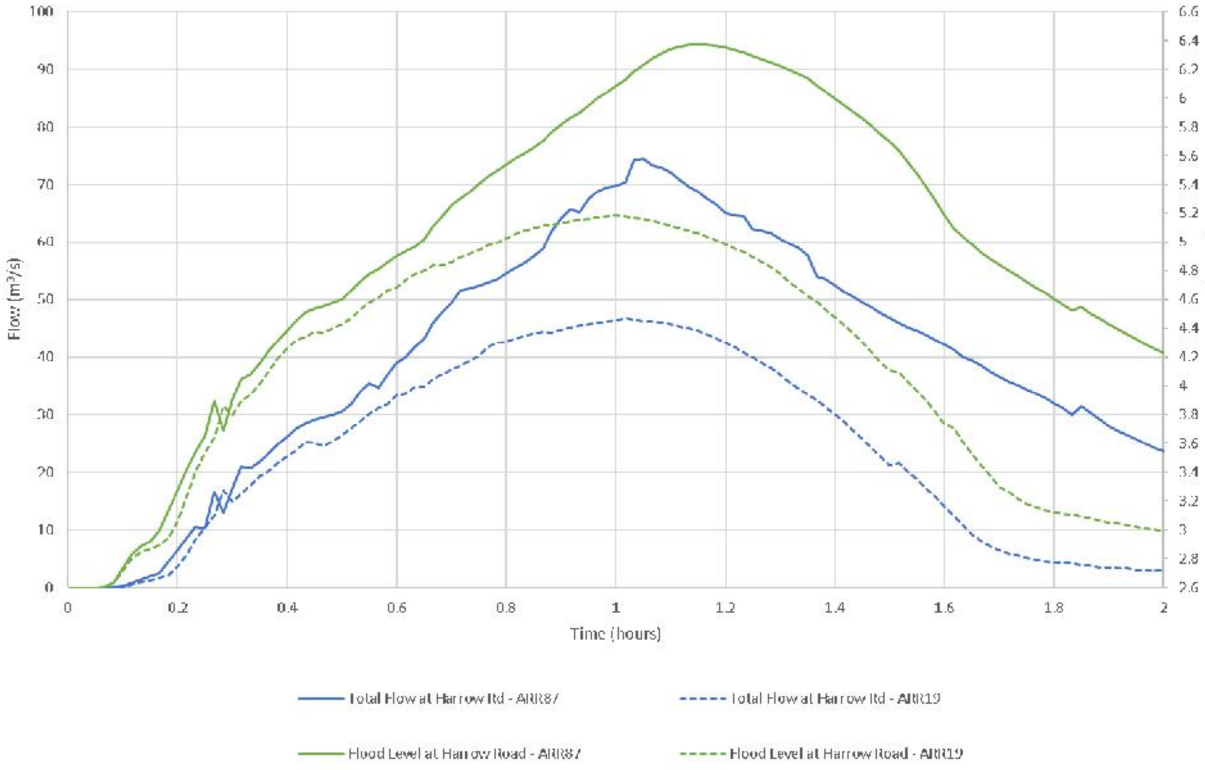
The change in the flows into and out of the basin as well as the flood level is shown on Diagram 5 for the 1% AEP event. The 2 hour ARR 1987 storm is compared with the 1 hour ARR 2019 storm for Frys Reserve detention basin. This graph demonstrates the lower peak flow arriving at Frys Reserve with ARR 2019 (due to the change in rainfall intensity and temporal pattern), resulting in a lower water level in the reserve. The internal peak burst which is a feature (and known problem) of the 2 hour ARR 1987 temporal pattern can be clearly seen on the inflow hydrograph, and is a major contributor to the differences in the results.

Diagram 5: Frys Reserve Detention Basin Hydrographs (ARR 1987 vs ARR 2019) for the 1% AEP critical duration event



The outflow from Frys Reserve then joins with overflows from the Hegerty Street railway underpass and crosses Harrow Road downstream of the railway. The difference in 1% AEP peak flow between ARR 1987 and ARR 2019 for the 1% AEP event is almost 30 m^3/s, and this has a pronounced effect on flood levels at Harrow Road, being up to 1.3 m lower (location 10), as shown in Diagram 6. The difference in peak flood levels between the 5% AEP and 1% AEP ARR 1987 events is also approximately 1.3 m at this location. The peak flood level response in this reach is highly sensitive to relatively small changes in peak flow, due to the nature of the hydraulic controls in this area. This indicates that the change in rainfall intensity (whereby the 1% AEP ARR 2019 rainfall is similar to the 5% AEP ARR 1987 rainfall for the critical durations of interest) is the primary driver of the change in flood level. A similar result can be found at locations 11 to 15, where areas of small storage have large decreases in flood level that are in line with changes between the ARR 1987 1% AEP and 5% AEP flood levels.

Diagram 6: Harrow Road Hydrographs (ARR 1987 vs ARR 2019) for the 1% AEP event



The change in peak flood level within Scarborough Ponds is due to the change in tailwater level and consideration of a longer more realistic critical duration for the ponds (implemented through a raised initial water level in the TUFLOW model). This results in an increase in the 1% AEP peak flood level of approximately 0.3 m.

Sans Souci

The change in the 5% AEP and 1% AEP peak flood levels across Sans Souci is shown in Figure 21 and Figure 22, respectively. In the Sans Souci model, the 1% AEP flood level generally decreases by up to 0.2 m. The changes in flood level are more consistent that other catchments in Bayside West. There are three locations of interest (locations marked on figures):

17. Depena Reserve, where flood levels increase by up to 0.2 m in the 5% AEP event and 0.3 m in the 1% AEP event.
18. Bado-Berong Creek, where flood levels decrease by up to 0.1 m along the length of the creek in both the 5% AEP and 1% AEP events, although there are some minor increases in the 5% AEP event as well (typically less than 0.02 m).
19. Goomun Creek, where the flood levels decrease by up to 0.2 m along the length of the creek (most pronounced around Kendall Street Reserve) in both the 5% AEP and 1% AEP events.

These changes across the catchment are again primarily driven by the change in rainfall intensity. As an indication, the change in flood level between the ARR 1987 5% and 1% AEP events is similar, being approximately 0.2 m – 0.3 m on Bado-Berong Creek and approximately 0.1 m – 0.2 m on Goomun Creek. This is similar to what is seen when comparing the ARR 2019 and ARR 1987 1% AEP results. The changes in levels in Depena Reserve are due to the updated tailwater conditions, which extend to Alice Street where the increase is approximately 0.15 m in the 1% AEP event. It is noted that this comparison is with the ARR 1987 rainfall runs, where tailwater levels were set to 1.0 mAHD.

6. DESIGN FLOOD BEHAVIOUR

6.1. Mapping of Results

The updated hydraulic models were used to produce design flood behaviour using ARR 2019 methodologies (Reference 9). Design flood behaviour was produced for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events, as well as the PMF. Design flood maps for each model area are presented in a separate Appendix as follows:

- Appendix C: Bardwell Creek
- Appendix D: Bonnie Doon
- Appendix E: Muddy Creek
- Appendix F: Sans Souci

In each Appendix, the following figures are provided:

- Peak flood depth, extent and level contours in Figure 1 to Figure 8
- Peak flow velocity in Figure 9 to Figure 16
- Hydraulic hazard in Figure 17 to Figure 24
- Hydraulic categories in Figure 25 to Figure 32
- Flood Emergency Response Classifications in Figure 33 and Figure 34

It is noted that due to the direct rainfall modelling methodology for Sans Souci, shallow flood depths need to be trimmed from the flood maps. A cutoff depth of 0.15 m was applied to all results for Sans Souci.

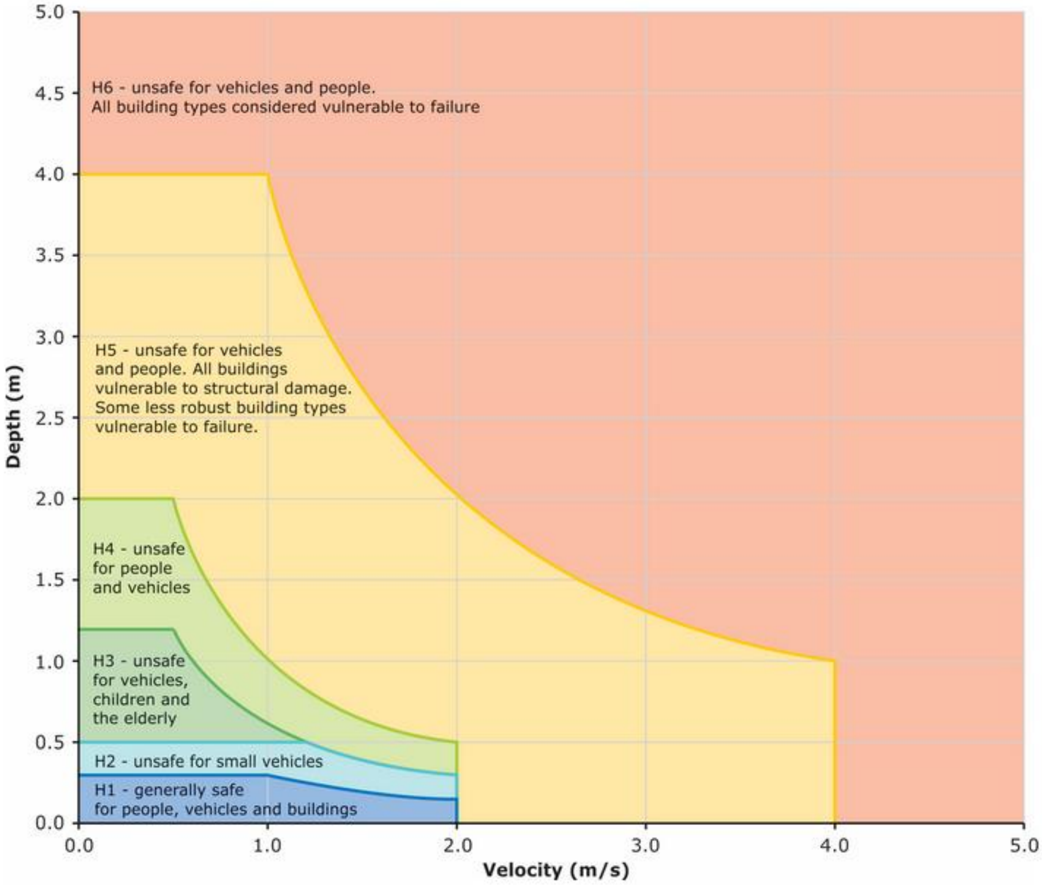
The 1% AEP flood extent maps also indicate the 1% AEP tailwater inundation extent. These were derived from the Cooks River Flood Study (Reference 15) and assuming a 1% AEP ocean level in Botany Bay of 1.7 mAHD (consistent with the Cooks River Flood Study). Adopting these levels, the flood extent was generated using the 2020 1 m LiDAR dataset.

6.2. Hydraulic Hazard

Hazard classification plays an important role in informing floodplain risk management in an area. Hydraulic hazard is a measure of potential risk to life and property damage from flood. Hydraulic hazard is typically determined by considering the depth and velocity of floodwaters. In recent years, there have been several developments in the classification of hazards. Research has been undertaken to assess the hazard to people, vehicles and buildings based on flood depth, velocity and velocity depth product.

Previously, hazard classifications were binary – either Low or High Hazard as described in the Floodplain Development Manual (Reference 1). However, in recent years there have been advances in the classification of hazard. *Managing the floodplain: a guide to best practice in flood risk management in Australia* (Reference 28), part of the Australian Disaster Resilience Handbook Series, provides revised hazard classifications which add clarity to the hazard categories and what they mean in practice. This hazard classification is also presented in ARR 2019 (Reference 9), and contains a more detailed distinction and practical application of hazard categories than the high/low classification method, identifying six classes of hazard as provided in Diagram 7.

Diagram 7: General flood hazard vulnerability curves



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

The hazard categories using this classification are presented in Figure 17 to Figure 24 of each relevant Appendix.

These hazards were reviewed in this study to consider other factors such as rate of rise of floodwaters, duration, threat to life, danger and difficulty in evacuating people and possessions and the potential for damage, social disruption and loss of production. These factors and related comments are given in Table 19.

Table 19: Weightings for Assessment of True Hazard

Criteria	Weighting[1]	Comment
Rate of Rise of Floodwaters	High	The rate of rise in the creek channels and onset of overland flow along roads would be very rapid, which would not allow time for residents to prepare for the onset of flooding
Duration of Flooding	Low	The duration for local catchment flooding will generally be less than around 6 hours, resulting in inconvenience to affected residents but not necessarily a significant increase in hazard.
Effective Flood Access	High	Roads within the catchment will generally be inundated prior to property inundation, which may restrict vehicular access during a flood.
Size of the Flood	Moderate	The hazard can change significantly at some locations with the magnitude of the flood. However, these changes in hazard are generally captured by mapping a range of events using the provisional hazard criteria
Effective Warning and Evacuation Times	High	There is very little, if any, warning time. During the day residents will be aware of the heavy rain but at night (if asleep) residential and non-residential building floors may be inundated with no prior warning.
Additional Concerns such as Bank Erosion, Debris, Wind Wave Action	Low	These issues are a relatively minor consideration in urban environments like Bayside West.
Evacuation Difficulties the Community	Low	Given the quick response of the catchment pre-flood evacuation is unlikely to occur. There may be significant difficulties evacuating people who become trapped in their houses, but only if the depth is sufficient to present a risk to life. This factor is already captured by the provisional hydraulic hazard classification, and therefore was not given significant weight for assessing true hazard.
Flood Awareness of the Community	Moderate	Urban communities in general have relatively low flood awareness and a short “community memory” for historical flood events. Community consultation in previous studies indicate relatively high awareness of flooding in Bayside West, however many newer residents have no awareness of flooding in the local catchment.
Depth and Velocity of Floodwaters	High	In areas of overland flow roads are subject to fast flowing water. In the main creek channels velocities and depth would be high. There is always a risk of a car or pedestrian being swept into the open channel while attempting to cross swiftly flowing waters at major creek crossings. However this factor is largely included in the provisional hydraulic hazard calculation metrics.

1 Relative weighting in assessing the preliminary true hazard

For the Bayside West study area, the factors with high weighting in relation to assessment of true hazard are generally related to the limited flood warning, the dangers of driving on flooded roads, and the potential for flooding of access to residential properties prior to above-floor flooding of buildings occurring. In many cases, it is likely that remaining inside the property will present less risk to life than attempting evacuation via flooded routes, as refuge can generally be taken on upper levels or even furniture above flooded areas. There may be some properties where remaining inside would present a high risk to life due to very high flood depths, but these properties will generally already be classified as high hazard using the adopted categorisation. An analysis indicated that there were only several buildings affected by high hazard (H4 and above) in the 1% AEP event. These buildings were inspected on Google Street View and they have raised floor levels which would produce a much lower flood hazard within the building. In the PMF event, there are numerous buildings that experience high hazard (H4 and above). The property database developed for this study (see Section 8.2.1) was used to estimate the flood hazard at the building, and those which were estimated to have high flood hazard (H4 and above) are indicated on the PMF hazard map (Figure 24 of each relevant Appendix).

In general, it was found that areas where a high flood hazard would be justified based on consideration of the high-weight criteria in Table 19, the area was already designated high hazard as a result of the depth/velocity criteria used to develop the provisional hazard. Therefore the "true" hazard categories were assessed to be the same as the mapped hydraulic hazard.

6.3. Hydraulic Categorisation (Flood Function)

Hydraulic categorisation involves mapping the floodplain to indicate which areas are most important for the conveyance of floodwaters and the temporary storage of floodwaters. This can help in planning decisions about which parts of the floodplain are suitable for development, and which areas need to be left as-is to ensure that flooding impacts are not worsened compared to existing conditions.

The 2005 NSW Government's Floodplain Development Manual (Reference 1) defines three hydraulic categories which can be applied to different areas of the floodplain depending on the flood function:

- Floodways,
- Flood Storage, and
- Flood Fringe.

Floodways are areas of the floodplain where a significant discharge of water occurs during flood events and if blocked would have a significant effect on flood levels and/or distribution of flood flow. Flood storages are important areas for the temporary storage of floodwaters and if filled would result in an increase in nearby flood levels and the peak discharge downstream may increase due to the loss of flood attenuation. The remainder of the floodplain is defined as flood fringe.

There is no quantitative definition of these three categories or accepted approach to differentiate between the various classifications. The delineation of these areas is somewhat subjective based on knowledge of an area and flood behaviour, hydraulic modelling and previous experience in categorising flood function. Several approaches are available, such as the method defined by Howells *et al* (Reference 29).

For this study, hydraulic categories were defined by the following criteria, which has been tested and is a reasonable representation of the flood function of this catchment. This was also adopted for the Bardwell Creek 2D Flood Study Review (Reference 8).

- Floodway is defined as areas where:
    - the peak value of velocity multiplied by depth (V x D) > 0.25 m^2/s, **AND** peak velocity > 0.25 m/s, **OR**
    - peak velocity > 1.0 m/s **AND** peak depth > 0.1 m.

The remainder of the floodplain is either Flood Storage or Flood Fringe,

- Flood Storage comprises areas outside the floodway where peak depth > 0.2 m, and
- Flood Fringe comprises areas outside the Floodway where peak depth ≤ 0.2 m.

The hydraulic categorisation using these criteria was undertaken with the results presented in Figure 25 to Figure 32 of each relevant Appendix.

6.4. Flood Emergency Response Planning

To assist in the planning and implementation of response strategies, the NSW State Emergency Service (SES) in conjunction with the NSW Government has developed guidelines to classify communities according to the impact that flooding has upon them. These Emergency Response Planning (ERP) classifications (Reference 30) consider flood affected communities as those in which the normal functioning of services is altered, either directly or indirectly, because a flood results in the need for external assistance. This impact relates directly to the operational issues of evacuation, resupply and rescue, which is coordinated by the SES. Based on the guidelines (Reference 30), communities are classified to assist in emergency response planning (refer to Table 20).

Table 20: Emergency Response Planning Classification of Communities

Classification	Description	Response Required		
		Resupply	**Rescue / Medivac**	**Evacuation**
High flood island	Area not flooded, but surrounded by floodwaters (cut off).	Yes	Possibly	Possibly
Low flood island	Area first surrounded by floodwaters (limiting evacuation) and is then inundated.	No	Yes	Yes
High trapped perimeter	Area not flooded, but is cut off by floodwaters and impassable terrain/structures.	Yes	Possibly	Possibly
Low trapped perimeter	Area first cut off by floodwaters and impassable terrain/structures, and is then inundated.	No	Yes	Yes
Area with overland escape route	Areas affected by flooding and where vehicle access is cut off, but evacuation on foot is possible.	No	Possibly	Yes
Area with rising road access	Areas affected by flooding, but where roads are accessible to vehicles, rising away from floodwaters.	No	Possibly	Yes
Indirectly affected areas	Areas not inundated, but may be subject to disruptions to utility supply, transport links or communications.	Possibly	Possibly	Possibly

These guidelines are generally more applicable to riverine flooding where significant flood warning time is available and emergency response action can be taken prior to the flood, or where long-term isolation may occur requiring possible resupply or medical evacuation. It is unclear how to apply the classifications in flash flood areas where there is little or no warning, and isolation times will be relatively short.

In urban areas like the Bayside West study area, flash flooding from local catchment and overland flow will generally occur as a direct response to intense rainfall without significant warning. For most flood affected properties in the catchment, remaining inside the home or building is likely to present less risk to life than attempting to drive or wade through floodwaters, as flow velocities and depths are likely to be greater in the roadway. This issue of flood isolation is less critical for urban flash flooding than for rural flooding as it is unlikely that access will be cut for more than a few hours. For example, it is unlikely that provision of food or other supplies to isolated areas will be required in the Bayside West study area. In addition, due to the steep nature of many parts of the study area and the nature of the urban street network means that access to many parts of the study area is maintained even in the PMF due to the presence of access routes following high ridges along major roads and the availability of alternative routes.

The SES does not provide definitive guidance on flood depth or velocity threshold before a road is "cut," or on "acceptable" isolation times. When classifying communities, consideration was given to flood depths for the purpose of being able to move through floodwaters on foot or in a vehicle, drawing on the hazard categories presented in Section 6.2. It is noted that while roads with shallow flooding (i.e. H1 hazard) is considered safe for vehicles, it is never recommended to drive through any depth of floodwater. Roads where access is cut in the relevant design flood event have been indicated on the ERP classification maps.

Key considerations for flood emergency response planning in the Bayside West study area include:

- Cutting of external access arterial roads isolating an area.
- Internal local roads being cut.
- Transport infrastructure being shut down or unable to operate at maximum efficiency.
- Flooding of any key response infrastructure such as hospitals, evacuation centres, emergency service sites.
- Risk of flooding to key public utilities such as gas, electricity and sewerage.
- The extent of the area flooded and the duration of inundation.

Flood liable land within the study area was classified according to the ERP classification above. The high flood island and high trapped perimeter areas have been combined into a single category, since they have the same emergency response planning considerations. Similarly, the low flood island and low trapped perimeter categories have also been combined. Each category is discussed below.

<u>Low Flood Island</u>

Low Flood Island was assessed as any property that was totally inundated in the relevant design flood event, with all potential evacuation routes unavailable at the peak of the flood, due to flood waters, topography or impassable structures. This encompasses the “Low Flood Island” and “Low Trapped Perimeter” categories of Reference 30. For this assessment, some areas have been classified as “Low Flood Island” where it was assessed that there is a real risk of injury or death if residents become trapped in their homes during a flood. Typically, by the time above-floor inundation occurs the roadways at the property frontages would already be inundated with high hazard flooding making evacuation unsafe. Low flood island areas were determined based on hazard categories of H4 and above in the relevant design flood event.

High Flood Island

High Flood Island was assessed as any area totally surrounded by Low Flood Island that is not inundated with all access roads closed and no overland or alternate road access possible. There is enough land higher that the flood level to cope with the number of people in the area. This encompasses the “High Flood Island” and “High Trapped Perimeter” categories of Reference 30. If a property is unaffected by above floor flooding but nearby streets are flooded, vehicular access from the area may be blocked, causing inconvenience or potentially threatening life if emergency medical care is required during a flood.

Overland Escape Route

These are areas where vehicle access is cut off, but evacuation on foot is possible. In urban areas, it is typical that overland flows are conveyed within the road corridor, and so the road itself may not be trafficable, but residents are still able to walk from their property to flood free areas if required.

Rising Road Access

The remaining area of the catchment where inhabited properties are affected by flooding, but are likely to have rising road access to other areas, services and facilities.

Indirectly Affected

It is safe to assume that in rare storm events that all areas of the catchment will be affected in some manner. These areas are not directly affected by flooding, but may experience disruptions such as loss of transport links, electricity supply, water supply, sewage or telecommunications services.

The Bayside West study area has been classified considering the above for the 1% AEP and PMF events, with the maps shown in Figure 33 and Figure 34, respectively, of the relevant Appendix for each model area and is summarised below.

Bardwell Creek

In the Bardwell Creek model in the 1% AEP event, there are a number of roads cut, particularly along the upper parts of Bardwell Creek and flow paths upstream of the East Hills railway line. Despite these cut roads, there are only a few isolated areas where vehicular access is cut to properties (classified as overland escape routes). Part of the Henderson Street industrial area of Turrella, north of the East Hills railway line, has been classified as high flood island. Low flood island areas are typically contained within drainage and creek corridors. In the PMF event, there are many roads cut along major flow paths, isolating areas or restricting vehicular access. The low flood island area is reasonably extensive and impacts properties, particularly those areas between the East Hills railway line and Wolli Creek in Kingsgrove and Turrella.

Bonnie Doon

In the Bonnie Doon area in the 1% AEP event, there is mostly rising road access. There are several areas that may be inaccessible by vehicles, including in the sag points upstream of Arncliffe Park, around Bonar Street, Arncliffe Street and Gertrude Street (overland escape routes). Access to the Kogarah Golf Club is also cut off (high flood island). In the PMF event, there are low flood islands on the main flow path upstream of the Illawarra railway lone (upper Bonnie Doon), with access roads cut. Downstream of the Illawarra railway (lower Bonnie Doon), there are low flood island areas adjacent to the Bonnie Doon channel, and some isolated areas (high flood island) or areas that would only be accessible on foot (overland escape route).

Muddy Creek

In the Muddy Creek model area in the 1% AEP event, the low flood island areas are mainly contained within the drainage and creek corridors, with several roads cut upstream of the Illawarra railway line, that does not significantly affect access due to the localised nature of inundation and alternative routes. Areas affected by flooding generally have rising road access, except for properties on Lynwen Crescent, Francis Avenue and some industrial properties in Rockdale. There are numerous properties surrounding Scarborough Ponds that are affected by flooding up to H3 hazard in the 1% AEP event. Due to the long duration storm that would fill the ponds and cause this flooding, it is assumed that evacuation would be possible as floodwaters rise slowly, but that roads would already be inundated and that it would be conducted on foot (overland escape route). In the PMF event, there are significantly more low flood island areas, particularly around the Spring Street Drain, the industrial area of Rockdale and around Scarborough Ponds. There are numerous roads where vehicular access is constrained at flow path crossings and adjacent to major flooding areas, resulting in pockets of high flood island and overland escape route areas.

Sans Souci

In Sans Souci the hazard generally remains low, resulting in most areas being accessible. There are several roads estimated to be cut, although this is only due to H2 hazard and may be trafficable for large vehicles. In areas adjacent to these inundated roads access would still be possible on foot (overland escape route). There is one area identified as high flood island – a property to the north of Noel Seiffert Reserve that is accessed from Napoleon Street via a private crossing of Bado-berong Creek. It is unclear whether this property has pedestrian access to either Sandringham Street or Russell Avenue. In the PMF event, a large portion of the Sans Souci catchment is considered high flood island. This is due to roads being cut to the north and south. It is assumed that as floodwaters rise in the main creeks, people would move away from the main creeks (if required to evacuate) and become trapped in areas between the creeks and/or Botany Bay. There are large portions of this high flood island that are H3 hazard, however, Rocky Point Road and other local roads near the catchment boundary serve as trafficable access routes for those located to the west of Goomun Creek. Those located nearest the creek may only be able to evacuate on foot (overland escape route), due to roads being inundated to H3 hazard. Generally, areas to the north of Alice Street can evacuate north.

6.5. Flood Planning Area

Local government has various floodplain management responsibilities under the NSW Flood Prone Land Policy. One of these responsibilities is to ensure that development is commensurate with flood risk. This is generally managed by the application of development controls to flood prone land through an LEP and DCP. Enforcement of these controls requires that Council understands the nature of flood risk within the LGA, and identifies the land where such development controls are applicable, which is referred to as the Flood Planning Area (FPA). This land is generally subject to notification through Section 10.7 planning certificates under the NSW Environmental Planning and Assessment Act. This notification is referred to as “flood tagging” in this report.

WMAwater previously undertook a flood tagging exercise (Reference 21) which identified flood control lots within the entire Bayside LGA, including the Bayside West study area. This identification of lots was based on the previous Flood Study results (see Section 2.1.2), tagging those properties affected by the 1% AEP and PMF events. A rigorous desktop analysis and ground-truthing process was adopted. Since the completion of this tagging exercise, there have been updates to legislation and planning guidelines outlined in Planning Circular PS 21-006 issued by the NSW Department of Planning, Industry and Environment on 14 July 2021 (DPIE, now DPE). The circular provides information about changes to Clause 7A of Schedule 4 of *Environmental Planning and Assessment Regulation 2000* (the Regulation), contained in the *Environmental Planning and Assessment Amendment (Flood Planning) Regulation 2021* (the Amendment).

The updated legislation does not change the primary mechanism by which flooding is considered as part of land-use planning in NSW. The previous legislation also required identification of lots on planning certificates (known as Section 149 certificates before being changed to Section 10.7 certificates) but was more rigid in the description of the FPA. This rigidity of the FPA definition in previous versions of the standard LEP instrument led to inconsistency with several elements of the Floodplain Development Manual (for example the application of varying freeboard rather than a single 0.5 m freeboard for all land use controls). The previous legislation also did not allow for the application of development controls for flood prone land beyond the 1% AEP extent (including freeboard), except via special planning provisions requiring submission to DPE. This also was inconsistent with the principles of the Floodplain Development Manual, which requires Council to consider and manage for the full range of flood risk, including extreme events with a probability less than (rarer than) 1% AEP. The primary changes resulting from the new legislation are:

- An altered definition of the FPA, to be consistent with that in the Floodplain Development Manual. Properties subject to flood-related development controls within the FPA require notification on Section 10.7 certificates under Clause 7A(1) of the Regulation, and
- An additional clause allowing the application of flood-related development controls to land between the FPA and PMF extents, for hazardous or sensitive uses, or situations where there is a particular risk to life or flood-related evacuation consideration. Properties subject to these controls require notification on Section 10.7 certificates under Clause 7A(2) of the Regulation.

The flood tagging exercise previously undertaken by WMAwater remains valid considering these legislative changes, since both the 1% AEP and PMF flood affectation was determined. Flood tagging based on the updated modelling for the Bayside West study area has not been undertaken for the current study. It is understood that Bayside Council is looking to provide consistency in flood modelling across all catchments and is in the process of determining the application of climate change considerations to the flood tagging process. It is likely that flood tagging for the Bayside West study area utilising the updated modelling will be undertaken in the future.

7. ADDITIONAL FLOOD ASSESSMENTS AND COMPARISONS

7.1. Tidal Inundation Assessment

Parts of the Bayside West study area are subject to tidal water level variation. The extents of tidal inundation are mapped as follows, using the tidal levels for the Cooks River from Table 2:

- Mean High Water Springs (MHWS, tidal level 0.7 mAHD) on Figure 35 of each Appendix relevant to each study area, and
- High High Water Solstice Springs (HHWSS, tidal level 1.1 mAHD) on Figure 36 of each Appendix relevant to each study area.

These tidal extents were derived using the available 2020 LiDAR data. The maps also indicate the extents for these tidal planes under scenarios with 0.4 m and 0.9 m sea level rise (climate change is discussed further in Section 7.4).

Wolli and Bardwell Creeks are tidal to just upstream of their confluence. The Bonnie Doon channel and Eve Street wetlands are tidal. Inundation of Cahill Park and Kogarah Golf Club is dependent on a connection to the Cooks River. Spring Street Drain is tidal up to just upstream of West Botany Street, and Muddy Creek is tidal up to approximately the Rockdale tennis club. Scarborough Ponds is tidal through the culvert connections to Botany Bay. The channels within Sans Souci are mostly tidal since they are very low-lying.

7.2. Pipe Capacity Assessment

The design flood results were used to determine how frequently the stormwater pipe system capacity is likely to be exceeded throughout the catchment. Defining the capacity of a pipe is not straightforward, as it depends on multiple factors including shape, the flow regime (e.g. upstream or downstream controlled), inlet and outlet connection, pipe grade, and other factors.

TUFLOW provides output indicating the proportion of the cross-section area of a pipe that has flow in it. For this assessment, pipes were assumed to be "full" when the flow area was equal or in excess of 85% of the pipe's cross-sectional area. This is the point at which circular pipes tend to be close to their most efficient, since at 100% of cross-sectional area the additional friction from the top of the pipe reduces pipe conveyance. Similarly, box culverts designed for a supercritical flow regime will typically be designed for free surface flow at approximately 80% of the depth of the culvert, as when flow touches the soffit it will typically "trip" the flow regime to become pressurised, resulting in lower capacity, depending on the grade. Additionally, due to energy losses associated with adjoining pits, inlets, bends etc., some culverts may never reach "100% full" capacity by waterway area, although they may be 90% full for a range of design events (e.g. from the 5% AEP through to the PMF). In such circumstances, it is informative to know the design storm for which the pipe is almost at its "100% full" capacity.

The results of the pipe capacity assessment for the modelled range of design events are shown in Figure 37 of each Appendix relevant to each study area. There is typically a large proportion of pipes that are full in the 20% AEP event:

- Bardwell Creek: 50%

- Bonnie Doon: 65%
- Muddy Creek: 75%
- Sans Souci: 70%

7.3. Comparison with Previous Studies

The 1% AEP design flood event was compared with the previous Flood Study results. The change in peak flood level is a result of the model updates (results reported in Section 4.4) and ARR 2019 updates (results reported in Section 5.9). The change in peak flood level figures (Figure 38 of each Appendix for each relevant model area) combine these to visualise the overall change to the previous studies.

7.4. Climate Change Assessment

7.4.1. Background

Intensive scientific investigation is ongoing to estimate the effects that increasing amounts of greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone) are having on the average earth surface temperature. Based on the latest research by the United Nations Intergovernmental Panel on Climate Change (IPCC), evidence is emerging on the likelihood of climate change and sea level rise because of increasing greenhouse gasses. The sixth assessment report (Reference 31) accepts that human-induced climate change is occurring, with observable increases in temperatures and extreme weather events. Changes to surface and atmospheric temperatures are likely to change the future climate and sea levels. The extent of any permanent climatic or sea level change can only be established with certainty through scientific observations over several decades. Nevertheless, it is prudent to consider the possible range of impacts regarding flooding and the level of flood protection provided by any mitigation works.

In this regard, the following points can be made:

- greenhouse gas concentrations continue to increase.
- global sea levels have risen approximately 0.15 m to 0.25 m in the past century.
- global surface temperatures have increased approximately 0.8°C to 1.3°C in the past century due to human-induced climate change.
- global averaged precipitation has likely increased over the past century with changes to precipitation patterns including the frequency and intensity of heavy precipitation events.
- many uncertainties limit the accuracy to which future rainfall intensity changes.
- sea level rises can be projected and predicted.

7.4.2. Rainfall Increase

The BoM has indicated that there is no intention at present to revise design rainfalls to take account of the impact of climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is uncertainty about whether the changes would in fact increase design rainfalls for major flood producing storms.

Any increase in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally drier catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally drier catchment conditions.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the study area under warmer climate scenarios.

In light of this uncertainty, the NSW State Government's advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime on the project at hand (NSW Floodplain Risk Management Guideline, Reference 32). Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be considered. ARR 2019, drawing on the previous IPCC fifth assessment report, recommends adopting a 5% increase in rainfall intensity for each degree of warming. Using climate modelling projections for Australia, the ARR datahub (Reference 23) provides climate projections under different emissions scenarios. ARR 2019 suggests using the Representative Concentration Pathways (RCPs) of 4.5 and 8.5. These RCPs have since been replaced by Shared Socio-economic Pathways (SSPs) in the IPCC sixth assessment report. The modelled increases in temperature are within the various scenario projections of the IPCC sixth assessment report and are considered valid for the purpose of a sensitivity assessment. The results for the study area centroid are provided in Table 21.

Table 21: Climate change projections for rainfall

Projection year	RCP 4.5		RCP 8.5	
	Temperature increase (°C)	Rainfall increase	Temperature increase (°C)	Rainfall increase
2030	0.869	4.3%	0.983	4.9%
2040	1.057	5.3%	1.349	6.8%
2050	1.272	6.4%	1.773	9.0%
2060	1.488	7.5%	2.237	11.5%
2070	1.676	8.5%	2.722	14.2%
2080	1.810	9.2%	3.209	16.9%
2090	1.862	9.5%	3.679	19.7%

For the horizons of 2050 and 2090, rainfall increases of 10% and 20% have been adopted. This approximately lines up with the RCP 8.5 emissions scenario.

7.4.3. Sea Level Rise

The NSW Sea Level Rise Policy Statement (Reference 33) was released by the NSW Government in October 2009. This Policy Statement was accompanied by the Derivation of the NSW Government's sea level rise planning benchmarks (Reference 34) which provided technical details on how the sea level rise assessment was undertaken. The Floodplain Risk Management Guideline: Incorporating sea level rise benchmarks in flood risk assessments 2010 (Reference 35) was also issued in light of this.

The Policy Statement says:
"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… However, the 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible" (Reference 33).

In light of this uncertainty, the NSW State Government's advice is subject to periodical review. As of 2012 the NSW State Government withdrew endorsement of sea level rise predictions but still requires sea level rise to be considered. In the absence of any other advice the previous NSW State Government benchmarks of sea level rise of 0.4 m by the year 2050 and 0.9 m by the year 2100 have been adopted in this study. These projections are similar to the projections contained in the recent IPCC sixth assessment report (noting these are increases in global mean sea level and this can vary regionally) and are considered valid for the purpose of a sensitivity assessment.

7.4.4. Climate Change Sensitivity Results

Potential future climate has been simulated considering climate change for the year 2050 and year 2090. The parameters for each horizon are contained in Table 22.

Table 22: Climate change simulations

Projection year	Rainfall increase	Sea level rise
2050	10%	0.4 m
2090[1]	20%	0.9 m

1. Sea Level rise projections for the year 2090 are adopting 2100 projections from Reference 33

Climate change projections were applied to the 1% AEP design flood event. Increases in rainfall intensity has been applied by increasing the total rainfall depth within the hydrologic modelling for each model area. The adopted temporal patterns, critical storm durations, rainfall losses and other hydrologic parameters remain the same as the design flood event.

Sea level rise was applied by raising the static tailwater level for each of the TUFLOW model boundaries (see Table 18 in Section 5.8). It is assumed that sea level rise projections would raise the Cooks River design flood levels by the same amount as the ocean. It is noted that there is slight amplification of the tides at Tempe Bridge (see Table 2), and considering the tide only, the future sea level is likely to be slightly higher at Tempe Bridge than Botany Bay. For the purpose of flood modelling, however, the peak flood levels in the Cooks River have been adopted, which are dominated by riverine flooding in the vicinity of Tempe Bridge, rather than tide levels. In this instance, sea level rise would likely be attenuated moving upstream. In these scenarios, however, the increase in rainfall intensity due to climate change would also raise the Cooks River flood levels in these locations that are further from the ocean. These complex considerations are outside the scope of the current assessment, and a simplified approach has been undertaken which is considered reasonable given the uncertainties associated with climate change projections.

For Scarborough Ponds, the initial water level assessment undertaken for the design flood events, as outlined in Section 5.5.3, was undertaken for the future climate scenarios. A new initial water level was selected such that the peak modelled level for the short duration events would account for the peak flood level in the ponds considering the increase in runoff and sea level rise for the longer critical duration.

The results of 2050 and 2090 climate change on the 1% AEP design flood event are shown in Figure 39 and Figure 40, respectively, of each Appendix for each relevant model area. A summary of the results is provided below.

Bardwell Creek

Under the 2050 climate scenario, typical increases on overland flow paths are less than 0.1 m. In Wolli and Bardwell Creeks, the increase is generally in the range of 0.1 m to 0.3 m. At the downstream end of the model, the sea level rise causes increases up to 0.4 m, which affects areas such as the Henderson Street industrial area and Lusty Street.

Under the 2090 climate scenario, typical increases on overland flow paths are up to 0.15 m. In Wolli and Bardwell Creeks, the increase is approximately 0.3 m to 0.5 m. At the downstream end of the model, the sea level rise causes increases up to 0.9 m, which affects areas such as the Henderson Street industrial area and Lusty Street with a number of newly flooded areas.

Bonnie Doon

Under the 2050 climate scenario, typical increases upstream of the Illawarra railway line are less than 0.1 m, except for Bonar Street, which increases by approximately 0.3 m. Downstream of the railway line, sea level rise causes increases in peak flood levels up to 0.4 m, with several newly flooded areas.

Under the 2090 climate scenario, typical increases upstream of the Illawarra railway line are up to 0.15 m, with Bonar Street up to 0.45 m. Downstream of the railway line, sea level rise increases peak flood levels by up to 0.9 m, causing a substantial area to be newly flooded including around Arncliffe Street and Innesdale Road.

Muddy Creek

Under the 2050 climate scenario, the increases on overland flow paths are typically less than 0.1 m. There are larger increases in flood storage areas, such as Frys Reserve detention basin where levels increase by approximately 0.2 m. This increase is also modelled for Scarborough Ponds. The increases due to sea level rise are up to 0.4 m and extend along Spring Street Drain and Muddy Creek, to approximately West Botany Street. There are newly flooded areas around areas such as Bruce Street and Bestic Street.

Under the 2090 climate scenario, the increases on overland flow paths are generally up to 0.1 m. In flood storage areas, the flood level increases by approximately 0.3 m, such as Frys Reserve detention basin. The increase for Scarborough Ponds is approximately 0.55 m. The increases due to sea level rise are up to 0.9 m and causes significant additional inundation of lower Muddy Creek, around the Rockdale industrial area and downstream.

Sans Souci

Under the 2050 climate scenario, the increases on upstream overland flow paths are up to 0.15 m. In the downstream reaches of the major creeks (south of approximately Russell Avenue), sea level rise causes increases up to 0.4 m, extending the inundation footprint.

Under the 2090 climate scenario, the increases on upstream overland flow paths are typically less than 0.1 m. In the downstream reaches of the major creeks (south of approximately Sandringham Street), sea level rise causes increases up to 0.9 m, causing significant inundation of areas previously not flooded.

7.5. Blockage Sensitivity

A sensitivity assessment was undertaken for the 1% AEP event for blockage. The design flood events consider blockage of hydraulic structures, as outlined in Section 5.7. Simulations were run without this blockage and the results were compared to the runs with blockage, for each model area. The results are provided in Figure 41 of the relevant Appendix for each model area and discussed below.

Bardwell Creek

The change in peak flood level without blockage is typically minor within overland flow paths, with slight reductions in flood level of up to approximately 0.02 m. Along Bardwell Creek this reduction can be up to 0.1 m and in flood storage areas the reduction is typically 0.2 m to 0.3 m (such as upstream of the East Hills railway line). The largest impact is the Bardwell Valley Golf Club culverts, where upstream flood levels decrease by up to 0.45 m and downstream flood levels increase by up to 0.2 m with the 20% blockage removed. The increases in Wolli Creek are less than 0.1 m.

Bonnie Doon

In Bonnie Doon there is typically negligible change in overland flow peak flood levels. There are some changes around Bonar Street, the SWSOOS and Arncliffe Street, however these are within ±0.03 m.

Muddy Creek

In Muddy Creek there are only small changes to overland flow flood depths, with changes typically within ±0.02 m. The largest change is within Frys Reserve detention basin where the flood levels decrease by approximately 0.15 m due to removal of the 20% blockage on the culvert under the railway. There are generally negligible changes in the downstream reaches of Spring Street Drain, Muddy Creek and Scarborough Ponds, with only some isolated areas displaying changes within ±0.1 m.

Sans Souci

In Sans Souci there is generally a decrease in peak flood levels, of up to 0.1 m at the outlet of Bado-berong Creek. The decreases further upstream and on the other creeks is less than this, with some minor increases (0.02 m) around Kendall Street Reserve.

7.6. Levee Failure Assessment

A levee failure assessment was undertaken for two levees in the study area – Frys Reserve detention basin in Kogarah and The Strand levee in Rockdale. These levees consist of concrete or brick walls and are shown in Photo 4 and Photo 5.

Photo 4: Frys Reserve Detention Basin wall

Photo 5: The Strand Levee wall

For each levee, two failure mechanisms were modelled – one where the levee fails before it is overtopped, and the other where the levee fails when it is just overtopped. A particular design flood event was selected for each of these failure mechanisms depending on peak flood levels, with the 1% AEP event selected as one of these events. Water level time series for the design storm events compared to the levee crest is shown in Diagram 8 and Diagram 9 for Frys Reserve Detention Basin and The Strand Levee, respectively. These show the lead time between the storm burst onset and peak water level or levee overtopping, as well as the duration of overtopping and inundation. A summary of the selected events and levels for the failure assessment is provided in Table 23.

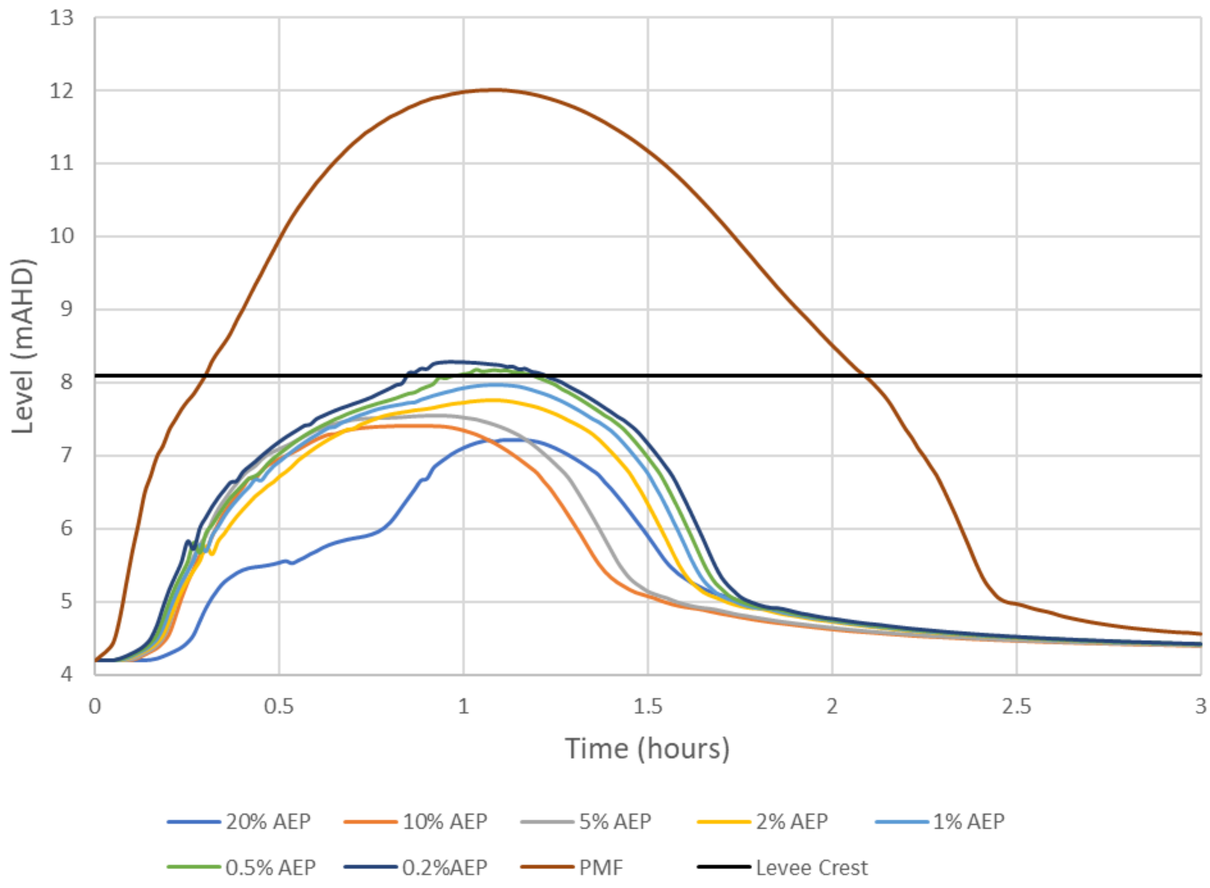


Diagram 8: Water level time series for design flood events in Frys Reserve Detention Basin

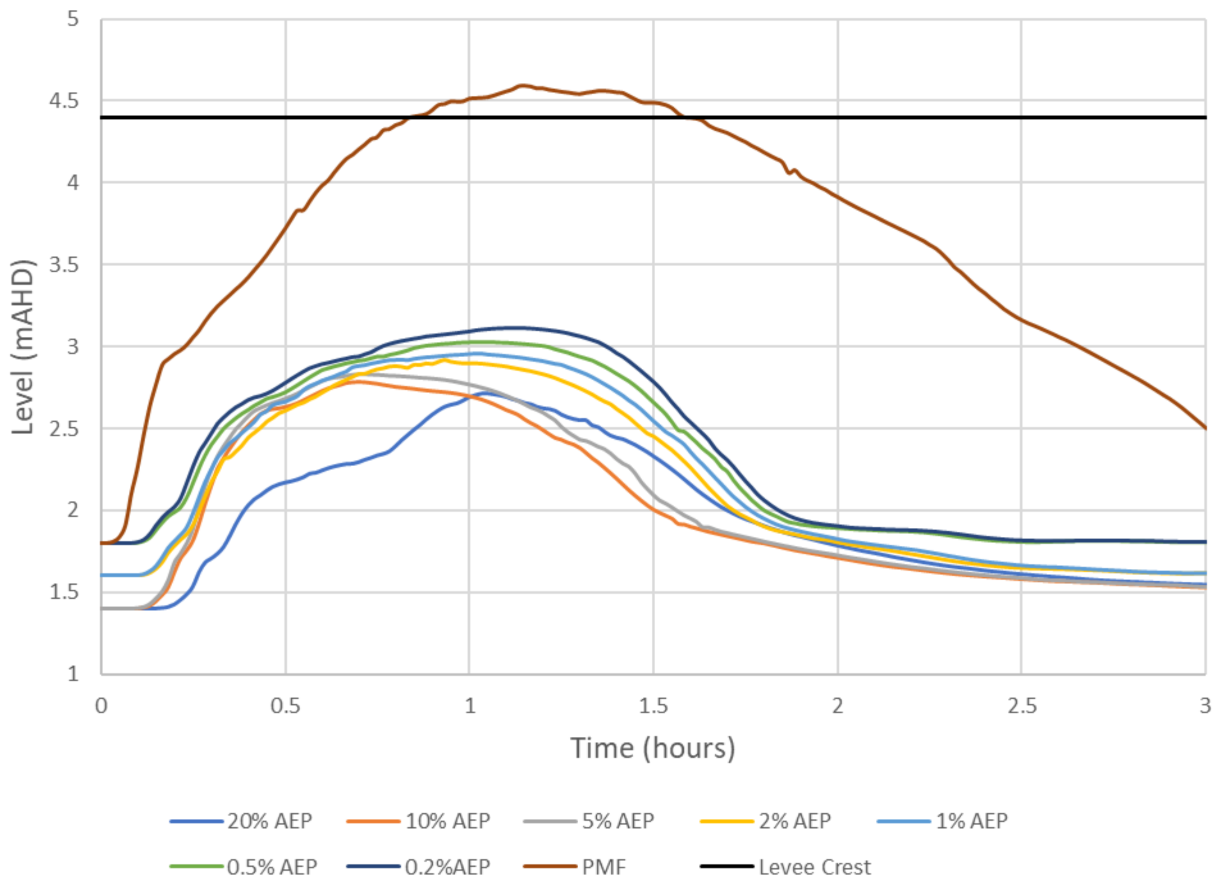


Diagram 9: Water level time series for design flood events at The Strand Levee

Table 23: Summary of levee levels and peak flood levels (mAHD) for levee failure assessment

Level	Frys Reserve Detention Basin	The Strand Levee
Levee crest	8.1	4.4
1% AEP	7.97	2.92
0.5% AEP	8.17	-
PMF	-	4.73

Frys Reserve detention basin is overtopped in the 0.5% AEP event, and as such the 1% AEP event was selected as the failure event without overtopping, and the 0.5% AEP event selected as the failure event with overtopping. Failure was assumed to occur along the concrete block wall section parallel to Warialda Street, over a length of 20 m. Complete failure was assumed to occur in less than one minute. The change in peak flood level for both the 1% AEP event and the 0.5% AEP overtopping event is shown in Figure E42 and Figure E43, respectively, in Appendix E. The results indicate that there is up to 0.3 m increase in peak flood level with failure of the levee in the 1% AEP event. The increase is highly localised, only affecting Warialda Street and Hegerty Street under the railway line. This is due to ponding of water on Warialda Street, to a level approximately 0.2 m below the basin peak water level, which aligns with the observed change in peak flood levels on Warialda Street with levee failure. In the 0.5% AEP overtopping event, the difference in peak water levels is approximately 0.4 m since the levee only just overtops. In the levee failure scenario, the water in the basin floods Warialda Street, causing an increase of up to 0.4 m. The impact extends along Muddy Creek to the Princes Highway.

The Strand Levee is only overtopped in the PMF event, and as such the 1% AEP event was selected as the failure event without overtopping, and the PMF event selected as the failure event with overtopping. Failure was assumed to occur along a 50 m stretch of the brick wall near the cul-de-sac end of The Strand (lowest part of the levee). Complete failure was assumed to occur in less than one minute. The change in peak flood level for both the 1% AEP event and the PMF overtopping event is shown in Figure E44 and Figure E45, respectively, in Appendix E. The results indicate that there is minimal change in peak flood levels (< 0.1 m) with failure of the levee in the 1% AEP event. This is because the water level in Muddy Creek is almost the same as the water level due to ponding of local runoff behind the levee. In fact, the ponding behind the levee is modelled to be slightly higher and hence levee failure reduces the peak flood level for properties on The Strand. In the PMF overtopping event, there is so much water that failure of the levee does not significantly change the modelled peak flood levels.

The other levee located in the Bayside West study area is located at the end of Hillcrest Avenue, Bexley. It is an earthen embankment that protects the lower residents of Hillcrest Avenue from Bardwell Creek flooding (Photo 6). The lowest part of the levee is located at approximately 11.2 mAHD, with the 10% AEP peak flood level in Bardwell Creek being just less than this. The overtopping event would be the 5% AEP event. The water level time series for the design flood events at the levee location is shown in Diagram 10. In the 5% AEP event and larger events, the water level inside the levee and within Bardwell Creek is the same, and levee failure is likely to be of no consequence to peak flood levels on Hillcrest Avenue. In the 20% AEP and 10% AEP events, the difference in water level in Bardwell Creek and on Hillcrest Avenue is approximately 0.5 m. In the event of a levee failure, there would be increased inundation on Hillcrest Avenue. In these events, however, this is only estimated to impact No. 20 (visible in Photo 6) and/or No. 27, depending on the location of the failure. Due to the steep nature of Hillcrest Avenue, the impact would be highly localised.

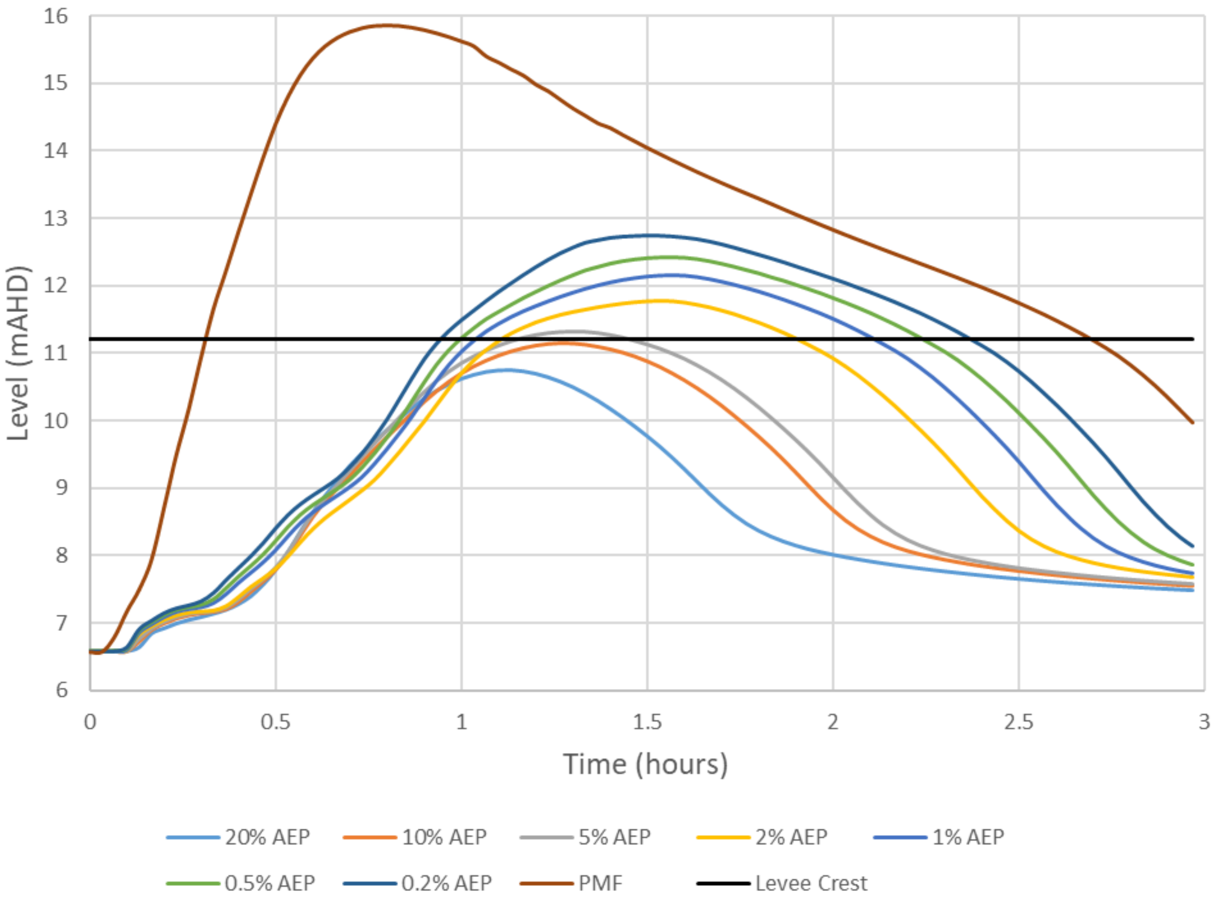


Diagram 10: Water level time series for design flood events at the Hillcrest Avenue Levee

Photo 6: Hillcrest Avenue levee

7.7. Assessment of Works on the Floodplain

There were no planned works on the floodplain that Council could supply plans of to assess potential flood impacts of individual projects or undertake a cumulative flood impact assessment. This assessment instead focusses on one development that was observed on site. The lot, located at 9 Banksia Avenue, consists of two apartment blocks developed in the early 2000's. It is located on an overland flow path from the sag point on Tabrett Street to Banksia Avenue. On site, it was observed that a high solid wall obstructs this overland flow path, with no observed allowance for overland flows (Photo 7). The Muddy Creek TUFLOW model was updated with this obstruction.

Photo 7: Development at 9 Banksia Avenue with a solid wall obstructing an overland flow path on the left

Council provided a copy of the WAE plans which indicate 8 x 1800 mm (W) x 800 mm (H) grilled openings to be provided in the solid fence to ensure that overland flow is not obstructed. These openings were added into the model to demonstrate the change in flood level that would occur if these openings existed. The changes in 5% AEP and 1% AEP peak flood levels are shown in Figure E46 and Figure E47, respectively, in Appendix E. With these openings, the upstream flood level reduces by approximately 0.7 m in the 5% AEP event and 0.9 m in the 1% AEP event, although this is less than 0.3 m on Tabrett Street and is quite localised. Downstream on Banksia Avenue, the flood level increases by up to 0.2 m, and continues to Short Street where the Spring Street Drain open channel commences. The impacts of this obstruction are reasonably localised, however, they demonstrate that works within the Bayside West floodplain, even on shallow overland flow paths (which is the dominant flood behaviour in the developed areas) can result in significant changes to flood behaviour. For this development at 9 Banksia Avenue, it is recommended that a detailed site inspection be undertaken to determine if there are any openings in the wall. If it is found that there are no openings as suspected, then it is recommended that openings be provided in the wall to allow overland flow through the site, in accordance with the development application.

Since 2004, the Cooks Cove Precinct has been considered for redevelopment for recreational, employment and residential use. DPE worked with Bayside Council to develop a Land Use and Infrastructure Strategy for the Bayside West Precincts including the Cooks Cove Precinct

(Reference 36). A planning proposal was received in 2022 for Cooks Cove for the development of Kogarah Golf Course into a business park. The gateway determination was approved in August 2022 and is currently in the pre-exhibition phase. As investigated in several reports since 2004, this change from a flood compatible use (golf course) will potentially significantly increase the risk to life and potential damages in a flood event and will require detailed consideration which is outside the scope of this FRMS. It is recommended that a site-specific Floodplain Risk Management Plan be prepared for the precinct, including:

- Flood modelling complying with ARR 2019 and a flood impact assessment,
- Consideration of different and coincident flood mechanisms,
- Consideration of climate change,
- Consideration of risk to life,
- Independent Peer Review.

8. ECONOMIC IMPACTS OF FLOODING

8.1. Background

The quantification of flood damages is an important part of the floodplain risk management process. It helps identify whether the benefits from various flood mitigation measures will outweigh the costs to implement those measures, and to prioritise which measures will be most cost-effective.

While flood damage assessment does not include all impacts or costs associated with flooding, it provides a basis for assessing the economic loss due to flooding, and a non-subjective means of assessing the merit of flood mitigation works such as detention basins, levees, drainage enhancements, etc. By quantifying flood damages for a range of design events, appropriate management measures can be evaluated in terms of their benefits (reduction in flood damage) versus the cost of implementation.

The cost of flood damage and disruption to a community depends on several factors which include:

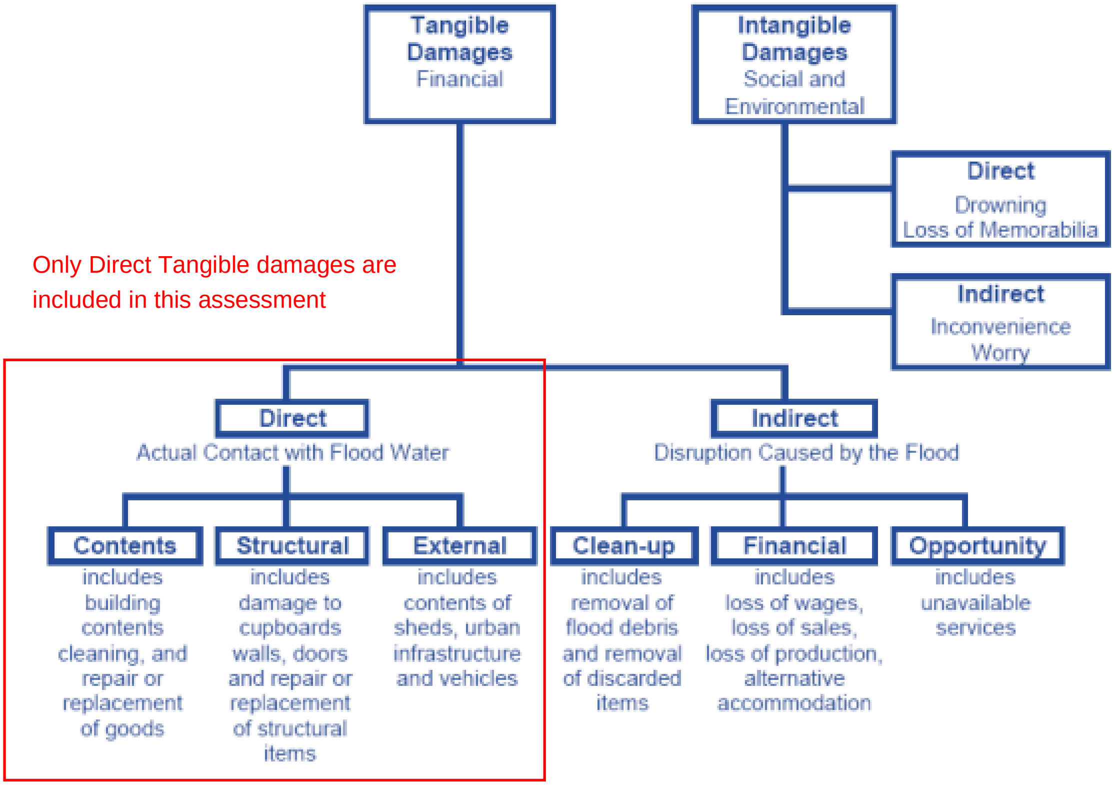
- Flood magnitude (depth, velocity and duration).
- Type of structures at risk and their susceptibility to damage.
- Nature of the development at risk (residential, commercial, industrial).
- Physical factors such as failure of services (e.g. utilities), flood borne debris, sedimentation, etc.
- Awareness and readiness of the community to flooding.
- Effective warning times.
- Availability of evacuation plans.

The potential damage associated with a particular flood event can be divided into a number of components, which are grouped into two major categories;

- Tangible damages – financial costs of flooding quantified in monetary terms.
- Intangible damages – social costs of flooding reflected in increased levels of mental stress, loss of sentimental items, inconvenience to people, injury or loss of life, etc.

Intangible damages are difficult to measure and impossible to meaningfully quantify in dollar terms. For this reason, intangible damages have not been assessed and the following damage assessment focuses on tangible damages only. Tangible damages can be further sub-divided into two categories, direct and indirect damages, as illustrated in Diagram 11.

Diagram 11: Types of flood damages



The total likely damages in any given flood event is difficult to quantify precisely, given the variable nature of flooding and the property and content values of houses affected. Design flood damages are estimated to obtain an indication of the magnitude of the flood problem and compare the economic effectiveness of proposed mitigation options. Understanding the total damages prevented over the life of a mitigation option in relation to current damages, or to an alternative option, can assist in the decision making process.

8.2. Approach

Flood damage estimation procedures have been formulated using data collected following historic flood events. Information collected includes identification of properties flooded, the extent of flooding, depth of flooding experienced, flooding mechanism etc. This information can then be used to guide and calibrate models used to calculate flood damages for a particular area. One of the most thoroughly studied flood damage assessments was that undertaken at Nyngan, following the flood in 1990.

Estimation of flood damage has focussed on residential and community buildings in the study area using guidelines issued by the NSW Government (Reference 37) and recognised damage assessment methodologies. The most common approach to present flood damage data is in the form of flood-damage curves for a range of property types, i.e. residential, commercial, public property, public utilities etc. These relate flood damage to depth of flooding above a threshold level (usually floor level). The estimation of damage is based upon a flood level relative to the floor level of a property.

8.2.1. Property Database

A property database was assembled using the available data, since it is not cost-effective to undertake detailed topographic survey of all or even a portion of flood prone properties in the study area. Bayside Council provided a GIS layer of a floor level survey for the Bonnie Doon Catchment Flood Risk Management Concept Design Report (Reference 17). The layer consisted of 2,112 properties, of which 141 had surveyed levels including residential, commercial and industrial properties.

The remaining property floor levels were estimated based on the following approach:

1. Determine properties affected by the 1% AEP flood extent for inclusion in the property database and estimate the height of the floor level above the ground level for these properties by undertaking a 'windscreen survey', utilising Google Street View where available. This task focussed on properties in the vicinity of hot spots where mitigation works are being considered or damages are especially critical. This involved looking at features such as number of steps into the building, number of bricks to the floor level or other visible features which can be used to provide an estimate of the difference between the floor level and adjacent ground level. For properties where it was difficult to estimate the floor height above ground due to obstructions, the lower level of confidence in the estimate was noted in the database.
2. Based on the above analysis, an indicative average floor level height above adjacent ground levels for each of the model areas was determined. These averages were:
    - Bardwell Creek = 0.44 m
    - Bonnie Doon = 0.38 m
    - Muddy Creek = 0.29 m
    - Sans Souci = 0.27 m
3. Determine additional properties flood affected up to the PMF and add these to the property database.
4. Use GIS analysis to determine the ground level adjacent to each building within the property database using LiDAR data (2020 LiDAR at 1 m grid resolution).
5. Estimate the floor level using, in order of preference:
    - Surveyed floor level (those properties in Bonnie Doon with available floor level survey).
    - Estimated floor level from ground level and task 1 (typically those within the 1% AEP extent where floor levels were visible from Google Street View).
    - Estimated floor level from ground level and task 2 (typically those properties outside the 1% AEP extent but within the PMF extent).

The level of accuracy for the estimated floor heights is considered suitable for two reasons. Firstly, the estimation of property damage due to flooding is inherently difficult to estimate, given the large variation in building types, their contents, the duration of flooding and other factors, and so the accuracy of floor heights should be in line with the accuracy and applicability of the flood damage curves. Secondly, the economic damages assessment is only intended to be used as an estimate of the LGA-wide flood affectation and not on a per-property basis.

The property database that was developed consisted of 8,273 properties and these are shown in Figure 23, Figure 24, Figure 25 and Figure 26 for the Bardwell Creek, Bonnie Doon, Muddy Creek and Sans Souci model areas, respectively. The database contained the following data:

- GIS point location at the building
- Property identification number and deposited plan number
- Address
- Lot area
- Type of development (residential, commercial or industrial)
- Number of dwellings. The cadastre provided by Council contains multiple stacked cadastral polygons where there is more than one title for the lot (for example a strata title). This information was used to estimate the number of dwellings within a lot.
- Model area
- Ground level
- Height of floor above ground
- Floor level
- Current flood tagging status

A summary of the floor levels within the property database is provided in Table 24.

Table 24: Summary of property floor levels for flood damage assessment

Catchment	Estimated with Street View		Surveyed	Representative Height[3]	Total
	High Confidence[1]	Low Confidence[2]			
Bardwell Creek	538	118	0	1,413	2,069
Bonnie Doon	130	0	141	431	702
Muddy Creek	1,790	64	0	1,776	3,630
Sans Souci	917	8	0	947	1,872
Total	3,375	190	141	4,567	8,273

1 Floor level estimated based on a clear view of a floor level above ground from Street View

2 Floor level obstructed on Street View, but estimated based on terrain, building type and features, adjacent properties, etc.

3 For those remaining properties in the catchment that are affected by the PMF and no surveyed or estimated Street View floor level exists, a representative height above ground was assigned.

Design flood levels were assigned to each property based on the modelled flood surface at the building or within 6 m of the building (3 TUFLOW grid cells). The database was used to determine the number and extent of properties inundated above protection level for the range of flood events modelled. No freeboard was included in these estimates.

8.2.2. Residential Damage

Flood damage of residential buildings was calculated using a residential damage spreadsheet developed by the NSW Government in 2007. This includes a representative stage-damage curve derived for a typical house on a floodplain to estimate structural, contents and external damage. The amount of damage is based on the flood inundation depth for a given flood event.

Several input parameters are required to determine which stage-damage curve will be adopted. The key parameters used in this assessment are shown in Table 25.

Table 25: Parameters adopted for Residential Damages Assessment

Parameter	Adopted Value	Comment
Post Flood Inflation Factor	1.4	Suggested range of 1.0 to 1.5 depending on the scale of impacts. It is likely that a flood event in these catchments would also cause flooding across the wider Sydney metropolitan area, which may affect the demand for required trades in the area.
Typical Duration of Immersion (hours)	2 hours	Short duration flooding.
Building Damage Repair Limitation Factor	0.85	Recommended for shorter periods of inundation.
Contents Damage Repair Limitation Factor	0.75	Recommended for shorter periods of inundation.
Effective Warning Time (hours)	0	It is likely that no effective warning time would be given for residents for flash flooding.
Level of flood awareness	Low	Guidelines suggest ‘low’ is adopted unless ‘high’ can be justified. While flooding has been experienced in the catchments, it is assumed that the level of awareness of the extent of flooding for major flash flood events is low.
House size	240 m^2	Typical house size of 240 m^2 adopted.

Typical costs were retained including the average cost of contents ($60,000 in 2001 dollars), external damage ($6,700 in 2001 dollars), clean up costs ($4,000 in 2001 dollars) and accommodation costs ($220 per week for a period of 3 weeks, in 2001 dollars). These parameters were applied to the residential damage curve for a single storey, slab-on-ground house (dominant house type in the study area). External damages were assumed to accumulate from 0.1 m below the habitable level of the house. External damage for those lots with more than one dwelling (e.g. strata title), was assumed to be a single lot, while internal damages were multiplied by the number of dwellings within the lot. Where the number of dwellings exceeded 12, it was assumed that these were apartment buildings with 4 ground floor apartments that could sustain flood damage.

The stage-damage curves within the NSW Government spreadsheet template are derived for late 2001. Average Weekly Earnings (AWE) are used to update residential flood damage curves to current dollars rather than the inflation rate measured by the Consumer Price Index (CPI). The most recent AWE value from the ABS at the time of the assessment was May 2021, and a factor of 1.93 was applied to all ordinates in the residential stage-damage curves based on the increase from November 2001 (base used by the spreadsheet). A regional cost variation factor of 1.00 was applied for the Sydney metropolitan region as per Rawlinson’s Australian Construction Handbook (Reference 38).

The AEP of the PMF event (primarily a function of the catchment size) was estimated to be 1 in 10^7 for the purposes of damages assessment for this study area, and no flood damage was assumed to be incurred in the 50% AEP event.

8.2.3. Non-residential Damage

Industrial and commercial property damage curves were developed considering the approach for other studies within the Bayside LGA, including the Mascot, Rosebery and Eastlakes FRMS&P (Reference 39) and the Botany Bay and Foreshore Beach FRMS&P (Reference 40). Both studies adopt commercial damage curves from the Queensland Government Natural Resources and Management Department's *Guidance on the Assessment of Tangible Flood Damages* (2002). This method utilises various stage-damage curves based on both building size and contents value categories. Due to the limited information on commercial activities conducted within the study area, it was assumed that all commercial properties are of a medium size (186 m^2 to 650 m^2) and of medium (Class 3) value. Industrial flood damage calculations were estimated using the suggested damages contained in the *Rapid Appraisal Method for Floodplain Management* (Victorian Government Natural Resources and Environment, 2000). This attributes damages based on building floor area. Industrial buildings were assumed to cover 90% of the total lot area. Given the nature of commercial and industrial properties in the study area (minimal external assets that would be impacted by flooding), it was assumed for this study that flood damages only accumulate when the flood level is above the floor level of the building.

8.2.4. Vehicle Damage

Vehicle damage is excluded from this assessment. Significant damage can be attributed to vehicles, but these damages are difficult to quantify due to the mobility of the vehicles and the ability to remove them from the path of flood waters. The damages associated with vehicles can be highly variable depending on the time of day, flood warning times, and other factors. It is also likely that vehicles are insured.

8.3. Estimated Tangible Flood Damages

An estimation of the number of properties impacted (flooding occurring on the property within 6 m of the dwelling/building), number of properties with above floor flooding and total damage costs for each modelled flood event was undertaken for each of the model areas.

Initial estimates of the number of properties impacted in frequent events was considered unusually high, and as such filtering of flood results was undertaken. A property was considered not to be flooded (sustaining no damage) if:

- Flood depth (modelled flood level minus LiDAR ground level) was less than 0.15 m. This ensures consistency across the study area with the filtered results for the Sans Souci model area that utilises direct rainfall. In addition, the Building Code of Australia (Reference 41) states that in most cases, a building slab height should not be less than 150 mm above external finished surfaces, such that building floor levels should not be inundated by shallow flows. These shallow depths would typically be considered as 'drainage' issues rather than 'flooding'; or
- Flood depth (modelled flood level minus LiDAR ground level) was less than 0.3 m and the flood level range (0.2% AEP flood level minus 20% AEP flood level) was less than 0.1 m. In these cases, it is likely that flooding is either ponding in the vicinity of the building, where a depression may fill with water to a similar depth in all events, or that this is very shallow

on-grade overland flooding where flood depths are similar in all events. In these cases, if there are flood damages sustained, these are unlikely to be 'real'. It is more likely that the estimated floor level of the building is incorrect, due to an inaccurate estimate of the height above floor, or there are artefacts in the LiDAR data close to the building that give lower ground levels (and hence a lower floor level). It is unlikely in such situations that inundation above floor level is realistic. Building floor levels would typically not be constructed such that it is frequently inundated by shallow flows since a similar flow behaviour is expected across a wide range of events This would imply that in events more frequent than the 20% AEP that a similar flood depth would be experienced to the other larger events, and it is unlikely that there would be a building in such a situation.

A typical measure used to estimate flood damages over a range of flood events is the Annual Average Damage (AAD). AAD represents the equivalent average damages that would be experienced by the community on an annual basis, by taking into account the probability of a flood occurrence over the long term. The AAD value is determined by multiplying the damages that can occur in a given flood by the probability of that flood actually occurring in a given year, and then summing across a range of floods. This method allows smaller floods, which occur more frequently to be given a greater weighting than the larger catastrophic floods that only occur rarely. The AAD for the existing case then provides a benchmark by which to assess the merit of flood management options.

A summary of the tangible flood damages is provided in, for each of the study areas. Residential, commercial/industrial and combined (both residential and commercial/industrial) damages are provided separately.

In each model area, there is typically a gradual increase in the number of properties affected with increasing flood magnitude, except for the PMF event in which the number of properties affected is substantially higher. Commercial and industrial properties account for approximately 5% to 40% of the affected properties, and up to 60% of the total flood damage cost, depending on the area and flood affectation of the commercial and industrial zones. The total damage cost is approximately between $10M and $30M for the 1% AEP event, with the AAD between $1.7M and $3.8M across the various model areas. The total AAD for the entire Bayside West study area is estimated to be approximately $10.6M.

Table 26: Summary of Estimated Tangible Flood Damages for Bardwell Creek

Flood Event	No. Lots Affected[1]	No. Lots Flooded Above Floor Level[2]	No. Properties Flooded Above Floor Level[3]	Total Damages for Event[4]	Average Damage Per Flood Affected Property[4]	% of AAD
Residential						
20% AEP	46	36	55	$ 6,014,500	$ 130,800	39%
10% AEP	51	41	60	$ 6,376,900	$ 125,000	27%
5% AEP	56	43	62	$ 6,757,200	$ 120,700	14%
2% AEP	76	58	77	$ 8,449,700	$ 111,200	10%
1% AEP	90	68	87	$ 9,395,600	$ 104,400	4%
0.5% AEP	95	72	91	$ 9,768,400	$ 102,800	2%
0.2% AEP	110	86	105	$ 11,422,800	$ 103,800	1%
PMF	584	464	561	$ 67,409,300	$ 115,400	3%
Average Annual Damages (AAD)				$ 2,326,000	$ 4,000	
Commercial and Industrial						
20% AEP	7	7	10	$ 687,400	$ 98,200	16%
10% AEP	7	7	10	$ 2,160,400	$ 308,600	22%
5% AEP	8	8	11	$ 2,226,800	$ 278,400	17%
2% AEP	11	11	14	$ 4,199,400	$ 381,800	15%
1% AEP	12	12	15	$ 4,267,100	$ 355,600	7%
0.5% AEP	14	14	17	$ 16,159,600	$ 1,154,300	8%
0.2% AEP	17	17	20	$ 16,265,500	$ 956,800	7%
PMF	46	46	107	$ 38,796,600	$ 843,400	8%
Average Annual Damages (AAD)				$ 648,700	$ 14,100	
Combined						
20% AEP	53	43	65	$ 6,701,900	$ 126,500	34%
10% AEP	58	48	70	$ 8,537,300	$ 147,200	26%
5% AEP	64	51	73	$ 8,984,000	$ 140,400	15%
2% AEP	87	69	91	$ 12,649,100	$ 145,400	11%
1% AEP	102	80	102	$ 13,662,700	$ 133,900	4%
0.5% AEP	109	86	108	$ 25,927,900	$ 237,900	3%
0.2% AEP	127	103	125	$ 27,688,300	$ 218,000	3%
PMF	630	510	668	$ 106,205,800	$ 168,600	5%
Average Annual Damages (AAD)				$ 2,974,600	$ 4,700	

1 - Floodwaters within 6 m of the building and are within 0.1 m of the floor level. This is the number of lots where external damage is estimated.
2 – Floodwater estimated to be above the building floor level for a lot.
3 – Floodwater estimated to be above the building floor level. This includes individual dwellings/buildings within a lot (for example a strata title with multiple villas in the lot).
4 - Rounded to the nearest $100.

Table 27: Summary of Estimated Tangible Flood Damages for Bonnie Doon

Flood Event	No. Lots Affected[1]	No. Lots Flooded Above Floor Level[2]	No. Properties Flooded Above Floor Level[3]	Total Damages for Event[4]	Average Damage Per Flood Affected Property[4]	% of AAD
Residential						
20% AEP	24	8	10	$ 1,420,700	$ 59,200	32%
10% AEP	34	12	14	$ 2,021,300	$ 59,500	26%
5% AEP	39	12	14	$ 2,340,300	$ 60,000	16%
2% AEP	48	16	18	$ 3,100,700	$ 64,600	12%
1% AEP	53	19	21	$ 3,442,500	$ 65,000	5%
0.5% AEP	68	21	23	$ 4,162,700	$ 61,200	3%
0.2% AEP	79	29	31	$ 5,167,900	$ 65,400	2%
PMF	223	148	174	$ 19,926,800	$ 89,400	4%
Average Annual Damages (AAD)				$ 666,700	$ 3,000	
Commercial and Industrial						
20% AEP	18	18	27	$ 844,700	$ 46,900	12%
10% AEP	18	18	27	$ 4,793,300	$ 266,300	28%
5% AEP	21	21	30	$ 4,967,700	$ 236,600	24%
2% AEP	26	26	35	$ 5,530,000	$ 212,700	15%
1% AEP	27	27	36	$ 5,577,000	$ 206,600	5%
0.5% AEP	36	36	48	$ 13,337,300	$ 370,500	5%
0.2% AEP	40	40	55	$ 20,455,300	$ 511,400	5%
PMF	69	69	114	$ 36,362,200	$ 527,000	6%
Average Annual Damages (AAD)				$ 1,020,300	$ 14,800	
Combined						
20% AEP	42	26	37	$ 2,265,400	$ 53,900	20%
10% AEP	52	30	41	$ 6,814,600	$ 131,100	27%
5% AEP	60	33	44	$ 7,308,000	$ 121,800	21%
2% AEP	74	42	53	$ 8,630,700	$ 116,600	14%
1% AEP	80	46	57	$ 9,019,400	$ 112,700	5%
0.5% AEP	104	57	71	$ 17,500,000	$ 168,300	4%
0.2% AEP	119	69	86	$ 25,623,100	$ 215,300	4%
PMF	292	217	288	$ 56,289,000	$ 192,800	5%
Average Annual Damages (AAD)				$ 1,686,900	$ 5,800	

1 - Floodwaters within 6 m of the building and are within 0.1 m of the floor level. This is the number of lots where external damage is estimated.
2 – Floodwater estimated to be above the building floor level for a lot.
3 – Floodwater estimated to be above the building floor level. This includes individual dwellings/buildings within a lot (for example a strata title with multiple villas in the lot).
4 - Rounded to the nearest $100.

Table 28: Summary of Estimated Tangible Flood Damages for Muddy Creek

Flood Event	No. Lots Affected[1]	No. Lots Flooded Above Floor Level[2]	No. Properties Flooded Above Floor Level[3]	Total Damages for Event[4]	Average Damage Per Flood Affected Property[4]	% of AAD
Residential						
20% AEP	65	34	63	$ 6,498,500	$ 100,000	27%
10% AEP	87	50	85	$ 8,683,200	$ 99,800	21%
5% AEP	126	71	112	$ 11,480,900	$ 91,100	14%
2% AEP	228	122	189	$ 18,659,100	$ 81,800	13%
1% AEP	333	200	270	$ 26,962,100	$ 81,000	6%
0.5% AEP	489	312	394	$ 39,373,400	$ 80,500	5%
0.2% AEP	606	439	554	$ 54,848,800	$ 90,500	4%
PMF	2177	1850	2531	$ 275,468,600	$ 126,500	9%
Average Annual Damages (AAD)				$ 3,555,700	$ 1,600	
Commercial and Industrial						
20% AEP	8	8	18	$ 1,135,200	$ 141,900	26%
10% AEP	12	12	31	$ 1,322,600	$ 110,200	19%
5% AEP	16	16	35	$ 2,292,900	$ 143,300	14%
2% AEP	26	26	45	$ 3,727,100	$ 143,400	14%
1% AEP	41	41	61	$ 4,236,400	$ 103,300	6%
0.5% AEP	54	54	80	$ 5,516,800	$ 102,200	4%
0.2% AEP	72	72	113	$ 9,066,400	$ 125,900	3%
PMF	246	246	433	$ 92,935,100	$ 377,800	15%
Average Annual Damages (AAD)				$ 225,700	$ 900	
Combined						
20% AEP	73	42	81	$ 7,633,800	$ 104,600	27%
10% AEP	99	62	116	$ 10,005,900	$ 101,100	21%
5% AEP	142	87	147	$ 13,773,800	$ 97,000	14%
2% AEP	254	148	234	$ 22,386,200	$ 88,100	13%
1% AEP	374	241	331	$ 31,198,500	$ 83,400	6%
0.5% AEP	543	366	474	$ 44,890,200	$ 82,700	5%
0.2% AEP	678	511	667	$ 63,915,200	$ 94,300	4%
PMF	2423	2096	2964	$ 368,403,600	$ 152,000	10%
Average Annual Damages (AAD)				$ 3,781,400	$ 1,600	

1 - Floodwaters within 6 m of the building and are within 0.1 m of the floor level. This is the number of lots where external damage is estimated.

2 – Floodwater estimated to be above the building floor level for a lot.

3 – Floodwater estimated to be above the building floor level. This includes individual dwellings/buildings within a lot (for example a strata title with multiple villas in the lot).

4 - Rounded to the nearest $100.

Table 29: Summary of Estimated Tangible Flood Damages for Sans Souci

Flood Event	No. Lots Affected[1]	No. Lots Flooded Above Floor Level[2]	No. Properties Flooded Above Floor Level[3]	Total Damages for Event[4]	Average Damage Per Flood Affected Lot[4]	% of AAD
Residential						
20% AEP	39	21	34	$ 3,495,600	$ 89,600	25%
10% AEP	64	35	55	$ 5,710,400	$ 89,200	22%
5% AEP	84	50	73	$ 7,734,400	$ 92,100	16%
2% AEP	118	71	119	$ 11,228,200	$ 95,200	13%
1% AEP	155	90	160	$ 15,248,500	$ 98,400	6%
0.5% AEP	204	121	221	$ 21,538,400	$ 105,600	4%
0.2% AEP	264	160	297	$ 26,592,700	$ 100,700	3%
PMF	1472	1334	2125	$ 202,903,400	$ 137,800	11%
Average Annual Damages (AAD)				$ 2,131,200	$ 1,400	
Commercial and Industrial						
20% AEP	3	3	3	$ 121,600	$ 40,500	35%
10% AEP	3	3	3	$ 141,800	$ 47,300	25%
5% AEP	3	3	3	$ 159,000	$ 53,000	15%
2% AEP	3	3	3	$ 175,700	$ 58,600	10%
1% AEP	3	3	3	$ 186,000	$ 62,000	3%
0.5% AEP	3	3	3	$ 199,400	$ 66,500	2%
0.2% AEP	3	3	3	$ 211,900	$ 70,600	1%
PMF	35	35	64	$ 4,123,000	$ 117,800	8%
Average Annual Damages (AAD)				$ 51,700	$ 1,500	
Combined						
20% AEP	42	24	37	$ 3,617,200	$ 86,100	25%
10% AEP	67	38	58	$ 5,852,200	$ 87,300	22%
5% AEP	87	53	76	$ 7,893,400	$ 90,700	16%
2% AEP	121	74	122	$ 11,403,900	$ 94,200	13%
1% AEP	158	93	163	$ 15,434,500	$ 97,700	6%
0.5% AEP	207	124	224	$ 21,737,800	$ 105,000	4%
0.2% AEP	267	163	300	$ 26,804,600	$ 100,400	3%
PMF	1507	1369	2189	$ 207,026,400	$ 137,400	11%
Average Annual Damages (AAD)				$ 2,182,900	$ 1,400	

1 - Floodwaters within 6 m of the building and are within 0.1 m of the floor level. This is the number of lots where external damage is estimated.

2 – Floodwater estimated to be above the building floor level for a lot.

3 – Floodwater estimated to be above the building floor level. This includes individual dwellings/buildings within a lot (for example a strata title with multiple villas in the lot).

4 - Rounded to the nearest $100.

The estimation of tangible flood damages is a high-level exercise, intended to capture the catchment-scale flood damages. It can provide a good indication of the average flood damage across a catchment. The accuracy of the results at individual properties can be affected by vagaries such as the variability in the flood level across the property, the location of the sampled flood level for the property, whether the floor level is consistent or varies through the building. This variability tends to average out across the catchment, particularly if many properties are considered.

8.4. Intangible Flood Damages

The intangible damages associated with flooding, by their nature, are inherently more difficult to estimate in monetary terms. In addition to the tangible damages discussed above, additional costs/damages are incurred by residents affected by flooding, such as stress, injury, loss of life, loss of sentimental items, etc. It is not possible to put monetary values on these intangible damages as they are likely to vary dramatically between each flood (from a negligible amount to significantly more than tangible damages) and depend on a range of factors such as size of flood, the individuals affected and community preparedness. However, it is still important that the consideration of intangible damages is included when assessing the impacts of flooding on a community.

Post flood damage surveys have linked flooding to stress, ill-health and trauma for residents. For example, the loss of memorabilia, pets, important documents and other items without fixed costs and of sentimental value may cause stress and subsequent ill-health. In addition, flooding may affect personal relationships and lead to stress in domestic and work situations. The actual flood event, resulting property damage, risk to life for the individuals or their family and the clean-up process can also add to the stress. In addition to the stress caused during an event, many residents who have experienced a major flood are fearful of the occurrence of another flood event and the associated damage and loss. The extent of stress depends on the individual and although most flood victims recover, these effects can lead to a reduction in quality of life for the flood victims.

During any flood event, these is the potential for injury as well as loss of life due to causes such as drowning, floating debris or illness from polluted water. Generally, the higher the flood velocities and depths, the higher the risk. However, there will always be localised areas of high risk where flows may be concentrated around buildings or other structures within low hazard areas. The intangible damages for the study area catchments may be substantial, due to the lack of warning time for a typical flood event.

9. FLOODPLAIN MANAGEMENT POLICY

Bayside Council (Council) is responsible for local planning and land management in the Bayside LGA, including the management of the floodplain and drainage systems. The planning policies held and used by Council in their management of the floodplain are underpinned and bound by national and state planning legislation. It is important to understand the national and state context prior to making recommendations for Council to amend its own local planning policies to ensure that any changes are consistent with the requirements of state and national legislation.

An overview of the national and state planning instruments is provided below to provide this background.

9.1. National Planning Provisions - Building Code of Australia

The Building Code of Australia (BCA) is part of the National Construction Code Series, an initiative of the Council of Australian Governments, developed to incorporate all on-site construction requirements into a single code. The BCA is produced and maintained by the Australian Building Codes Board on behalf of the Australian Government and each State and Territory Government.

The BCA is a uniform set of technical provisions for the design and construction of buildings and other structures throughout Australia (Reference 41). The goals of the BCA are to enable the achievement and maintenance of acceptable standards of structural sufficiency, safety, health and amenity for the benefit of the community now and in the future.

The BCA contains requirements to ensure new buildings and structures and, subject to State and Territory legislation, alterations and additions to existing buildings located in flood hazard areas do not collapse during a flood when subjected to flood actions resulting from the 'defined flood event' (DFE). The DFE is "*the flood event selected for the management of flood hazard for the location of specific development as determined by the appropriate authority"*. In NSW this is typically the 1% AEP event.

Flood hazard areas are identified by the relevant State/Territory or Local Government authority (such as via a Floodplain Risk Management Study). The BCA is produced and maintained by the Australian Building Codes Board and given legal effect through the *Building Act 1975,* which in turn is given legal effect by building regulatory legislation in each State and Territory. Any provision of the BCA may be overridden by, or subject to, State or Territory legislation. The BCA must, therefore, be read in conjunction with that legislation.

The BCA provides general requirements for measures to keep water out of the building structure and foundations, such as setting minimum heights above ground, and minimum paved apron requirements graded to direct runoff away from the building. Section 3.1.2.3 of the BCA refers specifically to drainage of surface water and finished slab heights, and contains the requirements shown below. Additional requirements for buildings in flood hazard areas, consistent with the objectives of the BCA, primarily aim to protect the lives of occupants of those buildings in events up to and including the defined flood event.

Building Code of Australia 3.1.3.3 Surface water drainage

Surface water must be diverted away from Class 1 buildings as follows:

(a) Slab-on-ground — finished ground level adjacent to buildings:
the external finished surface surrounding the slab must be drained to move surface water away from the building and graded to give a slope of not less than (see Figure 3.1.2.2):

(i) 25 mm over the first 1 m from the building in low rainfall intensity areas for surfaces that are reasonably impermeable (such as concrete or clay paving); or

(ii) 50 mm over the first 1 m from the building in any other case.

(b) Slab-on-ground — finished slab heights:
the height of the slab-on-ground above external finished surfaces must be not less than (see Figure 3.1.2.2):

(i) 100 mm above the finished ground level in low rainfall intensity areas or sandy, well-drained areas; or

(ii) 50 mm above impermeable (paved or concreted areas) that slope away from the building in accordance with (a); or

(iii) 150 mm in any other case.

9.2. State Planning Provisions

9.2.1. State Provisions – NSW Environmental Planning and Assessment Act 1979

The NSW Environmental Planning and Assessment Act 1979 (EP&A Act) provides the framework for regulating and protecting the environment and controlling the impact of development. Pursuant to Section 9.1(2) of the EP&A Act, the Minister has directed that councils have the responsibility to facilitate the implementation of the NSW Government's Flood Prone Land Policy. The policies and guidelines described in this Section fall under the EP&A Act. The objects of the Act are set out below.

Environmental Planning and Assessment Act 1979 No 203

1.3 Objects of Act

The objects of this Act are as follows:

(a) to promote the social and economic welfare of the community and a better environment by the proper management, development and conservation of the State's natural and other resources,

(b) to facilitate ecologically sustainable development by integrating relevant economic, environmental and social considerations in decision-making about environmental planning and assessment,

(c) to promote the orderly and economic use and development of land,

(d) to promote the delivery and maintenance of affordable housing,

(e) to protect the environment, including the conservation of threatened and other species of native animals and plants, ecological communities and their habitats,

(f) to promote the sustainable management of built and cultural heritage (including Aboriginal cultural heritage),

(g) to promote good design and amenity of the built environment,

(h) to promote the proper construction and maintenance of buildings, including the protection of the health and safety of their occupants,

(i) to promote the sharing of the responsibility for environmental planning and assessment between the different levels of government in the State,

(j) to provide increased opportunity for community participation in environmental planning and assessment.

9.2.2. NSW Flood Prone Land Policy

The primary objectives of the NSW Government's Flood Prone Land Policy are:

(a) to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone land, and

(b) to reduce public and private losses resulting from floods whilst utilising ecologically positive methods wherever possible.

The NSW Floodplain Development Manual 2005 (FDM, Reference 1) relates to the development of flood prone land for the purposes of Section 733 of the Local Government Act 1993 and incorporates the NSW Flood Prone Land Policy. Section 733 of the Local Government Act 1993 provides councils with statutory indemnity for decisions made and information provided in good faith from the outcomes of the management process (undertaken in accordance with the FDM).

The FDM outlines a merits approach based on floodplain management and recognises differences between urban and rural floodplain issues. At the strategic level, this allows for the consideration of social, economic, cultural, ecological and flooding issues to determine strategies for the management of flood risk.

9.2.3. Flood Prone Land Package

On the 14th July 2021, DPIE (now DPE) implemented updates to the Flood Prone Land Package. The purpose of the package is to increase flood resilience in New South Wales, reduce loss of life and property damage. The package provides councils additional land use planning tools to manage flood risk beyond the 1% AEP flood event and strengthen evacuation consideration in land use planning.

The changes include:

- A revised Ministerial Direction 4.3 regarding flooding issued under Section 9.1 of the Environmental Planning and Assessment Act 1979,
- A revised planning circular on flooding
- A new guideline: Considering Flooding in Land Use Planning
- Revised Local Environmental Plan flood clauses,
- Amendments to Schedule 4, Section 7A of the Environmental Planning and Assessment Regulation 2000,
- State Environmental Planning Policy Amendment (Flood Planning) 2021.

The key changes and implications are outlined below:

- Amendments to Schedule 4 of EP&A Regulation including changes to Clause 7A(1), Clause 7A(2). These amendments now require councils to note on Section 10.7 certificates if any flood related development controls apply to the land relating to either the FPA, hazardous materials / industry, sensitive, vulnerable or critical uses.
- The Ministerial Direction 4.3 has been amended to remove the requirement for councils to seek exceptional circumstances to apply residential development controls to land outside the 1% AEP flood event (currently included in Clause 7 of Direction 4.3).
- Two proposed LEP clauses relating to the FPA, and Special Flood Consideration.
  - The FPA clause allows council to extend the FPA to include more extreme flood events where the flood risk requires land use planning tools.
  - The clause relating to Special Flood Consideration provides councils the mechanism to apply development controls to land outside the FPA but within the PMF. This clause is specific to land with a significant risk to life, sensitive, vulnerable or critical uses, or land with hazardous materials or industry.

9.2.4. Ministerial Direction 4.3

Direction 4.3 was one in a list of directions issued on the 1st July 2009. The directions were issued by the then Minister for Planning to relevant planning authorities under Section 9.1(2) (previously Section 117(2)) of the *Environmental Planning and Assessment Act 1979.* Direction 4 pertains to "Hazard and Risk", with Direction 4.3 relating specifically to Flood Prone Land. Direction 4.3 was updated on the 14th July 2021, the revised clause is shown below.

Objectives

(1) The objectives of this direction are:

(a) to ensure that development of flood prone land is consistent with the NSW Government's Flood Prone Land Policy and the principles of the Floodplain Development Manual 2005,

(b) to ensure that the provisions of a local environmental plan that apply to flood prone land are commensurate with flood behaviour and include consideration of the potential flood impacts on and off the subject land.

Clause (3) of Direction 4.3 states:

(3) This direction applies when a planning proposal authority prepares a planning proposal that creates, removes or alters a zone or a provision that affects flood prone land.

Clauses (4)-(9) of Direction 4.3 state:
(4) A planning proposal or draft LEP must include provisions that give effect to and are consistent with:

(a) The NSW Flood Prone Land Policy, and

(b) The principles of the Floodplain Development Manual 2005 (or its update), and

(c) The Considering flooding land use planning guideline.

(5) A planning proposal or draft LEP must not rezone land within the Flood Planning Area from Recreation, Rural, Special purpose zones or Environmental Zones to a Residential, Business, Industrial, or Special Purpose Zone
(6) A planning proposal or draft LEP must not contain provisions that apply to the Flood Planning Area which:

(a) permit development in a floodway,

(b) permit development that will result in significant flood impacts to other properties,

(c) permit residential development in high hazard areas,

(d) permit a significant increase in the dwelling density of that land,

(e) permit the development of centre-based child care facilities, hostels, boarding houses, group homes, hospitals, residential care facilities, respite day care centres and seniors housing in areas where the development cannot effectively self-evacuate,

(f) permit development to be carried out without development consent except for the purposes of exempt development or agriculture. Dams, drainage canals, levees, buildings structures or filling in floodways or high hazard areas, still require development consent,

(g) are likely to result in a significantly increased requirement for government spending on emergency management services, and flood mitigation and emergency response measures, which can include but not limited to road infrastructure, flood mitigation infrastructure and utilities or
(h) permit hazardous industries or hazardous storage establishments where hazardous materials cannot be effectively contained during floods.

(7) A planning proposal or draft LEP must not contain provisions that apply to the Regional Evacuation Consideration Area which:

(a) permit development in areas that will exceed the capacity of an established regional evacuation route(s).

(8) For the purposes of a draft LEP, a council's Flood Planning Level(s) must be consistent with the Floodplain Development Manual 2005 (or its update) or as otherwise determined by an adopted

Floodplain Risk Management Study.

(9) A planning proposal may be inconsistent with the terms of this direction only if the planning proposal authority can satisfy the Secretary of the Department of Planning, Industry and Environment (or their nominee) that:

> *(a) the planning proposal is in accordance with a floodplain risk management plan prepared by the relevant council/s in accordance with the principles and guidelines of the Floodplain Development Manual 2005 (or its update), and/or*
>
> *(b) the planning proposal is supported by a flood and risk impact assessment or Council adopted flood study consistent with the relevant planning authorities' requirements, and/or*
>
> *(c) the provisions of the planning proposal that are inconsistent are of minor significance.*

Note: In this direction:
(a) "flood prone land" "flood storage" "floodway" and "high hazard" have the same meaning as in the Floodplain Development Manual 2005.
(b) "flood planning level" "flood behaviour" and "flood planning area" has the same meaning as in the Considering flooding in land use planning guideline 2021.
(c) Special flood considerations are outlined in the Considering flooding in land use planning guideline 2021 and an optional clause in the Standard Instrument (Local Environmental Plans) Order 2006.
(d) Under the floodplain risk management process outlined in the NSW Government's Floodplain Development Manual 2005, councils may produce a flood study followed by a floodplain risk management study and floodplain risk management plan.

9.2.5. Planning Circular PS 07-003 and PS 21-006

Planning Circular PS 07-003 (31st January 2007) provided advice on a package of changes concerning flood-related development controls for land above the 1-in-100 year flood and up to the PMF. A revised planning circular '*Considering flooding in land use planning: guidance and statutory requirements'* PS 21-006 was released with the recent changes to the Flood Prone Land Package on 14th July 2021. The revised circular provides advice on a package of changes regarding how land use planning considers flooding and flood-related constraints, including Section 10.7 Planning Certificates, local planning direction 4.3, LEP clauses and associated guidelines.

In Planning Circular PS21-006 it is noted that: *"Section 733 of the* Local Government Act 1993 *(the LG Act) protects councils from liability if they have followed the requirements of the Manual".*

9.2.6. Considering flooding in land use planning guideline

The guideline aims to provide councils with mechanisms to manage flood risk for the full range of flooding up to the PMF and give further consideration to evacuation constraints. Within the proposed Flood Prone Land package, there are two main categories council can use to address flooding impacts namely, FPAs or special considerations.

Historically, the focus has been on managing the 1% AEP flood event. The Flood Prone Land Package aims to provide councils the ability to apply development controls to areas outside the flood extent where the flood risk requires it. The FDM identifies either the 1% AEP flood event or an equivalent historic event as an appropriate starting point when selecting the DFE. However, it recommends considering selecting a more extreme flood event where there are significant economic, social, environmental or cultural risks associated with a larger event.

The Special Flood Considerations category provides council the ability to apply controls to land outside the FPA but within the PMF flood event where there is a significant risk to life or risk of hazardous material impacting the community or environment.

9.2.7. Section 10.7 Planning Certificates

Formerly known as Section 149 Planning Certificates, Section 10.7 Planning Certificates describe how a property may be used and the development controls applicable to that property. The Planning Certificate is issued under Section 10.7 of the Environmental Planning and Assessment Act 1979.

When land is bought or sold, the Conveyancing Act 1919 and Conveyancing (Sale of Land) Regulation 2010 requires that a Section 10.7 Planning Certificate be attached to the contract of sale for the land.

Section 10.7 of the EP&A Act states:

(1) A person may, on payment of the prescribed fee, apply to a council for a certificate under this section (a planning certificate) with respect to any land within the area of the council.
(2) On application made to it under subsection (1), the council shall, as soon as practicable, issue a planning certificate specifying such matters relating to the land to which the certificate relates as may be prescribed (whether arising under or connected with this or any other Act or otherwise).
(3) (Repealed)
(4) The regulations may provide that information to be furnished in a planning certificate shall be set out in the prescribed form and manner.
(5) A council may, in a planning certificate, include advice on such other relevant matters affecting the land of which it may be aware.
(6) A council shall not incur any liability in respect of any advice provided in good faith pursuant to subsection (5). However, this subsection does not apply to advice provided in relation to contaminated land (including the likelihood of land being contaminated land) or to the nature or extent of contamination of land within the meaning of Schedule 6.
(7) For the purpose of any proceedings for an offence against this Act or the regulations which may be taken against a person who has obtained a planning certificate or who might reasonably be expected to rely on that certificate, that certificate shall, in favour of that person, be conclusively presumed to be true and correct.

The Environmental Planning and Assessment Regulation 2000, Schedule 4 specifies the information to be disclosed on a Section 10.7 (2) Planning Certificate. In particular, Schedule 4, 7A refers to flood related development control information and requires councils to provide the following information:

(1) If the land or part of the land is within the flood planning area and subject to flood related development controls.
(2) If the land or part of the land is between the flood planning area and the probable maximum flood and subject to flood related development controls.
(3) In this clause—
flood planning area has the same meaning as in the Floodplain Development Manual.
Floodplain Development Manual means the *Floodplain Development Manual*(ISBN 0 7347 5476 0) published by the NSW Government in April 2005.
probable maximum flood has the same meaning as in the Floodplain Development Manual.

Section 10.7 (2) and (5) certificates contain the information prescribed in Schedule 4 described above and additional information relating to the property. In a flooding context, additional information may include notations on flood hazard, percentage of the lot affected by flooding, or peak flood depths and levels on the property, or *“advice on other such relevant matters affecting the land of which it may be aware” (EP&A Act, 10.7 (5)).*

9.2.8. State Environmental Planning Policy (Exempt and Complying Development Codes (2008))

The aims of the State Environmental Planning Policy (Exempt and Complying Development Codes) (SEPP) 2008 are presented below.

This Policy aims to provide streamlined assessment processes for development that complies with specified development standards by:

(a) providing exempt and complying development codes that have State-wide application, and
(b) identifying, in the exempt development codes, types of development that are of minimal environmental impact that may be carried out without the need for development consent, and
(c) identifying, in the complying development codes, types of complying development that may be carried out in accordance with a complying development certificate as defined in the Act, and
(d) enabling the progressive extension of the types of development in this Policy, and
(e) providing transitional arrangements for the introduction of the State-wide codes, including the amendment of other environmental planning instruments.

Part 3 of the SEPP contains standards relating to development in flood control lots. This is described below.

9.2.9. State Environmental Planning Policy (Exempt and Complying Development Codes) Amendment (Housing Code) 2017

Part 3 of the SEPP relates to the *"Housing Code”.* This section replaces the former *“General Housing Code”,* which was repealed in June 2017. Part 3 is divided into 5 “Divisions”, with Division

2 containing General standards relating to land type. Part 3.5 specifically relates to Complying Development on flood control lots and is reproduced below.

3.5 *Complying development on flood control lots*

1) *Development under this code must not be carried out on any part of a flood control lot, other than a part of the lot that the council or a professional engineer who specialises in hydraulic engineering has certified, for the purposes of the issue of the relevant complying development certificate, as not being any of the following:*
   a) *a flood storage area,*
   b) *a floodway area,*
   c) *a flow path,*
   d) *a high hazard area,*
   e) *a high risk area.*
2) *If complying development under this code is carried out on any part of a flood control lot, the following development standards also apply in addition to any other development standards:*
   a) *if there is a minimum floor level adopted in a development control plan by the relevant council for the lot, the development must not cause any habitable room in the dwelling house to have a floor level lower than that floor level,*
   b) *any part of the dwelling house or any attached development or detached development that is erected at or below the flood planning level is constructed of flood compatible material,*
   c) *any part of the dwelling house and any attached development or detached development that is erected is able to withstand the forces exerted during a flood by water, debris and buoyancy up to the flood planning level (or if an on-site refuge is provided on the lot, the probable maximum flood level),*
   d) *the development must not result in increased flooding elsewhere in the floodplain,*
   e) *the lot must have pedestrian and vehicular access to a readily accessible refuge at a level equal to or higher than the lowest habitable floor level of the dwelling house,*
   f) *vehicular access to the dwelling house will not be inundated by water to a level of more than 0.3m during a 1:100 ARI (average recurrent interval) flood event,*
   g) *the lot must not have any open car parking spaces or carports lower than the level of a 1:20 ARI (average recurrent interval) flood event.*
3) *The requirements under subclause (2) (c) and (d) are satisfied if a joint report by a professional engineer specialising in hydraulic engineering and a professional engineer specialising in civil engineering states that the requirements are satisfied.*
4) *A word or expression used in this clause has the same meaning as it has in the* Floodplain Development Manual, *unless it is otherwise defined in this Policy.*
5) *In this clause:*

   flood compatible material *means building materials and surface finishes capable of withstanding prolonged immersion in water.*

   flood planning level *means:*
   (a) the flood planning level adopted by a local environmental plan applying to the lot, or

(b) if a flood planning level is not adopted by a local environmental plan applying to the lot, the flood planning level adopted in a development control plan by the relevant council for the lot.

Floodplain Development Manual *means the* Floodplain Development Manual *(ISBN 0 7347 5476 0) published by the NSW Government in April 2005.*

flow path *means a flow path identified in the council's flood study or floodplain risk management study carried out in accordance with the* Floodplain Development Manual*.*

high hazard area *means a high hazard area identified in the council's flood study or floodplain risk management study carried out in accordance with the* Floodplain Development Manual*.*

high risk area *means a high risk area identified in the council's flood study or floodplain risk management study carried out in accordance with the* Floodplain Development Manual.

9.3. Local Planning Provisions

Updated and relevant planning controls are important in flood risk management. Appropriate planning restrictions, ensuring that development is compatible with flood risk, can significantly reduce future flood damages. Planning instruments can be used as tools to guide new development away from high flood risk locations and ensure that new development does not increase flood risk elsewhere. They can also be used to develop appropriate evacuation and disaster management plans to better reduce flood risks to the existing population. Councils use LEPs and DCPs to govern control on development with regards to flooding.

9.3.1. Local Environmental Plan

Environmental Planning Instruments such as LEPs guide land use and development by zoning all land and identifying appropriate land uses allowed in each zone. LEPs are used as tools to guide new development away from high flood risk locations and ensure that new development does not adversely affect flood behaviour. LEPs can also be used to develop appropriate evacuation and disaster management plans to better reduce flood risks to the existing population.

Since the amalgamation of the City of Rockdale and City of Botany Bay Councils, Bayside Council has been working towards harmonising their planning controls. The Bayside LEP (Reference 42) came into effect on 27th August 2021, replacing the Botany Bay LEP 1995, Botany Bay LEP 2013 and Rockdale LEP 2011, and is applicable to the Bayside West study area. On the 14th July 2021, the NSW Government's Flood Prone Land Package commenced and a revised flood clause (Clause 5.21 Flood Planning) was introduced across all LEPs in NSW, including the Bayside LEP 2021. This clause allows for the FPA to include areas outside the 1% AEP event where the damages in more extreme flood events warrant additional development controls. The standard instrument clause is shown below.

(1) The objectives of this clause are as follows—

(a) to minimise the flood risk to life and property associated with the use of land,

(b) to allow development on land that is compatible with the flood function

and behaviour on the land, taking into account projected changes as a result of climate change,
(c) to avoid adverse or cumulative impacts on flood behaviour and the environment,
(d) to enable the safe occupation and efficient evacuation of people in the event of a flood.

(2) Development consent must not be granted to development on land the consent authority considers to be within the flood planning area unless the consent authority is satisfied the development—
(a) is compatible with the flood function and behaviour on the land, and
(b) will not adversely affect flood behaviour in a way that results in detrimental increases in the potential flood affectation of other development or properties, and
(c) will not adversely affect the safe occupation and efficient evacuation of people or exceed the capacity of existing evacuation routes for the surrounding area in the event of a flood, and
(d) incorporates appropriate measures to manage risk to life in the event of a flood, and
(e) will not adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses.

(3) In deciding whether to grant development consent on land to which this clause applies, the consent authority must consider the following matters—
(a) the impact of the development on projected changes to flood behaviour as a result of climate change,
(b) the intended design and scale of buildings resulting from the development,
(c) whether the development incorporates measures to minimise the risk to life and ensure the safe evacuation of people in the event of a flood,
(d) the potential to modify, relocate or remove buildings resulting from development if the surrounding area is impacted by flooding or coastal erosion.

(4) A word or expression used in this clause has the same meaning as it has in the Considering Flooding in Land Use Planning Guideline unless it is otherwise defined in this clause.

(5) In this clause—
***Considering Flooding in Land Use Planning Guideline** means the Considering Flooding in Land Use Planning Guideline published on the Department's website on 14 July 2021.*
***flood planning area** has the same meaning as it has in the Floodplain Development Manual.*
***Floodplain Development Manual** means the Floodplain Development Manual (ISBN 0 7347 5476 0) published by the NSW Government in April 2005.*

The Flood Prone Land Package included a second optional clause '5.22 Special flood considerations' which provides councils the mechanism to apply development controls to land outside the FPA but within the PMF. This clause is specific to land with a significant risk to life, sensitive, vulnerable or critical uses, or land with hazardous materials or industry. Council has expressed an interest in opting into this clause. The Department is currently preparing the associated amendments to allow the implementation of the clause, which is expected in the near future. The current draft standard instrument clause is shown below.

Provides specific controls relating to risk to life, hazardous materials and sensitive, vulnerable or critical uses. It provides councils mechanisms to additional development controls where there is a risk to life. Key extracts included in this clause are:

(1) The objectives of this clause are as follows—

(a) to enable the safe occupation and evacuation of people subject to flooding,

(b) to ensure development on land is compatible with the land's flood behaviour in the event of a flood,

(c) to avoid adverse or cumulative impacts on flood behaviour,

(d) to protect the operational capacity of emergency response facilities and critical infrastructure during flood events,

(e) to avoid adverse effects of hazardous development on the environment during flood events.

(2) This clause applies to—

(a) for sensitive and hazardous development—land between the flood planning area and the probable maximum flood, and

(b) for development that is not sensitive and hazardous development—land the consent authority considers to be land that, in the event of a flood, may—

(i) cause a particular risk to life, and

(ii) require the evacuation of people or other safety considerations.

(3) Development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the development—

(a) will not affect the safe occupation and efficient evacuation of people in the event of a flood, and

(b) incorporates appropriate measures to manage risk to life in the event of a flood, and

(c) will not adversely affect the environment in the event of a flood.

(4) A word or expression used in this clause has the same meaning as it has in the Considering Flooding in Land Use Planning Guideline unless it is otherwise defined in this clause.

(5) In this clause:

***Considering Flooding in Land Use Planning Guideline**—see clause 5.21(5).*

***flood planning area**—see clause 5.21(5).*

***Floodplain Development Manual**—see clause 5.21(5).*

***probable maximum flood** has the same meaning as it has in the Floodplain Development Manual.*

***sensitive and hazardous development** means development for the following purposes—*

(a) [list land uses]

***Direction—** Only the following land uses are permitted to be included in the list—*

(a) boarding houses,

(b) caravan parks,

(c) correctional centres,

(d) early education and care facilities,

(e) eco-tourist facilities,

(f) educational establishments,
(g) emergency services facilities,
(h) group homes,
(i) hazardous industries,
(j) hazardous storage establishments,
(k) hospitals,
(l) hostels,
(m) information and education facilities,
(n) respite day care centres,
(o) seniors housing,
(p) sewerage systems,
(q) tourist and visitor accommodation,
(r) water supply systems.

9.3.2. Development Control Plan

DCPs support the implementation of the objectives of the LEP, providing specific guidance for design and assessment of proposed developments. Two DCPs currently cover the Bayside LGA:

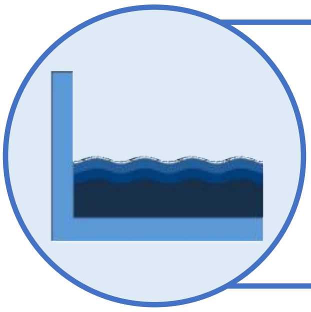
- Rockdale Development Control Plan 2011 (Reference 43)
- Botany Bay Development Control Plan 2013 (Reference 44)

The DCPs were updated to reference the new Bayside LEP (Reference 42), and came into effect on 27th August 2021. The Rockdale Development Control Plan applies to the Bayside West study area.

Bayside Council intends to develop a comprehensive DCP covering the former Rockdale and Botany Bay Council areas, harmonising the existing DCPs. WMAwater was provided with the draft Flood Planning Controls (Reference 45), which was reviewed as part of this FRMS&P. The draft Flood Planning Controls provide a range of objectives and controls to manage the impacts of flooding in accordance with the Bayside LEP. This covers things such as floor levels, car parking, building components, fencing, evacuation, earthworks and storage of hazardous substances. Prescriptive controls are applied based on a matrix approach considering the land use category and flood hazard of the development site. The draft DCP was placed on Public Exhibition from 7th September to 5th October 2022. The draft DCP is further reviewed in Section 10.3.7.

10. FLOODPLAIN RISK MANAGEMENT MEASURES

The 2005 NSW Government's Floodplain Development Manual (Reference 1) separates risk management measures into three broad categories, as shown below.

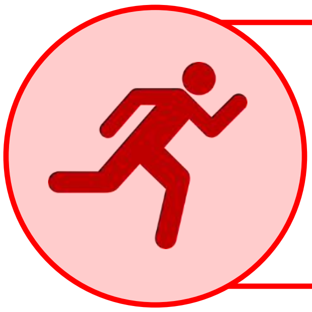


FLOOD MODIFICATION MEASURES

Modify the physical behaviour of a flood including depth, velocity and direction of flow paths. Typical measures include flood mitigation dams, retarding basins, channel improvement, levees, culvert or bridge modifications, flow path redirection and defined floodways. Pit and pipe improvement and even pumps may also be considered where practical.

PROPERTY MODIFICATION MEASURES

Modify the existing land use or development controls for future development. This is generally accomplished through means such as flood proofing, house raising or sealing entrances, strategic planning such as land use zoning, building regulations such as flood-related development controls or voluntary purchase / voluntary house raising.



RESPONSE MODIFICATION MEASURES

Modify the response of the community to flood hazard by educating flood affected residents about the nature of flooding so that they can make better informed decisions. Examples of such measures include provision of flood warning and emergency services, improved information, awareness and education of the community, and the provision of flood insurance.

A summary of the typical floodplain risk management measures that have been assessed for the current study is shown in Table 30. These options are discussed in detail in the subsequent sections.

Table 30: Floodplain Risk Management Measures

Flood Modification	Property Modification	Response Modification
Levees	Voluntary house raising	Flood warning
Temporary defences	Voluntary purchase	Flood emergency management
Channel construction	Flood proofing	Community awareness
Channel modification	Land use zoning	Improved evacuation access
Major structure modification	Flood planning levels	Flood plan / recovery plan
Drainage network modification	Flood planning area	
Drainage maintenance	Changes to planning policy	
Retarding basins	Modification to S10.7 Certificate	
	Flood Insurance	

10.1. Identification of Options and Assessment Methodology

This FRMS assessed a range of options for the management of flood risk within the Bayside West study area. The floodplain risk management option assessment process starts with identifying options that may be effective in mitigating flood risk. Consideration is given to flooding hot spots (either observed or modelled at properties and on roads) and areas with high property damages (either observed or using the flood damages assessment).

Several options were identified from the following sources:

- The existing FRMS&Ps that are available for the study area
- Bayside Council identified several options to investigate
- WMAwater identified some potential options while undertaking a site visit of the study area and upon review of the design flood modelling results

This identification process resulted in over 150 options to be investigated. Once these options were identified, an assessment process was undertaken, as outlined in Diagram 12. A high-level assessment was undertaken as a screening tool to eliminate options that would not be feasible or effective. Factors considered include:

- Physical and technical feasibility
- Support by the community and key decision-makers
- Compatibility with the management of other hazards and issues
- Effectiveness of reducing flood risk to the community
- Potential impacts on flooding to the existing community that cannot be offset
- Indicative costs and potential disbenefits
- Adaptability to address future risks

Property and response modification options that were not eliminated were progressed to the multi-criteria analysis stage. Flood modifications options that were not eliminated were subject to two intermediate steps. Firstly, a hydraulic assessment was conducted by undertaking flood modelling for the option to determine the extent of impact on flood behaviour. The 5% AEP and 1% AEP events were initially run for this assessment. Options that had a favourable outcome were then subject to a detailed assessment which included modelling of all design flood events, calculation of the reduction in flood damages and an estimation of the capital and ongoing maintenance costs to conduct a cost-benefit analysis. Flood modification options that had a cost-benefit ratio (CBR) close to, or greater than 1, were progressed to the multi-criteria analysis stage. The multi-criteria analysis assesses the relative benefits of options to determine the overall prioritisation of option implementation.

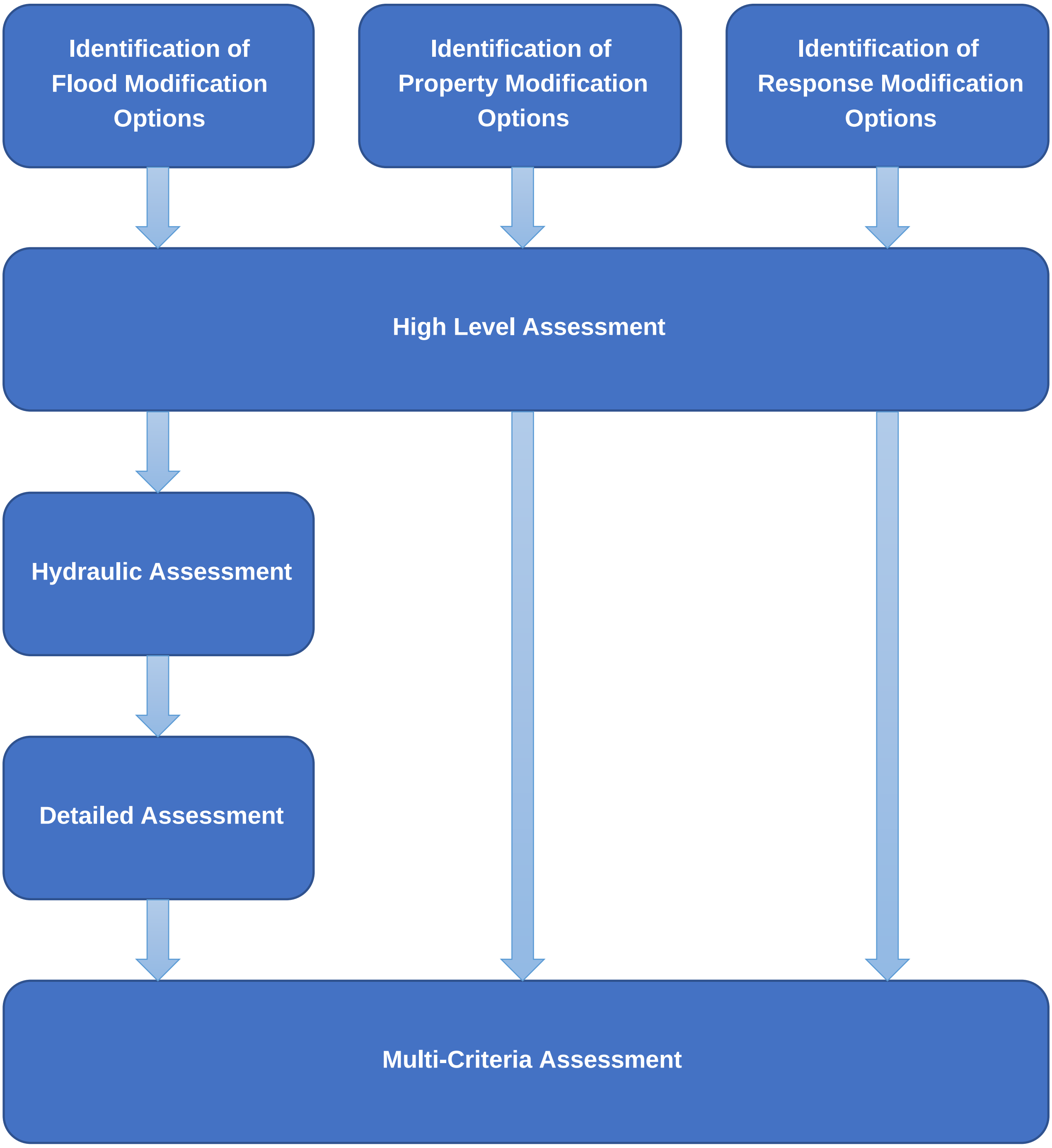


Diagram 12: Floodplain Risk Management Option Assessment Methodology

10.2. Flood Modification Options

Flood modification measures aim to modify the behaviour of a flood by reducing flood levels or velocities, or by excluding water from areas under threat. Typical measures involve structural works such as levee banks, retarding basins and drainage networks, and are generally installed to modify flood behaviour on a wider scale. Depending on the type of flood behaviour, spatial constraints and catchment conditions, different flood modification measures will be better suited to reducing flood risk than others. A key consideration when assessing potential flood modification options is ensuring that, in the pursuit of reducing flood risk in one area, the option (e.g. a basin or levee) does not adversely affect other areas.

A brief overview of some common types of flood modification measures appropriate for the study area is provided below. Other options, such as diversion channels, major channel modification, and dams are only relevant to larger riverine floodplains, and therefore have not been considered as part of this FRMS. Given the highly urbanised nature of the Bayside West study area, there are significant limitations to the construction of flood modification measures. The measures are required to be compatible with the existing land use, considering aspects such as land availability, land ownership, existing assets and constructability. It was noted that some of the flood modification measures recommended in the previous FRMS&Ps were not feasible (for example, 'upgrade drainage infrastructure in this area' or 'formalise overland flow path through these properties'). It was the aim of this FRMS&P to develop solutions that are practical and feasible, giving Council the means to target options that are achievable and would provide tangible benefits to reducing flood risk in the Bayside West area.

10.2.1. Types of Flood Modification Options

10.2.1.1. Detention Basins

Detention basins work by storing floodwaters during an event and controlling the release of the water. They can be built above or below ground and can be installed either as part of a new development to prevent increases in runoff rates or retrofitted into existing catchment drainage systems to assist in alleviating existing flood problems. Like the rest of the drainage system, detention basins have maintenance requirements.

The effectiveness of detention basins depends on their capacity, which for retrofitting options, can be significantly constrained by existing assets and development. However, they can also substantially reduce peak flows and are typically cost effective and easy to implement, provided there is a suitable location available (this is the most significant issue in an urban area). Hydraulic structures, such as low flow culverts at the bottom of a basin, can be used to restrict the discharge rates from the basin to a variable rate, dependent on rainfall volumes and the water level in the detention basin. Depending on the outlet design and operation, however, they can increase the duration of flooding by prolonging the release of floodwaters.

Whilst detention basins appear to be a simple and effective means of controlling runoff and water quality in urban catchments there are a number of potential issues that need to be considered, including:

- Basins only reduce flood levels downstream, not upstream. Unless considerable excavation is undertaken the flood levels at the site of the basin and possibly upstream will increase.
- Specific flood benefits of basins can be difficult to quantify, as it depends on the basin and storm characteristics. Small basins generally provide the greatest peak flow reduction in small more frequent events, when the basin volume is a high percentage of the total flood volume. However, in these events there is often only minor above floor damage or minor hazard to mitigate. In large events, basins (unless very big) are largely ineffectual from both a water quality and peak flow reduction perspective. Also, for multi-peaked rainfall events the basin may provide some benefit in the initial peak but very little when the second

or third peak arrives. The basin will be most effective when it is empty before the arrival of the storm burst, however, this is not always the case.
- Availability of land and appropriate topography – a significant area is needed to achieve the necessary storage capacity;
- Basin costs can sometimes be difficult to quantify at early planning stages, since significant excavation is usually required and the presence of utilities, services, rock, hazardous fill, etc. can significantly increase costs.
- The intentional impounding of water can produce hazardous depths within the basin, and public safety measures such as limiting the basin depth, shallow batters or fencing may need to be considered. Basins with dual purposes (such as playing fields) can increase the utility of the land, but can also pose safety risks. The risk of failure and release of water from the basin also needs to be considered.

All basins will provide some flow mitigation and water quality benefit. The benefit that can be achieved must be balanced against the loss of use of the land, the economic, social and environmental costs and concerns about liability if construction of a basin increases the flood hazard in the area.

10.2.1.2. Levees

Levees involve the construction of raised embankments between the watercourse and flood affected areas to prevent the ingress of floodwater up to a design height. Levees usually take the form of earth embankments but can also be constructed of concrete walls or similar where there is limited space or other constraints. They are more commonly used on large river systems, for example on the Hunter River at Maitland or at Lismore, but can also be found on small creeks in urban and rural areas and in overland flow situations where they usually take the form of smaller bunds. The levee needs to tie in with high ground to fully protect an area and the crest can also be used as an access path or road.

Once constructed, levee systems generally have a low maintenance cost although the levee system needs to be inspected on a regular basis for erosion or failure. Although a levee can keep out flood waters, flooding can occur within the levee due to local runoff being unable to drain. Flood gates, non-return valves and pumps are often associated with levees to prevent backing up of drainage systems in the area protected by a levee and/or to remove ponding of local water behind the levee. Management of the local drainage from behind a levee is a major design challenge for these structures. In addition, as the levee causes a displacement of water from one area of the floodplain to another the design requires consideration of hydraulic modelling to ensure the levee does not increase flood risk to an adjacent area.

The design height of the levee is the event for which it prevents flooding and usually also includes a freeboard to allow for settlement of the structure overtime or variations in flood levels due to the behaviour of the flood event, wave action from passing vehicles and effects of wind. Levees, however, can obstruct views of the waterway and provide those protected with a false sense of security, increasing flood risk in the event of overtopping or failure.

10.2.1.3. Temporary Flood Barriers

Temporary flood barriers include demountable defences, wall systems and sand bagging which are deployed prior to the onset of flooding and removed once the event has receded. Demountable defences can be used to protect large areas or specific buildings and are often used to assist current mitigation measures rather than sole protection measure (for example, fill gaps in levees or low points of road crossings, or to raise them as the risk of levee overtopping develops). A recent example is provided in Reference 46. The effectiveness of these measures relies on sufficient warning time, the availability of a workforce to install them, and suitable sites for storage when not in use. They are more likely used for mainstream fluvial flooding which have sufficient warning time and are not a suitable technical for smaller catchments with limited warning times. Temporary flood barriers may provide some benefit as a property-level protection measure, and this is discussed further in Section 10.3.3.

10.2.1.4. Road Raising

Depending on the topography of an area, floods can leave communities isolated by overtopping access routes. Raising roads to provide flood free access to such areas is commonly investigated in the floodplain risk management process as it can reduce evacuation time and improve accessibility as the flood progresses. Raised roads can also act like levees and increase flood levels unless culverts or overland bridge spans are upgraded as well (discussed below). Road raising may not only need to consider construction of the road, but also technical issues with existing services and infrastructure, as well as the possibility of diverting floodwaters into adjoining property or simply creating new flood paths across roadways.

10.2.1.5. Bridge and Culvert Modifications

Hydraulic controls such as bridges or major culverts on significant waterways can affect upstream flood levels due to backwatering effects. By increasing hydraulic conveyance, flood levels upstream of a structure can be decreased (and vice versa). Generally the most effective way of increasing hydraulic conveyance is by increasing the cross-sectional area (normal to the flow direction). This is often done by increasing the size of a culvert, widening a bridge or raising the deck level. However as flood levels are reduced upstream there is less temporary floodplain storage upstream and thus a slight increase in peak flow downstream. Reducing the structure capacity will increase flood level upstream and possibly reduce levels downstream.

10.2.1.6. Channel Modifications

Channel modifications are undertaken to improve the conveyance and/or capacity of a creek or drainage system. This includes a range of measures from straightening, concrete lining, removal / augmentation of structures, dredging and vegetation clearing. Channel modifications may reduce flood levels at the location of the works but need careful planning to ensure that the flood risk is not exacerbated downstream, or that the works do not create ongoing difficulties and expense with maintenance and erosion. In Bayside West, channels are typically concrete lined and heavily constrained by existing urban development, with little opportunity for improvement.

10.2.1.7. Channel Construction

New channels or flow path diversions can sometimes be an effective way to transfer and confine flow in a flooding situation and can aid in reducing peak flood levels, extents and duration, particularly in overland flow areas. In Bayside West, there is generally little scope to undertake this measure as there are existing development constraints, and where viable will often have already been undertaken. This measure may require additional land take, will generally involve significant costs and may have adverse environmental impacts.

10.2.1.8. Local Drainage Network Modification

The drainage network outside the creek and open channel system comprises Council's pit and pipe network. Local drainage systems typically reach capacity in an event equivalent to a 20% AEP event and excess runoff flows overland, potentially posing a threat to pedestrians, motorists, and if of sufficient depth, properties. Increasing the size of pipes or installing more inlet capacity (possibly to compensate for blockage) will have some benefit, decreasing the quantity of overland flow and thus flood levels. Hydraulic restrictions in the system affect upstream flood levels due to backwatering effects. However due to the relatively small percentage of flow carried by the pipe system in a large (1% AEP) event any improvements will have minimal benefit except in the smaller events (typically < 10% AEP). As such, these types of works will have minimal benefit in the large floods which generally are the cause of above floor inundation, however, may reduce the severity or frequency of nuisance inundation, particularly along roads, and could be beneficial to the community. It is noted that local drainage network modifications may fall into the purview of Council’s stormwater management rather than floodplain risk management, however they have still been investigated and modelled (where appropriate) as part of this study.

10.2.1.9. Drainage Network Maintenance

Maintenance of the drainage network is important to ensure it is operating with maximum efficiency and to reduce the risk of blockage or failure. Maintenance involves regularly removing unwanted vegetation and other debris from the drainage network, particularly at culverts and small bridges. Blockage has the potential to increase peak flood levels as water is unable to efficiently drain away. A proactive approach to drainage maintenance will help manage the risk of blockage occurring during a flood event. Installation of gross pollutant traps, particularly in proximity to at risk structures, can also ensure that the structures remain clear.

A common issue with all residents in flood liable areas is the perceived lack of maintenance within the creek or piped drainage systems. This perception arises as residents see the build-up of debris either before during or after the flood and think that this is a major contributor to flooding. Whilst debris build-up does contribute to increased flood levels the issue is more complex than may be first assumed for the following reasons:

- Council already has a routine debris removal program for the pit and pipe network.
- Council does undertake creek clearing if advised of major debris build up (fallen trees or similar).
- It is generally only during a storm event that there is a major release of debris into the drainage system due to fallen trees, wheelie bins swept into the creek, fences fall over or

water and wind sweeping debris from yards or other sources. Maintenance prior to the event does little to reduce these debris sources.

- Blockage of small culverts has little impact in large events as the percentage of flow in these structures is very small and thus has only a small impact on peak flood levels.

Structure blockage can be improved with the introduction of maintenance protocols or policies to ensure that drainage assets are effectively managed and regularly maintained. These policies aim to ensure that assets will perform when they are needed. Alternatively the implementation of trash racks or bollards upstream of structures could be considered by Council to keep structures free of debris. The cost of trash racks or bollards varies greatly depending upon the nature of the structure.

Some Councils have introduced silt and vegetation management plans to address this issue. However it is acknowledged that these schemes are costly for Councils to operate and must be continued in perpetuity to be effective. These schemes are generally welcomed by the residents who appreciate that Council is listening and addressing their concerns.

10.2.2. Flood Modification Options Rejected with High Level Assessment

The high-level assessment was undertaken as a screening tool to eliminate options that would not be feasible or effective. Based on the outcome of this assessment, the option was either not pursued further, or was subject to a hydraulic assessment. This section records those options that were not pursued further. These options fall into one of three categories:

1. Previous FRMS&P options that were previously rejected
2. Previous FRMS&P options that were implemented
3. Additional options that have been assessed to not be viable

Each of these are discussed in the following sections, as well as a brief discussion on the Dominey Reserve Detention Basin option which was also rejected with a high-level assessment.

10.2.2.1. Previous FRMS Flood Modification Options Rejected

Several flood risk mitigation options were investigated but rejected in the previous FRMS&P's. Each of these were reviewed and it was found that the reasons for rejection were still valid, and hence these options were not investigated further in the current study, but are documented here for completeness. These are listed in Table 31 and shown in Figure 31. Further information about these options can be found in the previous FRMS&P reports (see Section 2.1.1).

Table 31: Previous Flood Modification Measures that were rejected at the FRMS stage

Map ID	FRMS&P Name and Location	Description/Comment
Wolli Creek, Bardwell Creek, Bonnie Doon Channel and Eve Street/Cahill Park Catchments		
1*	Canterbury Golf Course Detention Site	In Canterbury City Council, rejected by Canterbury City Council.
2	Kingsgrove Avenue Reserve Detention Site (near Beaumont St), Kingsgrove	Would raise upstream water levels, no downstream benefit. Occupied by soccer fields.
3	St Kilda St Park Detention Site St Kilda St near Oliver St, Bexley North	No buildings benefited downstream.
4	Stots Reserve Detention Site Barnsbury Grove Bardwell Park	No buildings benefited downstream.
5*	Olds Park Detention Site Forest Road Penshurst	In Hurstville City Council, downstream benefits are small.
6*	Penshurst Park Detention Site King Georges Road Penshurst	In Hurstville City Council, downstream benefits are small.
7*	Beverly Hills Park Detention Site Bundara St Kingsgrove	In Hurstville City Council, raises upstream flood levels.
8*	Hurstville Oval Detention Site Gordon St, Hurstville	Upper catchment, limited downstream benefit.
9	Bexley Road Detention Site Bardwell Creek at Bexley Road	On main creek, only 3 properties benefit downstream.
10	Bexley Park Detention Site Henderson Rd, Bexley	Small catchment, no downstream benefit.
11	WC1 Levee Kingsgrove Ave, Kingsgrove	700 m levee. Low CBR and flood impacts.
12	WC1 Footbridges Bonalbo St, Kingsgrove	Raise 3 footbridge crossings at Kooreela, Bonalbo and Flatrock. Low CBR.
14*	WC1 Detention Rosebank Ave, Kingsgrove	Excavated basin. Within Hurstville Council and benefit restricted to Hurstville LGA.
15	WC2 Levee Slade Rd, Bardwell Park	Levee to protect RSL club. Not economical.
17	WC3 Weir and Footbridge Henderson St, Turrella	Remove weir, raise footbridge. No benefit to flooding.
18	WC3 Detention Basin Henderson St, Turrella	High cost, little benefit. It would be difficult to get a basin configuration that provides substantial benefit without impacting other areas. Not justifiable for flood mitigation alone.
19	BC1 Footpath Raising Bridge St, Bexley	Raise eastern footpath to prevent overland flow from channel. Low CBR. Other Bridge Street options investigated.
23	BC2 Enlarge Road Culverts Preddys Rd, Bexley North	Enlarge culverts at Oliver St, Coveney St and Preddys Road. Large flood reductions, but low CBR as few properties flooded in the 1% AEP event.
24	BC3 Raise Coping Canonbury Grove, Bexley North	Raise channel coping by 0.6 m. Low CBR.
25	BC4 Levee Bexley Rd, Bexley	140 m long levee at rear of properties. Low CBR.
27	BC5 Levee Hillcrest Ave, Bardwell Valley	Raise levee by 2 m (0.5 m freeboard) over 120 m. Significant social problems and increased risk in large flood events.
31	BC5 Lower Golf Course Pile St, Bardwell Valley	Channel 10 m wide, 1-2 m below current level. Adverse flood impacts, low CBR.

Map ID	FRMS&P Name and Location	Description/Comment
34	BC6 Levee The Glen Rd, Bardwell Valley	180 m long levee to protect No. 25. Low CBR.
38	BC6 Levee Hannam St, Bardwell Valley	Restricts access, local drainage issues, tie in is difficult, Low CBR.
39	BC6 Widen East Hills Line Bridge Hannam St, Bardwell Valley	Bridge widening from 10.5 m wide to 15 or 20 m. Not viable for flood mitigation only – very high cost and benefits are limited to immediately upstream.
43	BDC Bonnie Doon Channel Arncliffe St, Wolli Creek	Options include covering the channel, re-construct channel, pressurised drainage or raising channel walls. This is further investigated in Section 10.2.3.10.
47	BD2 Upgrade Pipes Hirst St, Arncliffe	Divert flows crossing Wollongong Rd/Hirst St to Wollongong Rd branch or Hirst St/Denison St branch. Would exacerbate flooding in East St.
48	BD2 Major/Minor System Walters St, Arncliffe	Purchase 11 houses and create pipe and overland flow system from Dowling St to Bonar St. Very high cost.
51	BD2 Increase Openings Allen St, Arncliffe	Opening arches that are bricked up. No significant impact on upstream industrial buildings affected in the 1% AEP event.
54	EC2 Additional Pipe Marsh St, Arncliffe	Additional pipe under Marsh St draining to Golf Course. No houses flooded – not economically viable.
55	EC2 Channel Valda Ave, Arncliffe	Excavate channel from Valda Ave to Marsh St Underpass. No houses flooded – not economically viable.
59	EC3 Overland Flowpath Charles St, Arncliffe	Overland flow path on the downstream side of Charles Street. Not economically viable – requires property acquisition.
Spring Street Drain, Muddy Creek and Scarborough Ponds Catchments		
114	2A Francis Ave Levee Francis Ave, Brighton-Le-Sands	Very low CBR, and updated modelling suggests Francis Ave is not affected by Muddy Creek flooding up to the 1% AEP event.
115	2C West Botany Street and Bay Street Bridge Raising West Botany St, Rockdale	Bridge works alone not recommended – would need channel upgrades as well. There is a significant cost to undertaking a full upgrade that does not provide significant benefit to properties.
116	3C Industrial Area Levee Chapel St, Rockdale	Causes unacceptable increase in flood levels.
117	4A Princes Highway Bridge and Approaches Upgrade Princes Hwy, Rockdale	Reduce traffic hazard, but likely to increase downstream flood levels.
118	5A Frys Reserve Detention Basin Enlargement Warialda St, Kogarah	Very expensive and not practical due to excavation in rock.
119	5D AE Watson Reserve Detention Basin Warialda St, Kogarah	Ineffective as it controls too small a proportion of the catchment area. Even if all flow from the reserve was captured, the uncontrolled flows from the remainder of the catchment are still sufficient to cause flooding in the main problem areas.
120	6B Covered Channel Union St, Kogarah	Covering the open channel is ineffective and will not prevent flooding.

Map ID	FRMS&P Name and Location	Description/Comment
127	10A Channel Upgrade Cook Park Trail, Banksia	Downstream channel improvements and wetland in Barton Park. No significant affect on flooding.
130	11B Covered channel Spring St, Banksia	Cover channels downstream of sewer. Will not solve flooding problems.
134	13B Formalise Flowpath Princes Hwy, Arncliffe	Upgrade of overland flowpath through private property would be difficult, not considered necessary.
138	18B Phillips Road Levee Phillips Road, Kogarah	Levee 1.8 m high. Protects 5 industrial and 1 residential property with low CBR.
139	17B Second Outlet for Scarborough Ponds Bath St, Monterey	New outlet from Scarborough Ponds to ocean. Largest size 2 x 2.4 m x 1.2 m. Reduces 1% AEP flood level by 0.3 m with low CBR.
140	18A Amplify Outlet for Scarborough Ponds Florence St, Ramsgate Beach	Amplify existing outlet by adding 2 x 2.4 m x 1.2 m culverts. Reduces 1% AEP flood level by 0.4 m with low CBR.
141	18C Ramsgate Road Overland Flowpath Ramsgate Rd, Ramsgate Beach	Formalise overland flowpath for events >1% AEP. Only just activated above 1% AEP. Most likely have adverse impacts through Sans Souci.
Sans Souci Catchments		
88	1A Channel Upgrade Alfred St, Sans Souci	Widen open channel in Alfred St. Limited benefits as flows in the channel are controlled by the upstream incoming pipes.
91	1D Enclose channel Alfred St, Sans Souci	Cover Alfred St open channel. No benefit.
94	2A Levee Horbury St, Sans Souci	New levee at rear of properties. Limited benefit as there are very few properties affected up to the 1% AEP event from Bado-berong Creek.
97	2D Flood Gate Riverside Dr, Sandringham	Install new tidal flood gate at Riverside Drive. Unacceptable environmental impact.
102	3B Diversion Moss St, Sans Souci	New 1800 mm diameter pipe along Moss St / Fountainbleau St / Brantwood St to Botany Bay. Very high cost.
103	3C Flood Gate Lawson St, Sans Souci	New flood gate on d/s headwall of Lawson St open channel. Adverse environmental impact, limited flood benefit as there are no properties directly affected by the Lawson Street channel.

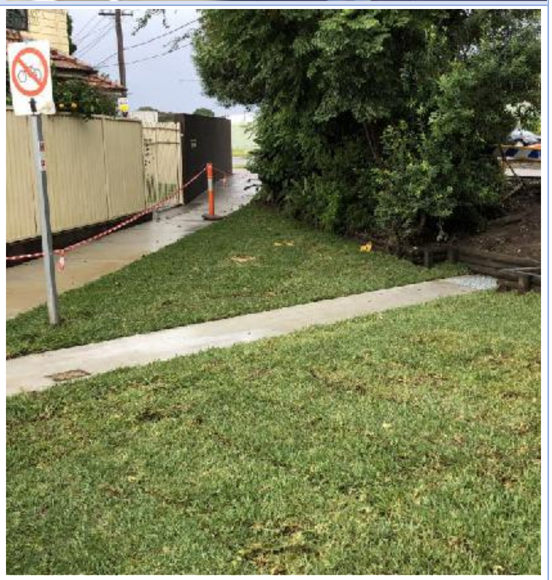
* Not shown on map – not within Bayside Council LGA

10.2.2.2. Previous FRMS Flood Modification Options Implemented

Several flood risk mitigation measures recommended in the previous FRMP's have now been implemented. These are documented here for completeness and were not investigated further. The structural measures implemented are listed in Table 32 and shown in Figure 32.

Table 32: Previous Flood Modification and Structural Measures that have been implemented

Map ID	Name and Location	Description	Comment	Photo[1]
Wolli Creek, Bardwell Creek, Bonnie Doon Channel and Eve Street/Cahill Park Catchments				
26	BC4 Flow Deflector Bardwell Creek at Veron Road	Deflector at 21 Veron Rd	Shotcrete wall observed on site.	
32	BC5 Debris Deflector Bardwell Valley Gold Course	Debris deflector on golf course culverts	Large debris deflector observed on site.	
33	BC6 Pile St Local Works	Minor earthworks in golf course to redirect flow into creek	Has been implemented.	

<table>
<tr><th>Map ID</th><th>Name and Location</th><th>Description</th><th>Comment</th><th>Photo[1]</th></tr>
<tr><td>37</td><td>BC6 House Raising</td><td>Hannam Street House Raising</td><td>Implemented through redevelopment of the site..</td><td></td></tr>
<tr><td>40</td><td>NA1 Flap Gate Lusty St Wolli Creek</td><td>Flap Gates on 4 culverts under railway line</td><td>Has been implemented.</td><td></td></tr>
<tr><td>41</td><td>NA1 Drainage Lusty St</td><td>Pressurised Drainage system</td><td>Has been implemented.</td><td></td></tr>
<tr><td>42</td><td>NA1 Re-development Lusty St</td><td>Redevelopment of this area aims to reduce flood hazard, including filling</td><td>Has been implemented through planning controls and redevelopment.</td><td></td></tr>
<tr><td>44</td><td>BD1 Re-development Arncliffe St Wolli Ck</td><td>Redevelopment reduces flood hazard</td><td>Has been implemented through planning controls and redevelopment.</td><td></td></tr>
<tr><td>56</td><td>EC2 Raised Kerb Valda Ave, Arncliffe</td><td>Raised kerb to deflect water from No. 32.</td><td rowspan="2">Connect Sydney has undertaken works at Valda Avenue including extension of an existing culvert to connect the Valda Street drainage network to the Marsh Street drainage network via a 375 mm pipe, regrading of a footpath to fall away from a property and provision of a v-drain to direct water to the re-established pit at the end of Valda Avenue.</td><td rowspan="2"></td></tr>
<tr><td>57</td><td>EC2 Local inlet works Valda Ave, Arncliffe</td><td>Reconnect the stub to the pit opposite No 32 together with lifting the pit.</td></tr>
</table>

Map ID	Name and Location	Description	Comment	Photo[1]
60	EC3 Stormwater Upgrade Charles St Arncliffe	Four design options considered for upgrading drainage	Pipes have been upgraded, plans provided by Council.	
Spring Street Drain, Muddy Creek and Scarborough Ponds Catchments				
62	3A Bridge Raising	Raise bridge over concrete channel.	New crossing has been constructed near Tennis Centre.	
63	3B Levee Rockdale Plaza Drive Tennis Centre	Construct new levee along northern channel bank	Brick wall levee constructed.	
Sans Souci Catchments				
92	1E Upgrade Culverts Sanoni Ave Sailing Club	Amplify existing culverts at Georges River Sailing Club	Has been constructed.	
93	1F Detention Pemberton Reserve Chuter Ave Sans Souci	New detention basin in Pemberton Reserve	Has been constructed	

1 Photo taken on site by WMAwater, or sourced from Google Street View

10.2.2.3. Additional Flood Modification Options Rejected with High Level Assessment

The remaining options (those not implemented or rejected in a previous FRMS as outlined above), were subject to a high-level assessment. Options that were rejected at this stage are listed in Table 33 and shown in Figure 33. These options were typically from the existing FRMS's.

Table 33: Options Rejected at High Level Assessment

Map ID	Name and Location	Description	Comment	Photo[1]
Wolli Creek, Bardwell Creek, Bonnie Doon Channel and Eve Street/Cahill Park Catchments				
13	WC1 Footbridges Rosebank Ave Kingsgrove	Replace footbridge railings at Kooreela, Bonalbo and Flatrock.	Site inspection and data review indicated obstruction from handrails is likely to be a minor influence on flood levels.	
21	BC1 Detention Basin Stoney Creek Road Bardwell Creek	2 or 3 shallow basins in Bexley Golf Course with wall at Stoney Ck Rd. 2 Options presented.	Shallow basins unlikely to provide significant downstream flood benefit. To be investigated as part of option FM01 (Section 10.2.4.4) and could have a dual water quality/reuse purpose.	
28	BC5 Internal Drainage Hillcrest Ave Bardwell Valley	Additional pits and pipes behind levee at Hillcrest Avenue	Hillcrest Avenue has a stormwater (pit and pipe) network that was not previously recorded in Council's asset database. Upgrade of these pipes is unlikely to provide any significant benefit to the low lying area of Hillcrest Avenue.	

Map ID	Name and Location	Description	Comment	Photo[1]
35	BC6 Bardwell Road Upgrade Bardwell Rd Bardwell Park	Upgrade culverts and raise road by 1m	Upgrading Bardwell Road crossing is unlikely to have a significant upstream benefit - there are not many properties affected by mainstream flooding at this location.	
45	BD2 Detention Basin Arncliffe Park, Arncliffe	2 options considered	Arncliffe Park synthetic field constructed, thus detention basin no longer feasible.	
53	EC1 Improve Drainage Gertrude Street, Wolli Creek	Improve maintenance or upgrade drainage to improve traffic disruption on Gertrude Street.	Modelling shows that Gertrude Street is affected by high Cooks River levels. Drainage is significantly constrained by tailwater conditions. Drainage upgrades will not have any benefit in large flood events.	
Spring Street Drain, Muddy Creek and Scarborough Ponds Catchments				
64	5B Channel Upgrade Wolseley St Bexley	Channel amplification or covering of open channel	Option lacks sufficient detail in previous FRMS. Channel works to be investigated as part of new catchment-wide option (see Section 10.2.5.4).	
68	8B/8C/8D Channel/pipe Upgrades Edgehill St Carlton	Upgrade pipes, raise walls and formalise flow path with easements	Options lack sufficient detail. Localised works to be investigated as part of new catchment-wide option (see Section 10.2.5.4).	

Map ID	Name and Location	Description	Comment	Photo[1]
72	9B/9C Flowpath management Connemarra St Bexley	Formalise overland flow path with easements and upgrade drainage	Options lack sufficient detail. Existing urban development makes this very difficult to implement.	
73	14A Detention Basin Gardiner Park Banksia	New detention basin in Gardiner Park	This option was ruled out due to high costs and relatively low benefit by a Cardno feasibility study in 2001. Gardiner Park is currently being upgraded.	
75	14B/C Flowpath management Godfrey St Banksia	Formalise overland flow path with easements and upgrade drainage	Options lacks sufficient detail. Existing urban development makes this very difficult to implement.	
76	18E Drainage Improvements Scarborough Park Kogarah	Drainage improvements near Phillips Rd targeted at minor storm events	Scarborough Pond level is too high to consider works in this area. There is little affected by local drainage in this area. It is more efficient to allow overland flows to discharge to the park and Scarborough Ponds.	
77	3D Drainage upgrades The Strand Rockdale	Local drainage upgrades	Water spills out of the channel in this location in the 5% AEP event, so local drainage upgrades will not be effective. The levee (ID 63) has been constructed to protect these properties.	

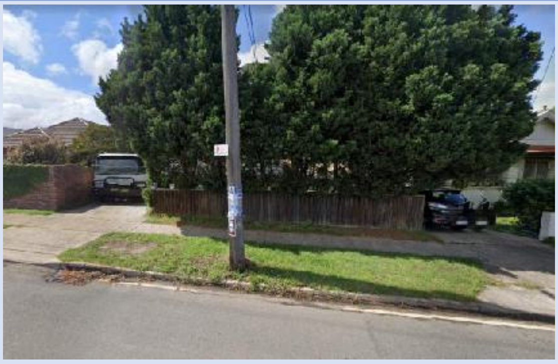
Map ID	Name and Location	Description	Comment	Photo[1]
78	4B Covered channel Rockdale Plaza Drive Muddy Creek	Cover open channel at McDonalds	This will have limited benefit to flooding. Mainstream flooding upstream of Princes Highway is largely contained. Would not be feasible to contain all flows within covered channel without major afflux further upstream.	
79	4C Bridge Upgrade Harrow Rd Kogarah	Raise approaches and new bridge	It would require significant works and there would be no benefit upstream (Hogben Park). It is also unlikely to reduce flood levels in the Frys Reserve detention basin and Warialda St/Hegerty St would still be flooded. Only benefit would be removal of short duration flooding across Harrow Road itself, on rare occasions.	
81	4E Flowpath management Subway Rd Rockdale	Overland flowpath improvement at Subway Road	Water ponds on Subway Road. Overland flow path management unlikely to result in significant improvements. Toyota site currently allows overland flow.	
82	5F Drainage upgrades Caledonian St Bexley	Trunk drainage upgrades	Major trunk upgrade of pipes through residential lots is not feasible. This will only be improved through redevelopment (upgrade pipes, allow overland flowpaths and development compatible with flood hazard)	

Map ID	Name and Location	Description	Comment	Photo[1]
83	6A Channel Upgrades Warialda St Kogarah	Widen concrete channel	Increasing channel capacity in the Frys Reserve detention basin area is not likely to have a significant benefit. The outlet from the detention basin under the railway line is the key hydraulic control in this location.	
84	11D Drainage Upgrades Spring St Banksia	Upgrade stormwater drainage	Widespread upgrades of the stormwater network are costly and not feasible with current development constraints.	
86	18D Outlet modification Grand Pde Ramsgate Beach	Install automatic tidal gates to prevent backflow into Scarborough Ponds.	To be considered as part of a catchment-wide option (see Section 10.2.5.6).	
87	2B Levee Bruce St Brighton-Le-Sands	Levee for Bruce Street	Bruce Street is not modelled to be affected by flooding from Muddy Creek up to the 1% AEP event.	

Map ID	Name and Location	Description	Comment	Photo[1]
122	6D Drainage Upgrade Warialda Street Kogarah	Upgrade to 10% AEP standard	Lacks detail in FRMS. Drainage upgrade will be extremely difficult due to crossing private property.	
123	7A Channel Widening Taylor Street Kogarah	Channel widening	Local benefit only, and potentially no benefit to properties.	
125	7C Drainage Upgrade Paine Street Kogarah	Upgrade drainage to 10% AEP standard	Will not reduce mainstream flooding, which is the primary concern in this location.	
128	10B Remove Bridge Eve Street Banksia	Remove access bridge.	Will only have a minor affect on flood levels. It is understood that this bridge will be replaced with proposed redevelopment in near future.	
129	11A Bridge Upgrade West Botany Street Banksia	Upgrade bridge crossing and channel upgrades to improve conveyance.	Minor affect on flood levels, very costly (CBR<0.04)	

Map ID	Name and Location	Description	Comment	Photo[1]
131	11C Diversion Channel Lywen Crescent Banksia	Lywen Cres diversion channel - relief drain in road corridor, continuing under West Botany St and into wetland (Opt 10A)	High costs for small benefits (60mm reduction), CBR=0.12	
132	12D Formalise Flowpath Lennox Street Rockdale	Formalise Overland Flowpath from Bestic St to Tabrett St	Not practical. Easement costs not included and CBR<0.2	
133	13A Drainage Upgrade	Drainage upgrade to 5% standard	Not practical. Easement costs not included and CBR<0.07	
137	17A Colson Crescent Levee Colson Crescent Monterey	Levee 2m high at rear of properties, 600m long. Need local drainage upgrade as well.	Difficult to tie into high ground. Levee would need to extend along length of 600m. 2m high, protects 25 houses. CBR= 0.12	
212	Trunk Drainage Upgrade Short Street Arncliffe	Possible upgrade to trunk drain constriction at Short St, depending on existing configuration.	While several CCTV reports were available for the trunk drainage lines upstream of the Short Street open channel, it is still unclear the exact configuration. From what was observed on site, the trunk drainage lines are not constricted at this location.	

Map ID	Name and Location	Description	Comment	Photo[1]
Sans Souci Catchments				
89	1B Flood Gate Peter Depena Reserve Dolls Point	Continue operation of sluice gate	Sluice gate could not be seen during site visit. It appears to have been removed.	
95	2B Culvert Upgrade Russell Avenue Sans Souci	Increase Russell Avenue size on Drain No. 2	Limited benefit upstream and may increase affectation downstream. Very costly.	
96	2C Culvert Upgrade Ida Street Sans Souci	Increase Ida Street size on Drain No. 2	Limited benefit upstream and may increase affectation downstream. Very costly.	
99	2F Overland flowpath Minton Avenue Sans Souci	Formalise flowpath or improve pipe drainage	This does not seem feasible given the existing development, including the utility (substation?) adjacent to Noel Seiffert Reserve. Overland flow depths are relatively shallow and manageable through development controls.	

Map ID	Name and Location	Description	Comment	Photo[1]
100	2G Overland flowpath Primrose Avenue Sandringham	Formalise flowpath or improve pipe drainage	Not likely to be possible due to existing development. Overland flow depths are relatively shallow and manageable through development controls.	
101	3A Channel Upgrade Lawson St Sans Souci	Widen channel	Section of channel parallel to Lawson Ave was widened and lined with rock on western side. Culverts at Meriel St was replaced (not enlarged). Channel capacity appears to be reasonable. Further upgrades unlikely to impact on problem area in the vicinity of Kendall St and Ida St. Kendall Street Reserve was investigated as a separate option (see Section 10.2.3.19).	
105	3E Overland flowpath Rocky Point Rd Sans Souci	Formalise flowpath or improve pipe drainage	Not possible due to existing development. Overland flow depths here are relatively shallow and manageable through development controls. Will need to be resolved by future planning and redevelopment.	

Map ID	Name and Location	Description	Comment	Photo[1]
106	3F Overland flowpath Rocky Point Road Sans Souci	Formalise flowpath or improve pipe drainage	Not possible due to existing development. Overland flow depths here are relatively shallow and manageable through development controls. Will need to be resolved by future planning and redevelopment.	

1 Photo taken on site by WMAwater, or sourced from Google StreetView

10.2.2.4. Dominey Reserve Detention Basin

This option consists of construction of a detention basin in Dominey Reserve – recommended as a high priority option in the previous FRMS (Option 5C, Reference 6). The reserve is in Bexley and bounded by Caledonian Street, Verdun Street, Rawson Avenue and private properties. Council has already purchased and cleared several properties on Rawson Avenue and Verdun Street, expanding the grassed area of Dominey Reserve. The Dominey Reserve detention basin investigation was undertaken by BMT for Council (Reference 19). The cost-benefit ratio was estimated to be 1.3. At the time of this FRMS&P, Council and Sydney Water were investigating the design of a detention basin in this area.

The details of the current basin design were unknown, however an indicative basin was modelled with the updated TUFLOW model. An embankment was placed along Rawson Avenue and Verdun Street, with a crest level of 34.0 mAHD, and a lowered spillway section at 33.6 mAHD. No other modifications were made. The changes in flood levels for the 5% AEP and 1% AEP design flood events are shown in Figure 34 and Figure 35, respectively. In the 5% AEP event, the reduction in flood level on the downstream flow path is typically between 0.1 and 0.2 m, with a 1 m reduction at Queen Victoria Street. There are reductions downstream of this to Frys Reserve, where the decrease is just less than 0.1 m. In the 1% AEP event, the reduction in peak flood levels downstream of the basin are typically up to 0.1 m, although these reach 0.6 m in the vicinity of Wolseley Street.

At the Bayside FRMC meeting in June 2022, Sydney Water presented the flood modelling results and preliminary dam break assessment for the Dominey Reserve detention basin design. The detailed analysis showed that the detention basin would have minimal benefit and the dam break assessment indicated that Dams Safety NSW would likely declare the proposed storage basin as a ‘dam’, adding a further complication. The cost of the design and construction of a declared dam would be significant, and monthly routine inspections and audit requirements would be costly. It is also noted that the consequence of a dam failure would be significant. FRMC members also raised concerns about the visual amenity of the embankment and issues such as park useability and water logging. The FRMC recommended that Council not proceed with the detention basin option at Dominey Reserve as it would not provide sufficient reduction in flood levels and would have significant construction and maintenance costs which would outweigh the benefits.

10.2.3. Flood Modification Options Rejected with Hydraulic Assessment

The hydraulic assessment stage involved undertaking flood modelling for the option to determine the extent of impact on flood behaviour. The 5% AEP and 1% AEP events were initially run for this assessment. The results of this assessment were used to determine if the option provided any substantial benefit to flooding. A substantial benefit was considered to be where flood levels were reduced by approximately 0.1 m or more, although this also depends on the nature of the flooding and the extent of the reduction and the properties affected. Based on the outcome of this assessment, the option was either not pursued further, or was subject to a detailed assessment. Options that were rejected at this stage are discussed below and shown in Figure 36.

10.2.3.1. Evatt Park and Flynns Reserve Detention Basin

Option Description

This option involves construction of detention basins in Evatt Park and/or Flynns Reserve. This was recommended as a low priority option in the previous FRMS&P, with an estimated CBR of less than 0.05.

A detention basin in Evatt Park (Photo 8) would be difficult to construct, as the park is quite steep. This would require substantial excavation or a high bund to contain water. A detention basin in Flynns Reserve (Photo 9) would most likely require excavation. There is a shallow trunk drainage line that runs through the park that may be a covered concrete channel. This would need to be discharged into the basin and then the outlet of the basin re-configured to discharge into the open channel downstream. There are assets in the park, including a large GPT that would need to be avoided. There is a flow path from Evatt Park to Flynns Reserve that follows the trunk drainage line that crosses Iliffe Street.

Photo 8: Evatt Park, looking upstream

Photo 9: Flynns Reserve, looking upstream

Option Impacts

A detention basin in Evatt Park was modelled with a bund at the downstream end with a crest elevation of 43.5 mAHD (approximately 1.5 m high). The decreases in downstream flood levels in the 1% AEP event were less than 0.1 m (typically around 0.05 m) and benefited very few houses. The modelled impacts are shown in Figure G1.

A detention basin in Flynns Reserve was modelled by maintaining the low point of the park at approximately 35.8 mAHD, excavating upstream of this and constructing a bund with a crest level of 37.5 mAHD (maximum depth 1.7 m). Water from the basin was discharged into the existing stormwater system (and to the open channel). The 1% AEP overland flows were able to be contained within the basin, with a depth of up to 0.5 m. There are some minor increases within the channel immediately downstream due to the changed configuration (in the order of 0.01 m). The benefit downstream of this, however, is minimal, with reductions of 0.01 to 0.02 m down to Bexley Golf Club. The modelled impacts are shown in Figure G2.

Conclusion

The reduction in flood levels (up to 0.05 m) and the extent benefited is not considered to be worth the construction of one or both basins. There would be substantial works required to construct the basins, including augmentation of the existing stormwater network and potential difficulties with landscaping and dam safety (if constructed above ground). Thus, these two basins were not considered viable options to pursue further.

A smaller bund was also investigated following the outcomes of these basins (see Section 10.2.3.2 below).

10.2.3.2. Flynns Reserve Swale or Bund

Option Description

Based on the hydraulic outcomes of constructing a basin in Flynns Reserve, an alternative option was developed involving the construction of a small bund on the northern side of the reserve to contain overland flows to the reserve and prevent inundation of up to five properties on Ade Street that back onto the reserve. The bund would only need to be 0.2 m high to prevent overland flows from entering these properties. This could be constructed as a raised access track that is already in use for trucks to access the GPT at the bottom end of the reserve. An alternative may be excavating a small swale along the boundary.

Option Impacts

A bund 0.5 m high was modelled along this path for this option. This prevents overland flows from entering properties bordering Flynns Reserve, although two properties are still affected by water breaking out of the open channel in the 1% AEP event. There are also changes to the behaviour of the breakout flow, with the bund causing minor (0.02 m) increases in flood levels in the 1% AEP event. This may be due to the extent and height of the bund tested and a smaller bund may have reduced impacts, although this is approaching the limits of what is considered reasonable to model in this catchment-wide flood model. The modelled impacts are shown in Figure G3.

Conclusion

This option was not considered worthwhile, as the existing flooding on these properties is very shallow (less than 0.2 m deep) and unlikely to cause above floor flooding. There are also potential complications with maintaining existing breakout behaviour from the channel in order to achieve no adverse impacts, although this is most likely due to the extent and height of the tested bund. Council is not aware of any flooding complaints from overland flows from Flynns Reserve at these properties. Local drainage works may be undertaken if these properties are subject to frequent nuisance flooding, and a small bund may be viable to direct water into the channel. This option was not pursued further as a flood mitigation option.

10.2.3.3. Bridge Street Channel Works

Option Description

This option involves works on Bridge Street and/or in the stormwater channel that runs along the western side of the road. Some options for this area included:

- Regrading of Bridge Street so that it falls toward the channel
- Raising the walls of the channel adjacent to Bridge Street to contain flows
- Covering the open channel from Unwin Street to Moore Street

These options can be seen in Diagram 13. It is noted that the previous FRMS identified that raising of the Bridge Street kerb/footpath on the eastern side of the road was not a viable option.

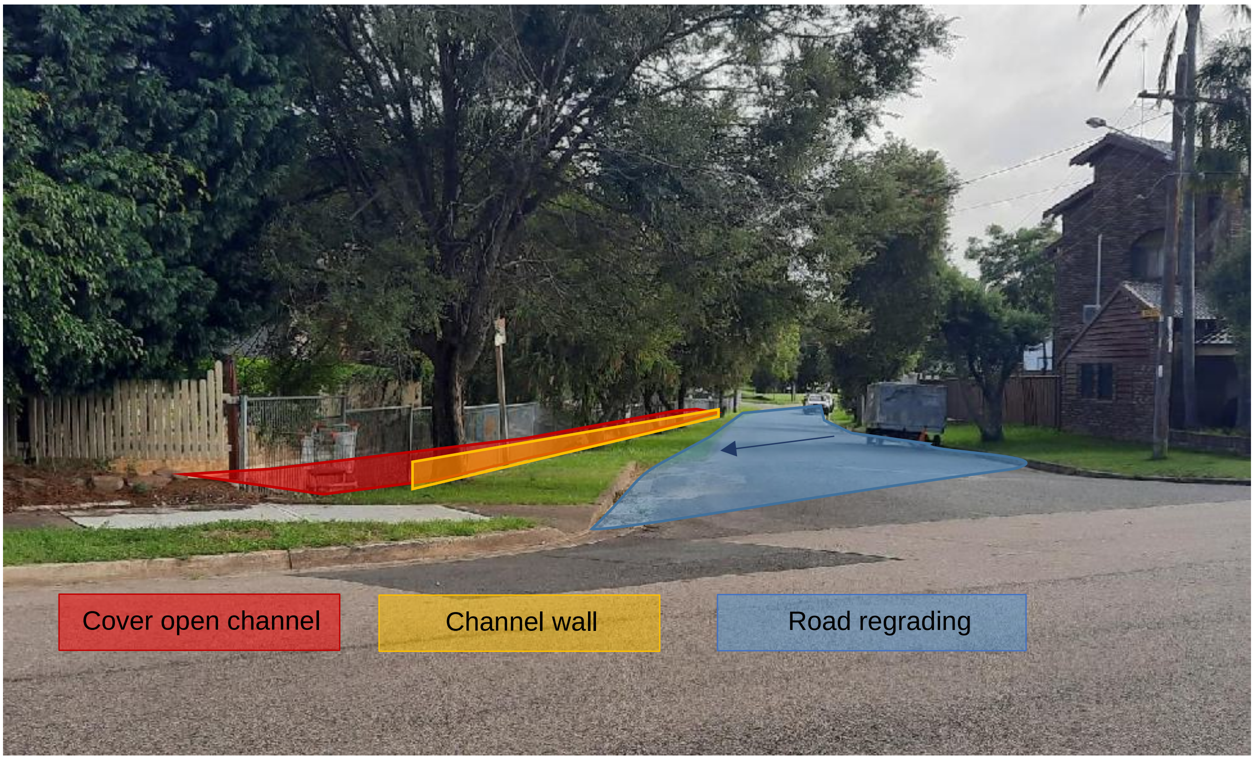


Diagram 13: Potential Flood Mitigation Works at Bridge Street

Option Impacts

The options above were tested for the 1% AEP event. The regrading of the road did not have any affect on flood levels at properties, provided the cut and fill is balanced. The covering of the open channel from Ada Street to Moore Street resulted in more flows overtopping Ada Street and flowing overland through the residential areas down to Moore Street. By installing walls on the channel from Ada Street to Moore Street, spills from the channel were minimised, and there was a benefit to areas between Unwin Street and Moore Street. Some overland flows, however, were unable to return to the channel in the vicinity of Ada Street, resulting in increased flood levels adjacent to the channel. Following optimising the location of the walls, the impact is shown in Figure G4. This shows that there are some increases in flood levels in the channel, which affect some areas upstream of Unwin Street. There are decreases in flood levels on Unwin Street and on Bridge Street, up to 0.2 m. The decrease at properties, however, is less than 0.1 m.

Conclusion

This option was not considered feasible, as the benefit to flooding is minimal compared with the extent of works required. The option would also require careful consideration of overland flows and how they can get into the channel and the altered hydraulics of the open channel. An alternative option for Bridge Street was investigated and progressed to the MCA stage.

10.2.3.4. Upgrade of Bardwell Valley Golf Course Culverts

Option Description

This option involves upgrading the existing twin 2.3 m diameter culverts in the Bardwell Valley Golf Course. The open channel ends in the golf course at approximately Sackville Street and flows are conveyed underground through the culverts (shown in Photo 10). The open channel recommences at Pile Street. The upgrade of the culverts would involve constructing new culverts adjacent to the existing structures. This option was investigated in the previous FRMS. It was rejected primarily due to the high costs, considering the culverts are approximately 4 m underground.

Photo 10: Bardwell Valley Golf Course Culverts

Option Impacts

This option was modelled for the 1% AEP event by duplicating the existing structure to a total of 4 x 2.3 m diameter pipes. The peak flood levels on the upstream side decrease by up to 2 m within the golf course. This decrease extends up to Hillcrest Avenue, where water levels inside the levee decrease by approximately 1.5 m. The benefit extends upstream to Bexley Road. The major benefit is only for the few houses at the lower end of Hillcrest Avenue. Downstream of the culvert upgrade, there are increases in peak flood levels of up to 0.6 m. These increases extend downstream into Wolli Creek, where flood level increases of up to 0.15 m are estimated. The modelled impacts are shown in Figure G5.

Conclusion

As indicated in the previous FRMS&P, the cost of implementing this option is likely to be very high. In addition to this, there is limited benefit to upstream properties (only in Hillcrest Avenue when the levee is overtopped), and significant increases in flood levels downstream. For these reasons this option was not considered feasible.

10.2.3.5. Additional Inlets on Bexley Aquatic Centre Flow Path

Option Description

The Bexley Aquatic Centre flow path was identified in the Flood Study as a flooding hotspot. The flow path has a 1.8 m x 0.9 m box culvert underground from Westbourne Street, that increases to 1.55 m x 1.23 m box culvert when it reaches the Bexley Aquatic Centre. There are significant overland flows along the flow path that affect numerous properties. It would be difficult to upgrade the stormwater infrastructure, as the pipes cross private properties including under buildings. Instead, an option was tested to increase the capacity by increasing the number of inlets.

Option Impacts

Several additional inlets were placed along the flow path, with a focus on those areas where there was substantial ponding of water. The model was run for the 5% AEP and 1% AEP events. In the 5% AEP event, the largest reduction was 0.06 m (Figure G6).

Conclusion

Although additional inlets are significantly less work than upgrading the underground culvert, there would still be substantial work in excavating, breaking into the existing culvert and constructing a new pit. These pits are also typically located on private property. The benefit to flooding is minimal and hence this option is not recommended.

10.2.3.6. Henderson Street Industrial Area Levee

Option Description

This option involves construction of a levee to protect the Henderson Street industrial area. This was recommended as a high priority option in the previous FRMS&P, with an estimated CBR of 3.8. The report also noted the option to simply fill the entire area.

Option Impacts

A levee protecting the entire area between the railway line and Wolli Creek from the 1% AEP flood was modelled with the impacts shown in Figure G7. The increases in peak flood level in Wolli Creek are within 0.02 m and fairly localised. There is a decrease in flood levels of approximately

0.1 m within the low point of the industrial area. There are also areas of minor increase within the industrial area due to local drainage issues behind the levee.

Conclusion

The reduction in flood levels (0.1 m) and the extent benefited is not considered to be worth the construction of a levee system. Consideration would also need to be given to upgrading the local drainage system, including additional drainage behind the levee and installation of non-return valves on pipe outlets. The area, being industrial in nature, would be difficult to obtain funding for the construction of a levee to protect the commercial properties. It is recommended that this area mitigate flood risk by allowing filling of this area when redevelopment occurs. The filling of this area is likely to have a similar impact on Wolli Creek flood levels as the levee option presented here.

10.2.3.7. Turrella Street Drainage Upgrade

Option Description

This option involved the upgrading of the existing stormwater network on Turrella Street including duplication of the existing 900 mm pipe from Turrella Street under the East Hills railway line to Wolli Creek. This was investigated to see if the ponding of water on Turrella Street could be reduced. The alignment of the pipe is through two industrial sites on either side of the railway, although there are no buildings over the pipe. Construction under the railway would be expensive as it requires pipe jacking and require special consideration due to the sensitive nature of the railway line to changes in vertical elevation.

Option Impacts

Increasing the capacity of the existing stormwater network on Turrella Street and duplication of the existing 900 mm pipe under the railway line does not provide a significant reduction in flood levels. The benefit in the 1% AEP event to the peak ponded flood level on Turrella Street is less than 0.04 m (Figure G8).

Conclusion

The reduction in flood levels on Turrella Street are minimal compared to the costs involved in duplicating the existing culvert. In particular, pipe jacking under the railway line is expensive and could easily incur costs over $1M. The benefit to properties on Turrella Street is not only minimal, but only affects approximately 6 residential houses and the industrial buildings adjacent to the railway. The benefit to road users is also minimal. This option was not considered to be cost-effective.

10.2.3.8. Lusty Street Reserve Detention Basin

Option Description

This option involved the construction of a detention basin within Lusty Street Reserve, at the western end of Lusty Street to reduce flooding on Lusty Street. There is an existing earthen pathway from Lusty Street, under the SWSOOS to Turrella Street and a flowpath could be constructed in this corridor, and the pathway formalised. There is public space to the north of this path that is currently much higher probably due to filling. There is potential to create a detention basin in this area and direct overland flows into the basin (refer Diagram 14).

Diagram 14: Potential Flood Mitigation Works at Lusty Street Reserve

Alternative options were also investigated, including just constructing the flow path from Lusty Street through Lusty Street Reserve to the SWSOOS, and duplicating the existing Lusty Street pipe network.

Option Impacts

A basin for Lusty Street is not effective. The primary issue is that the water ponded at the SWSOOS is a higher level than the water in Lusty Street in the 1% AEP event. This means that any connection between these two areas results in water flowing from the reserve back into Lusty Street, causing an increase in flood levels on Lusty Street. This occurs to some degree with the detention basin, and more so with the alternative option of having a direct overland flow path. The flood impacts with the basin option for the 1% AEP event are shown in Figure G9.

For the basin to work, the low flow outlet would need to have a non-return valve on it, although the outflow from the basin would be stopped by the high tailwater level. The outlet would need to be taken under the railway and discharge into Wolli Creek for this to be effective. However, there is minimal grade to get the water from the street to the basin.

Doubling the Lusty Street drainage system only resulted in a benefit of less than 0.04 m within Lusty Street.

Conclusion

These options for Lusty Street are not effective at reducing flood levels, and in some cases make flooding worse. Redevelopment in this area has contributed to reduced flood risk, as high density residential apartments have been constructed with raised floor levels. The hazard to pedestrian and vehicle traffic, however, still exists.

10.2.3.9. Catchment Diversion from East Street to Bardwell Creek

Option Description

This option involves diverting some of the Bonnie Doon catchment to the Bardwell Creek catchment and was previously investigated in a 2001 Webb, McKeown & Associates study (Reference 14). This study relied on an ILSAX hydrologic model to undertake a preliminary assessment of an option that involved a diversion pipeline from Fripp Street down East Street, then along Lower Wilson Road and into Bardwell Creek. A 1.5 m diameter pipe was required to carry the peak flow of 8.8 m^3/s. This option was estimated to cost $2.6 million (2001 $). The impact on Bardwell Creek flood levels was estimated to be negligible.

With the recent 2D modelling that has been undertaken, a more accurate estimate of overland flows has been developed since the 2001 study. The area is included in both the Wolli/Bardwell Creek model and Bonnie Doon model as the catchment divide is ill defined. Some flows from Lorraine Avenue go towards the Bonnie Doon channel, while some crosses into the Bardwell Creek catchment. The existing drainage network drains to Bardwell Creek, along East Street. In the Wolli/Bardwell Creek model, overland flows are simulated to capture flows into the stormwater network only. The overland flows that continue toward Bonnie Doon channel are not included. In the Bonnie Doon model, it is assumed that all flows generated in this area are conveyed toward the Bonnie Doon channel (disregarding the stormwater network and overflows to Bardwell Creek), providing an upper limit of the overland flows through this area.

Option Impacts

To test diversion of the catchment upstream of East Street towards Bardwell Creek, the flows generated by this catchment were removed from the Bonnie Doon model altogether (assuming they could be captured and piped to Bardwell Creek). The 1% AEP event was simulated with this configuration. There were benefits in the upper catchment with reductions in flood levels of up to 0.2 m at the sag points on Kembla Street and Walters Street. On overland flow paths, the reduction in flood level is typically less than 0.1 m. It is noted that this modelled reduction would be an upper limit, considering some flows would be conveyed to the Bardwell Creek catchment by the existing drainage network). The modelled impacts are shown in Figure G10.

Conclusion

The modelled impacts are the maximum expected benefit, with the actual benefit expected to be less due to two reasons:

- The conservative approach in modelling the Bonnie Doon catchment in the base case as this assumes all overland flow in this area stays within the Bonnie Doon catchment.
- Assuming that the proposed diversion (most likely consisting of pits and pipe infrastructure) would be 100% effective in capturing all overland flows.

It would be difficult to capture all the shallow overland flows that occur in this upper catchment area and would most likely require not just the pit and pipe infrastructure upgrade, but also road regrading as well. The largest benefits occur at the sag locations on Kembla and Walters Streets, however, the flood depth at these locations is between 0.7 m and 0.9 m, and hence flooding would not be eliminated at these locations. For these reasons this option has not been investigated further.

10.2.3.10. Wollongong Road Pipe and Downstream Trunk Upgrades

Option Description

Several upgrade options are available for the Wollongong Road drainage system. These options include the upgrade of the existing pipe along Wollongong Road, upgrade of the existing pipe along Hirst Street, upgrade of the culverts under the Illawarra railway line and Bonnie Doon channel upgrades.

This option was investigated in the previous FRMS, although it was identified that drainage works on Wollongong Road would provide little tangible benefit. Traffic disruption and service relocation were also noted as potential significant constraints. Nonetheless, options to upgrade the drainage system along Wollongong Road was retained as a high priority, although specific details are not provided.

Option Impacts

The following options were modelled:

- Duplicate pipes along Wollongong Road
- Duplicate pipes and pits along Wollongong Road
- Duplicate pipes along Hirst Street
- Duplicate pipes and pits along Hirst Street
- Duplicate the existing 1.5 m diameter pipe under the railway to Bonnie Doon channel
- Duplicate pipes along Wollongong Road and duplicate box culvert under railway to Bonnie Doon channel
- Duplicate pipes along Wollongong Road, duplicate box culvert under railway to Bonnie Doon channel and duplicate the Bonnie Doon channel to the outlet

These options were run for the 1% AEP event. The results are as follows:

- Duplication of the Wollongong Road pipes resulted in lower flood levels on the flow path from Fripp Street through Arncliffe Park to Bonar Street by up to 0.1 m. Flood levels reduce in Bidjigal Road by up to 0.2 m. There are downstream impacts up to 0.03 m on Arncliffe Street and 0.1 m within the Bonnie Doon channel upstream of the Princes Highway.
- Adding in the duplication of the culvert under the railway (in addition to duplication of Wollongong Road pipes) resulted in slightly better benefit upstream of the railway, increases upstream of the SWSOOS are removed, although the downstream impacts within the Bonnie Doon channel are slightly higher.
- Adding in the duplication of the Bonnie Doon channel removes the downstream impacts and results in a lowering of up to 0.2 m within the channel and 0.02 m on Arncliffe Street.

The flood impacts for the Wollongong Road duplication to the railway for the 1% AEP event are shown in Figure G11, while the impacts for the duplication all the way to the Cooks River are shown in Figure G12.

The additional options tested yielded the following results:

- Duplication of the Hirst Street pipes resulted in minimal changes in flood levels (within 0.03 m).
- Duplication of inlet pits for the Wollongong Road and Hirst Street options did not significantly change the outcomes.
- Duplication of the existing 1.5 m diameter pipe under the railway resulted in a decrease in flood levels of up to 0.04 m on Wollongong Road and Bidjigal Road, 0.1 m reductions upstream of the SWSOOS, with minor increases up to 0.02 m in the Bonnie Doon channel upstream of the Princes Highway. These changes are highly localised.

Conclusion

The benefits of upgrading the Wollongong Road drainage line are not significant, with typical benefits of just 0.02 m on the overland flow path between Fripp Street and Bonar Street. Flood levels also increase downstream. To avoid these downstream impacts, the trunk drain under the railway line would also require upgrading, which would be expensive. Further downstream impacts in the Bonnie Doon channel could be mitigated by upgrading the channel. This entire system upgrade would be extremely expensive and would not be feasible considering the minimal flood benefits. There is not considered to be any cost-effective measure at this location for upgrading the stormwater network.

10.2.3.11. Bonar Street Drainage Upgrade

Option Description

This option investigated the recent Bonar Street drainage works to determine if there were any additional improvements that could be made. The works are quite substantial and there was no real opportunity to provide significant improvements. Due to a diversion of pipes into the new system, one option was investigated that involved provision of additional inlets near the Hirst Street and Bonar Street low point.

Option Impacts

The modelling of additional pit inlets resulting in a reduction of 0.1 m in the 1% AEP flood level at the sag point near the Hirst Street and Bonar Street intersection. There were also some minor increases downstream of the railway (less than 0.02 m) as shown in Figure G13.

Conclusion

The benefit to flood levels was not significant, considering the flood depths of over 0.8 m at this location in the 1% AEP event. This option, however, does suggest that there may be some additional capacity in the existing pipe network given the recent Bonar Street drainage works that may be leveraged when this area is subject to redevelopment.

10.2.3.12. Arncliffe Street Overland Flow Path

Option Description

Council has purchased land located on Arncliffe Street, Wolli Creek. The block is approximately 23 m wide and borders the Bonnie Doon channel at the rear. It is the intention of Council to extend Gertrude Street to Arncliffe Street via this land acquisition. Council had a preliminary design of the road which included a new stormwater connection from Arncliffe Street to the Bonnie Doon channel, replacing the existing 600 mm diameter pipe with a 1.2 m x 0.6 m box culvert. The site of the new road is shown in Photo 11. There is also an opportunity to construct a detention tank under the road, however, this has been investigated separately in Section 10.2.4.11.

Photo 11: Arncliffe Street at the site of the proposed road connection (*Source: Google Street View*)

Option Impacts

This option was modelled by removing the existing building on the site and estimating the proposed road level, assuming it matches existing ground levels. This would act as an overland flow path. The 600 mm diameter pipe from Arncliffe Street to Bonnie Doon channel was removed and replaced with a 1.2 m x 0.6 m box culvert.

The flood behaviour at Arncliffe Street is complicated, particularly in the 1% AEP event. The critical duration for the 1% AEP event at this location was modelled to be the 90 minute storm. For this event, the water level is similar in Arncliffe Street as the Bonnie Doon channel, with water just flowing from Arncliffe Street to the Bonnie Doon channel. In this event, there is negligible change in flood level with this option (within 0.01 m).

In the 30 minute event, although the overall peak flood levels are lower than the 90 minute storm, the water levels are higher in the channel relative to Arncliffe Street, meaning that Arncliffe Street is inundated by backwater flooding from the Bonnie Doon channel. In this event, there is an increase in flood levels on Arncliffe Street with this option (approximately 0.04 m), due to the increased connectivity to the Bonnie Doon channel.

In the 540 minute storm, the flood levels on Arncliffe Street are higher relative to the Bonnie Doon channel, meaning that water flows from Arncliffe Street to the Bonnie Doon channel. In this event, there is a reduction in flood level on Arncliffe Street due to the increased connectivity to the Bonnie Doon channel. This outcome is similar to the 5% AEP event, where water levels on Arncliffe Street are higher relative to the Bonnie Doon channel. The reduction in peak flood level for the 5% AEP event is approximately 0.07 m and is shown in Figure G14.

The change in peak flood level on Arncliffe Street is driven by the flood behaviour whether water is flowing into or out of the Bonnie Doon channel. The creation of a wider overland flow path facilitates the exchange of water between Arncliffe Street and the Bonnie Doon channel which may reduce or increase flood levels depending on the relative water levels.

Conclusion

The change in peak flood levels (either increases or decreases) are not significant, typically being within 0.1 m for the 5% AEP and 1% AEP events modelled. While this is not recommended as a flood mitigation option, there is opportunity to consider flooding when designing the new road and drainage. Climate change causing sea level rise should also be considered, as Arncliffe Street is more likely to be inundated by water from Bonnie Doon channel with rising tailwater levels. Redevelopment in this area has contributed to reduced flood risk, as high density residential apartments have been constructed with elevated floor levels. The hazard to pedestrian and vehicle traffic, however, still exists.

10.2.3.13. Cahill Park Levee

Option Description

This option investigated the potential for construction of a levee in Cahill Park, Wolli Creek. This option was previously recommended as a high priority option for further studies in the previous FRMS. Two levees were suggested – one at the 5% AEP level (1.9 mAHD) and one at the 1% AEP level (2.2 mAHD). This would protect Gertrude Street and Levey Street from inundation from the Cooks River. The indicative CBR was 0.6, without any drainage modifications or land acquisition.

Option Impacts

While there are several options for the construction of this levee, the following has been tested:

- Levee crest at 1.9 mAHD (Cooks River 5% AEP level at Cahill Park), although the levee should consider some freeboard to protect to the 5% AEP level.
- Levee alignment is along the Princes Highway, along the rear of properties on Gertrude Street and Levey Street, adjacent to Rockwell Avenue and along the bank of the Cooks River to Kogarah Golf Club. This allows Cahill Park to be flooded, but excludes Cooks River flooding from residential areas and roads.
- There are 8 stormwater pipes that cross this levee alignment that would require non-return valves to protect the area inside the levee from backwater flooding.
- No flap gate has been assumed on the Bonnie Doon channel, as this only affects areas upstream of the Princes Highway, in the vicinity of Arncliffe Street.

This option was run for the 1% AEP event (assuming a coincident 5% AEP Cooks River level) and the 5% AEP event (assuming a coincident 2 year ARI Cooks River level). The modelling indicates that the benefit to the Gertrude Street area is minimal. In the 1% AEP event, the reduction in flood level is approximately 0.07 m. There are, however, increases in flood level of just over 0.01 m on Arncliffe Street, due to increased levels on the downstream side of the levee. The modelled impact for the 1% AEP event is shown in Figure G15. In the 5% AEP event, the reduction in flood level on Gertrude Street is approximately 0.03 m, while there are increases on Levey Street of 0.05 m due to water ponding behind the levee.

Conclusion

This option does not significantly improve flood levels in the vicinity of Gertrude Street. Although the area is very low-lying and impacted by elevated Cooks River levels, the area is also impacted by local runoff. The modelling demonstrated that local runoff ponding behind the levee results in peak flood levels similar to that with backwater from Cooks River, in both the 5% AEP and 1% AEP events (with coincident Cooks River levels). Redevelopment in this area has contributed to reduced flood risk, as high density residential apartments have been constructed with elevated floor levels. The hazard to pedestrian and vehicle traffic, however, still exists.

10.2.3.14. Beaconsfield Street Drainage Diversion

Option Description

This option investigated the potential to construct a new stormwater pipe from Verdun Street to Beaconsfield Street. This is immediately downstream of Dominey Reserve, where a detention basin was previously investigated (see Section 10.2.2.4). The existing drainage line consists of a 1050 mm diameter pipe from Verdun Street to Beaconsfield Street. This pipe crosses under residential properties and the overland flow path follows this alignment. The drainage diversion attempts to capture more water in Verdun Street, and divert it into a new pipe that runs along Verdun Street and then Beaconsfield Street, within the road corridor. The new pipe length is approximately 230 m. It would connect into a box culvert commencing from Beaconsfield Street.

Option Impacts

A new 900 mm diameter pipe was added to the model, with additional inlet capacity on Verdun Street. This was run for the 5% AEP and 1% AEP events. The largest benefit was seen in the 1% AEP event, with peak flood levels on the overland flow path reduced by up to 0.1 m, although the benefit is typically half this. Peak flood depths of up to 0.8 m are expected at some locations on the flow path, and hence flooding is not removed. These impacts are shown in Figure G16.

Conclusion

The modelled benefit to flood levels on this overland flow path is minimal and there are also only a small number of houses that would benefit from this option. In addition to this, the pipe would be difficult to construct. The corner of Verdun Street and Beaconsfield Street is approximately 2.5 m higher than the Verdun Street sag elevation. It is estimated that to maintain a constant falling grade on the pipe, the trench would need to be approximately 6 m deep at this intersection. The Dominey Reserve detention basin is expected to reduce flood levels on this overland flow path, which may reduce the benefits of this option.

This option was recommended as a high priority option in the previous FRMS, as it noted that it eliminates most overland flow through private property (when constructed in conjunction with the Dominey Reserve detention basin). Details of the diversion are not explicit, and it is thought that that the primary driver for reducing flooding is the detention basin, with the basin low flow outlet being diverted down Beaconsfield Street rather than connecting to the existing system. This would be considered as part of the Dominey Reserve detention basin investigations.

10.2.3.15. Oswell Street to Wolli Creek Road Drainage Diversion

Option Description

This option investigated the potential for a new drainage line from Oswell Street to Wolli Creek Road, adjacent to Gardiner Park. Water in excess of the stormwater network capacity flows from the Oswell Street sag point down Holland Avenue and through residential properties on Holland Avenue to Wolli Creek Road. This is also the path of the existing stormwater lines.

Option Impacts

A new 900 mm diameter pipe was tested running from the Oswell Street sag point along Oswell Street and down Wolli Creek Road to the sag point, where it joins the existing 1200 mm diameter pipe on Wolli Creek Road. The 5% AEP and 1% AEP events were simulated with this option. The change in peak flood level was similar in both events, with flood levels being reduced adjacent to the Wolli Creek Road sag point by up to 0.25 m, although this is highly localised. The reductions along the overland flow path are typically less than 0.05 m. There is some reduced capacity in the downstream stormwater network due to the additional flows being discharged into the system, and hence some localised slight increases in flood levels on the overland flow path between Gardiner Avenue and Railway Street. The impacts for the 1% AEP event are shown in Figure G17.

Conclusion

This option was recommended as a high priority option in the previous FRMS&P (option 14A, Reference 6), but was coupled with a detention basin in Gardiner Park, with the purpose of the drainage diversion to get more water into the basin. The detention basin at Gardiner Park was rejected with the high-level assessment due high costs and relatively low benefit in a feasibility study in 2010. Gardiner Park is also currently being upgraded. This option alone (i.e. without the Gardiner Park detention basin) is not considered feasible. The reduction in flood levels is minor on the overland flow path where properties are affected, with the potential for causing an increase in flood levels downstream of the works.

10.2.3.16. Bruce Street Drainage Upgrade

Option Description

Two options were investigated for the Bruce Street area in Brighton-Le-Sands. Water ponds at a sag point on the corner of Hinkler Street and Aero Street, and at the western end of Bruce Street.

One option was to provide additional inlets and upgrade the stormwater line from the Hinkler Street/Aero Street sag point to the box culvert (1.5 m x 0.6 m) that was constructed as part of the Brighton Terrace development. There is currently a 750 mm diameter pipe along this route to the box culvert. The length of the upgrade is approximately 100 m through drainage easements. It was assumed, however, that the stormwater line from the Brighton Terrace development to Muddy Creek would also need to be upgraded (currently a 900 mm pipe), and this is approximately 120 m in length.

The other option investigated involved construction of an additional stormwater pipe from the Hinkler Street/Aero Street sag point along Bruce Street and discharging into the playing fields adjacent to Muddy Creek via an access pathway. Upon detailed investigation, however, it was determined that this would need to be piped all the way to Muddy Creek, due to the low elevation of the Hinkler Street/Aero Street sag point. This is a length of approximately 450 m.

Option Impacts

Both options were tested in the model. The first option consisted of upgrading the existing 750 mm diameter culvert to a 1.5 m x 0.6 m box culvert, running from the Hinkler Street/Aero Street sag point to the Brighton Terrace box culvert. This option reduces the 1% AEP flood level by up to 0.09m at the sag point, and 0.01 m at the Bruce Street cul-de-sac.

The second option consisted of a new 1200 mm diameter pipe from the sag point to Muddy Creek, with additional inlet capacity at the sag point. This provides more benefit, reducing 1% AEP flood levels by up to 0.27 m at the sag point, although there is still limited benefit in Bruce Street, being less than 0.02 m, as shown in Figure G18. The reduction in flood level in the 5% AEP event is 0.25 m. This would primarily benefit properties between Bruce Street and Hinkler Street.

Conclusion

The first option (box culvert upgrade) provides limited benefit to flood levels. The second option (new pipe construction) provides substantial benefit to flood levels at the Hinkler Street and Aero Street sag point, reducing 1% AEP flood depths on the road by approximately 50%. This, however, benefits a limited number of properties. This option would require significant works, with a trench approximately 450 m in length. Although much of this would be through the open space of the fields, the excavation depths would reach approximately 2.5 m. This option also has a low grade on the pipe, at approximately 0.2% assuming it outlets to 0 mAHD. This would also mean that the pipe would be subject to tidal backwater unless a non-return valve is placed on the end. The 1% AEP Cooks River flood level is slightly lower than the ground level at this location. Due to the extensive nature of the works and potential issues with backwater and the low grade of the pipe, it is not considered feasible for the properties benefitted.

10.2.3.17. Tindale Reserve Detention Basin

Option Description

This option consists of a detention basin in Tindale Reserve. The reserve is located immediately downstream of the junction of two flow paths on Mill Street, Carlton. Overland flow continues through the park to Short Street. Approximately 170 m downstream of the reserve is where the open channel commences at Willison Road. The reserve is quite steep and consists of open grassed areas, gardens, mature trees and a playground, as shown in Photo 12. There is a 1.98 m x 1.44 m box culvert running underneath the reserve.

Photo 12: Tindale Reserve

Option Impacts

This option was tested by simply constructing a 1.2 m high bund at the downstream end of the reserve to detain overland floodwater. The existing landform within the reserve was retained. The detention basin did not provide any benefit to downstream flood levels in the 1% AEP event, as shown in Figure G19. There is a redistribution of flow on Short Street, but no benefit to downstream properties.

Conclusion

The proposed basin does not have sufficient storage to significantly reduce downstream flooding in the 1% AEP event. The reserve would require significant modification to store a significant amount of water, and it would be difficult to modify the existing features of the reserve to accommodate widespread changes, such as gardens, mature trees, existing stormwater line, lighting and amenities.

10.2.3.18. Reading Road Drainage Upgrade

Option Description

There is an overland flow path and sag point between Bestic Street and Rowley Street, Brighton-Le-Sands. This is adjacent to Reading Road and occurs through private property. Water also ponds at the Reading Road and Rowley Street intersection. There is an existing 525 mm diameter pipe that runs along Reading Road, connecting to a 600 mm diameter pipe along Bestic Street that outlets to a small channel adjacent to Bestic Street near the community gardens. This option investigates upgrading this pipe system and outlet to Muddy Creek.

Option Impacts

This option was modelled by duplicating the existing pipes along Reading Road and Bestic Street to the Bestic Street outlet. In the 5% AEP and 1% AEP events, there was a reduction in peak flood level of approximately 0.2 m at the sag point where residential properties are located, and a reduction of less than 0.05 m on Reading Road. There was an increase in peak flood levels, however, at the Bestic Street outlet of up to 0.02 m. The impacts for the 1% AEP event are shown in Figure G20. Improving the channel and outlet from Bestic Street to Muddy Creek did not produce any benefit to flooding.

Conclusion

While there was a benefit to flooding on private property, it is likely that the dwellings are high enough that flood damages are not significant. The upgrade of the drainage line is also a substantial undertaking, particularly with Bestic Street being a main road. There is also the issue of downstream impacts that would need to be managed. For these reasons, this drainage upgrade was not considered to be feasible.

10.2.3.19. Kendall Street Reserve Mitigation Works

Option Description

This option investigated Kendall Street Reserve and the areas upstream in Sans Souci. In the past the reserve has been used as a market garden and for horse agistment. In the 1970's the site was filled by Council to address localised flooding issues and to create a public reserve. The site is currently owned by the Department of Education and is zoned for school use, with Council having a lease over the land. There are areas of flooding between Ida Street and Kendall Street. Options investigated included local works on Ida Street and in Goomun Duke Park, upgrading the channel around Kendall Street Reserve and a detention basin in the reserve.

Option Impacts

Minor works on Ida Street and in Goomun Reserve were tested. This included a bund on Ida Street, west of the Goomun Creek channel, to prevent overland flows entering properties. A small channel through Goomun Duke Park was also tested to drain overland flows to the channel. Both options made negligible difference to the 1% AEP flood levels, as the area is affected by backwater from the channel. Options within Kendall Street Reserve also did not make a substantial difference to flood levels. The installation of a detention basin in the reserve reduced upstream flood levels by just 0.03 m in the 1% AEP event. This is shown in Figure G21.

Conclusion

The existing Goomun Creek channel is reasonably effective given the very flat terrain of Sans Souci. Mitigation options investigated in this area were not effective at reducing flood levels.

10.2.3.20. Park Road Flow Path Management

Option Description

This option was identified in the previous FRMS simply as improve the overland flow path on Margate Street to 29 and 33 Park Road. This was a medium priority option. Details of this option are not provided in the previous study. The flow path is already reasonably well managed, being located on open space with minimal impact on dwellings. For this option, a detention basin was investigated within the open space adjacent to Margate Street, upstream of Park Road. This flow path is not considered to be a significant issue to properties, but water does overtop Park Road and flow through properties and adjacent to Bado-berong Creek. A small detention basin was tested to throttle these flows.

Option Impacts

A detention basin within the open space was modelled with a bund approximately 0.8 m high, with some excavation and a 900 mm diameter pipe outlet to the stormwater system on Park Road. Water was still modelled to overtop Park Road in the 1% AEP event and downstream reductions in flood level were up to 0.05 m, but did not extend far, as shown in Figure G22.

Conclusion

This option did not produce any significant benefit to flooding.

10.2.3.21. Meriel Street Flow Path Management

Option Description

This option was identified in the previous FRMS&P as improving the overland flow path on Meriel Street. This seems to indicate a proposal to have a flow path along Meriel Street, between the sag point on Meriel Street and Brantwood Street. There is a ridge a metre high, however, between these two locations and a flow path along the road is not considered viable. It is also likely to just increase ponding at the Brantwood Street sag point. For this option, the Brantwood Street and Tuffy Avenue drainage from the low point was investigated for upgrading. This area has the largest flood depths, being up to 0.7 m in the 1% AEP event on Brantwood Street and 0.5 m on Tuffy Avenue.

Option Impacts

Both the drainage lines from Brantwood Street (600 mm diameter pipe, 230 m in length) and Tuffy Avenue (375 mm diameter pipe, 90 m in length) were duplicated to test the benefit to flood levels. In the 1% AEP event, the peak flood level reduced by 0.1 m on Brantwood Street and 0.07 m on Tuffy Avenue. The impacts, however, are fairly localised to the sag point as shown in Figure G23.

Conclusion

Upgrading these stormwater lines is not a simple task, particularly as they cross Riverside Drive and would require an additional outlet into Botany Bay. While there is substantial ponding at these locations in the 1% AEP event, the reduction in flood level is minor considering the depths and does not benefit many properties. For these reasons this option was not considered feasible.

10.2.3.22. Russell Lane Drainage Upgrade

Option Description

One of the more flood affected areas of Sans Souci is Russell Lane, and areas adjacent to Goomun Creek downstream to Toyer Avenue. Street drainage on parallel streets upstream of Russell Lane (for example Bonanza Parade and Bonanza Lane) drain east to Bado-berong Creek, while Russell Lane drains south to the start of the Goomun Creek channel, immediately downstream of Russell Avenue. There are currently 750 mm diameter pipes on Russell Lane and 900 mm diameter pipes on Russell Avenue, but only a 450 mm diameter pipe connecting these systems. However, upgrading this 450 mm line would be difficult as it traverses private property between Russell Lane and Russell Avenue. An alternative option was investigated to divert water east to Bado-berong Creek, as the upstream streets currently do. This new drainage line could follow Russell Lane, Napoleon Street and Russell Avenue, discharging into Bado-berong Creek downstream of Russell Avenue.

Option Impacts

A new 750 mm diameter pipe was modelled from the Russell Lane sag point to Bado-berong Creek downstream of Russell Avenue. In the 1% AEP event, this did not provide any benefit to flood levels on Russell Avenue. There was minimal benefit downstream of this, with flood levels reducing by approximately 0.02 m on Russell Avenue. There were also minor increases in the order of 0.01 m downstream of Ida Street on Bado-berong Creek. These impacts are shown in Figure G24.

Conclusion

There are minimal flooding benefits of this option for the significant amount of work required to construct a new drainage line. This option was not considered feasible.

10.2.4. Flood Modification Options Selected for Detailed Assessment

Options that provided reasonable benefits to flooding at the hydraulic assessment stage were selected for detailed assessment. This included modelling of all design flood events, calculation of the reduction in flood damages and an estimation of the capital and ongoing maintenance costs to conduct a cost-benefit analysis. Based on the outcome of this assessment, the option was either not pursued further, or was included in the multi-criteria assessment. These options are shown in Figure 37.

10.2.4.1. Flood Modification Option Costs

A preliminary cost estimate was undertaken for most options subject to a detailed assessment. Costs were estimated by first compiling a schedule of rates for tasks that will be required. The source of these rates was primarily from Rawlinsons Australian Construction Handbook (Reference 38). The rates published for Sydney (the upper rate if a range was supplied) were used for this investigation. It was assumed that the regional cost factor for Bayside West was 1.0 (i.e. the same as Sydney metropolitan area). The published rates from 2018 were increased by 10% to account for inflation (based on the CPI provided by the ABS to April 2022). It is noted that recent rises in CPI would alter the estimated costs, however, there are several other factors which affect construction costs (such as the price of steel and concrete) and the costs estimated here are preliminary estimates for the purpose of determining a cost-benefit ratio. Bayside Council also provided a schedule of rates from a contractor who recently undertook major drainage upgrade works in Arncliffe. Where applicable, these rates were used or compared with those provided by Rawlinsons. The schedule of rates is contained in Appendix I.

A set of standard costs were included for each option related to direct costs incurred by Council, pre-construction costs and construction contingencies. These are outlined in Table 34.

Table 34: Additional costs factored into costing

Item	Cost / Rate
Pre-construction Costs	
Design (including survey, investigation design, geotechnical investigations, REF, detailed design, etc.)	15% of construction cost
Project Management of Design	15% of design costs
Pre-construction contingency	40% of total pre-construction costs
Construction Costs	
Establishment (project inception, management and coordination)	$10,000
Preparation and implementation of preliminaries (CEMP, SMP, TCP, QMP, etc)	$20,000
Construction management / supervision	15%
Construction contingency	40% of total construction costs

The following assumptions were also made:

- No major tree clearing is necessary.
- All excavations are in 'light soil'. Costs will be higher in soils with high clay content or through rock.
- No service relocation costs have been included, which can be a significant cost if required.
- No land acquisition costs have been included, which can be a significant cost if required.

A breakdown of the cost estimates for each option is also contained in Appendix I.

10.2.4.2. Modification Option Benefits

The benefits to flooding for most options were mapped for the 5% AEP and 1% AEP flood events. These maps indicate the change in peak flood level and indicate the magnitude and extent of flood benefits. The economic benefits of the option were quantified by estimating the reduction in AAD. AAD was estimated using the same methodology outlined in Section 8, noting that only tangible damages have been considered in this assessment. It is likely that options may also provide additional benefit to indirect tangible damages and intangible damages that have not been quantified in this assessment.

10.2.4.3. Flood Modification Option Cost-Benefit Analysis

A cost-benefit analysis (CBA) was undertaken to determine a cost-benefit ratio (CBR). This was done by comparing the Net Present Value (NPV) of the reduction in AAD (benefit) with the capital cost of the works. To calculate NPV, an asset life of 25 years with a discount rate of 7% was applied (in accordance with NSW Treasury Guidelines, Reference 47). For most options, it was assumed that capital works costs were the only costs, with no additional annual costs (such as maintenance of the stormwater system) incurred to Council beyond current expenditure.

10.2.4.4. Option FM01 Regrade Bexley Golf Course

Description of Flooding

In current conditions, flood water impacts Bridge Street. The source of this water is primarily the open channel that runs along the western side of Bridge Street. Channel flows in excess of the culvert under Unwin Street also exit the channel, flow over Unwin Street and down Bridge Street toward Bexley Golf Course. There is some additional overland flow from Unwin Street, east of Bridge Street, that crosses through private properties towards the channel and Bexley Golf Course. There are reasonably large depths of water on Bridge Street, particularly near the intersection with Moore Street, reaching almost 1 m in the 20% AEP event, 1.1 m in the 1% AEP event and exceeding 2 m in the PMF event.

Option Description

This option was originally linked to investigations around Bridge Street, which were discussed in Section 10.2.3.3. In those investigations, it was found that a significant contribution to ponding of water on Bridge Street was the capacity for overland flows to be discharged into the Bexley Golf Course. The earthworks associated with the golf course have resulted in raising of ground levels near the Bridge Street entrance to the golf course, for fairways and other features of the course. This option considered a 10 m wide overland flow path from the corner of Moore Street and Bridge Street through the golf course to where there is a flow path to Bardwell Creek. This flow path would be around the existing fairway green and adjacent to, or made part of the existing access track. This is shown in Diagram 15.

Diagram 15: Option FM01 – Bexley Golf Course Flow Path (*Image Source: Google Street View*)

This option would be relatively easy to construct, involving earthworks to construct the flow path and some rehabilitation of the area – including grass and potential work to the access track. No tree clearing would be required and there is likely to be minimal interaction with underground utilities in this area. It is assumed that no major regrading of the road is required. The flow path could be incorporated into the existing landscape features of the golf course. Consultation with the golf course would be required for this option.

Option Impacts

A 10 m wide flow path was modelled from the corner of Moore Street and Bridge Street to the flow path in the golf course to Bardwell Creek. The upstream invert level was assumed to be 31.1 mAHD, with the downstream level being 30.1 mAHD. The benefit to flood levels on Bridge Street was up to 0.25 m in the 1% AEP and 0.21 m in the 5% AEP, with benefits extending to Unwin Street. There were some minor increases within the golf course and downstream to

Preddys Road. These impacts could be managed by additional works within the golf course that have not been investigated as part of this study. The implementation of detention basins is likely to mitigate this impact and it is recommended that these be investigated future feasibility studies. The impacts for the 5% AEP and 1% AEP events are shown in Figure H1 and Figure H2, respectively.

The benefit to private property is minimal, with only three properties benefitted, located on the eastern side of Bridge Street. There are benefits to the road as well, with flood depths reaching almost 1 m in the 20% AEP event in existing conditions. While the modelled reduction would not improve trafficability at the peak of the design flood events, it would reduce the peak flood level and duration of inundation in the road. This may also improve trafficability in more frequent flood events and access to properties on Bridge Street.

There are likely to be minimal negative social impacts, with only slight disruption to the golf course while regrading works are taking place. There are likely to be minimal negative environmental impacts, with cleared land able to be re-landscaped and no large tree removal required.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $200,000, with no ongoing maintenance costs directly associated with this option. Details of costs are provided in Appendix I.

The benefit of this option was assessed by comparing the AAD of the option with the base case. The benefit to tangible AAD was estimated to be $19,000. The NPV of this benefit was estimated to be approximately $235,000. A summary of the benefits to flood damages is provided in Table 35. For the change in the number of properties affected, a negative number indicates a decrease in the number of properties and a positive number indicates an increase in the number of properties affected. The reduction in damages is provided as a negative number.

Table 35: Summary of flood damage benefits for FM01

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	-1	0	-$43,200	-1	0	-$43,200
10% AEP	-1	-1	-$44,900	-1	-1	-$44,900
5% AEP	-2	-1	-$99,800	-2	-1	-$99,800
2% AEP	-1	-1	-$89,200	-1	-1	-$89,200
1% AEP	0	-1	-$76,200	0	-1	-$76,200
0.5% AEP	0	-1	-$78,500	0	-1	-$78,500
0.2% AEP	-1	0	-$54,900	-1	0	-$54,900
PMF	0	0	-$54,300	0	0	-$54,300
Average Annual Damages			-$18,900	Average Annual Damages		-$18,900

The CBR of this option was therefore estimated to be approximately 1.2.

Summary and Recommendation

☑	**FM01: Regrade Bexley Golf Course**
Description	• Regrade land from Bridge Street into Bexley Golf Course to allow overland flows to Bardwell Creek.
Benefits	• Reduces road inundation on Bridge Street to Unwin Street, improving driver safety and flood immunity. • Reduces property impacts for several properties on Bridge Street.
Concerns	• Consultation required with golf course. • Regrading would need to be designed with consideration to golf course layout.
Approximate Cost	$200,000
CBR	Approximately 1.2 considering direct tangible benefits. Additional benefits to driver safety and access.
Responsibility	Council, in liaison with Bexley Golf Course.
Outcome	These works are recommended.
Priority	High

10.2.4.5. Option FM02 Dowsett Park Detention Basin

Description of Flooding

A detention basin was investigated for Dowsett Park, Kingsgrove. The Park is currently located on an overland flow path, with a 900 mm diameter pipe running underneath the park. The overland flow direction is from south (crossing Todd Street) to north (flowing over Dowsett Road). There is also flow parallel to this down Caroline Street, which has a 750 mm diameter pipe running underneath it. At Dowsett Road, another flow path joins from the east, serviced by a 525 mm diameter pipe. These three flow paths and pipe systems join at Dowsett Road to continue north. The pipe continues as a 900 mm diameter pipe while overland flow traverses residential properties and crosses Edward Street and The Avenue. Downstream of this, Our Lady of Fatima Catholic Primary School and Kingsgrove RSL Club are also affected before water ponds on Shaw Street and impacts the East Hills railway line. Flood depths downstream of Dowsett Road are typically in the order of 0.3 m in the 1% AEP event, although can be up to 0.6 m. Ponding of water occurs on the school's sporting fields and courts of up to 0.8 m, being blocked by the RSL Club.

Option Description

The proposed basin would be constructed within the open grassed area of Dowsett Park. To avoid the need for a large embankment on the downstream side of the park (which could have potential failure risks for properties immediately downstream), an excavated basin is proposed. The invert of the basin would be at the existing 900 mm diameter pipe invert, estimated to be approximately 23.7 mAHD. The pipe through the park would require a discharge point at the upstream extent of the basin, and the pipe would be re-instated with a headwall at the downstream end. The embankment of the basin would be at approximately 25.6 mAHD, with a spillway 0.2 m lower than this. The spillway, at approximately 25.4 mAHD, is approximately 0.3 m above the lowest ground level on the flow path as it exits the park. This provides a basin depth of 1.7 m from the invert to the spillway. The basin would be formed within the existing boundary of mature trees lining the perimeter of the park and the playground. The basin concept is shown in Diagram 16.

Diagram 16: Option FM02 – Dowsett Park Detention Basin (*Image Source: Google Street View*)

The basin is considered feasible to construct, with no major issues identified at this stage. The main concern would be the existing pipe as its location and invert levels may alter the basin design. Existing infrastructure and trees would remain in place. It is expected that there would be minimal interference with services. The park would need to be closed while construction takes places.

Option Impacts

A basin was implemented in the TUFLOW model as described above. The basin has approximately 3,900 m^3 of storage up to the spillway level. The 900 mm diameter culvert under the park was assumed to terminate and discharge into the basin, and be re-connected with a headwall at the basin invert as the low flow outlet. The basin can contain the 20% AEP and 10% AEP flows, and first spills in the 5% AEP event. This option results in a reduction of no more than 0.1 m in the 1% AEP event on the flow path downstream of the basin. In the 5% AEP event, these reductions are up to 0.15 m. The impacts for the 5% AEP and 1% AEP events are shown in Figure H3 and Figure H4, respectively.

The benefit to private property is substantial, with numerous properties downstream benefitting, including Our Lady of Fatima Catholic Primary School and Kingsgrove RSL Club. There are also benefits to roads that the flow path crosses, including Dowsett Road, Edward Street, The Avenue, Brocklehurst Lane and Shaw Street, improving trafficability. The East Hills railway line would also benefit with reduced ponding of water in the rail corridor.

There are likely to be minimal negative social impacts, with only closure of the park during construction and potential construction nuisances (such as truck traffic and noise) to neighbours. There are likely to be minimal negative environmental impacts, with the basin to be grassed as per the existing park and no large tree removal required.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $4.4M, with no ongoing maintenance costs directly associated with this option. The largest single item in the cost estimate is the disposal of clean fill, with a cost of almost $2M. A rate of $209 per tonne has been assumed in accordance with Rawlinsons (Reference 38) for disposal of clean fill. The total volume of excavated soil to be disposed of was estimated to be approximately 5,850 m^3, or 9,370 t, assuming 1.6 t/m^3. If Council can use this fill elsewhere, or dispose of in a more cost-effective manner, the total cost of the project could be significantly reduced. Details of costs are provided in Appendix I.

The benefit of this option was assessed by comparing the AAD of the option with the base case. The benefit to tangible AAD was estimated to be approximately $107,000. The NPV of this benefit was estimated to be approximately $1.33M. A summary of the benefits to flood damages is provided in Table 36. Note that flood damages increase slightly in the PMF event due to the way the basin overtops.

Table 36: Summary of flood damage benefits for FM02

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	-3	-3	-$267,500	-3	-3	-$267,500
10% AEP	-4	-4	-$360,700	-4	-4	-$360,700
5% AEP	-5	-5	-$449,800	-5	-5	-$449,800
2% AEP	-3	-3	-$279,500	-3	-3	-$279,500
1% AEP	-2	-3	-$194,400	-3	-4	-$217,000
0.5% AEP	-2	-3	-$178,200	-4	-5	-$229,700
0.2% AEP	-1	-1	-$93,200	-2	-2	-$127,500
PMF	0	0	$8,000	0	0	$7,800
Average Annual Damages			-$106,500	Average Annual Damages		-$107,000

The CBR of this option was therefore estimated to be approximately 0.3. As discussed above, the soil disposal costs were a significant portion of the estimated capital cost of the works. The CBR increases to 1.7 if there were no soil disposal costs. Soil disposal costs would need to be approximately 15% of the current rate (i.e. approximately $30/t) for the CBR to be 1.0.

Summary and Recommendation

☑	**FM02: Dowsett Park Detention Basin**
Description	• Excavate Dowsett Park to form a detention basin. • Remove a section of 900 mm pipe such that it discharges into the basin and forms the low flow outlet of the basin.
Benefits	• Reduces property impacts on the overland flow path downstream of the basin, including residential properties, Our Lady Fatima Catholic Primary School and Kingsgrove RSL Club. • Reduces road inundation on Dowsett Road, Edward Street, The Avenue, Brocklehurst Lane and Shaw Street, improving driver safety and flood immunity. • Reduces flooding on the East Hills railway line.
Concerns	• Basin design would depend on actual invert level of 900 mm pipe and grading requirements.
Approximate Cost	$4.4M
CBR	Approximately 0.3 considering direct tangible benefits. CBR may be as high as 1.7 if soil disposal costs can be minimised. Additional benefits to driver safety and access.
Responsibility	Council
Outcome	These works are recommended for further investigation.
Priority	Medium

10.2.4.6. Option FM03 Kingsland Road South Overflow Management

Description of Flooding

There is shallow flow modelled along Kingsland Road South, typically less than 0.1 m deep in all events. This flow is from an overland flow path that discharges onto Kingsland Road South between Godwin Street and Abercorn Street (as well as runoff from the road itself). The water on Kingsland Road South, when it overtops the gutter, can flow towards a flow path that runs parallel to Kingsland Road South, through private property, crossing Highgate Street and towards Kingsland Road Reserve. While this was not identified as a 'hotspot' for flooding, a resident of Kingsland Road provided information that in heavy storm events, water does overtop the Kingsland Road South gutter and affects No's 17-23 Kingsland Road South. Photos and videos of this were provided, with an example shown in Photo 13.

Photo 13: Water overtopping Kingsland Road at No. 17 during the February 2021 storms (*Image Source: Kingsland Road South Resident*)

Option Description

The options for this area are more aligned with drainage works than flood mitigation. Options include formation of a flow path from the gutter on Kingsland Road South to Highgate Street, and construction of a small barrier on Kingsland Road where No’s 17-23 are located. These options are shown in Diagram 17.

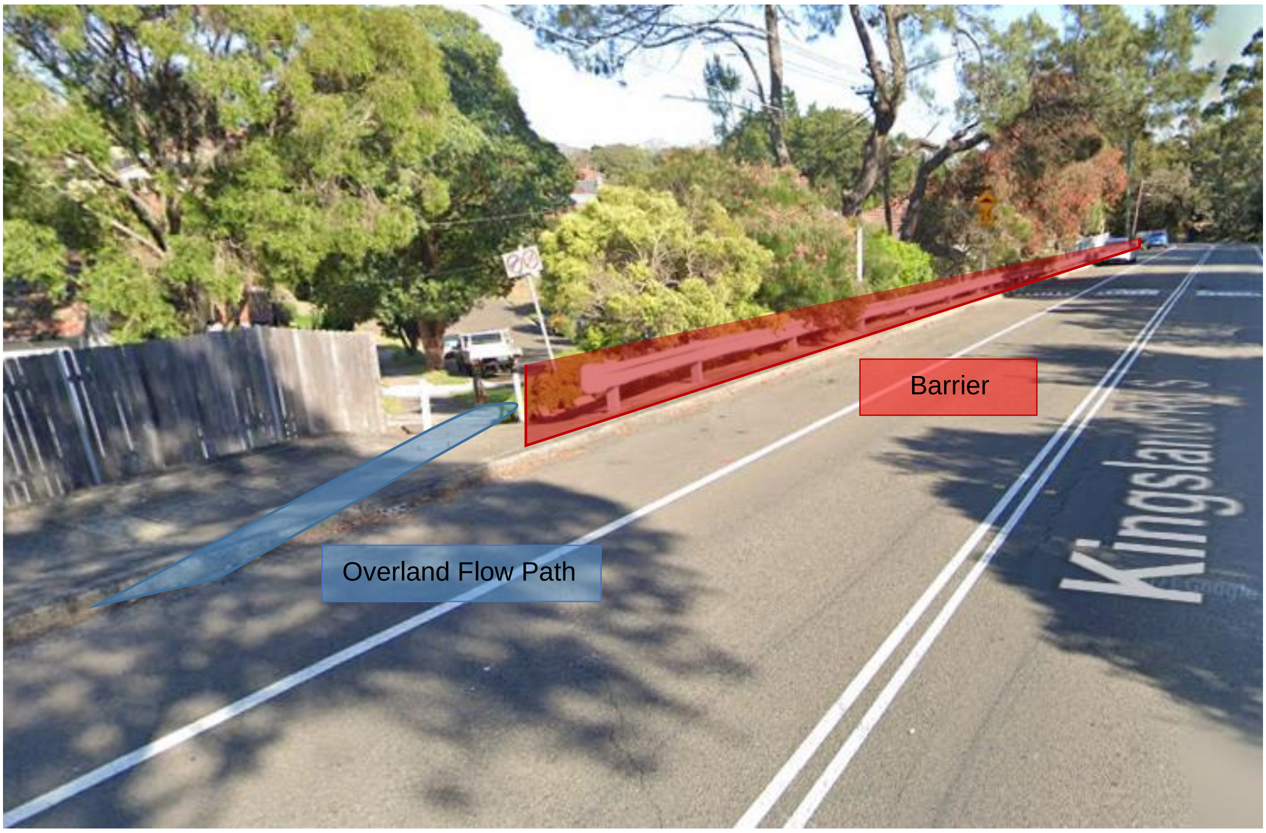


Diagram 17: Option FM03 – Kingsland Road South Flow Path Management (*Image Source: Google Street View*)

The flow path would follow the existing access laneway and discharge onto Highgate Street, where it would flow to the sag point. This would take water from the flow path crossing Kingsland Road that flows along the gutter down Kingsland Road (some flow is modelled to cross the road and flow down driveways, etc). This would reduce flow along the road in front of No's 17-23, where overflows have been observed. The barrier would consist of construction of a small impermeable wall that would stop the overflow of water from Kingsland Road South into the properties located at No's 17-23. The first point of overflow would be downstream of the properties and into Kingsland Road Reserve. The barrier could simply be raising the kerb height to prevent overflows, or construction of an actual wall. There is currently a guard rail along the road, due to the elevation of the road above the surrounding ground where the properties are located. An option may be to replace the guard rail with a concrete F-Type Jersey barrier. This would be subject to road safety requirements. The solution for this area may be one or both options.

These options are relatively easy to construct, with no significant constraints. The flow path solution would require consideration of integration with the existing footpath, and ensuring discharge into the road corridor so it does not impact on properties on Highgate Street. The barrier solution would require consideration of the driveway at No. 23, and ensuring that water is not diverted down the driveway, but into Kingsland Road Reserve.

Option Impacts

Both options were implemented as a single solution in the TUFLOW model – the overland flow path to Highgate Street and also the barrier along Kingsland Road South. The results indicated that there are no significant impacts to flooding – demonstrating that it is a drainage issue. The implementation of the options results in no overflows from Kingsland Road South through numbers 17-23. This catchment-wide TUFLOW model is at the limit of what is possible to measure when looking at options that are essentially within the gutter. The impacts for the 5% AEP and 1% AEP events are shown in Figure H5 and Figure H6, respectively.

The benefit is to remove shallow overland flows through the four properties fronting Kingsland Road South at this location (numbers 17-23). There should be no adverse impacts to residents and road users, with flows remaining within the Highgate Street and Kingsland Road South gutters.

There are likely to be minimal negative social impacts, with only slight disruption to Kingsland Road during the construction phase. If the barrier option is implemented, there will be loss of some view to numbers 17-23 Kingsland Road, although there is already a large retaining wall at this location and the benefits of removing overflows are likely to be considered worthwhile. There are likely to be minimal negative environmental impacts, with works being undertaken in areas already concreted.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $75,000, with no ongoing maintenance costs directly associated with this option. Details of costs are provided in Appendix I. This was for implementing both the flow path and barrier. The actual costs may be less than this depending on what is required.

The properties that benefit from this option did not have any damages assigned, due to the shallow nature (<0.1 m) of water that affects the area. A proper CBA was therefore not undertaken for this option.

Summary and Recommendation

☑	**FM03: Kingsland Road South Overflow Management**
Description	• Management of drainage on Kingsland Road South via overland flow path to Highgate Street and/or barrier on Kingsland Road South to prevent overflow.
Benefits	• Removes overflow from Kingsland Road South into properties 17-23.
Concerns	• Works would need to consider existing footpath between Kingsland Road South and Highgate Street. • Works would need to consider driveway at 23 Kingsland Road South. • Road safety requirements and visual amenity would need to be considered.
Approximate Cost	$75,000
CBR	No CBR is possible since damages are minimal
Responsibility	Council
Outcome	These works are recommended as a drainage upgrade, rather than a floodplain management measure.
Priority	Medium

10.2.4.7. Option FM04 Powys Avenue Drainage Upgrade

Description of Flooding

In current conditions, flood water is modelled to pond upstream of the East Hills railway line at Powys Avenue. This was noted as a hot spot in the Flood Study, with ponding depths of up to 0.9 m on the road in the 20% AEP and 1.4 m in the 1% AEP event. Overland flows are blocked by the noise walls constructed for the railway line. There is a 900 mm diameter pipe that carries flow from the street drainage network on Powys Avenue under the railway line to Wolli Creek. This drainage network extends upstream to Peacock Street. In addition to the underground pipe, there are openings in the noise wall that allow overland flows to enter the railway corridor. These are shown in Photo 14.

Photo 14: Openings for overland flow under the noise wall at Powys Avenue (*Image Source: WMAwater*)

In the TUFLOW model, these openings are represented by 12 box culverts 0.75 m (W) x 0.3 m (H). The blockage applied to these openings was 90%, due to the propensity for blockage that has been observed in the past. Once water crosses the noise wall, it ponds within the railway corridor, due to the embankment and ballast that the railway lines are sited on. In each of the design events, the ponding on Powys Avenue is higher than the ponding in the railway corridor.

Option Description

Several options were considered here, including upgrading the underground stormwater network, removing the design blockage on the existing openings through the noise wall, and duplicating these openings. The options to increase capacity through the noise wall were most beneficial. With the current assumed 90% blockage for the design flood events, removal of this blockage was effective. Once this blockage was removed, additional culverts did not provide any further substantial benefit to Powys Avenue. This is because the ponding level in the railway corridor and on Powys Avenue can equalise with the removal of blockage, however, flow is still blocked by the railway embankment. In this case, additional culvert capacity does not provide any further benefit, as water is ponded to the same level on both sides of the noise wall.

Blockage and the prevention of blockage is complex in nature, and as such there is not one solution that can provide a definite benefit in all events. If there is no blockage in one event, blockage prevention devices will not provide any additional benefit. If there is significant blockage in another event, the effectiveness of blockage prevention devices will depend on the type, magnitude and location of the material that is blocking the culvert. In this case, it is also unclear if there is any drainage infrastructure within the railway corridor or how much of the railway embankment is ballast that may allow ponded water to drain through to Wolli Creek. These uncertainties make it difficult to assess particular mitigation options.

Nonetheless, the recommended option for this location is the installation of blockage prevention devices. The following features could be considered:

- Provision of wider openings on the culvert screens, ensuring that the screen still provides adequate safety.
- Provision of sloped screens, so rather than debris collecting against a vertical screen, it tends to be pushed up to the top of the culvert, reducing blockage of the barrel. An example is shown in Photo 15.
- Provision of debris deflector walls that operate in a similar way to the sloped screens, where large debris that span the culvert width tend to be pushed to the top of the culvert. An example is shown in Photo 16.

Photo 15: Example of a sloped culvert screen *Image Source:* https://australianmade.com.au/licensees/ej/gms-headwall--box-culvert-screens

Photo 16: Example of a debris deflector *Image Source: Australian Rainfall and Runoff 2019*

The effectiveness of these features will depend on the type of debris blockage that is typically experienced at this location. It is recommended that historic blockages of the culverts be investigated through consultation with residents to understand the nature and frequency of blockage in the past. This may help guide the selection of blockage prevention device and estimate its effectiveness. Consultation would also be required with Transport for NSW. Regular maintenance and clearing of the existing screens, or any future blockage prevention devices is also recommended to ensure effective operation.

Option Impacts

Two scenarios were modelled, one where the assumed 90% design blockage on the Powys Avenue culverts was removed, and one with blockage removed and the culvert capacity doubled. The additional culverts did not provide any substantial benefit over the blockage removal, for the reasons discussed above. The option presented here is the removal of blockage as an indication of the benefits of installing blockage prevention devices. The outcome of this assessment is indicative only, and is subject to the actual blockage in any one event, the effectiveness of blockage prevention devices and also the drainage within the railway corridor which is unknown. The impacts for the 5% AEP and 1% AEP events are shown in Figure H7 and Figure H8, respectively.

The benefit to the ponded water level on Powys Avenue is approximately 0.12 m in the 5% AEP event and 0.2 m in the 1% AEP event. This reduction improves flooding for approximately five properties on Powys Avenue in the 1% AEP event. Trafficability would be improved, although with flood depths of up to 0.9 m in the 20% AEP event, the benefit may simply be reduced duration of inundation. There are increases in peak level within the railway corridor, of up to 0.3 m in the 1% AEP event. This increased level just reaches the top of the railway embankment and would reduce the flood immunity of the railway line, depending on what drainage infrastructure is currently within the railway corridor.

There are likely to be minimal negative social and environmental impacts, although potential impacts within the rail corridor should be discussed with Transport for NSW.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $35,000, with annual maintenance costs of approximately $2,000. Details of capital costs are provided in Appendix I. The NPV of these costs over the life of the asset was estimated to be approximately $60,000.

The benefit of this option was assessed by comparing the AAD of the option with the base case. The benefit to tangible AAD was estimated to be approximately $33,500. The NPV of this benefit was estimated to be approximately $420,000. A summary of the benefits to flood damages is provided in Table 37.

Table 37: Summary of flood damage benefits for FM04

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	-1	-1	-$97,200	-1	-1	-$97,200
10% AEP	-1	-1	-$101,200	-1	-1	-$101,200
5% AEP	0	0	-$16,100	0	0	-$16,100
2% AEP	-2	-2	-$198,400	-2	-2	-$198,400
1% AEP	-1	-1	-$125,300	-1	-1	-$125,300
0.5% AEP	0	0	-$48,200	0	0	-$48,200
0.2% AEP	-1	-1	-$161,400	-1	-1	-$161,400
PMF	-1	-2	-$322,700	-1	-2	-$322,700
Average Annual Damages			-$33,500	Average Annual Damages		-$33,500

The CBR of this option was therefore estimated to be approximately 6.8.

Summary and Recommendation

☑	FM04: Powys Avenue Blockage Prevention
Description	• Implement blockage prevention on openings under noise wall. • May include structural options (screens with wider openings, sloped screens, debris deflectors) and regular maintenance.
Benefits	• Reduces tendency for blockage and should improve ponding on Powys Avenue.
Concerns	• Uncertainty associated with blockage may not provide the modelled benefits. • Impacts within railway corridor and consultation required with Transport for NSW.
Approximate Cost	$35,000 capital cost plus $2,000 annual maintenance cost.
CBR	Approximately 6.8 considering direct tangible benefits. Additional benefits to driver safety and access.
Responsibility	Transport for NSW (Sydney Trains)
Outcome	These works are recommended.
Priority	Medium

10.2.4.8. Option FM05 SWSOOS Flow Path

Description of Flooding

In current conditions, flood water will pond upstream of the East Hills railway line where the SWSOOS crosses under the railway line. The flood depths in this area are approximately 0.3 m in the 20% AEP event and 1 m in the 1% AEP event. Water in this area originates from the area around Turrella Street in Turrella, where water also ponds. Water enters the depressed SWSOOS area near the intersection of Turrella Street and Thompson Street. Up to approximately the 5% AEP event, the ponding in Turrella Street is higher than the SWSOOS, with water flowing into the SWSOOS area when ponding is high enough. In larger events, the water levels at the SWSOOS and in Turrella Street are at the same level. It is in these larger events that additional flow capacity to discharge water from the SWSOOS would be beneficial to Turrella Street.

Option Description

Options in this location were originally investigated for the Lusty Street area, located to the east of the SWSOOS. It was found that flood levels in the SWSOOS area were higher than Lusty Street, as discussed in Section 10.2.3.8. Due to this, options for the ponding around the SWSOOS were investigated. During a site visit, it was found that the openings adjacent to the SWSOOS, under the railway line, were partially blocked with concrete, and only small circular openings (approximately 300 mm diameter on one side and 600 mm in diameter on the other) exist. These are shown in Photo 17 and Photo 18.

Photo 17: Western opening under the East Hills railway line adjacent to the SWSOOS

Photo 18: Eastern opening under the East Hills railway line adjacent to the SWSOOS

The option investigated here is to simply remove the concrete walls and maintain an open connection between the upstream area and Wolli Creek on either side of the SWSOOS.

This option would be relatively easy to construct, removal of the concrete walls and clearing of the area between the SWSOOS and railway abutments. It is assumed that the concrete walls form no structural support to either the SWSOOS or railway bridge. These openings would likely require porous security fencing. Consultation with both Sydney Water (asset owners of the SWSOOS) and Transport for NSW (asset owners of the railway bridge). It is also noted that the SWSOOS is also heritage listed, which may bring about additional constraints.

Option Impacts

The openings were modelled assuming a box culvert configuration 1 m wide and 4 m high on each side. Blockage of 50% was applied to each side assuming that there would be some blockage of the fencing that would be required. In the 5% AEP event, the flood level at the SWSOOS decreases by approximately 0.35 m, however, this does not provide any benefit to areas outside this depression area, due to the flood behaviour described above. In the 1% AEP event, the reduction in flood level is only 0.1 m at the SWSOOS, however the benefit extends onto Turrella Street, where the reduction is approximately 0.06 m. The impacts for the 5% AEP and 1% AEP events are shown in Figure H9 and Figure H10, respectively.

The benefit to private property is minimal, with flood levels in the vicinity of Turrella Street reducing by less than 0.1 m in the 1% AEP event. There would also be some minor benefits to trafficability on Turrella Street.

There are likely to be minimal negative social and environmental impacts, due to the minimal amount of works required.

It should be noted that in all design events, the peak flood level on the upstream side of the railway line was higher than on the downstream side in Wolli Creek. There is potential, however, for a Wolli Creek event to backflow into the SWSOOS depressed area. This may occur in events as small as the 20% AEP event in Wolli Creek. Significant inundation of the SWSOOS area would only occur in the 2% AEP Wolli Creek event (peak flood level above 2 mAHD). It is only in events that reach above approximately 2.5 mAHD that the Turrella Street area would begin to be impacted, which occurs in approximately a 0.5% AEP event. This issue is important as there may be some situations where increasing the capacity of these openings may worsen flooding (in rare events when Wolli Creek is in flood without coincident local runoff of a similar magnitude). It is likely, however, in these large events that there is substantial local runoff as well and in most circumstances this would not pose an issue.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $70,000, with no ongoing maintenance costs directly associated with this option. Details of costs are provided in Appendix I.

The benefit of this option was assessed by comparing the AAD of the option with the base case. The benefit to tangible AAD was estimated to be just $824. The NPV of this benefit was estimated to be just over $10,000. A summary of the benefits to flood damages is provided in Table 38.

Table 38: Summary of flood damage benefits for FM05

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	0	0	$-	0	0	$-
10% AEP	0	0	$-	0	0	$-
5% AEP	0	0	$-	0	0	$-
2% AEP	0	0	-$12,000	0	0	-$12,000
1% AEP	0	0	-$20,100	0	0	-$20,100
0.5% AEP	0	0	-$32,100	0	0	-$32,100
0.2% AEP	-1	-1	-$121,300	-1	-1	-$121,300
PMF	0	0	$-	0	0	-$600
Average Annual Damages			-$800	Average Annual Damages		-$800

The CBR of this option was therefore estimated to be approximately 0.2.

Summary and Recommendation

☒	FM05: SWSOOS Flow Path
Description	• Remove concrete walls and obstructions to open flow path between Turrella Street and Wolli Creek under the railway line, adjacent to the SWSOOS.
Benefits	• Slight reduction in flood levels on Turrella Street, although only in events >5% AEP.
Concerns	• Consultation required with Sydney Water and Transport for NSW. • Safety concerns – would need to be fenced. • Enlarged openings could worsen flooding on Turrella Street in rare events where Wolli Creek water levels are high.
Approximate Cost	$70,000
CBR	Approximately 0.2 considering direct tangible benefits.
Responsibility	Council, Sydney Water and Transport for NSW (Sydney Trains).
Outcome	These works are not recommended.
Priority	NA

10.2.4.9. Option FM06 Bexley Road Upgrade

Description of Flooding

Bexley Road is one of three road crossings of Wolli Creek within the Bayside LGA (on its northern boundary). Kingsgrove Road is located upstream and Harthill-Law Avenue is located downstream of Bexley Road. Bexley Road is the most flood-prone of these crossings, having been inundated in the past on numerous occasions (Photo 19). In current conditions, the 20% AEP event overtops the road with peak flood depths of approximately 1 m. Peak flood levels and depths for the existing conditions are provided in Table 39. This was identified as a flooding hot spot in the Flood Study.

Table 39: Peak flood depths and levels over Bexley Road for current conditions

Event	Peak Flood Level (mAHD)	Peak Flood Depth on Bexley Road (m)
20% AEP	7.9	1.1
10% AEP	8.3	1.5
5% AEP	8.5	1.7
2% AEP	8.8	2.0
1% AEP	9.0	2.2
0.5% AEP	9.2	2.4
0.2% AEP	9.5	2.7
PMF	13.6	6.8

Photo 19: Example of inundation of Bexley Road (*Source: Bardwell Creek 2D Flood Study Review, WMAwater 2019*)

Option Description

Bexley Road has a steep grade downward to the crossing of Wolli Creek, between the intersection with Kingsgrove Avenue and the Wolli Avenue/M5 East southbound on ramp. This is because Bexley Road crosses over the East Hills railway line at Bexley North railway station, which is located adjacent to Kingsgrove Avenue. From this overpass it descends steeply to Wolli Creek, before rising again on the other side. The distance between the Kingsgrove Avenue and M5 East intersections is approximately 160 m. Wolli Creek currently crosses under Bexley Road through three arched culverts. The minimum deck level of the road is approximately 6.8 mAHD. The level at the intersection with Kingsgrove Avenue is approximately 9.5 mAHD, while the M5 East on ramp is much higher than this. This means that it appears feasible to raise the road to have flood immunity for the 1% AEP event, given these existing road controlling levels. Any road raising that does not increase the capacity of the existing culverts would lead to higher flood levels on the upstream side, and result in the road being overtopped in any case. The most beneficial configuration for flooding would be to span Wolli Creek with a bridge structure, allowing the maximum waterway area underneath the structure. This is shown in Diagram 18.

Diagram 18: Option FM06 – Bexley Road Upgrade (*Image Source: WMAwater*)

If a bridge structure is proposed, the upstream flood level would decrease. In this case, the flood levels outlined in Table 40 could be used to estimate the deck level of the proposed structure for a given flood immunity.

Table 40: Peak flood levels at Bexley Road assuming a bridge structure with soffit above the flood level

Event	Peak Flood Level (mAHD)
20% AEP	7.7
10% AEP	8.1
5% AEP	8.3
2% AEP	8.6
1% AEP	8.9
0.5% AEP	9.1
0.2% AEP	9.3

The bridge would need to span approximately 50 m to 80 m, depending on where the abutments are positioned and the level of the bridge soffit. Construction would be difficult, and likely to require at least partial closure of Bexley Road. There are likely to be several services that are under

Bexley Road that would require relocation, and this is likely to be a significant cost. Consideration would need to be given to tying into the existing roads, particularly the Kingsgrove Avenue intersection. There is also a driveway to the west of the Wolli Creek crossing at a level of approximately 7.5 mAHD. This would most likely require re-configuration to work with the raised road. The upgrade of Bexley Road is likely to be a complex and costly exercise. The road is under the ownership of Transport for NSW, and hence any further investigations into the upgrade of this road would need to be driven by them. Bayside Council should support any Bexley Road upgrade that would improve flood risk to motorists.

Option Impacts

For modelling of this option, the existing road was removed, along with the culverts and road embankment. A bridge structure was modelled with a soffit level above the 1% AEP flood level. A typical form loss of 0.2 was applied below the deck to account for a typical pier configuration. This bridge structure resulted in a reduction in peak flood level upstream, since water no longer banks up behind the road before overtopping it. In the 1% AEP event, the reduction in peak flood level upstream is up to 0.24 m. There is some increase in flood level on Bexley Road near the intersection with Kingsgrove Avenue. This is just due to the assumed embankment and bridge abutment that would extend from Kingsgrove Avenue to where the bridge structure commences. This portion of the road is assumed to be raised to accommodate the bridge level, and hence overland flows from Kingsgrove Avenue that run down Bexley Road are now at a much higher level. There is negligible change in peak flood levels downstream of the bridge. This is because approximately the same flow is being passed downstream of the bridge. In the existing case, this was through the culverts and overtopping the road, in the proposed case this is all conveyed underneath the bridge. The storage behind the existing road embankment is therefore minimal, and removal of it does not alter downstream flood behaviour. The impacts for the 5% AEP and 1% AEP events are shown in Figure H11 and Figure H12, respectively.

There is no material benefit to private property, as upstream of Bexley Road, Wolli Creek is contained within the creek corridor. The primary benefit is to the improved flood immunity of Bexley Road. These benefits are indirect tangible damages and intangible damages that have not been quantified here. These benefits cover items such as:

- improved driver safety,
- improved accessibility (for both the public, commercial transit services and emergency services, with consideration for evacuation route access,
- reduced travel times and improved access to major roads such as the M5 East),
- potential for reduction in motor vehicle damage, injuries and fatalities,
- reduction on load for emergency services (for setting up and maintaining road closures, and also flood rescues),
- the potential to reduce the stress and anxiety of residents worried about if Bexley Road is flooded and being redirected to another route in the event of its closure.

There are likely to be substantial social impacts during construction, but significant post-construction social benefits with improved reliability of access. This would also improve access for emergency response vehicles during flood events. There are likely to be minimal negative environmental impacts, although some land clearing on the banks of Wolli Creek may be required. It is recognised that Wolli Creek is mapped as a Key Fish Habitat by NSW Fisheries, and as such any works should consider impacts to fish habitat in accordance with the Fisheries Management Act 1994.

Cost-Benefit Analysis

The cost of implementing this option was not estimated in detail, due to the complexity and number of unknowns. However, it is estimated to be in the order of $20M to $100M. This would be a cost to Transport for NSW, rather than Bayside Council. As discussed above, the benefits were not quantified in terms of a monetary value, and hence a cost-benefit analysis has not been undertaken.

Summary and Recommendation

☑	**FM06: Bexley Road Upgrade**
Description	• Upgrade Bexley Road crossing Wolli Creek.
Benefits	• Improve flood immunity, reduced flood risk and improved reliability for motorists.
Concerns	• Structure design and tie in with existing road and intersections. • Construction method and need for road closure.
Approximate Cost	$20M to $100M
CBR	Not estimated
Responsibility	Transport for NSW (Roads and Maritime Services).
Outcome	These works are recommended for Bayside Council to support.
Priority	High

10.2.4.10. Option FM07 Bardwell Park Station Levee

Description of Flooding

Bardwell Park railway station is located adjacent to Wolli Creek near Harthill-Law Avenue bridge. Overtopping of the railway embankment occurs when overbank flows from Wolli Creek inundate the railway line at the low point at the south-western end of the Earlwood Bardwell Park RSL Club carpark. The overtopping level is approximately 5.6 mAHD. When the water level in Wolli Creek is above this, it can start to flow around the carpark and into the railway corridor. Design peak water levels in Wolli Creek are shown in Table 41. The low point of the railway is located just to south-west of the end of the platform. The ground levels at the southwestern end of the station are approximately 6.0 mAHD, with the platform being at approximately 7.5 mAHD. Bardwell Park station was identified as a flooding hot spot in the Flood Study, having been inundated on numerous occasions in the past (Photo 20).

Table 41: Peak flood levels in Wolli Creek at Bardwell Park tation

Event	Peak Flood Level (mAHD)	Peak Flood Depth* (m)
20% AEP	5.9	0.3
10% AEP	6.2	0.6
5% AEP	6.4	0.8
2% AEP	6.7	1.1
1% AEP	6.9	1.3
0.5% AEP	7.0	1.4
0.2% AEP	7.2	1.6
PMF	10.5	4.9

* Approximate maximum flood depth over the railway line

Photo 20: Flooding of Bardwell Park Station in 2015 (*Source: Bardwell Creek 2D Flood Study Review, WMAwater 2019*)

While the 20% AEP Wolli Creek event can enter the railway corridor, it is the 10% AEP event that begins to cause inundation of the railway at the south-western end of the Bardwell Park station platform. In the 1% AEP event, flood depths reach approximately 1 m at the south-western end of the platform, and larger than 1 m at the low point in the railway corridor, although the platform itself is not inundated. The railway is in a cutting, with development on the southern side being much higher than the railway, and not affected by Wolli Creek flooding, and the Earlwood Bardwell Park RSL Club also located on higher ground, only being affected in the PMF event. Ponding within the Slade Road Reserve is due to local runoff that is blocked by the noise walls for the railway line.

There are also local runoff and discharge of stormwater drains into the rail corridor, which is modelled to cause ponding, although this may depend on what drainage infrastructure there is within the railway corridor that has not been included in the model.

Option Description

The option identified for Bardwell Park station is a levee. The levee would need to be at least 200 m long and be at a minimum level of 7.2 mAHD (plus freeboard) to protect the station in the 1% AEP Wolli Creek flood event. This would require a levee with a height of up to 1.6 m above the existing ground level. The levee could be constructed within the railway corridor, along an existing access track. The start of the levee, at the end of the Earlwood Bardwell Park RSL Club car park, is shown in Diagram 19.

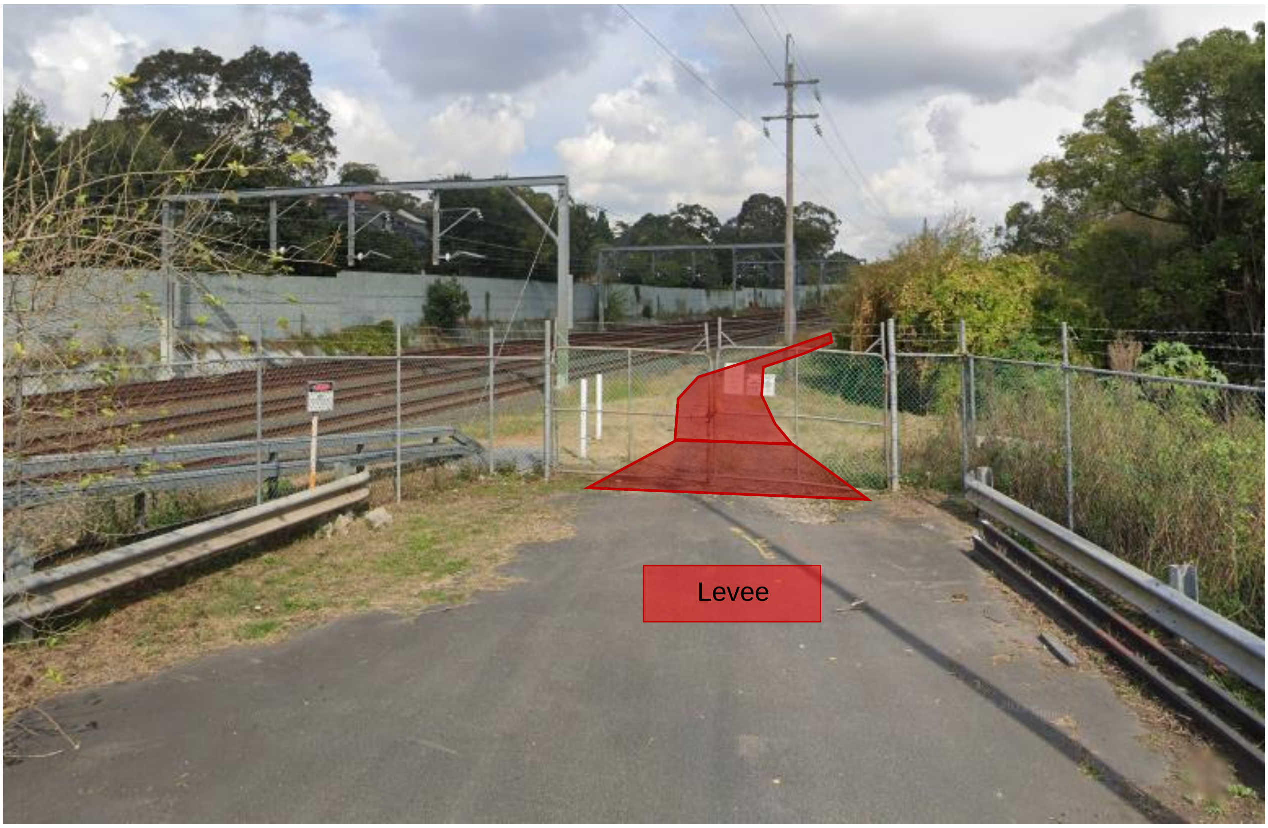


Diagram 19: Option FM07 – Bardwell Park Train Station Levee (*Image Source: Google Street View*)

The most significant constraint to construction would likely be construction within the railway corridor, including limited space and safety considerations. Levee and embankment stability would need to be assessed to determine suitability, particularly given the heavy rail use of the railway line. Local drainage may also require upgrading, such as non-return valves to ensure compatibility with the levee. The railway corridor is under the ownership of Transport for NSW, and hence any further investigations would need to be driven by them. Bayside Council should support any levee construction that reduces flood risk to Bardwell Park station.

The railway line is also inundated between Bardwell Park and Bexley North stations, although to a smaller depth than experienced at Bardwell Park station. A levee at this location was also tested, indicating increases in peak flood levels in the order of 0.6 m in the 1% AEP event within both Wolli Creek (due to Wolli Creek floodplain being constricted) and within the railway corridor (this area now becomes a flood storage area with local runoff building up behind the levee). It would require significant drainage works to resolve these issues and this measure was not investigated further in this study.

Option Impacts

A levee above the 1% AEP level was modelled for this option. This levee raises peak flood levels in Wolli Creek, while reducing them within the railway corridor. The increase in Wolli Creek was up to 0.03 m in the 5% AEP event, and 0.06 m in the 1% AEP event. These impacts extend from

Bexley Road to 500 m downstream of Harthill-Law Avenue, with the magnitude of the impact diminishing further from the levee location. These increases do not appear to have a significant impact as they are contained within the creek corridor. The benefit to flood levels within the railway corridor is up to 0.6 m in the 1% AEP event. This is approximately half the depth without the levee. The residual flooding is due to local runoff. The impacts for the 5% AEP and 1% AEP events are shown in Figure H13 and Figure H14, respectively.

There is no material benefit to private property, with all benefits contained within the railway corridor. There may be direct tangible damage benefits, such as reduction in damage to the railway line (such as ballast washout) and trains, with benefits to indirect tangible damages and intangible damages (such as clean up and inspection costs, increased accessibility and reliability of trains, etc.), that have not been quantified here. Given the previous incidents of flooding, Transport for NSW would be in the best position to estimate these damage costs. There are likely to be social benefits due to improved reliability of the rail network. There are likely to be minimal negative environmental impacts, although some land clearing may be required for construction. Impacts on the ecology and geomorphology of Wolli Creek should be investigated in subsequent studies as a result of the increase in flood levels and changes in velocity and flow behaviour.

Cost-Benefit Analysis

The cost of implementing this option was not estimated in detail. However, it is estimated to be in the order of $300,000. This would be a cost to Transport for NSW, rather than Bayside Council. As discussed above, the benefits were not quantified in terms of a monetary value, and hence a CBA has not been undertaken.

Summary and Recommendation

☑	**FM07: Bardwell Park Station Levee**
Description	• Construct levee to protect Bardwell Park station from Wolli Creek flooding.
Benefits	• Improve flood immunity and railway access during flood events.
Concerns	• Construction may be difficult within the railway corridor. • Local drainage may require upgrading, as well as consideration of embankment stability.
Approximate Cost	$300,000
CBR	Not estimated
Responsibility	Transport for NSW (Sydney Trains).
Outcome	These works are recommended for Bayside Council to support.
Priority	High

10.2.4.11. Option FM08 Guess Avenue Underground Storage

Description of Flooding

Flooding on Arncliffe Street in the suburb of Wolli Creek occurs frequently. The street is low-lying and the opportunity to drain the area is limited due to water levels in the Bonnie Doon channel, located parallel to Arncliffe Street. The channel is tidal in nature, with the Cooks River water levels influencing water levels in the channel. There are also significant trunk drainage lines that discharge into the channel, which can elevate water levels in the channel. High water levels in the channel make draining of Arncliffe Street very difficult. Ground levels on Arncliffe Street are as low as 1.2 mAHD, noting that the High High Water Spring Solstice (the highest high tide) in Botany Bay is approximately 1.1 mAHD and the 2 year ARI flood level for the Cooks River is approximately 1.45 mAHD at the Bonnie Doon channel outlet. Peak flood depths on Arncliffe Street are approximately 0.8 m in the 20% AEP event and 1.3 m in the 1% AEP event in the gutter.

Due to the low-lying nature of Arncliffe Street, the flood behaviour can be complicated, with flooding originating from local runoff as well as backwater from the Bonnie Doon channel. Factors such as Cooks River levels, flows in the Bonnie Doon channel from the upper catchment trunk drains and local rainfall runoff can play a part depending on the storm duration and AEP. For example, the critical duration for the 1% AEP event at this location was modelled to be the 90 minute storm. For this event, the water level is similar in Arncliffe Street as the Bonnie Doon channel, with water just flowing from Arncliffe Street to the Bonnie Doon channel. In the 30 minute event, although the overall peak flood levels are lower than the 90 minute storm, the water levels are higher in the channel relative to Arncliffe Street, meaning that Arncliffe Street is inundated by backwater flooding from the Bonnie Doon channel. In the 540 minute storm, the flood levels on Arncliffe Street are higher relative to the Bonnie Doon channel, meaning that water flows from Arncliffe Street to the Bonnie Doon channel.

Option Description

At the time of the project inception in late 2020, Council envisaged acquisition of land at No 2 Guess Avenue, Wolli Creek. In 2022, Council was successful in acquiring No 4 Guess Avenue for the purpose of creating a new park to service the recreational needs of the local community in an area of high-density development. The site was previously excavated to a depth of approximately 2 m and capped as part of site decontamination works by Property NSW prior to purchase of the land by Council. A concept design has been developed for the park that consists of a large open grassed area, active and play spaces with landscaping features including drainage swales and WSUD measures. Council has also purchased land located on Arncliffe Street for the proposed extension of Gertrude Street to Arncliffe Street (as identified in Section 10.2.3.12). A preliminary design for the road has been prepared.

It was considered that in the redevelopment of these sites, an underground storage tank could be constructed to help mitigate flood risks on Arncliffe Street. The site at No 4 has a smaller catchment area from which runoff can be captured and hence would be less effective in mitigating flood levels in Arncliffe Street. The site, however, is located on higher ground and there is an opportunity to drain a tank via gravity. A detention tank at No 2 would require pumping, due to the low lying nature of the site, however, it has the ability to be filled directly from ponded water on Arncliffe Street. A detention tank under the proposed Gertrude Street would be simple to construct, however this would also be low-lying and have similar issues to No 2 Guess Avenue. WMAwater completed the assessment of this option based on a detention tank at No 2 to reduce flooding on Arncliffe Street. Arncliffe Street and the site at No 2 Guess Avenue are shown in Photo 21.

Photo 21: Arncliffe Street, with the site on the corner of Guess Avenue with an acquisition reservation (*Image: WMAwater*)

This option would be difficult to construct. Not only would it require significant excavation, but the works also reduces the options for redevelopment of the site. For example, a 10,000 m^3 tank would essentially be an entire level of an underground carpark (discussed further below). The construction of a tank this large would limit the opportunity to develop any structure with an underground component. In addition to this, it is understood that there is a large high-pressure gas main at the Arncliffe Street and Guess Avenue intersection, and power transmission lines that were a significant constraint for recent drainage upgrade works on Arncliffe Street. Additional inlet capacity would need to be constructed on Arncliffe Street to get water into the tank, and it would require pumping to empty the tank, since the invert is likely to be below 0 mAHD.

The pumping out of water post-flood would need to consider the location of discharge (potentially the existing and proposed stormwater pipelines to Bonnie Doon channel), and also the timing, to ensure that the flood has passed and the tide is low. Additional considerations for storage tanks include the reliance on pumping and the possibility that the tank may be full or partially full at the onset of the storm. If, for example, the pump was broken and there were two storm events in quick succession, it is likely that the first storm could fill the storage such that there is no capacity to mitigate the second storm.

Option Impacts

Since the site at No 2 Guess Avenue would be subject to redevelopment, there are minimal constraints in terms of storage tank size that could be implemented. In the model, various detention tank sizes were modelled, from 1,000 m^3 to 10,000 m^3. For reference, a large detention tank was constructed as part of a development on Lusty Street. This tank had a capacity of approximately 750 m^3. The implementation of this tank resulted in reductions in 1% AEP flood levels on Lusty Street of just 0.02 m. The size of a 1,000 m^3 tank would, for example, cover an area of 20 m x 25 m and be 2 m deep. A 10,000 m^3 tank would be, for example, cover an area of approximately 90 m x 37 m and be 3 m deep. This is essentially an entire floor of an underground carpark of a large building covering most of No 2 Guess Avenue site. The benefits to the 1% AEP flood level on Arncliffe Street in the critical 90 minute storm are shown in Table 42 below.

Table 42: Reduction in 1% AEP peak flood levels on Arncliffe Street with varying storage tank size

Storage Tank Size (m^3)	**Reduction in Peak Flood Level (m)**
10,000	0.68
5,000	0.25
2,000	0.05
1,000	0.03

While there is a substantial reduction with a 10,000 m^3 tank, the benefits diminish below a 5,000 m^3 tank. In addition to the tank size, the mechanism producing flooding on Arncliffe Street needs to be considered, as discussed above. The tank will be most effective when Arncliffe Street is flooded by local runoff only, as the tank can store a portion of the water that is usually stored on Arncliffe Street. If Arncliffe Street is flooded by Bonnie Doon channel as well, then the tank would be less effective, since the tank can store some water, but the volume that the channel can discharge onto Arncliffe Street is larger than the volume of local runoff only. Flooding from the Bonnie Doon channel also depends on the water level in the channel – whether this is driven by a Cooks River flood, a tidal level, of flood flow from the upper Bonnie Doon catchment. Each of these floods will have a different water level hydrograph in the Bonnie Doon channel, and the peak level and duration of flooding above the level at which water can enter Arncliffe Street will dictate how much flow/volume can enter Arncliffe Street, how effective water can drain into the channel and subsequently how effective the storage would be. A summary of the reduction in 1% AEP peak flood levels on Arncliffe Street is provided in Table 43 for various storm events and a 5,000 m^3 tank.

Table 43: Reduction in 1% AEP peak flood levels on Arncliffe Street with varying storm events and durations, with a 5,000 m^3 storage tank size

Storm Event	Existing Conditions Peak Flood Level (mAHD)	FM08 Peak Flood Level (mAHD)	Reduction in Peak Flood Level (m)
5% AEP 30 min	1.97	1.61	0.36
5% AEP 720 min	1.98	1.81	0.17
1% AEP 30 min	2.16	1.68	0.48
1% AEP 90 min	2.28	2.03	0.25
1% AEP 540 min	2.23	2.23	0.0
0.5% AEP 30 min	2.52	2.44	0.08
0.5% AEP 90 min	2.58	2.58	0.0
0.5% AEP 540 min	2.40	2.40	0.0

When comparing the different durations for the 1% AEP event, there are varying benefits. For the critical 90 minute duration, the benefit is a reduction in peak flood level of 0.25 m. For a shorter duration event (30 minute), the benefit is even greater, at nearly 0.5 m, even though floodwater can enter Arncliffe Street from the Bonnie Doon channel. In the short duration event, the storage tank can store a larger proportion of the floodwater. In a longer duration (540 minute), there is no benefit, as the storm produces a large volume and fills the storage tank quickly. In the 5% AEP events, there is less flood volume and hence the storage tank provides flood benefits in the short duration (30 minute) and long duration (720 minute) events, although there is a larger benefit for the shorter duration. In the 0.5% AEP event, there is almost no benefit in any event, even the shorter duration events as flooding on Arncliffe Street is exacerbated by a high tailwater level in the Cooks River. It is this complex interaction between storm duration (runoff hydrograph and runoff volume) and Bonnie Doon channel water levels (controls how much flow/volume enters Arncliffe Street from the channel and how effective water can drain from the street to the channel), which will dictate the effectiveness of a storage tank.

The impacts for the 5% AEP and 1% AEP events (envelope of durations) are shown in Figure H15 and Figure H16, respectively for the 5,000 m^3 tank.

The benefit to private property extends along Arncliffe Street, from the bend in the road at No 34, to the shopping centre at No 78-96. The benefits also partially extend up Willis Street and Guess Avenue, depending on the level of ponding on Arncliffe Street. In this area, there has been significant redevelopment, with apartment buildings lining much of the street. These developments have been constructed well above ground levels, presumably to comply with minimum floor levels due to flooding. An example is shown in Photo 22. In this case, the flood damages due to frequent events is minimal. Flood damages that occur in more frequent events are primarily the remaining industrial buildings.

Photo 22: Typical apartment redevelopment on Arncliffe Street, with high floor levels and garage entrance crest levels (*Image: Google Street View*)

There would be substantial benefits to the road in terms of access and reduction in damage of cars parked on the street. An example of recent flooding on Arncliffe Street in February 2022 is shown in Photo 23.

Photo 23: Flooding on Arncliffe Street, February 2022

There are likely to be minimal negative social impacts, with construction occurring during redevelopment of the site. There are likely to be minimal negative environmental impacts, with the land being cleared for redevelopment in any case, and the storage tank being constructed underground.

Cost-Benefit Analysis

The cost of implementing this option would depend on the nature of the development on site and costs would be linked to the entire development, rather than being a standalone item. For example, design, construction preliminaries, land clearing, excavation works and landscaping works would be linked to the proposed redevelopment. The cost of the storage tank itself may be in the order of $1M - $8M, depending on the size to be implemented. For the purposes of the cost-benefit analysis, a cost of $4M was estimated. There would be ongoing maintenance costs associated with electricity costs, regular inspections and pump maintenance, which is estimated to be approximately $10,000 annually. The NPV of these annual costs over the life of the asset was estimated to be approximately $125,000, bringing the total estimated NPV of the project to be approximately $4.1M.

The benefit of this option was assessed by comparing the AAD of the 5,000 m^3 tank option with the base case. The benefit to tangible AAD was estimated to be approximately $32,000. The NPV of this benefit was estimated to be approximately $400,000. A summary of the benefits to flood damages is provided in Table 44. The reduction in flood damages is primarily attributed to how the damages are calculated below the floor level of the apartment buildings. These apartment buildings, having been constructed recently, are likely to be resistant to flood damage below the floor level (for example using flood compatible materials and having no electrical services below the flood planning level). In this case, it is likely that the reduction in flood damage is overestimated. However, it has been retained as images of flooding on Arncliffe Street in the past have shown a number of cars parked on the street which have presumably sustained flood damage, and hence these reductions in flood damages are considered reasonable.

Table 44: Summary of flood damage benefits for FM08

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	-1	0	-$96,900	-1	0	-$96,900
10% AEP	-1	0	-$103,700	-1	0	-$103,700
5% AEP	-1	0	-$103,700	-1	0	-$103,700
2% AEP	0	0	-$13,700	-1	-1	-$25,300
1% AEP	0	0	$-	-1	-1	-$11,600
0.5% AEP	0	0	$-	0	0	$-
0.2% AEP	0	0	$-	0	0	$-
PMF	0	0	$-	0	0	$-
Average Annual Damages			-$31,600	Average Annual Damages		-$31,900

The CBR of this option was therefore estimated to be approximately 0.1.

Summary and Recommendation

☑	FM08: Guess Avenue Storage Tank
Description	• Construct an underground flood storage tank under No 2 or No 4 Guess Avenue when redeveloped, or under the proposed Gertrude Street extension.
Benefits	• Reduces road inundation on Arncliffe Street, improving driver safety and flood immunity. • Reduces property impacts for several properties on Arncliffe Street, although most have high floor levels.
Concerns	• Would depend on proposed redevelopment and future use of the site. • Constraints include underground services. • Reliance on storage being empty at the start of the storm and reliance on pumping of water out of the tank.
Approximate Cost	$1M - $8M
CBR	Approximately 0.1 considering direct tangible benefits and vehicle damage. Additional benefits to driver safety.
Responsibility	Council
Outcome	These works are recommended for further investigation during redevelopment.
Priority	Low

10.2.4.12. Option FM09 Queen Victoria Street Drainage Diversion

Description of Flooding

There is a flow path that originates near Glenfarne Street, and it traverses private properties and roads in a south easterly direction. Near Caledonian Street there is another small catchment that joins this flow path. At Beaconsfield Street, it is joined by the flow path from Verdun Street (and Dominey Reserve). This combined flow discharges into an open channel before entering a 1800 mm pipe. This discharges into a 1.9 m (W) x 1.21 m (H) box culvert and is conveyed under Queen Victoria Street and discharges into an open channel near Washington Street.

Upstream of Caledonian Street, the flood depth on the flow path in the 1% AEP event is typically less than 0.3 m, while it reaches just over 0.3 m between Caledonian Street and Beaconsfield Street. Downstream of Beaconsfield Street, the depth can reach over 0.5 m on the flow path and over 2 m in the channel. Flood depths on Queen Elizabeth Street also reach over 0.5 m in the 1% AEP event.

Option Description

This option was originally proposed in the previous FRMS as a high priority measure. The scheme consisted of a variety of components, of which one was a new 900 mm pipe down Queen Victoria Street. Currently there is a drainage network down Queen Victoria Street, from Monomeeth Street to Caledonian Street. A 750 mm diameter pipe continues down Caledonian Street to the sag point (where the overland flow path is located). This option looks at diverting this line straight down the western side of Queen Victoria Street as a 900 mm diameter pipe, and joining it to the box culvert before it crosses under Queen Victoria Street. This would be a 900 mm diameter pipe. This option is shown in Diagram 20. This would help alleviate flows on the overland flow path from Caledonian Street through private properties.

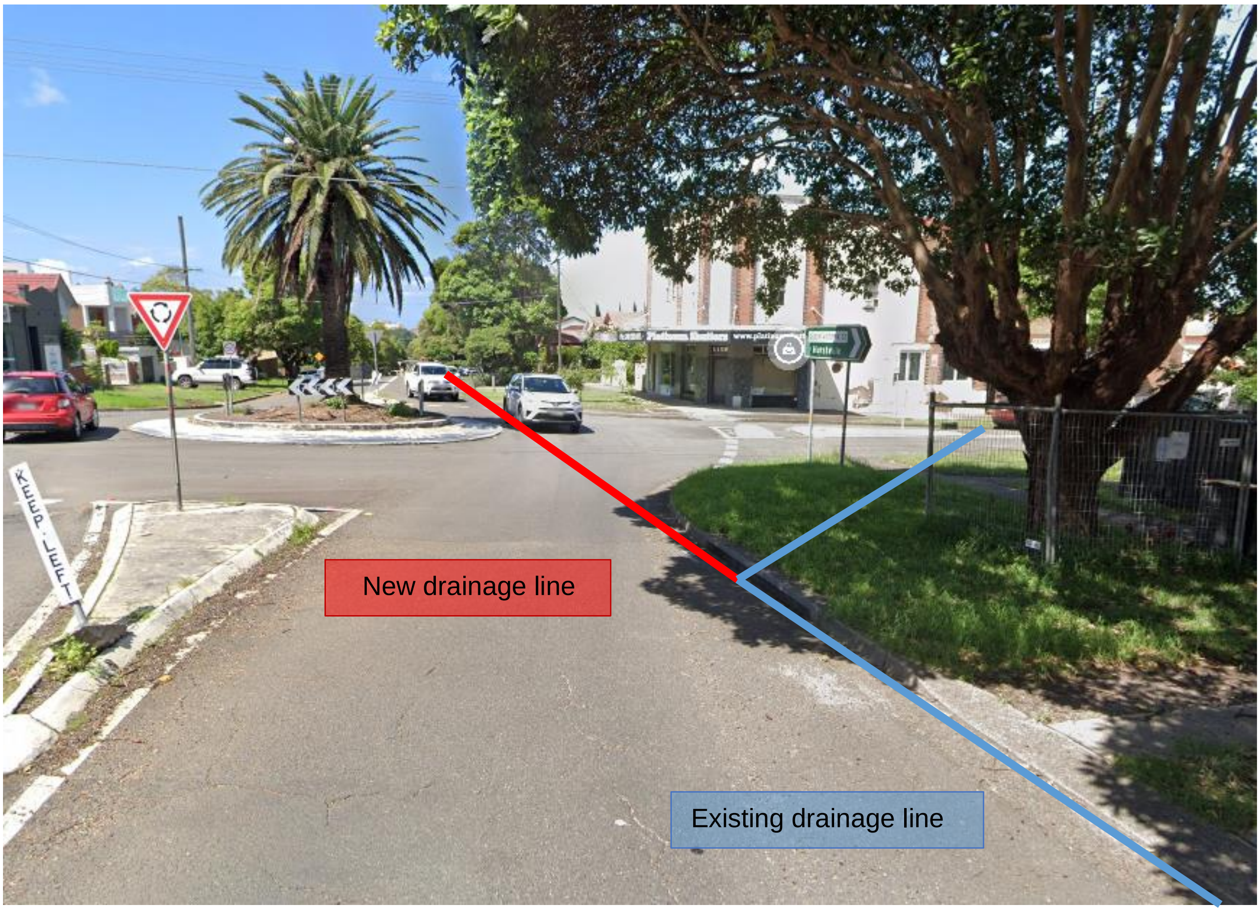


Diagram 20: Option FM09 – Queen Victoria Street Drainage Diversion (*Image Source: Google Street View, looking south down Queen Victoria Street at Caledonian Street*)

This option would be feasible to construct. There is an existing upstream pit and pipe network to collect runoff, and the new 900 mm diameter pipe would be approximately 350 m in length. The road is on a continual downward grade and there is sufficient grade for a pipe. It would need to cross three intersections, two of which are roundabouts. Queen Victoria Street is wide, with room for a driving lane and parking lane in each direction. It is envisaged that the pipe could be laid along the parking lane, removing the need to close the road for traffic and avoiding mature trees which line the sidewalk in the nature strip. There may be several services that would need to be avoided or relocated, which may be a significant constraint. In addition, it is unknown to what extent the mature tree roots would extend and the implications of digging a trench on the road. There is also a small drainage network in the vicinity of Beaconsfield Street that outlets to a 450 mm pipe that runs down Queen Victoria Street and connects to the box culvert. This drainage would require reconfiguration, potentially discharging into the new line.

Option Impacts

The current TUFLOW model is limited in the pipe network that it contains. The main drainage line is included, from Glenfarne Street to Caledonian Street, however the upstream branch network from Queen Victoria Street is not included in the model. The catchment that this branch drains is assumed to be catchment MC27 in the XP-RAFTS model, which is input into the TUFLOW model at the Caledonian Street low point. To model this option, the new drainage line was included along Queen Victoria Street, from Caledonian Street to the box culvert just downstream of Connemarra

Street. Sub-catchment flows from MC27 were applied directly to this pipe (rather than to the pits on Caledonian Street.

The pipe was modelled to contain flows up to and including the 0.5% AEP event. Since the pipe carries these flows, the existing pipe network can carry more flow and this reduces the overland flows from Northbrook Street to Queen Victoria Street. Reductions on the overland flow path are up to 0.2 m in the 5% AEP event, and 0.1 m in the 1% AEP event. Reductions on Queen Victoria Street at the sag point are only 0.01 m in the 5% AEP event and 0.03 m in the 1% AEP event. In the 5% AEP event, there are slight increases downstream of Queen Victoria Street, of up to 0.05 m, although these are typically within the channel. In the 1% AEP event, the benefit continues downstream, with reductions of up to 0.1 m just upstream of Wolseley Street. The impacts for the 5% AEP and 1% AEP events are shown in Figure H17 and Figure H18, respectively.

The benefit to private property is reasonable, with several properties located on the overland flow path that benefit from the new pipe. These properties, however, are not significantly flood affected in current conditions due to the shallow nature of flooding on the flow path.

There are likely to be minimal negative social impacts, with only some disruption during construction to traffic on Queen Victoria Street, and particularly access implications for properties on the western side of the road. There are likely to be minimal negative environmental impacts, with the pipe constructed under the existing road and no clearing of land required.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $2.3M with no ongoing maintenance costs directly associated with this option. Details of costs are provided in Appendix I.

The benefit of this option was assessed by comparing the AAD of the option with the base case. The benefit to tangible AAD was estimated to be $55,600. The NPV of this benefit was estimated to be approximately $700,000. A summary of the benefits to flood damages is provided in Table 45.

Table 45: Summary of flood damage benefits for FM09

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	-5	-1	-$126,200	-5	-1	-$126,200
10% AEP	-5	-1	-$126,200	-6	-2	-$140,900
5% AEP	-4	-1	-$177,700	-4	-1	-$209,600
2% AEP	-2	-5	-$191,500	-2	-5	-$198,600
1% AEP	-4	-5	-$475,100	-4	-5	-$478,900
0.5% AEP	-3	-10	-$560,400	-3	-10	-$564,600
0.2% AEP	-1	-9	-$477,600	-1	-9	-$488,100
PMF	-1	-7	-$345,400	-1	-7	-$347,800
	Average Annual Damages		-$53,000	Average Annual Damages		-$55,600

The CBR of this option was therefore estimated to be approximately 0.3.

Summary and Recommendation

☑	**FM09: Queen Victoria Street Drainage Diversion**
Description	• Construct a new 900 mm diameter pipe along Queen Victoria Street, from Caledonian Street to the sag point just downstream of Connemarra Street.
Benefits	• Reduces flooding on overland flow path through properties. • Minor benefits to sag points on Caledonian Street, Beaconsfield Street, Connemarra Street and Queen Victoria Street.
Concerns	• Potential underground utilities that may need to be avoided or relocated, as well as tree roots. • Need to reconfigure existing drainage network on Queen Victoria Street to accommodate the new pipe. • Disruption to traffic and residents on Queen Victoria Street during construction.
Approximate Cost	$2.3M
CBR	Approximately 0.3 considering direct tangible benefits.
Responsibility	Council
Outcome	These works are recommended for further investigation.
Priority	Low

10.2.4.13. Option FM10 Seaforth Park Detention Basin

Description of Flooding

In current conditions, there is a flow path down Dunmore Street. Seaforth Park is located at the southern end of Dunmore Street, at the intersection with Caledonian Street. There is an existing 600 mm diameter pipe under Seaforth Park, and flows in excess of the stormwater network flow over land through the park. This flow path continues downstream of Seaforth Park, through private properties and crossing roads. It eventually ponds on Warialda Street, stopped by the Frys

Reserve detention basin wall, and flows under the railway via Hegerty Street and then into Muddy Creek. 1% AEP flood depths on this flow path downstream of Seaforth Park reach just over 0.5 m in some locations, although it is typically less than 0.3 m.

Option Description

This option was originally proposed in the previous FRMS as a high priority measure. A cascading basin configuration was proposed, consisting of two basins. It was demonstrated that a cascading basin configuration could reduce downstream peak flows by up to 50%, with the basins storing up to 3,000 m^3 in the 1% AEP event. It was considered necessary to combine the basin option with additional stormwater upgrades since there remained significant overland flows downstream of the basins.

The same cascading basin configuration is proposed here, with an upper and lower basin. The basins would primarily be excavated, with a small bund on the downstream side. These basins are shown in Diagram 21 and Diagram 22.

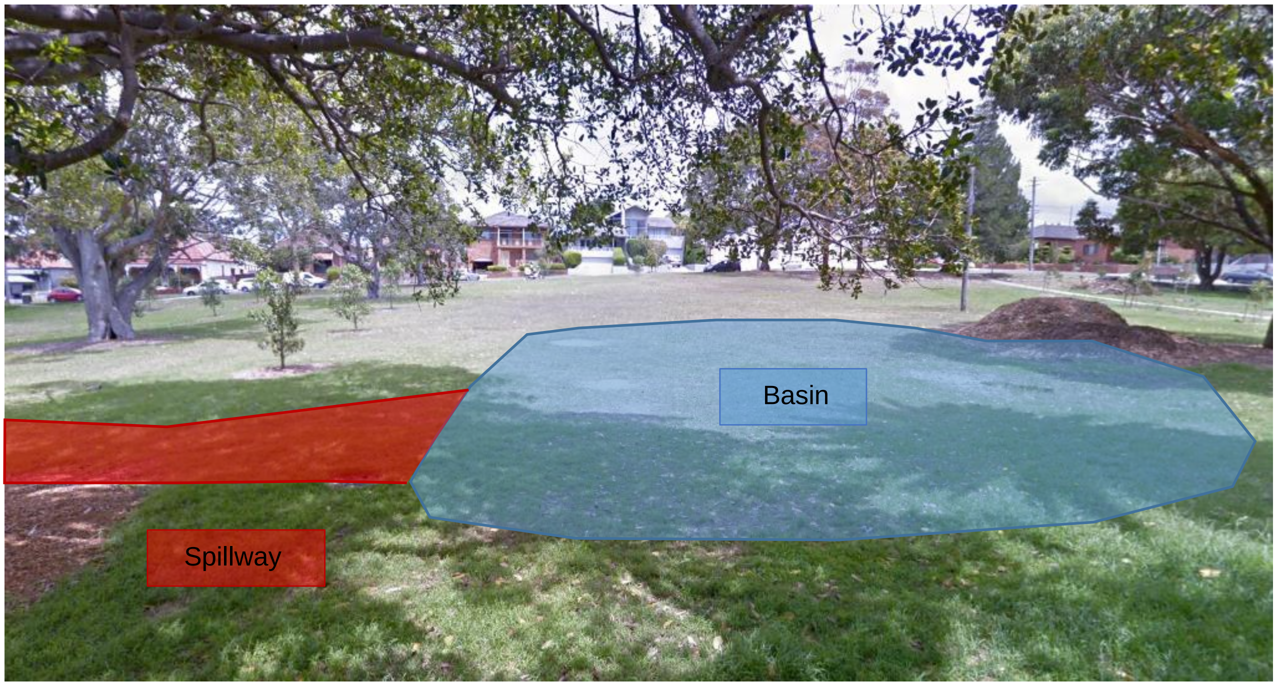


Diagram 21: Option FM10 – Seaforth Park Detention Basin – Upper Basin (*Image Source: Google Street View*)

Diagram 22: Option FM10 – Seaforth Park Detention Basin – Lower Basin (*Image Source: WMAwater*)

It is assumed that the existing 600 mm diameter pipe under the park would be retained, and that basin excavations would avoid the pipeline. Minor works would be required on Caledonian Street to direct over land flows into the park on the western side, where the basins would be located. The existing pathway running through the park could also be raised slightly to help contain water within the basins. Both basins would be connected to the underground 600 mm diameter pipe as a low flow outlet, and have a designated spillway for flows in excess of the basin volume.

This option would be relatively easy to construct, involving earthworks within the open grass areas to excavate the basins. The pipe is already under the park and would just require two new pits connected to it. A small bund would be required around each basin and some minor works on Caledonian Street to direct flows into the basins. The mature trees in the park would be avoided. There is likely to be minimal services crossing under the park.

Option Impacts

A cascading basin configuration was tested in the TUFLOW model, with the features presented in Table 46. This would require a net cut of approximately 5,000 m^3 to form these two basins.

Table 46: Seaforth Detention Basins Configuration

Basin Design Element	Upper Basin	Lower Basin
Invert Level (mAHD)	32.9	29.9
Spillway Level (mAHD)	33.9	30.8
Crest Level (mAHD)	34.2	31.0
Excavation Area (m^2)	1,760	1,260
Volume to Spillway (m^3)	1,500	975

The basins were modelled to have the capacity to store overland flows up to and including the 1% AEP event, without any overtopping of the lower basin. There were minor increases to flood levels on the edge of Caledonian Street to get water into the basins, however this should not affect trafficability of the road. There were no overland flows on Beaconsfield Street up to the 1% AEP event. From Dunmore Street, where overland flows from downstream of Seaforth Park are modelled, there are reductions in overland flood levels down to Warialda Street, and even extending into Muddy Creek downstream of the railway. The reduction in flood levels is typically 0.05 m in the 5% AEP and 1% AEP events, although there are reductions up to 0.1 m at sag locations such as Connemarra Street and Warialda Street. The benefits to Muddy Creek are minimal, being less than 0.03 m. The impacts for the 5% AEP and 1% AEP events are shown in Figure H19 and Figure H20, respectively.

The benefit to private property is reasonable, with properties along the 500 m flow path from Seaforth Park to Warialda Street experiencing reduced flooding. Flood depths in the 1% AEP event are typically 0.1 m to 0.3 m, so it is likely that above floor flooding is not common, and hence the tangible benefit to properties may not be that significant. There are additional benefits to the road sag points, with reduced peak levels and duration of inundation.

There are likely to be minimal negative social impacts, with only disruption to the western half of Seaforth Park during construction. The grass areas would still be able to be used in dry conditions. There are likely to be minimal negative environmental impacts, with cleared land able to be re-landscaped and no large tree removal required.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $3.9M, with no ongoing maintenance costs directly associated with this option. The largest single item in the cost estimate is the disposal of clean fill, with a cost of $1.7M. A rate of $209 per tonne has been assumed in accordance with Rawlinsons (Reference 38) for disposal of clean fill. The total volume of excavated soil to be disposed of was estimated to be just over 5,000 m^3, or approximately 8,130 t, assuming 1.6t/m^3. If Council can use this fill elsewhere, or dispose of in a more cost-effective manner, the total cost of the project could be significantly reduced. Details of costs are provided in Appendix I.

The benefit of this option was assessed by comparing the AAD of the option with the base case. The benefit to tangible AAD was estimated to be $82,200. The NPV of this benefit was estimated to be approximately $1M. A summary of the benefits to flood damages is provided in Table 47.

Table 47: Summary of flood damage benefits for FM10

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	-2	-5	-$185,500	-2	-5	-$185,900
10% AEP	-2	-5	-$181,500	-2	-5	-$181,500
5% AEP	-3	-1	-$396,600	-3	-1	-$396,600
2% AEP	-4	-1	-$526,500	-4	-1	-$526,500
1% AEP	-3	-1	-$313,100	-4	-2	-$327,300
0.5% AEP	-2	0	-$183,800	-2	0	-$185,300
0.2% AEP	-5	0	-$443,700	-5	0	-$445,300
PMF	-1	-1	-$69,000	-1	-1	-$70,100
		Average Annual Damages	-$81,400	Average Annual Damages		-$81,600

The CBR of this option was therefore estimated to be approximately 0.3, noting the estimated costs for disposal of fill discussed above. The CBR increases to 1.3 if there were no soil disposal costs. Soil disposal costs would need to be approximately 10% or the current rate (i.e. approximately $20/t) for the CBR to be 1.0.

Summary and Recommendation

☑	FM10: Seaforth Park Detention Basin
Description	• Excavate Seaforth Park to form two detention basins. • Construct pit outlets in the basin that connect to the existing 600 mm pipe under the park.
Benefits	• Reduces impacts for properties downstream of the basin on the overland flow path to Warialda Street. • Improves flooding on roads such as Connemarra Street and Warialda Street, improving driver safety and flood immunity.
Concerns	• It is assumed that the 600 mm pipe under the park can be used ‘as is’ to form the low flow outlet of the basin and there is no need to relocate it and that the basin excavation will not interfere with it.
Approximate Cost	$3.9M
CBR	Approximately 0.3 considering direct tangible benefits. CBR may be as high as 1.3 if soil disposal costs can be minimised. Additional benefits to driver safety and access.
Responsibility	Council
Outcome	These works are recommended for further investigation.
Priority	Medium

10.2.4.14. Option FM11 Subway Road Drainage Upgrade

Description of Flooding

Downstream of the railway line, Muddy Creek is a concrete lined channel that runs through the suburb of Rockdale. While most branches upstream of the railway line join Muddy Creek at Frys Reserve, there is one branch that joins downstream of the railway line. This branch runs to Rockdale railway station, near Frederick Street and the Seven Ways. From there flow is conveyed under the railway line through a box culvert. On the downstream side of the railway, it continues primarily as a 1350 mm diameter pipe. This pipe crosses Hegerty Street and Subway Road. From Subway Road to Muddy Creek, it is a 1.8 m x 1 m box culvert that runs under the current Stewart Toyota Rockdale site on the corner of Subway Road and Princes Highway. There is shallow flooding on Hegerty Street (less than 0.1 m) in the 1% AEP event. There is a sag point on Subway Road where water ponds to depths over 0.5 m in the 1% AEP event. Deep flooding is mostly restricted to just the sag point on the road. Overland flows can also run through the Toyota site to Muddy Creek.

Option Description

This option was originally proposed in the previous FRMS&P as a medium priority measure as a drainage upgrade, and a low priority measure as improving the overland flow path at Subway Road. It is noted that the drainage improvements were not investigated in detail, and the overland flow path from Subway Road to Muddy Creek was to be investigated as part of site redevelopment (presumably the site of the current Stewart Toyota Dealer). Several options were investigated as part of the current FRMS, including upgrading of the drainage line and construction of a new drainage line along Hegerty Street (adjacent to the railway line) to Muddy Creek. Upgrades of the drainage line downstream of the railway did not provide any improvement to flooding upstream of the railway. Downstream of the railway, the only area of concern is the sag point of Subway Road. As such, the option presented is duplication of the existing box culvert from Subway Road to Muddy Creek. The purpose of this option is to maintain the existing trunk drainage line to Muddy Creek, while providing a dedicated drainage line for Subway Road. The line duplication is shown in Diagram 23.

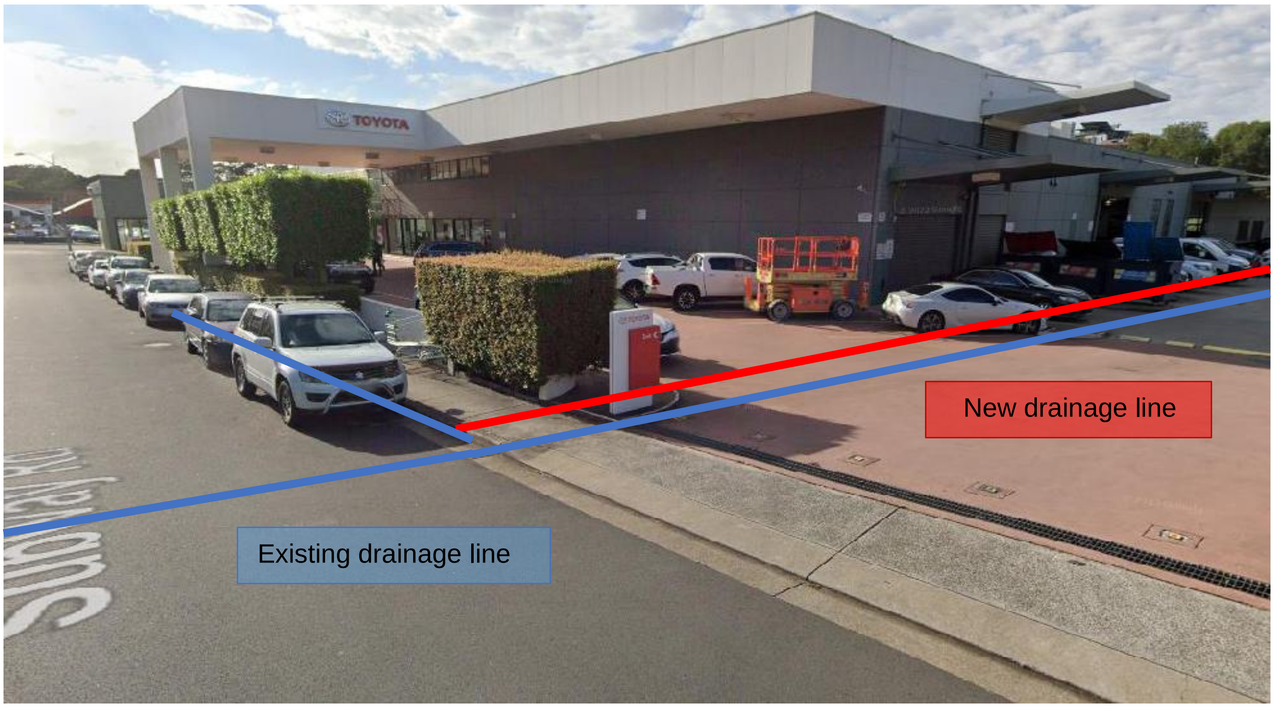


Diagram 23: Option FM11 – Subway Road Drainage Upgrade (*Image Source: Google Street View*)

The new drainage line would be approximately 75 m in length, and would need to run under the existing Toyota site. This would require works within the street, on existing paved areas within the site, and under buildings at the rear of the site. There are also likely to be services that would need to be avoided.

Option Impacts

This option was modelled by duplicating the existing drainage line from Subway Road to Muddy Creek. This resulted in a reduction in flood levels on Subway Road of 0.45 m in the 5% AEP event, and 0.55 m in the 1% AEP event, meaning that flood depths on Subway Road would be less than 0.1 m. This also removes overland flow from Subway Road to Muddy Creek. The impacts for the 5% AEP and 1% AEP events are shown in Figure H21 and Figure H22, respectively.

The benefit is primarily to the Toyota dealership and the industrial buildings on the opposite side of Subway Road. There would be benefits to road users of Subway Road, significantly reducing hazard to vehicles, although it is noted that there are only 12 residential lots on Subway Road, and alternative access is available via Hegerty Street.

This upgrade would be a significant undertaking and cause disruption to Subway Road and the Toyota dealership. There would be minimal environmental impact, as the work would be carried out in areas already paved.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $1.6M, with no ongoing maintenance costs directly associated with this option. Costs associated with building removal for the Toyota site or any additional compensation required for this site (for example a wider drainage easement) have not been included. Details of costs are provided in Appendix I.

The benefit of this option was assessed by comparing the AAD of the option with the base case. The benefit to tangible AAD was estimated to be $7,800. The NPV of this benefit was estimated to be almost $100,000. A summary of the benefits to flood damages is provided in Table 48.

Table 48: Summary of flood damage benefits for FM11

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	0	0	$-	-1	-1	-$16,900
10% AEP	0	0	$-	-1	-1	-$11,600
5% AEP	0	0	$-	-1	-1	-$38,500
2% AEP	0	0	$-	-1	-1	-$56,100
1% AEP	0	0	$-	-1	-1	-$60,500
0.5% AEP	0	0	$-	-1	-1	-$65,200
0.2% AEP	0	0	$-	-1	-1	-$70,600
PMF	0	0	$-	0	0	$700
Average Annual Damages			$-	Average Annual Damages		-$7,800

The CBR of this option was therefore estimated to be approximately 0.1.

Summary and Recommendation

	FM11: Subway Road Drainage Upgrade
Description	• Duplicate existing drainage line from Subway Road to Muddy Creek.
Benefits	• Reduces road inundation on Subway Road, improving driver safety and flood immunity. • Minor reduction in property affectation – primarily to commercial/industrial sites.
Concerns	• Construction within existing Toyota dealership site, including crossing of paved areas and buildings. • Potential conflicts with services.
Approximate Cost	$1.6M
CBR	Approximately 0.1 considering direct tangible benefits. Additional benefits to driver safety and access.
Responsibility	Council
Outcome	These works are not recommended as part of this FRMS&P, however, should be considered as part of future development of the land.
Priority	NA

10.2.4.15. Option FM12 Mutch Avenue Drainage Line

Description of Flooding

Flooding occurs in Mutch Avenue, Tancred Avenue and Owen Avenue in Kyeemagh due to local runoff. These roads are located adjacent to the Cooks River. Local runoff ponds at two trapped low points, one at the corner of Tancred Avenue and Owen Avenue, and the other at the cul-de-sac of Mutch Avenue. Ponding at the corner of Tancred Avenue and Owen Avenue is between 0.3 m and 0.4 m deep across the range of flood events from the 20% AEP to 0.2% AEP. This is because once water ponds high enough, it can flow down Owen Avenue and discharge into the Cooks River. At the Mutch Avenue sag point, water cannot freely discharge to the Cooks River, and modelled flood depths range from almost 0.5 m in the 20% AEP event to 0.8 m in the PMF event. Once water ponds high enough, it flows through a public reserve and discharges to the Cooks River via the Kyeemagh boat ramp. There is currently a 450 mm diameter pipe that runs from the Tancred Avenue and Owen Avenue low point, crossing Mutch Avenue and continuing in a north-west direction to discharge into Muddy Creek. The Mutch Avenue and Owen Avenue cul-de-sacs are serviced by 300 mm diameter pipes that discharge to the Cooks River.

Option Description

Several options were investigated for the ponding at these locations, including:

- An overland flowpath from the Mutch Avenue cul-de-sac to the Cooks River.
- Tripling the existing stormwater pipes (450 mm diameter) from Tancred Avenue to Muddy Creek.
- Duplicating the existing stormwater pipes on Tancred Avenue (450 mm diameter), and providing a new stormwater line down Mutch Avenue (600 mm diameter) that would outlet to the Cooks River (900 mm diameter).
- New pipe (900 mm diameter) from the Mutch Avenue cul-de-sac to the Cooks River.

The overland flow path was modelled to be 10 m wide and have a maximum invert level at 2.25 mAHD. This provides 0.5 m freeboard above the Cooks River 1% AEP flood level. With a gutter invert level of approximately 1.95 mAHD, this still results in a minimum of 0.3 m of ponding on the street before the flow path is activated. The modelled flow path only reduces the activation level by approximately 0.1 m over the existing flow path activation level. This results in very little change (-0.02 m) to the ponding depths on Mutch Avenue. For the flow path to be beneficial, it would need to be much lower, although this risks inundation from the Cooks River. The flowpath, however, would still be above the 1% AEP Cooks River flood level.

The tripling of the Tancred Avenue pipes produced only 0.03 m and 0.02 m reductions in flood levels in this area for the 5% AEP and 1% AEP events, respectively. The duplication of this line with a new outlet to the Cooks River had more substantial benefits, up to 0.3 m in the 5% AEP and 0.2 m in the 1% AEP event. Much of this impact, however, is the new outlet from Mutch Avenue to the Cooks River. As such, the option investigated further was simply a new 900 mm pipe from the Mutch Avenue cul-de-sac to the Cooks River (Diagram 24). This would be connected to pit inlets at the end of Mutch Avenue, in a similar manner to the existing 300 mm diameter pipe.

Diagram 24: Option FM12 – Mutch Avenue Drainage Line (*Image Source: Google Street View*)

Option Impacts

A new 900 mm diameter pipe was modelled from the end of Mutch Avenue to the Cooks River. This was connected to two pit inlets on Mutch Avenue, and had an upstream invert level of 0.52 mAHD and downstream invert level of 0.23 mAHD. This means the culvert would be subject to tidal inundation.

The reduction in peak flood level was up to 0.34 m in the 5% AEP event and 0.17 m in the 1% AEP event. This only affected the Mutch Avenue low point, although the reduction in ponding extends up to Tancred Avenue. The impacts for the 5% AEP and 1% AEP events are shown in Figure H23 and Figure H24, respectively. There are benefits to private property on Mutch Avenue as well as road trafficability.

There is likely to be minimal environmental impact with this option. The alignment should be able to avoid any trees in the public reserve between Mutch Avenue and the Cooks River, and any disturbance can be reinstated with landscaping. There may be requirements to consider the water quality of the discharge to the Cooks River. Outlet works should adhere to the Guidelines for Controlled Activities on Waterfront Land (DPE) and consider impacts to fish habitat in accordance with the Fisheries Management Act 1994, as the Cooks River is mapped as a Key Fish Habitat by NSW Fisheries. There are likely to be minimal social impacts, as construction may only temporarily restrict access at the very end of the Mutch Avenue cul-de-sac and within the public reserve.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $400,000, with no ongoing maintenance costs directly associated with this option. These costs may also depend on the configuration of the Cooks River outlet, which is assumed to just be a headwall at this stage. Details of costs are provided in Appendix I.

The benefit of this option was assessed by comparing the AAD of the option with the base case. There is no tangible benefit of this option, since none of the properties on Mutch Avenue were estimated to be inundated above floor level. The flood depths at the dwelling locations are estimated to be less than 0.2 m in events up to and including the 0.2% AEP event. In the PMF event, where properties are inundated, the option makes negligible difference to the flood levels. As such, there is no direct tangible benefits calculated based on residential flood damages. There may be some external damages avoided, although this is likely to be minimal with the ponded nature of water. There may be some vehicle damage for cars parked on the street, although these could easily be moved in the event of rising waters.

The CBR of this option was therefore estimated to be zero.

Summary and Recommendation

☒	**FM12: Mutch Avenue Drainage Line**
Description	• Construct a new pipe from Mutch Avenue to Cooks River.
Benefits	• Reduction in road inundation on Mutch Avenue, improving driver safety and flood immunity.
Concerns	• No significant concerns.
Approximate Cost	$400,000
CBR	Zero, considering direct tangible benefits.
Responsibility	Council
Outcome	These works are not recommended for further investigation, however, there may be opportunity for Council to improve the overland flow path through the park during future open space upgrades.
Priority	NA

10.2.4.16. Option FM13 Alice Street Drainage Line

Description of Flooding

Waradiel Creek runs through the eastern side of Sans Souci, from north to south. The main flow path runs from Pemberton Reserve to Alice Street. At Alice Street, it is piped one block to the east, and continues along an open channel down the middle of Alfred Street. At Sandringham Street, it is piped again and discharges into the open channel at Peter Depena Reserve, which discharges into Botany Bay under Sanoi Avenue at the Georges River sailing club. There are several areas of ponding along this flow path, however, one of the most significant is the ponding between Pemberton Reserve (Park Road) and Alice Street. 5% AEP flood depths reach 0.5 m and 1% AEP flood depths reach 0.9 m in this area.

Option Description

This option was originally proposed in the previous FRMS as a medium priority measure. With an estimated cost of $1.8M, the CBR was only 0.2. The new box culvert that was investigated was 1.8 m x 1.2 m in size, running a length of 473 m from the corner of Chuter Avenue, along Alice Street to Botany Bay (Diagram 25). The same option was investigated as part of this study. The culvert would take flows from the open channel at the corner of Chuter Avenue and Alice Street where there is currently a 1200 mm diameter pipe and 750 mm diameter pipe. The 1200 mm pipe crosses Alice Street diagonally and runs through properties to the open channel on Alfred Street. The 750 mm pipe crosses Chuter Avenue and runs east along Alice Street before crossing Alice Street and discharging into the Alfred Street open channel. The new box culvert would most likely cross Chuter Avenue and run along the northern side of Alice Street, where the existing 750 mm diameter pipe runs. The culvert would then cross the Grand Parade and run through Cook Park to discharge into Botany Bay.

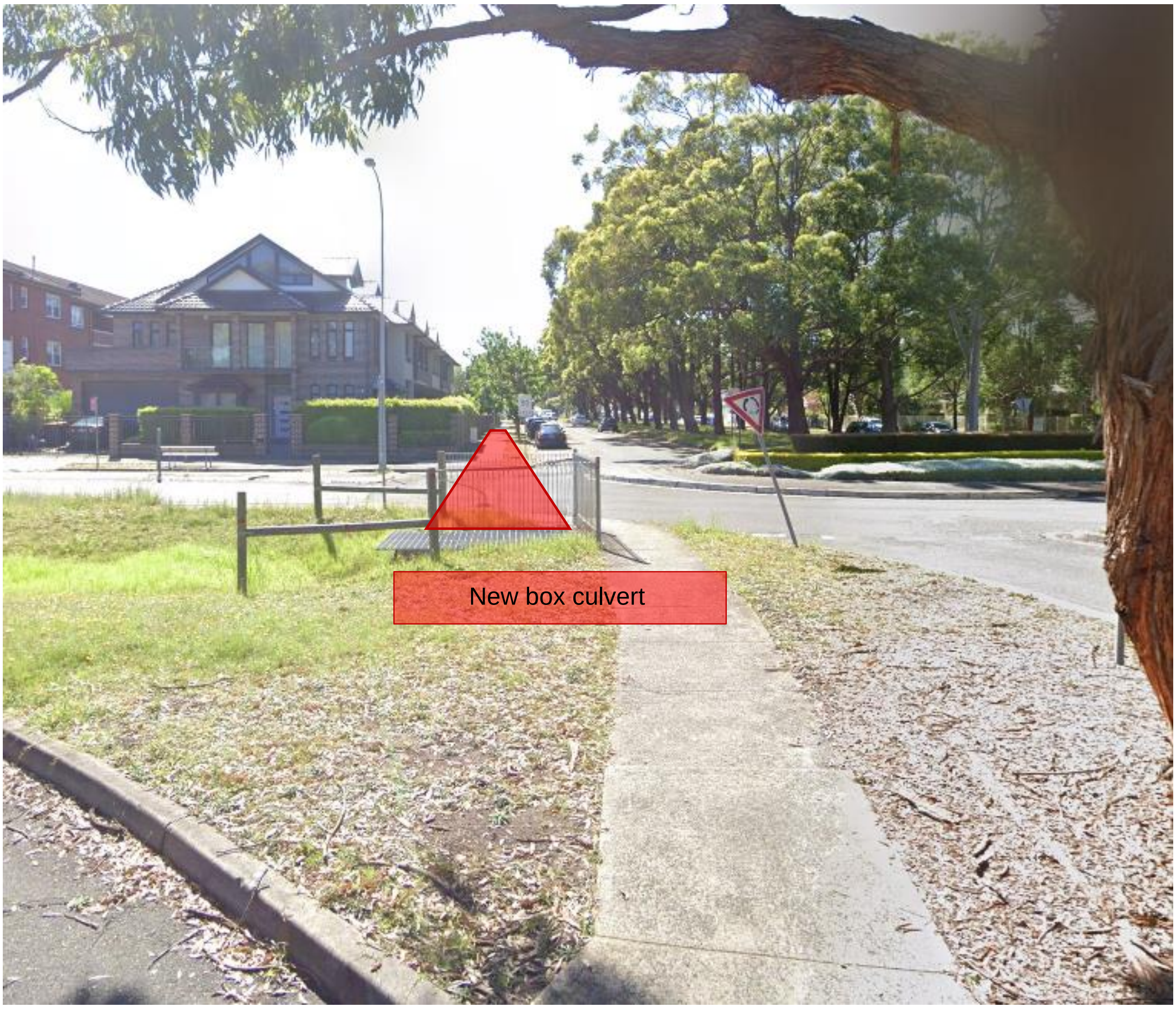


Diagram 25: Option FM13 – Alice Street Drainage Line (*Image Source: Google Street View*)

This option would need to avoid the existing 750 mm diameter pipe, and other drainage lines that cross Alice Street at Alfred Street. Trees in Cook Park would need to be avoided, and hence following the existing footpath would be the most feasible option. There is a rock groyne near this location that could serve as an outlet location if discharge of stormwater across the beach was not desirable. There are likely to be several services that would need to be avoided or relocated. Construction on/under main roads, such as The Grand Parade, would be difficult.

Option Impacts

A new 1.8 m (W) x 1.2 m (H) box culvert was modelled from the corner of Chuter Avenue and Alice Street to Botany Bay. The upstream invert level was 0.85 mAHD (the modelled channel invert) and the downstream level was set to 0 mAHD. This is a grade of approximately 0.17% over the 500 m length of the culvert. This would also mean that the culvert would be subject to tidal inundation if a non-return valve was not fitted. The upstream channel would already be subject to tidal inundation, being connected to Botany Bay at the Waradiel Creek outlet.

The reduction in peak flood levels in the upstream channel with the new pipe is up to 0.5 m in the 1% AEP event, and 0.6 m in the 5% AEP event. The benefit extends upstream to Pemberton Reserve, where flood levels are reduced by up to 0.2 m in both events. There are slight benefits to flooding on Alice Street (less than 0.1 m reduction), and benefits in the Alfred Street channel downstream of up to 0.4 m, although flooding remains within the channel at this location. There are minor benefits downstream in Peter Depena Reserve of up to 0.03 m. The impacts for the 5% AEP and 1% AEP events are shown in Figure H25 and Figure H26, respectively.

There are benefits to private property, particularly between Park Road and Alice Street. There are only minor benefits to flooding on roads such as Alice Street.

There is potential for some environmental impacts. This may include disturbance of vegetation in Cook Park, and potential for tree removal, depending on the alignment. There is likely to be a need for installation of a GPT on the line to ensure discharge into Botany Bay is clean. Consideration should also be given to the stormwater quality that will be discharged into the bay and WSUD requirements. There are likely to be social impacts, including disruption from partial closure of Alice Street and The Grand Parade. Parts of Cook Park in the vicinity of the Pine Park playground would also need to be closed during construction. There may be community criticism about a new stormwater outlet in the vicinity of the beach areas.

Cost-Benefit Analysis

The cost of implementing this option was estimated to be approximately $7.9M, with no ongoing maintenance costs directly associated with this option. These costs may also depend on the configuration of the outlet, which is assumed to just be a headwall with some scour protection at this stage. Details of costs are provided in Appendix I.

The benefit of this option was assessed by comparing the AAD of the option with the base case. The benefit to tangible AAD was estimated to be $116,000. The NPV of this benefit was estimated to be approximately $1.45M. A summary of the benefits to flood damages is provided in Table 49.

Table 49: Summary of flood damage benefits for FM13

Event	Residential Flood Damages			Total Flood Damages		
	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages	Change in # Properties Affected	Change in # Properties Flooded Above Floor	Reduction in Damages
20% AEP	-4	0	-$86,400	-4	0	-$86,400
10% AEP	-8	-3	-$278,300	-8	-3	-$278,300
5% AEP	-10	-4	-$470,000	-10	-4	-$470,000
2% AEP	-13	-16	-$1,491,500	-13	-16	-$1,491,500
1% AEP	-16	-19	-$1,690,300	-16	-19	-$1,690,300
0.5% AEP	-16	-15	-$1,529,700	-16	-15	-$1,529,700
0.2% AEP	-22	-19	-$1,839,500	-22	-19	-$1,839,500
PMF	-26	-60	-$6,078,400	-27	-61	-$6,153,600
Average Annual Damages			-$116,300	Average Annual Damages		-$116,300

The CBR of this option was therefore estimated to be approximately 0.2.

Summary and Recommendation

☑	FM13: Alice Street Drainage Line
Description	• Construct a new box culvert from the corner of Chuter Avenue and Alice Street to Botany Bay.
Benefits	• Reduces property impacts for numerous properties, particularly between Park Road and Alice Street. • Reduces road inundation slightly.
Concerns	• Significant construction required on major roads and through Cook Park. • Stormwater outlet to Botany Bay would need to consider water quality and other coastal constraints. • Low grade of culvert and tidal affectation to be considered.
Approximate Cost	$7.9M
CBR	Approximately 0.2 considering direct tangible benefits.
Responsibility	Council
Outcome	These works are recommended for further investigation.
Priority	Low

10.2.5. Catchment-Wide Flood Modification Options Investigated

Several additional flood modification options were investigated that are not site-specific, but rather are catchment-wide strategies. These are discussed in the following sections.

10.2.5.1. FM14 Channel and Drainage Maintenance

Option Description

Maintenance of the drainage network is important to ensure it is operating with maximum efficiency and to reduce the risk of blockage or failure. Maintenance involves regularly removing unwanted vegetation and other debris from the drainage network, particularly at culverts, inlet pits and within channels.

Blockage has the potential to increase peak flood levels as water is unable to efficiently drain away. A proactive approach to drainage maintenance will help manage the risk of blockage occurring during a flood event. Installation of GPTs, particularly in proximity to at risk structures, can also ensure that the structures remain clear.

Discussion

Whilst debris build does contribute to increased flood levels the issue is more complex than may be first assumed for the following reasons:

- Council already has a rigorous debris removal program for the pit and pipe network.
- Council does undertake creek clearing if advised of major debris build up (fallen trees or similar).
- It is generally only during a storm event that there is a major release of debris into the drainage system due to fallen trees, wheelie bins swept into the creek, fences fallen over or water and wind sweeping debris from yards or other sources. Maintenance prior to the event does little to reduce these debris sources.
- Blockage of small culverts has little impact in large events as the percentage of flow in these structures is very small and thus has only a small impact on peak flood levels.

Vegetation within channels is also a form of blockage. It is often community perception that an open channel full of vegetation has significantly less capacity and exacerbates overbank flooding. The real benefits to 'clearing out the creek', however, are minimal and there are numerous environmental limitations. A test was done throughout Sans Souci, where there are numerous vegetated open channels. A reduction in channel vegetation was modelled by changing the Manning's 'n' of the channels from 0.045 to 0.02 (essentially concrete lined). This resulted in no discernible change to the 1% AEP peak flood level across Sans Souci. It is not recommended to completely clear out vegetated creeks.

Council currently has a service level guarantee to sweep the gutters of every street within the LGA twice per month. A manual sweeping crew has been created to sweep out from behind parked cars in areas where the gutter is generally inaccessible. Council also has a dedicated creeks and drains crew and every pit across the LGA is inspected once per annum and cleaned as required. All inlets and outlets are cleared 10 m upstream or downstream of the stormwater drainage structure at a minimum on a quarterly basis. This channel and drainage maintenance scheme is appropriate. Council is aware of specific areas prone to blockage, however, Council should periodically review and update these areas based on feedback from the community. Council staff can also use the blockage sensitivity maps presented in Figure 41 of Appendix C, D, E and F for each model area and discussed in Section 7.5 to determine which locations are sensitive to blockage that may require additional attention.

Summary and Recommendation

☑	FM14: Channel and Drainage Maintenance
Description	Maintenance involves regularly removing unwanted vegetation and other debris from the drainage network, particularly at culverts, inlet pits and within channels.
Benefits	Removal of vegetation and debris blockage from structures will enable a more efficient conveyance of water.
Concerns	• The major release of debris is during the storm event, and hence regular maintenance may not necessarily reduce blockage during a flood event. • Vegetation in open channels is not a significant constraint to the hydraulic capacity of the channel.
Approximate Cost	No additional cost.
CBR	NA
Responsibility	Council
Outcome	Council already has an appropriate creek and drainage maintenance program, and it is recommended to continue this program. Council is aware of specific areas prone to blockage, however, Council should periodically review and update these areas based on feedback from the community. Council should also inspect and record channels and drainage structures following flood events to assess debris build up and clear blockages.
Priority	High

10.2.5.2. FM15 Levee inspection and Maintenance Program

Option Description

Levees consist of raised walls or embankments designed to keep floodwaters out of a particular area. Due to their nature, they require regular maintenance to ensure that the risk of failure is low. Risk of failure can increase if the embankment has experienced erosion, or if there are structural issues with a wall. This option implements an inspection and maintenance program to ensure that all levees are in optimal condition and have minimal risk of failure.

Discussion

The Bayside West study area has two designed ‘wall’ type levees – one at Fry’s Reserve detention basin and the other at The Strand. An earthen embankment levee exists at Hillcrest Avenue. These levees are described further in Section 7.6, where the results of a levee failure assessment are also presented. The levee failure assessment for these levees indicated that failure did not produce significant impacts on adjacent and downstream areas, primarily due to the build up of local runoff behind each levee that meant that failure did not significantly increase peak flood levels outside of the levee. It is envisaged, however, that depending on the storm characteristics, that there could be a situation where peak flood levels in the mainstream creek are significantly higher than the local runoff ponding inside the levee, and as such levee failure may produce more adverse impacts. In any case, it is important that these levees remain structurally sound to ensure the risk of failure during a flood event is minimal.

Bayside Council currently does not have a regular levee inspection and maintenance program.

Summary and Recommendation

☑	FM15: Levee Inspection and Maintenance Program
Description	Regularly inspect levees for signs of weakness (e.g. erosion or cracks) and maintain them, including drainage systems behind the levee and filling of gaps.
Benefits	Ensures risk of levee failure is minimised during flood events.
Concerns	Needs to be regularly inspected and maintained (e.g. at least annually).
Approximate Cost	$10,000 per annum
B/C Ratio	NA
Responsibility	Council
Outcome	It is recommended that Council implements a regular levee inspection and maintenance program.
Priority	Medium

10.2.5.3. FM16 Drainage Capacity Upgrades

Option Description

This option investigates catchment-wide drainage upgrades for the pit and pipe network, with the view to reducing flooding and improve access on roads across the Bayside West study area. It is likely that the pit and pipe network was only designed for say a 20% AEP event, and even in that event, there is still inundation on roads (as water makes its way into pits, bypasses pits or in areas where capacity is exceeded). This option was originally envisaged by Council as implementing a pit and pipe system capable of conveying the 5% AEP design flows. It is difficult to specify a pipe size for a specific design standard in an area such as Bayside West, as the pipe capacity depends on the catchment to the pipe, the pipe capacity upstream and downstream, and the 'feeder' network, that is, the pit and pipe system that is designed to collect local runoff and convey it into trunk drainage lines.

Discussion

As shown in various other options to upgrade the pipe network, there is often very little difference to overland flood levels. The pit and pipe network typically carries only a very small proportion of flows, and hence increasing capacity does not tend to reduce the magnitude of inundation of roads. Upgrade of these stormwater systems is also difficult in fully developed urban areas such as Bayside West. It would require digging up the road, kerb and gutter, existing pits and pipes, and laying new pipes and potentially new pits, pit inlets, gutters, road surfaces and verges. This can be complicated by things such as trees alongside roads, utilities and services, and sections of the pipe network that may cross through private property or even under buildings in some cases. This option is not realistic to achieve.

A pipe capacity assessment was undertaken with the results presented in Section 7.2. This indicated that a significant portion of pipes are at capacity in the 20% AEP event. In some cases there are downstream pipes which appear to not be at capacity in larger flood events, however, this may just be a function of the upstream pipes throttling flows. If upstream pipes were enlarged to allow a greater flow, then it may be that this pipe would also be at capacity in smaller events such as the 20% AEP event. The actual ‘capacity’ of urban stormwater networks is difficult to quantify and specifying a certain AEP capacity at a catchment-wide scale is difficult to implement with piece-meal upgrades.

As an example, all stormwater pipes were doubled in each of the models to observe the change in peak flood levels. The change in 5% AEP and 1% AEP peak flood levels with duplicating the stormwater network for each of the study areas is shown in Figure H27 to Figure H34. General comments on the results include:

- There is typically minimal change in peak flood levels on overland flow paths (reductions within 0.02 m).
- On some major overland flow paths or within flood storage areas, the reduction can be larger, although typically less than 0.2 m.
- There can be increases within downstream creek systems, typically up to 0.1 m.

The most sensitive area is the Muddy Creek catchment, where there are localised decreases over 1 m. This is partially because the stormwater upgrades in this catchment include culvert crossings of concrete lined channels, and the way that catchment flows are input directly into the stormwater network. In general, however, catchment-wide stormwater upgrades either make very little difference in overland flow areas or can make flooding worse in downstream areas. In areas where there are substantial improvements, local drainage upgrades have been investigated.

Summary and Recommendation

☒	FM16: Drainage Network Upgrades
Description	Increase pit and pipe network capacity to cater for say, the 5% AEP event.
Benefits	Reduced flooding on roads.
Concerns	Very difficult to achieve on a catchment-wide basis.
Approximate Cost	NA
B/C Ratio	NA
Responsibility	Council, Transport for NSW (Roads and Maritime Services and Sydney Trains), Sydney Water.
Outcome	This option is not feasible, however, Council should encourage the upgrading of pipelines in areas of redevelopment to increase the existing capacity of the stormwater network where this is feasible.
Priority	Not recommended as a flood mitigation option.

10.2.5.4. FM17 Channel Upgrades

Option Description

This option investigates catchment-wide channel upgrades, typically for the concrete lined channels within the study area, but also for the vegetated channels. Channel modifications are undertaken to improve the conveyance and/or capacity if a creek or drainage system. This includes measures such as straightening, concrete lining, removal/augmentation of structures, dredging or widening.

Discussion

The channels within the study area are typically concrete lined, with some vegetated channels in Sans Souci. These channels are constrained by urban development, and channel widening is not feasible in most locations. Structures over the channels are also typically single spans with no piers that do not significantly restrict the channel capacity.

A review was undertaken of the channel network to identify any areas of improvement. Some of these were investigated in more detail and were found not to be feasible or provide any significant flood benefit. Even simple options such as covering open channels or providing walls for the channel had significant difficulties in implementation and not causing adverse impacts elsewhere. The only option to avoid this is large-scale upgrades of the whole channel, which is not realistic. As a catchment-wide option, this was not pursued further.

Summary and Recommendation

☑	FM17: Channel Upgrades
Description	Increase the conveyance or capacity of channels in the study area.
Benefits	Reduced overbank flooding on roads and through properties.
Concerns	Very difficult to achieve on a catchment-wide basis, particularly with existing constraints.
Approximate Cost	NA
B/C Ratio	NA
Responsibility	Council and Sydney Water
Outcome	This option is not feasible.
Priority	Not recommended as a flood mitigation option.

10.2.5.5. FM18 Filling of Low-Lying Land

Option Description

The filling of low-lying land is a flood mitigation measure in response to rising sea levels due to climate change. Typically filling of flood prone land is not encouraged, as it displaces floodwater elsewhere, causing adverse impacts. The filling of areas affected by tidal inundation, however, can displace water back into the ocean, and have negligible impact on 'flood' levels due to tidal inundation.

Discussion

This is a climate change adaptation pathway suited to the low-lying regions of the study area, such as the suburbs of Wolli Creek and Arncliffe, lower Muddy Creek, Scarborough Ponds and Sans Souci. It would involve systematic and widespread filling of areas predicted to be inundated by rising sea level. This typically involves the raising of roads, as well as filling of private lots during redevelopment.

Modelling was undertaken for the Sans Souci area. In this scenario, all private land and roads were filled to ensure a minimum elevation of 2.6 mAHD (the 1% AEP Botany Bay level + 0.9 m sea level rise). Public areas, including the Botany Bay foreshore and creeks remain at existing levels. The 1% AEP flood was simulated with this adjustment to the topography as well as the 1% AEP event with 0.9 m sea level rise, with the results presented in Figure H35 and Figure H36, respectively. In each case, the impact map shows the change in peak flood level compared to the base case with no filling. The results indicate that there are increases in peak flood level in the upstream areas, up to 0.4 m. This is primarily due to raising of roads that avoids overtopping and hence was level within the upstream creeks increase. This is partially exacerbated by some filling of the flood fringes. This is most evident on Bado-berong Creek. In the downstream reach, however, there is a decrease in flood level of up to 0.2 m. This is also the case on the other major creeks, although to a lesser extent. Some areas of ponding outside of the major creeks show an increase in flood level purely due to the raised terrain. In the 1% AEP event with sea level rise, there are increases across the entire area, up to approximately 0.4 m.

It is recommended that a study should be undertaken to investigate the viability of this option. This would be similar in nature to a climate change adaptation study recently undertaken for the suburbs of Davistown and Empire Bay (Reference 48). These suburbs are low lying, with sea level rise projections estimated to have a significant impact on infrastructure and properties. The climate change adaptation plan identified several pathways through which these suburbs can adapt to sea level rise, including development controls, levees and filling strategies. The filling strategy for these areas is not straightforward, with consideration needed to be given to:

- the timing of filling (noting that properties/infrastructure will be developed/redeveloped/filled at different rates),
- residual areas of high hazard or flood impacts from partial filling,
- what is to be filled (including roads, public spaces and private properties),
- how the cost is distributed between public and private funding, and the nature of local drainage upgrades that would also be required.

The first step for any adaptive filling is to incorporate filling criteria into Council's DCP, driven by an overarching climate change policy (see Section 10.3.9).

Summary and Recommendation

☑	**FM18: Filling of Low-Lying Land**
Description	Filling of low lying land to achieve protection from rising sea levels.
Benefits	Protection of properties and infrastructure from sea level rise.
Concerns	Widespread filling that involves both public and private land is difficult to achieve in a way that is consistent and does not cause intermediate impacts to land holders.
Approximate Cost	NA
B/C Ratio	NA
Responsibility	Council (investigate, develop policy, raise local roads), private landowners (raise private land).
Outcome	It is recommended that an investigative study be undertaken if Council and residents wish to pursue this option.
Priority	Low

10.2.5.6. FM19 Automatic Tidal Gates

Option Description

Automatic tidal gates are installed on creeks that discharge to the ocean. They prevent the ingress of tidal water into the creek system. They typically consist of a mechanical flap that is automatically driven by buoyancy on open waterways, or a simple flap or inline non-return valve (Photo 24) on pipe outlets.

Photo 24: Inline non-return valve on a Cahill Park outlet to the Cooks River (*Source: Bayside Council*)

Discussion

Automatic tidal gates could be installed on culvert and channel outlets to Botany Bay and the Cooks River to prevent inundation of tidal waters that can cause inundation of land or exacerbate flooding during a storm event. While these would prevent tidal inundation there are several issues to consider:

- Non-return values can be prone to blockage and require regular maintenance. Blockages can also prop the gate open; such that tidal ingress is possible.
- Needs to ensure that ground levels are high enough to prevent inundation over land (i.e. a levee needs to be in place for the culvert devices to work efficiently.
- Sea level rise should be considered. This may prevent drainage of inland areas and raise water levels anyway.
- This option may have environmental impacts within the coastal protection zone, in addition to changing the water composition behind the tidal gates from being salt water or brackish, to being fresh water. This has widespread implications for ecological communities within the riparian zone.

Summary and Recommendation

	FM19: Automatic Tidal Gates
Description	Installation of automatic tidal gates on drainage outlets to prevent tidal backflow.
Benefits	Will prevent tidal inundation of some low-lying land.
Concerns	Although simple in nature, the environmental constraints would need to be considered in addition to considering issues such as sea level rise and inundation of areas over land (rather than from the drainage system).
Approximate Cost	NA
B/C Ratio	NA
Responsibility	Council
Outcome	This option is not considered feasible.
Priority	Not recommended as a flood mitigation option.

10.3. Property Modification Options

Property modification measures aim to reduce flood risk to existing and future developments. Options to modify the existing land use include voluntary house raising and flood proofing that can be implemented to reduce damage to existing properties, while voluntary purchase schemes can be implemented to remove dwellings from areas of high flood hazard, thereby reducing the number of residents at risk and potentially improving flood conveyance. Flood risk to future developments can be managed via land use planning and flood related development controls which regulate where and how various types of developments are constructed based on the flood affectation of the land. The key tools Council uses to regulate development are the LEP and the DCP. This section discusses each of the property modification options investigated and assesses their suitability for implementation in the study area.

10.3.1. PM01: Voluntary House Raising

Description

Voluntary house raising (VHR) seeks to reduce the frequency of exposure to flood damage of the house and its contents by raising the house above the FPL. This results in a reduction in the frequency of household disruption and associated trauma and anxiety, however other external flood risks remain, such as the need to evacuate prior to properties being isolated by floodwaters.

VHR schemes are eligible for state government funding based on criteria set out in the *Guidelines for Voluntary House Raising Schemes* (Reference 49). In accordance with these guidelines, VHR is generally excluded for properties located within floodways; is limited to low hazard areas; and applies only to houses constructed before 1986. House raising is most suitable for non-brick single storey buildings on piers, and is typically not feasible for slab-on-ground constructions. However, advances in construction techniques and other alternatives may make house raising a viable option for slab-on-ground properties, and therefore individual assessments are required. Repurposing the ground floor for non-habitable use and constructing a second story (above the

FPL) for habitable uses may also be a possibility. The VHR guideline states that "*VHR can be an effective strategy for existing properties in low flood hazard areas where mitigation works to reduce flood risk to properties are impractical or uneconomical"* (Reference 49).

An indicative cost to raise a house is between $30,000 and $100,000 (Reference 50) though this can vary considerably depending on the specific details of the house (such as topography, structural integrity of the house, services to reconnect, access stairs, laying of a slab underneath, etc). Additionally, the type of construction of a house can make raising unfeasible, either technically or economically. There can be many additional construction difficulties (brick fire place, brick garage attached to house, awnings or similar attached to a house). Additional costs relate to temporary relocation costs during construction and unwillingness of the home owner to pay the unfunded portion of the raising costs.

Discussion

Voluntary house raising as a mitigation measure has been successful in the past in areas where regular mainstream flooding occurs frequently. However, as these older houses are nearing the end of their useful life, re-building has become comparatively much cheaper than in the past and landowners want modern features in their houses (en-suite, air conditioning, several bathrooms) there are few opportunities for house raising to be a viable measure. This trend has been further increased with developers and land owners seeing the opportunity to re-develop an old house as a dual occupancy.

Most houses within the study area are a brick construction, and there were no specific flood prone properties that were identified that met the criteria for house raising. As such, house raising as a flood mitigation option in the Bayside West study area is unlikely to be a viable due to the lack of suitable buildings. However, this measure is always available for residents to pursue if they are interested.

Experience has also shown that many owners of houses that potentially could be raised are not interested for reasons such as:

- they do not want an elevated entry to their house,
- the house is old without modern facilities and will be re-developed in the near future,
- owners will have to live elsewhere during the construction phase (possibly 2 months),
- owners are unwilling to pay the costs not funded under the grant scheme (attached garage or fireplace),
- whilst it is possible to raise most single storey non brick houses many owners consider the inconvenience too much of a burden,
- flood insurance is now available,
- the owners of any low lying building that has experienced frequent above floor inundation over the past 30+ years will generally have addressed the issue by modifying the entrance to the building (constructing minor walls or landscaping) as the above ground water depths are shallow (less than 0.3m) and thus a local measure can eliminate or significantly reduce the problem.

Properties that were identified for VHR in the previous FRMS reports include No 69 Hannam Street in Bardwell Valley, six properties in the Upper Bonnie Doon catchment (not individually identified) and five properties near Spring Street Drain, immediately upstream of West Botany Street in Banksia. No 69 Hannam Street has recently been redeveloped, and hence flood damages have been reduced, assuming that the new floor level is at the FPL (Photo 25). VHR of the properties identified in Upper Bonnie Doon were rejected due to a low CBR. The remaining properties near Spring Street Drain were a medium priority and to be investigated on a case-by-case basis. There does appear to be four houses on West Botany Street and one house on Lynwen Crescent that would be suitable for house raising, however it is unlikely to be economically viable. The AAD for these properties totals just $4,250 and floor levels are only estimated to be inundated in events larger than the 1% AEP event.

Photo 25: Redevelopment of No 69 Hannam Street, Bardwell Valley (*Image: Google Street View*)

Summary and Recommendation

☒	**PM01: Voluntary House Raising**
Description	Physically raise existing dwelling structures above the FPL to reduce exposure to flood damage
Concerns	Construction type of housing stock in Bayside West is typically brick/rendered, slab on ground or multi-storey buildings.
Outcome	Voluntary house raising is not recommended for Bayside West.

10.3.2. PM02: Voluntary Purchase

Description

Voluntary Purchase (VP) schemes are a long-term option to remove residential properties from areas of high flood hazard. VP is recognised as an effective floodplain risk management measure for existing properties in areas where:

- There are highly hazardous flood conditions and the principal objective is to remove people living in these properties and reduce the risk to life of residents and potential rescuers,
- A property is located within a floodway and its removal may contribute to a floodway clearance program that aims to reduce significant impacts of flood behaviour elsewhere in the floodplain by improving the conveyance of the floodway, or
- Purchase of a property enables other flood mitigation works to be implemented (e.g. channel improvements or levee construction).

In the NSW Government *Guidelines for Voluntary Purchase Schemes* (Reference 51), the eligibility criteria notes that VP will be considered only where no other feasible flood risk management options are available to address the risk to life at the property, and that subsidised funding is generally only available for residential properties. Once a house is purchased it would be demolished, and a restriction placed upon the lot to prevent future residential or commercial development.

The NSW Government Guideline sets out the way in which a VP scheme should be undertaken and how properties should be valued. Valuations are to assume there are no flood related development constraints applied to the property. The aim of this is to allow those who take up voluntary purchase to be able to buy a similar property in a location not subject to flood risk, acknowledging that flood impacted properties often have lower value.

Discussion

VP is an effective strategy where it is impractical or uneconomic to mitigate high flood hazard to an existing property and it is often employed as part of a wider management strategy. The median house price in the study area is between $1.5M and $2.2M, depending on the suburb. The average annual damage experienced per property is between $1,500 and $6,000, which makes this option economically not viable.

The following properties were identified for voluntary purchase in the previous studies:

- No 20 Hillcrest Ave, Bexley (high priority).
- No’s 18 and 27 Hillcrest Ave, Bexley (not recommended - not economically viable)
- No 71 Hannam Street, Bardwell Valley (not recommended – not in a high hazard area, this property has also since been redeveloped).
- Potential VP of properties along flow path upstream of Arncliffe Park for drainage upgrade and overland flow path (high priority).
- No 19 Union Street, Kogarah (high priority).

- One or more properties on the Connemarra Street, Bexley, between Beaconsfield Street and Washington Street (it was noted that the property owners did not favour this option, and hence the Queen Victoria Street drainage diversion was recommended).

No houses were previously identified for voluntary purchase in the Spring Street Drain, Scarborough Ponds or Sans Souci catchments. The VP of the above properties are either not economically viable or were recommended as part of wider drainage improvement options. The two exceptions were the VP of No 20 Hillcrest Avenue, Bexley and No 19 Union Street, Kogarah. No 20 Hillcrest Avenue has since been subject to redevelopment, with habitable floor levels raised above the ground, presumably at the FPL (Photo 26). No 19 Union Street, Kogarah, is modelled to be up to H3 hazard and only just on the edge of the floodway in the 1% AEP event, and hence is likely not eligible for voluntary purchase. No houses have been identified as suitable for voluntary purchase.

Photo 26: Redevelopment of number 20 Hillcrest Avenue, Bexley (*Image: WMAwater*)

Summary and Recommendation

	PM02: Voluntary Purchase
Description	Purchase existing properties to remove them from high hazard.
Concerns	High cost of properties in the current housing market reduces economic viability, opposition from land owners and minimal properties in high hazard areas.
Outcome	Voluntary purchase is not recommended for Bayside West.

10.3.3. PM03: Flood Proofing

Description

Flood proofing is a strategy that is often applied to non-residential buildings and is often divided into two categories; wet proofing and dry proofing. Wet proofing assumes that water will enter a building and aims to minimise damages and/or reduce recovery times through use of water-resistant materials, locating electricals above the FPL, and facilitation of drainage and ventilation after flooding. Dry proofing aims to totally prevent flood waters from entering a building and is typically best incorporated into a structure at the construction phase, though can also be retrofitted to existing buildings. Dry proofing measures are typically installed at doorways or garage entry points, however other openings (such as for ventilation) should also be considered. Retrofitting permanent flood proofing measures can be difficult and costly, and therefore permanent flood proofing is best implemented during construction and allowed under development controls. As such, flood proofing can be stipulated within Council's DCP as requirements for structures below the FPL. For example, for commercial property, controls may allow floor levels at a lower level with flood proofing up to the FPL.

As an alternative to retrofitting permanent flood proofing measures to existing properties, individual temporary flood barriers can be used. These include sandbags, plastic sheeting and flood barriers which fit over doors, windows and vents and are deployed by the occupant before the onset of flooding. Temporary flood barriers such as sandbagging and floodgates can be a cost-effective option for existing properties, and can be useful where there is frequent shallow flooding. However, it relies on someone being available to implement it and therefore requires adequate flood warning times. Sandbagging, often used in conjunction with plastic sheeting, can provide a solution for dealing with flooding in smaller areas and at individual properties. Whilst sandbags and plastic sheeting seldom prevent the ingress of floodwaters entirely, they can substantially decrease the depth of over floor flooding and the foulness of floodwaters, thus aiding the clean-up process.

Discussion

Given the limited warning time available in the study area, dry flood proofing measures such as doorframe-mounted barriers would be an effective alternative to sandbags as they can be stored on the premises and quickly installed in the event of a flood, or alternatively, permanent flood barriers could be retrofitted to existing doorframes. Existing basement driveways which are impacted by flooding can be retrofitted with automatic hydraulic flood barriers which do not rely on electricity to operate.

When installed properly, such barriers could be expected to have the following benefits:

- Can be implemented by business owners (with little or no SES or Council assistance).
- Reduce time needed to prepare the building, particularly if proactive measures are adopted (e,g, relocating stock etc), allowing more time for staff to evacuate safely.
- Reduce or eliminate need for sandbagging.
- Reduce property damages.
- Allow premises to reopen as soon as safe access and services are restored.
- Reduction of days of lost business during recovery period.
- Greatly reduce clean up required.
- Range of products available from $1,000 - $5,000.
- Create regular staff training and drills, providing opportunity for community activity and flood education to be implemented.
- Increased continuity of work (and hence wages) for employees of affected businesses.
- Improved social amenity of being able to access and use key facilities and shops.

There have been considerable advances in the principles and approaches to flood proofing properties, both in the retrofitting and construction phases, to commercial and residential properties. Two guidelines of particular note are:

- *Reducing Vulnerability of Buildings to Flood Damage: Guidance on Building in Flood Prone Areas* (2006), Hawkesbury-Nepean Valley Floodplain Management Steering Committee.
- *Flood Resilient Building Guidance for Queensland Homes* (2019), State of Queensland (Queensland Reconstruction Authority).

Many councils support flood proofing principles for existing development and structures which are below the FPL to reduce flood damages. This includes considering flood compatible material to reduce impacts during a flood event, ease clean up afterwards, and maintain structural integrity; and locating electrical fixtures and sewer services above the FPL.

Access to community facilities, shops, healthcare services, sporting facilities and pubs are key to a community's recovery from a flood event and contribute significantly to community resilience and emotional recovery. While such premises would still not be operational during a flood nor immediately afterwards (pending safe access, reconnection of utilities etc.), flood proofing would significantly decrease the duration of business closures after the event. It is noted however that flood proofing individual buildings would not reduce external flood damages (e.g. to carparks or stock yards). Furthermore, if buildings are wet-proofed there would still be clean-up costs incurred, as well as days of business lost during the flood itself and the immediate recovery period.

Flood proofing can also be an option for sensitive and hazardous land uses, where controls would require, aspects to the essential operation, such as generators to be located above the FPL, while allowing a lower floor level. The risks and consequences of a lower floor level would need to be assessed.

The Floodplain Development Manual (Reference 1) allows for greater flexibility for business to manage and recover from flooding. Specifically, referencing that FPLs could be based upon more frequent flood events than required for residential purposes. By allowing FPLs for floor levels to be lower, but still requiring flood proofing to a higher FPL, damages can be minimised and the acceptable level of risk becomes a business decision, trading off potential damages with lower initial set up costs.

New commercial buildings can be required to be flood proofed to the FPL when constructed which would include consideration of suitable materials, electrical and other service installations, and efficient sealing of any possible entrances for water. Council would make these requirements through planning controls in the DCP, by stipulating an FPL for flood proofing. It is recommended that planning controls allow some flexibility in the type of proofing adopted. Flood policy is further discussed in Section 10.3.7.

The previous FRMS reports identified flood proofing as a management option for several commercial and industrial properties and areas. The areas within Bayside West that would benefit from flood proofing include the Henderson Street industrial area in Turrella, industrial buildings on/near Arncliffe Street in Wolli Creek, commercial buildings in the vicinity of Banksia railway station, the commercial and industrial area around West Botany Street in Rockdale, and industrial buildings around Production Avenue and Phillips Road in Kogarah.

Flood proofing is the responsibility of the property owner or business, and as such there is no Government funding for flood proofing of commercial and industrial buildings.

Summary and Recommendation

☑	**PM03: Flood Proofing**
Description	Flood proofing of non-residential buildings with temporary flood barriers (both existing and new structures, where floor levels are allowed to lower). This could also be extended to existing residential development, but not recommended for new residential development where floor level controls should be applied instead.
Concerns	Costs and implementation of flood proofing measures are the responsibility of the property owner / business.
Outcome	Include options for the use of flood proofing to the FPL for non-residential land uses within Council's DCP. This will enable new and existing buildings to be developed with due consideration given to their flood risk and minimisation of internal flood damages.

10.3.4. PM04: Land Use Zoning

Description

Appropriate land use planning can assist in reducing flood risk and ensure development on flood affected areas is flood compatible. Appropriate land use controls in flood affected areas can prevent inappropriate development from occurring and thus reduce flood risk. Land use zones are generally governed by an LEP. To make any significant changes to the provisions of a LEP, a planning proposal must be prepared.

Discussion

Zoning can be a powerful tool in reducing flood damages, however, overly restrictive zoning can discourage redevelopment that is more flood compatible causing areas to degenerate over time. Progressive zoning can be used to encourage long term change in flood resilience. The current land use zones for the Bayside West study area comply with the current NSW standards. No changes to the current land use zoning are recommended from a floodplain management perspective.

For future planning proposals, Council should consider flood affectation of the site and the proposed zoning changes. Council currently considers flooding for planning proposals. As an example, Council recently undertook a flood constraints review for a planning proposal to qualify for grant funding under the NSW Public Spaces Legacy Program. It was found that the flood constraints identified for specific areas do not prohibit development of those sites and future development applications will be required to demonstrate compliance with the flood-related development controls. It is likely that the planning proposal will improve the feasibility of redevelopment in those lots where it would currently be impractical to meet flood-related development controls. This is primarily due to the consolidation of lots and the permissibility of larger, taller buildings that provide greater flexibility in the development design to accommodate flow paths, minimum floor levels and safe refuge areas. This has previously been undertaken in areas such as Wolli Creek with success. Rezoning and redevelopment in areas such as Arncliffe has also facilitated large scale trunk drainage upgrades. This has allowed the formation of Bidjigal Road as an overland flow path and the Bonar Street trunk upgrade works, with Section 7.11 contributions (formerly Section 94) supporting the cost of these works.

Summary and Recommendation

☑	**PM04: Land Use Zoning**
Description	To ensure existing and future land use zoning is consistent with flood risk.
Outcome	No changes to the current land use zoning are recommended from a flooding perspective. The current land use zones for the study area comply with current NSW standards. Any changes to current land use zones must consider the potential flood implications.

10.3.5. PM05: Flood Planning Levels

FPLs are an important tool in floodplain risk management. Appendix K of the Floodplain Development Manual (Reference 1) provides a comprehensive guide to the purpose and determination of FPLs. The FPL is derived from a combination of a flood event and a freeboard and provides a development control measure for managing future flood risk (e.g. by elevating floors above a particular flood level), reducing potential damage, and setting minimum levels for floodplain mitigation works. Typically, this level would be the 1% AEP flood level plus a freeboard of 500 mm for residential development.

The FPL for planning purposes is generally the height at which new (or redeveloped) building floor levels should be built to minimise the frequency of inundation and associated damage. It may also refer to the height to which flood proofing could be applied to reduce damages to commercial properties, required levels for evacuation or height of storage for hazardous goods. FPLs can vary for different types of land use categories depending on the level of risk, consequences of inoperability or vulnerability of occupants. For example, residential development could be considered more vulnerable due to people being present, whilst commercial development could be considered less vulnerable, acknowledging that businesses may be better placed to recover from flood related damages or implement flood protection/mitigation measures compared to residents. Less vulnerable development could therefore be prescribed lower floor levels but may then be subject to other controls, such as flood proofing, up to the level of the FPL. This allows a decision around the acceptable level of risk to be a business decision, allowing a trade-off of responsibility between Council and present and future business owners. For developments more vulnerable to flooding (hospitals, schools, electricity substations, seniors housing, etc.) consideration should be given to events rarer than the 1% AEP when determining their FPL or situating those developments outside the floodplain where possible.

Until recently the NSW Government planning framework allowed for the FPL to be initially defined within the LEP and supported through subsequent controls in the DCP. Recent changes to the NSW Government planning framework in relation to flooding came into effect on the 14th July 2021 (discussed in Section 9.2.3). These changes removed the definition of the FPL from the LEP. Flood planning controls for Bayside, including FPLs, are defined via the DCP, which is consistent with the changes that came into effect on 14th July 2021. Flood policy is further discussed in Section 10.3.7.

Discussion of Design Event

FPLs for typical residential development would generally be based on the 1% AEP event plus an appropriate freeboard. Assuming the average lifetime or the design life of a structure is 70 years, the likelihood of at least one 1% AEP flood event occurring is 50%. Given this potential, it is considered reasonable from a risk management perspective to adopt the 1% AEP flood as the design flood event for residential development. Consideration of more or less frequent events can be appropriate for different land uses, with considerations around level of risk, consequences of inoperability or vulnerability of occupants. In the case of sensitive and hazardous uses and the available land within this zone, it is appropriate for the PMF to be considered. This aligns with the FPLs in Bayside Council's Draft DCP (discussed further in Section 10.3.7).

It is also considered reasonable to include climate change projections for the design flood event. FPLs will be used for setting floor levels of buildings that will have a certain design life, typically in the order of 50 to 100 years. In this circumstance, it is reasonable to assume that these buildings will be subject to a future climate and should be protected considering potential future design flood levels. This is discussed further in Section 10.3.9.

Discussion of Freeboard

As noted above, the FPL is typically derived from a design flood event (usually the 1% AEP) plus a freeboard allowance. The freeboard can be considered as a compulsory 'safety factor' used to provide reasonable certainty that the reduced flood risk exposure provided by selection of a particular flood as the basis of an FPL, is actually provided given the following factors:

- Uncertainty in estimating flood levels,
- Differences in water level because of local factors,
- Increases due to wave action,
- Climate change, and
- The cumulative effect of subsequent infill development.

The Floodplain Development Manual (Reference 1) states that, in general, the FPL for a standard residential development would be the 1% AEP event plus a freeboard which is typically 0.5 m. This FRMS offers an opportunity to consider if a 0.5 m freeboard is appropriate.

A key aspect to consider is the scale of flood behaviour that occurs within the catchment. Typically, overland flooding is shallower in nature, in most circumstances, and flood levels are generally not sensitive to factors such as wave action, wind setup or local obstructions. Importantly, the modelled flood behaviour in overland areas does not scale as significantly with event size, i.e., flood behaviour in the 0.5% AEP is generally not significantly greater than that of the 1% AEP, meaning that even if design rainfall estimates were to vary significantly (e.g. due to climate change), the overland flood behaviour would remain relatively consistent. Within the study area, flood levels generally vary by between 0.1 m and 0.6 m, between the 20% AEP and 0.2% AEP events. These aspects suggest that in some circumstances a freeboard less than 0.5 m may be appropriate to provide reasonable certainty that the flood risk in the 1% AEP is accounted for. While consideration could be given for low risk overland flow areas (for example, where flood depths are less than 150 mm), it is assumed that these areas would be removed from the FPA due to the lot-based selection process (see Section 10.3.6).

Discussion of Sensitive and Hazardous Uses

The FPL may also be raised depending on the vulnerability of the building/development to flooding. The vulnerability of a building may arise from its use (e.g. power supply, sewerage treatment plant) or from its occupants (e.g. children or the elderly). The Floodplain Development Manual (Reference 1) lists the following as examples of critical facilities: fire, ambulance and police stations, hospitals and nursing homes, schools, water and electricity supply installations, interstate highways, bus stations and chemical plants. For such facilities, the consequences of flooding are significantly more severe, and so the avoidance (or limitation) of flood damage is particularly important. In addition, the changes to the NSW Government planning framework in relation to flooding that came into effect on the 14th July 2021, allows councils to opt-in to a second LEP clause to allow controls to be applied to these more vulnerable land uses, particularly in the area between the FPA and the PMF extent or land that is subject to non-direct evacuation constraints.

Due to the flood behaviour in the study area, the floodplain is relatively constrained, and it is likely to be possible to avoid developing critical utilities or vulnerable facilities within the FPA or even floodplain (i.e. PMF extent) altogether. In some Councils, the PMF is used as the FPL for critical utilities and vulnerable facilities, as it allows developers to design new utilities or facilities with consideration of the full range of flood risk that may occur. It is therefore recommended that critical utilities and vulnerable facilities, if possible, are located outside of the PMF extent. If this is not possible, and the use is considered suitable, it is recommended that the PMF level be set as the FPL.

As for commercial development, the FPLs for critical utilities may refer to the minimum level to which flood proofing is applied, if it is impractical to elevate floor levels to the FPL. However, the risk to the lives of occupants of vulnerable facilities must be appreciated when considering the application of the FPL requirement. If the lowest habitable floor level cannot practically be raised to the FPL, the suitability of the vulnerable facility (such as residential aged care or child care) in the proposed location must be carefully considered.

Summary and Recommendation

☑	PM05: Flood Planning Levels
Description	FPLs are typically based on a design flood event plus freeboard. It is used to determine the FPA and set minimum floor levels.
Concerns	A freeboard of 500 mm in overland flow areas may be excessive given the scale in the range of flood events. Consideration should also be given to potential future climate scenarios appropriate for the design life of the structure.
Outcome	The Draft DCP design flood of the 1% AEP for habitable floors is considered appropriate. The Draft DCP freeboard of 500 mm for habitable floors is considered reasonable since there is no distinction between overland and mainstream flood affectation. The application of the FPA (discussed in Section 10.3.6) should ensure that properties with minimal overland flow affectation are not subject to this freeboard. The Draft DCP requires critical and sensitive uses and facilities to have habitable floors at the PMF level or the 1% AEP flood level plus 0.5 m, whichever is higher. This is considered appropriate for this land use type. The application of development controls outside the FPA is discussed further in Section 10.3.7. The Draft DCP removes the freeboard requirement for non-habitable floors and is considered appropriate. For recreational and non-urban uses, the floor level of 300 mm above existing ground levels and 200 mm above the existing ground level for concessional development is considered appropriate and protects buildings from shallow overland flows, which is the primary source of flood affectation across the study area. WMAwater provided feedback on an early draft of the DCP, and these comments were incorporated into the latest draft DCP.

10.3.6. PM06: Flood Planning Area

Description

The FPA is the area of land at or below the FPL. It identifies the area to which flood planning controls apply.

Discussion

Bayside currently adopts a lot-based tagging process to identify land within the FPA and flood-prone land. This avoids the complications of the traditional approach of selecting a flood level, adding freeboard (typically 0.5 m), and ‘stretching’ this FPL surface to identify additional land that is above the flood level but below the FPL. This process is difficult to apply in steeper areas of overland flow where the land adjacent to the flow path does not rise more than 0.5 m above the flood surface. Adding the freeboard and stretching this surface leads to erroneous identification of areas that may not even be flood prone. Additional issues also arise from detailed 2D modelling now available. For example, Sans Souci adopts a direct rainfall approach, and hence filtering of flood depths is required to obtain 'flooded' areas. However, there can often be isolated areas of ponding that may not be 'flooding' and do not warrant a lot to be tagged.

Bayside Council engaged WMAwater to undertake the lot-based tagging process in 2019 (Reference 21). This involved a three-step process:

1. GIS analysis: automated spatial analysis identifying the properties subject to flooding from the modelling results.
2. Desktop analysis: manual visual review of tagged lots to identify areas that may have been omitted or incorrectly tagged.
3. Ground truthing: detailed assessment of flood behaviour at individual lots including examination of Google Street View to determine the final tagging status.

This tagging process adopts a clear and defensible methodology for identifying flood affected properties under Section 10.7 of the *Environmental Planning and Assessment Act*. The tagging identified lots affected by the 1% AEP (plus a consideration of freeboard, i.e. the FPA) and the PMF (flood-prone land). These can be directly correlated with tagging for Clause 7A(1) and 7A(2) of the new *Environmental Planning and Assessment Amendment (Flood Planning) Regulations 2021*.

Summary and Recommendation

☑	**PM06: Flood Planning Area**
Description	The FPA is area of land at or below the FPL to which flood planning controls apply.
Concerns	There are issues with the traditional approach of applying freeboard and 'stretching' the surface to identify the FPA, particularly with steep overland flow paths in urban areas.
Outcome	It is recommended to retain the current lot-based tagging approach, and update the tagging status based on the updated modelling undertaken as part of this FRMS.

10.3.7. PM07: Flood Planning Policy

Description

Appropriate planning instruments ensure that development can be undertaken considering compatibility with the flood risk. Effective planning instruments can reduce residual flood risk over time as redevelopment occurs. Planning instruments can be used as tools to:

- Reduce risk to life,
- Reduce damage to the proposed development itself, and
- Reduce damage to the broader floodplain and existing development.

The types of controls (this list is not exhaustive) that achieve each of the objectives listed above are shown in Table 50.

Table 50: Planning Instrument Objectives – Control Type

Objective	Type of Control
Reduce Risk to Life	Evacuation considerations, vulnerable land use and occupant considerations, flood awareness and education (Section 10.7 certificates), prevention of ingress of water to car parks.
Flood Damage to New Development	FPLs, location considerations including, hydraulic hazard and category considerations, structural requirements.
Flood Damage to Existing Development	Flood impact consideration, design considerations, location considerations including, hydraulic hazard and category considerations.

The primary planning instruments used by local Councils are the LEP and DCP. The LEP is a legal planning instrument that guides planning decisions for Council through zoning and development controls. They provide a framework for the way land can be developed and used. The DCP support the objectives of the LEP and are used by Council to define and articulate the specific standards needed for different types of developments. Flood related development controls are a key aspect for development that occurs on flood prone land.

Discussion

Examination of existing risk throughout the study area indicates that managing this risk is problematic due to the very short warning times available. However, effective planning policy has the power to reduce this risk over time as the areas redevelop. Council should consider the long-term management of these areas and how this can be facilitated by planning tools. A key example is the redevelopment that has occurred in the suburbs of Wolli Creek. Rezoning and redevelopment have reduced flood risk through the application of planning controls such as setting minimum floor levels and ensure safe flood refuge is available.

Development in the Bayside West study area is currently governed by the Bayside Local Environment Plan 2021 (Reference 42) and Rockdale Development Control Plan 2011 (Reference 43). The DCP originates from the former Rockdale LGA DCP, and was recently updated to ensure consistency with the LEP. Bayside Council has plans to develop a consolidated DCP for the entire LGA, which is currently split between the Rockdale DCP 2011 (former City of Rockdale LGA) and Botany Bay DCP 2013 (former City of Botany Bay LGA). A draft of the Flood Planning Controls section of the DCP (Reference 45) was provided to WMAwater. A review of these documents was undertaken in Section 9.3.

In general, Section 5.21 of the Bayside LEP 2021 (Reference 42) contains the overall objectives and guidance for development on flood prone land, while Section 4.1.3 of the Rockdale DCP 2011 (Reference 43) and associated Flood Management Policy contain specific flood-related development controls. For the purposes of this FRMS, the latest Draft DCP (Reference 45) has been reviewed. It is currently at a stage where amendments can be made with the view of Council adopting it in the future. The LEP and draft DCP are comprehensive and cover a range of flood aspects. Key considerations and whether they are included in the documents are provided in Table 51.

Table 51: Flood-related Development Control Considerations

Aspect/Control	Contained in LEP/DCP	Comment
Terminology	Yes	Uses consistent terminology in line with current Floodplain Development Manual 2005 and ARR 2019.
Flood Planning Level	Yes	Discussed in Section 10.3.5.
Flood Planning Area	Yes	Discussed in Section 10.3.6. Ensure map is available on Council's website if separate from the DCP, since changes to the NSW Government planning framework in relation to flooding has removed the FPA overlay from the LEP.
Consideration of flood affectation and land use	Yes	A matrix approach is used considering the flood hazard (H1-H6 categories) of the site and land use to apply flood-related development controls.
Minimum Floor Level	Yes	Minimum floor levels are specified, typically being the 1% AEP level, 1% AEP level plus 500 mm freeboard or the PMF level depending on the type of development and its flood hazard category.
Minimum Carpark Level	Yes	Minimum carpark levels, including basement carparks, are specified in the DCP at appropriate levels (1% AEP plus 500 mm or PMF level for basement car parks).
Flood Proofing	Yes	Consideration of flood compatible building materials, electrical components, structural soundness and storage of hazardous materials are included in the DCP. Flood proofing of garage areas is also addressed (discussed in Section 10.3.3).
Flood Impacts	Yes	DCP stipulates that the proposed development does not result in increased flooding elsewhere in the floodplain and outlines requirements of a flood impact assessment.
Evacuation	Yes	Evacuation requirements are contained in the DCP, including consideration of an Emergency Response Flood Plan and on site flood refuge areas. It is recognised that the SES promotes evacuation with 'shelter-in-place' only for existing development where evacuation cannot be undertaken safely. NSW DPE recently released a draft shelter-in-place guideline (Reference 52). It is recommended that when this guideline is finalised, that evacuation considerations in the DCP align with this guideline.
Fencing	Yes	Fencing is listed under the objectives and performance criteria (i.e. *Fencing is to be designed and constructed in such a manner that it will not modify the flow of floodwaters and cause damage to surrounding land*). This is also listed as a prescriptive control for fences and gates to be open-form up to the 1% AEP level.
Special Flood Considerations	Partial	The LEP currently does not include the *Special Flood Considerations* clause. Changes to the NSW Government planning framework in relation to flooding allows Council the opportunity to include a second clause within their LEPs which applies to land between the FPA and the PMF extent and considers sensitive and hazardous uses in addition to those

Aspect/Control	Contained in LEP/DCP	Comment
		uses which may have evacuation constraints. This inclusion empowers Council to apply controls that ensure the developers of such facilities appropriately consider and plan for the full range of flood risk at the site, so as to reduce potential property damages and minimise the risk to life in future flood events. There are controls in the Draft DCP to this effect, which should be applied by opting in for the *Special Flood Considerations* clause in the LEP. This would also require a map of the area to which this clause applies to be available in Council's DCP.
Future Climate	Partial	The draft DCP considers climate change only for the purpose of a flood assessment, where climate change impacts are required to be modelled to manage the risk of future climate change on the development proposal. Climate change, however, is not integrated into any of the other flood related development controls. As discussed in Section 10.3.5 in regard to FPLs, it is recommended that Council includes climate change in flood-related development controls considering best available climate change data to combat future sea level rise and increased rainfall intensity. Climate change policy is discussed further in Section 10.3.9.

Summary and Recommendation

☑	**PM07: Flood Planning Policy**
Description	Flood planning policy is typically governed by the LEP and DCP, which outline flood-related development controls.
Outcome	Consideration should be given to the following: • Inclusion of climate change in the full range of flood related development controls. • Implementation of the draft DCP. • Provision of special flood considerations clause in the LEP.

10.3.8. PM08: Section 10.7 Certificates

Description

Section 10.7 Planning Certificates (formerly S149 Planning Certificates) are issued in accordance with the *Environmental Planning & Assessment Act 1979*. They contain information on how a property may be used and the restrictions on development that apply. A person may request a Section 10.7 Planning Certificate at any time to obtain information about his or her own property, but generally the certificate will be requested when a property is to be redeveloped or sold. When land is bought or sold the *Conveyancing Act 1919* requires that a Section 10.7 Planning Certificate be attached to the Contract for Sale.

Schedule 4 of the *Environmental Planning and Assessment Regulations 2000* gives requirements for inclusion on Section 10.7 Planning Certificates under Section 10.7(2) of the Act. Schedule 4, Clause 7A refers to flood related development control information and requires that Council include whether or not development on the land or part of the land is subject to flood related development controls. Recent changes to the flood prone land package now require notifications to be placed on land between the FPA and the PMF and is subject to flood-related development controls (Clause 7A(2)).

Discussion

Bayside Council currently provides flood information on Section 10.7 certificates in terms of land that is subject to flooding in the 1% AEP (Clause 7A(1)) and the PMF (Clause 7A(2)). Bayside Council also provides a Flood Advice service, whereby residents can request lot-specific flood advice. This includes information such as:

- Flood notation,
- Relevant Flood Study,
- Peak flood levels for the 1% AEP and PMF events,
- Flood risk exposure (type of flooding, flood function and hydraulic hazard),
- Flood commentary,
- Flood planning level,
- Fencing requirements,
- Applicable flood-related development controls,
- Image of 1% AEP flood depths.

The more informed a homeowner is, the greater the understanding of their flood risk. During a flood event, having this understanding helps prepare residents for evacuation, and improves the ability of residents to recover following an event. Improved flood risk awareness may also reduce the number of residents that elect to shelter in place in high hazard areas, which can increase pressure on the SES if they are isolated or their homes inundated.

Land owners will be required to be notified of changes to both the 10.7 (2) and 10.7 (5) Planning Certificates. Land owners can be concerned as to how a notification may impact on their property value or insurance, for example. The Insurance Council of Australia provides detailed fact sheets on how flood information is used for insurance pricing. This should be considered when developing a consultation strategy for notification of any changes related to S10.7 Planning Certificates.

Summary and Recommendation

☑	PM08: Section 10.7 Certificates
Description	Section 10.7 Certificates are required to show flood notation. This informs the land owner of flood risk and applicable development controls.
Outcome	The current provision of information to land owners is considered adequate. This involves Section 10.7 notifications plus the provision of a flood advice services that details flood affectation of individual properties. Bayside Council also has an online mapping system that shows flood extents, flood hazard and flood affected lots. Section 10.7 Certificate information should be updated with information from this FRMS&P.

10.3.9. PM09: Climate Change Policy

Description

Climate change policies have currently been adopted by a number of NSW local councils, including Central Coast Council, Ku-ring-gai Council, Ballina Shire Council, Shoalhaven City Council and Eurobodalla Shire Council. These climate change policies are centred around achieving net-zero emissions, but also outline adaptation and resilience strategies, of which flood and coastal management are a key consideration. These policies are typically broad in nature and do not have specific outcomes for flood risk management. These would be guided by a climate change action/adaptation plan which would sit under the policy and may also contain a number of individual plans or strategies, such as a 'sea level rise policy'.

Sutherland Shire Council, for example, adopted a sea level rise policy in May 2016, which outlines sea level rise projections that are to be applied to all planning instruments, policies, flood and coastal studies. This provides for a predicted 0.72 m increase in sea level for the year 2100 horizon. The same projection has been used in Eurobodalla Shire Council's Interim Coastal Hazard Adaptation Code that applies planning controls to proposed developments in the coastal zone. Several other Councils have also chosen to adopt sea level rise projections in flood planning levels or certain aspects of their DCP requirements (such as Georges River Council, Northern Beaches Council, Shoalhaven City Council and Port Stephens Council). Other Councils, however, have recently rescinded their climate change response policy (Port Macquarie Hastings Council).

Discussion

The results of the impact of climate change (both rainfall intensity increases and sea level rise projections) were documented in Section 7.4. These results indicate that there are parts of the Bayside West study area that are at risk from climate change. In particular, low-lying areas around the suburbs of Wolli Creek and Arncliffe (Bonnie Doon), lower Muddy Creek, Scarborough Ponds and throughout Sans Souci are particularly at risk from sea level rise. A policy (or sub-policy) that outlines Council's adoption of an IPCC AR6 (Reference 31) emissions scenario, planning horizon and hence projected sea level rise is recommended for future planning for these areas. An overarching climate change policy and sub-policies would ensure consistency in Council's approach to climate change, and sea level rise in particular, across a range of asset design and maintenance sectors as well as coastal and floodplain management. This would ultimately feed into flood policy (Section 10.3.7), FPAs (Section 10.3.6) and FPLs (Section 10.3.5).

New development, such as buildings, have a typical design life in the order of 50 to 100 years. Given this, Council should consider a planning horizon and account for future climate change based on best available climate projections for both increases in rainfall intensity and sea level rise. Council should consider a year 2100 planning horizon for the potential effects of climate change on developments. Major infrastructure works may have a design life over 100 years, in which case a longer planning horizon, such as the year 2150, should be considered. For example, depending on the proposed development life, a sea level rise projection could be incorporated into the FPL to ensure the flood risk of the site is maintained into the future.

It is noted that across the previous Flood Studies for Bayside West, and current Flood Studies for the Bayside East area a range of tailwater levels have been adopted. If sea level rise is to be adopted for the Bayside LGA, it would be prudent to adopt consistent tailwater conditions for Botany Bay and the Cooks River (as has been done for this study). This ensures the same baseline conditions and projected sea level rise is applied to all areas of the LGA.

Summary and Recommendation

☑	**PM09: Climate Change Policy**
Description	A climate change policy guides Council's operations and policies at a high level. This would likely feed into other Council operations such as coastal management, asset design, flooding and planning controls. Climate change adaptation should also be considered at an LGA-wide scale.
Outcome	It is recommended that Bayside Council pursue a climate change policy, particularly as there are several low-lying areas that will be impacted by future sea level rise. This requires a holistic approach from Bayside Council, as climate change and sea level rise does not just affect flooding, but a range of Council assets, plans and policies. It is recommended that the policy outlines the scientific basis for climate change, adopts a planning horizon (or different planning horizons for different applications) and specify rainfall increase and sea level rise parameters, and outline its application to Council's operations, planning instruments, policies and floodplain management strategy.

10.4. Response Modification Options

The measures described in this section relate to how the Bayside West community receives information about floods, and responds to and recovers from flood emergencies. Response modification options aim to reduce risk to life and property in the event of flooding through improvements to flood prediction and warning, improvements to emergency management capabilities, evacuation and planning, and supporting greater community flood awareness and preparedness.

10.4.1. RM01: Flood Emergency Management Planning and Coordination

Description

The SES is the legislated combat agency for flood, storm and tsunami response, responsible for the control of operations. The SES prepares a range of documents that cover preparedness, response and coordination measures that are essential to the management of storm and flood risk. These documents include FloodSafe brochures, Local Flood Plans, regionally based information webpages (Southern Sydney region), StormSafe brochures in addition to information and brochures on preparedness strategies for urban areas. The SES website (www.ses.nsw.gov.au) also contains an array of information that residents can access.

During a flood event in the study area, the two main response agencies are the SES and Council. Each have defined roles and responsibilities, as outlined in the Bayside Flood Emergency Sub Plan (Reference 53). Council plays a significant role in ensuring the safety of its community in times of emergency, including preparedness of the organisation in the lead up to an event such as a flood, its response, integration with other emergency services and recovery from the event. During a local storm or flash flood event, Council is responsible for responding to issues relating to public areas and infrastructure, for example, road closures, cleaning out drains, and pumps, and debris removal within road reserves or riparian corridors.

The SES is responsible for the control of flood operations, including the coordination of evacuation, undertaking flood rescues, assisting with flood damage and welfare of affected communities. The SES can respond to calls regarding private property, including storm damage, evacuations (if appropriate) and rescues (e.g. motorists or pedestrians who have entered floodwaters). It is important to share information about the typical roles of each agency with community members, to allow them to contact the appropriate agency in the event of a flood related emergency, to ensure their call is responded to without unnecessary delay, and not place additional burden on agencies that cannot assist directly.

Discussion

Flood emergency planning and coordination is an important aspect of reducing flood risk in the study area. In terms of planning, dissemination of information to the community is an integral aspect. A FloodSafe brochure exists for the former Rockdale LGA (Bayside West study area) and is available on the SES website (https://www.ses.nsw.gov.au/media/1945/brochure-rockdale-city-floodsafe-guide.pdf). Although the information is general, it provides information to residents on flood risks, how to prepare and what to do during a flood. This brochure could be updated and included as part of an ongoing flood education and awareness program.

A Local Flood Plan is also available for the Bayside LGA, published in June 2021 (Reference 53). The document contains an overview of the flood hazard and risk in the area (Volume 2, not publicly available), prevention and mitigation measures, as well as preparation before a flood, response during a flood, and recovery following a flood. This is a high-level document, with most of the information not being specific to the Bayside LGA. It is assumed that Volume 2 of the plan, which is not publicly available, would provide more detailed information about flood risk. It is recommended that this be updated to include the modelling and results available as part of this FRMS.

Coordination between responsible agencies (primarily Council and SES) is critical to providing an adequate level of service during flood events. It is recommended that regular meetings and exercises be held to improve plans at the strategic level. There would be significant benefit in including a broader range of representatives from each agency in these meetings. In particular, the inclusion of Council engineering and outdoor staff, and SES volunteers and volunteer coordinators, would ensure that the individuals who are most likely to be active during the event would benefit from the training exercises, and could add input from their own experience. Not only will this help more responders prepare for flood events but increase familiarity between representatives of each agency.

Difficulties in achieving the above objectives stem from the logistics of gathering the relevant parties at a mutually convenient time, staff changeover within agencies, and location and availability of out-of-area volunteers. It may be more feasible to have regular, smaller meetings, where representatives from each agency can attend and report back to their teams, and perhaps aim to hold a larger scale gathering and training day on an annual basis to ensure individuals can plan their attendance well in advance.

Summary and Recommendation

☑	**RM01: Flood Emergency Management Planning and Coordination**
Description	The NSW SES is the legislated combat agency for floods, including the preparation, response and recovery phases. The SES provides information to residents and assists during flood events. Council also has responsibilities and works with the SES to achieve these goals.
Outcome	It is recommended that the SES: • Use the information and modelling developed as part of this FRMS to update their local flood plan for Bayside. • Consider providing an updated FloodSafe brochure or information on their website specific for the flood risk in Bayside. • Provide guidance to Bayside Council with regard to evacuation and shelter in place as floodplain management strategies. It is recommended that Bayside Council and SES hold regular meetings of all responders and training exercises between flood events to identify roles and responsibilities in practice and build relationships between agencies and/or community groups.

10.4.2. RM02: Flood Warning Systems

Description

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

A wide range of prediction tools are available, from basic flash flood information systems that use real-time rainfall triggers, to complex flash flood warning systems that run real-time hydrodynamic models informed by radar rainfall estimates. There is a need to find the appropriate balance between the risk presented by the flooding, model complexity (and cost), available warning time, and accuracy of prediction. The flood prediction then needs to be interpreted in terms of what area, people and infrastructure are at risk. This is then required to be disseminated to the appropriate people and areas for them to take appropriate action. Providing sufficient warning time is necessary for people to prepare and act (for example, moving goods to a higher level and evacuating to higher ground) has the potential to reduce the social impacts of the flood as well as reducing the strain on emergency services.

Discussion

The BoM is responsible for monitoring and predicting flood events. Flood Watches and Flood Warnings, however, are only provided for large river systems where it is possible to predict flooding more than 6 hours in advance. This is provided for the Cooks River, which affects the Bayside West area, but has not been investigated in detail in this study. The focus of this study is on the local catchments, for which the BoM does not provide Flood Watches or Flood Warnings for. Even the largest creeks in the study area (such as Wolli Creek), have a response time of a few hours (< 6 hours). Typical critical durations across the study area range from 30 minutes to 90 minutes for major overland flow paths and creeks. This would be categorised as ‘flash flooding’, that is typically the result of intense local rainfall and characterised by rapid rises in water levels, occurring within 6 hours. Due to the nature of overland flow in the study area, flood warnings are difficult to prepare and disseminate. The quick catchment response time does not allow time to interpret recorded rainfall data, construct and disseminate a flash flood warning, with enough time for the community to be able to take meaningful action to prepare.

While the BoM does not provide warnings for flash flood catchments, it does provide forecasts and warnings for severe weather conditions that can potentially cause flash flooding. Flash flood warnings themselves are provided by State and local government where gauges and warning systems are available. While these can be developed, maintained and monitored for a cost, its usefulness is dictated by how well rainfall predictions or rainfall observations can be translated into accurate flash flood warnings that provide adequate warning time without triggering false alarms. This balance is difficult in areas such as Bayside West. It is also difficult to justify based on a cost-benefit analysis, as the reduction in tangible damages is limited and it is the reduction of intangible damages that a flood warning system generally benefits. Additional issues include vandalism, maintenance and the ability or willingness of residents to respond accordingly.

As an alternative to a flash flood warning system in the study area, severe weather warnings issued by the BoM can be used as a warning of the potential onset of flooding in overland flow areas coupled with education and awareness. Severe weather warnings are issued when severe weather or thunderstorms are expected – these are the types of storms that can cause flash flooding in the study area. The warning may also note the hazards associated with the storm including damaging wind gusts, large hail and flash flooding. These alerts are available through the BoM website, BoM weather app, the SES website and a variety of other platforms (such as news outlets and social media). Recently, the BoM updated its app so that users can receive push notifications for severe weather warnings. A flood awareness campaign can assist in providing guidance to residents on how to interpret BoM weather warnings and how to manage flooding.

Summary and Recommendation

☑	**RM02: Flood Warning System**
Description	A flood warning system is designed to provide advice on impending flooding so people can take action to minimise its negative impacts.
Outcome	A dedicated flash flood warning system for the Bayside West study area is not viable. It is recommended that the severe weather and severe thunderstorm warnings issued by the BoM be used to prepare for potential flash flooding events. Community awareness campaigns may assist residents in interpreting warnings from the BoM, anticipating the impacts and preparing accordingly.

10.4.3. RM03: Community Flood Awareness and Education

Description

A key step towards modifying the community's response to a flood event is to ensure that the community is fully aware that floods are likely to interfere with normal activities in the floodplain. Flood awareness is a vital component of flood risk management for people residing and working in the floodplain, as well as for those reliant on services operated from within flood prone areas. Flood awareness can be developed through a range of strategies with varying levels of community participation. Strong flood awareness can significantly improve the way a community prepares for, responds to, and recovers from flooding.

Key messages to be communicated to the community include:

- General information about how overland flow in the Bayside West study area is generated, where it is conveyed and typical durations of inundation.
- Specific information about flow paths and associated flood behaviour (for key areas at risk.
- Guidance on the roles and responsibilities of the SES and Council, and contact details of each agency.
- What to do when BoM issues a severe weather warning for the study area.

- General information regarding personal safety during a flash flood event, particularly, the risks of driving across flooded roads, even if flow is shallow.

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

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

It is difficult to accurately assess the benefits of a community flood education program, but the consensus is that the benefits far outweigh the costs. Nevertheless, sponsors must appreciate that ongoing funding is required to sustain the gain that has been made.

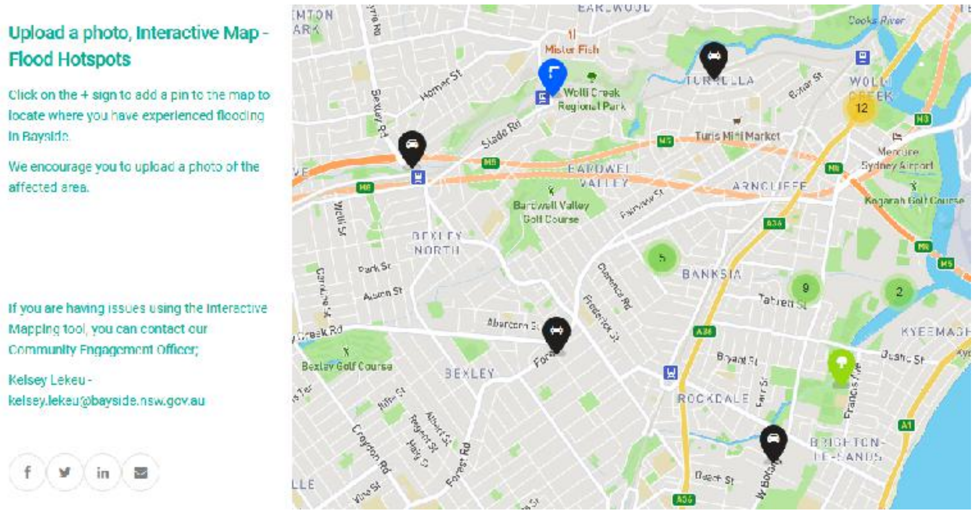
Ongoing flood awareness campaigns can be costly and can become ineffective over time with residents becoming bored or dismissive of messaging, particularly in periods of little rainfall. The community’s perception of flooding may be more driven by flood risk occurring in large river systems, and overland flow flood risk may be perceived as less important or hazardous in comparison. Overland flow events do occur, and bring with them their own risks, particularly relating to flash flooding of roads, and driver safety. It is key to keep overland flow flood awareness current, as flash floods can occur frequently and quickly.

Table 52 provides a list of commonly applied methods to build and sustain flood readiness, which may be developed and supported by NSW SES and Council. These include methods both to inform and to prepare the community, with the objective of building resilience.

Table 52: Methods to Increase Flood Awareness and Preparedness

Method	Comment
Council website	Council already provides flood information on their website, via the “Floodplain Management” section and also through their “online mapping system”. It is recommended that upon completion of this study, that Council update the website to provide up to date flood information for Bayside West.  Council should consider continuing to update and expand their website to provide both technical information on flood levels as well as qualitative information on how residents can make themselves flood aware. This would provide an excellent source of knowledge on flooding within the study area (and elsewhere in the LGA) as well as on issues such as climate change. Information about what to do in the event of a flood, and how to stay safe, could also be provided. This could include, for example, links to SES Floodsafe Materials and campaigns such as “15 to Float”, “If it’s flooded forget it” and “Turn Around Don’t Drown”, which aim to improve driver safety during flood events. It is recommended that Council’s website continue to be updated as and when required.
Community Champions Program	There could be an opportunity for the SES and Council to liaise with these trusted community members to trial a community champion program. This would also provide a valuable two way conduit between the local residents and Council. The SES Community Action Team Volunteers is an SES program where community members volunteer to help prepare and protect their community during severe weather events. There may be members of the local community well suited for involvement in an SES Community Action Team group and this team should be more widely promoted to encourage involvement.
Community Working Group	Council could initiate a Community Working Group framework (undertaken in other catchments elsewhere) and this would provide a valuable two-way conduit between the local residents and Council.
Letter/pamphlet from Council	A leaflet containing specific information about flood behaviour, and what to do in the event of a flash flood is an effective way of providing information without necessarily requiring active participation from residents. A leaflet/pamphlet from Council may be sent (annually or biannually) with the rate notice (electronically or by mail). A Council database of flood liable properties/addresses makes this a relatively inexpensive measure which can be effective if  residents take the time to absorb and apply the suggestions. The pamphlet can inform residents of on-going implementation of actions identified in the FRMS&P, changes to flood levels or development controls, reinforce the differences between sources of flooding, provide information on the actions Council is taking to reduce the flood risk in their area and direct residents to further information. It could be also be combined with other general council information, reducing the potential fatigue from repeated messages.

Method	Comment
School engagement	Engagement with school students can be a successful means of not only informing the younger generation about flooding but can also lead to infiltration to parents. This can be implemented through various techniques including: adopting messaging about not playing in or driving in floodwaters into appropriate lessons, school projects where students can learn about historical floods by interviewing older residents and documenting what happened, and hosting “flood awareness” days where members of the local SES visit schools and participate in flood safety activities. While this FRMS focuses on flood risk only, this approach can be combined to include other topics relating to water quality, drainage management, etc.
S10.7 certificate notifications	This option is discussed in detail in Section 10.3.8, and is a useful tool as a ‘point in time’ awareness exercise, but has limited use as a method to maintain flood awareness in the community, as generally the certificates will only be requested when a property is to be redeveloped or sold. Council may wish to advise interested parties, when they inquire during the property purchase process, regarding flood information currently available, how it can be obtained and the cost. Some Councils have conducted “briefing” sessions with real estate agents and conveyancers.
A range of media	A range of media and community engagement methods should be used to publish interest pieces on flooding, and to promote flood awareness activities. Communication means include council newsletters, social media, local newspapers and the radio. Ongoing pieces in newsletters or the local paper will ensure that flood issues are not forgotten.
Library display	The library could collect historical flood photos and stories to prepare a display, which could be accompanied by appropriate flood safety messages and tips for responding to future flood events. This could also be set up at any number of other sites, such as shopping centres.
NSW SES Business FloodSafe Breakfast	The NSW SES has prepared a FloodSafe Business template, which businesses can use to plan for flooding. A breakfast barbeque could be convened at an appropriate location to promote completion of plans and to provide site-specific flood information.
‘Meet the street’ events	‘Meet-the-street’ events involve NSW SES and Council setting up a ‘stall’ at an appropriate time and visible location. The event would be advertised through a specific letter box drop to the targeted neighbourhood or vulnerable site. The stall could consist of flood maps on boards, NSW SES banners, NSW SES materials to hand out. These materials are used to engage with people and make them aware of flood risk, encourage preparedness behaviours (e.g. develop emergency plans) and help them understand what to do during and after a flood. A meeting could also encourage property owners to develop self-help networks and particularly people checking on neighbours if a flood is imminent. Longer-term residents with flood experience could be used to help provide other residents with an understanding of previous floods and how to prepare for future flooding.

Method	Comment
Flood Information Signage	 Flood information signs could be implemented in locations known to flood to inform residents of the risk, and appropriate responses. Like the Sydney Water 'flood zone' that are currently around the study area in areas where concrete open channels are fenced. This can also take the form of historical flood markers, where signs or marks can be prominently displayed on telegraph poles or such like to indicate the level reached in previous floods. Depth indicators advise of potential hazards. These are inexpensive and effective but in some flood communities not well accepted as it is considered that they affect property values.
Collection of peak water level data from future floods	Collection of data (photographs) assists in reinforcing to the residents that Council is aware of the problem and ensures that the design flood levels are as accurate as possible. This might also include establishment of peak water level marker poles and which house floors are inundated. Following the recent storm events of February 2022, Bayside Council initiated a "Flood Prone Hotspots" page on their website where residents can drop a pin on a map and upload photos and information about flooding. This is a valuable tool for collecting flood information and it is recommended that this be kept open, or re-opened after every flood event in the LGA. 

Discussion

These options for community education include both passive (pamphlet, flood signage, library displays, etc) and interactive methods of engagement (community champions, SES Breakfast, Meet the Street events and school engagement, etc), and target various sectors of the community (businesses, residents etc), and can be implemented by various organisations (Council, SES, schools, community groups). It is therefore recommended that a program which utilises a variety of approaches and looks to engage a wide cross section of the community is developed, for implementation ongoing implementation over the coming 5-10 years. Learnings from other recent engagement activities can be used to formulate a program most suited to the Bayside West study area catchment and its community.

At a minimum, it is recommended that the following three community education methods are enacted for the Bayside West study area:

1. Council website: Council should continue to develop and expand the flood section of their website. It currently comprises of information specific to each catchment and includes links to flood studies. This could be expanded to include information about preparing for floods and what to do in a flood event. It is also recommended that Council's "Flood Prone Hotspots" page be kept open, or re-opened after every flood event in the LGA.
2. Leaflet: It is recommended that the existing "Rockdale City Council Area" leaflet published by the SES be updated with the latest information and include specific information related to flooding in the Bayside West catchments. Development of the leaflets would need to be undertaken outside of the FRMS project, as a collaborative exercise between Council and the SES, ensuring use of appropriate branding and approvals and licencing obtained where necessary. Due consideration of the sensitivity of the information is also needed, as the use of specific street names when describing affected areas may be off-putting to residents who may perceive property values are negatively affected. The leaflet could be distributed to residents via mail or at a minimum uploaded on SES and Council websites and promoted through social media and other Council announcement mediums. This could also take the form of a more modern digital format (for example, suitable for viewing on mobile phones).
3. Section 10.7 Certificates: Section 10.7 Certificates are described in detail (Section 10.3.8) and are issued by Council in accordance with the *Environmental Planning & Assessment Act 1979*. A person may request a Section 10.7 Planning Certificate at any time to obtain information about his or her own property, but generally the certificate will be requested when a property is to be redeveloped or sold. When land is bought or sold the *Conveyancing Act 1919* requires that a Section 10.7 Planning Certificate be attached to the Contract for Sale. Provision of flood information to residents via Section 10.7(2) and (5) Planning Certificates can be an effective method of providing site-specific flood information to residents. Council should continue to provide the Flood Advice service in addition to this, where residents can request more detailed flood information specific to their property.

Summary and Recommendation

☑	RM03: Community Flood Awareness and Education
Description	Flood awareness is a vital component of flood risk management for people residing and working in the floodplain. Flood awareness can be developed through a range of strategies with varying levels of community participation. Strong flood awareness can significantly improve the way a community prepares for, responds to, and recovers from flooding.
Outcome	It is recommended to design and implement an ongoing community flood education program to maintain a high level of flood awareness and understanding of the risk and appropriate response to flooding in the Bayside West study catchments. At a minimum, this should include ongoing development of Council's website as a hub for flood information, development and distribution of a leaflet and continuing to provide flood information through Section 10.7 certificates and flood advice letters.

10.4.4. RM04: Improvements to Driver Safety

Description

One of the key hazards associated with flooding in the study area is inundation of roads. In urban areas such as Bayside West, the risk to life is generally low if people stay indoors. Usually the riskiest thing to do in a flood event is drive a vehicle. It can be difficult to estimate the depth of water and velocity of flow over a road, and many people attempt to cross flooded roads, believing that the vehicle is safe to do so (this regularly occurs on Bexley Road). Research has shown that a small car can begin to lose traction in just 15 cm of water. In urban areas, the duration of inundation is typically short, and alternative routes are often available. Flood signage can be an effective measure to inform drivers of road inundation and deter them from attempting to drive through flood waters.

Discussion

This section contains a discussion of the practical considerations that are involved when installing new flood signage on roads that are subject to inundation, in addition to suggested locations. It is recommended that an investigation be undertaken by Council to confirm the most appropriate locations for and types of flood signage, and complementary education programs to reduce flood risk most effectively to motorists and consequences to flood behaviour in surrounding areas (such as wave action and flow diversion). Flood depth signage may also act as a passive reminder to residents of the potential for flooding on local streets.

Due to the flash flooding nature of the catchments within the Bayside West area, water can rise to dangerous depths and velocities before a formal road closure can be implemented, and traffic rerouted safely. Flooding in the study area can cause several roadways to become overtopped, depending on the location and intensity of rainfall. In most cases, alternative safe routes can be taken, however, unless residents are aware of them, some may attempt to cross through flood waters, putting themselves and others at risk. This is particularly likely if visibility is poor during heavy rain, as water over the road is either not noticed, or the risk of driving through it is not appreciated.

A recent campaign by the Victorian Sate Government (15tofloat.com.au) highlighted that "a small car can be moved by water only 15 cm deep". Driving through even shallow floodwater can put the driver at risk and increase the demand on SES resources (and risk to their lives) if rescue is required. It is noted that deeper water at lower velocities is also hazardous to vehicles, as identified in Reference 28, which has been used to categorise the design flood behaviour in the study area into 6 hazard categories, from H1 to H6. The hazard over roads in both the 20% AEP (representing frequent flooding) and in the 1% AEP (representing a large flood event) was checked across the entire study area. In general, roads that experienced at least H2 (unsafe for small vehicles) in the 20% AEP event and H3 (unsafe for vehicles, children and the elderly) in the 1% AEP event were identified. Consideration was also given to the nature of the road (for example, a main road compared to a cul-de-sac) and length of inundation to assess an indicative risk. A total of 16 locations were identified across the Bayside West study area that were considered a flood risk to road users. These are listed in Table 53 and shown in Figure 38.

Table 53: Potential Locations for Flood Warning Signage and/or Depth Markers

ID	Location	Hazard Classification in 20% AEP event	Hazard Classification in 1% AEP event
1	Bridge Street	H4	H5
2	Stoney Creek Road	H1	H5
3	Bexley Road	H4	H5
4	Slade Road	H3	H3
5	Powys Avenue	H3	H4
6	Turrella Street	H3	H3
7	Wollongong Road / Martin Avenue	H3	H4
8	Arncliffe Street	H2	H3
9	Gertrude Street	H2	H3
10	Subway Road	H3	H5
11	Lynwen Crescent	H3	H3
12	Bestic Street	H2	H3
13	Warialda Street	H3	H4
14	President Avenue	H2	H3
15	Robinson Street	H2	H3
16	Barton Street	H3	H3

To communicate potential flood risk to drivers, it is recommended that appropriate signage is installed at key locations. Such signage might include depth indicators, warning signs, hinged flood signs, or signs fitted with flashing lights.

Flood signs must be installed in accordance with AS1742.2-2009 *Manual of Uniform Traffic Control Devices* (Reference 54*) Part 2: Traffic Control Devices for General Use*, which stipulates that *"The 'ROAD SUBJECT TO FLOODING, INDICATORS SHOW DEPTH' sign shall be erected on the left side of the road on which Depth Indicators are used, to advise drivers that the road* *ahead may be covered by floodwaters…the NEXT x km sign may be used in conjunction with this sign when there are two or more floodways ahead, not more than 2km apart." (Clause 4.10.6.9)*

Where flood depths are more than 1.5 m, the G9-22-1 depth indicator sign is to be used (refer to Diagram 26). This is the same depth indicator that can be found on Bexley Road crossing Wolli Creek (Photo 27).

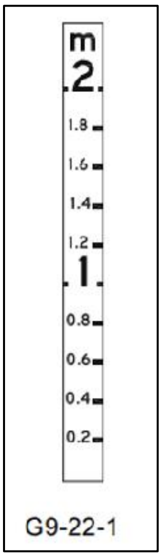


Diagram 26: G9-22-1 Flood Depth Indicators (Reference 54)

Photo 27: Flood depth indicator on Bexley Road crossing Wolli Creek (*Image: Google Street View*)

Where special attention is required due to the "extreme severity of the hazard to which they refer, or lack of adequate sight distance to the hazard, or a combination of the two", flashing lights can be set up alongside the warning signs. The flashing lights must comply with the requirements of AS2144 and consist of 200 mm diameter traffic signal lanterns flashing at a rate of 40 to 60 flashes per minute with the light on for 40 to 60% of the time (Reference 54). An example is provided in Diagram 27.

Diagram 27: Examples of Warnings Signs with Flashing Lights (Reference 54)

With the potential for Council resources to be focused on storm-related responses (e.g. debris removal from roads), it is recommended that where possible, flood signs that require manual activation are not installed. Instead, warning signs and/or depth indicators (with or without automated flashing lights), that can give information to or warn drivers, without increasing the burden on Council's staff are likely to be preferable. Depending on the location and size of the event, installation of depth indicators or warning signs will not replace the need for Council to formally close roads, though they may assist in dissuading drivers to enter flood waters before the road is officially closed.

Placement of depth markers in an overland flow area requires careful consideration. If depth markers are placed where flooding is short-lived or shallow, they may be dismissed, which may lead to drivers ignoring depth markers at roads overtopped by fast flowing water. In addition, residents may be concerned that installation of depth markers or other flood warning signs may detract from the amenity of their area, and or perceived to affect property values. Conversely, if road closure signs are left out for hours or days after water has drained away, drivers are likely to ignore the signs and drive through. This may lead to future complacency or dismissiveness when the road is flooded.

Installation of depth markers or other flood signs should be undertaken in conjunction with extensive community education, for three key reasons:

- to ensure drivers understand what the depth marker shows (i.e. depth of water over road),
- to educate the community about the potential flood risk associated with water at that depth, and the danger of driving through even shallow water, as velocity can be hard to judge, and

- to educate the community regarding the potential consequences to flood behaviour such as wave generation, flow diversion and impacts on property.

Recommendations relating to community flood education and awareness are provided in Section 10.4.3.

Summary and Recommendation

☑	**RM04: Improvements to Driver Safety**
Description	Installation of flood signs and flood depth indicators can improve driver safety, in conjunction with community education about the risks of driving through floodwaters.
Outcome	Specific locations have been identified as potential flood sign locations. Further consideration of the factors discussed above is needed to identify the most appropriate type of sign, specific placements and accompanying community education needed to convey flood risk most effectively to motorists. It is recommended that a detailed study is undertaken to confirm the preferred locations, residual flood risk (i.e. need for road closure) and safe alternative routes and how traffic can be diverted in flood events. Following the detailed study, installation can proceed in accordance with the outcomes of that study.

11. MULTI-CRITERIA MATRIX ASSESSMENT

The Floodplain Development Manual (Reference 1) recommends the use of multi-criteria matrix assessment (MCMA) when comparing flood risk mitigation measures. An MCMA provides a method by which options can be assessed against a range of criteria and offers a greater breadth of assessment than is available by considering only the reduction in flood risk or economic damages. Such additional criteria may include social, political and environmental considerations and intangible flood impacts that cannot be quantified or included in a cost-benefit analysis. It should be noted that the assessment of the suitability of floodplain mitigation options is a complex matter, and an MCMA will not give a definitive ‘right’ answer. Rather, it provides a tool to debate the relative merits of each option.

11.1. Scoring System

A scoring system has been devised to allow stakeholders to assess the various options across a consistent basis to allow for direct comparison. The scoring system is divided into key areas such as flood behaviour, economic, social and environmental considerations. Scores for each criterion are to be assigned to each option then summed to determine the overall score. Options with higher scores indicate benefits across a range of criteria and should be prioritised over those with lower positive scores, which may be more neutral or have a combination of positive and negative aspects. Conversely, options with the lowest negative scores indicate the option would cause adverse outcomes in several criteria and should not be considered further. Each of the criterion were also weighted, based on feedback from the Floodplain Risk Management Committee (FRMC). FRMC members were asked to assign a score to each of the categories, indicating its relative importance in the MCMA. The scoring system is provided in Table 54, and the outcomes of the assessment shown in Table 55. Discussion of the results is provided in Section 11.3.

Table 54: Multi-criteria Matrix Assessment – Scoring System

	Criteria	Metric	Score -3	-2	-1	0	1	2	3
Economic	Economic Merits	Comparison of the economic benefits against the capital and ongoing costs (BC may be estimated)	BC < 0.1	BC: 0.1 - 0.5	BC: 0.5-0.9	BC = 1	BC: 1.0 - 1.4	BC: 1.4 - 1.7	BC >1.7
	Technical Feasibility	Potential design, implementation and operational challenges and constraints. Risk can increase with implementation timeframe	Major constraints and uncertainties which may render the option unfeasible	Constraints or uncertainties which may significantly increase costs or timeframes	Constraints or uncertainties which may increase costs or timeframes moderately	NA	Constraints that can be overcome easily	No constraints or uncertainties	No construction requirements
	Long term performance	Maintenance burden, design life	Significant increase requiring additional resources and / or <10 year design life	Moderate increase in maintenance requirements, <20 year design	Minor increase in maintenace requirements	No change	Can be incorporated in current planned maintenance	Some reduction to current maintenance requirements, > 30 year design life	Some reduction to current maintenance requirements, > 30 year design life
	Staging of works	Ability to stage works	NA	NA	NA	Works cannot be staged	Some minor components of the works may be staged	Some major components of the works may be staged	NA
Social	Impact on Emergency Services	Change in demand on emergency services (SES, Police, Ambulance, Fire, RFS etc).	Major Disbenefit	Moderate Disbenefit	Minor Disbenefit	Neutral	Minor Benefit	Moderate Benefit	Major Benefit
	Road Access	Flood depths and duration changes for critical transport routes	Key access roads become flooded that were previously flood free	Significant increase in main road flooding	Moderate increase in local or main road flooding	No Change	Moderate decrease in local or main road flooding	Significant decrease in main road flooding	Local and main roads previously flooded now flood free
	Impact on critical and/or vulnerable facilities[1]	Disruption to critical facilities	Inoperational for several days	Inoperational for one day	Inoperational for several hours	No Change	Period of inoperal or reduced by 0 4 hours	Period of inoperal or reduced by > 4 hours	Prevents disruption of critical facility altogether
	Impact on Properties	No. of properties flooded over floor. Across all events	>5 adversely affected	2-5 adversely affected	<2 adversely affected	None	<2 benefitted	2 to 5 benefitted	>5 benefitted
	Impact on flood hazard	Change in hazard classification	Significantly increased in highly populated area (Increasing to H5/H6)	Moderately increased in populated area (Increasing by 2 or more categories)	Slightly increased (Increase by 1 category)	No Change	Slightly reduced (Decrease by 1 category)	Moderately reduced in populated area (Decrease by 2 or more categories)	Significantly reduced in highly populated area (Decrease from H5/H6)
	Community Flood Awareness	Change in community flood awareness, preparedness and response	Significantly reduced	Moderately reduced	Slightly reduced	No Change	Slightly improved	Moderately improved	Significantly improved
	Climate Change Adaptability	Performance under future climate change conditions, contribution to mitigation of or adaptation to changing climate	Increases risk	Benefits entirely eroded in future	Benefits partially eroded in future	Neutral	Provides some mitigation to changing climate	Provides moderate mitigation to changing climate	Entirely mitigates changing climate
	Social disruption	Closure of or restricted access to community facilities (including recreation)	Normal access significantly reduced or facilities disrupted for > 1 day	Normal access routes moderately reduced or facilities disrupted for 6-24 hours	No change to access but facilities disrupted for up to 6 hours	No Change	Reduces duration of access disruption or facility disruption by up to 6 hours	Reduces duration of access disruption or facility disruption by 6-24 hours	Prevents disruption of access or facility altogether
	Community and stakeholder support	Level of agreement (expressed via formal submissions and informal discussions)	Strong opposition by numerous submissions	Moderate opposition in several submissions	Individual submissions with opposition	Neutral	Individual submissions with support	Moderate support in several submissions	Strong support by numerous submissions
Environmental	Environmental and Ecological Impacts	Impacts or benefits to flora/fauna	Likely broad-scale vegetation/habitat impacts	Likely Isolated vegetation/habitat impacts	Removal of Isolated trees, minor landscaping.	Neutral	Planting of isolated trees, minor landscaping.	Likely Isolated vegetation/habitat benefits	Likely broad-scale vegetation/habitat benefits
	Heritage Conservation Areas/Items	Impacts to heritage items	Likely impact on State, National or Aboriginal Heritage Item	Likely impact on local heritage item	Likely impact on contributory item within a heritage conservation area	No impact	Reduced impact on contributory item within a heritage conservation area	Reduced impact on local heritage item	Reduced impact on State, National or Aboriginal Heritage item
	Acid Sulfate Soils and Contaminated Land	Disruption of PASS and/or Disruption of Contaminated Land		Any works within Class 1 or 2 ASS area or Excavation >1m within Class 3 ASS area or Excavation >1m within Class 4 ASS area	Surface works within Class 2 ASS area or Excavation <1m or surface works within Class 3 ASS area or Excavation <2m or surface works within Class 4 ASS area	Works not within areas identified as PASS or contaminated land	NA	NA	NA
Other Aspects	Financial Feasibility and Funding Availability	Capital and ongoing costs and funding sources available	Significant capital and ongoing costs, or no external funding or assistance available	Moderate capital and ongoing costs, no funding available	High capital and ongoing costs, partial funding available	NA	Moderate capital and ongoing costs, partial funding available	Low to moderate capital and ongoing costs, partial funding available	Full external funding and management available
	Compatibility with existing Council plans, policies or projects	Level of compatibility	Conflicts directly with objectives of several plans, policies or projects	Conflicts with several objectives or direct conflict with one or few objectives	Minor conflicts with some objectives, with scope to overcome conflict	Not relevant	Minor support for one or few objectives	Some support for several objectives, or achieving one objective	Achieving objectives of several plans, policies or projects

Notes:

1 Critical facilities are those properties that, if flooded, would result in severe consequences to public health and safety. These may include fire, ambulance and police stations, hospitals, water and electricity supply, buses/train stations and chemical plants. Vulnerable facilities refer to those properties with vulnerable occupants, such as nursing homes or schools.

Table 55: Multi-criteria Matrix Assessment – Results

			Economic				Social									Environmental			Other Aspects			
Category	ID	Option	Economic Merits	Technical Feasibility	Long term performance	Staging of works	Impact on Emergency Services	Road Access	Impact on critical and/or vulnerable facilities1	Impact on Properties	Impact on flood hazard	Community Flood Awareness	Climate Change Adaptability	Social disruption	Community and stakeholder support	Environmental and Ecological Impacts	Heritage Conservation Areas/Items	Acid Sulfate Soils and Contaminated Land	Financial Feasibility and Funding Availability	Compatibility with existing Council plans, policies or projects	Total Score	Overall Rank
		Weight	90%	95%	85%	62%	70%	82%	87%	82%	93%	72%	78%	68%	73%	77%	68%	77%	80%	72%		
Flood Modification Measures	FM01	Regrade Bexley Golf Course	1	2	0	1	1	1	0	2	1	0	2	0	0	0	0	0	1	1	10.6	**11**
	FM02	Dowsett Park Detention Basin	-1	-1	0	1	1	1	0	2	1	1	1	0	0	0	0	0	1	1	5.9	**18**
	FM03	Kingsland Road Overflow Management	-1	1	0	1	0	0	0	1	0	0	2	0	1	0	0	0	-1	1	3.7	**19**
	FM04	Powys Avenue Drainage	3	2	-1	0	1	1	0	1	1	0	2	0	0	0	0	0	-1	1	8.5	**14**
	FM05	SWSOOS Flow Path	NOT RECOMMENDED																		NA	**NA**
	FM06	Bexley Road Upgrade	-2	-2	2	1	3	3	0	0	3	2	1	2	0	0	-2	0	0	2	9.6	**12**
	FM07	Bardwell Park Station Levee	1	1	2	1	0	0	0	0	2	0	1	2	0	0	0	0	0	1	8.9	**13**
	FM08	Guess Avenue Underground Storage	-2	-2	-1	1	1	1	0	1	1	1	-1	1	2	0	0	-2	1	1	1.4	**21**
	FM09	Queen Victoria Street Drainage Diversion	-2	-3	0	1	0	0	0	1	1	0	1	0	0	-1	0	0	0	1	-1.6	**23**
	FM10	Seaforth Park Detention Basin	1	-1	0	2	1	1	0	2	1	1	1	0	0	0	0	0	1	1	8.3	**15**
	FM11	Subway Road Drainage Upgrade	NOT RECOMMENDED																		NA	**NA**
	FM12	Mutch Avenue Drainage Line	NOT RECOMMENDED																		NA	**NA**
	FM13	Alice Street Drainage Line	-2	-2	0	1	1	1	0	1	1	0	-1	0	0	-1	0	-2	1	1	-1.4	**22**
	FM14	Channel and Drainage Maintenance	1	2	0	0	0	1	0	0	1	1	1	0	0	0	0	0	1	2	8.3	**15**
	FM15	Levee Inspection and Maintenance	1	2	-1	0	0	1	0	1	1	0	0	0	0	0	0	0	1	1	6.0	**17**
	FM16	Drainage Capacity Upgrades	NOT RECOMMENDED																		NA	**NA**
	FM17	Channel Upgrades	NOT RECOMMENDED																		NA	**NA**
	FM18	Filling of Low-Lying Land	-2	-3	1	2	1	1	1	2	1	2	3	-1	0	-1	-1	-1	-1	-1	1.8	**20**
	FM19	Automatic Tidal Gates	NOT RECOMMENDED																		NA	**NA**
Property Modification Measures	PM01	Voluntary House Raising	NOT RECOMMENDED																		NA	**NA**
	PM02	Voluntary Purchase	NOT RECOMMENDED																		NA	**NA**
	PM03	Flood Proofing	3	1	0	3	2	0	2	3	1	1	0	2	0	0	0	0	3	2	17.9	**4**
	PM04	Land Use Zoning	NO CHANGE TO CURRENT PRACTICE																		NA	**NA**
	PM05	Flood Planning Levels	3	3	1	0	1	0	3	3	1	1	2	0	0	0	0	0	2	3	19.1	**2**
	PM06	Flood Planning Area	3	3	1	0	1	0	1	3	0	1	2	0	0	0	0	0	2	3	16.5	**5**
	PM07	Flood Planning Policy	3	3	1	0	0	0	3	3	1	1	2	0	0	0	0	0	2	3	18.4	**3**
	PM08	Section 10.7 Certificates	3	3	1	0	0	0	0	3	0	2	2	0	0	0	0	0	2	3	15.6	**7**
	PM09	Climate Change Policy	3	3	2	0	1	1	2	3	1	2	3	0	0	0	0	0	2	1	20.0	**1**
Response Modification Measures	RM01	Flood Emergency Management Planning	3	3	1	3	3	0	0	0	0	1	2	0	0	0	0	0	2	2	15.7	**6**
	RM02	Flood Warning Systems	2	3	0	1	1	0	0	0	0	2	2	0	0	0	0	0	1	2	11.2	**10**
	RM03	Community Flood Awareness	2	3	0	3	3	0	0	0	0	3	2	0	0	0	0	0	1	3	15.3	**8**
	RM04	Improvements to Driver Safety	1	2	0	2	3	0	0	0	1	2	2	0	0	0	0	0	1	2	12.3	**9**

11.2. MCMA Results

The results of the multicriteria assessment are provided in Table 55, with each of the assessed management measures scored against the range of criteria. It is important to note that the approach undertaken does not provide an absolute "right" answer as to what should be included in the Management Plan but is rather for the purpose of providing an easy framework for comparing the various options on an issue by issue basis, which stakeholders can then use to make a decision.

For the same reason, the total score given to each option, is only an indicator to be used for general comparison. Options with positive scores indicate that the benefits of the option outweigh negative aspects. These options have been recommended for inclusion in the Floodplain Risk Management Plan.

11.3. Discussion of MCMA Results

The multi-criteria matrix assessment results, presented in Table 55, can be used to both understand the benefits and disadvantages of individual options, but to also see trends across the full suite of options assessed in the FRMS&P. The following results and trends are noted:

- Property Modification Measures related to policy changes or updates ranked the highest, as they are cost effective methods to reduce property damages in the study area, and have additional benefits relating to improvements to community flood awareness.
- Response Modification Measures also rank higher than Flood Modification Measures, as they also are relatively cost-effective to implement and can have substantial impact on the preparedness for floods, as well as changes to the actions and attitudes of the community.
- Flood Modification Measures rank the lowest, with varying degrees of benefits and disbenefits across the range of criteria assessed.

The results of the MCMA have been used to identify a priority list of options, shown in Table 56.

Table 56: Rank of Flood Risk Mitigation Measures

Rank	Option	Priority
1	PM09 Climate Change Policy	**High**
2	PM05 Flood Planning Levels	**High**
3	PM07 Flood Planning Policy	**High**
4	PM03 Flood Proofing	**High**
5	PM06 Flood Planning Area	**High**
6	RM01 Flood Emergency Management Planning	**High**
7	PM08 Section 10.7 Certificates	**High**
8	RM03 Community Flood Awareness	**High**
9	RM04 Improvements to Driver Safety	**High**
10	RM02 Flood Warning Systems	**Medium**
11	FM01 Regrade Bexley Golf Course	**High**
12	FM06 Bexley Road Upgrade	**High**
13	FM07 Bardwell Park Station Levee	**High**
14	FM04 Powys Avenue Drainage	**Medium**
15	FM10 Seaforth Park Detention Basin	**Medium**
15	FM14 Channel and Drainage Maintenance	**High**
17	FM15 Levee Inspection and Maintenance Program	**Medium**
18	FM02 Dowsett Park Detention Basin	**Medium**
19	FM03 Kingsland Road Overflow Management	**High**
20	FM18 Filling of Low-Lying Land	**Low**
21	FM08 Guess Avenue Underground Storage	**Low**
22	FM13 Alice Street Drainage Line	**Low**
23	FM09 Queen Victoria Street Drainage Diversion	**Low**
NA	PM04: Land Use Zoning	**No Change**

Rank	Option	Priority
NA	PM01: Voluntary House Raising	Not Recommended
NA	PM02: Voluntary Purchase	
NA	FM05 SWSOOS Flow Path	
NA	FM11 Subway Road Drainage Upgrade	
NA	FM12: Mutch Avenue Drainage Line	
NA	FM16: Drainage Capacity Upgrades	
NA	FM17: Channel Upgrades	
NA	FM19: Automatic Tidal Gates	

This will form the basis of the Floodplain Risk Management Plan (Section 12).

12. DRAFT FLOODPLAIN RISK MANAGEMENT PLAN

The Floodplain Risk Management Plan (Table 57) summarises the recommended measures that have been investigated as part of the Floodplain Risk Management Study. The recommended flood modification options that have a specific location are shown in Figure 39. Measures have been assessed for effectiveness against a range of criteria. The assessment criteria included how the option affected property damages, community flood awareness, impact on the SES, and economic merits, and a range of other factors. Recommended options are prioritised based upon how readily the management measures can be implemented, their capital cost, what constraints exist and how effective the measures are. Measures with little cost that can readily be implemented, and which are effective in reducing damage or personal danger would have high priority.

The Floodplain Risk Management Plan has been prepared in accordance with the NSW Floodplain Development Manual (Reference 1).

- *Is based on a comprehensive and detailed evaluation of factors that affect and are affected by the use of flood prone land;*
- *Represents the considered opinion of the local community on how to best manage its flood risk and its flood prone land; and*
- *Provides a long-term path for the future development of the community.*

The Floodplain Risk Management Plan provides input into the strategic and statutory planning roles of Council and provides a plan for Council to effectively manage flood liable land. It lists the mitigation measures that have been recommended in the Floodplain Risk Management Study for implementation and describes the purpose of the measure, as well as its priority, cost, timeframe and the party responsible for its implementation. Detailed description of each recommendation is provided in Section 10 of the Study.

12.1. Funding and Implementation

There are several sources of funding for the investigation and implementation of the recommended flood risk mitigation measures. The DPE offers support to local Councils through Floodplain Management Grants. Assistance under this program is usually provided at a ratio of 2:1 State Government funding to local council funding. There are also schemes such as Resilience NSW's Get Ready Program which distributes practical resource kits and supports local councils to build resilient communities and help prepare for disasters such as flooding. There are also schemes supported by the Federal Government as well that are typically channelled through the State Government.

In addition to government funding, Council could also approach other organisations (such as Transport for NSW and SES) or private owners (such as property developers where appropriate) to assist with funding of measures.

Implementation of the Plan should be overseen by the Bayside FRMC. The local community should continue to be informed of progress through regular updates.

12.2. Ongoing Review of the Plan

This Floodplain Risk Management Plan should be reviewed and amended as required over time. It is recommended that this occurs every 10 years at a minimum. This ensures the Plan remains relevant to the requirements of the area. Reviews can also be undertaken following flood events, or where new information becomes available that may be relevant. Changes in State or Local Government legislation or alterations to funding availability may also trigger the need for a review.

Table 57: Bayside West Floodplain Risk Management Plan

	Option ID Report Section	Option	Description	Benefits	Concerns	Responsibility	Funding	Cost	CBR	Priority
Flood Modification Options	FM01 10.2.4.4	Regrade Bexley Golf Course	Regrade land from Bridge Street into Bexley Golf Course to allow overland flows to Bardwell Creek.	• Reduces road inundation on Bridge Street to Unwin Street, improving driver safety and flood immunity. • Reduces property impacts for several properties on Bridge Street.	• Consultation required with golf course. • Regrading would need to be designed with consideration to golf course layout.	Council, in liaison with Bexley Golf Course	May be eligible for NSW Government funding	$200,000	1.2	High
	FM06 10.2.4.9	Bexley Road Upgrade	Upgrade Bexley Road crossing Wolli Creek.	• Improve flood immunity, reduced flood risk and improved reliability for motorists.	• Structure design and tie in with existing road and intersections. • Construction method and need for road closure.	Transport for NSW	Transport for NSW / State Government	$20M - $100M	N/A	High
	FM07 10.2.4.10	Bardwell Park Station Levee	Construct levee to protect Bardwell Park station from Wolli Creek flooding.	• Improve flood immunity and railway access during flood events.	• Construction may be difficult within railway corridor. • Local drainage may require upgrading, as well as consideration of embankment stability.	Transport for NSW	Transport for NSW / State Government	$300,000	N/A	High
	FM14 10.2.5.1	Channel and Drainage Maintenance	Maintenance involves regularly removing unwanted vegetation and other debris from the drainage network, particularly at culverts, inlet pits and within channels. Council already has an appropriate creek and drainage maintenance program, and it is recommended to continue this program. Council is aware of specific areas prone to	• Removal of vegetation and debris blockage from structures will enable a more efficient conveyance of water.	• The major release of debris is during the storm event, and hence regular maintenance may not necessarily reduce blockage during a flood event. • Vegetation in open channels is not a significant constraint to	Council	Internal (Existing Drainage Maintenance Program)	N/A	N/A	High

	Option ID Report Section	Option	Description	Benefits	Concerns	Responsibility	Funding	Cost	CBR	Priority
Flood Modification Options			blockage, however, Council should periodically review and update these areas based on feedback from the community. Council should also inspect and record channels and drainage structures following flood events to assess debris build up and clear blockages.		the hydraulic capacity of the channel.					
	FM03 10.2.4.6	Kingsland Road South Overflow Management	Management of drainage on Kingsland Road South via overland flow path to Highgate Street and/or barrier on Kingsland Road South to prevent overflow.	• Removes overflow from Kingsland Road South into property No's 17-23.	• Works need to consider existing footpath between Kingsland Road South and Highgate Street. • Works would need to consider driveway at No 23 Kingsland Road South. • Road safety requirements would need to be considered as well as visual amenity.	Council	Likely Council funded	$75,000	N/A	High
	FM04 10.2.4.7	Powys Avenue Blockage Prevention	Implement blockage prevention on openings under noise wall. This may include structural options (screens with wider openings, sloped screens, debris deflectors) and regular maintenance.	• Reduces tendency for blockage and should improve ponding on Powys Avenue.	• Uncertainty associated with blockage may not provide the modelled benefits. • Impacts within railway corridor and consultation required with Transport for NSW.	Transport for NSW	Transport for NSW / Council	$35,000 capital costs $2,000 annual mainten-ance cost	6.8	Medium
	FM10 10.2.4.13	Seaforth Park Detention Basin	Excavate Seaforth Park to form two detention basins. Construct pit outlets in the basin that connect to the existing 600 mm pipe under the park.	• Reduces property impacts for properties downstream of the basin on the overland flow path to Warialda Street.	• It is assumed that the 600 mm pipe under the park can be used 'as is' to form the low flow outlet of the basin and there is no	Council	May be eligible for NSW Government funding	$3.9M	0.3	Medium

	Option ID Report Section	Option	Description	Benefits	Concerns	Responsibility	Funding	Cost	CBR	Priority
				• Improves flooding on roads such as Connemarra Street and Warialda Street, improving driver safety and flood immunity.	need to relocate it and that the basin excavation will not interfere with it.					
Flood Modification Options	FM15 10.2.5.2	Levee Inspection and Maintenance Program	Regularly inspect levees for signs of weakness (e.g. erosion or cracks) and maintain them, including drainage systems behind the levee and filling of gaps.	• Ensures risk of levee failure is minimised during flood events.	• Needs to be regularly inspected and maintained (e.g. at least annually).	Council	Internal	$10,000 per annum	N/A	Medium
	FM02 10.2.4.5	Dowsett Park Detention Basin	Excavate Dowsett Park to form a detention basin. Remove a section of 900 mm pipe such that is discharges into the basin and forms the low flow outlet of the basin.	• Reduces property impacts on the overland flow path downstream of the basin, including residential properties, Our Lady Fatima Catholic Primary School and Kingsgrove RSL Club. • Reduces road inundation on Dowsett Road, Edward Street, The Avenue, Brocklehurst Lane and Shaw Street, improving driver safety and flood immunity. • Reduces flooding on the East Hills railway line.	• Basin design would depend on actual invert level of 900 mm pipe and grading requirements.	Council	May be eligible for NSW Government funding	$4.4M	0.3	Medium
	FM18 10.2.5.5	Filling of Low - Lying Land	Filling of low-lying land to achieve protection from rising sea levels.	• Protection of properties and infrastructure from sea level rise.	• Widespread filling that involves both public and private land is difficult to achieve in a way that is consistent and does not	Council and private land owners	Council and private land owners	Not Estimated	N/A	Low

	Option ID Report Section	Option	Description	Benefits	Concerns	Responsibility	Funding	Cost	CBR	Priority
					cause intermediate impacts to land holders.					
Flood Modification Options	FM08 10.2.4.11	Guess Avenue Storage Tank	Construct an underground flood storage tank under No 2 or No 4 Guess Avenue site during redevelopment, or under the proposed Gertrude Street extension.	• Reduces road inundation on Arncliffe Street, improving driver safety and flood immunity. • Reduces property impacts for several properties on Arncliffe Street, although most have raised floor levels.	• Would depend on proposed redevelopment and future use of the site • Constraints include underground services • Reliance on storage being empty at the start of the storm and reliance on pumping of water out of the tank.	Council / future developer	Council / future developer	$1M - $8M	0.1	Low
	FM13 10.2.4.16	Alice Street Drainage Line	Construct a new box culvert from the corner of Chuter Avenue and Alice Street to Botany Bay	• Reduces property impacts for numerous properties, particularly between Park Road and Alice Street. • Reduces road inundation slightly.	• Significant construction required on major roads and through Cook Park. • Stormwater outlet to Botany Bay would need to consider water quality and other coastal constraints. • Low grade of culvert and tidal affectation to be considered.	Council	May be eligible for NSW Government funding	$7.9M	0.2	Low
	FM09 10.2.4.12	Queen Victoria Street Drainage Diversion	Construct a new 900 mm diameter pipe along Queen Victoria Street, from Caledonian Street to the sag point just downstream of Connemarra Street.	• Reduces flooding on overland flow path through properties. • Minor benefits to sag points on Caledonian Street, Beaconsfield Street, Connemarra Street and Queen Victoria Street.	• Potential underground utilities that may need to be avoided or relocated, as well as tree roots. • Need to reconfigure existing drainage network on Queen Victoria Street to accommodate the new pipe. • Disruption to traffic and residents on Queen	Council	May be eligible for NSW Government funding	$2.3M	0.3	Low

	Option ID Report Section	Option	Description	Benefits	Concerns	Responsibility	Funding	Cost	CBR	Priority
					Victoria Street during construction.					
Property Modification Measures	PM09 10.3.9	Climate Change Policy	A climate change policy guides Council's operations and policies at a high level. This would likely feed into other Council operations such as coastal management, asset design, flooding and planning controls. Climate change adaptation should also be considered at an LGA-wide scale.	• Ensures future climate and sea levels are incorporated into current planning controls and infrastructure design.	• Uncertainties in future climate and sea level predictions. The changes expected for future rainfalls and runoff response is largely unknown.	Council	Internal	N/A	N/A	High
	PM05 10.3.5	Flood Planning Levels	Bayside Council's current adopted FPL is considered appropriate. It is recommended to update flood levels based on the updated modelling developed as part of this FRMS&P and consider incorporating climate change projections into FPLs.	• Ensures new buildings are protected to an appropriate level.	• A freeboard of 500 mm in overland flow areas may be excessive given the scale in the range of flood events.	Council	Internal	N/A	N/A	High
	PM07 10.3.7	Flood Planning Policy	Flood planning policy is typically governed by the LEP and DCP, which outline flood-related development controls. Consideration should be given to the following: • Inclusion of climate change in the full range of flood related development controls. • Implementation of the draft DCP.	• Ensures adequate flood planning controls to reduce the flood damage and risk to life for new developments.	• Clarity in planning controls and their application to ensure adherence.	Council	Internal	N/A	N/A	High

	Option ID Report Section	Option	Description	Benefits	Concerns	Responsibility	Funding	Cost	CBR	Priority
			• Provision of special flood considerations clause in the LEP.							
Property Modification Measures	PM03 10.3.3	Flood Proofing	Flood proofing of non-residential buildings with temporary flood barriers (both existing and new structures, where floor levels are allowed to be lower). This could also be extended to existing residential development, but not recommended for new residential development – floor level controls should be applied instead.	• Reduce flood damages in the event of a flood	• Costs and implementation of flood proofing measures are the responsibility of the property owner / business.	Council (policy) and property owners (cost of flood proofing)	Internal (policy) Private (flood proofing)	Varies	N/A	High
	PM06 10.3.6	Flood Planning Area	It is recommended to retain the current lot-based tagging approach, and update the tagging status based on the updated modelling undertaken as part of this FRMS&P.	• Ensures that flood planning controls are applied to lots that are flood affected.	• There are issues with the traditional approach of applying freeboard and 'stretching' the surface to identify the FPA, particularly with steep overland flow paths in urban areas.	Council	Internal	N/A	N/A	High
	PM08 10.3.8	Section 10.7 Certificates	Section 10.7 Certificates are required to show flood notation. This informs the land owner of flood risk and applicable development controls.	• Informs land owners of flood affectation of the lot and applicable flood planning controls.	• Typically only accessed for the purpose of redevelopment or in the sale/purchase of land.	Council	Internal	N/A	N/A	High
	RM01 10.4.1	Flood Emergency Management Planning and Coordination	It is recommended that the SES: • Use the information and modelling developed as part of this FRMS to update their local flood plan for Bayside.	• Flood emergency planning enables a more coordinated, timely and targeted response to flood events.	• As the interval between flood events increases, the coordination of flood response can lack attention.	Council and SES	Internal	N/A	N/A	High

	Option ID Report Section	Option	Description	Benefits	Concerns	Responsibility	Funding	Cost	CBR	Priority
			• Consider providing an updated FloodSafe brochure or information on their website specific for the flood risk in Bayside. It is recommended that Bayside Council and SES: • Hold regular meetings of all responders and training exercises between flood events to identify roles and responsibilities in practice and build relationships between agencies and/or community groups.							
Response Modification Measures	RM03 10.4.3	Community Flood Awareness and Education	It is recommended to design and implement and ongoing community flood education program to maintain a high level of flood awareness and understanding of the risk and appropriate response to flooding in the Bayside West study catchments. At a minimum, this should include ongoing development of Council's website as a hub for flood information, development and distribution of a leaflet and continuing to provide flood information through Section 10.7 certificates and flood advice letters.	• An informed community can better respond to flood risks, including preparation for and making wise decisions during flood events.	• Community education programs are typically well received by those interested in and already aware of flood risk, and it is difficult to engage the wider community.	Council	Internal with opportunities for State Government assistance.	Varies	N/A	High

	Option ID Report Section	Option	Description	Benefits	Concerns	Responsibility	Funding	Cost	CBR	Priority
Response Modification Measures	RM04 10.4.4	Improvements to Drive Safety	Installation of flood signs and flood depth indicators can improve driver safety, in conjunction with community education about the risks of driving through floodwaters. It is recommended that a detailed study is undertaken to confirm the preferred locations, residual flood risk (i.e. need for road closure) and safe alternative routes and how traffic can be diverted in flood events. Following the detailed study, installation can proceed in accordance with the outcomes of that study.	• One of the primary risks for flash flooding in urban areas is motorists driving through floodwaters. This reduces that risk by warning motorists of flooded roads.	• There is the chance that these signs and warnings will be ignored by motorists.	Council and Transport for NSW where applicable.	Council and Transport for NSW, with opportunities for State Government funding.	Not Estimated	N/A	High
	RM02 10.4.2	Flood Warning System	It is recommended that the severe weather and severe thunderstorm warnings issued by the BoM be used to prepare for potential flash flooding events. Community awareness campaigns may assist residents in interpreting warnings from the BoM, anticipating the impacts and preparing accordingly.	• Enable Council and SES to be on alert to potential flash flooding events. The community can also benefit by being aware of potential flash flooding as respond accordingly.	• Education about what these warnings means and actions that should be taken by residents in different locations is key.	Bureau of Meteorology, Council, SES.	Internal	N/A	N/A	Medium

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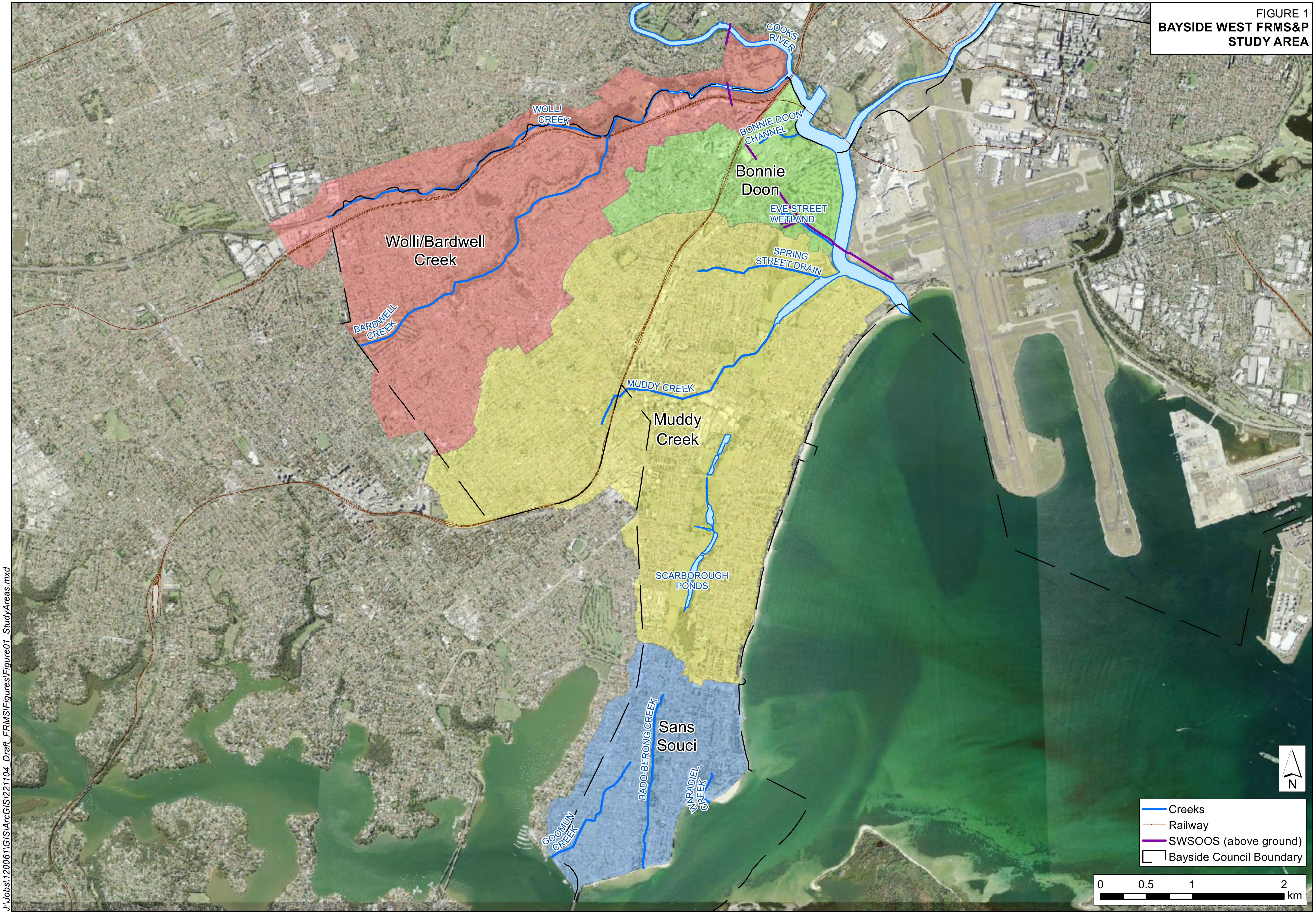
FIGURES

Figures

FIGURE 1
BAYSIDE WEST FRMS&P STUDY AREA



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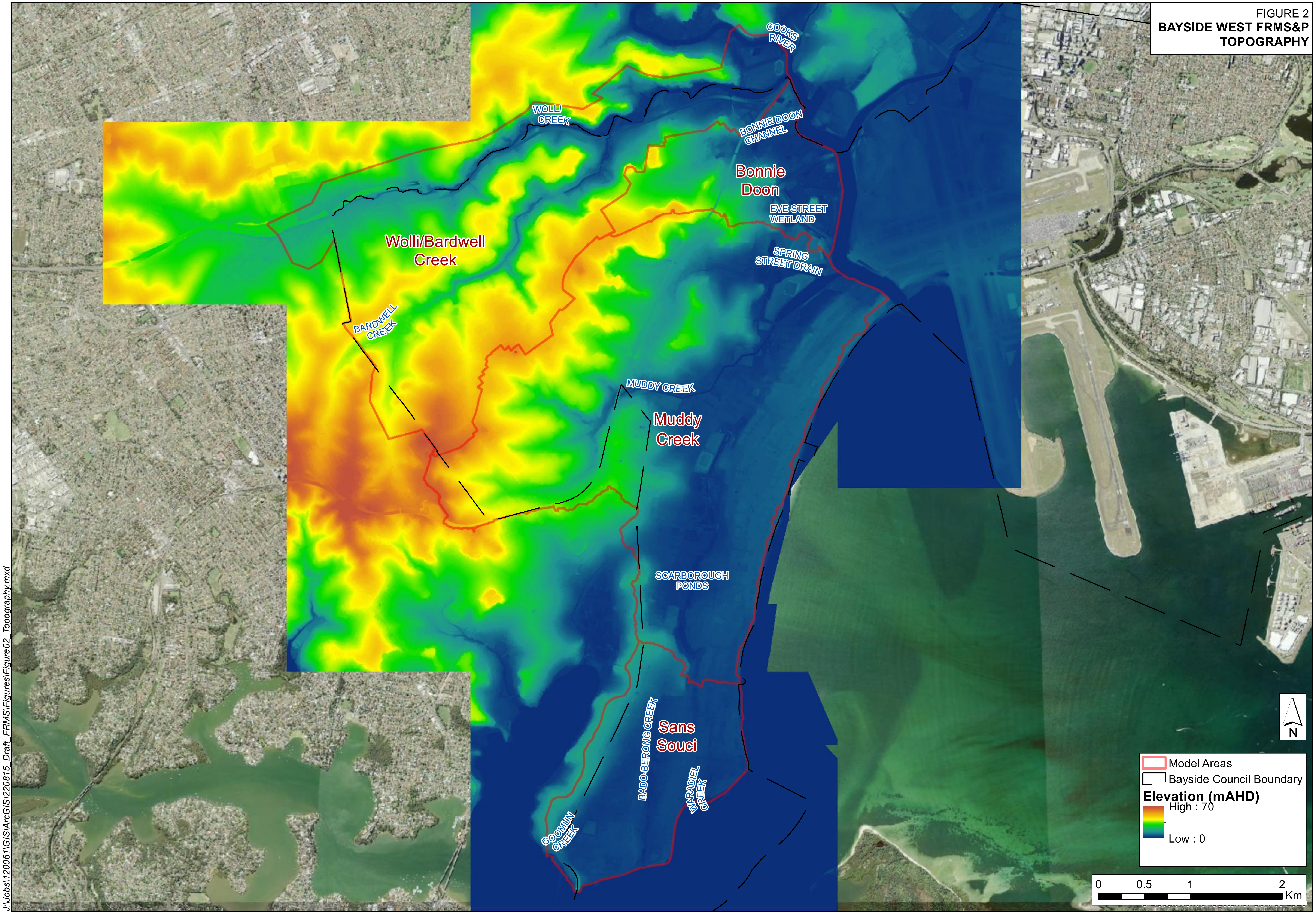

FIGURE 2
BAYSIDE WEST FRMS&P
TOPOGRAPHY
COOKS RIVER
WOLLI CREEK
BONNIE DOON CHANNEL
Bonnie Doon
EVE STREET WETLAND
SPRING STREET DRAIN
Wolli/Bardwell Creek
BARDWELL CREEK
MUDDY CREEK
Muddy Creek
SCARBOROUGH PONDS
BADO-BERONG CREEK
Sans Souci
WARADIEL CREEK
GOOMUN CREEK
N
Model Areas
Bayside Council Boundary
Elevation (mAHD)
High : 70
Low : 0
0 0.5 1 2
Km
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FIGURE 3
BAYSIDE WEST FRMS&P: BARDWELL CREEK MODEL UPDATES

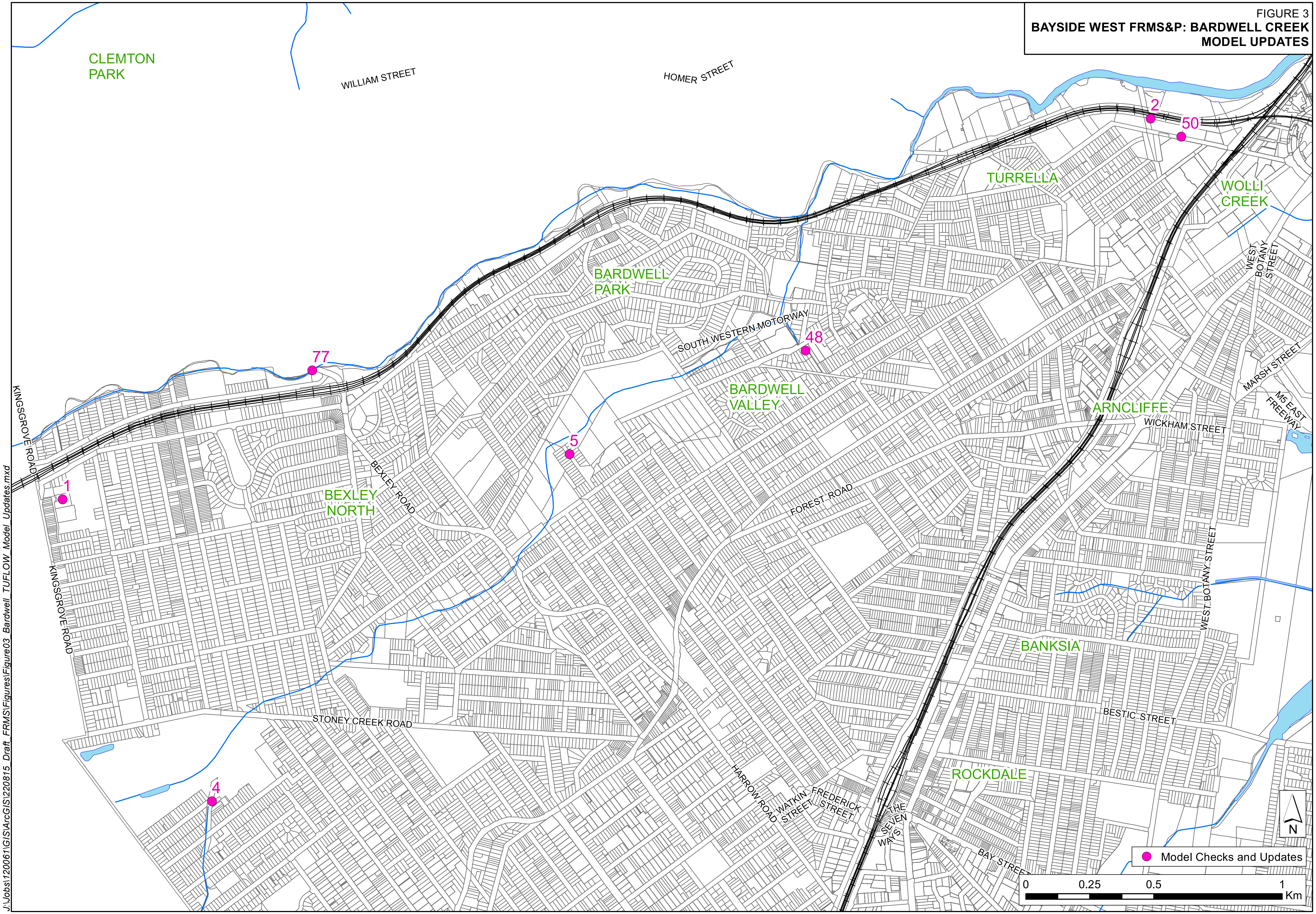
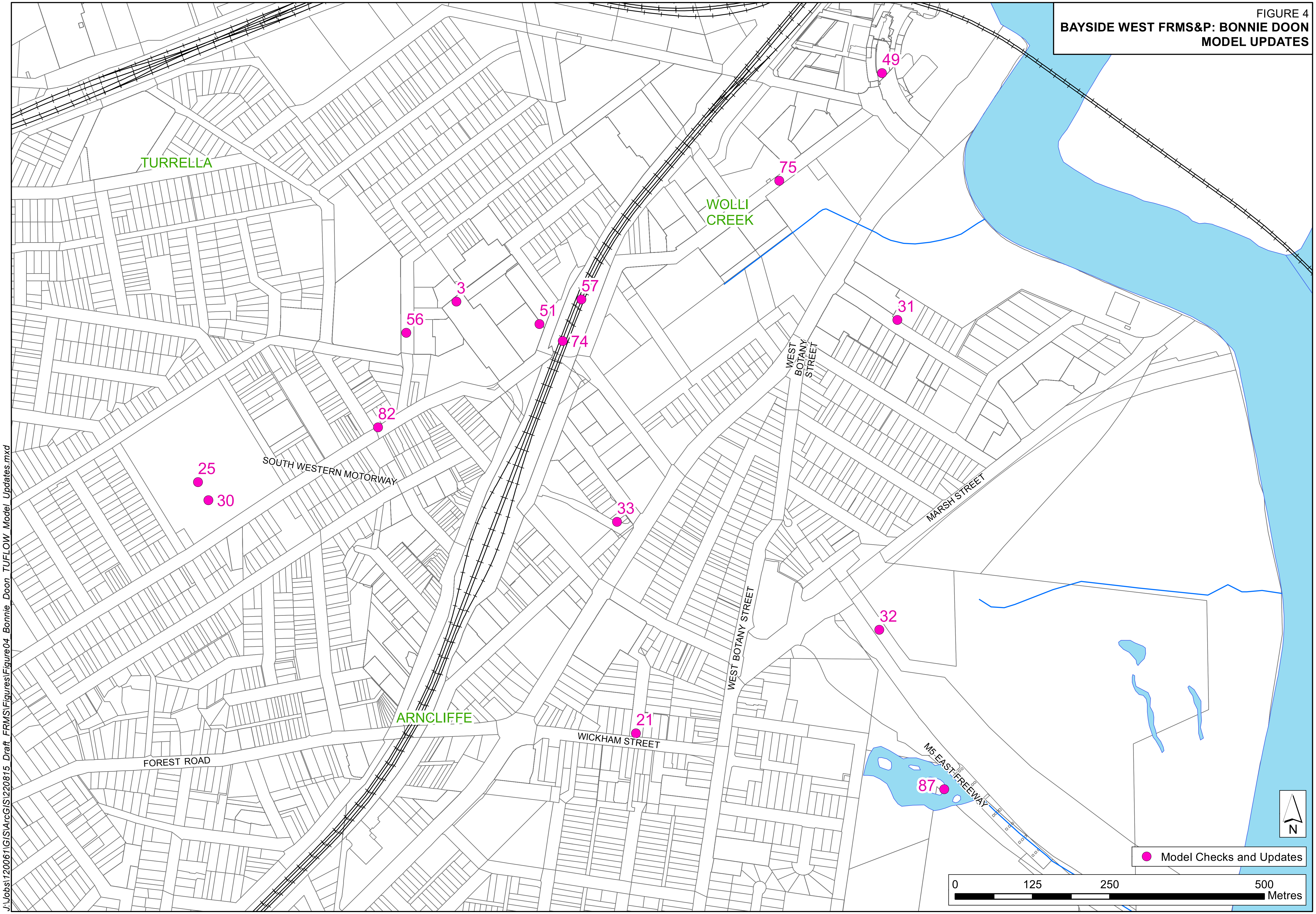


FIGURE 4
BAYSIDE WEST FRMS&P: BONNIE DOON MODEL UPDATES



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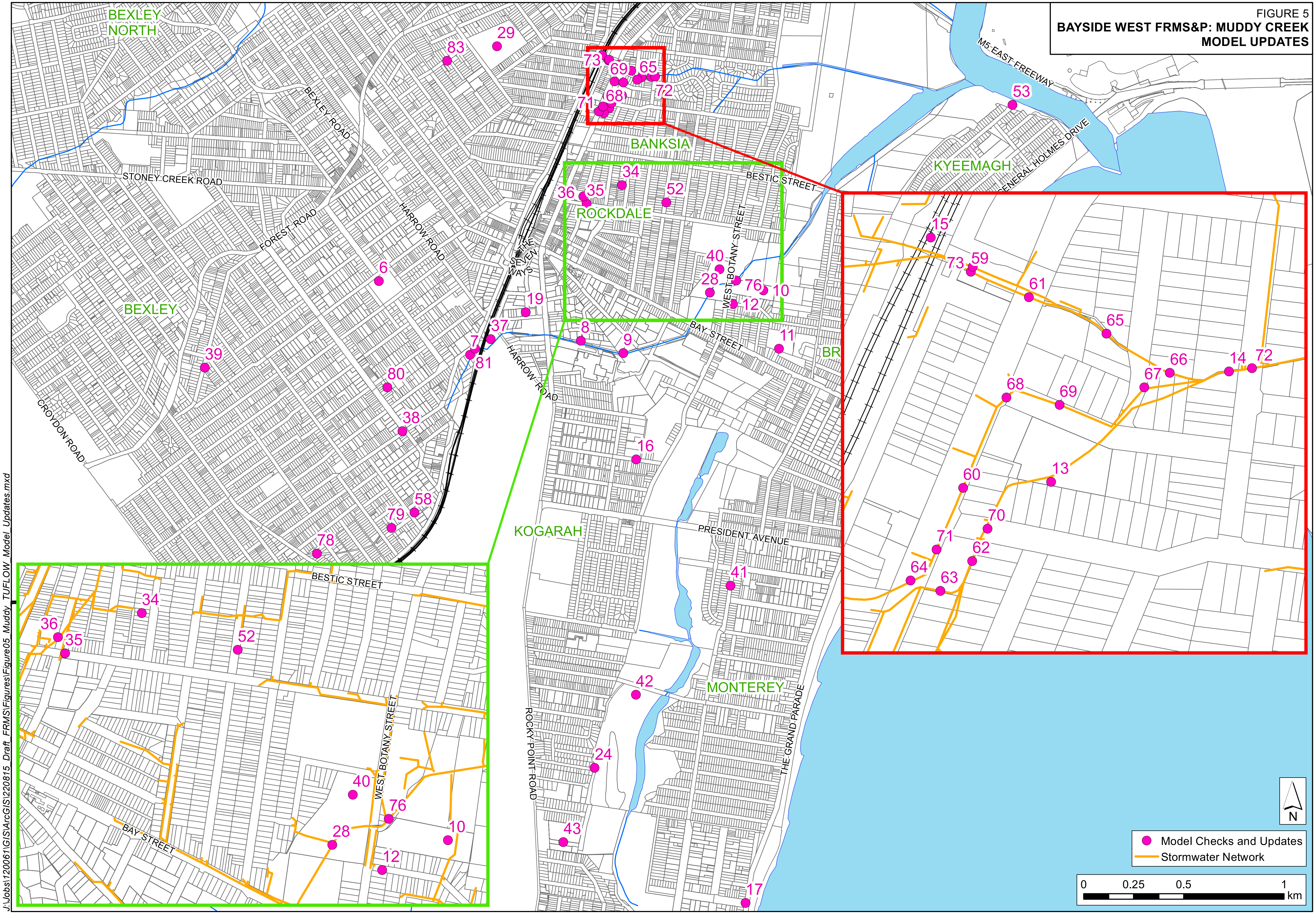

FIGURE 5
BAYSIDE WEST FRMS&P: MUDDY CREEK MODEL UPDATES

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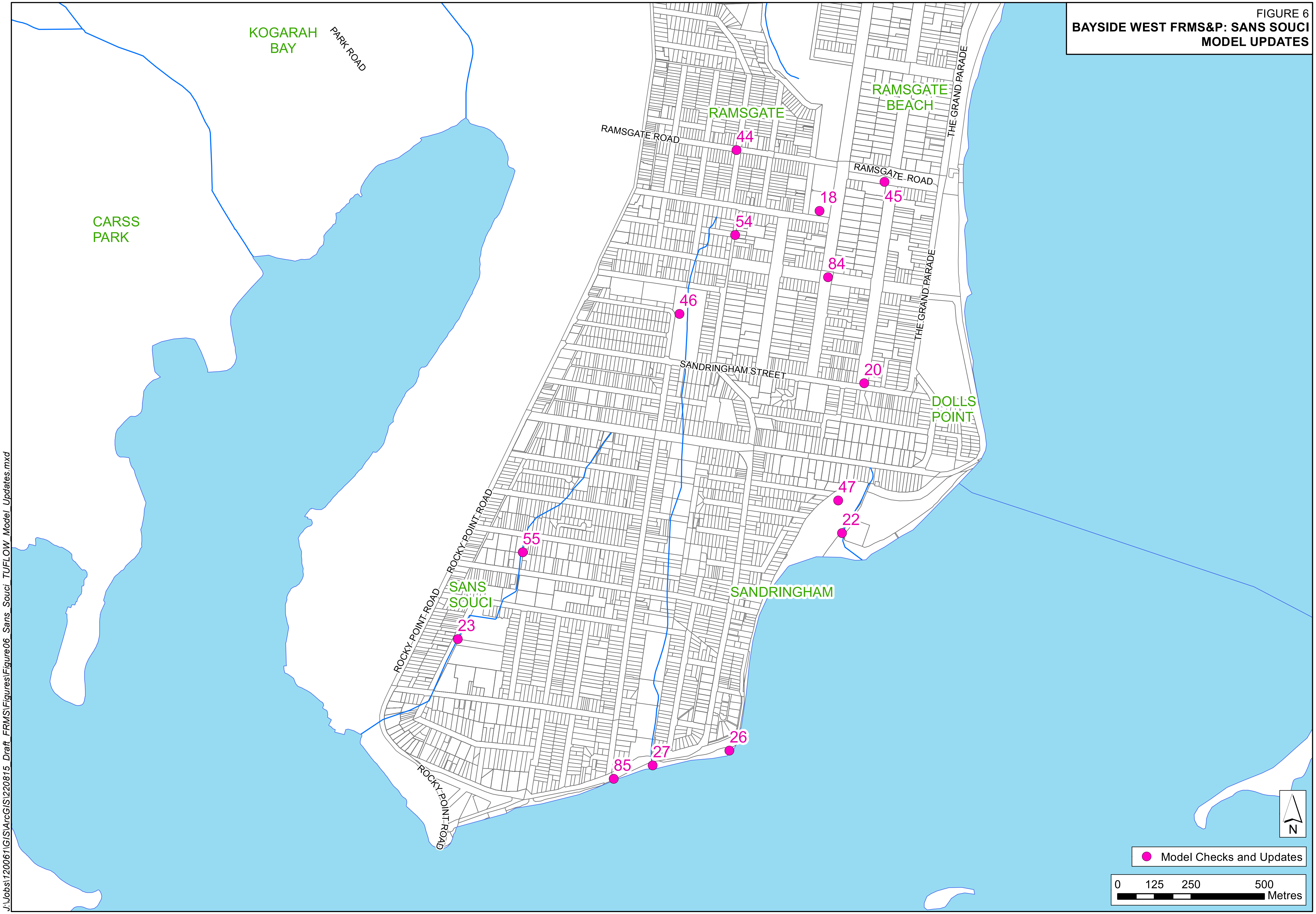
FIGURE 6
BAYSIDE WEST FRMS&P: SANS SOUCI MODEL UPDATES



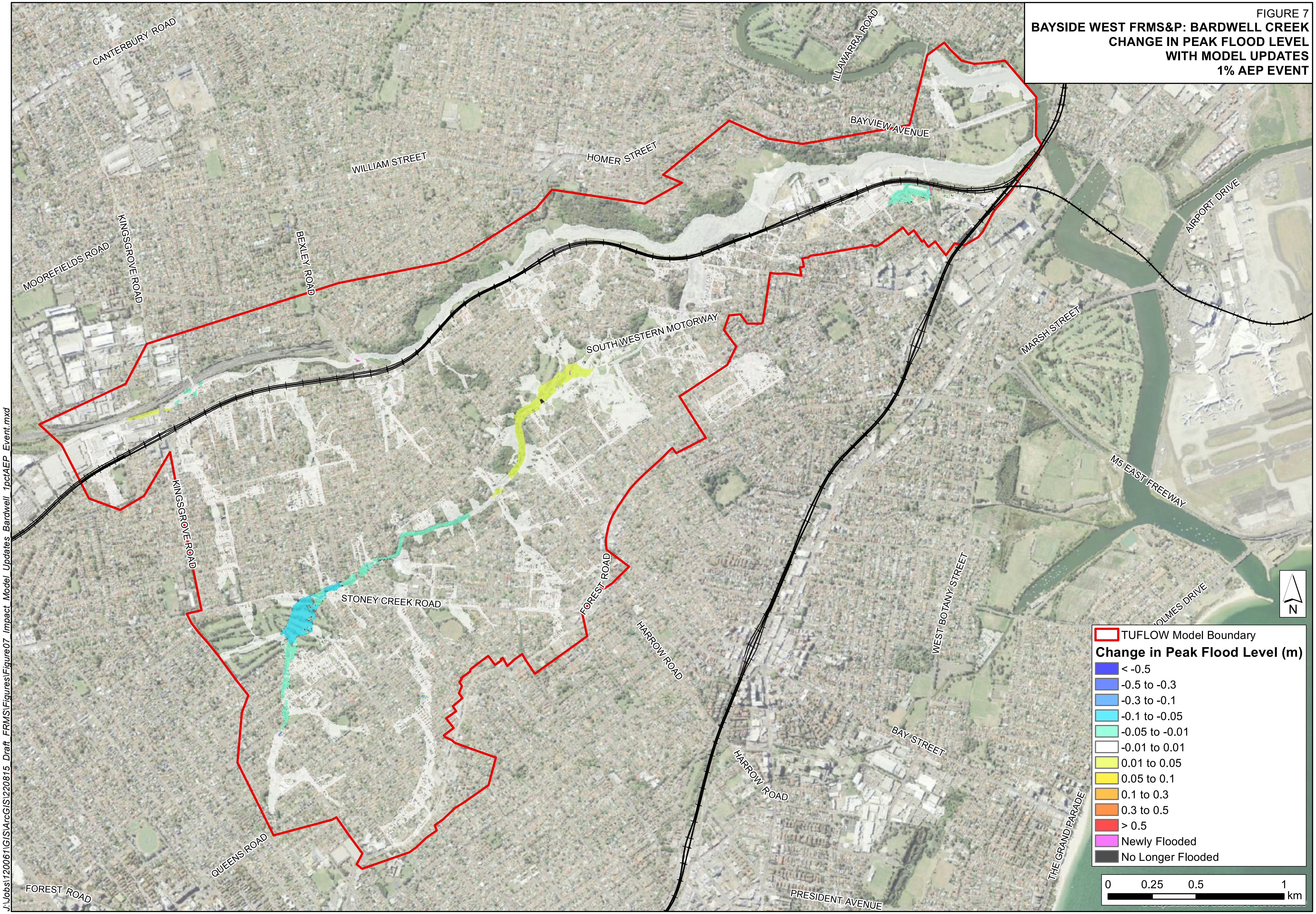
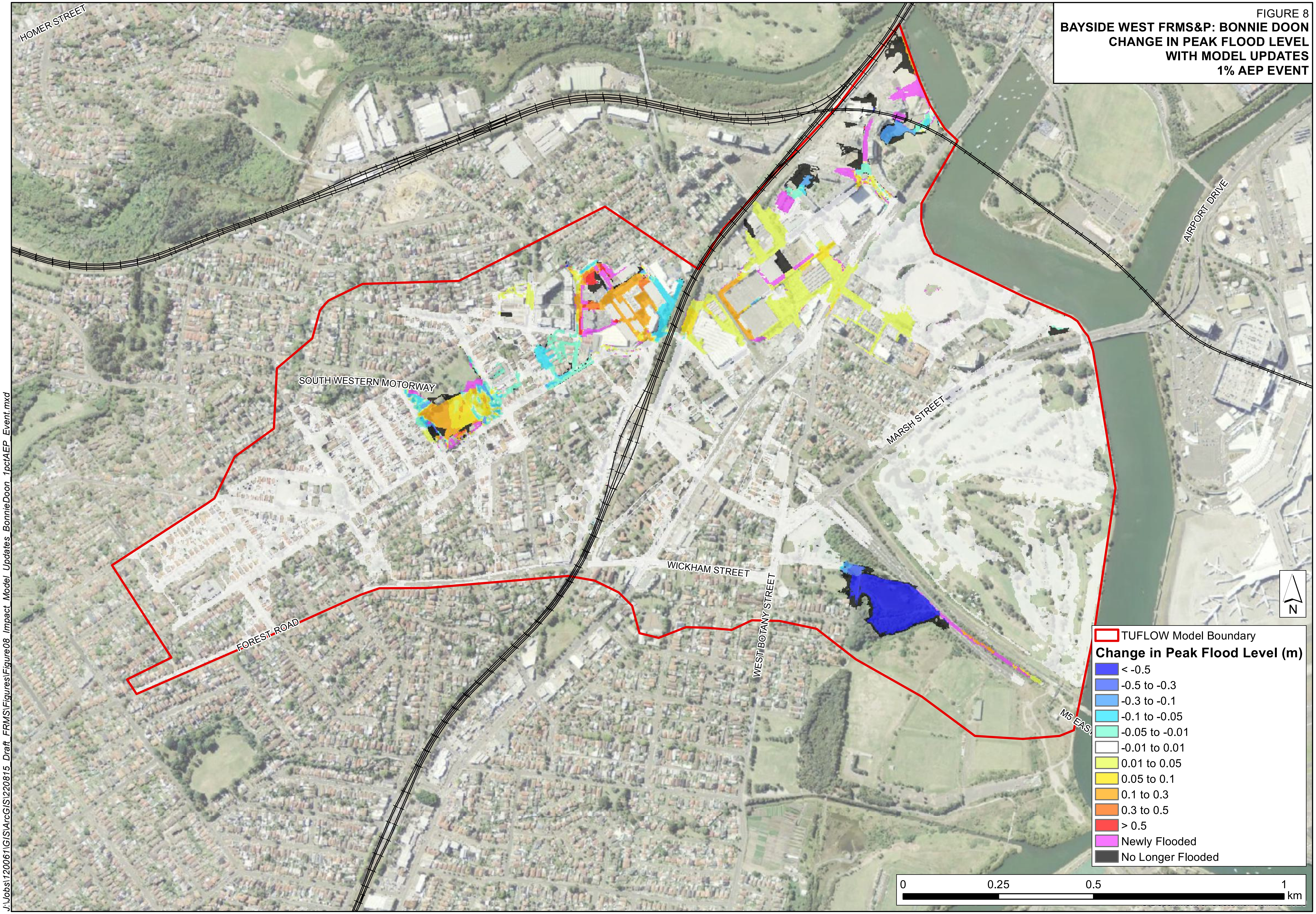


FIGURE 7

BAYSIDE WEST FRMS&P: BARDWELL CREEK CHANGE IN PEAK FLOOD LEVEL WITH MODEL UPDATES 1% AEP EVENT

FIGURE 8

BAYSIDE WEST FRMS&P: BONNIE DOON CHANGE IN PEAK FLOOD LEVEL WITH MODEL UPDATES 1% AEP EVENT



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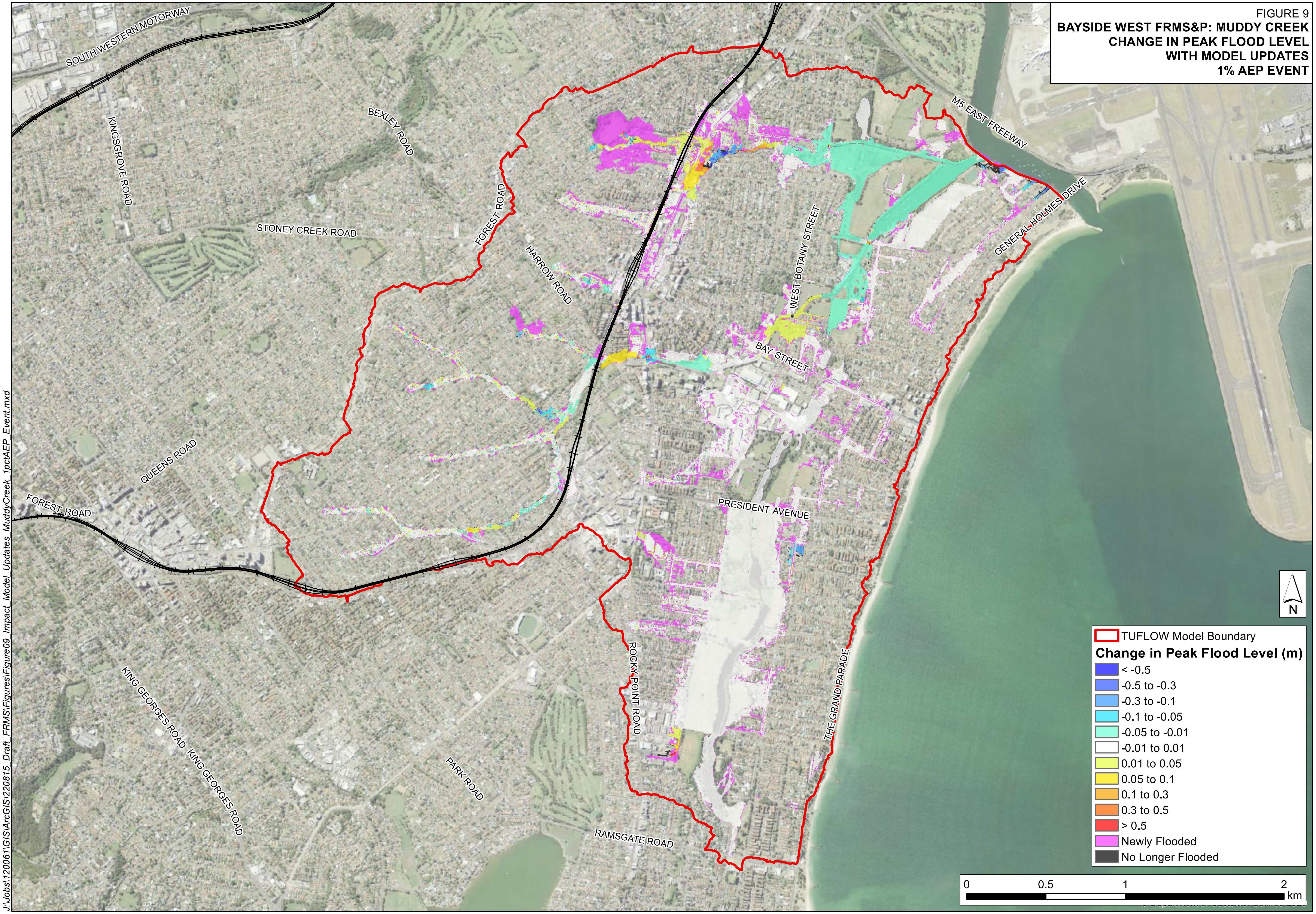

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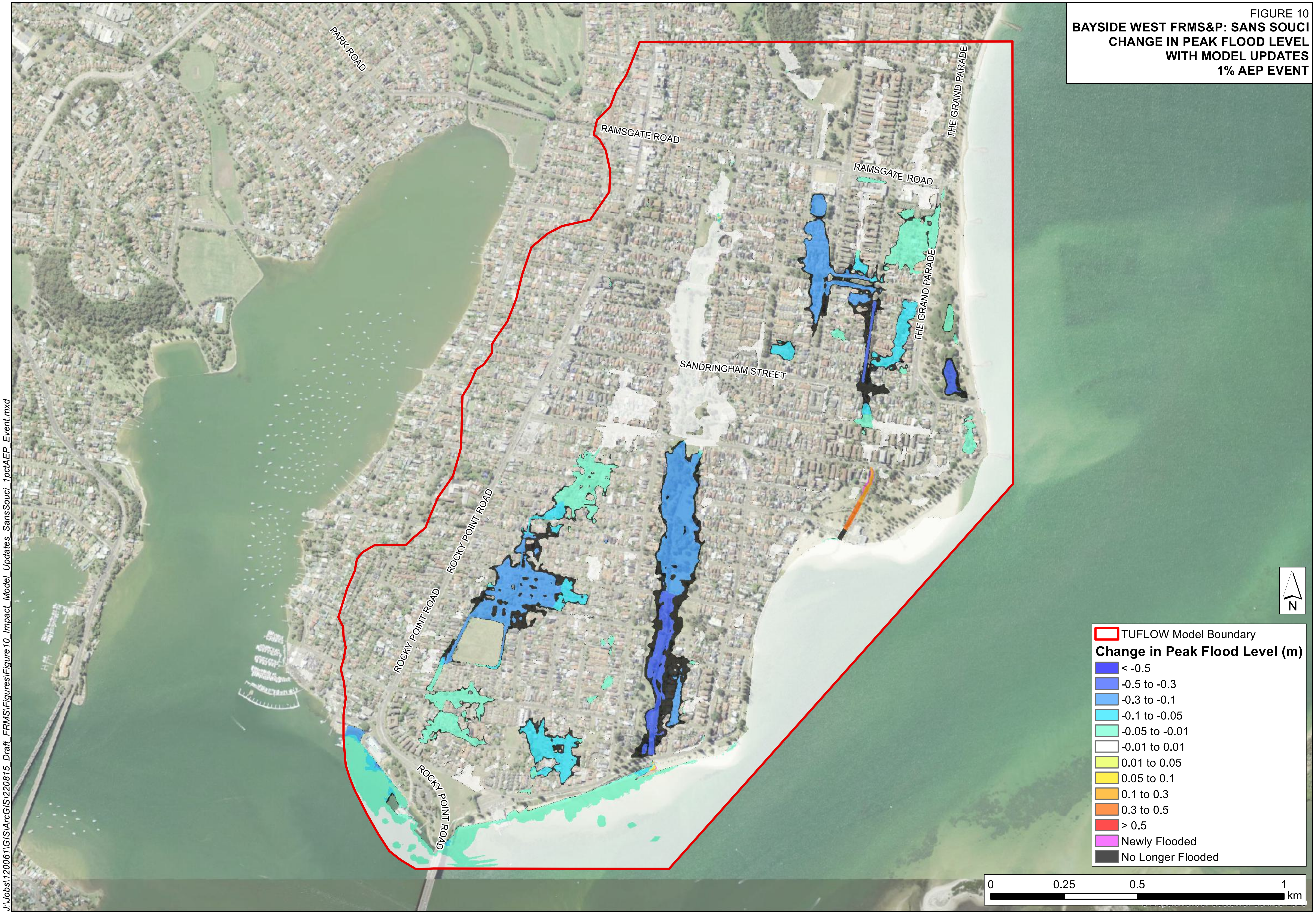
FIGURE 10
BAYSIDE WEST FRMS&P: SANS SOUCI
CHANGE IN PEAK FLOOD LEVEL
WITH MODEL UPDATES
1% AEP EVENT



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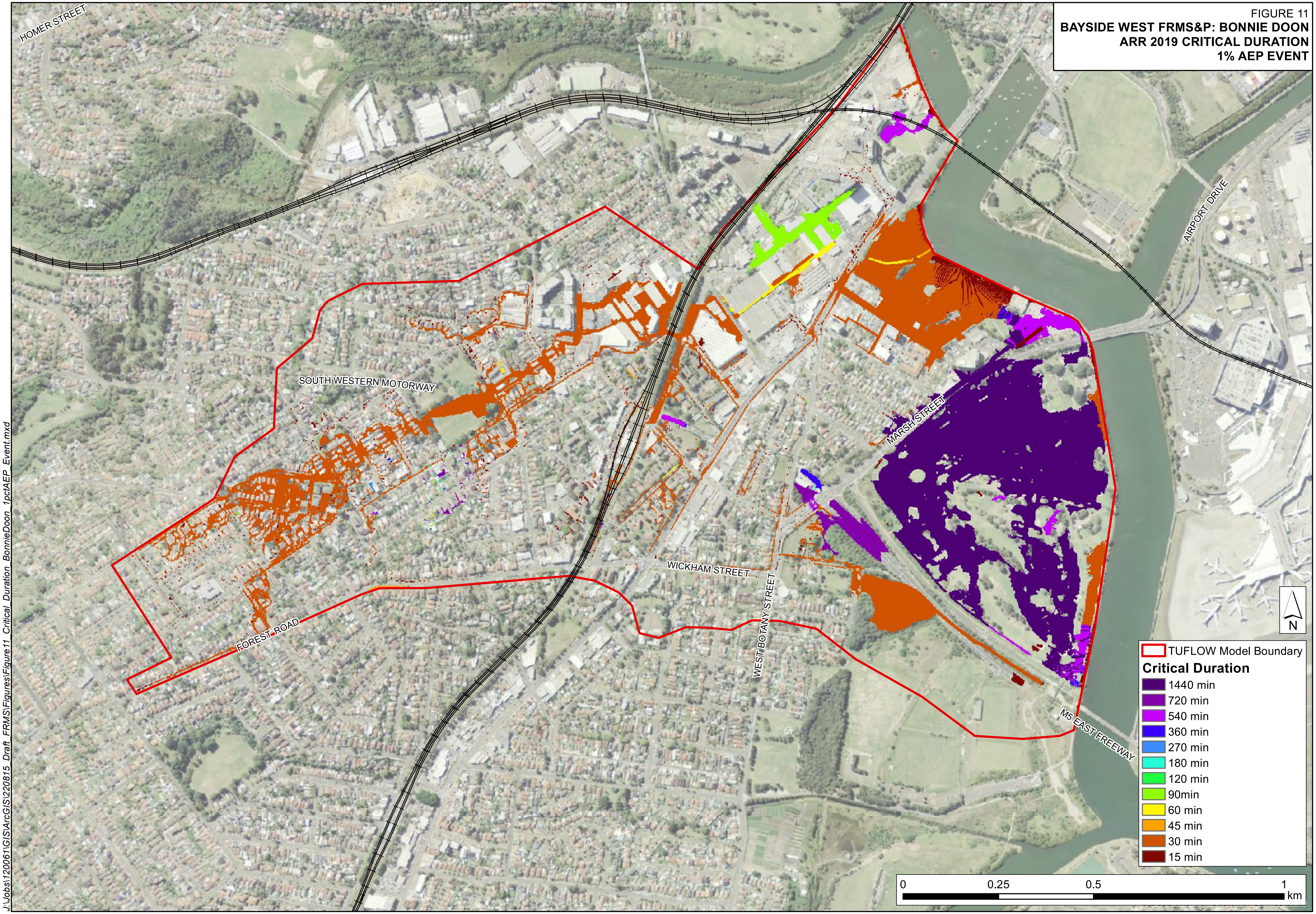
FIGURE 11
BAYSIDE WEST FRMS&P: BONNIE DOON
ARR 2019 CRITICAL DURATION
1% AEP EVENT
HOMER STREET
AIRPORT DRIVE
SOUTH WESTERN MOTORWAY
MARSH STREET
WICKHAM STREET
WEST BOTANY STREET
FOREST ROAD
M5 EAST FREEWAY
N
TUFLOW Model Boundary
Critical Duration
1440 min
720 min
540 min
360 min
270 min
180 min
120 min
90min
60 min
45 min
30 min
15 min
0
0.25
0.5
1
km
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FIGURE 12
BAYSIDE WEST FRMS&P: BONNIE DOON PEAK FLOOD LEVEL DIFFERENCE ADOPTED STORMS VS MEAN PEAKS 1% AEP EVENT

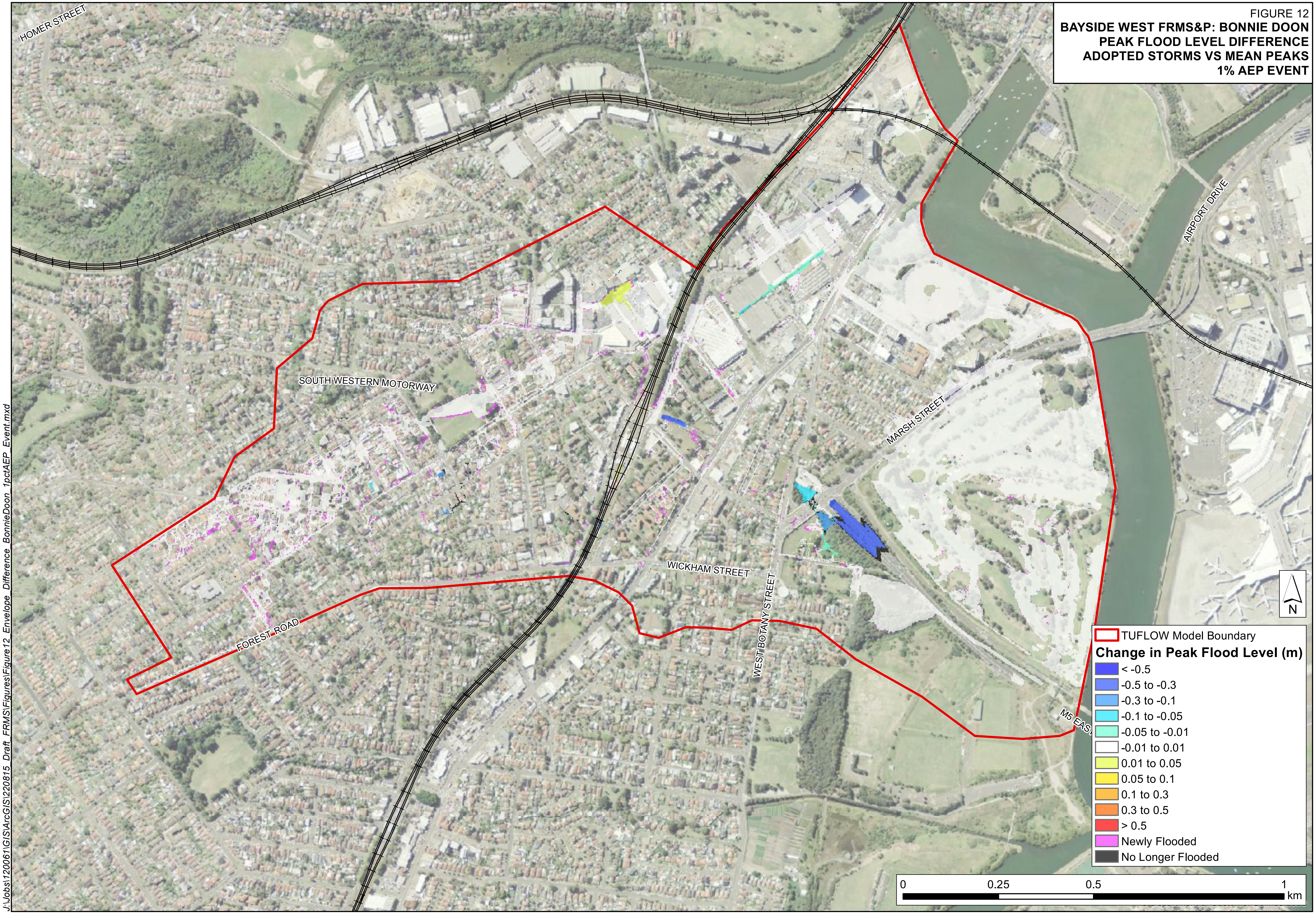

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FIGURE 13

BAYSIDE WEST FRMS&P: SANS SOUCI
ARR 2019 CRITICAL DURATION
1% AEP EVENT

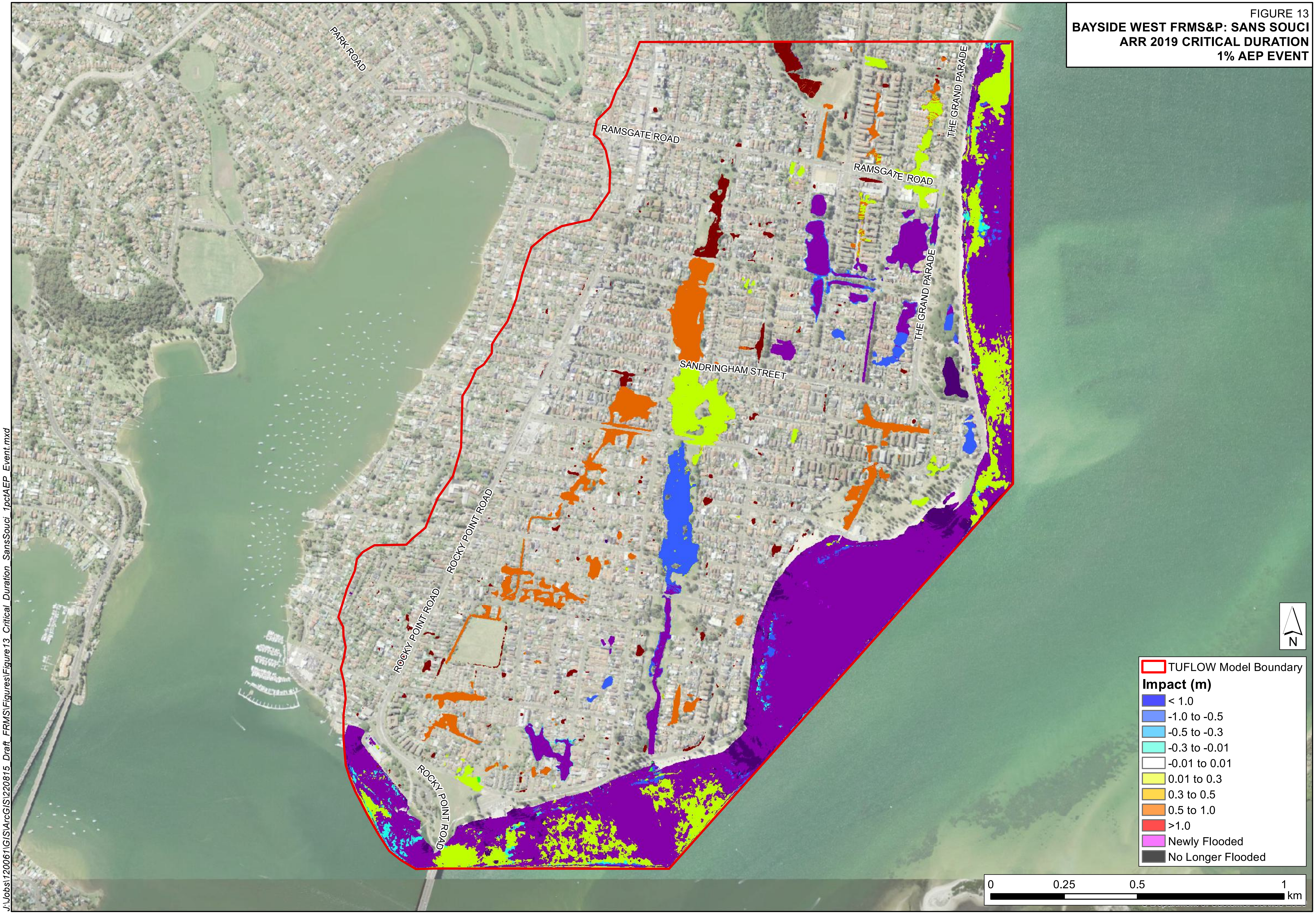

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FIGURE 14
BAYSIDE WEST FRMS&P: SANS SOUCI PEAK FLOOD LEVEL DIFFERENCE ADOPTED STORMS VS MEAN PEAKS 1% AEP EVENT

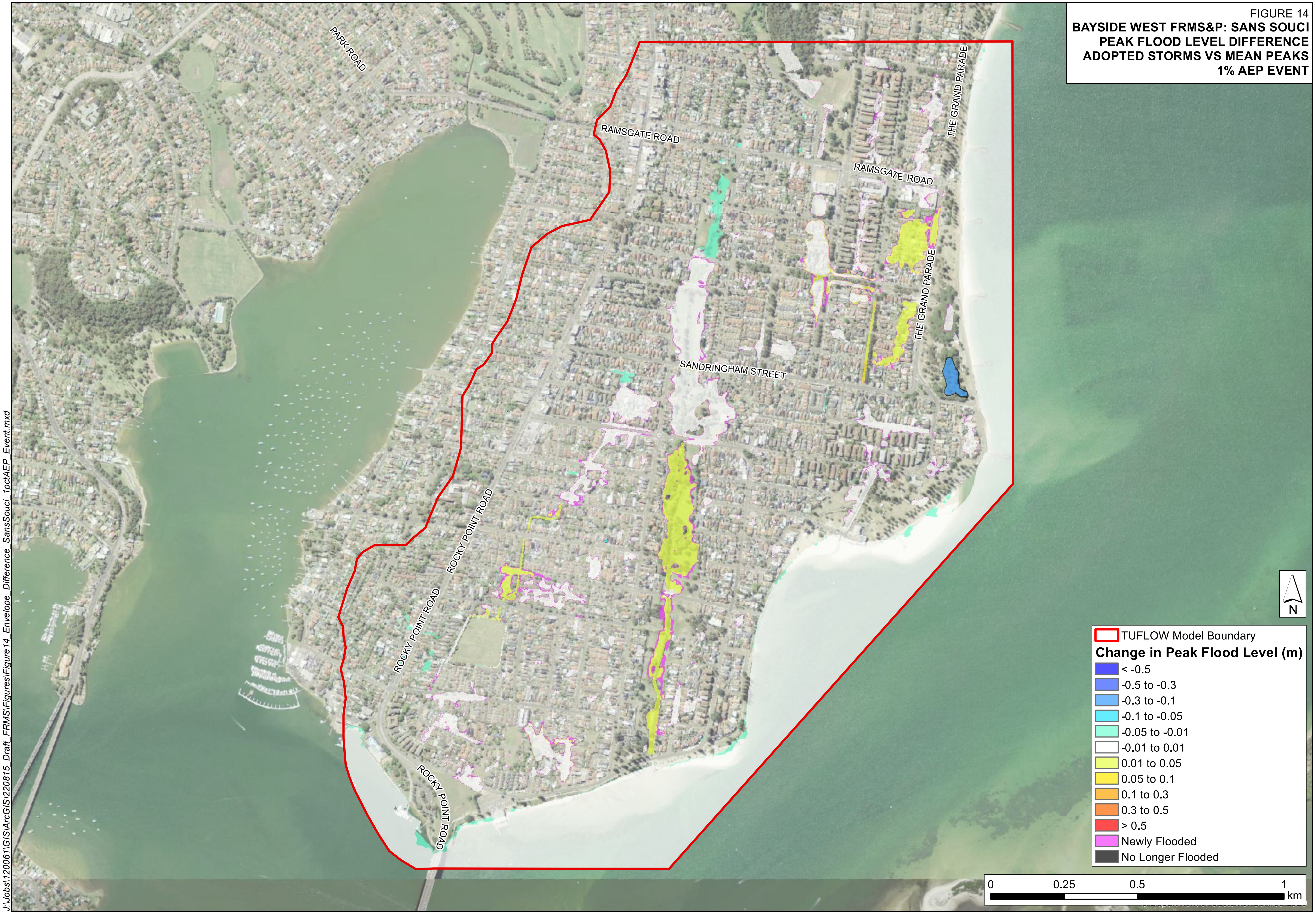

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FIGURE 15

BAYSIDE WEST FRMS&P: BARDWELL CREEK CHANGE IN PEAK FLOOD LEVEL WITH ARR 2019 UPDATES 5% AEP EVENT

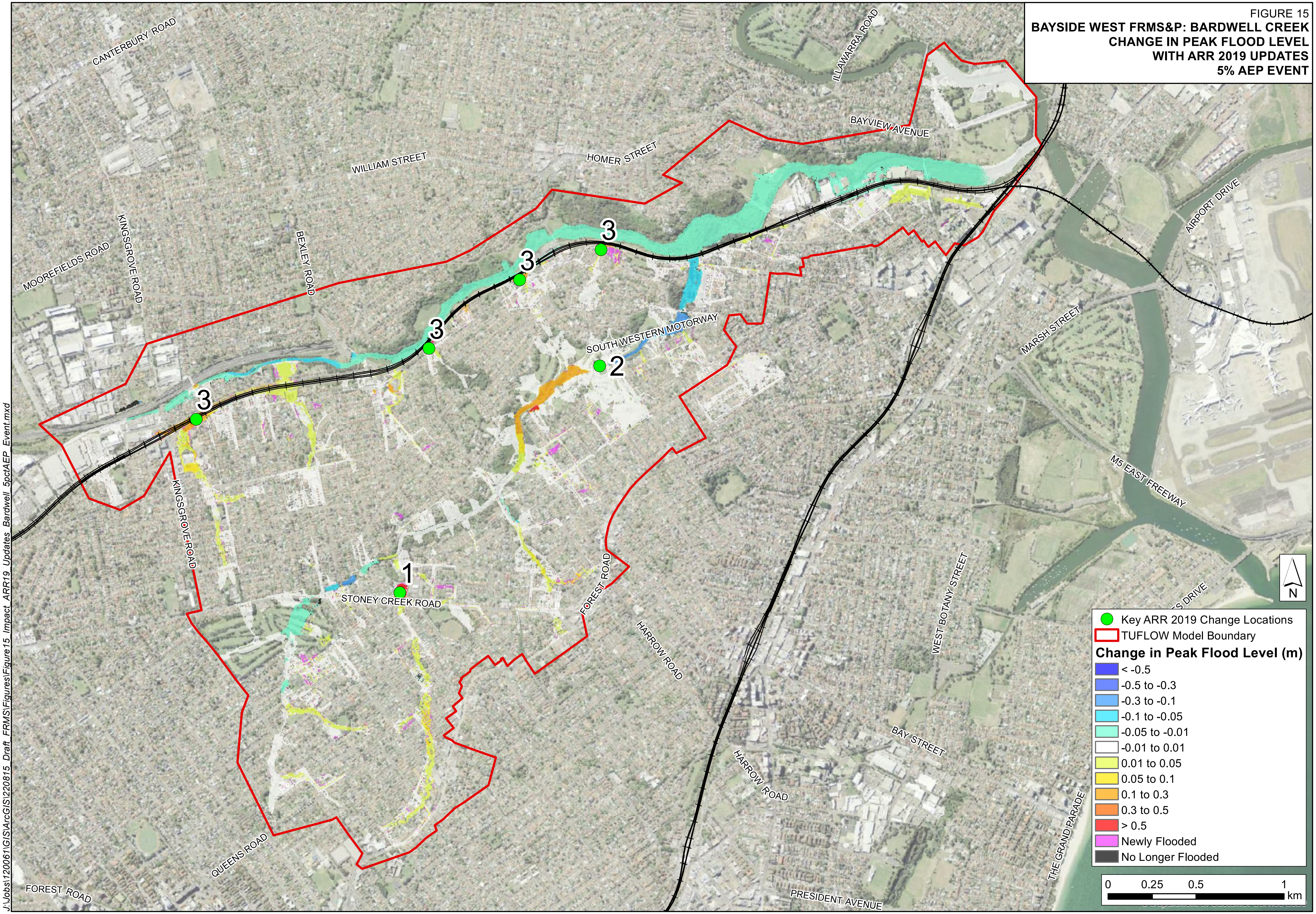
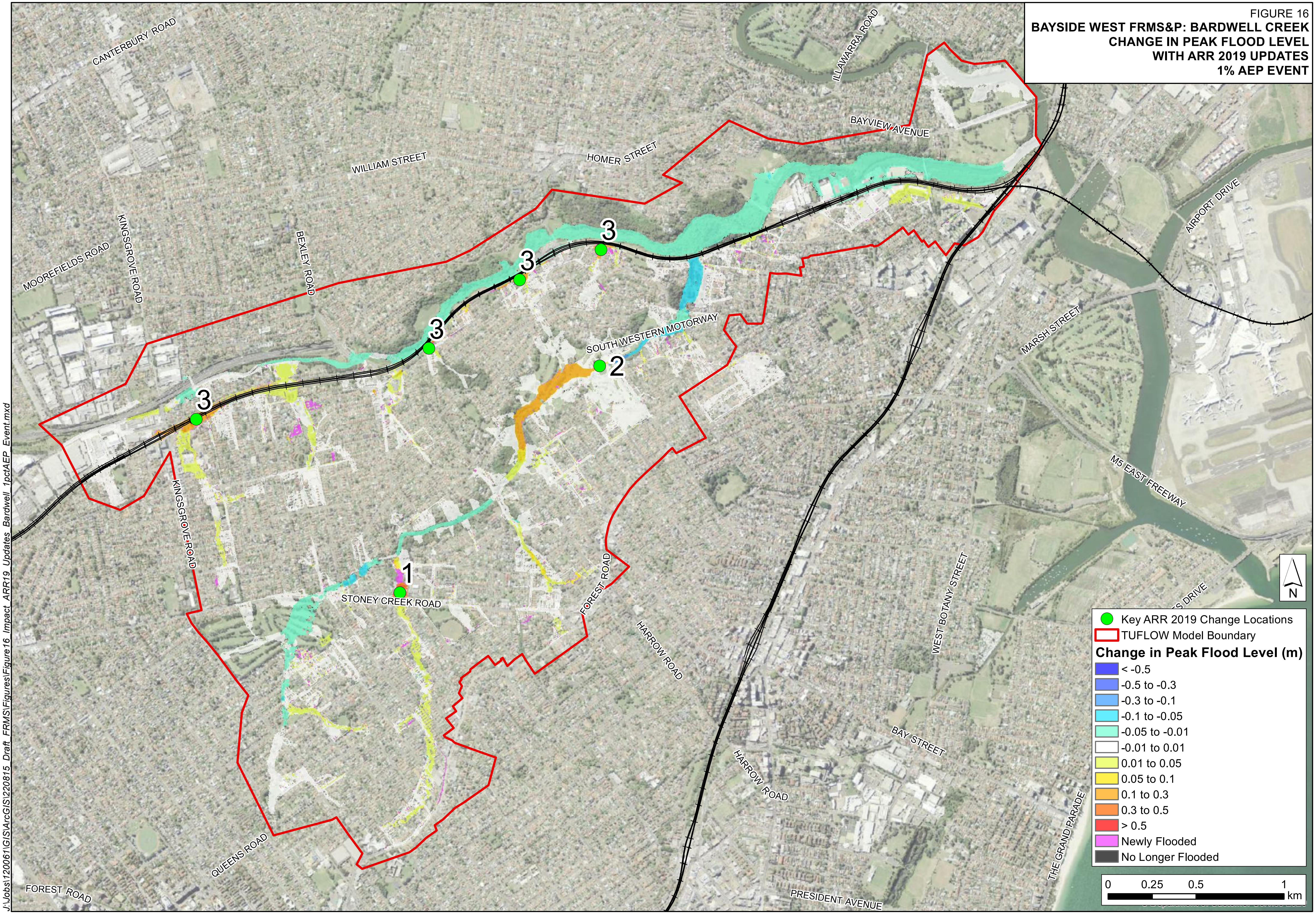
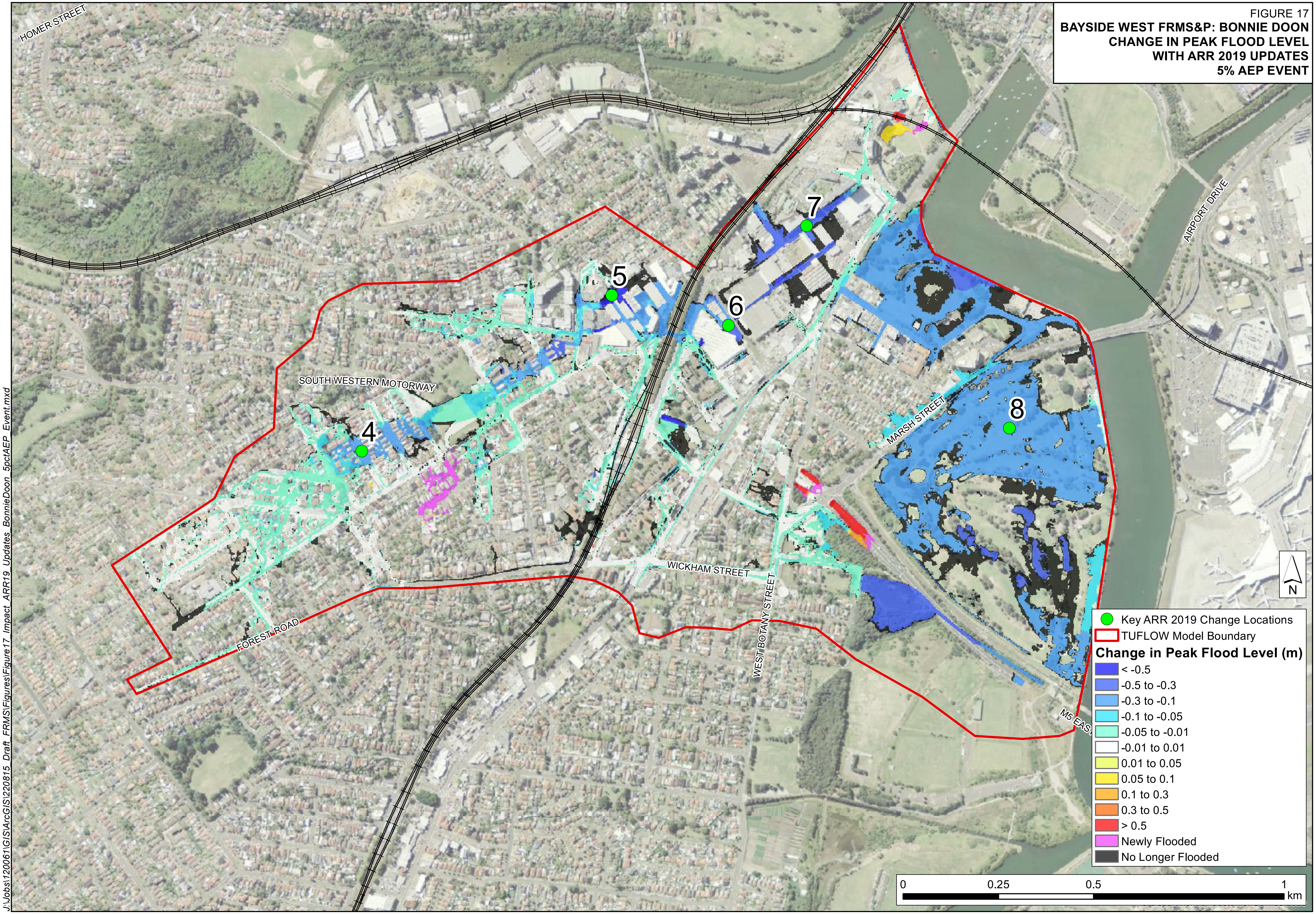
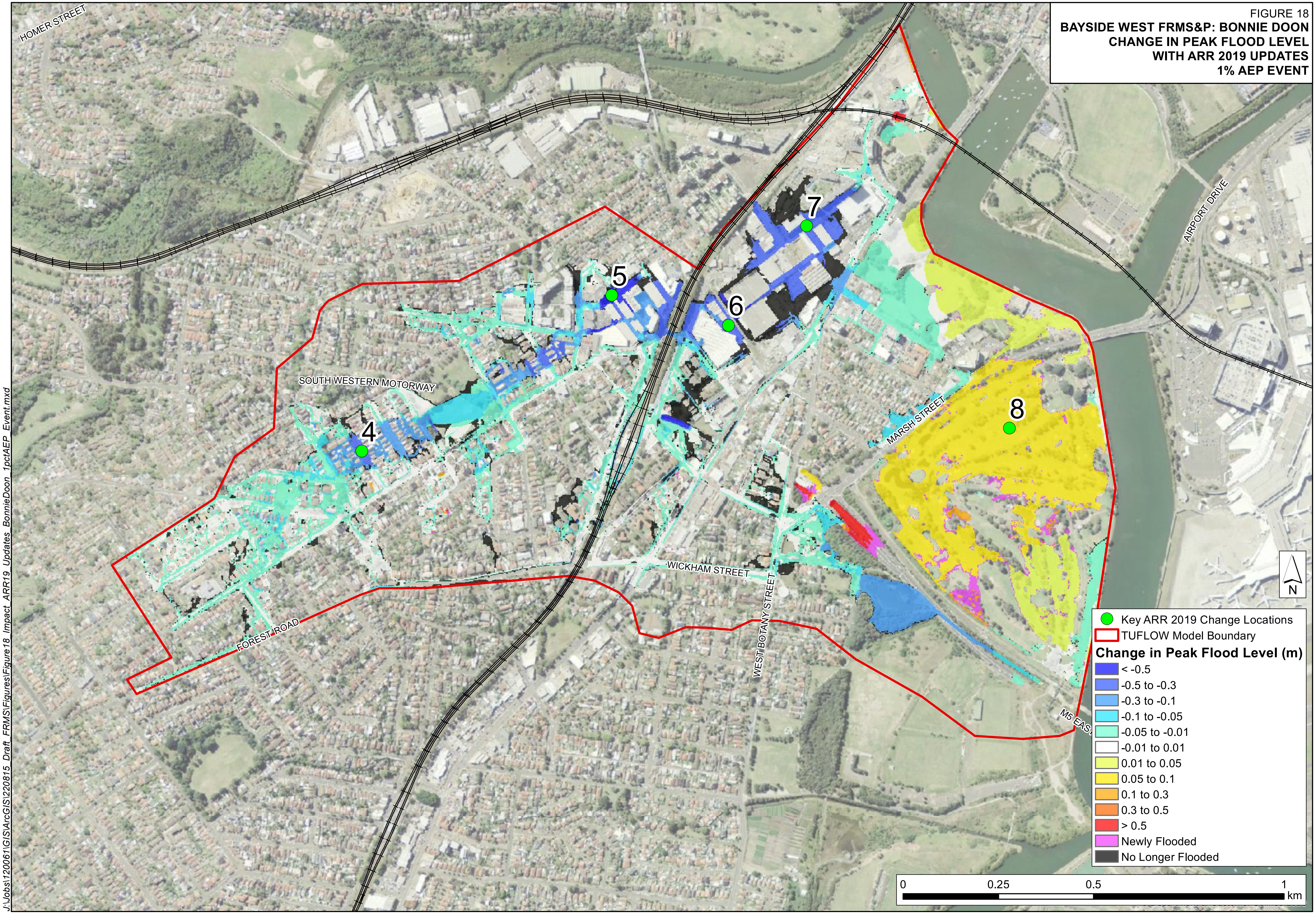


FIGURE 16
BAYSIDE WEST FRMS&P: BARDWELL CREEK CHANGE IN PEAK FLOOD LEVEL WITH ARR 2019 UPDATES 1% AEP EVENT





J:\Jobs\120061\GIS\ArcGIS\220815_Draft_FRMS\Figures\Figure17_Impact_ARR19_Updates_BonnieDoon_5pctAEP_Event.mxd



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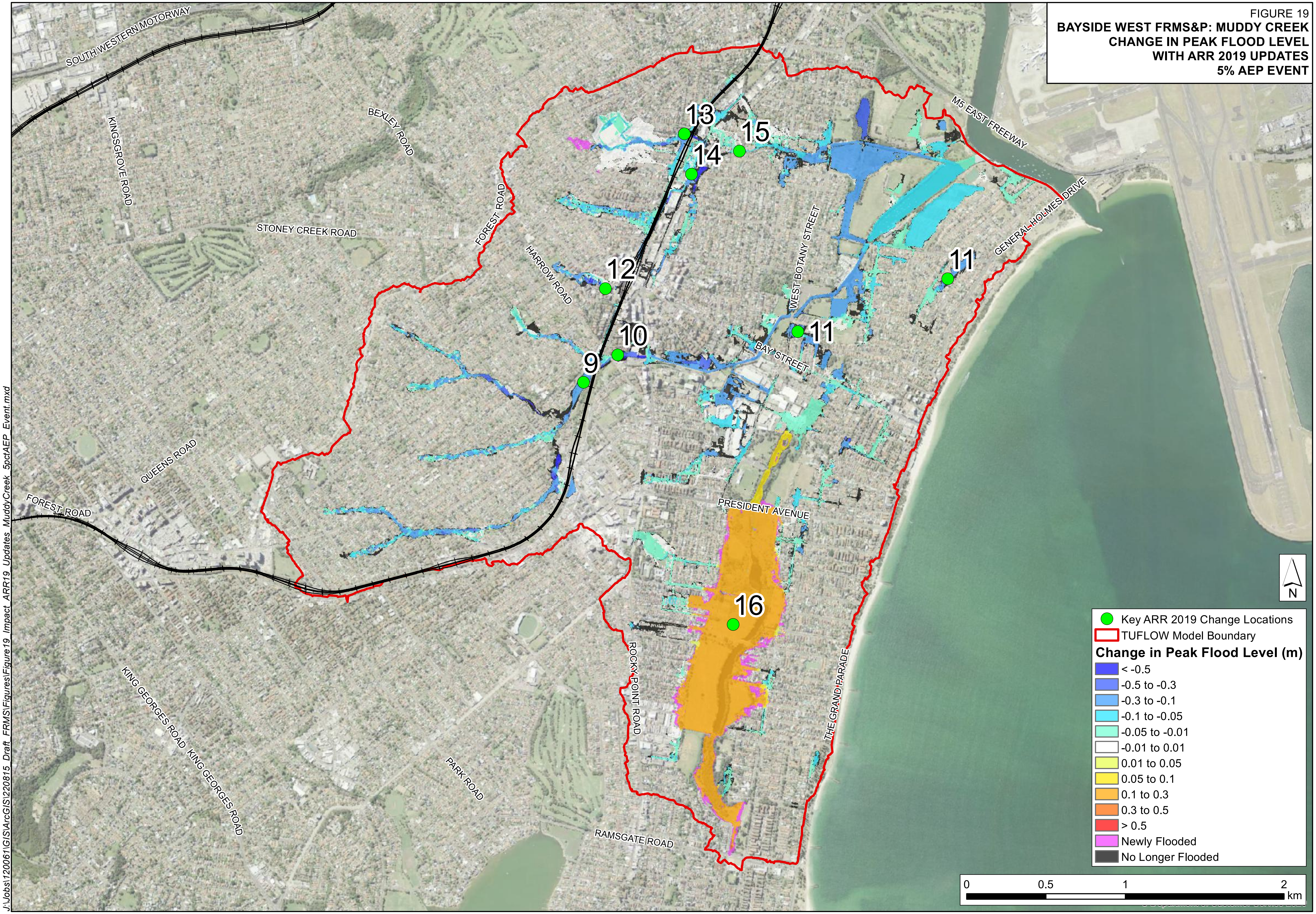

FIGURE 19
BAYSIDE WEST FRMS&P: MUDDY CREEK
CHANGE IN PEAK FLOOD LEVEL
WITH ARR 2019 UPDATES
5% AEP EVENT
SOUTH WESTERN MOTORWAY
KINGSGROVE ROAD
BEXLEY ROAD
FOREST ROAD
STONEY CREEK ROAD
HARROW ROAD
WEST BOTANY STREET
BAY STREET
M5 EAST FREEWAY
GENERAL HOLMES DRIVE
QUEENS ROAD
FOREST ROAD
PRESIDENT AVENUE
ROCKY POINT ROAD
THE GRAND PARADE
KING GEORGES ROAD
KING GEORGES ROAD
PARK ROAD
RAMSGATE ROAD
9
10
11
11
12
13
14
15
16
N
Key ARR 2019 Change Locations
TUFLOW Model Boundary
Change in Peak Flood Level (m)
< -0.5
-0.5 to -0.3
-0.3 to -0.1
-0.1 to -0.05
-0.05 to -0.01
-0.01 to 0.01
0.01 to 0.05
0.05 to 0.1
0.1 to 0.3
0.3 to 0.5
> 0.5
Newly Flooded
No Longer Flooded
0
0.5
1
2
km
J:\Jobs\120061\GIS\ArcGIS\220815_Draft_FRMS\Figures\Figure19_Impact_ARR19_Updates_MuddyCreek_5pctAEP_Event.mxd

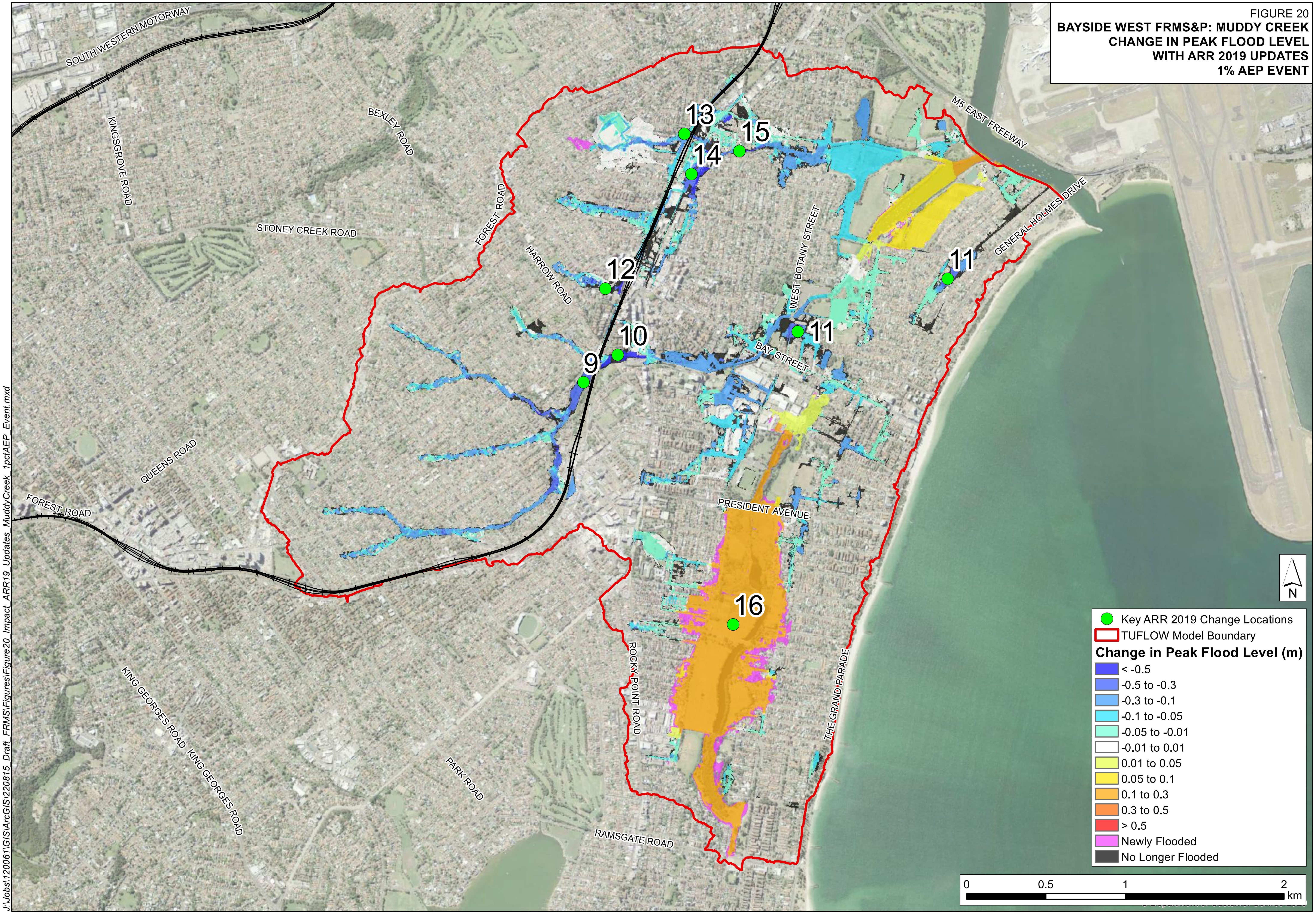

FIGURE 20
BAYSIDE WEST FRMS&P: MUDDY CREEK CHANGE IN PEAK FLOOD LEVEL WITH ARR 2019 UPDATES 1% AEP EVENT

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FIGURE 21
BAYSIDE WEST FRMS&P: SANS SOUCI
CHANGE IN PEAK FLOOD LEVEL
WITH ARR 2019 UPDATES
5% AEP EVENT

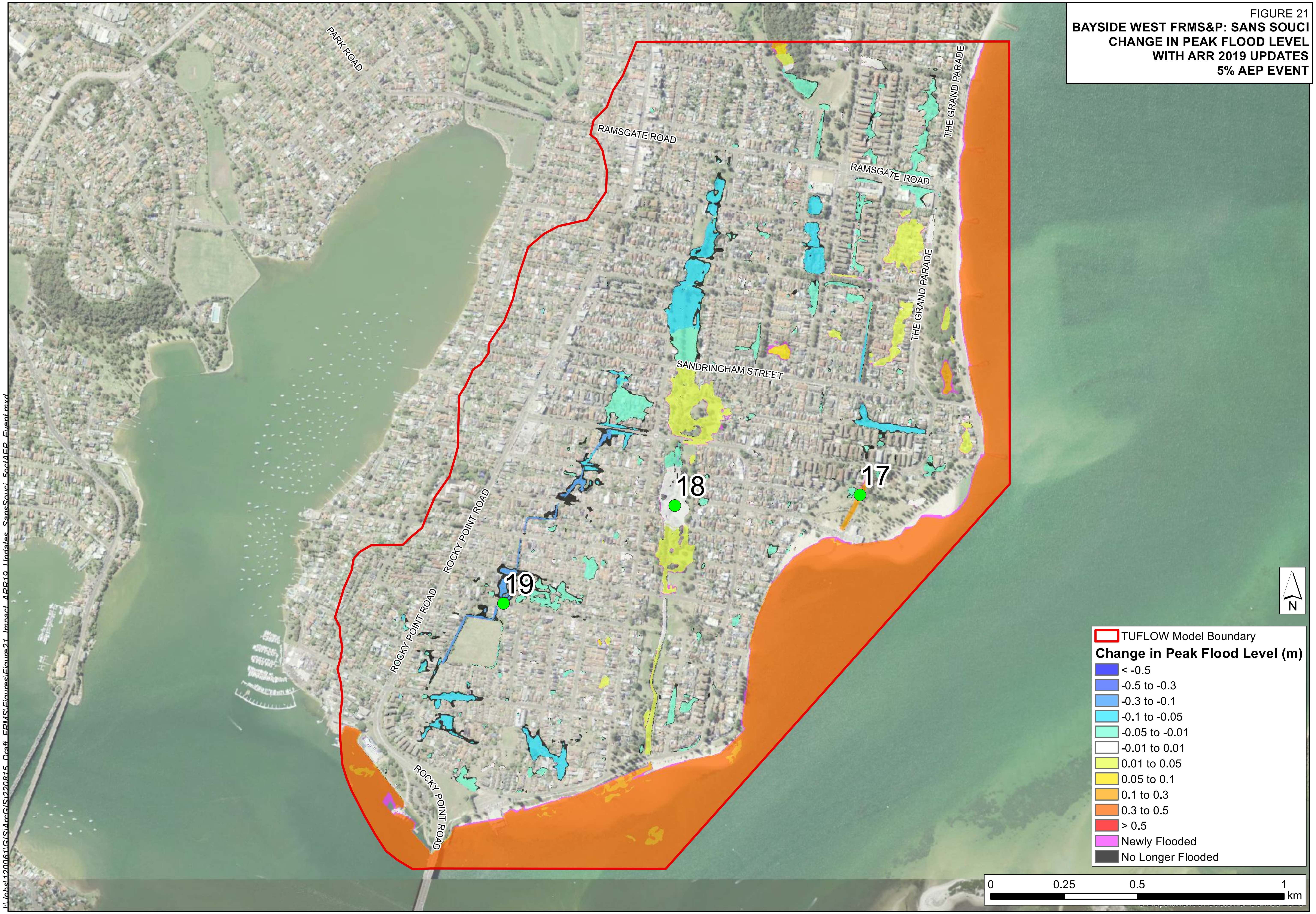

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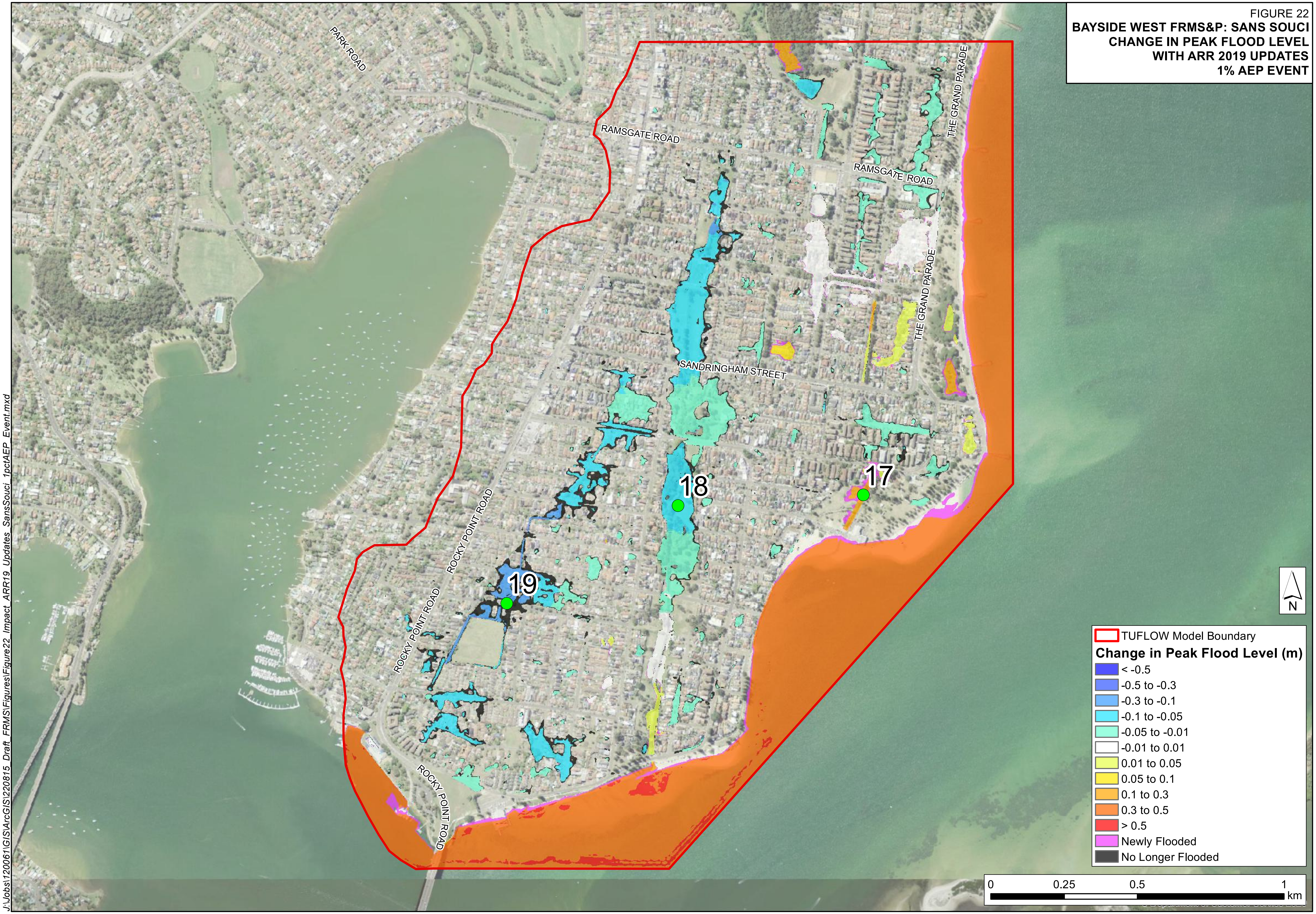
FIGURE 22
BAYSIDE WEST FRMS&P: SANS SOUCI CHANGE IN PEAK FLOOD LEVEL WITH ARR 2019 UPDATES 1% AEP EVENT



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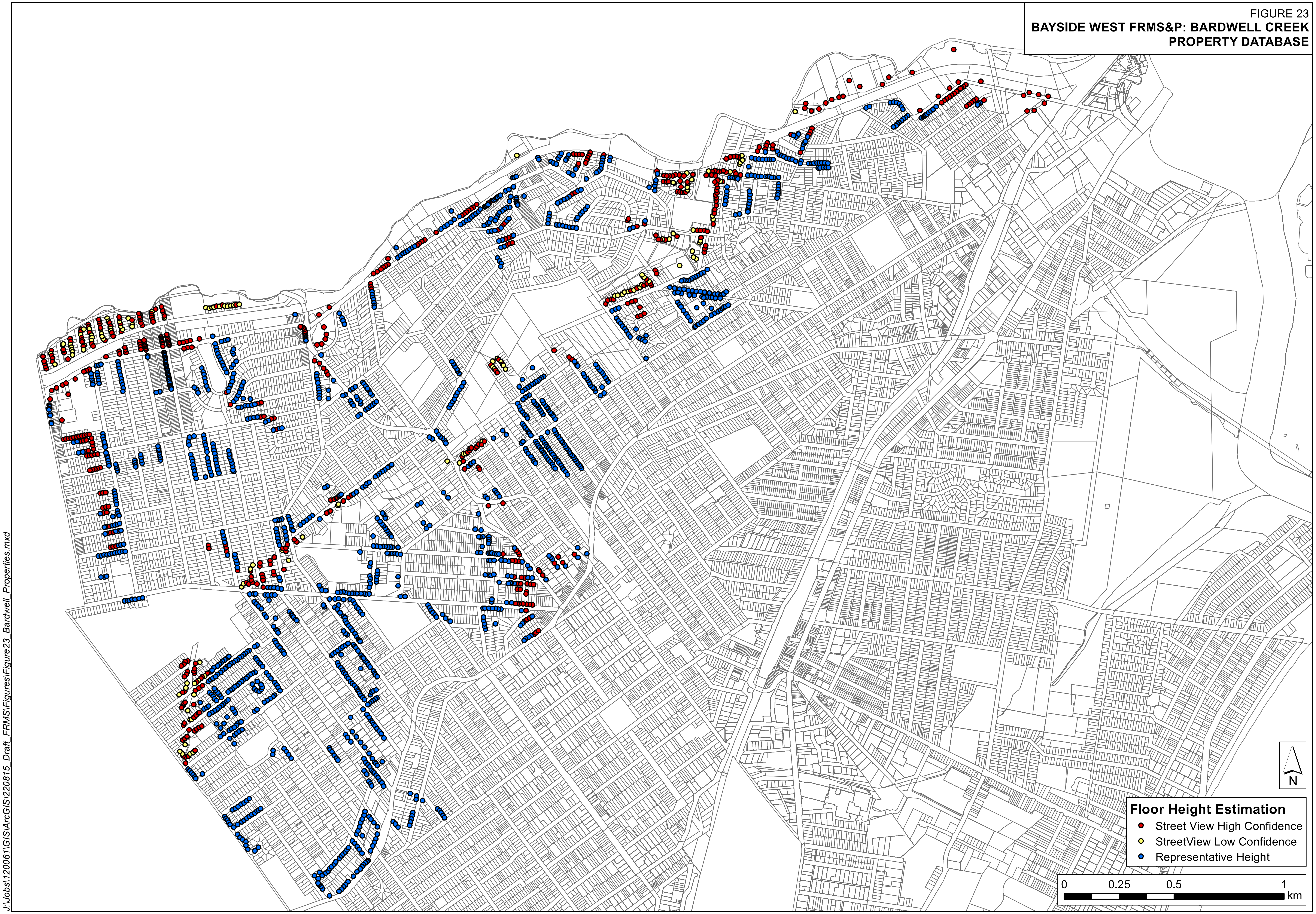
FIGURE 23
BAYSIDE WEST FRMS&P: BARDWELL CREEK
PROPERTY DATABASE
Floor Height Estimation
Street View High Confidence
StreetView Low Confidence
Representative Height
0
0.25
0.5
1
km
N
J:\Jobs\120061\GIS\ArcGIS\220815_Draft_FRMS\Figures\Figure23_Bardwell_Properties.mxd

FIGURE 24

BAYSIDE WEST FRMS&P: BONNIE DOON PROPERTY DATABASE