Narrabeen Lagoon Floodplain Risk Management Plan – Revised Draft

59915102

Prepared for
Northern Beaches Council

27 September 2018

Cardno
Shaping the Future

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Document Information

Prepared for	Northern Beaches Council
Project Name	Narrabeen Lagoon Floodplain Risk Management Study and Plan
File Reference	59915102 R009 v1 Narrabeen Lagoon Draft FRMP.docx
Job Reference	59915102
Date	27 Sept 2018
Version Number	C
Effective Date	27 Sept 2018
Date Approved:	27 Sept 2018

Document History

Version	Effective Date	Description of Revision	Prepared by:	Reviewed by:
A	17/03/2016	Preliminary Draft	Tanja Mackenzie	Michael Hughes
B	22/04/2016	Draft	Tanja Mackenzie & Martin Griffin	Michael Hughes
C	27/09/2018	Revised Draft	Tanja Mackenzie	Daniel Wood

Cover photo: Narrabeen Lagoon (Source: http://www.narrabeenlagoon.org.au/Forums/forum%20history.htm)

Foreword

The NSW Government Flood Prone Land Policy is directed towards providing solutions to existing flood problems in developed areas, and ensuring that 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 prone land is the responsibility of Local Government. The State Government subsidises flood management measures to alleviate existing flooding problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities. The Commonwealth Government also assists with the subsidy of floodplain modification measures.

The Policy identifies the following floodplain management 'process' for the identification and management of flood risks:

1. Formation of a Committee -

Established by a Local Government Body (Local Council) and includes community group representatives and State agency specialists.

2. Data Collection -

The collection of data such as historical flood levels, rainfall records, land use, soil types etc.

3. Flood Study -

Determines the nature and extent of the flood problem.

4. Floodplain Risk Management Study –

Evaluates floodplain management measures for the floodplain in respect to both existing and proposed development.

5. Floodplain Risk Management Plan –

Involves formal adoption by Council of a management plan for the floodplain.

6. Implementation of the Plan –

Implementation of actions to manage flood risks for existing and new development.

This Narrabeen Lagoon Floodplain Risk Management Plan has been developed based on the Narrabeen Lagoon Flood Study prepared by BMT WBM in 2013 for the former Warringah and Pittwater Councils (now Northern Beaches Council), and follows on from the Narrabeen Lagoon Floodplain Risk Management Study prepared in conjunction with this Plan.

Executive Summary

Overview and Purpose

This Floodplain Risk Management Plan (FRMP) for the Narrabeen Lagoon floodplain has been prepared by Cardno for Northern Beaches Council (formerly Northern Beaches Council and Pittwater Council) in accordance with the New South Wales (NSW) Flood Prone Land Policy and the principles of the Floodplain Development Manual (NSW Government, 2005).

The Narrabeen Lagoon FRMP has been developed to direct and co-ordinate the future management of flood prone land within the Narrabeen Lagoon catchment. It also aims to educate the community about flood risks so that they can make more informed decisions regarding their individual exposure and responses.

The preparation of this FRMP follows on from previous documents which have been prepared to assist in addressing flood risk for the Narrabeen Lagoon floodplain; namely the Narrabeen Lagoon Flood Study (BMT WBM, 2013) and the Draft Narrabeen Lagoon Floodplain Risk Management Study (FRMS) (Cardno, 2016).

Study Area

The Narrabeen Lagoon catchment is located within the Northern Beaches LGA on Sydney's northern beaches. The catchment occupies a total area of approximately 55 km^2 and drains to the Tasman Sea through a narrow channel at the lagoon entrance on North Narrabeen Beach.

Narrabeen Lagoon is the largest coastal lagoon located in the Sydney metropolitan region, with a waterway area of 2.2 km^2. The catchment can be separated into several major sub-catchments including Nareen Creek, Mullet Creek, Narrabeen Creek (incorporating Fern Creek), Deep Creek, Middle Creek (incorporating Snake Creek, Oxford Creek and Trefoil Creek) and South Creek (incorporating Wheeler Creek).

Existing Flood Behaviour and Economic Damages

During flood events the peak water level in Narrabeen Lagoon is generally similar across the entire waterbody, with very little water level gradient. At the downstream end of the lagoon small flood water level gradients are generated from Pittwater Road Bridge through to the entrance. In high magnitude low frequency events, the Ocean Street Bridge becomes an influence, controlling the amount of flow that can be discharged through the entrance. Depending on entrance conditions and ocean levels, flood waters can remain elevated for many hours.

Critical flood levels in Narrabeen Lagoon are controlled by longer duration rainfall events, but flood waters in the upper floodplain have the potential to rise quickly. Flash-flooding is an issue in the upper catchment, as is overtopping of roads and the limited capacity of some culverts and other structures to convey larger magnitude events. Consequently there may be little opportunity for warning or assistance before or during a flood.

The average annual damages for the Narrabeen Lagoon floodplain under existing conditions is $11,540,886. There is potential for substantial damages to occur in relation to relatively small flood events such as the 20% AEP (occurs every five years on average) flood event, due to inundation occurring above the floor level for 229 properties. In the rarer 1% AEP (occurs every 100 years on average) 659 properties are inundated above the floor level.

Preferred Management Options and Implementation Program

The Floodplain Risk Management Study examined a range of flood mitigation options aimed at reducing the likelihood and / or consequences of flooding. These included:

> Flood modification measures (e.g. levees, detention basins, channel works and upgrades);

> Property modification measures (e.g. house raising, voluntary purchase, land swap);

> Emergency management measures (e.g. flood warning systems, evacuation planning); and

> Flood planning levels.

This plan is based on the preferred options from the FRMS, which are shown in the table below.

Option ID	Description	Overall Ranking	Capital Cost (Excl. GST)	Cost of Implementation (Excl. GST)*	Responsibility / Potential Funding Partners	Priority**
FM4	Extraction of entrance shoals upstream and downstream of the entrance bridge	1	$1,160,000	$5,443,000	Council / OEH	H
FM9	Waroon Road Levee	2	$185,000	$208,000	Council / OEH	H
FM10	Wabash Avenue Levee	2	$309,000	$341,000	Council / OEH	H
FM6	Alkira Circuit Drainage Upgrade	4	$484,000	$499,000	Council / OEH	H
FM14	Ponderosa Parade Drainage Upgrade	5	$874,000	$889,000	Council / OEH	H
EM1	Local Evacuation Measures	6	-	-	Council / SES	H
EM2	Public awareness and education	6	-	-	Council / SES	H
EM5	Flood Warning Systems	8			Council / OEH / SES	M
FM11	Tatiara By-pass Overland Flowpath	9	$679,000	$719,000	Council / OEH	M
EM3	School Education Programs	10	-	-	Council / SES	M
EM4	Flood Markers and Signage	11	-	-	Council / OEH	L
-	Entrance Management Strategy	-			Council / OEH	H
-	Data collection	-	-	-	Council / OEH	H
Total cost of implementation (excl. non-structural options):			**$3,691,000**	**$8,099,000**		

*Net present worth of cost of implementation, incorporating both capital and maintenance costs over the implementation period of 50 years.

**H = higher priority; M = medium priority; L = lower priority

This FRMP represents the considered opinion of the local community on how to best manage its flood risk and its flood prone land. It provides a long-term guide for the future development of the community, and will be subject to periodic revision.

Glossary and Abbreviations

Australian Height Datum (AHD)	A standard national surface level datum approximately corresponding to mean sea level.
Average Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded each year; it would occur relatively often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded each year; it would be relatively rare and it would be relatively large. The 1% AEP event is equivalent to the 1 in 100 year Average Recurrence Interval event.
Average Recurrence Interval (ARI)	The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. It is implicit in this definition that periods between exceedances are generally random. That is, an event of a certain magnitude may occur several times within its estimated return period.
Acid Sulfate Soils (ASS)	Acid sulfate soils (ASS) are naturally occurring sediments and soils containing iron sulfides (mostly pyrite). When these sediments are exposed to the air by excavation or drainage of overlying water, the iron sulfides oxidise and form sulphuric acid. ASS are widespread among low lying coastal areas of NSW, in estuarine floodplains and coastal lowlands.
Cadastre, cadastral base	Information in map or digital form showing the extent and usage of land, including streets, lot boundaries, water courses etc.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
DCP	Development Control Plan.
Design flood	A significant event to be considered in the design process; various works within the floodplain may have different design events. For example some roads may be designed to be overtopped in the 1% AEP flood event.
Development	The erection of a building or the carrying out of work; or the use of land or of a building or work; or the subdivision of land.
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
DISPLAN	NSW SES endorsed Disaster Plan (which are now mostly superseded by equivalent EMPLAN's).
EMPLAN	NSW SES endorsed Emergency Plan.
FDM	NSW Floodplain Development Manual: The Management of Flood Liable Land (NSW Government, 2005).
Flash flooding	Flooding which is sudden and often unexpected because it is caused by sudden local heavy rainfall or rainfall in another area. Often defined as flooding which occurs within 6 hours of the rain which caused it.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or overland runoff before entering a watercourse and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
Flood fringe	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood hazard	Potential risk to life and limb caused by flooding.
Flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event, i.e. the maximum extent of flood liable land. Floodplain Risk Management Plans encompass all flood prone land, rather than being restricted to land subject to designated flood events.
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e. flood prone land.
Floodplain management measures	The full range of techniques available to floodplain managers.

Floodplain management options	The measures which might be feasible for the management of a particular area.
Flood Planning Area (FPA)	The area of land below the flood planning level and thus subject to flood related development controls.
Flood Planning Levels (FPLs)	Flood levels selected for planning purposes, as determined in floodplain management studies and incorporated in floodplain management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of land use and for different flood plains. The concept of FPLs supersedes the "Standard flood event" of the first edition of the Manual. As FPLs do not necessarily extend to the limits of flood prone land (as defined by the probable maximum flood), floodplain management plans may apply to flood prone land beyond the defined FPLs.
Flood storages	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often, but not always, aligned with naturally defined channels. Floodways are areas which, even if only partially blocked, would cause a significant redistribution of flood flow, or significant increase in flood levels. Floodways are often, but not necessarily, areas of deeper flow or areas where higher velocities occur. As for flood storage areas, the extent and behaviour of floodways may change with flood severity. Areas that are benign for small floods may cater for much greater and more hazardous flows during larger floods. Hence, it is necessary to investigate a range of flood sizes before adopting a design flood event to define floodway areas.
FRMS	Floodplain Risk Management Study.
FRMP	Floodplain Risk Management Plan.
Geographical Information Systems (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
High hazard	Flood conditions that pose a possible danger to personal safety, make evacuation by trucks difficult, mean able-bodied adults would have difficulty wading to safety, and have potential for significant structural damage to buildings.
Hydraulics	The term given to the study of water flow in a river, channel or pipe, in particular, the evaluation of flow parameters such as stage and velocity.
Hydrograph	A graph that shows how the discharge changes with time at any particular location.
Hydrology	The term given to the study of the rainfall and runoff process as it relates to the derivation of hydrographs for given floods.
ICOLL	Intermittently Closed and Open Lake or Lagoon.
LEP	Local Environmental Plan.
LGA	Local Government Area.
Low hazard	Flood conditions such that, should it be necessary, people and their possessions could be evacuated by trucks and able-bodied adults would have little difficulty wading to safety.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of the principal watercourses in a catchment. Mainstream flooding generally excludes watercourses constructed with pipes or artificial channels considered as storm water channels.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff and stream flow. These models are often run on computers due to the complexity of the mathematical relationships. In this report, the models referred to are mainly involved with rainfall, runoff, pipe and overland stream flow.

NLFRMWG	Narrabeen Lagoon Floodplain Risk Management Working Group.
NPER	National Professional Engineers Register. Maintained by Engineers Australia.
NSW	New South Wales.
Obvert	The internal top of a culvert, equal to the invert plus the culvert diameter.
OEH	New South Wales Department of Office of Environment and Heritage.
Overland Flow	The term overland flow is used interchangeably in this report with “flooding”.
Peak discharge	The maximum discharge occurring during a flood event.
POM	Plan of Management.
Probable Maximum Flood (PMF)	The flood calculated to be the maximum that is likely to occur.
Probability	A statistical measure of the expected frequency or occurrence of flooding. For a more detailed explanation see Average Recurrence Interval.
RCBC	Reinforced Concrete Box Culverts.

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1 Introduction

Cardno (NSW/ACT) Pty Ltd ('Cardno') was commissioned by Northern Beaches Council (formerly Northern Beaches Council and Pittwater Council) to undertake a Floodplain Risk Management Study and Plan for the Narrabeen Lagoon catchment shown in **Figure 1-1**.

The purpose of the Floodplain Risk Management Study (FRMS) was to define the existing flooding behaviour and flood hazards of the study area, and to investigate possible options to reduce flood damage and risk. The Draft FRMS report details the flood damages assessment, and the investigations undertaken into potential flood mitigation options.

The Floodplain Risk Management Plan (FRMP) describes how flood prone land in the Narrabeen Lagoon catchment is to be used and managed, and presents the preferred flood risk management options identified in the FRMS.

Both documents have been prepared in accordance with the New South Wales (NSW) Flood Prone Land Policy and the principles of the Floodplain Development Manual (NSW Government, 2005), and both have been undertaken alongside community consultation to ensure that community concerns are addressed appropriately

This project has been completed with financial and technical assistance from the NSW Office of Environment and Heritage (OEH).

1.1 Purpose of the Plan

In the past, flooding of the Narrabeen Lagoon catchment (**Figure 1-1**) has caused property damage, restricted property access and has been a general inconvenience to the community. These flooding issues have prompted Northern Beaches Council, through an established Working Group[1], to prepare a comprehensive and integrated Floodplain Risk Management Study and Plan for the Narrabeen Lagoon floodplain.

The preparation of the Narrabeen Lagoon Floodplain Risk Management Study and Plan follows on from the Narrabeen Lagoon Flood Study (BMT WBM, 2013). This FRMP represents the fifth stage of the floodplain risk management process as defined by the Floodplain Development Manual (NSW Government, 2005):

1. Formation of a Floodplain Management Committee;
2. Data collection;
3. Flood Study;
4. Floodplain Risk Management Study;
5. **Floodplain Risk Management Plan**; and
6. Implementation of the Floodplain Risk Management Plan.

The objectives of the FRMP are to:

> Provide a practical framework and implementation plan for managing flood risk within the study area;

> Formulate a cost effective plan for the study area based on the findings of the FRMS;

> Provide a priority program for implementation of the recommended works and measures in accordance with Appendix H of the Floodplain Development Manual (NSW Government, 2005);

> Provide governance and leadership direction for floodplain risk management;

> Ensure that intergenerational equity is maintained through achieving a balance between reducing flood vulnerability for the current and future generation, without overly burdening the current generation with costs and avoiding the transfer of costs or risk to future generations;

[1] The Narrabeen Lagoon Flood Risk Management Working Group (NLFRMWG).

- Disseminate the outcomes of the FRMP to the community and state agencies including those directly impacted by the decisions identified (e.g. police and emergency services); and
- Provide for the management of flood risks to public assets (such as services and utilities) and private property.

1.2 Floodplain Risk Management Objectives

The objectives for management of the Narrabeen Lagoon floodplain are in accordance with the overarching NSW Flood Prone Land Policy. The primary objective of the Policy is to reduce private and public losses resulting from floods utilising ecologically positive methods wherever possible, and within the constraints of available funding.

The specific management objectives for the Narrabeen Lagoon floodplain are to:

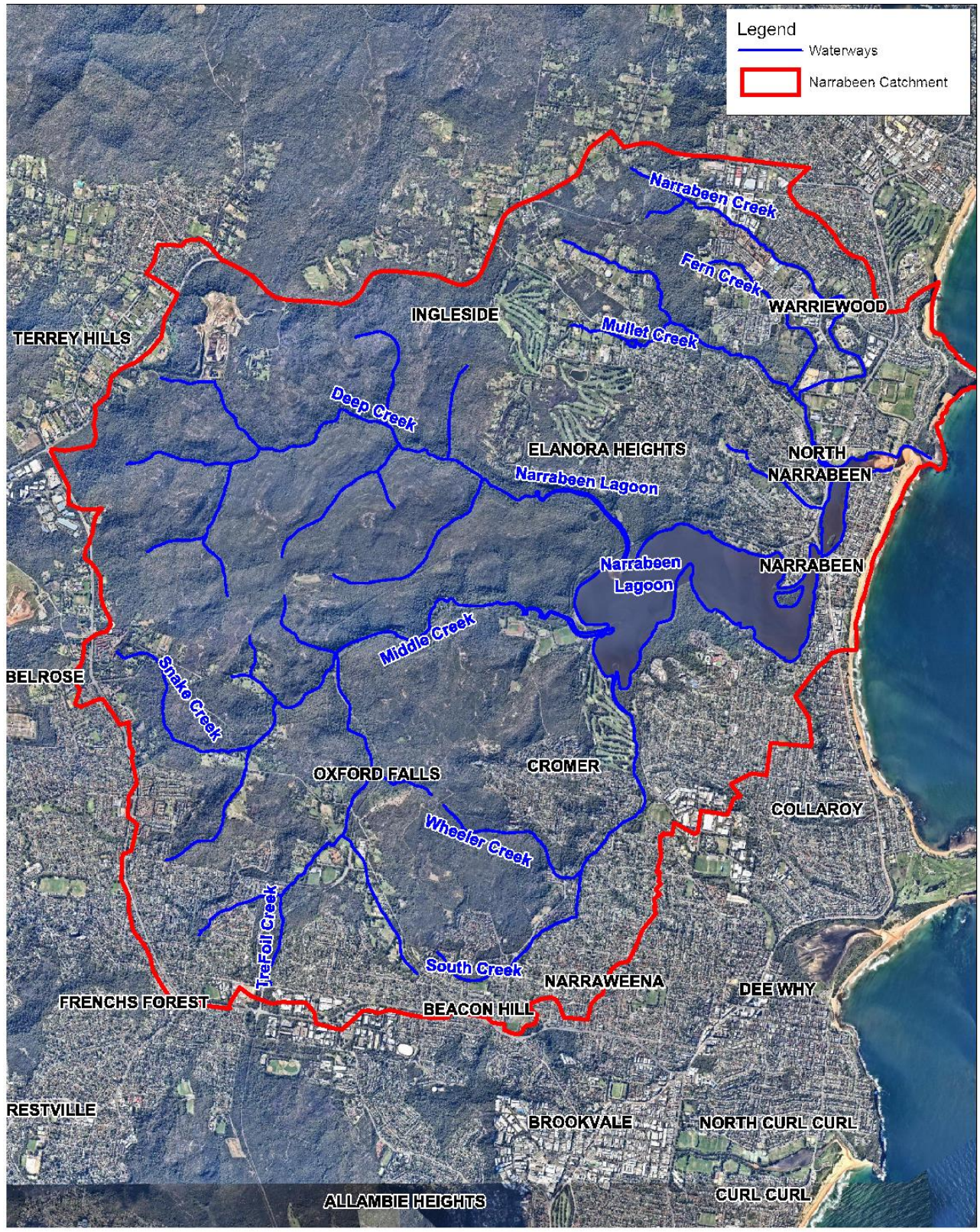
- Reduce the flood damage (and associated losses) to property, and danger to personal safety in the existing community;
- Minimise the disruption that results from flooding;
- Ensure future development is controlled in a manner consistent with the flood risk and associated danger to personal safety, taking into account the potential impacts of climate change;
- Ensure compatibility with the objectives of relevant State government policies including the Flood Prone Land Policy;
- Satisfy the objectives and requirements of the *Environmental Planning and Assessment Act 1979*;
- Ensure that the FRMP is integrated with the local emergency management plan (flood plan) and other relevant catchment management plans;
- Ensure that the FRMP is integrated with Council's existing corporate, business and strategic plans and proposed environmental planning instruments, and Council's obligations under the *Local Government Act 1993*;
- Ensure that the FRMP has the support of the local community;
- Ensure actions arising out of the FRMP are sustainable in social, environmental, ecological and economic terms and maximise positive and minimise negative impacts; and
- Establish a program for implementation of the management plan including a mechanism for funding that should include priorities, staging, funding and responsibilities.

Council has undertaken the floodplain risk management process in accordance with the Floodplain Development Manual (NSW Government, 2005) to ensure that these objectives are achieved. This will occur through implementation of the proposed floodplain risk management actions that are set out in **Section 4** of this FRMP. The implementation program set out in **Section 5** provides the framework for implementing the proposed management actions.

1.3 Structure of the Plan

The structure of this FRMP is outlined below:

- **Chapter 2** provides a description of the flood behaviour;
- **Chapter 3** summarises the outcomes of the FRMS, including the preferred options to be adopted in the FRMP;
- **Chapter 4** provides guidance on implementation of the Plan;
- **Chapter 5** includes concluding remarks;
- **Chapter 6** identifies qualifications relevant to the FRMP; and
- **Chapter 7** includes a list of references used in this report.



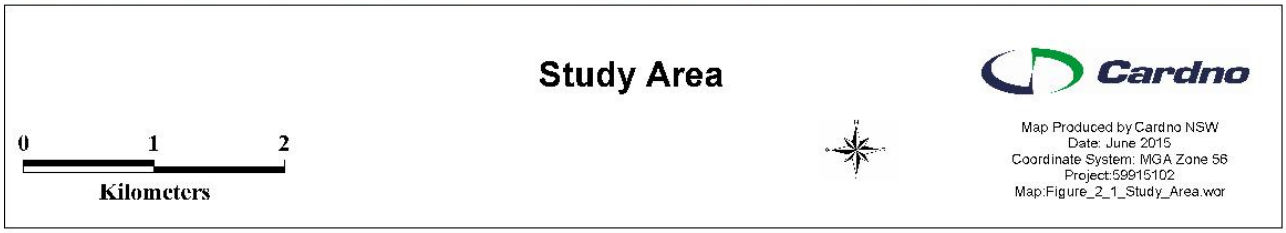


Figure 1-1 Study Area

2 Flood Behaviour and Economic Damages

2.1 Catchment Characteristics

The Narrabeen Lagoon catchment is located on Sydney's northern beaches (**Figure 1-1**). The catchment occupies a total area of approximately 55 km^2 and drains to the Tasman Sea through a narrow lagoon entrance channel at North Narrabeen Beach.

Narrabeen Lagoon is the largest coastal lagoon located in the Sydney metropolitan region with a waterway area of 2.2 km^2. The catchment can be separated into several major sub-catchments including Nareen Creek, Mullet Creek, Narrabeen Creek (incorporating Fern Creek), Deep Creek, Middle Creek (incorporating Snake Creek, Oxford Creek and Trefoil Creek) and South Creek (incorporating Wheeler Creek).

The catchment contains a mixture of land uses including urban (residential, commercial and industrial), recreational and bushland (including Garigal National Park). The urban suburbs of Elanora Heights, parts of North Narrabeen and Collaroy Plateau are located on the elevated land to the north and south of Narrabeen Lagoon. The suburbs of Narrabeen and parts of North Narrabeen have been developed along the lower floodplain and coastal strip separating the lagoon from the Tasman Sea. Warriewood Valley to the north of the lagoon is significantly urbanised. The western and southern boundaries of the catchment are also urbanised; including the suburbs of Terrey Hills, Frenchs Forest, Beacon Hill and Cromer.

The catchment area to the west of the lagoon is largely natural bushland (incorporating Garigal National Park) covering an area of approximately 20 km^2. There are also several recreational reserves located around the lagoon and three major golf courses within the catchment (Mitchell McCotter, 1992).

The topography of the catchment is undulating and grades relatively steeply from the upper slopes in the north-west of the catchment around Terrey Hills, down to the floodplain areas around Narrabeen Lagoon and Warriewood Valley. The areas of minor to moderate slopes are concentrated around the fringes of Narrabeen Lagoon, Warriewood Valley and Oxford Falls in the central area of the catchment, which is within the Middle Creek sub-catchment.

2.2 Existing and Historical Flood Behaviour

In the lower catchment, around Narrabeen Lagoon, flood behaviour is generally related to lagoon water levels and the lagoon entrance condition. There is a large amount of low-lying development around the foreshore of Narrabeen Lagoon, and these areas are inundated during a flood event. The foreshore of Narrabeen Lagoon has been subjected to flooding numerous times over the past century with events of particular note occurring in 1911, 1931, 1942, 1956, 1958, 1961, 1974, 1975, 1977, 1978, 1986, 1987, 1998, 2003, 2011 and 2016. Over 580 properties can be impacted by flooding from the lagoon. Flooding in Narrabeen Lagoon can occur after heavy rain in the catchment, or from the ocean in the form of storm surge and king tides, or a combination of both.

While the critical flood levels in Narrabeen Lagoon may be controlled by longer duration rainfall events, flood waters have the potential to rise quickly. Consequently there may be little opportunity for warning or assistance before or during a flood. Depending on entrance conditions and ocean levels, flood waters around the lagoon could remain elevated for many hours.

Higher in the catchment, local catchment flooding is more tightly linked to rainfall and flash flooding occurs in some areas. The creek channels are generally incised, and inundation of adjacent development occurs when the banks are overtopped. Structures such as bridges, culverts and roads can impede flood flows, and consequently exacerbate flooding. Similarly, debris can partially or fully block stormwater inlet pits, pipes, open channels and culverts, causing a significant reduction in the system's capacity and exacerbating flooding as the stormwater runoff is conveyed overland.

Peak flood depths modelled in the study area are shown in **Figures 2-2 and 2-3** for the 10% Annual Exceedance Probability (AEP) event and the 1% AEP event respectively. A more detailed discussion on flood behaviour in the Narrabeen Lagoon catchment can be found in the FRMS and the Narrabeen Lagoon Flood Study (BMT WBM, 2013).

2.3 Future Flood Behaviour

The NSW Floodplain Development Manual (NSW Government, 2005) requires consideration of climate change in the preparation Floodplain Risk Management Studies and Plans. Guidelines on assessing climate change include:

> Floodplain Risk Management Guideline – Practical Consideration of Climate Change (DECC, 2007); and

> Flood Risk Management Guide – Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW, 2010).

Climate change impacts on flooding are typically assessed in two ways:

> Sea level rise – Floodplains are expected to be affected by potential sea level rise in the future; and

> Rainfall increase – In NSW, it is common for rainfall intensity increases resulting from climate change to be modelled.

Sensitivity testing of the hydraulic model for the impact of climate change was conducted as part of the *Narrabeen Lagoon Flood Study* (BMT WBM, 2013). The Flood Study found that the Narrabeen Lagoon floodplain is sensitive to the impacts of climate change in relation to both sea level rise and rainfall increase. In comparison, the floodplain is not as sensitive to coincident ocean surge, which can elevate lagoon water levels and prevent the outflow of floodwaters.

The key findings of the climate change sensitivity analysis conducted by BMT WBM (2013) are listed below.

> In the lower catchment around Narrabeen Lagoon, sea level rise alone is expected to increase flood levels by 0.2 to 0.5 metres for the 1% AEP flood event.

> The upper catchment is not sensitive to sea level rise, however it is sensitive to increases in rainfall intensity, and peak flood level increases of between 0.1 and 0.5 metres for the 1% AEP event are predicted, depending on the nature of the specific creek section.

> When sea level rise and increased rainfall intensity are modelled together, the increase in flood levels in Narrabeen Lagoon is effectively the sum of the impacts of each component. That is, a 20% rainfall increase provides an increase in flood levels of around 0.2 metres, and a 0.4 metre rise in sea level provides a similar increase of 0.2 metres. When these two climate change parameters are modelled together, the flood level in Narrabeen Lagoon increases by around 0.4 metres for the 1% AEP event.

Further information on the impact of climate change on flood behaviour can be found in the Flood Study (BMT WBM, 2013) and the FRMS.

2.4 Economic Damages from Flooding

An assessment of flood damages was undertaken for both the existing catchment conditions, and for a range of scenarios investigating the potential economic benefits of implementing some of the individual flood management options. The assessment findings are reported in the FRMS.

The results from the damages assessment are shown in **Table 2-1**.

The average annual damage value attempts to quantify the flood damage that a floodplain would receive on average during a single year. The average annual damages for the Narrabeen Lagoon floodplain under existing conditions is $11,540,886.

The results show that there is potential for substantial damages to occur in relation to relatively small flood events such as the 20% AEP design flood event (which has a 20% chance of occurring in any given year, or will occur on average once in every 5 years), due to inundation above the floor level for 229 properties.

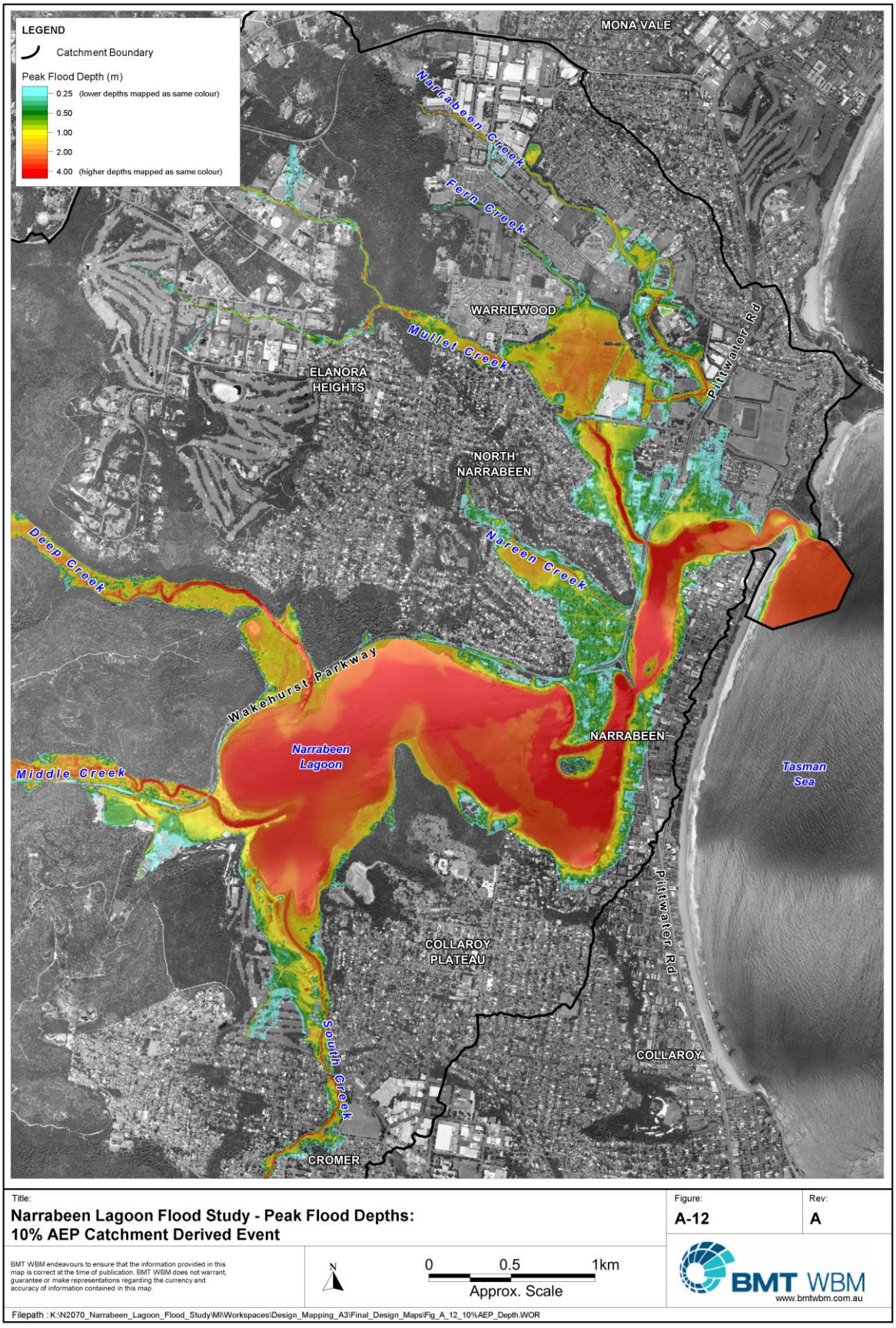


Figure 2-1 10% Annual Exceedance Probability Catchment Derived Flood Depths, from Narrabeen Lagoon Flood Study (BMT WBM, 2013)

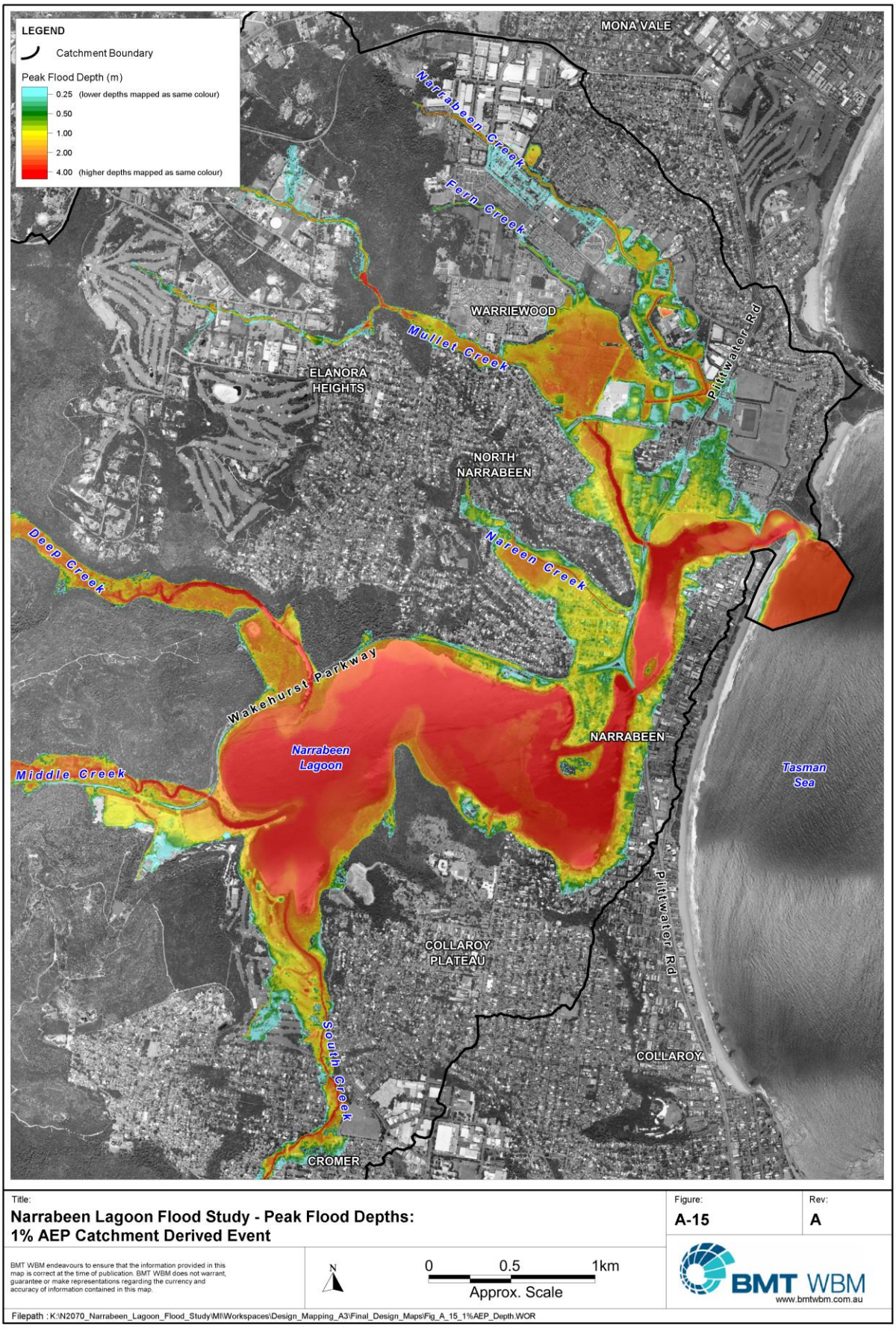


Figure 2-2 1% Annual Exceedance Probability Catchment Derived Flood Depths, from Narrabeen Lagoon Flood Study (BMT WBM, 2013)

There is a substantial increase in damages for the 5% AEP event (which has a 5% chance of occurring in any given year) due to the associated substantial increase in the number of residences experiencing overfloor flooding.

In a 1% AEP event (which has a 1% chance of occurring in any given year), the number of properties that would experience overfloor flooding does not increase dramatically when compared to the 5% AEP event.

The number of properties with overfloor flooding in the Probable Maximum Flood (PMF) is more than double the number of properties flooded in the 1% AEP event, leading to a substantial increase in flood damages for that event.

Table 2-1 Total Damages from Flooding in the Narrabeen Lagoon Catchment – Existing Condition

	Properties with over floor flooding *	Average Over floor Flooding Depth (m)	Maximum Over floor Flooding Depth (m)	Properties with overground flooding**	Total Damages ($) (Excl. GST)
PMF					
Residential	1234	1.31	3.25	2066	$91,994,601
Commercial	129	2.29	2.94		$19,466,997
Industrial	29	2.42	2.86		$7,731,891
PMF Total	*1392*				*$119,193,489*
0.1% AEP					
Residential	737	0.66	2.17	1616	$51,958,656
Commercial	122	1.06	1.62		$15,112,957
Industrial	28	1.14	1.54		$4,412,128
0.1% AEP Total	*887*				*$71,483,741*
1% AEP					
Residential	526	0.43	1.7	1415	$38,782,480
Commercial	106	0.73	1.16		$11,872,887
Industrial	27	0.72	1.09		$3,235,632
1% AEP Total	*659*				*$53,890,999*
5% AEP					
Residential	373	0.2	1.32	1305	$29,808,483
Commercial	90	0.48	0.83		$9,094,356
Industrial	27	0.38	0.75		$2,281,701
5% AEP Total	*490*				*$41,184,540*
20% AEP					
Residential	124	0.15	0.8	1116	$18,825,848
Commercial	84	0.28	0.61		$6,042,055
Industrial	21	0.23	0.52		$1,314,274
20% AEP Total	*229*				*$26,182,176*

* Properties include individual units within a block of units

** Used for garden damages and only calculated for residential properties.

2.5 Floodplain Management Issues

The FRMS identified the following key issues in the Narrabeen Lagoon floodplain.

> Flooding of existing developed areas (residential and commercial) results in economic and social impacts (e.g. damage to property, social disruption).

- Flooding damages public assets and critical infrastructure.
- Due to rapid onset of flooding (generally less than one hour), there is not enough time to evacuate the floodplain before the existing road network is inundated.
- There are several precincts in the catchment that are proposed for urban development. Development controls have been implemented to ensure that these development precincts do not increase flood risk in the catchment.
- There is a need to ensure ongoing management of the lagoon entrance for appropriate flood risk management.
- Climate change-related increases in rainfall intensity and sea level rise are predicted to exacerbate current flooding levels.
- The entrance management regime, and in particular the trigger level for mechanical openings, will require review in future due to sea level rise.

These issues form the basis of the options assessment presented in the FRMS, and this FRMP seeks to address these issues through the implementation of identified actions (**Section 3**).

2.6 Consultation

The draft Narrabeen Floodplain Risk Management Study and Plan have been placed on Public Exhibition together, with the purpose of the Public Exhibition being to seek community feedback on the options selected for implementation. As part of the Public Exhibition, an information brochure has been sent to approximately 3000 home owners within the extent of the Probable Maximum Flood, advertisements have been placed in the Manly Daily, two drop-in sessions have been organised, and displays have been set up in the Customer Service foyer of each Council.

The Narrabeen Lagoon Floodplain Risk Management Working Group (NLFRMWG) has played an important role in assisting Council in the preparation and implementation of the Floodplain Risk Management Study and Plan. The NLFRMWG is a forum that brings together the expertise and community knowledge of a diverse range of stakeholders. Regular meetings have been held throughout the project to enable discussion and feedback.

Early in the project, an information brochure describing the study and a questionnaire designed to gauge community awareness of flood related issues and request feedback were sent to approximately 3000 home owners within the extent of the Probable Maximum Flood.

A project website was developed at the commencement of the project, with links from the Warringah Council and Pittwater Council websites. It provides information about the project and its progress, with interim reports being posted at the end of each key stage of the project.

3 Development and Planning Considerations

3.1 Review of Relevant Planning Instruments, Policies and Practices

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 flood damages. Planning instruments can be used as tools to guide new development away from high risk flood 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 Local Environmental Plans (LEPs) and Development Control Plans (DCPs) to govern control on development with regards to flooding.

A LEP is a planning instrument that designates land uses and permissible development in the Local Government Area (LGA), whilst a DCP regulates development using specific guidelines and parameters. Management policies and plans are often used to provide additional information regarding development guidelines and parameters.

Following amalgamation harmonised the way that flooding is managed, including the relevant DCP clauses and design standards that stipulate the requirements for development on flood prone land.

The whole of the Narrabeen Lagoon catchment lies within the Northern Beaches Council LGA. Prior to Council amalgamation in May 2016, the part of the catchment south of the lagoon was within the former Warringah LGA, and the northern part was within the former Pittwater LGA. The Local Environment Plans (LEPs) of these former Councils still apply.

The FRMS provided a review of flood controls covered by the LEP, DCP and relevant policies and plans. It should be noted that recommendations provided in the FRMS arose from a review of the relevant planning documentation within the context of flooding behaviour of the Narrabeen Lagoon floodplain, and may not be appropriate for all floodplains across the Northern Beaches LGA.

3.1.1 Review of Flood Planning Levels

A review of the existing Flood Planning Levels (FPLs) adopted by Northern Beaches Council was undertaken to identify any potential modifications that may be required for the Narrabeen Lagoon catchment. This review, which is reported in full in the FRMS was completed via an assessment of the flood risk associated with different FPLs in relation to the:

> Potential impacts of climate change;

> Adopted freeboard levels; and

> Flood Planning Area definition (i.e. the area below the FPL, within which flood-related planning controls are applied).

The Warringah LEP 2011 defines the flood planning level as "*the level of a 1:100 ARI (Average Recurrence Interval) flood event plus 0.5 m freeboard*"; and

The Pittwater LEP 2014 defines the flood planning level as "*the level of a 1:100 ARI (Average Recurrence Interval) flood event plus 0.5 m freeboard, or other freeboard determined by an adopted floodplain risk management plan*".

Council has updated the Development Control Plans (DCPs) for the two former Councils to create a consistent set of controls which apply across the entire Northern Beaches. These controls are found in Part E11 of the Warringah DCP and in Section B3.11 of the Pittwater 21 DCP.

Pittwater 21 DCP also contains additional requirements for 'intensification of development' which are described within the following section.

Pittwater 21 Development Control Plan

The Pittwater 21 DCP existing policy addresses climate change by applying the year 2100 climate scenario of 0.9 metres of sea level rise and 30% rainfall increase as the design event within the FPL for 'intensification of development'.

The adopted design event for all of the above development types is the 1% AEP event.

It is recommended a consistent approach to addressing climate change is investigated on an LGA wide scope. This will improve continuity of policy within the LGA.

3.1.2 Review of Policies for Basement Car Parking

The flood risks associated with basement car parking in a development can be highly critical. Basement carparks have the potential to accommodate a large number of occupants at any one time, are enclosed and therefore provide a limited number of evacuation points for occupants. There is often a very small response time in the event of flooding because the basement can fill with floodwaters very quickly. Therefore the flood risk to life is significant.

The DCPs identify development requirements for various types of car storage. The requirements for basement (enclosed) car parks in residential developments are:

> *All enclosed car parks must be protected from inundation up to the relevant flood planning level. For example, basement carparks must be provided with a crest at the entrance, the crest of which is at the relevant Flood Planning Level.*
>
> *All access, ventilation and any other potential water entry points to any enclosed car parking shall be above the relevant Flood Planning Level.*
>
> *Council will not accept any options that rely on electrical, mechanical or manual exclusion of the floodwaters from entering the enclosed carpark*

The requirements for basement (enclosed) car parks in vulnerable development or for critical infrastructure are:

> *All enclosed car parks must be protected from inundation up to the Probable Maximum Flood level or Flood Planning Level whichever is higher. For example, basement carparks must be provided with a crest at the entrance, the crest of which is at the relevant Probable Maximum Flood level or Flood Planning Level whichever is higher. All access, ventilation and any other potential water entry points to any enclosed car parking shall be above the relevant Probable Maximum Flood level or Flood Planning Level whichever is higher.*

The policy review presented in the FRMS considered these requirements infeasible for most sites in the Narrabeen Lagoon floodplain. The 1% AEP flood depth is between 0.8 and 1.0 metres above ground level, which would translate to a requirement for basement carpark entries to be set at 1.3 to 1.5 metres above ground level when freeboard is taken into account.

There are several potential solutions suggested in the FRMS that could be further explored by Council and presented to developers as viable design alternatives to resolve the issue:

- Provision of multiple evacuation routes from the basement, noting that this does not address risk to property; and
- First floor car parks can elevate cars above the PMF level thus removing risk to life and property. While this solution provides the best flood risk mitigation, from a development point of view it elevates building heights which may not be either permissible under planning controls, or in fact desirable from an urban planning perspective. While it is a viable solution, it needs careful consideration to ensure the implications are understood and accepted by the community.

3.1.3 Flood Risk from Future Development

There are several development precincts located in the Narrabeen Lagoon catchment, including the:

- Ingleside Land Release Area;

> Oxford Falls area;

> North Narrabeen Commercial Area; and

> Warriewood Valley Urban Land Release Area.

While the FRMS found that further development of these areas is unlikely to significantly impact flood behaviour in the Narrabeen Lagoon catchment, it is considered sensible to ensure that appropriate planning controls are in place to ensure that these developments do not negatively impact flood risk.

All Development Applications submitted to Council must provide evidence that stormwater discharge from the post-development site does not exceed existing values. While these development controls do not apply to complying development, these types of development must satisfy On Site Detention requirements outlined in AS3500 - National Plumbing and Drainage and therefore it is assumed that post-development flows will be attenuated at least partially.

The Ingleside Precinct Planning Area and Warriewood Valley Urban Release Area both lie within the Warriewood Valley, therefore the Warriewood Valley Water Management Specification (Lawson & Treloar, 2001) is applicable. The Specification requires that existing peak flows in the 1% AEP event are matched post-development, and that the flows throughout the flood hydrograph are expected to be comparable (+/- 5%) to the existing (undeveloped) condition.

This suite of policies is considered adequate to manage the potential impacts of future development on flood risk in the Narrabeen Lagoon catchment.

3.1.4 Review of Entrance Management Procedures

Flooding in the Narrabeen Lagoon catchment is affected by the estuary entrance condition; i.e. whether it is open, heavily shoaled or closed. There are two types of flood mitigation operations undertaken at the lagoon entrance: reactive mechanical opening and proactive entrance clearance. The existing approach to each operation is detailed in the Lagoon Entrance Management Operation Management Standard OMS 455 (Warringah Council, 2014).

Presently the lagoon is mechanically opened at short notice for flood mitigation purposes. In addition there is larger-scale excavation of the entrance and flood tide delta approximately every three to five years. This sand clearance every few years shifts the entrance from its equilibrium condition by creating a short-term improvement in the hydraulic efficiency of the entrance channel. The driving processes are not changed significantly from their existing regime, however, and the system response is a dampened one directed toward re-establishing the existing equilibrium of a heavily shoaled to closed entrance.

Entrance Clearance Operations

As part of the FRMS, a review and assessment of a range of entrance management options was undertaken, including:

> Ongoing entrance clearance works in accordance with OMS 455 (Warringah Council, 2014);

> Dredging of the flood tide delta upstream of the Ocean Street bridge; and

> The removal of bed rock from the entrance channel.

The outcomes of the modelling have demonstrated that Council's current entrance management policy is effective in mitigating flood risk. The results have also shown that the removal of the bed rock at the entrance may further act to reduce low recurrence catchment event (1% AEP or less frequent) peak flood levels and durations by allowing more entrance scour during flood events. However, flooding from ocean based events could be worse, and the removal of bed rock would be a significant undertaking for several reasons:

> It would likely require an extensive REF process and approvals;

> The process would involve significant capital expenditure; and

> There is inherent public safety risk for undertakings of this nature, particularly with the close proximity to highly trafficked areas.

Given the considerations listed above, and the fact that that the removal of the entrance rock would only provide significant flood mitigation for very rare (1% AEP or less frequent) flooding events, it is concluded that Council's present entrance management strategy is the most effective of those assessed.

Reactive Mechanical Opening

In addition to the regular entrance sand management strategy, Northern Beaches Council mechanically opens the lagoon entrance in accordance with its Lagoon Entrance Management Operational Management Standard 455. Under OMS 455, the mechanical opening of the lagoon for flood mitigation purposes is triggered when water levels are between approximately 1.0 m and 1.3 m AHD.

Currently, mechanical openings shall be undertaken when either of the following conditions occur:

- Scenario 1 - The lagoon has been closed for an extended period of time (months) at a level approximately between 1.0 and 1.3m AHD, there is potential damage to threatened and protected species and moderate to heavy rainfall is forecast.
- Scenario 2 - The lagoon water level is at or exceeding 1.3m AHD, water level recorders indicate increasing lagoon water levels and moderate to heavy rainfall is forecast.

In order to review the trigger level at which mechanical opening occurs, and assess the consequences of changing that trigger level, the FRMS investigated a range of different trigger level scenarios as part of the FRMS. These investigations considered both current mean sea level and two sea level rise scenarios of 0.4 metres and 0.9 metres for a planning horizon of 2050 and 2100 respectively.

The selection of a mechanical entrance opening level is a trade-off between flood mitigation and other practical and logistical issues such as available response time (choosing a lower trigger level will allow more time to respond before flooding reaches critical levels), frequency of openings (lower trigger levels will result in more frequent openings), and entrance conditions (for instance, a level below about 1.0m AHD without rainfall is unlikely to result in a successful opening).

The assessment found that the current trigger level of 1.3m AHD for mechanical opening of the entrance provides an appropriate balance between mitigating flood risk and cost and logistical requirements. It is noted that this finding relates to present day mean sea level conditions, and it is expected that as sea level rise continues beyond 0.4 metres the flood mitigation value derived from mechanical entrance opening will rapidly diminish.

While the effectiveness of mechanical opening of the entrance as a flood mitigation strategy will probably decrease with time due to sea level rise, it remains the most appropriate approach at present. There is presently too much uncertainty regarding how Narrabeen Lagoon entrance will respond under future climate change scenarios to assess precisely when the benefits will be lost.

3.2 Emergency Response Arrangements

Flooding in the Narrabeen Lagoon catchment generally occurs as flash flooding, that is, inundation occurs quickly from increased water levels that may be elevated for only short periods of time. The flooding of Narrabeen Lagoon itself occurs primarily due to runoff from the catchment entering the lagoon rather than tidal inundation from elevated ocean water levels, but the latter does influence the lagoon water levels achieved during an event. This flooding behaviour results in a limited time period in which to provide a flood warning or to arrange for evacuations.

When determining the flood risk to life, the flood hazard for an area does not directly imply the danger posed to people in the floodplain. This is due to the capacity for people to respond and react to flooding, and ensuring they do not enter floodwaters. This concept is referred to as flood emergency response.

To help minimise the flood risk to occupants, it is important that there are provisions for flood emergency response. There are two main forms of flood emergency response that may be adopted:

- Evacuation – the movement of occupants out of the floodplain before the property becomes flooded; and
- Shelter-in-place – the movement of occupants to a building that provides vertical refuge on the site or near the site before their property becomes flood affected.

The FRMS reviewed the current emergency response systems that are in place and the feasibility for flood evacuation based on critical infrastructure and vulnerable developments, key locations of road overtopping,

and the evacuation timeline for the floodplain. In addition the shelter-in-place potential was assessed, and based on guidance for emergency response in flash flooding, a comment on evacuation versus shelter-in-place was made for the Narrabeen Lagoon Catchment.

Regional Evacuation

The review found that the regional evacuation potential of the lower Narrabeen Lagoon floodplain in the event of flooding is limited for the following reasons.

> The majority of key road locations within the floodplain are overtopped in frequent events (50% AEP and less). This means that for a regional evacuation strategy to be effective, evacuation will need to be triggered frequently.

> There is insufficient time for a regional evacuation to be co-ordinated, due to the flash-flooding nature of the floodplain.

> The currently implemented Northern Beaches Flood Information Network program does not provide sufficient time to evacuate in short duration events, because a warning is not initiated until after three hours of rainfall. Due to the flash-flooding nature of the floodplain, the only feasible warning system that could be implemented is rainfall forecasting, but due to the level of uncertainty involved this is not widely adopted as an evacuation warning tool.

Local Evacuation

Compared to the regional timeline above, localised evacuation significantly reduces the time required to evacuate. Given the rate of rise of floodwaters in the Narrabeen Lagoon floodplain, localised evacuation strategies for developments in certain locations within the floodplain are feasible, particularly on the fringes of the floodplain where evacuation routes are shorter.

In accordance with guidance provided in the Australasian Fire and Emergency Service Authorities Council (AFAC, 2013) guideline, wherever possible, local evacuation should be the preferred emergency response for the Narrabeen Lagoon floodplain.

Shelter-in-Place

While not the preferred form of emergency response, the review conducted in the FRMS found that shelter-in-place is a feasible form of emergency response for some parts of the Narrabeen Lagoon floodplain. In accordance with the AFAC guideline, where localised evacuation is not possible, shelter-in-place is seen as an acceptable alternative if designed appropriately.

4 Floodplain Management Options

Flood risk can be categorised as existing, future or residual risk.

> Existing Flood Risk – existing buildings and developments on flood prone land. Such buildings and developments by virtue of their presence and location are exposed to an 'existing' risk of flooding.

> Future Flood Risk – buildings and developments that may be built on flood prone land, or on land that may become flood affected in the future. Such buildings and developments would be exposed to a flood risk when they are built.

> Residual Flood Risk – buildings and development that would be at risk if a flood were to exceed management measures already in place. Unless a floodplain management measure is designed to withstand the PMF, it will be exceeded by a sufficiently large event at some time in the future.

The various approaches to managing these risk categories are outlined in **Table 4-1**.

Table 4-1 Flood Risk Management Alternatives (after: SCARM, 2000)

Alternative	Examples
Preventing / avoiding risk	Relocating existing or future development so that it is outside the floodplain.
Reducing likelihood of risk	Structural measures that modify flood behaviour, such as drainage augmentation, levees, and detention basins.
Reducing consequences of risk	Development controls to ensure structures located in the floodplain are built to withstand flooding.
Transferring risk	Via insurance – may be applicable in some areas depending on insurer.
Financing risk	Natural disaster funding to assist in recovery from a flood event.
Accepting risk	Accepting the risk of flooding as a consequence of having development in the floodplain.

A range of flood risk management options were considered as part of the FRMS, and subjected to a cost-benefit analysis to assist in identifying appropriate, reasonable and technically feasible options for implementation in this FRMP. Further information can be found in Sections 11 to 13 of the FRMS, which details each of the options and assesses their relative costs and benefits.

The findings of the FRMS are briefly summarised in **Sections 4.1 to 4.5**.

4.1 Flood Modification Measures

Flood modification measures modify the behaviour of the flood itself by reducing flood levels or flow velocities, or by excluding floodwaters from areas under threat (NSW Government, 2005).

Flood modification measures are a common and effective means of reducing flood risk; however, they are often costly and can result in negative impacts on the natural environment (NSW Government, 2005). The adoption of any individual flood modification measure is therefore a trade-off between economic factors, social benefits, and the potential environmental impacts of the option.

A total of 20 flood modifications options were developed and subjected to a detailed assessment, including hydraulic modelling, in the FRMS. The purpose of the hydraulic modelling is to simulate the implementation of the option, and see how successful it is in reducing flood impacts. The locations of the final flood modification options are shown in **Figure 4-1**. Note that options have been proposed for the following sub-catchments of Narrabeen Lagoon:

- South Creek (five options);
- Nareen Creek (three options);
- Warriewood Valley (four options); and
- Narrabeen Lagoon itself (three options including two regional options).

A brief description of the floodplain modification measures is provided in the following sub-sections.

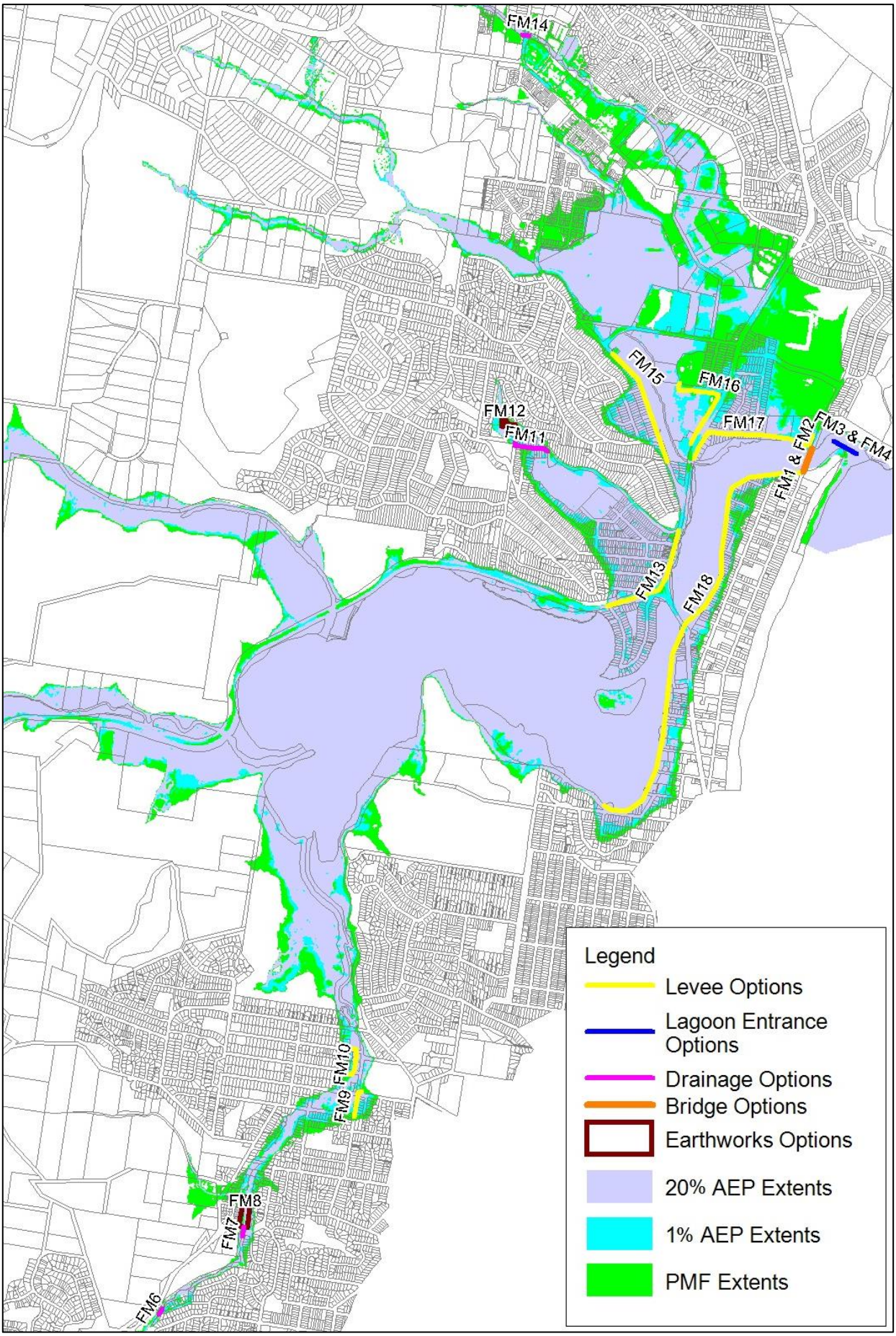


Figure 4-1 Location of Flood Modification Options for Narrabeen Lagoon

4.1.2 FM1 – Ocean Street Bridge Extension

The existing northern embankment of the Ocean Street Bridge encroaches into the lagoon a distance of 42 m. The Option 1 figure (**Appendix B**) shows the general layout of the system. In the existing 1% AEP scenario there is an approximately 0.1 m water level difference between upstream and downstream of Ocean Street, which suggests that the bridge acts as a significant constriction to flow. If the bridge was extended to the north and the embankment removed, the additional flow path width has the potential to lower flood levels in the northern portion of the Lagoon including Nareen Creek, Lakeside, and Warriewood Valley. This option was previously assessed in Narrabeen Lagoon FRMS (2002), but it was not assessed in detail.

4.1.3 FM2 – Reconstruction of Ocean Street Bridge to be above the 1% AEP Flood Level

The current Ocean Street Bridge is quite low relative to the potential water levels present during a flood event. The replacement of the existing bridge with a bridge that no longer poses a flow obstruction during events up to the 1% AEP event may result in a reduction in water levels upstream of the bridge.

4.1.4 FM3 - Entrance Bed Rock Removal

Description

This would involve removal of the underlying bedrock at the Lagoon entrance, which presently acts as a limiter for entrance scour during flood events. The bedrock would need to be blasted out, or sawn using rock cutters.

The intention is that once the bedrock is removed, the entrance will be allowed to scour to a greater extent during a flood, thereby allowing a more rapid release of flood waters and reducing flood levels.

4.1.5 FM4 – Extraction of Entrance Shoals Upstream and Downstream of the Ocean St Bridge

This would involve using a mechanical excavator to dredge the flood tide delta shoals upstream and downstream of the Ocean St Bridge. The extraction of these shoals reduces the build-up of sediment behind the entrance and enables the break out of the entrance during a flood event to occur sooner, reducing the peak flood levels experienced inside the lagoon.

This option is the lagoon management approach that has been implemented for Narrabeen Lagoon since 1975, with clearance occurring on average every 4-5 years.

4.1.6 FM4a – Dry Earth Sand Winning with Beach Cut and Cover Pipeline

This option has not been specifically modelled within this report, since the option has the same effective function as the current entrance management system (option FM4) just described. This modified option has been assessed to identify if it has more merit than the current option. In all cases involving extraction of shoals in the lagoon it was assumed that a small cutter-suction dredge would be used and costs estimated accordingly (GHD, 2013).

This option entails utilising a mechanical excavator to remove the sand. This sand is then placed in a hopper and slurrified through the addition of water before being pumped to beach replenishment locations. The potential benefit of this approach is that while a significant upfront infrastructure cost is required, this may be offset by efficiencies gained over future extraction projects.

This would involve extracting the flood tide delta shoals upstream and downstream of the Ocean St Bridge (i.e. FM4) in conjunction with option FM1 to extend the bridge, which may reduce the observed flow constriction around the bridge observed in the model results for extreme AEP events and thus locally reduce flood levels. It has been assumed that mechanical excavators would be used to dredge the flood tide delta and costs estimated accordingly.

4.1.7 FM6 - Alkira Circuit Drainage Upgrade

This would involve upgrading the current culvert network (three 1350mm pipes and one 1500mm pipe) under the low-lying Alkira Circuit crossing (road level is only 2.3 metres above channel invert) from the current 20% AEP capacity to convey the 1% AEP event and avoid overland flow being diverted from the road surface into residential properties downstream. Three 3.2W x 1.5H Reinforced Concrete Box Culverts (RCBC) would be required to achieve this outcome. This option may result in no overtopping of Alkira Circuit up to the 1%

AEP event, potentially removing flood affectation from 10 properties. This option was previously considered as part of *South Creek FRMS* (2008).

4.1.8 FM7 - Willandra Road Reserve Lowering

The public reserve on the western bank downstream of Willandra Road is elevated (approximately 12m AHD), while the eastern bank which has flood affected residential properties is lower (approximately 11m AHD). If the western bank was lowered then flooding of the reserve could alleviate flooding of neighbouring residential properties to the east. Downstream of the roadway a small area of excavation has been undertaken in a currently undeveloped area of green space.

4.1.9 FM8 Willandra Road Culvert Upgrade and Channel Vegetation Clearing

There are two 3.0W x 1.55H Reinforced Concrete Box Culverts (RCBC) conveying flow under Willandra Road, which has a low point to the east of the culvert crossing diverting flows to residential properties downstream. Capacity is exceeded in the 20% AEP event and flow overtops the road reserve diverting flood waters through several low-lying residential properties downstream.

In order to improve conveyance through the roadway as described in Option FM7, a 3.0W x 1.55H RCBC through the road has been considered. To cater for the increased culvert conveyance, vegetation clearance has been undertaken downstream of the roadway. The intention of this is to offset the increased flow coming through the culverts and improve the flood immunity of the local properties. This option was previously considered as part of *South Creek FRMS* (2008).

4.1.10 FM9 - Waroon Road Levee

Dalpura Street residential properties have an unused vegetated road reserve at their rear where a levee could protect the region from flooding up to the 1% AEP event. This option requires a levee with a maximum height of 1.4 m above the existing surface and approximately 150 m in length. This option may result in the removal of flooding on 10 residential properties for the 1% AEP event.

4.1.11 FM10 - Wabash Avenue Levee

A levee can be constructed to encompass both the flood affected properties and the two cul-de-sac road reserves protecting them from flooding up to the 1% AEP event. This option requires a levee with a maximum height of 1.7m above the existing surface, and a length of approximately 210 m. This option may result in the removal of flooding on 4 residential properties for the 1% AEP event. This option was previously considered as part of *South Creek FRMS* (2008).

4.1.12 FM11 - Tatiara By-pass Overland Flow path

The Tatiara Crescent crossing of Nareen Creek is a low lying local road crossing. There is a 2.96W x 1.22H culvert conveying flow with capacity exceeded in the 20% AEP event. Overland flow overtops into the road reserve with flow through several residential properties downstream and flooding of Nareen Parade before flowing into Narroy Park downstream. This option would involve lowering Tatiara Crescent and Nareen Parade by up to 1.8 metres over a distance of 200 metres.

Under this option, regrading of both Tatiara Crescent and Nareen Parade would be required to encourage flow along the roads instead of through the properties on Tatiara Crescent. Alternatively, an additional culvert along the existing street system could be utilised.

This option has the opportunity to make residential properties flood free up to the 1% AEP event depending on the depth of cut within the road reserve. This option may also be considered as an underground asset to minimise surface disruption and crossover modifications.

4.1.13 FM12 - Basin at Narrabeen RSL, Pipe Diversion along Tatiara Cres and Nareen Parade to Open Channel

An alternative option for the alleviation of Tatiara Crescent flooding described in Option FM11 above is the construction of a detention basin in available land in the Narrabeen RSL upstream of Tatiara Crescent. This would assist in reducing peak flows from Nareen Creek downstream. In addition a second culvert (with the same dimensions as the existing) would be constructed along the Tatiara Crescent and Nareen Parade road reserves to increase capacity.

4.1.14 FM13 - Pittwater Road & Wakehurst Parkway Raising / Levee

Flooding of low-lying residential and commercial areas of North Narrabeen west of Pittwater Road in events greater than the 20% AEP event are predominantly caused by lagoon backwater flooding, but there is also a secondary form of flooding from Nareen Creek upstream. Raising the already elevated regional roads could protect North Narrabeen from lagoon flooding in the 1% AEP event with the majority of the existing Pittwater Road above the 5% AEP.

For the 1% AEP event Wakehurst Parkway would need to be raised up to 1 metre for a distance of 150 m, and Pittwater Road would need to be raised up to 0.6 m for a distance of 300 m. A flood gate would be required at the Nareen Creek outlet to limit backwaters through the outlet.

4.1.15 FM14 – Ponderosa Parade Drainage Upgrade

Flooding of Narrabeen Creek in upper Warriewood Valley is generally contained within channel up to the 1% AEP event. Flooding does occur via the low lying Ponderosa Parade crossing (road level is only 2.1 metres above channel invert). There are twin 1800 mm diameter pipes conveying flow under the local road. Capacity is exceeded in the 5% AEP event and flow overtops into the road reserve with overland flow through several large residential developments downstream to the south.

This option includes upgrading the current culvert network from the current 20% AEP capacity to convey the 1% AEP event and contain flows within Narrabeen Creek channel. A 4.5W x 1.8H RCBC has been selected to convey this flow.

4.1.16 FM15 – Garden Street Levee

Significant flooding of a large area of low-lying residential and commercial areas to the west of Garden Street occurs in the 20% AEP event and greater. Flooding in this lower floodplain is predominantly caused by lagoon backwater, but there is also a secondary form of flooding from Mullet Creek to the east. Construction of a levee on the eastern side of Garden Street in Progress Park, to the west of Mullet Creek, may mitigate some of this flooding.

To construct the levee to the 1% AEP level would require raising the existing ground level about 1.5 – 1.7 m over a distance of approximately 700 m. This option would address both Mullet Creek flooding and Narrabeen Lagoon flooding for properties west of Garden Street. This option was previously considered within the *Narrabeen Lagoon FRMS* (1992)

4.1.17 FM16 - Pittwater Road / Narrabeen Sports High Levee Bank

On the east side of Mullet Creek, there is a low lying area of residential properties and schools surrounding Pittwater Road, which are flood affected in the 20% AEP event. To protect Pittwater Road and the surrounding properties, a levee bank is proposed to be extended along the Pittwater Road frontage of Narrabeen Sports High and along the frontage to Namona Street. To protect up to the 1% AEP event the levee would need to be raised up to 0.5 - 0.8 metres over a distance of 590 metres. Note that while this protects the area from Mullet Creek flooding, for this option to be effective the Lakeside Levee (Option FM17) also needs to be constructed to protect from Narrabeen Lagoon flooding to the south.

4.1.18 FM17 - Lakeside Levee

Flooding of the low-lying caravan park and large residential area to the east of Pittwater Road on the northern bank of Narrabeen Lagoon occurs in the 20% AEP event. This option includes construction of a levee on the northern bank of Narrabeen Lagoon within the public reserve and caravan park. If the 1% AEP is the chosen design event, then the levee would need to be raised up to 1.0 - 1.5 metres over a length of 810 metres. As noted in Option FM13, this option also requires construction of the Narrabeen Sports High School levee to protect from Mullet Creek flooding to the east.

4.1.19 FM18 - East Bank Levee

The entire eastern bank of Narrabeen Lagoon, from Mactier Street in the south to Malcolm Street in the north, is low lying and flood affected in events as frequent as the 20% AEP event. It includes a 2.4 km long stretch of residential / commercial and industrial properties in the suburb of Narrabeen. Construction of a

levee along the lagoon bank would protect these properties. To achieve protection up to the 1% AEP design event, the levee would need to be raised up to 1.0 - 2.0 metres over a length of 2400 metres.

4.1.20 Economic Assessment of Flood Modification Options

The preferred options are listed in **Table 4-2**, and their locations have been mapped in **Figure 4-1**. Options FM3, FM5 and FM13 have not been included as they are considered to be non-viable.

Table 4-2 Preferred Flood Modification Options

Option ID	Description	Cost of Implementation*	Benefit / Cost Ratio	Overall MCA Ranking
FM4	Extraction of entrance shoals upstream and downstream of the entrance bridge	$5,443,000	6.52	1
FM9	Waroon Road Levee	$208,000	4.12	2
FM10	Wabash Avenue Levee	$341,000	1.95	2
FM6	Alkira Circuit Drainage Upgrade	$499,000	0.83	4
FM14	Ponderosa Parade Drainage Upgrade	$889,000	1.03	5
FM11	Taitara By-pass Overland Flowpath	$719,000	2.16	9
FM2	Reconstruction of Ocean Street Bridge to be above the 1% AEP Flood Level	$20,875,000	0.18	12
FM1	Ocean Street Bridge Extension	$5,440,000	0.68	13
FM15	Garden Street Levee	$3,161,000	3.39	14
FM12	Basin at Narrabeen RSL, Pipe Diversion along Tatiara Cres and Nareen Parade to Open Channel	$6,783,000	0.43	16
FM5	Ocean Street Bridge Extension & Upstream and Downstream Shoal Dredging	$9,104,000	4.22	17
FM4a	Dry Earth Sand Winning with Beach Cut and Cover Pipeline	$5,878,000	6.04	18
FM7	Willandra Road Reserve Culvert Upgrade and Lowering / Detention Basin	$566,000	0.21	19
FM8	Willandra Road Culvert Upgrade and Vegetation Removal	$1,000,000	0.25	19
FM16 and FM17	Pittwater Road Levee Bank and Lakeside Levee	$18,874,000	0.73	21
Total Cost of Implementation of Flood Modification Options:		**$154,796,000**		

*Net present worth of cost of implementation, incorporating both capital and maintenance costs over the implementation period of 50 years.

4.2 Property Modification Measures

Property modification measures are focused on preventing, avoiding or reducing consequences of flood risks. Rather than modify the flood behaviour, these measures aim to modify existing properties (e.g. by house raising) and/or impose controls on property and infrastructure development (NSW Government, 2005). Property modification measures, such as effective land use planning and development controls, are essential for ensuring that future flood damages are appropriately contained, while at the same time allowing ongoing development and use of the floodplain.

The FRMS assessed the following four property modification measures:

> House raising, a measure designed to reduce the incidence of over-floor flooding of existing buildings through works funded by Council, and with assistance from the NSW Office of Environment and Heritage (OEH);

- Voluntary purchase, involves properties being purchased by Council at an equitable price and only when voluntarily offered, and is an alternative to the construction of flood modification measures for properties where house raising is not possible;
- Land swap, an alternative to voluntary purchase is a land swap program whereby Council swaps a parcel of land outside of the flood prone area, such as an existing park, for a parcel of flood prone land with the appropriate transfer of any existing facilities to the acquired site; and
- Council re-development, an alternative to voluntary purchase whereby Council buys a flood affected property and re-develops it in a flood compatible manner.

None of the property modification measures listed above were considered reasonable or feasible for the Narrabeen Lagoon floodplain. This is due to the high cost of property in the floodplain, and the inherent challenges in making an equitable land swap that does not unduly impact community assets such as parks and reserves.

The flood planning level review option FPL1 is, however, strongly recommended for inclusion in the implementation plan. The recommendations from the FRMS review of flood planning levels in the Narrabeen Lagoon floodplain are summarised in **Section 3.1.1** of this FRMP.

4.3 Emergency Management Measures

Emergency response modification measures aim to reduce the consequences of flood risks by:

- Increasing the effective warning time, such as via the use of flood warning systems;
- Planning the evacuation of an area so that it proceeds smoothly during a flood event;
- Preparing for a flood event (e.g. stockpiling sand and sandbags for future deployment); and
- Enabling recovery following a flood event.

These types of measures are typically incorporated into the local flood plan, and education of the community on the contents of the plan is very important. As noted within the Floodplain Development Manual (NSW Government, 2005) these measures effectively modify the response of the community at risk to better cope with a flood event.

Of all the floodplain risk management options available for consideration, it is only emergency management modifications (which includes community planning) that addresses the residual flood risk after all the flood and property modification options have been implemented. Emergency management and education measures are an effective ongoing flood risk management tool (NSW Government, 2005).

The findings of the FRMS review of emergency response arrangements in the Narrabeen Lagoon floodplain are summarised in **Section 3.2** of this FRMP.

A total of five emergency management options were developed:

- EM1 – Local evacuation measures: Using detailed local procedures to improve emergency response at a local scale for four high risk areas within the floodplain.
- EM2 - Public awareness and education: A program of flood awareness for the entire LGA is recommended as well as the implementation of more targeted and detailed education strategies for flood warning systems.
- EM3 – School education programs: Improving the flood awareness of school children by educating them on flood risk in Narrabeen Lagoon.
- EM4 - Evacuation route mapping and implementation of flood warning signs at critical locations to assist evacuees and to reduce time required for evacuation.
- EM5 - Flood warning systems: Using water level gauges to trigger evacuation provides more certainty of imminent flooding than rainfall gauges, and provides a faster warning time, improving the time available for evacuation.

It is recommended that all of these are adopted as actions in this FRMP.

4.4 Data Collection

In addition to the options discussed in **Sections 4.1 - 4.3**, a flood data collection strategy is also recommended. This would involve the collection of relevant data such as survey of flood marks and records of property flooding following a flood event. This data could then be analysed to develop further information about flooding behaviour in the catchment.

4.5 Multi Criteria Assessment of Options

A multi-criteria analysis (MCA) was used for the comparative assessment of all options identified. A similar approach to that recommended in the *Floodplain Development Manual* (2005) was adopted. This approach uses a subjective scoring system to assess the merits of each option. The principal value of such a system is that it allows comparisons to be made between alternatives using a common index. In addition, it makes the assessment of alternatives “transparent” (i.e. all important factors are included in the analysis).

The scoring system subjectively ranks each option against a range of criteria given the background information on the nature of the catchment and floodplain as well as community preferences. The scoring is based on a triple bottom line approach; incorporating economic, social and environmental criteria. The criteria and scoring system adopted include:

Economic	Benefit cost ratio
	Capital and operating costs
	Reduction in risk to property
	Feasibility
	Protection of Vulnerable Developments and Critical Infrastructure
Social	Reduction in risk to life in PMF
	Reduction in risk to life in 1% AEP
	Reduction in social disruption
	Community support
	Compatibility with policies and plans
Environmental	Compatibility with surface water quality objectives
	Fauna / Flora impacts
	Acid sulfate soils

Table 4-3 provides a ranked list of management options. The current entrance management strategy is identified as the most suitable option for entrance management. This option provides a good Benefit/Cost ratio as well as having strong community support and minimal impact on the current environmental conditions. The Waroon Road and Wabash Avenue levee options are identified as the options which are most likely to provide significant (albeit localised) improvements.

Table 4-3 Summary of MCA Evaluation for Options

Option No.	Description	Total Score	Overall Rank	Rank (Structural / Non Structural)
FM4	Extraction of entrance shoals downstream of the entrance bridge	3.00	1	S-1
FM9	Waroon Road Levee	2.87	2	S-2
FM10	Wabash Avenue Levee	2.87	2	S-2
FM6	Alkira Circuit Drainage Upgrade	2.40	4	S-4
FM14	Ponderosa Parade Drainage Upgrade	2.20	5	S-5
EM1	Local Evacuation Measures	2.00	6	NS-1
EM2	Public awareness and education	2.00	6	NS-1
EM5	Flood Warning Systems	1.80	8	NS-3
FM11	Taitara By-pass Overland Flowpath	1.67	9	S-6
EM3	School Education Programs	1.60	10	NS-4
EM4	Flood Markers and Signage	1.40	11	NS-5
FM2	Reconstruction of Ocean Street Bridge to be above the 1% AEP Flood Level	1.33	12	S-7
FM1	Ocean Street Bridge Extension	1.13	13	S-8
FM15	Garden Street Levee	1.07	14	S-9
FPL1	Flood Planning Level Revision	1.00	15	NS-6
FM12	Basin at Narrabeen RSL, Pipe Diversion along Tatiara Cres and Nareen Parade to Open Channel	0.87	16	S-10
FM5	Ocean Street Bridge Extension & Upstream Shoal Dredging	0.73	17	S-11
FM4a	Dry Earth Sand Winning with Beach Cut and Cover Pipeline	0.73	18	S-12
FM7	Willandra Road Reserve Culvert Upgrade and Lowering / Detention Basin	0.53	19	S-13
FM8	Willandra Road Culvert Upgrade and Vegetation Removal	0.53	19	S-13
FM16 and FM17	Pittwater Road Levee Bank and Lakeside Levee	0.27	21	S-15

5 Implementation Program

5.1 Overview

The floodplain management options outlined in **Section 4** are recommended for implementation as an outcome of the Floodplain Risk Management process. In order to achieve the implementation of relevant management actions, a program of implementation has been developed.

The steps in progressing the floodplain risk management process from this point onwards are:

- The Narrabeen Lagoon Floodplain Risk Management Working Group will consider the Draft Plan and make recommendations;
- Council will adopt the final Plan;
- Recommended management actions will be implemented in accordance with the established priorities as funds become available from the OEH, the Commonwealth, other state government agencies and/or from Council's own resources; and
- In some cases implementation will require more detailed cost benefit analysis, assessment and mitigation of environmental impacts and / or detailed design.

5.2 Implementation Plan

Due to the high cost of implementation of the full list of recommended management options (**Tables 4-2** and **4-3**), a sub-set of the options has been developed into an implementation plan. These represent the 11 highest ranked management options, as well as the data collection recommendation.

Table 5-1 lists the following information relevant to the implementation of the management actions:

- An estimate of implementation costs over a 50 year period (including capital and recurrent costs) for each structural action (this may, in some cases, include existing staff and funding);
- The agency or organisation likely to be responsible for the action;
- The priority for implementation (higher, medium, or lower) as an outcome of the FRMS; and
- Performance measures to allow for the evaluation of the implementation of the FRMP.

5.3 NSW Floodplain Management Authority Project Assessment and Priority Ranking

The FRMS adopted a multi-criteria assessment approach to better understand the reduction in flood risk and other benefits and impacts of the various options considered. The recommendations of the FRMP have been based on the outcomes of this assessment. Funding and implementation of these recommendations will not necessarily be undertaken in accordance with the ranking of the options.

The NSW Government's floodplain management grants support local government to manage flood risk. The funding for these grants comes from two programs, the NSW Floodplain Management Program and the Floodplain Risk Management Grants Scheme (jointly funded by the NSW Office of Emergency Management and the Commonwealth Government).

Applications for funding can be made by Northern Beaches Council for the implementation of actions identified in a FRMP. The information provided in the applications for each management action is used to rank the priority for funding of all actions across NSW.

The information presented in the FRMS and this FRMP can be used to complete the relevant applications for funding.

Table 5-1 Implementation Plan

Option ID	Description	Benefit Cost Ratio	Overall Ranking	Capital Cost (Excl. GST)	Cost of Implementation (Excl. GST)*	Responsibility / Potential Funding Partners	Priority **	Performance Measure
FM4	Extraction of entrance shoals upstream and downstream of the entrance bridge	6.04	1	$1,160,000	$5,443,000	Council / OEH	H	Entrance clearance works implemented every 4-5 years.
FM9	Waroon Road Levee	4.12	2	$185,000	$208,000	Council / OEH	H	Levee constructed
FM10	Wabash Avenue Levee	1.95	2	$309,000	$341,000	Council / OEH	H	Levee constructed
FM6	Alkira Circuit Drainage Upgrade	0.83	4	$484,000	$499,000	Council / OEH	H	Drainage works are complete.
FM14	Ponderosa Parade Drainage Upgrade	1.03	5	$874,000	$889,000	Council / OEH	H	Drainage works are complete.
EM1	Local Evacuation Measures	-	6	-	-	Council / SES	H	Local evacuation plan(s) complete.
EM2	Public awareness and education	-	6	-	-	Council / SES	H	Education program is undertaken and documented.
EM5	Flood Warning Systems	-	8			Council / OEH / SES	M	Flood warning system is developed and implemented.
FM11	Tatiara By-pass Overland Flowpath	2.16	9	$679,000	$719,000	Council / OEH	M	Bypass constructed
EM3	School Education Programs	-	10	-	-	Council / SES	M	Education program is undertaken and documented.
EM4	Flood Markers and Signage	-	11	-	-	Council / OEH	L	Signs are installed and maintained.
-	Entrance Management Strategy					Council / OEH	H	Completion of Entrance Management Strategy
-	Data collection	-	-	-	-	Council / OEH / SES	H	Flood data collected during and following a flood event.
	Total cost of implementation (of structural options):			**$3,691,000**	**$8,099,000**			

*Net present worth of cost of implementation, incorporating both capital and maintenance costs over the implementation period of 50 years.

**H = higher priority; M = medium priority; L = lower priority.

6 Conclusions

This report presents the Floodplain Risk Management Plan for Narrabeen Lagoon.

The investigations and consultations undertaken as part of the Floodplain Risk Management Study identified several issues for the floodplain; including but not limited to flash flooding, the role of the ocean entrance condition and elevated ocean water levels. To address these issues, a series of floodplain management measures has been developed.

The assessment of management options in the Floodplain Risk Management Study facilitated the identification of the most beneficial options (in terms of hydraulics, economics, environmental and social issues). A priority list has been recommended in this Floodplain Risk Management Plan that is a mix of structural and non-structural options to reduce the likelihood and / or consequence of flooding at locations in the catchment.

This plan should be regarded as a dynamic instrument requiring review and modification over time. The catalysts for change include new flood events and experiences, legislative change, alterations in the availability of funding and reviews of Council planning policies. In any event, a review every five years or so is warranted to ensure the ongoing relevance of the Plan.

7 Qualifications

This report has been prepared by Cardno for Northern Beaches Council. It should not be used by a third party without proper reference.

The investigation and modelling procedures adopted for this project follow industry standards and considerable care has been applied to the preparation of the results.

Model set-up and calibration depends on the quality of data available, and the flow regime and flow control structures are complicated and can only be represented by schematised model layouts. Hence there will be a level of uncertainty in the results and this should be borne in mind in their application.

The report relies on the accuracy of the survey data provided.

Study results should not be used for purposes other than those for which they were prepared.

8 References

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