Narrabeen Lagoon Floodplain Risk Management Study

59915102

Prepared for
Northern Beaches Council

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Foreword

The NSW Government Flood Prone Land Policy aims to provide solutions to existing flood problems in developed areas and ensure that new development is compatible with the flood hazard and does not contribute to an increase in flood risk.

Under the Policy, the management of flood prone land is the responsibility of Local Government. The State Government supports the implementation of 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 in some circumstances.

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

1. Formation of a Committee

Established by the Local Council and includes representatives of the local community representatives and State agencies.

2. Data Collection

Involves the collection of data such as historical flood levels, rainfall records, land use, soil types etc. to inform our understanding of flood behaviour.

3. Flood Study

Determines the nature and extent of the flood problem in the catchment under consideration.

4. Floodplain Risk Management Study

Identifies and evaluates potential floodplain management measures for both existing and proposed development.

5. Floodplain Risk Management Plan

Identifies the preferred floodplain management measures that will be implemented, and involves formal adoption by Council of the management plan.

6. Implementation of the Plan

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

This Narrabeen Lagoon Floodplain Risk Management Study represents the fourth stage of the NSW Government floodplain management process.

Executive Summary

The Narrabeen Lagoon Floodplain Risk Management Study has been prepared by Cardno on behalf of Northern Beaches Council (Council), formerly known as Pittwater, Warringah and Manly Councils. It builds upon the previous work presented in the Narrabeen Lagoon Flood Study (BMT WBM, 2013).

Catchment Description and Environmental and Social Summary

The Narrabeen Lagoon catchment is located on Sydney's northern beaches. The catchment is around 55 km^2 and drains to the Tasman Sea via the lagoon entrance discharging at North Narrabeen Beach. The catchment encompasses 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). Flooding in the catchment can pose a risk to some residents and other properties located near creeks and around Narrabeen Lagoon.

Narrabeen Lagoon is the largest coastal lagoon located in the Sydney metropolitan region, with a waterway area of 2.2 km^2. It is an Intermittently Closed and Open Lake or Lagoon (ICOLL) with a relatively narrow entrance channel. The entrance channel condition can act as a significance control on flood behaviour in the lower catchment.

This section has provided an overview of the key environmental and social characteristics of the catchment of relevance to the assessment of potential floodplain management options in **Section 11**. The key considerations identified are as follows:

> The catchment topography, geology and soil landscapes (including ASS) can influence the design and construction of any flood modifications options, and therefore the cost of implementation. The need for further investigations to inform the design and construction methodology should be considered at the time of implementation;

> The demographic characteristics are useful for informing the development of emergency response modification measures. The results in **Section 2.2** indicate that education materials and/or evacuation warnings may need to be prepared in languages other than English to ensure they target the community at risk from flooding. Apart from specific locations where there may be concentrations of less mobile people associated with vulnerable developments such as hospitals and child care facilities (refer **Section 5.4.5**), the demographics indicate a community that is above average socio-economic status and relatively young, and therefore likely capable of responding in the event of an emergency evacuation;

> The impacts on listed heritage items (**Section 2.6**) and flora, fauna, ecological communities and estuarine macrophytes (**Section 2.5**) should also be considered with respect to the potential impacts of management options. These impacts should be assessed to inform the design and construction of any options, and should in the first instance be avoided (where possible). This should include assessment of direct and indirect impacts on riparian and intertidal vegetation and wetlands, irrespective of their legal status; and

> There are a range of environmental aspects that can influence the approval pathway and need for additional permits, licences or approvals for implementation of any flood modification options, in particular the biodiversity and heritage listings (**Sections 2.5 and 2.6**). Both the approvals requirements and the need for any associated environmental management measures (including biodiversity offsetting) can impact the cost of a flood modification option, and the timeline for implementation.

Flood Behaviour

During flood events the peak water level in Narrabeen Lagoon is generally similar across the entire waterbody, with very little water level gradient. Accordingly the foreshore inundation can be tied to a representative lagoon water level. 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.

Longer duration (volume driven) events are typically more significant for peak flood levels in the lagoon. The 9 hour, 18 hour and 24 hour rainfall events all result in similar peak flood levels in Narrabeen Lagoon.

While the critical flood levels in Narrabeen Lagoon may be controlled by longer duration rainfall events, flood waters in the upper floodplain 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 can remain elevated for many hours.

In the upper catchment flooding in some areas is confined to the channel with limited overbank flow (e.g. Narrabeen and Mullet Creeks), whereas in other areas overbank and overland flow poses greater concern (e.g. the Warriewood Valley and lower reaches of South creek). 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.

Impact of Flooding

The number of properties considered to be “flood affected” in the Narrabeen Lagoon Catchment ranges from 2,200 for the 20% AEP event, to 3,013 for the 1% AEP event. Of these, 229 and 659 properties for each event respectively, are expected to experience above-floor flooding. Based on a total damage assessment using residential, commercial and industrial damage curves, the average annual damage for the Narrabeen Lagoon floodplain under existing conditions is $11,540,886.

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 relatively short periods of time. A publicly accessible webpage hosted by Manly Hydraulics Laboratory (MHL) is available to inform the public via real-time water level gauge data, advise of flood trigger levels and where flooding may be occurring. Alarms and trigger levels on selected gauges are used to send an SMS to relevant personnel in NSW SES and Councils to prompt response action.

This study has demonstrated that the existing road network for the Narrabeen Lagoon floodplain is not suited for *regional* evacuation of residents in the event of flooding, because most evacuation routes overtop in frequent flood events (less than 50% AEP in most cases). Examples include both the major regional roads: Wakehurst Parkway and Pittwater Road.

The overall time required for evacuation of the Narrabeen Lagoon floodplain was estimated to be a minimum of 5 hours, whereas critical flood levels in parts of the catchment can occur in less than 1 hour. Evacuation is not suitable for some flood affected locations even when considering the 20% AEP instead of the usual PMF. The duration of inundation is generally sub-daily for the majority of the floodplain, however, thus shelter-in-place is a feasible option where flood free refuges are available.

Community Consultation

As part of the community consultation process, an information brochure describing the study and a questionnaire designed to gauge community awareness of flood related issues and request feedback were produced and distributed. Together with a covering letter, these were sent to 3004 flood affected property owners on 24 April 2015, with details of the project website and questionnaire also advertised in the local newspaper on 2 May 2015.

Based on the feedback provided within the completed questionnaires the following key outcomes have been derived.

> There was a high level of understanding within the community that the Narrabeen Catchment is subject to flooding, with 74% indicating concern for flooding in their local area. Some 34% of respondents believed that their own property is flood affected;

> Most respondents (73%) believed that flooding in their area is primarily attributable to riverine flooding or stormwater issues, with few (19%) respondents believing elevated sea levels is the key contributor;

> Most respondents believed that the climate is changing (89%), with the majority of respondents (63%) concerned about the impact that an uncertain climate will have on flooding in Narrabeen Lagoon;

> A majority of respondents (71%) believed that the council should be addressing the impacts of an uncertain climate future;

> Most respondents (80%) were aware of Flood Planning Levels (FPLs). Almost all (92%) agreed that Flood Planning Levels are a necessary method for flood risk management, at least to some extent. Most respondents (78%) also believed that the uncertain future climate should be taken into account, at least to some degree, in FPLs;

> Respondents were mixed with respect to the level of control Council should place on new development to minimise flood-related risks, with 36% believing placing restrictions on development is appropriate (e.g. minimum floor levels and/or the use of flood compatible building materials). Some 23% suggested that Council should advise people of flood risks, and allow individuals to choose how they would reduce flood damage; and

> Most respondents believed that mechanical opening of the lagoon entrance is the most suitable mitigation option for the catchment; with planning controls, drainage upgrades and the existing clearance program the next preferred options.

Flood Risk Management Options

Measures that were considered in this study include flood modification measures, emergency response modification measures and property modification measures.

Flood modification measures are options aimed at preventing, avoiding or reducing the likelihood of flood risks. These measures reduce the risk through modification of the flood behaviour in the catchment. For the Narrabeen Lagoon study area there are regional and local flood modification measures.

> Regional flood modification measures are intended to lower flood levels within the lagoon. While these measures are unlikely to completely remove flood risk at any location, they attempt to alleviate flooding across a large area. Two types of regional measures have been considered:

  o Lagoon entrance management options to remove the flood tide delta and berm, and

  o Upgrade of bridge crossings to alter major flow constrictions;

> Local flood modification measures target specific flood-affected areas and attempt to remove, or significantly reduce, the flood impact. Assessment of these options must consider potential adverse impacts on other parts of the floodplain not targeted by the option. The types of local options considered for Narrabeen Lagoon were:

  o The construction of levee banks to create barriers to flood waters,

  o Drainage upgrades and channel works to improve conveyance and thus lower flood levels in the area, or divert floodwaters away from existing development,

  o Road raising, and often improving flows under roadways, to limit road overtopping which can often divert floodwaters into adjoining properties, and

  o Detention basins to reduce the amount of flood affectation downstream;

The proposed locations of flood modification options are shown in the figure below, and they include 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).

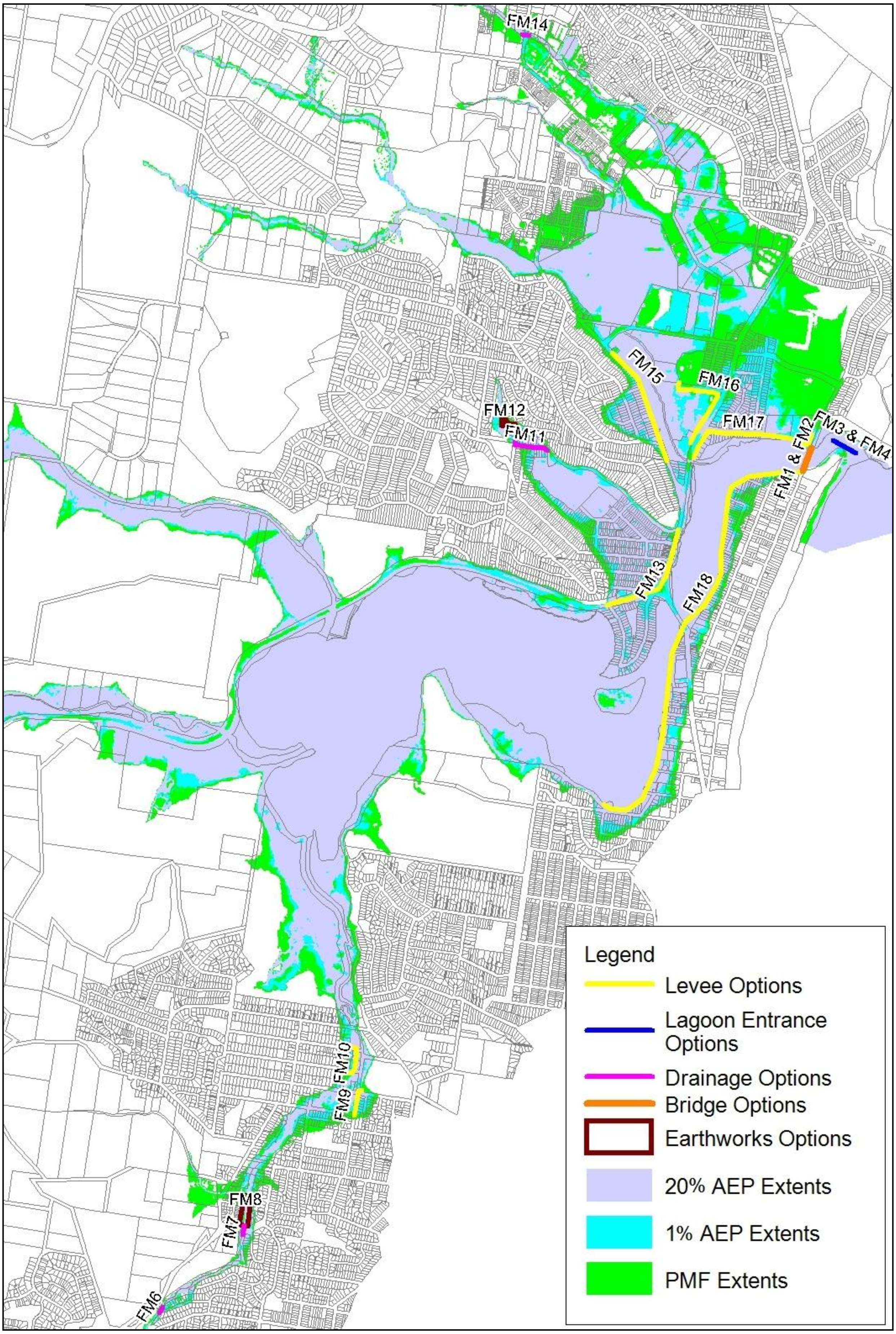
Emergency response modification measures aim to reduce the consequences of flood risks, generally by modifying the behaviour of people during a flood event. Improved emergency response, warning measures and increased community awareness are specific outcomes. The following emergency response options are proposed.

> Local evacuation measures – using detailed procedures to improve emergency response at a local scale for four high risk areas within the floodplain;
> Public awareness and education – a program of flood awareness for the entire LGA is recommended as well as implementing more targeted and detailed education strategies and flood warning systems;
> School education programs – improving the flood awareness of school children by educating them of flood risk in Narrabeen Lagoon;
> Evacuation route mapping and flood warning signs – installing maps and signage at critical locations to assist evacuees and to reduce time required for evacuation; and
> Flood warning systems – using water level gauges to trigger evacuation thus providing more certainty of imminent flooding than rainfall gauges, providing a faster warning time, and improving the time available for evacuation.

Property modification measures are focused on preventing, avoiding and reducing consequences of flood risks. Rather than modifying the flood behaviour, these measures aim to modify properties so that there is a reduction in flood risk. A review of significant property modification measures including Voluntary House Raising and Voluntary Purchase found that these modification options were not feasible for the Narrabeen Lagoon catchment for the following reasons:

> Few properties in the catchment met the flood risk and hazard criteria for consideration under these schemes, as set-out by the OEH;
> The properties that were eligible were either commercial land use or multi-unit residential apartments, thus house raising and voluntary purchase were not cost-effective or feasible; and
> The high median house price meant that any voluntary purchase or land swap was unlikely to be cost effective.

While these conventional property modification measures were found to be not feasible, property modification in the form of development controls can be an effective way of reducing flood risk.


FM14
FM15
FM16
FM17
FM12
FM11
FM1 & FM2
FM3 & FM4
FM13
FM18
FM10
FM9
FM8
FM7
FM6
Legend
Levee Options
Lagoon Entrance Options
Drainage Options
Bridge Options
Earthworks Options
20% AEP Extents
1% AEP Extents
PMF Extents

Outcomes and Recommendations

A Multi-Criteria Assessment (MCA) was used to investigate the performance of both structural and non-structural options based on a range of social, environmental, and economic factors. The MCA scores for the emergency management and flood modification options have been combined to produce a ranking of options and an implementation preference list (see table below).

The highest ranked option is Option FM4 representing the current practice for Narrabeen Lagoon entrance management of mechanical dredging of the shoals upstream and downstream of Ocean Street. In terms of economic performance this option was one of the best two options, with the other being the alternative dredging approach of constructing a permanent pipeline for placement of dredged material (Option FM4a). While the economic benefits were slightly higher for the Option FM4a alternative, the social and economic scores for the current approach were far higher and the environmental impacts were well understood. Comparatively, the alternative dredging approach scored worse in the social and environmental criteria resulting in an overall ranking of 18th.

The four options ranked 2nd to 5th highest are all small scale structural works proposed within the lagoon tributaries in the upper catchment to protect residential properties in the local area up to the 1% AEP design event. These options are:

> FM9 - Waroon Road Levee (South Creek);
> FM10 – Wabash Avenue Levee (South Creek);
> FM6 – Alkira Circuit Drainage Upgrade (Narrabeen Creek); and
> FM14 - Ponderosa Parade Drainage Upgrade (South Creek).

These options all have reasonably good economic performance; as the scope of works involved is relatively minor, the cost of implementation is low, and the reduction in flood damages up to the 1% AEP is significant. These options are expected to have good community support due to their low cost and the tangible benefits they provide to the community in the local area. The relatively minor scope of works means that limited social disruption is anticipated and the expected environmental impacts are expected to be minor.

The five emergency management options all score well, with all five ranking between 6th and 11th based on the outcomes of the MCA. Though these options produce negligible reductions in flood damages and therefore tangible economic benefits, these options score well due to significant reduction in risk to life, low costs, ease of implementation, and strong community support.

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

Option No.	Description	Total Score	Overall Rank	Rank (Structural / Non Structural)
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
FM18	East Bank Levee	0.27	21	S-15
FM3	Entrance Bed Rock Removal	-0.20	23	S-17

The preparation of an Entrance Management Strategy, which was not scored through the MCA process is considered a strategic priority. The dynamics and management of Narrabeen Lagoon entrance is complex and a study which investigates the coastal and flood processes at the entrance and investigates long-term management options under current and future climatic conditions will enable a best-practice approach.

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. The 20% AEP event roughly equates to a 1 in 5 year recurrence.
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. ASSs 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.
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	Disaster Plan (which are now mostly superseded by equivalent EMPLAN's).
EMPLAN	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	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.
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

Table of Contents

Tables

Figures

Appendices

1 Introduction

Cardno (NSW/ACT) Pty Ltd ('Cardno') was commissioned by Northern Beaches Council (formerly Pittwater, Warringah and Manly Councils) to prepare a Floodplain Risk Management Study and Plan for the Narrabeen Lagoon catchment (**Figure 1-1**). This Floodplain Risk Management Study (FRMS) represents the first phase of the project. It describes the existing flood behaviour and associated hazards, and investigates the range of possible flood risk management options for reducing the impact of flooding on infrastructure risk to life. As well as considering existing flood risk, the FRMS has considered future flood risk through the assessment of potential impacts of changes in rainfall and mean sea level rise on flood behaviour.

The Narrabeen Lagoon Flood Study, prepared in 2013 by BMT WBM for the former Warringah Council and Pittwater Council, to define the 'mainstream' flood behaviour in the catchment, and is the key input to this FRMS in terms of data on flood behaviour. The Flood Study (BMT WBM, 2013) was adopted by both Councils prior to their merger with Manly Council in 2016 to form Northern Beaches Council.

As part of this FRMS several options to manage flood risk in the Narrabeen Lagoon catchment have been identified and examined. in accordance with the NSW Floodplain Development Manual: The Management of Flood Liable Land (NSW Government, 2005).

This study has been prepared with the assistance of the NSW Office of Environment and Heritage (OEH).

1.1 Study Context

In the past flooding in the Narrabeen Lagoon catchment has caused property damage, restricted property access, and triggered evacuations, impacting a broad section of the local community. These flooding issues have prompted Northern Beaches Council to review its approach to floodplain risk management in the Narrabeen Lagoon catchment and prepare a new, integrated Floodplain Risk Management Study and Plan for the Narrabeen Lagoon floodplain. The Floodplain Risk Management Study and Plan will update the existing Floodplain Risk Management Study (prepared in 1992) and Floodplain Risk Management Plan prepared in 2002 in accordance with the requirements of the NSW Government (2005) Floodplain Development Manual.

The preparation of this FRMS follows on from the Narrabeen Lagoon Flood Study (WBM BMT, 2013) and forms the fourth 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.

This report summarises the outcomes of the FRMS. The second component of this project, the Floodplain Risk Management Plan (FRMP), will be prepared based on the outcomes of this FRMS.

1.2 Report Structure

The structure of this report is outlined below:

> Description of the key features of the catchment and floodplain (**Section 2**);

> Details of the data used to inform the study and how it was obtained (**Section 3**);

> A review of the community consultation process and outcomes (**Section 4**);

> An overview of the existing flood behaviour and issues (**Section 5**);

> An assessment of the existing and future economic impact of flooding (i.e. flood damages) (**Section 6**);

> A review of the existing emergency response arrangements (**Section 7**)

> A review of the current policies and plans relevant to flooding including a review of the flood planning levels for development (**Section 8**);

> An assessment of the future flood risk , including the potential impacts of future development in the catchment on flood behaviour (**Section 9**);

> A review of the current lagoon entrance management processes (**Section 10**);

> An assessment of the potential flood management options suitable for managing flood risk in various parts of the Narrabeen Lagoon floodplain (**Section 11**);

> Economic assessment of flood management options based on their anticipated costs and benefits (**Section 12**);

> A triple bottom line evaluation of management options to identify the preferred management options (**Section 13**);

> Conclusions and recommendations of the FRMS for the next stage in the floodplain management process, the FRMP (**Section 14**); and

> References (**Section 15**).

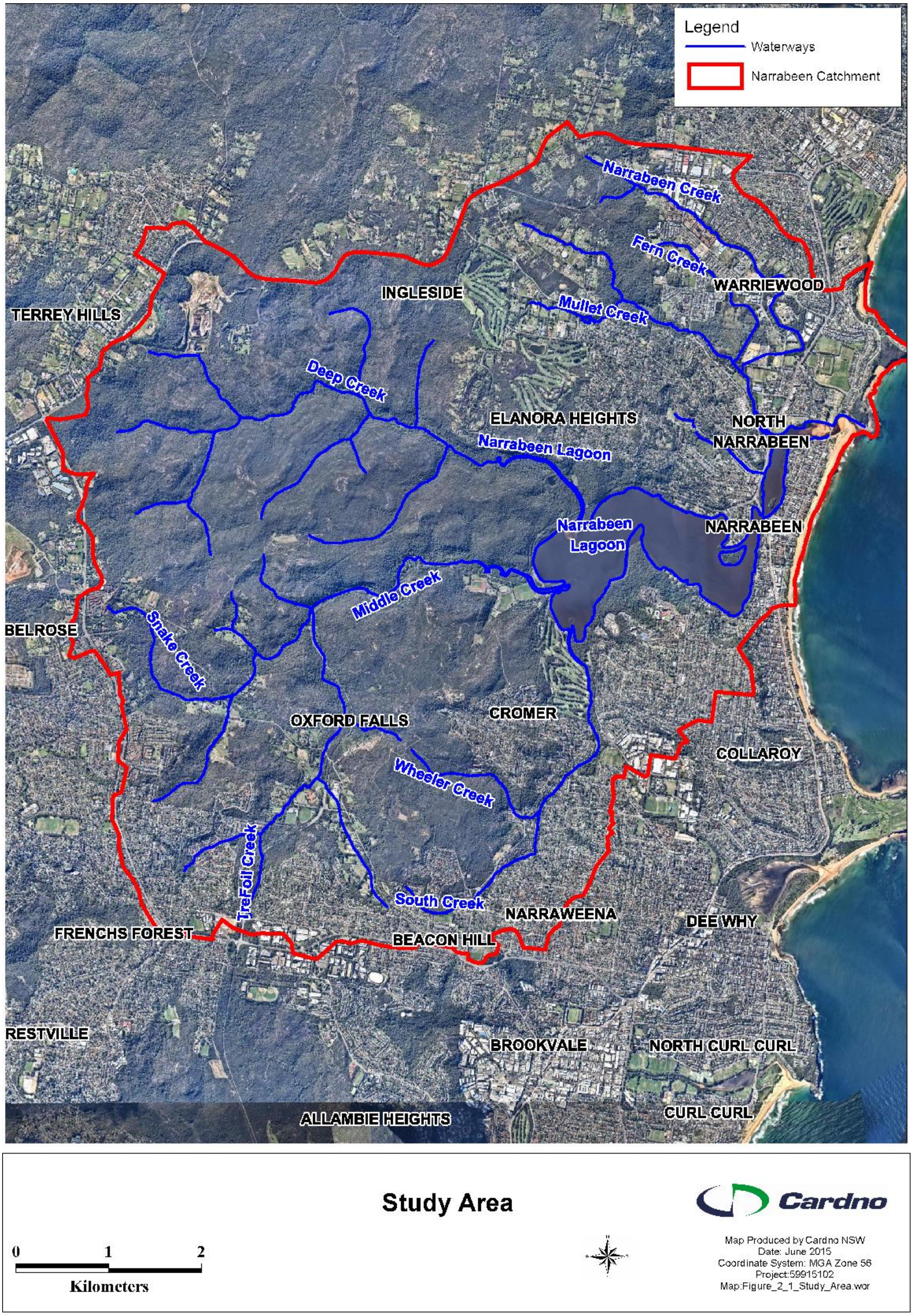


Figure 1-1 Narrabeen Lagoon Study Area

2 Catchment Description

The physical, environmental and social characteristics of the study area may influence the type and location of flood management options considered in the FRMS. Environmental characteristics such as topography, soils, environmentally sensitive areas, and threatened species and ecological communities can influence the engineering feasibility, cost and/or planning approvals pathway for different flood modification options. Social characteristics such as housing and demographics may influence the community's response to flooding and therefore affect the type of emergency response modifications options proposed, for example.

The following physical, environmental and social characteristics have been considered in this overview of the catchment characteristics:

> Catchment topography;
> Land use;
> Demographic characteristics;
> Geology and soils;
> Flora and fauna; and
> Aboriginal and non-Aboriginal cultural heritage.

It is noted that the information presented in this section of the FRMS has been collated for purposes of preliminary identified of potential constraints to inform the options assessment and was current at the time the report was prepared (or as otherwise indicated in the text). It is assumed that the relevant data would be updated as required in the event that any of the floodplain management options in this FRMS are adopted and implemented. This is particularly relevant for aspects such as threatened species / communities listings (refer **Section 2.5**) and heritage listings (refer **Section 2.6**), which are regularly updated.

2.1 Catchment Topography

The Narrabeen Lagoon catchment is located on the northern boundary of the former Warringah local government area (LGA) and the south-eastern boundary of the former Pittwater LGA on Sydney's northern beaches (**Figure 1-1**). The catchment is around 55 km^2 and drains to the Tasman Sea via the lagoon entrance, discharging at North Narrabeen Beach through a narrow lagoon entrance channel at North Narrabeen Beach. The catchment encompasses 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). Narrabeen Lagoon is the largest coastal lagoon located in the Sydney metropolitan region, with a waterway area of 2.2 km^2.

Details of the major sub-catchments within the wider Narrabeen Lagoon catchment are presented in **Table 2-1**.

Table 2-1 Sub-Catchment Details (Source: PWD, 1990)

Sub-Catchment	Creek Length (km)	Area (km^2)	% Total Area
Warriewood Valley (Mullet, Fern & Narrabeen Creeks)	5.76	9.7	18%
Deep Creek	7.34	15.6	29%
Middle Creek	8.12	14.2	26%
South Creek	4.96	7.9	14%
Nareen Creek	2.52	1.6	3%
Narrabeen Lagoon	N/A	2.2	4%
Other Areas (Local Catchments / Lagoon Foreshore)	N/A	3.6	6%
Total		**54.8**	

The topography of the catchment is shown in Figure 2-1. Elevations reach approximately 200 m AHD in the north-west of the catchment around Terrey Hills, and 150 m AHD in the south and south-west of the catchment around Belrose and Frenchs Forest. The topography of the catchment is undulating, and grades relatively steeply from these upper slopes down to the floodplain areas around Narrabeen Lagoon and Warriewood Valley. Areas of minor to moderate slopes occur around the fringes of Narrabeen Lagoon, Warriewood Valley and Oxford Falls in the central area of the catchment, and in the Middle Creek sub-catchment.

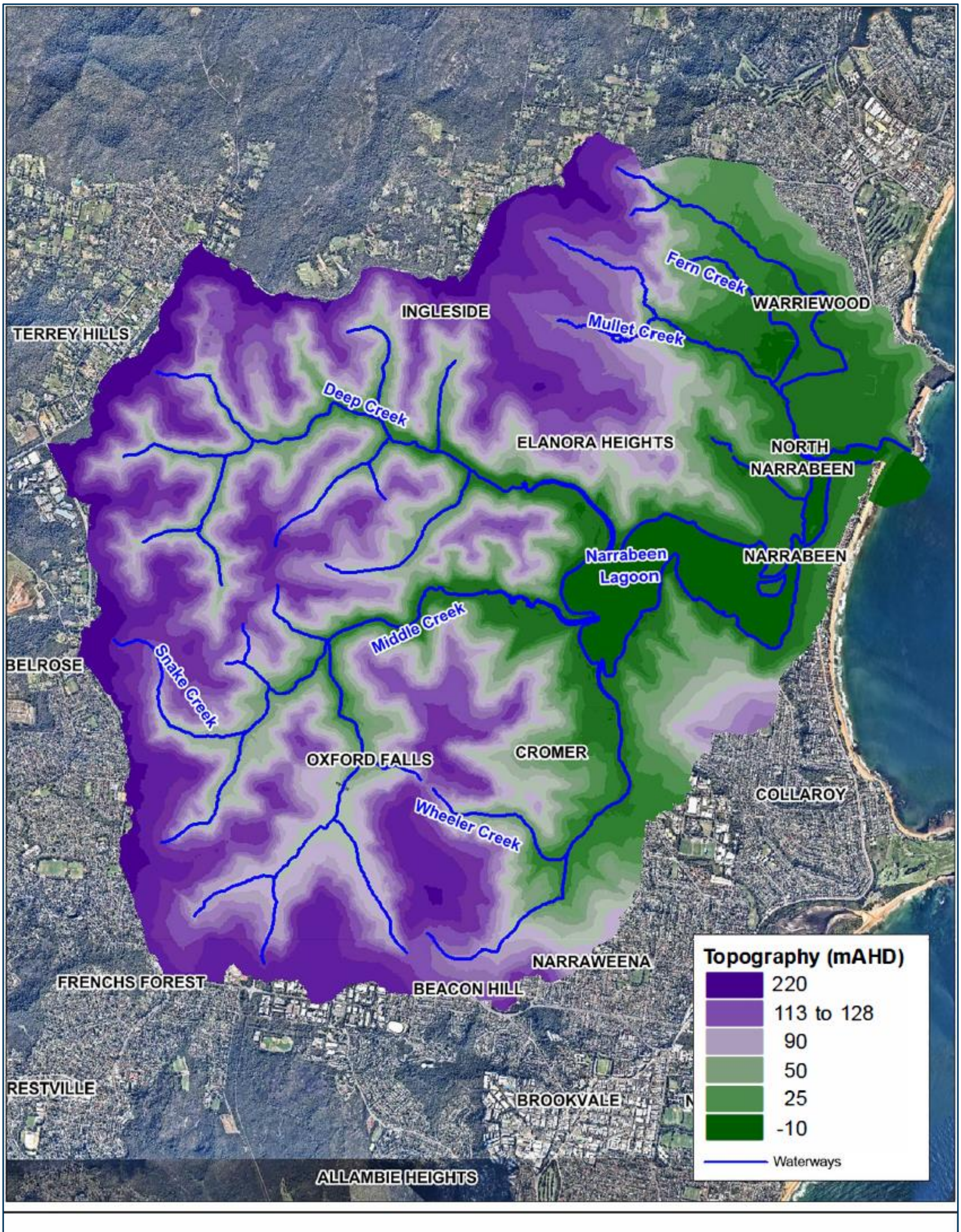


Figure 2-1 Narrabeen Lagoon Catchment Topography

2.2 Demographic Characteristics

Knowledge of the demographic characteristics of residents living in the catchment assists with preparing and evaluating emergency response modification options that are appropriate for the local community. For example, flood evacuation information may need to be presented in a range of languages and special arrangements may need to be made for less mobile members of the community.

The demographic characteristics of the Narrabeen Lagoon catchment considered in this study include the following suburbs:

- Beacon Hill;
- Belrose;
- Collaroy;
- Cromer;
- Elanora Heights;
- Frenchs Forest;
- Ingleside;
- Narrabeen;
- Narraweena;
- North Narrabeen;
- Oxford Falls;
- Terrey Hills; and
- Warriewood.

Population data was sourced primarily from the Australian Bureau of Statistics (ABS) 2011 Census and aggregated to produce an overall synopsis for the catchment. The demographic data is summarised below (ABS, 2011):

- The median age of people living in the Narrabeen Lagoon catchment was 40, with 72% of the population aged below 55 years. This indicates a community that may be able to evacuate effectively and/or assist with evacuation procedures;
- In the Narrabeen Lagoon catchment 84.8% of people were born in Australia. The most common countries of birth outside of Australia were England, New Zealand, South Africa, Italy and China;
- English was the only language spoken in around 85% of homes. The most common languages spoken at home other than English were Italian, Mandarin, Armenian, Cantonese, German and Serbian. There may therefore be a requirement for flooding information to be prepared in languages other than English;
- The average median weekly income for individuals in the region was $688, compared to the NSW average of $561. This trend of above average income for the region compared to the NSW average was also evident for family ($2,000 compared to $1,477 for NSW) and household incomes ($1,720 compared to $1,237 for NSW). This may have implications for the economic damages incurred on property contents during a flood event; and
- In the catchment, the average median house price was $1,198,900, and the unit price was $605,000 (Property Data, 2015). In NSW, the median house price was $566,000 and unit price was $585,000 (Australian Property Monitors, 2015). This information has implications for the economic damages incurred during a flood event.

2.3 Land Use

The catchment contains a mixture of land uses including urban (residential, commercial and industrial), recreational and bushland (including Garigal National Park). The 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 also 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.

To the west of the lagoon the catchment 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).

A detailed breakdown of land use zonings for the catchment is included in **Section 8.1**.

2.4 Geology and Soils

2.4.1 Geology

When developing floodplain management options it is important to understand the geology of the catchment to ensure appropriate consideration of geotechnical constraints on flood modification options, such as the need for suitable foundations, which can have cost implications.

The geology of the Narrabeen Lagoon catchment is summarised below:

> The Narrabeen Lagoon catchment is situated on lithologies of the Hawkesbury Group and Narrabeen Group, and alluvium, with a small area near Frenchs Forest situated on lithologies of the Wianamatta Group;

> In the catchment the Hawkesbury Group consists mostly of sandstone that was laid down in the Middle Triassic period between 180 and 220 million years ago (Herbert and Helby, 1980). The Hawkesbury Sandstone consists of massive and cross-bedded units with minor siltstone and mudstone beds;

> The Narrabeen Group was laid down in the Late Permian to Middle Triassic period and consists of quartz-lithic to quartzose sandstone, conglomerate, mudstone, siltstone and coal;

> Channel and floodplain alluvium consists of gravel, sand, silt and clay; and

> The Wianamatta Group was laid down in the Triassic Period and consists of sandstone, siltstone and shale.

Geological constraints on floodplain management depend on the management options selected, but no significant constraints to the options proposed in this FRMS have been identified. This does not preclude the need for site specific investigations for any management options progressed by Council as actions in the FRMP.

2.4.2 Soils

According to the Soil Landscape Map of Sydney (Scale 1:100,000), the Narrabeen Lagoon catchment is situated on the Blacktown, Deep Creek, Disturbed Terrain, Erina, Gymea, Hawkesbury, Hornsby, Lambert, Lucas Heights, Narrabeen, Newport, Oxford Falls, Somersby, Tuggerah, Warriewood and Watagan landscape groups (refer **Figure 2-2**). A description of each landscape group is listed in **Table 2-2**. The majority of soils found in the study area have a high soil erosion hazard, which can exacerbate flooding. Any flood modification works should consider the impacts from the numerous soil landscapes.

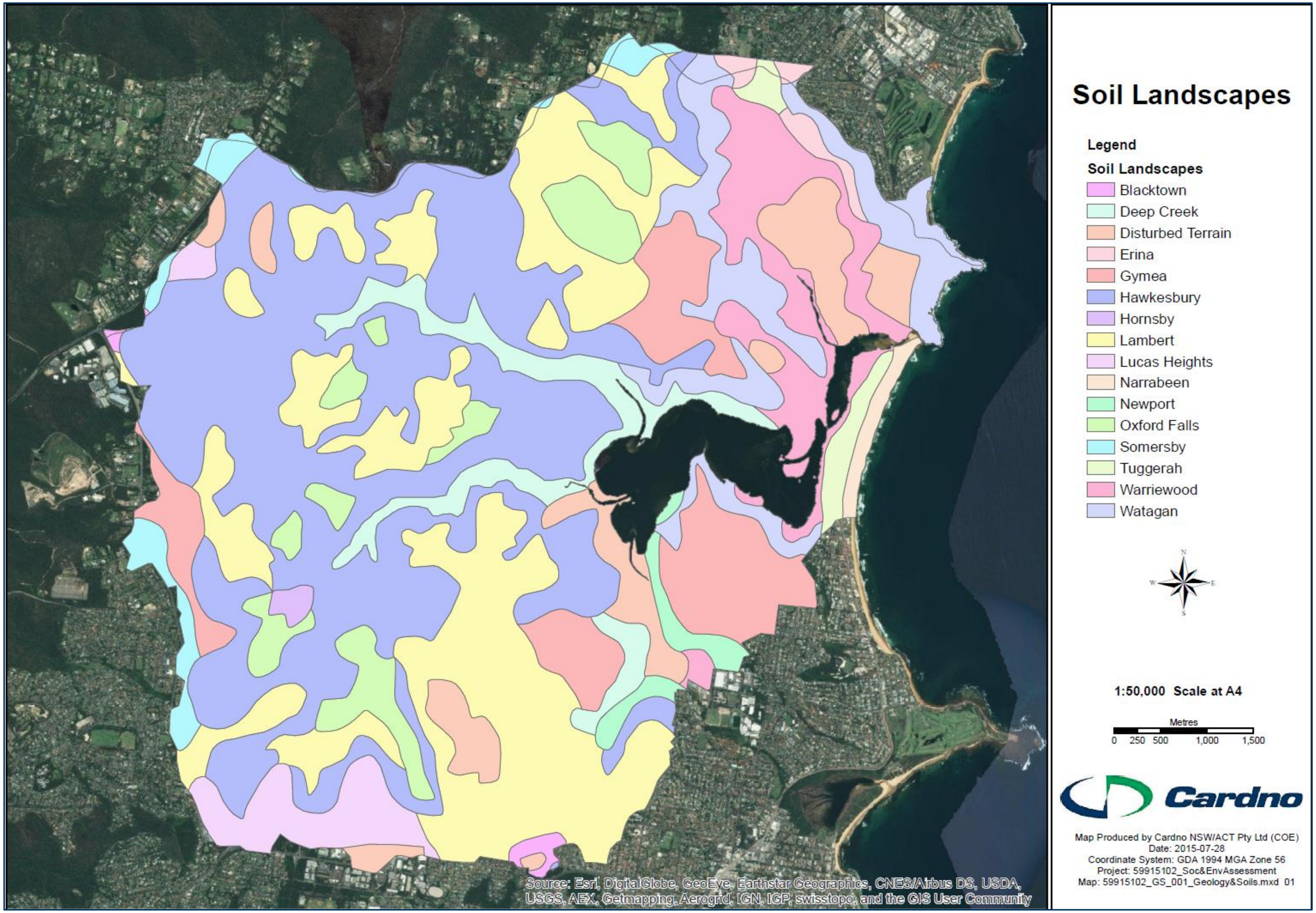


Figure 2-2 Soil Landscapes

Table 2-2 Soil Landscapes in the Narrabeen Lagoon Catchment

Soil Landscape Group	Description
Blacktown	Gently undulating rises. Broad rounded crests and ridges with gently inclined slopes. The limitations of this soil landscape group are the moderately reactive highly plastic subsoil and poor soil drainage.
Deep Creek	Level to gently undulating alluvial floodplain. The limitations of this soil are flooding, extreme soil erosion hazard, sedimentation hazard and permanently high water tables.
Erina	Undulating to rolling rises and low hills. Rounded narrow crests with moderately inclined slopes. The limitations of this soil landscape group are the very high soil erosion hazard, localised run-on and seasonal waterlogging.
Gymea	Soils of the Gymea Group are derived from Hawkesbury Sandstone and consist of medium-to coarse-grained quartz sandstone with minor shale and laminate lenses. The limitations of this soil landscape group are the high soil erosion hazard and very low soil fertility.
Hawkesbury	Rugged, rolling to very steep hills. Narrow crests and ridges, narrow incised valleys, steep side slopes with rocky benches, broken scarps and boulders. Limitations include extreme erosion hazard, mass movement, steep slopes and highly permeable soil.
Hornsby	Gently undulating rises to steep low hills on deeply weathered basaltic breccia. Limitations of this soil are low wet-strength, highly reactive subsoil, occasional steep slopes with an extreme erosion hazard and localized mass movement hazard.
Lambert	Undulating to rolling low hills. Broad ridges, gently to moderately inclined slopes, wide rock benches with low broken scarps, small hanging valleys and areas of poor drainage. Limitations of this soil include very high erosion hazard, seasonally perched water tables, and shallow highly permeable soil.
Lucas Heights	Gently undulating crests and ridges on plateau surfaces. Limitations of this landscape include low available water capacity.
Narrabeen	Narrabeen soils occur on exposed mainland and barrier beaches, with relief and elevation of less than 6 m, and slopes of less than 3%. The topography is subject to continuous change as a result of varying wave energy and tidal dynamics. Soils are typically deep (>200 mm), non-cohesive and subject to extreme wind and wave erosion (Chapman and Murphy, 1989).
Newport	The Newport landscape group is characterised by gently undulating plains to rolling rises of Holocene sands mantling other soil materials or bedrock. The limitations of this soil landscape group include a very high soil erosion hazard, localised steep slopes, very low soil fertility and non-cohesive topsoil.
Oxford Falls	Hanging valleys with occasional broad benches and broken scarps, valley floors are relatively wide, gently inclined and often poorly drained. Limitations include very high soil erosion hazard, perched water tables and swamps, highly permeable soil and localized rock outcrop.
Somersby	Gently undulating to rolling rises on deeply weathered Hawkesbury Sandstone plateau. Limitations of this landscape include localized permanently high water tables and highly permeable soil.
Tuggerah	Gently undulating to rolling coastal dune fields. North-south oriented dunes with convex narrow crests, moderately inclined slopes and broad gently inclined concave swales. Limitations of this landscape include extreme wind erosion hazard, highly permeable soil, localized flooding and permanently high water tables.
Warriewood	The Warriewood soil landscape is typically found in swales and infilled coastal lagoons on Quaternary sands. These soils are deep and are prone to localised flooding and run-off, have high water tables and are highly permeable (Chapman and Murphy, 1989).
Watagan	Rolling to very steep hills on fine-grained Narrabeen Group sediments. Limitations of this landscape include mass movement hazard, steep slopes and severe soil erosion hazard.

2.4.3 Acid Sulfate Soils

Acid Sulfate Soils (ASS) occur when soils containing iron sulfides are exposed to air and the sulfides oxidise producing sulfuric acid. This usually occurs when soils are disturbed through excavation. The production of sulfuric acid can result in numerous issues such as fish kills and damage to infrastructure. It is therefore important to be aware of the distribution of ASS so that potential management options are developed and assessed in a manner that is sensitive to the level of risk presented by any identified ASS (potential and actual ASS). OEH has identified five different classes of ASS, with Class 1 being greatest risk of ASS and Class 5 being lowest risk. The location of ASS classes for the catchment is shown in **Figure 2-3**.

Narrabeen Lagoon and its foreshores have a high probability of ASS (significant environmental risk if ASS materials are disturbed by activities such as shallow drainage, excavation or clearing). There are resultant threats to the surrounding environment (e.g. the release of acid and/or the mobilisation of heavy metals) if high risk materials are disturbed. Soil investigations would be necessary should any flood modification options be proposed in the vicinity of the Lagoon.

2.4.4 Contaminated Land and Licensed Discharges

Contaminated land refers to any land which contains a substance at such concentrations that it poses a risk of harm to human or environmental health, as defined in the *Contaminated Land Management Act 1997*. The Environment Protection Authority (EPA) regulates contaminated land and maintains a record of written notices in relation to the investigation or remediation of site contamination. A search of the Contaminated Land Record on 23 July 2015 identified the Narrabeen Shotgun Range at the Sydney Academy of Sport on Wakehurst Parkway as a contaminated site. Flood modification works in this area should consider the impacts that may be caused due to this contaminated site, and further detailed investigation may be necessary.

A search of the public register under Section 308 of the *Protection of the Environment Operations Act 1997* (POEO Act) on 23 July 2015 identified four premises within the catchment licensed by the EPA (**Table 2-3**). Flood modification works within the catchment should consider the impacts that may arise from any potential discharges from these licensed premises.

Table 2-3 POEO Act Premises Licensed by the EPA

Location Name	Address	Licensed Activity
Warriewood Sewage Treatment Plant	Warriewood Road, Warriewood	▪ Sewage treatment processing by small plants
Prysmian Telecom Cables & Systems Australia Pty Ltd	1 Thew Parade, Cromer	▪ Metal waste generation
Numeve Pty Ltd	100 Meatworks Avenue, Oxford Falls	▪ Recovery of general waste ▪ Waste storage - other types of waste
Kimbriki Resource Recovery Centre	Kimbriki Road, Terrey Hills	▪ Composting ▪ Recovery of general waste ▪ Waste storage - other types of waste ▪ Land-based extractive activity ▪ Waste disposal by application to land

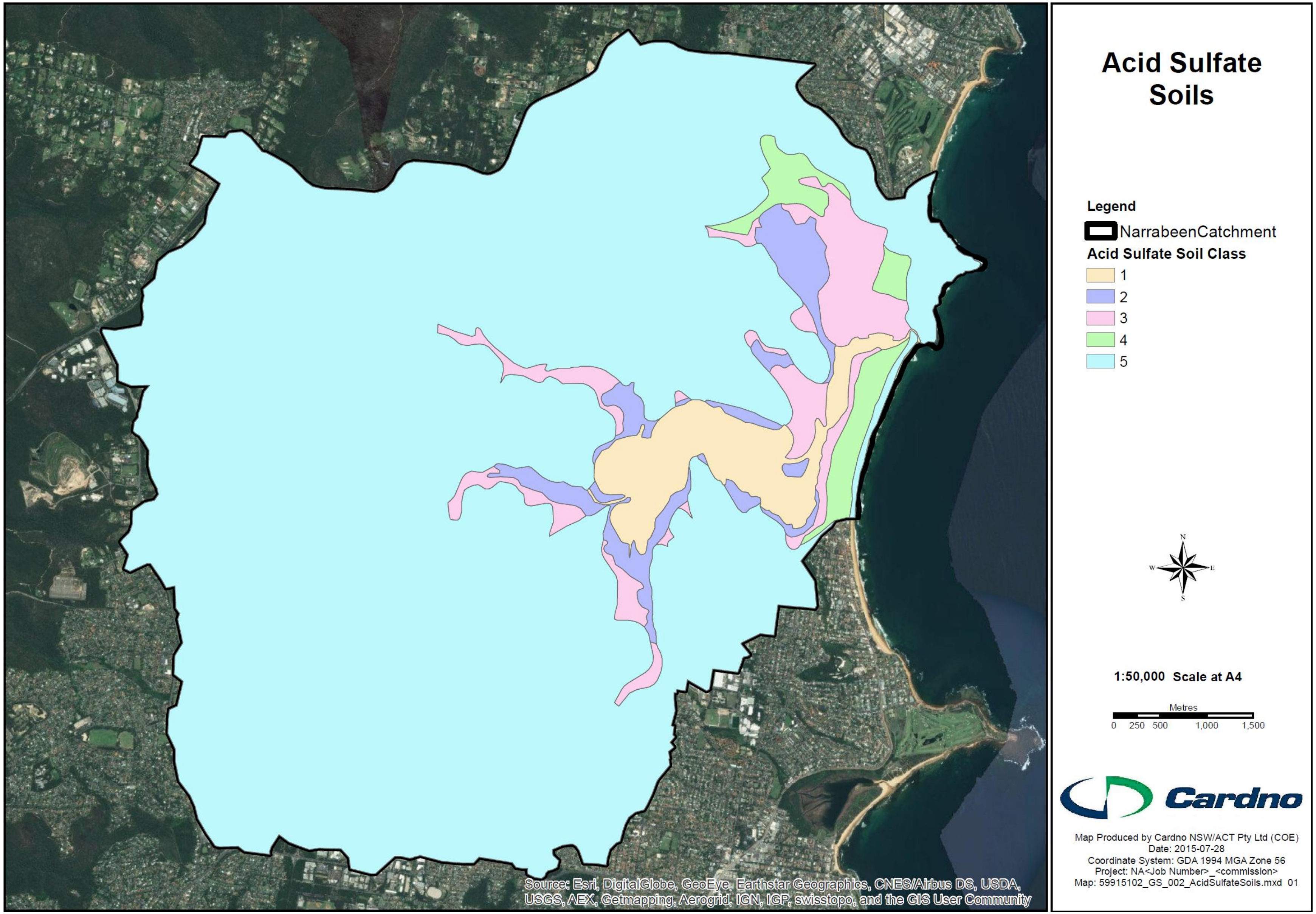


Figure 2-3 Acid Sulfate Soil Risk (After: OEH, 2013)

2.5 Biodiversity

There is a range of legislation of relevance to the protection and conservation of terrestrial and aquatic fauna, including the:

> NSW *Biodiversity Conservation Act 2016* (BC Act), which identifies threatened species, populations and ecological communities listed at the State level;

> Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which provides protection for Matters of National Environmental Significance, including threatened species, populations and ecological communities; and

> NSW *Fisheries Management Act 1994* (FM Act), which identifies threatened aquatic species and populations, and provides protection for aquatic habitat and vegetation. The FM Act also provides protection for marine vegetation including mangroves and seagrasses.

Where flood management options are proposed that have potential to impact on species, populations, communities and other areas protected under these legislation, this would influence the approvals pathway for any such options. Additional permits or licences may be required for the works, and there may be additional costs associated with biodiversity offsetting of any identified impacts.

2.5.1 Threatened Flora and Fauna

A search of the NSW BioNet database conducted on 18 September 2018 for threatened species listed under the BC Act adopting a 10 km^2 search area surrounding the catchment showed historical records of 68 species of fauna and 23 flora species. **Figure 2-4** shows the distribution of threatened species records from the BioNet database.

The BioNet database search also included records of aquatic threatened species protected under the BC Act including the Green Turtle (*Chelonia mydas*) and Humpback Whale (*Megaptera novaeagnliae*), although these species are unlikely to occur in the lagoon. In total, 28 species of fish (including species of syngnathids), five species of marine mammal and five species of marine turtle were considered either known or likely to occur in the study area. This includes several species of protected sygnathiformes, including the Slender Seamoth (*Pegasus volitans*) and the Hairy Pipefish (*Urocampus carinorostris*), both of which have confirmed records for the study area.

There may be potential for the Australian Grayling (*Protoctroctes maraena*), threatened species under the FM Act, to occur. However, no threatened species have been confirmed from the lagoon.

A search was also undertaken using the EPBC Act Protected Matters Search Tool within a 10 km^2 search area surrounding the catchment, which included:

> Nine threatened ecological communities:
  - Castlereagh Scribbly Gum and Agnes Banks Woodlands of the Sydney Basin Bioregion,
  - Coastal Swamp Oak (*Casuarina glauca*) Forest of New South Wales and South East Queensland,
  - Coastal Upland Swamps in the Sydney Basin Bioregion,
  - Cooks River/Castlereagh Ironbark Forest of the Sydney Basin Bioregion,
  - Littoral Rainforest and Coastal Vine Thickets of Eastern Australia,
  - *Posidonia australis* seagrass meadows of the Manning-Hawkesbury ecoregion,
  - Shale Sandstone Transition Forest of the Sydney Basin Bioregion,
  - Western Sydney Dry Rainforest and Moist Woodland on Shale,
  - Subtropical and Temperate Coastal Saltmarsh;

> 91 threatened species; and

> 57 migratory species.

Several threatened species have been recorded within the immediate catchment area including the following threatened bat species:

> Eastern Bent-wing Bat (Miniopterus schreibersii oceanensis);
> Little Bent-wing Bat (*Miniopterus australis*);
> Southern Myotis (*Myotis macropus*);
> Grey-headed Flying-fox (*Pteropus poliocephalus*);
> Eastern Freetail-bat (*Mormopterus norfolkensis*);
> Large-eared Pied Bat (*Chalinolobus dwyeri*);
> Little Bentwing-bat (*Miniopterus australis*);
> Eastern Bentwing-bat (*Miniopterus schreibersii oceanensis*);
> Southern Myotis (*Myotis macropus*); and
> Greater Broad-nosed Bat (*Scoteanax rueppellii*).

Threatened bat species may utilise culverts as roosting habitat. Some species, such as the Osprey (*Pandion haliaetus*), which is a threatened species known listed under both the BC Act and EPBC Act, are known to use the lagoon as foraging habitat. Any proposed flood modification measures or flood protection works should consider the potential impacts on roosting bat species, or the habitat of any other of the identified threatened species that could be affected.

2.5.2 Vegetation

Based on vegetation mapping of the Sydney metropolitan area (The Native Vegetation of the Sydney Metropolitan Area. Volume 1: Technical Report) 35 plant communities have been mapped as occurring within the Narrabeen Lagoon catchment. These plant communities and corresponding endangered ecological communities are listed in **Table 2-4** with the location of the communities shown in **Figure 2-4**. Of these vegetation communities, 11 are identified as Endangered Ecological Communities as listed under the BC Act.

Estuarine macrophyte mapping prepared by the NSW Department of Primary Industries (DPI) – Fisheries in 2009 (Creese *et al.,* 2009) shows:

> Small areas of coastal saltmarsh growing around the lagoon, in particular in Elanora Heights Reserve and Pipeclay Point Park;
> Some very small areas of mangroves;
> Large areas of mixed *Zostera* and *Halophila* seagrass beds in the central basin and near Pipeclay Point Park;
> Large beds of *Halophila* seagrass in the western basin near the northern and southern shorelines;
> Beds of *Zostera* seagrass throughout the lagoon, including small beds in the western basin, large beds in the central basin, and medium sized beds in the eastern basin.

Riparian and intertidal vegetation (including the coastal saltmarsh discussed above) perform an important function as habitat for a range of species and in ecological functions, such as bank stabilisation and mediating the impact of runoff on the catchment waterways. Irrespective of its legal status (i.e. whether the subject vegetation is afforded protection or otherwise regulated under the BC Act, FM Act, *Water Management Act 2000* or other legislation) it is preferably to avoid indirect or direct impacts on riparian and intertidal vegetation. This is relevant to a range of flood management options, including entrance opening (refer **Section 10**), which changes estuarine water levels and can therefore alter patterns of inundation of intertidal vegetation and wetlands.

Table 2-4 Plant Communities of the Narrabeen Lagoon Catchment

Plant Communities	Corresponding Endangered Ecological Communities
Coastal Enriched Sandstone Dry Forest	
Coastal Sandstone Foreshores Forest	
Coastal Sandstone Riparian Forest	
Coastal Sandstone Gully Forest	
Sydney North Exposed Sandstone Woodland	
Sydney Ironstone Bloodwood-Silvertop Ash Forest	Duffys Forest Ecological Community
Coastal Sand Bangalay Forest	Bangalay Sand Forest
Coastal Alluvial Bangalay Forest	River Flat Eucalypt Forest
Coastal Flats Swamp Mahogany Forest	Swamp Sclerophyll Forest on Coastal Floodplains
Coastal Freshwater Swamp Forest	
Riverflat Paperbark Swamp Forest	Swamp Sclerophyll Forest on Coastal Floodplains
Estuarine Swamp Oak Forest	Swamp Oak Floodplain Forest (also listed under the EPBC Act as Coastal Swamp Oak (*Casuarina glauca*) Forest of New South Wales and South East Queensland ecological community)
Coastal Swamp Paperbark-Swamp Oak Scrub	Swamp Oak Floodplain Forest (also listed under the EPBC Act as Coastal Swamp Oak (*Casuarina glauca*) Forest of New South Wales and South East Queensland ecological community)
Sandstone Cliff-face Soak	
Coastal Upland Damp Heath Swamp	Coastal Upland Swamp
Coastal Upland Wet Heath Swamp	Coastal Upland Swamp
Coastal Freshwater Wetland	Freshwater Wetlands on Coastal Floodplains Sydney Freshwater Wetlands
Estuarine Reedland	Swamp Oak Floodplain Forest (depending on floristic composition, may correspond to Coastal Swamp Oak (*Casuarina glauca*) Forest of New South Wales and South East Queensland as listed under the EPBC Act)
Beach Spinifex Grassland	
Coastal Headland Grassland	Themeda Grassland on Sea cliffs and Headlands
Coastal Headland Clay Heath	
Coastal Sand Tea-tree-Banksia Scrub	
Coastal Foredune Wattle Scrub	
Coastal Sandstone Heath-Mallee	
Coastal Sandstone Rock Plate Heath	
Coastal Sandstone Gallery Rainforest	
Coastal Warm Temperate Rainforest	
Coastal Escarpment Littoral Rainforest	Littoral Rainforest (may correspond to Littoral Rainforest and Coastal Vine Thickets listed under the EPBC Act)
Estuarine Saltmarsh	Coastal Saltmarsh (may correspond to Subtropical and Temperate Coastal Saltmarsh listed under the EPBC Act)
Seagrass Meadows	
Coastal Enriched Sandstone Moist Forest	
Coastal Shale-Sandstone Forest	
Central Coast Escarpment Moist Forest	
Central Coast Escarpment Dry Forest	

Plant Communities	Corresponding Endangered Ecological Communities
Coastal Flats Tall Moist Forest	

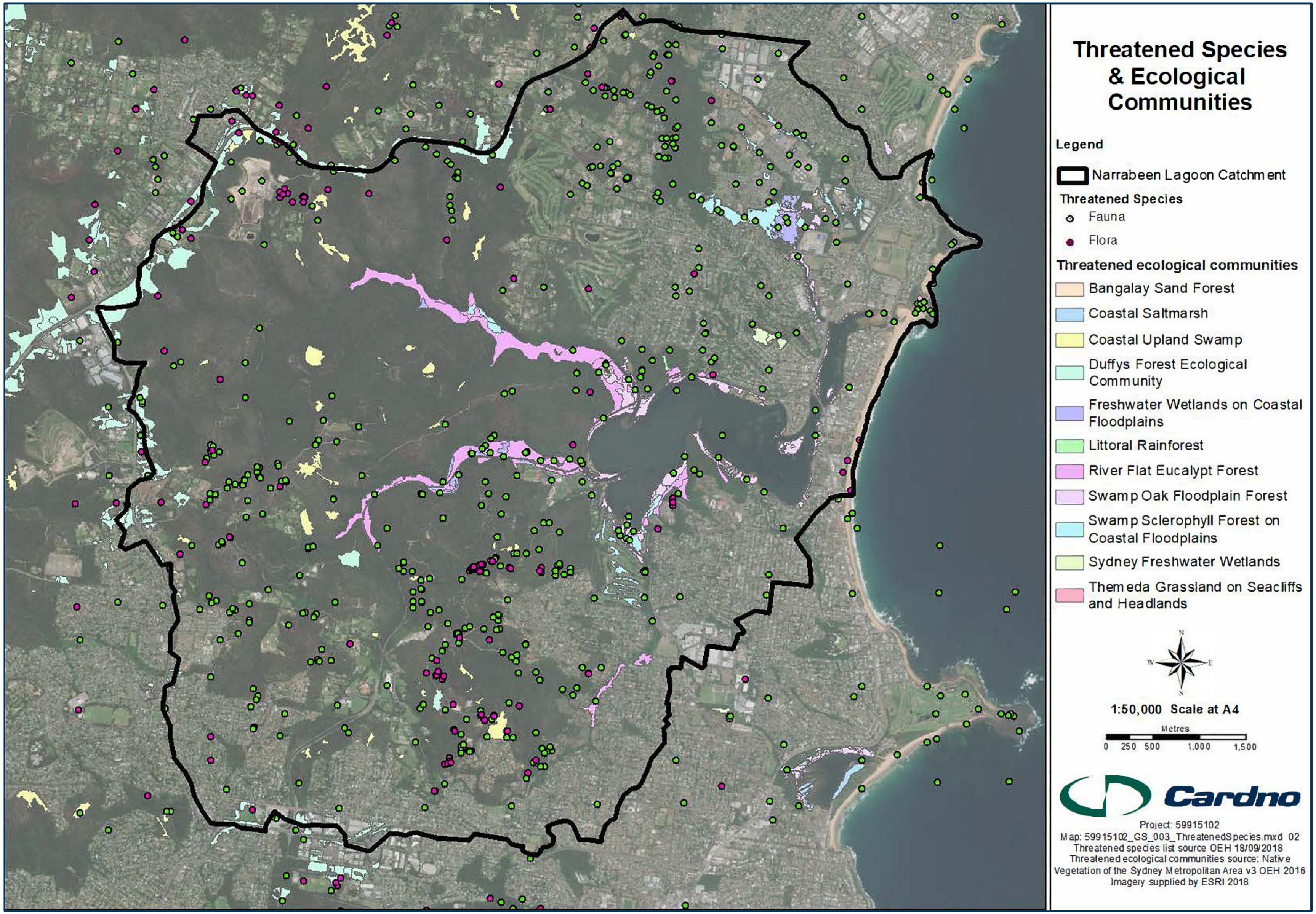


Figure 2-4 BC Act Listed Threatened Species and Ecological Communities

2.6 Aboriginal and Non-Aboriginal Cultural Heritage

2.6.1 Aboriginal Cultural Heritage

A preliminary investigation of indigenous heritage was undertaken by searching the Aboriginal Heritage Information Management System (AHIMS) (OEH, 2015) in July 2015 for known or potential indigenous archaeological or cultural heritage sites within or surrounding the Narrabeen Lagoon catchment. Over 80 sites were identified within the vicinity of Narrabeen Lagoon and Garigal National Park.

Aboriginal sites are protected under the *National Parks and Wildlife Act 1974* (NPW Act) and therefore any management options that have potential to impact on sites or locations of Aboriginal cultural heritage assessment must be considered in accordance with the requirements of the NPW Act and the Due Diligence Code of Practice for the Protection of Aboriginal Objects in New South Wales (OEH, 2010).Additional permits may be required for works with potential to impact on Aboriginal cultural heritage sites or items listed under the NPW Act.

2.6.2 Non-Aboriginal Heritage

There are three different types of statutory heritage listings for non-Aboriginal heritage sites and items. The category of an item depends on whether it is considered to be significant to the nation, state or a local area. Items of national heritage significance may be listed under the EPBC Act and items of state significance are listed under the NSW *Heritage Act 1977*. The significance of an item is a status determined by assessing its historical, scientific, cultural, social, archaeological, architectural, natural or aesthetic value.

A desktop review of non-Aboriginal heritage listings was undertaken for the catchment. Several databases were searched to determine the cultural heritage within the area, including:

> Australian Heritage Database (incorporates World Heritage List; Register of the National Estate, Commonwealth Heritage List);
> NSW Heritage Office – State Heritage Register;
> Pittwater Local Environment Plan (LEP) 2014; and
> Warringah LEP 2011.

Ten items within the catchment are listed on the Register of the National Estate (non-statutory archive):

> Beacon Hill and Governor Phillip Lookout Reserves;
> Belrose Grevillea Caleyi Site;
> Betty Moloney Garden;
> Deep and Middle Creeks Area;
> Ingleside House Garden;
> Narrabeen Fire Station;
> Narrabeen Lagoon Catchment;
> Narrabeen Rock Pool;
> Tumbledown Dick Road Cutting; and
> Upper Middle Harbour Area.

A further 38 local heritage items of significance were found within the catchment listed under Schedule 5 of both the Pittwater LEP 2014 and Warringah LEP 2011. The State Heritage Register records did not indicate any sites or items located within the catchment.

A review of non-Aboriginal heritage was also conducted as part of the *Narrabeen Lagoon Draft Plan of Management* (POM) (SMEC, 2011). The location of heritage items located as part of that investigation are shown in **Figure 2-5**.

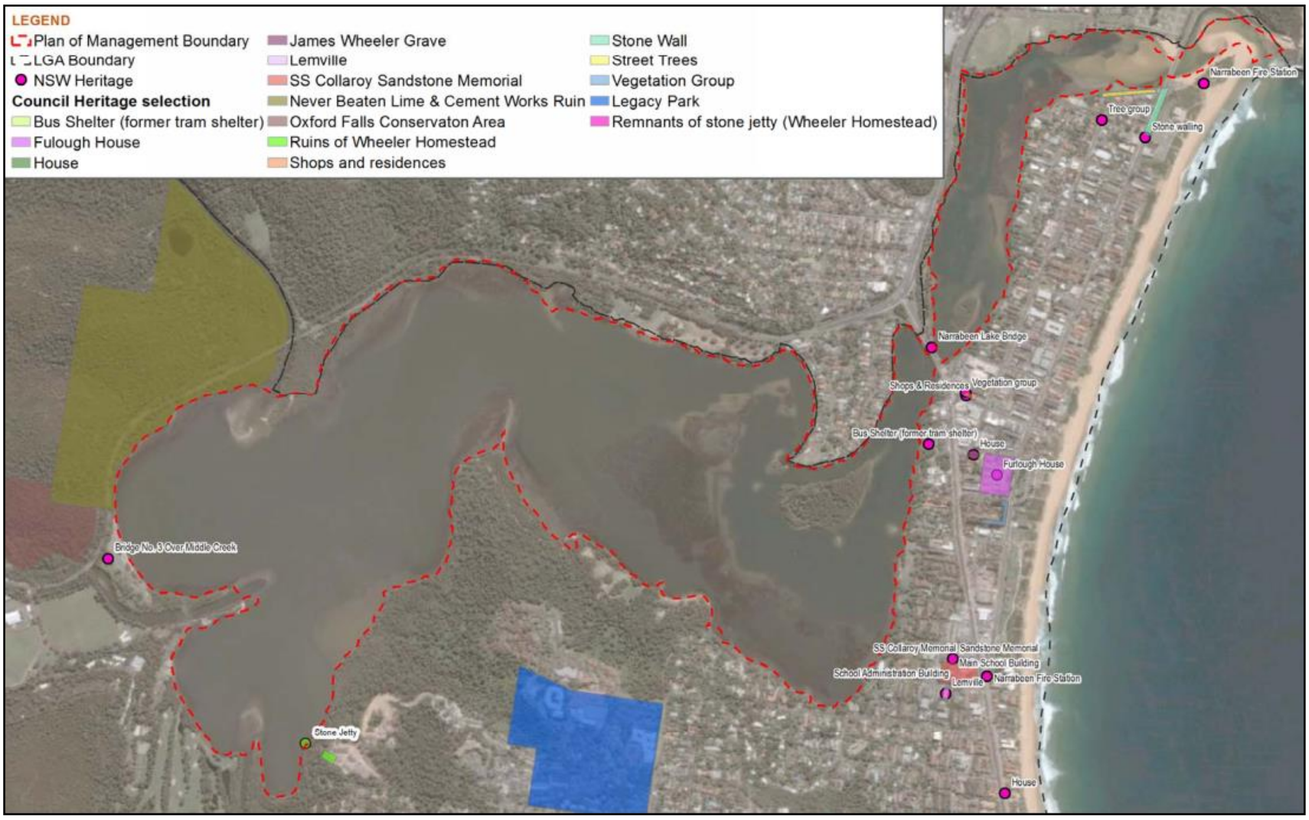


Figure 2-5 Heritage Items for Narrabeen Lagoon (Source: SMEC, 2011)

Part 5, Clause 5.10, of both the Pittwater LEP 2014 and Warringah LEP 2011 provides an outline of the provisions that must be followed in relation to heritage items. It is recommended that an assessment of potential impacts on heritage is undertaken prior to the implementation of any floodplain management options, and the findings considered with respect to the planning approvals required for the works.

2.7 Summary of Key Catchment Characteristics

This section has provided an overview of the key environmental and social characteristics of the catchment of relevance to the assessment of potential floodplain management options in **Section 11**. The key considerations identified are as follows:

> The catchment topography, geology and soil landscapes (including ASS) can influence the design and construction of any flood modifications options, and therefore the cost of implementation. The need for further investigations to inform the design and construction methodology should be considered at the time of implementation;

> The demographic characteristics are useful for informing the development of emergency response modification measures. The results in **Section 2.2** indicate that education materials and/or evacuation warnings may need to be prepared in languages other than English to ensure they target the community at risk from flooding. Apart from specific locations where there may be concentrations of less mobile people associated with vulnerable developments such as hospitals and child care facilities (refer **Section 5.4.5**), the demographics indicate a community that is above average socio-economic status and relatively young, and therefore likely capable of responding in the event of an emergency evacuation;

> The impacts on listed heritage items (**Section 2.6**) and flora, fauna, ecological communities and estuarine macrophytes (**Section 2.5**) should also be considered with respect to the potential impacts of management options. These impacts should be assessed to inform the design and construction of any options, and should in the first instance be avoided (where possible). This should include assessment of direct and indirect impacts on riparian and intertidal vegetation and wetlands, irrespective of their legal status; and

> There are a range of environmental aspects that can influence the approval pathway and need for additional permits, licences or approvals for implementation of any flood modification options, in particular the biodiversity and heritage listings (**Sections 2.5 and 2.6**). Both the approvals requirements and the need for any associated environmental management measures (including biodiversity offsetting) can impact the cost of a flood modification option, and the timeline for implementation.

3 Review of Available Data

3.1 Previous Reports and Studies

Several studies of the Narrabeen Lagoon catchment have been conducted in recent years, and were reviewed as part of the Narrabeen Lagoon Flood Study (BMT WBM, 2013). The key studies reviewed as part of this project are summarised in **Table 3-1**.

Table 3-1 Previous Studies of the Narrabeen Lagoon Catchment

Study / Report	Description
Narrabeen Lagoon Flood Study (Final Report) (BMT WBM, 2013)	This flood study describes the process undertaken to describe flood behaviour for a range of design flood events for the Narrabeen Lagoon Catchment. The flood study developed a RAFTS hydrological model and a TUFLOW hydraulic model to define the flooding behaviour in the study area. The models were calibrated to the April 1998 event. This calibration was validated against two additional historical events, August 1998 and March 2011. The flood study assessed the 20%, 5%, 2% and 1% Annual Exceedence Probability (AEP) events, and the Probable Maximum Flood (PMF) event. The design events were modelled for both catchment and ocean flooding. For major events, catchment derived flows controlled the majority of flooding within both the Lagoon and catchment. Whilst ocean inundation scenarios produce flooding of some foreshore areas, the extent and severity of flooding is significantly less than that which occurs for the corresponding catchment derived flood event. The flood behaviour in the study area was found to have some sensitivity to the berm conditions. For a 0.7 m increase in the initial (i.e. pre-flood) berm level (i.e. 2.0 m AHD instead of 1.3 m AHD), an increase of 0.2 m in peak flood level was recorded within the Lagoon. The flood study found roads throughout the study area were overtopped by flood waters in multiple locations in the 5% AEP event. The study also found that flooding within the study area was particularly sensitive to sea level rise associated with climate change.
OMS455 Lagoon Entrance Management (Warringah Council, 2013)	This Entrance Management Policy describes: ▪ The procedures to be followed by Council when artificially opening Narrabeen Lagoon entrance; ▪ The conditions that should be satisfied prior to an artificial opening; ▪ The responses that may be requested of relevant agencies in the event of an artificial opening; and ▪ A summary of the Narrabeen Lagoon Entrance Clearance Operations that are to occur periodically. The Policy notes that entrance behaviour has significant impacts on flood behaviour, as well as Lagoon water quality, recreational activities, and the Lagoon ecology.

Study / Report	Description
Narrabeen Lagoon Plan of Management (SMEC, 2011)	This Plan of Management (PoM) was prepared for Warringah Council as a framework to guide the future planning, monitoring and management of the Lagoon. Consultation with the local community and with stakeholders such as DPI and OEH led to the identification of a set of key environmental and recreational values that guided the development of the PoM: ▪ Natural Environment (Aquatic and Terrestrial Habitat); ▪ Recreation; ▪ Amenity; and ▪ Flood Mitigation. A total of 29 management actions were developed to address the issues identified under these four key values. They included the promotion of the lagoon for educational purposes, working with adjacent landowners (OEH, Sydney Water and Pittwater Council) to minimise poor water quality runoff discharging into the lagoon, adjusting water depth where appropriate to improve recreational access without compromising environmental values, and developing a financial management model.
Alternative Management Strategies for Clearing Narrabeen Lagoon Entrance (MHL, 2009)	A study was undertaken to determine the feasibility of the existing scenario along with six alternative options for entrance management: ▪ Existing entrance clearance/beach replenishment method (excavation and trucking); ▪ Dry earth sand winning and directionally drilled pipeline; ▪ Dry earth sand winning with beach cut-and-cover pipeline; ▪ Dry earth sand winning with pipeline on beach; ▪ Dry earth sand winning with pipeline in road reserve; ▪ Slurrified sand winning and pipeline on beach; and ▪ Slurrified sand winning and pipeline road reserve. Wave and sediment transport modelling was undertaken, including preliminary evaluation of two potential beach replenishment discharge locations. The report investigated the options from both a cost-benefit approach and through analysis of the constraints. It was concluded that the Dry Earth Sand Winning with Beach Cut and Cover Pipeline was the most viable alternative management strategy. Sea level rise was not considered as part of this assessment.
Narrabeen Lagoon Entrance Clearance Post-completion Report (Cardno, 2012)	The entrance to Narrabeen Lagoon periodically closes naturally through the movement of marine sand into the lagoon entrance due to wave, current and wind processes. This infilling generally results when the amount of sand moved into the lagoon entrance by the incoming tide exceeds the amount of sand removed by the outgoing tide. Closure of the lagoon entrance has environmental and socio-economic impacts on the lagoon and surrounding areas which may include: ▪ Should a flood occur while the entrance is closed, there is potential for an increase in the extent or depth of inundation of low-lying development on the lagoon foreshores or adjacent to tributary creeks. This is due to the inability of floodwaters to flow out to sea, and may be alleviated once the lagoon entrance is breached (whether artificially or naturally); ▪ Changes in lagoon water quality, particularly near the entrance, due to a lack of tidal flushing from the entrance and an increase in the influence of catchment inflows on water quality. This primarily relates to parts of the Lagoon near the entrance; and ▪ Changes in biodiversity due to reduced recruitment of fish and other marine species through the entrance. To assist in managing the potential flood impacts Warringah and Pittwater Councils, with the assistance of the NSW Government, undertook entrance clearance works in 2011, the progress of which is discussed in Cardno (2012). These operations involved the removal of approximately 36,000 m^3 of sand from the entrance.

Study / Report	Description
South Creek Floodplain Risk Management Study and Plan (Cardno, 2008)	This FRMS&P was developed for the South Creek sub-catchment of the Narrabeen Lagoon catchment. Preparation of the FRMS&P involved a flood study and community consultation to gain an appreciation of the key management issues faced within the floodplain. The primary objectives of the study were to identify and examine options for the management of flooding within the South Creek floodplain, and reduce flood risk based on environmental, social, economic, financial and engineering considerations. These options included: ▪ Flood modification measures; ▪ Property modification measures; and ▪ Emergency response modification measures. Management measures identified in in Cardno (2008) will be considered in the preparation of the Narrabeen Lagoon FRMS&P.
Narrabeen Lagoon Estuary Management Study and Plan (WBM, 2002)	This management study and plan included data compilation and substantial community consultation, which identified key management issues that affected the overall condition and health of Narrabeen Lagoon. Key issues identified included water quality, sedimentation and control of catchment inputs to the lagoon. Based on these key management issues, a series of management objectives were developed and grouped under five broad categories: ▪ Water quality; ▪ Sedimentation; ▪ Ecology; ▪ Waterway and foreshore usage; and ▪ Bank erosion and foreshore management.
Pittwater Overland Flow Mapping and Flood Study (Cardno, 2013)	This study aimed to identify and map the areas in the Pittwater LGA affected by overland flow, rather than mainstream flooding. The study used a Sobek hydraulic model to define the flooding behaviour in the study area through an assessment of the 20%, 5% and 1% AEP events, and the PMF event. It identified that up to 1,936 properties are likely to experience overland flow flooding in the 1% AEP event. When climate change (0.9 m sea level rise and 30% increase in rainfall intensity) is factored into the modeling, the number of affected properties increases to 2,276.
Narrabeen Lagoon Flood Risk Management Plan (SMEC, 2002)	This FRMP was aimed at developing an action plan for implementation by Warringah Council based on previously identified floodplain management options. This report identified 9 management actions for implementation within the catchment. The action items included: ▪ Reviewing the FRMP; ▪ Reviewing the 1996 Entrance Management Policy; ▪ Constructing wetlands on Middle Creek; ▪ Raising Wakehurst Parkway at Middle Creek; ▪ Reviewing property flood controls; ▪ Implementing a voluntary house raising program; ▪ Developing a Local Flood Plan; ▪ Developing a Community Awareness Program; and ▪ Sedimentation control measures. Management measures identified in SMEC (2002) will be considered in preparing the new Narrabeen Lagoon FRMS&P.

Study / Report	Description
Narrabeen Lagoon Flood Risk Management Study (Mitchell McCotter, 1992)	The objective of this FRMS was to broadly identify works and measures to reduce the impact of flooding and economic damages caused by flooding, It concluded that the most appropriate strategy for floodplain management is a combination of: ▪ Formalised management of the lagoon entrance; ▪ Requirements for minimum floor levels for certain types of development; ▪ Levee banks; and ▪ The development of a flood response plan to improve community awareness. Management measures identified in Mitchell McCotter (1992) will be considered in preparing the new Narrabeen Lagoon FRMS&P.
Warriewood Valley Strategic Review – Hydrology Study (Cardno, 2011)	This strategic review provided advice regarding the potential development of a number of land parcels within the Warriewood Valley. The report developed outcomes based on primarily the Warriewood Valley Flood Study (Cardno, 2005), updated to incorporate the impact of climate change. The study reviewed the impacts development would have on flooding, flood storage and water quality. The report provided recommendations on potential requirements for development including the provision of onsite detention, water quality systems, overland flow management and evacuation procedures.
Warriewood Valley Flood Study and Addendum 1 (Cardno, 2005)	This flood study was aimed at defining the nature and extent of flooding within the Warriewood Valley catchment. The flood study was undertaken for the existing climate conditions scenario only. The study indicated that flooding within the lower parts of the catchment was widespread, with Pittwater Road likely to be overtopped in several locations in the 1% AEP event. It was also identified that in the upstream reaches of the catchment flooding is generally confined to the creeks or adjacent areas. Addendum 1 of the flood study report was undertaken to determine the impact of flooding due to new development within the catchment. The addendum reviewed the impact of new developments on the 1% AEP and the PMF event.

3.2 Survey Information

The following survey information was provided by Council:

> Two LiDAR data sets in *.las format:
  - HawkesburySOUTH2011; and
  - SydneyNorth2013.

> Floor level survey from multiple data sources including:
  - South Creek Catchment Floor Levels (334) captured in 2004;
  - Warriewood Valley Catchment Floor Levels (464) captured in 2006; and
  - Nareen Creek Catchment Floor Levels (420) captured in 2006.

> Bathymetry information for the Narrabeen Lagoon Entrance in *.tif format.

Indicative survey information for the rock weir underneath the lagoon entrance channel, obtained in 1976, was also acquired from the Narrabeen Lagoon Entrance Study (MHL, 1989).

In addition to the survey information provided by Council, a broad-scale floor and level registered ground survey was undertaken as part of this study. This ground survey resulted in 1,091 floor and block levels being captured, including the pickup of multiple floor levels within apartment complexes where relevant. This dataset was incorporated into the existing level survey provided by council. The extent covered by the compiled datasets is shown on **Figure 3-1** and **Figure 3-2.**

At the completion of the survey, a small number of floor levels for buildings potentially impacted by the PMF event remained unknown. Levels for these floors have been estimated based on the floor levels of surrounding properties. These estimates have been used only for the purposes of the annual average damage calculations (refer **Section 6.3**). The levels are not intended to be used by Council in determining which properties are flood affected. This approach is considered adequate as the locations are only affected in very rare events and do not contribute significantly to the average annual flood damages.

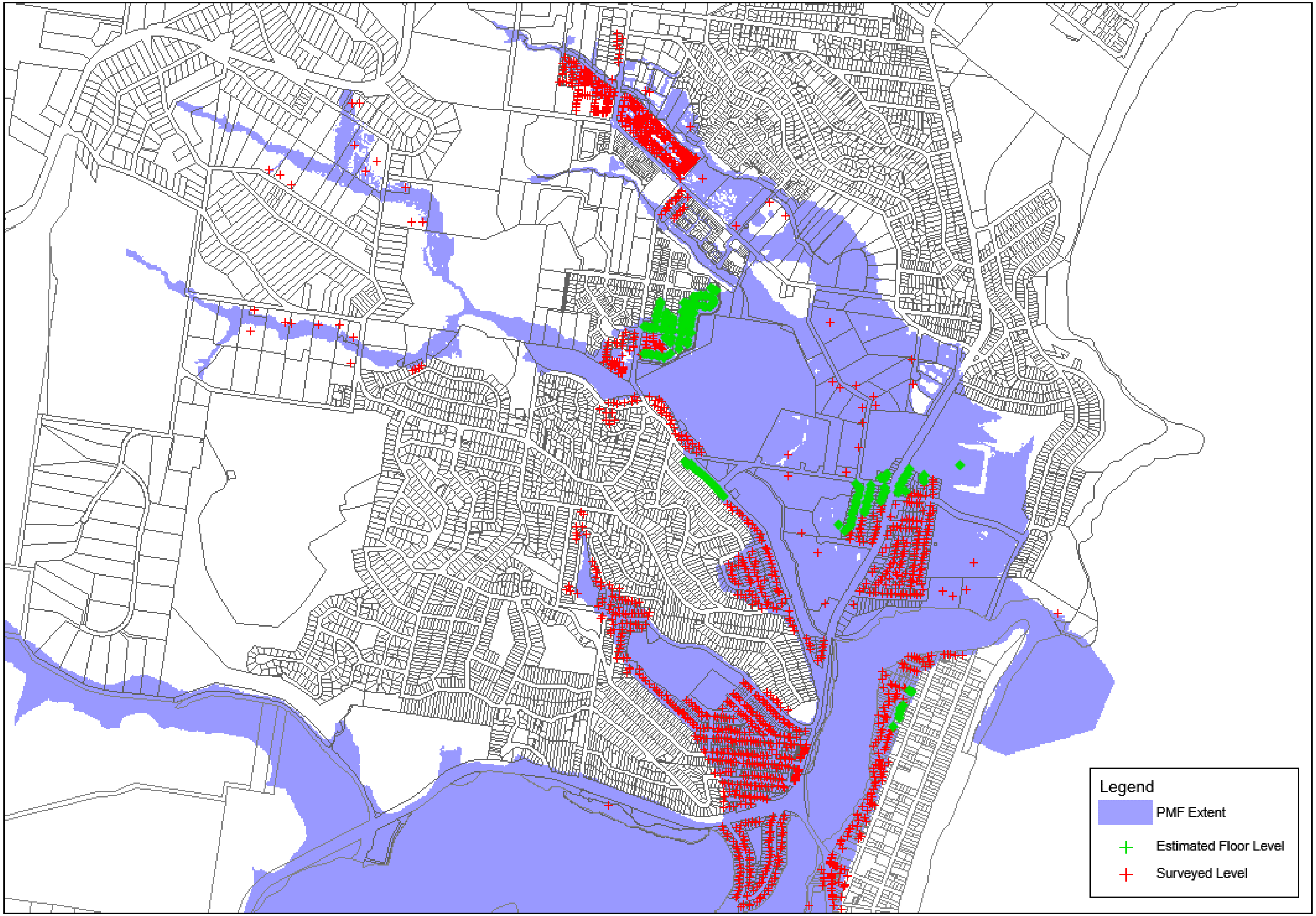


Figure 3-1 Level Survey – Northern lagoon catchment

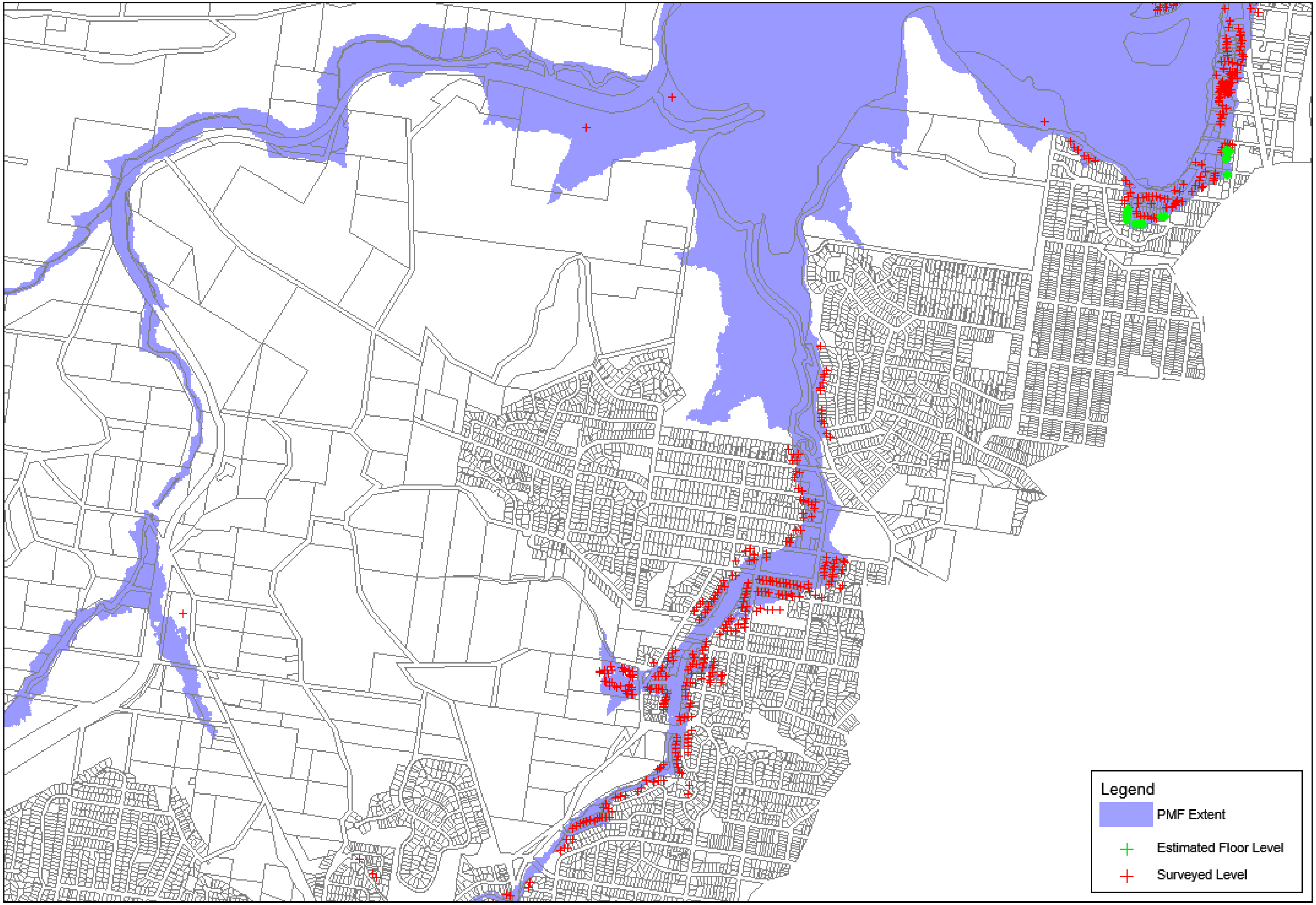


Figure 3-2 Level Survey – Southern lagoon catchment

3.3 GIS Data

The following GIS datasets were provided from former Warringah Council records:

> Cadastre, Pits, Pipes, Catchment Area, Contours (2 m) in *.shp format;

> Warringah Local Environment Plan Land Use Zones (2014) in *.TAB format; and

> Flood Mapping outputs from the Narrabeen Lagoon Flood Study in *.asc format.

The following datasets were provided from former Pittwater Council records:

> Cadastre, Flood Extents, Contours (1 m), Road Centrelines, Pipes, Pits in *.TAB format;

> Pittwater Local Environment Plan Land Use Zones (2014) in *.TAB format; and

> Stream Mapping Information in *.TAB format.

3.4 Previous Modelling

The Flood Study undertaken in 2013 (BMT WBM) developed hydrological and hydraulic models to assess the flood behaviour in the study area. Hydrological modelling was undertaken using the RAFTS software package, and the hydraulics using the TUFLOW software package.

3.4.1 Hydrology

A RAFTS model was prepared during the Flood Study investigations to model the site hydrology. The model was calibrated to three historical events. The hydrological model constructed appears appropriate for the catchment based on the following:

> The adopted initial and continuing losses of 10 mm and 2.5 mm/hr have been considered suitable for pervious surfaces in catchments of this nature;

> Sub-catchment sizes are relatively uniform;

> Pervious and impervious splits for sub-catchments are appropriate for sub-catchment land uses; and

> Design rainfalls have been calculated in accordance with the Australian Rainfall and Runoff (AR&R) guidelines (Engineers Australia, 1987).

The use of this hydrological model is therefore considered suitable for the purpose of developing this FRMS.

3.4.2 Hydraulics

The Flood Study developed a TUFLOW model to assess the flood behaviour of the region. The model was calibrated to one historical event, and further validated to two other historical events. The suitability of the model for use in this FRMS is discussed in the following sections.

3.4.2.1 Model Extent

The hydraulic model extends from Narrabeen Lagoon and covers the entirety of the Narrabeen Lagoon catchment. This extent covers the critical areas of the study area, and is suitable for assessing flood management options for the region.

3.4.2.2 Digital Elevation Model

A Digital Elevation Model (DEM) was developed as part of the Flood Study. No alterations to this DEM have been undertaken for the purposes of this FRMS. A sensitivity analysis (**Section 3.4.2.7**) was undertaken to determine the impact of development since the flood study was completed.

3.4.2.3 Model Roughness

The roughness values adopted in the model are summarised in **Table 3-2**. These values are within the typical ranges for the land uses they represent.

Table 3-2 Model Roughness Values

Land Use	Roughness (Manning's 'n')
Lagoon Waterbody	0.025
Roads	0.02
Medium Vegetation	0.08
Heavy Vegetation	0.10
Recreational Land	0.04
Tributary Channel	0.04 - 0.08
Sand	0.03
High Density Residential	0.08
Commercial/Business/Industrial	0.15
Low Density Residential	0.05
Other	0.04

3.4.2.4 Hydraulic Structures

The model includes thirty-three major hydraulic structures (refer **Table 3-3**). The model does not incorporate local drainage as defined in the Floodplain Development Manual (NSW Government, 2005). Details of these structures were collected during the Flood Study, and confirmed during the Flood Study site inspection.

Table 3-3 Hydraulic Structures within the Model

ID	Location	Structure Type
S1	Ocean Street (Narrabeen Lagoon)	Bridge (approx 65 m span)
S2	Pittwater Road (Mullet Creek)	Bridge (approx 18 m span)
S3	Pittwater Road (Narrabeen Lagoon)	Bridge (approx 51 m span)
S4	Wakehurst Parkway (Deep Creek)	Bridge (approx 43 m span)
S5	Wakehurst Parkway (Middle Creek)	Bridge (approx 40 m span)
S6	Wakehurst Parkway (Middle Creek)	Culvert (2 x 1.5 m pipe)
S7	Sydney Water Access Rd (Middle Creek)	Culvert (3 x 1.5 m pipe)
S8	Wakehurst Parkway (Middle Creek)	Bridge (approx 23 m span)
S9	Wakehurst Parkway (Middle Creek)	Bridge (approx 15 m span)
S10	Wakehurst Parkway (Middle Creek)	Culvert (2 x 1.8 m pipe)
S11	Dreadnought Road (Middle Creek)	Culvert (2 x 4.3 m x 1.8 m box)
S12	Dreadnought Road (Middle Creek)	Culvert (2 x 1.5 m pipe)
S13	Toronto Avenue (South Creek)	Bridge (approx 12 m span)
S14	Carcoola Road (South Creek)	Culvert (5 x 3.3 m x 1.8 m box)
S15	Willandra Road (South Creek)	Culvert (2 x 3 m x 1.5 m box)
S16	Akira Circuit (South Creek)	Culvert (4 x 1.35 m pipe)
S17	McIntosh Road (South Creek)	Culvert (2 x 1.8 m pipe)
S18	Willandra Road (Lower) (South Creek)	Culvert (1 x 3 m x 1.5 m box + 1 x 0.75 m pipe)

ID	Location	Structure Type
S19	Willandra Bungalows Retirement Community (Wheeler Creek)	Bridge (approx 15 m span)
S20	Little Willandra Road (Wheeler Creek)	Culvert (2 x 2.7 m x 1.6 m box + 1 x 2.7 m x 1.8 m box)
S21	Pittwater Road (Nareen Creek)	Culvert (8 m x 1.7 m box)
S22	Pittwater Road (Nareen Creek)	Culvert (7.1 m x 1.5 m box)
S23	Narroy Road (Nareen Creek)	Culvert (2 x 3.4 m x 1.2 m box)
S24	Jacksons Road (Mullet Creek)	Culvert (3 x 2.4 m x 2.4 m box)
S25	Garden Street (Mullet Creek)	Culvert (4 x 1.8 m pipe)
S26	Jacksons Road (Narrabeen Creek)	Culvert (3 x 2.45 m x 2.45 m box)
S27	Boondah Road (Narrabeen Creek)	Culvert (3 x 1.05 m pipe)
S28	Macpherson Street (Narrabeen Creek)	Culvert (3 x 1.2 m pipe)
S29	Ponderosa Parade (Narrabeen Creek)	Culvert (2 x 1.8 m pipe)
S30	Jubilee Avenue (Narrabeen Creek)	Bridge (approx 14 m span)
S31	Garden Street (Fern Creek)	Culvert (1.8 m x 3 m box)
S32	Ingleside Road (Mullet Creek)	Culvert (3.4 m x 0.9 m box)
S33	Powder Works Road (Mullet Creek)	Culvert (3 x 1.8 m pipe)

3.4.2.5 Ocean Berm

The ocean berm was modelled in the Flood Study using a TUFLOW morphological module. This module allows the berm to erode when it is overtopped during a storm event, with the rate and extent of scour determined from the overtopping conditions. The previously used morphological TUFLOW module is still under development, and is not publicly available at the present time.

As the module was not available to this study, the ocean berm was modelled here using a similar, publicly available morphological module that replicated the results of the Flood Study. Further discussion of the updated morphology modelling of the lagoon is included in **Section 3.4.2**. The model was used to review potential flood management options.

3.4.2.6 Downstream Boundary

For the Flood Study the downstream (ocean) boundary was modelled as a tidal sea level height time series. For catchment derived design flood events, the boundary was the normal tide series, and was calculated in accordance with Appendix A of the Draft Flood Risk Management Guide (DECWW, 2009). The peak tide level was timed to coincide with the peak catchment flow. This tidal boundary was used for all catchment-derived design flood events.

For ocean-derived design flood events the boundary was determined based on an assessment of barometric pressure, wind set-up, astronomical tide and wave set-up, as outlined in the Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments (DECCW, 2010).

3.4.2.7 Sensitivity

In order to determine the impact of development that have occurred since the Flood Study model was built, the existing hydraulic model was updated to incorporate the following developments in the various sectors of Warriewood Valley:

1. Meriton Development – 79-91 Macpherson Street;
2. Meriton Development – 14-18 Boondah Road, Warriewood;
3. Ibis Estate – 61 Warriewood Road, Warriewood;

4. ARV development – Macpherson Street;
5. Raising of Boondah Road and Macpherson St;
6. Synthetic Sports Field at Narrabeen Sport High School;
7. Warriewood Valley Sector 8 Detention Basins/District Playground; and
8. Jubilee Avenue development.

It is noted that the Sector 8 detention basins were included within LiDAR data used to inform the Flood Study hydraulic model. Therefore, their impacts have already been accounted for in the Flood Study model and no revision to the model was required at that location.

Figure 3-3 shows the results of the analysis. The numbers correspond to the numbering in the above list of developments. The sensitivity analysis indicates that in general the new developments have minimal impact on the overall floodplain. Some minor increases in water level are present east of Boondah Road, due to the raising of Boondah Road near Macpherson Street. Similarly, very minor increases in water level occur south of Bandicoot Close, but all impacts are contained within the creek channel. The sports field at Narrabeen Sports High School also indicates a very local increase in water level because the topography in the area has been modified, resulting in flooding of previously unaffected portions of the field.

The sensitivity analysis shows that the impact of recent development on the floodplain is minor and consequently a revision to the existing flood model is considered unnecessary at this stage.

3.4.2.8 Suitability

Based on this review and the outcomes of the sensitivity analysis, it was determined that all hydraulic parameters utilised within the Flood Study (BMT WBM, 2013) are appropriate and that the extent of the model is sufficient to determine the risk associated with flooding in the catchment. The model is therefore suitable for use within this FRMS.

3.4.3 Morphological Model

The morphological module utilised in the Narrabeen Lagoon Flood Study (BMT WBM, 2013) is not publicly available thus, precluding its use for this FRMS. A Delft3D model was therefore constructed for the study area. The Delft3D model is capable of modelling failure and erosion of the ocean berm, and of assessing flood flows upstream of the berm within the lagoon. The sediment transport module within Delft 3D supports both bed load and suspended load transport of non-cohesive sediment. This Delft 3D model was coupled with the existing TUFLOW hydraulic model to produce a modified model that replicated the previous Flood Study results, and is considered suitable for use within this study.

3.4.3.1 Model Development

The hydrodynamic model was established using the Delft3D modelling system. The model grid was developed as a curvilinear grid structure of variable grid cell resolution (**Figure 3-4**). Model resolution is highest at the entrance and other regions containing hydrodynamic controls, such as the Ocean Street and Pittwater Road bridges. In these regions grid cell sizes are approximately 4 to 7 m. This level of resolution is necessary to adequately describe these hydrodynamic controls, as well as their morphological evolution during a severe flood event.

In order to gain computational efficiency, lower levels of resolution were used offshore and in the southern and western lagoon basins. In these regions grid cell sizes are approximately 15 to 25 m. The curvilinear grid structure allows model grid lines to follow the prevailing flow paths and to adequately describe the estuary boundaries in upstream tributaries.

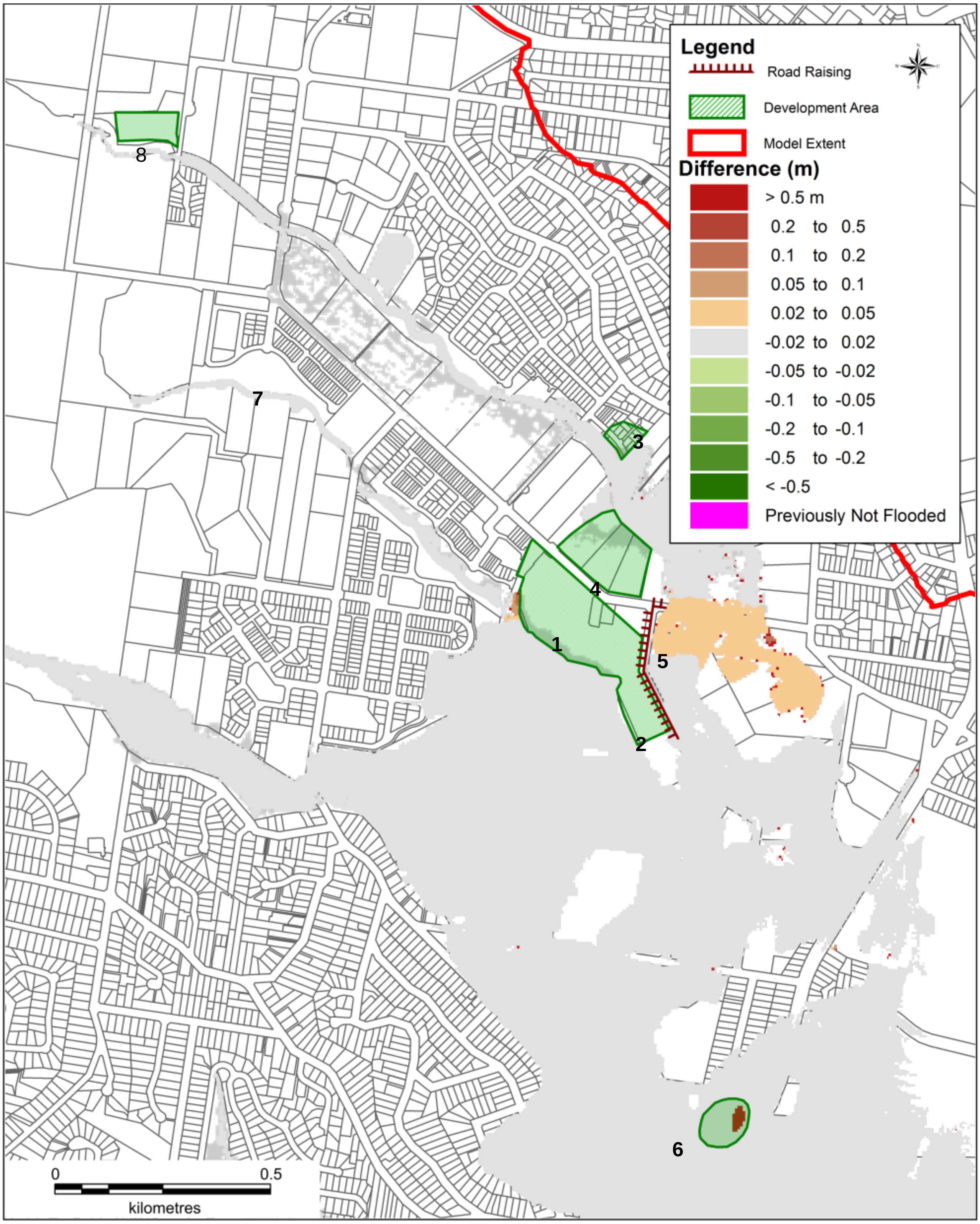


Figure 3-3 Model Sensitivity Results – 1% AEP Event

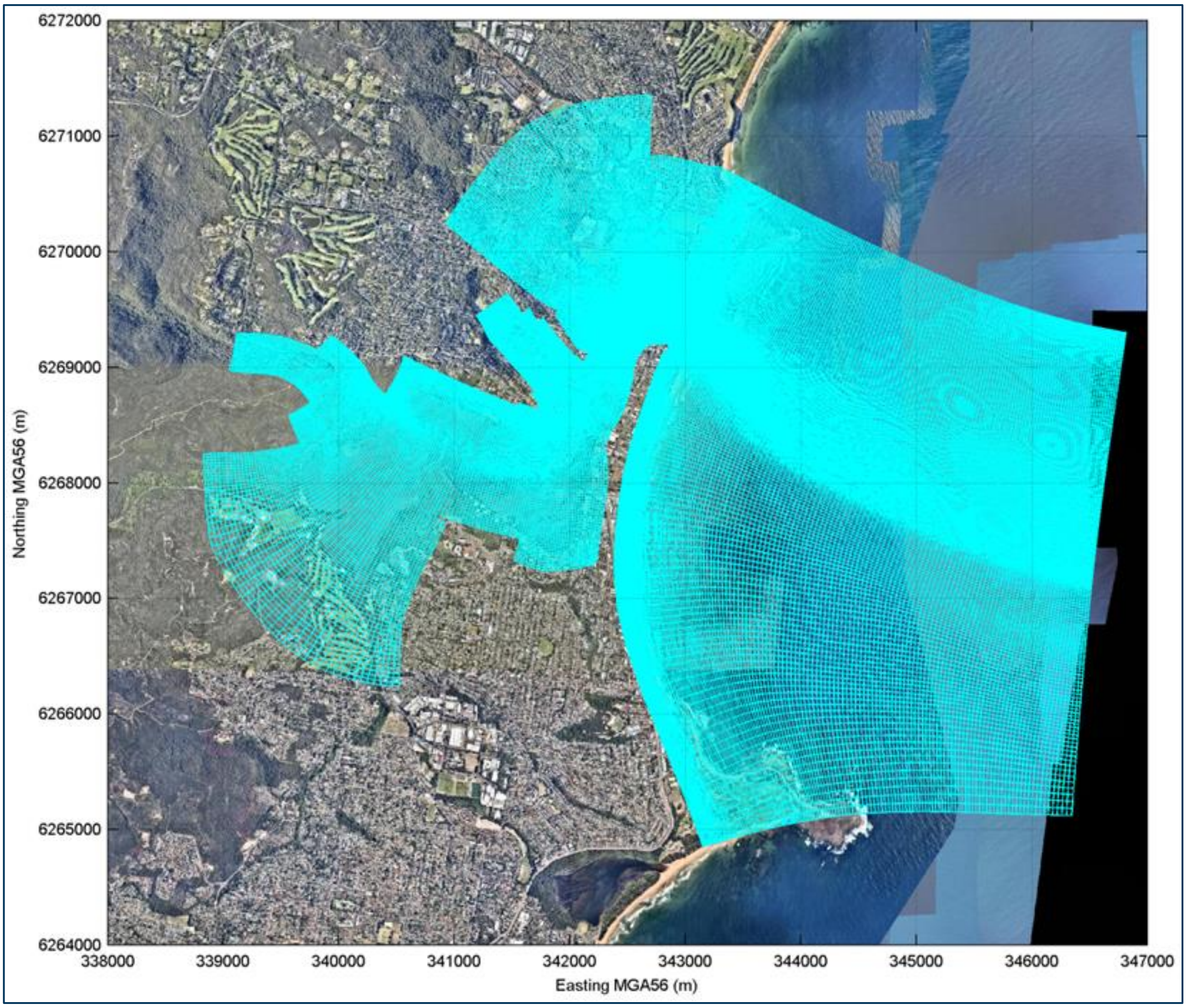


Figure 3-4 Delft 3D Hydrodynamic Model Setup

The topographic and bathymetric data for the lagoon and its foreshores were adopted from the TUFLOW model used in the Narrabeen Lagoon Flood Study (BMT WBM, 2013). Additional bathymetric data for the nearshore and offshore model regions was adopted from navigation chart AUS197, which provided bathymetric contours and spot levels of sufficient accuracy and resolution. The resultant model bathymetry is shown in **Figure 3-5**. The underlying bedrock at the entrance was incorporated into the Delft3D model by digitising the rock shelf survey reported in the Narrabeen Lagoon Entrance Study (MHL, 1989).

The downstream (ocean) boundary condition is represented by a water level time series. Cross-shore boundaries are input as "Neumann" boundaries, which impose the alongshore water level gradient and ensure computational stability. Upstream boundary conditions are represented by tributary discharge time-series.

The various bridges in the study area were represented in the model domain as 3D Gate Structures in Delft3D. In the model these act as a thin dam with a limited height/depth (and positioned in the vertical) used to model a vertical constriction of the horizontal flow. The levels and widths of these bridges were obtained from LiDAR data.

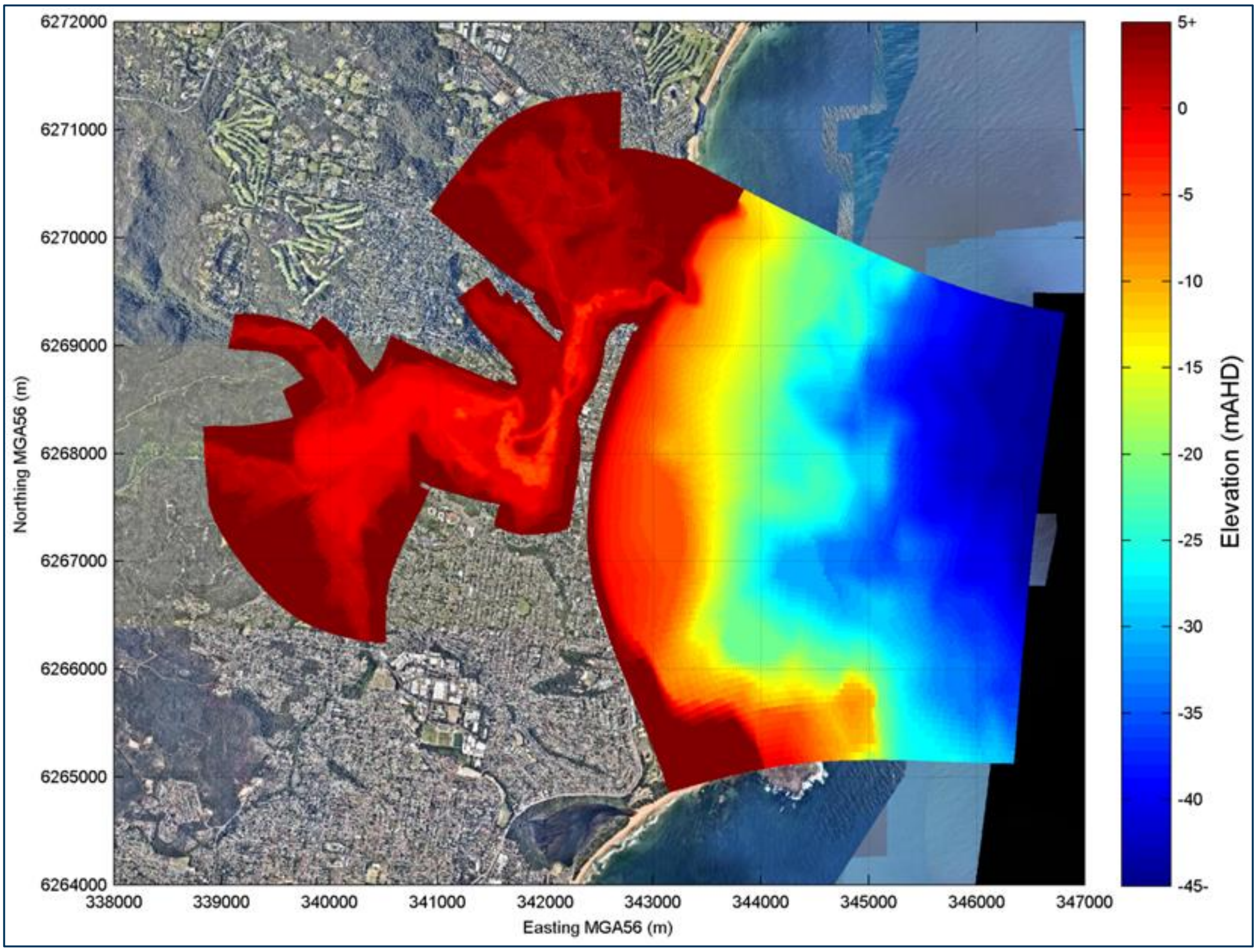


Figure 3-5 Delft 3D Hydrodynamic Model Bathymetry

3.4.3.2 Model Validation

Model validation was undertaken for the 24-hour 1% AEP catchment flood event modelled as part of the Narrabeen Lagoon Flood Study (BMT WBM, 2013). The Delft3D model included catchment (upstream) and ocean water level (downstream) forcings, as well as rainfall. To ensure a robust validation, outputs from the Flood Study model were utilised as inputs to the Delft3D model for both the upstream and downstream boundary conditions.

Results from the simulation are presented in **Figure 3-6** for several model output locations within the main body of the lagoon, consistent with those previously reported in the Narrabeen Lagoon Flood Study (BMT WBM, 2013). **Table 3-4** directly compares flood levels from Delft3D with the Flood Study, and the results are virtually identical, indicating good model validation.

Table 3-4 Delft3D Hydrodynamic Model Validation – 1% AEP Catchment Flood Levels (m AHD)

Location - as defined in BMT WBM (2013)	BMT WBM (2013)	Delft3D Validation Simulation
US Ocean St Bridge	2.9	2.8
US Pittwater Rd Bridge (Mullet Creek)	2.9	2.9
US Pittwater Rd Bridge (Narrabeen Lagoon)	3.0	3.0
US Deep Creek Bridge	3.0	3.0
US Middle Creek Bridge 1	3.0	3.0

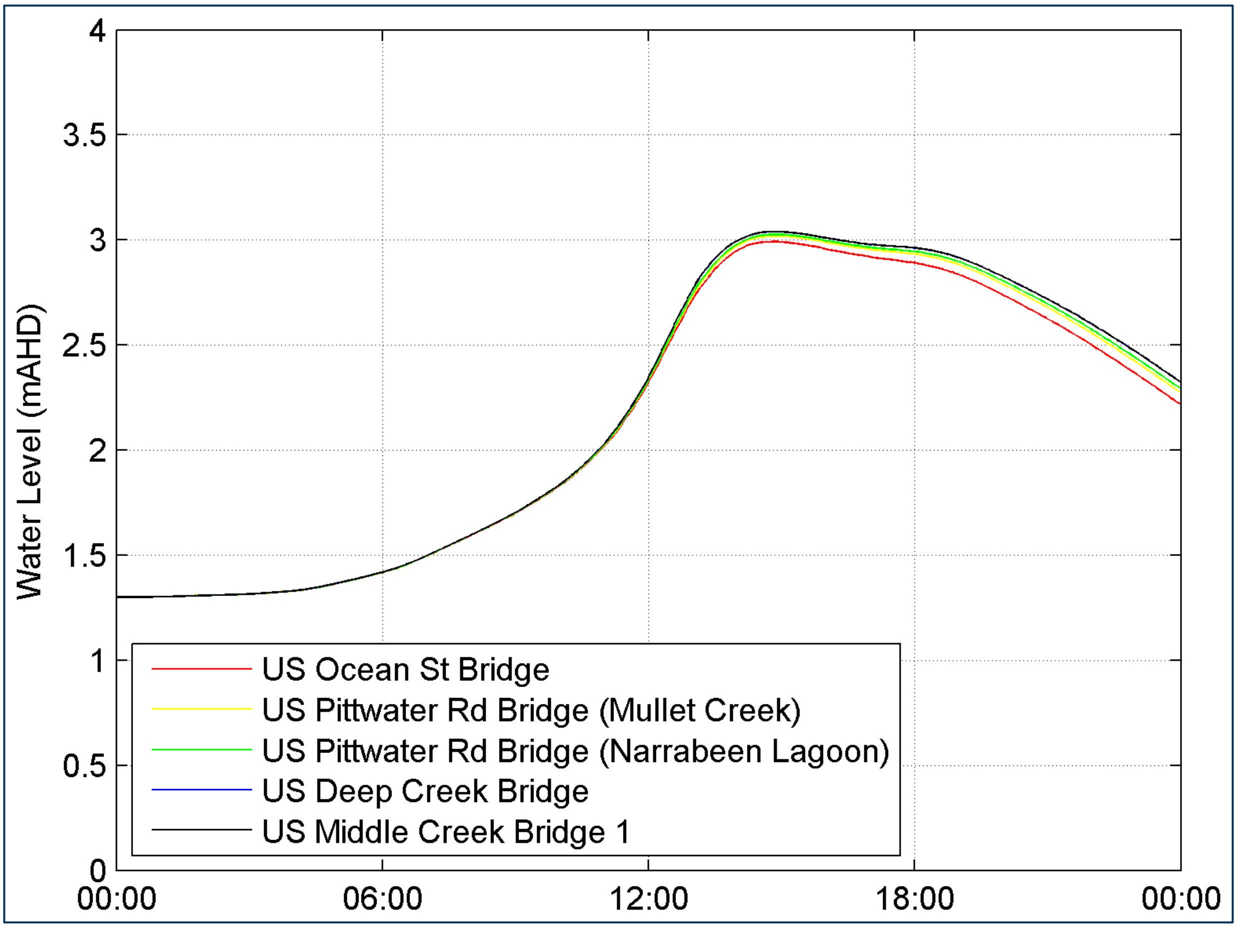


Figure 3-6 Delft3D Hydrodynamic Model Validation – 1% AEP Catchment Flood Levels

A comparison of the Delft3D modelled results with the Flood Study (BMT WBM, 2013) results through a long section of the estuary is shown in **Figure 3-7** (the location of the long section is shown in **Figure 3-8**). The comparison shows good agreement between the two models in terms of peak flood levels within the main body of the lagoon.

Upstream of the Ocean Street Bridge the DELFT3D model results show particularly good agreement with the Flood Study (BMT WBM, 2013) results, and are generally within 0.01 m to 0.02 m. Some deviation from the Flood Study results is observed in the downstream region of the lagoon in between the Ocean Street Bridge and the entrance berm. In this region differences between DELFT3D and TUFLOW levels are in the range of 0.02 m to 0.20 m, with the DELFT3D model generally showing lower flood levels.

These differences are likely due to differences in the sediment transport schemes adopted by DELFT3D and TUFLOW respectively, which have resulted in different scour patterns through the entrance berm. It is important to note that these differences are localised to the lagoon entrance, where the greatest influence on flood levels is from the morphology.

In summary, the DELFT3D hydrodynamic and morphological model developed during this study replicates the spatial and temporal flood behaviour for the lagoon system identified by the previous Flood Study (BMT WBM, 2013), and is therefore appropriate for use in this FRMS.

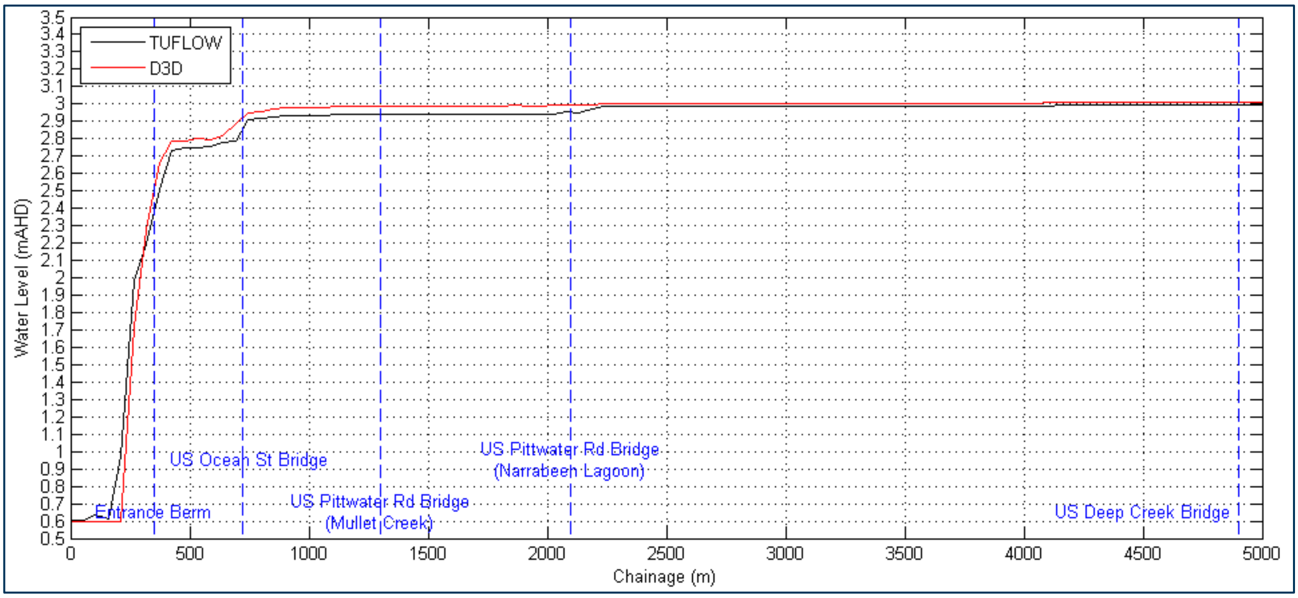


Figure 3-7 Comparison of Delft3D and TUFLOW – Peak 1% AEP Catchment Flood Levels

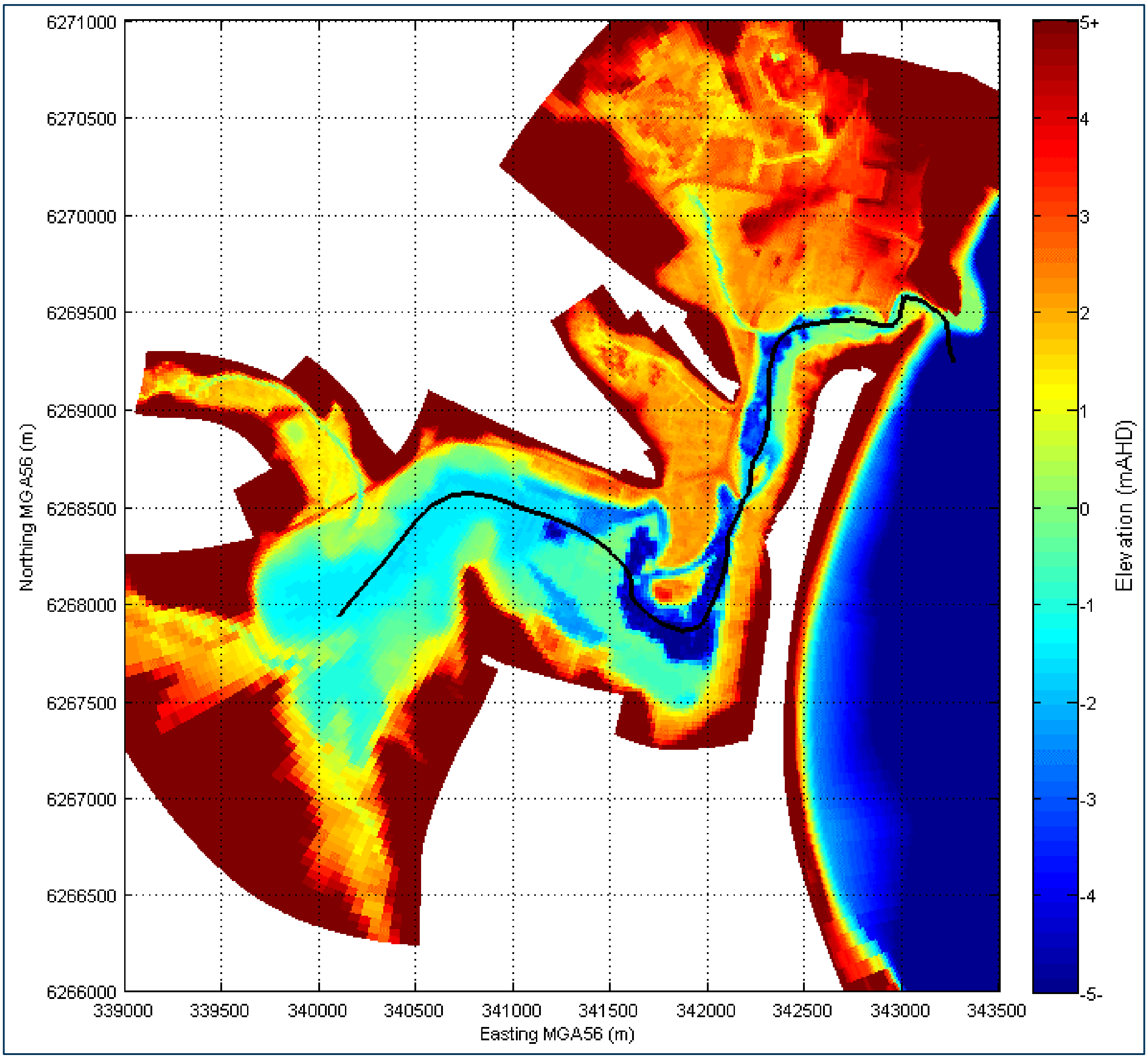


Figure 3-8 Estuary Long Section Location and the DELFT3D Elevation Model

4 Community Consultation

4.1 Community Consultation Process

Community consultation is an important component in the development of a FRMS&P. Consultation provides an opportunity to collect feedback and observations from the community on problem areas and potential floodplain management measures. It also provides a mechanism to inform the community about the current study, and the flood risk in the study area, and seeks to improve their awareness and readiness for dealing with flooding.

The main consultation elements for this project are:

> An information brochure and questionnaire sent to all affected properties;
> A project website that keeps the community informed about the progress of the project;
> A request for information from all affected stakeholders within the catchment;
> Regular meetings with the Narrabeen Lagoon Floodplain Risk Management Working Group (NLFRMWG);
> Public exhibition of Draft FRMS and Draft FRMP, including drop-in sessions; and
> Collation and acknowledgement of written submissions during the public exhibition period(s).

This process ensures that there is ample opportunity for community participation during the development of the FRMS&P.

4.2 Narrabeen Lagoon Flood Risk Management Working Group

The NLFRMWG was formed to provide input to the Narrabeen Lagoon Flood Study (BMT WBM 2013). The NLFRMWG is a forum that brings together the expertise and community knowledge of a diverse range of stakeholders. Regular meetings enable discussion and feedback at key stages throughout the project.

4.3 Information Brochure and Questionnaire

4.3.1 Background

An information brochure describing the study, which included a questionnaire designed to gauge community awareness of flood related issues and request feedback, were prepared as part of the community consultation process (**Appendix A**). Together with a covering letter, these were sent to 3,004 flood affected property owners on 24 April 2015.

Details of the project website and questionnaire was also advertised in the Manly Daily on 2 May 2015.

At the close of the survey period on 25 May 2015, 175 submissions had been received. Of the submissions received, 109 were received in hardcopy and 66 were received via the online survey portal.

The key questionnaire results are tabulated in **Appendix A**. All community responses have been collated in spreadsheet format and supplied to Council.

4.3.2 Outcomes of Community Questionnaire

Based on the completed questionnaires received, the following key outcomes have been derived:

> There was a general consensus within the community that the Narrabeen Catchment is subject to flooding, with 74% indicating concern for flooding in their local area. Some 34% of respondents believed that their own property is flood affected;
> Most respondents (73%) believed that flooding in their area is primarily attributable to mainstream creek flooding or stormwater issues, with few (19%) respondents believing elevated ocean water levels is the key contributor;
> Most respondents believed that the climate is changing (89%) with the majority of respondents (63%) concerned about the impact that an uncertain climate will have on flooding in Narrabeen Lagoon;

> Most respondents (71%) believed that the Council should be addressing the impacts of an uncertain climate future;

> Many respondents (80%) were aware of Flood Planning Levels. Almost all (92%) agreed that Flood Planning Levels are a necessary method of flood risk management, at least to some extent. Most respondents (78%) also believed that the uncertain future climate should be taken into account, at least to some degree, in Flood Planning Levels;

> Respondents were mixed in their views as to the level of control Council should place on new development to minimise flood-related risks, with 36% believing that placing restrictions on development (e.g. minimum floor levels and/or the use of flood compatible building materials) is appropriate. Some 23% responded that Council should advise people of flood risks, and allow individuals to choose how they would reduce flood damage;

> Most respondents believed that mechanical opening of the lagoon entrance is the most suitable mitigation option for the catchment, with planning controls, drainage upgrades and the existing clearance program the next most preferred options.

Table 4-1 lists the preferred floodplain management options based on the community questionnaire. Each option had its total score calculated based on the number of nominations and the options were ranked from most nominated to least.

Table 4-1 Preferred Floodplain Management Options

Floodplain Management Option	Rank
Mechanically open the lagoon entrance when a trigger water level is reached.	1
Planning and flood related development controls to ensure future development does not add to the existing flood risk.	2
Improve drainage, such as upgrades to stormwater pits and pipes to improve capacity	3
Continue the existing program of lagoon entrance clearance every 4 years.	4
Improve creek channels (including removal of weeds and bank stabilisation)	5
Flood forecasting, flood warning, evacuation planning and emergency response such as early warning systems, improved local SES capabilities/ resources or improved radio and phone communications.	6
Education of the community, providing greater awareness of the potential hazards.	7
Detention basins	8
Maintain the beach height at the entrance at a specified level and allow to open 'naturally' when the height is exceeded.	9
Voluntary house raising subsidies to assist property owners to raise existing floor levels for flood protection.	10
Levee banks	11
Increase the size of culverts or bridge opening	12
Voluntary house purchase of the worst affected properties.	13
Permanently open the lagoon entrance with hard structural measures (e.g. training walls, breakwaters, sea walls or groynes)	14
Install pipes at the lagoon entrance	15

These outcomes have been taken into account during the formulation and assessment of potential flood management options.

5 Existing Flood Behaviour

5.1 Flooding Behaviour

Flooding in the Narrabeen Lagoon catchment is caused by a number of different factors, and these factors often vary depending on where in the catchment the flooding occurs. The following sections discuss the flood behaviour in the lagoon and along the reaches of several creeks within the catchment.

5.1.1 Narrabeen Lagoon and Foreshores

As an ICOLL, one of the key drivers of flooding within the lagoon systems is the entrance condition. The entrance berm is the sand bar that separates the lagoon from the ocean during periods when the entrance is closed. When the entrance is closed, both catchment inputs and in-lake processes are the key influences on factors such as circulation and water quality.

Rainfall events lead to stormwater runoff that flows into the lagoon raising water levels. Following inflow events water levels gradually decrease due to evaporation from the water surface and seepage through the berm, particularly at higher lake water levels. Successive inflows will eventually cause the water levels to rise above the berm crest height and overtop the berm initiating scouring of the berm sands to form a channel connecting the lagoon to the ocean. During this breakout process, significant volumes of water can flow out of the lake over a period of hours. The frequency with which the entrance breaks out is therefore determined by rainfall patterns in the catchment and the volume or capacity of the lake that is in turn determined by the berm height prior to break out.

During flood events the peak water level in the lagoon is generally similar across the entire waterbody, with very little spatial variation due to a lack of a 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 low frequency events, the Ocean Street Bridge becomes an influence on flood behaviour, controlling the amount of flow that can be discharged through the entrance channel.

Longer duration flood events (with larger volumes of flood waters) are typically more critical in determining peak flood levels in the lagoon. The 9-hour, 18-hour and 24-hour rainfall events all result in similar peak flood levels in Narrabeen Lagoon (BMT WBM, 2013). In general, catchment driven flood events control peak water levels in the lagoon for design flood events; however, elevated ocean levels can also result in flooding within the Lagoon when the entrance is open. High ocean levels can also reduce the efficiency with which floodwaters flow out of the entrance of the lagoon in the event of catchment flooding, resulting in higher water levels than would occur with the entrance closed (i.e. due to catchment flooding alone).

While the critical flood levels in Narrabeen Lagoon may be controlled by longer duration rainfall events, floodwaters have the potential to rise quickly. Consequently, there may be little opportunity for warning or evacuation/emergency management prior to or during a flood. Depending on the entrance conditions (i.e. whether it is open or closed) and ocean levels, flood waters could remain elevated for many hours.

When the entrance is open, coastal processes play a more significant role in the hydrodynamics of the lagoon. Tidal processes influence lagoon water levels and the exchange of lagoon and ocean waters, thereby influencing water quality and circulation patterns in the lake. During this time, however, the action of coastal waves and currents that drive littoral sediment transport will also gradually begin to fill in the entrance channel and re-build the berm. The sand that previously formed the entrance berm gets deposited in the nearshore zone as an ebb tide delta during the entrance breakout event.

During flood tides both cross-shore and long-shore currents transport this sand from this nearshore area into the open lake entrance channel, where the lower energy environment leads to deposition and formation of a flood tide delta. In this manner, more and more sand is deposited back into the entrance and the berm re-builds. The duration of entrance open conditions is determined by these coastal processes, and in high energy coastal environments such as those occurring in the study area, the lake entrance will typically close over a period of days to weeks. As the channel accretion process progresses, the magnitude of tidal exchange gradually decreases, until the berm crest exceeds ocean high tide and blocks the ocean waters from entering the lagoon.

The entrance condition reflects a balance between these two sediment transport forces: catchment inflows and coastal processes. The natural balance between these competing processes is interrupted by mechanical opening of the lake before/during heavy rainfall events. Past land use and development in low-lying areas around the foreshore of the lake has resulted in a practice of entrance management for flood mitigation.

During open entrance periods, elevated ocean water levels (e.g. storm surge) can propagate into the lagoon and inundate low lying areas around the foreshore of the lagoon. Periods of high energy waves conditions offshore (such as during east coast lows) can result in elevated nearshore water levels due to a high contribution of wave-setup, which can result in still water levels landwards of the wave breaking zone being 0.5 to 1.0 m higher than the offshore still water level. The elevated ocean water levels can also exacerbate catchment flooding by slowing (and in some cases preventing) the release of catchment flooding to the ocean. Furthermore, elevated entrance ocean levels can reduce the hydraulic head difference between the ocean and the lagoon, thereby reducing the rate of lagoon outflow and the resulting entrance scour.

5.1.2 Warriewood Valley (Mullet, Fern and Narrabeen Creeks)

The Warriewood Valley is a densely populated, highly urbanised region of the Narrabeen Lagoon catchment. Significant development of flood prone land along the creeks has occurred in recent years.

In the upper reaches of Narrabeen Creek and Mullet Creek, flooding is generally confined to the creek channels with limited overbank flows. The contributing catchment areas are relatively small and, recent in-stream works to increase or maintain channel capacity have been effective in confining floodwaters to the creek channels, even during major flood events.

The Narrabeen Lagoon Flood Study (WBM BMT, 2013) indicates that the capacity of the existing culvert at Ponderosa Parade on Narrabeen Creek may be exceeded in events greater than the 10% AEP event, resulting in overtopping of the road. Once this occurs, some flows bypass the creek channel and are conveyed along Macpherson Street.

The Warriewood Wetlands are located in the middle reaches of the catchment, with Mullet and Fern Creeks draining directly into the wetlands. Outflow from the wetlands is controlled by the culverts under Jacksons Road. The flood storage provided by the wetlands is relatively small in comparison to the flood volumes generated by the contributing catchments in major rainfall events. Peak flood levels in the wetlands are driven by the flood condition in Narrabeen Lagoon.

In the lower reaches of Mullet Creek, the Garden Street area is affected by flooding. A significant proportion of this land, which is largely occupied by existing development, is at 2.0 m AHD or lower. Accordingly, this area is subject to significant inundation in a major flood event, and is also prone to flooding in more frequent events, such as the 20% AEP event.

5.1.3 Nareen Creek

The Nareen Creek catchment is fully developed, with the exception of Narroy Park. The creek channel is small and has limited capacity. Whilst the local catchment is subject to some risks from flash flooding, the primary cause of flooding is from elevated water levels in Narrabeen Lagoon.

5.1.4 Deep Creek

The Deep Creek catchment is largely undeveloped, with the exception of the Kimbriki Resource Recovery Centre. The upstream reaches of the catchment are subject to flash flooding; however, since there is little development in the catchment, the risk associated with this flooding is low.

Wakehurst Parkway traverses Deep Creek near its confluence with the Lagoon. The Deep Creek bridge has a deck level of approximately 3.5 m AHD, which is above the 1% AEP flood level of 3.0 m AHD. The western approach to the bridge dips to a level of around 2.5 m AHD at approximately 200 m south-west of the bridge. This low point is susceptible to flooding in events greater than the 20% AEP.

5.1.5 Middle Creek

The Middle Creek catchment is a large, largely undeveloped catchment. There is some urban development at the very top of the catchment in Frenchs Forest and Oxford Falls; however, there is little development affected by mainstream flooding of Middle Creek. Wakehurst Parkway runs adjacent to Middle Creek for the majority of its length, crossing the creek four times.

The Middle Creek channel and floodplain is relatively narrow, and is confined through the upper and middle reaches. Near its confluence with the lagoon, the floodplain widens and flattens, allowing flood flows to spread and resulting in more extensive areas of inundation. The Sydney Academy of Sport and Recreation is located near the confluence with the Lagoon. Due to the low-lying position of this site (approximately 2.0 – 2.2 m AHD) significant inundation may occur for events greater than the 20% AEP.

5.1.6 South Creek

South Creek has a densely populated catchment with development present along its entire main channel. The catchment is characterised by having a relatively narrow and steep channel and floodplain, thus there is some significant inundation in the upper and middle reaches.

Throughout the catchment there are numerous road crossings and culverts that act as local hydraulic controls. Several of these crossings are overtopped in major flood events. In the majority of cases the bridge or culvert crossing is at the low point in the road, such that floodwaters overtopping the road immediately re-enter the creek channel downstream and have limited effect on adjacent properties.

One location which is affected by insufficient culvert capacity is Alkira Circuit. Once the culvert capacity is exceeded and road overtopping occurs, the flow is conveyed down Alkira Circuit, effectively by-passing the creek channel. The by-pass flow eventually re-enters the South Creek channel via overland flow through several properties.

Flooding in South creek is generally controlled by local catchment flooding; the influence of Narrabeen Lagoon flood levels only extends to a few hundred metres downstream of Toronto Avenue. Downstream of Toronto Avenue significant inundation can occur, which is largely confined to Cromer Golf Course.

5.2 Historical Flooding

The foreshore of Narrabeen Lagoon has been flooded 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 (Pittwater Council's Website, 2010). Flooding in Narrabeen Lagoon can occur after heavy rain in the catchment, or from the ocean in the form of elevated ocean water levels due to storm surge and king tides, or a combination of both.

5.3 Infrastructure Blockage

Blockages of the stormwater drainage system, such as inlet pits, pipes, open channels and culverts, can cause significant reductions in the system's capacity. This can consequently exacerbate flooding as the stormwater runoff is conveyed overland. Blockages of major culverts and overtopping of road crossings have historically occurred during large storm events, as observed in Wollongong in 1998 and Newcastle in 2007. During those events, some stormwater culverts were completely blocked by debris.

Several modes of blockage of the stormwater drainage system may occur. Blockage may result from a build-up of debris such as leaves, litter, and/or sediment, which progressively accumulate over time. During storm events debris from building sites, unsecured items from properties, tree branches and even vehicles can also cause blockages.

As part of the Narrabeen Lagoon Flood Study (BMT WBM, 2013) a sensitivity test on the design flood conditions was undertaken to consider the potential impact of blockage of structures on flood behaviour. Map A43 of BMT WBM (2013) shows the results of that sensitivity analysis. It found that the blockage of structures resulted in some significant flood impacts, such as a 0.2 to 0.5 m increase in flood levels in Warriewood, and a flood level increase of over 0.5 m in South Creek upstream of the Toronto Avenue bridge. Flood levels in Narrabeen Lagoon were unaffected by modelled blockages.

5.4 Flood Hazard

The objective of this section of the FRMS is to establish flood hazard categories that identify areas where there may be significant risk to property and or to life; that is, to pedestrians, vehicles and people in buildings. The flood risk at any given location in the floodplain is a function of the likelihood of a flood event occurring and the potential consequences (i.e. loss of life or property damage) resulting from the flood event. The flood risk is described in flood hazard categories based the following factors:

> Flood hazard threshold curves to identify the depth and velocity of floodwaters at which stability of pedestrians, vehicles and buildings are at risk (**Section 5.4.1**); and

> The design flood event adopted as the basis for the flood hazard category (**Section 5.4.2**).

5.4.1 Hazard Thresholds

Provisional hydraulic hazard, which addresses the first point above and is a function of velocity and depth, is mapped for the full range of design flood events (i.e. AEPs) in accordance with Figure L2 of the NSW Government's Floodplain Development Manual (2005) (**Figure 5-1**). There are two hazard categories using this approach:

> High hazard – the velocity and/or depth are sufficiently high as to present a risk to personal safety. Evacuation by trucks is difficult, able-bodied adults would have difficulty in wading to safety, and there is potential for significant structural damage to buildings; and

> Low hazard – the velocity and/or depth are lower and, should it be necessary, trucks could evacuate people and their possessions, and able-bodied adults would have little difficulty in wading to safety.

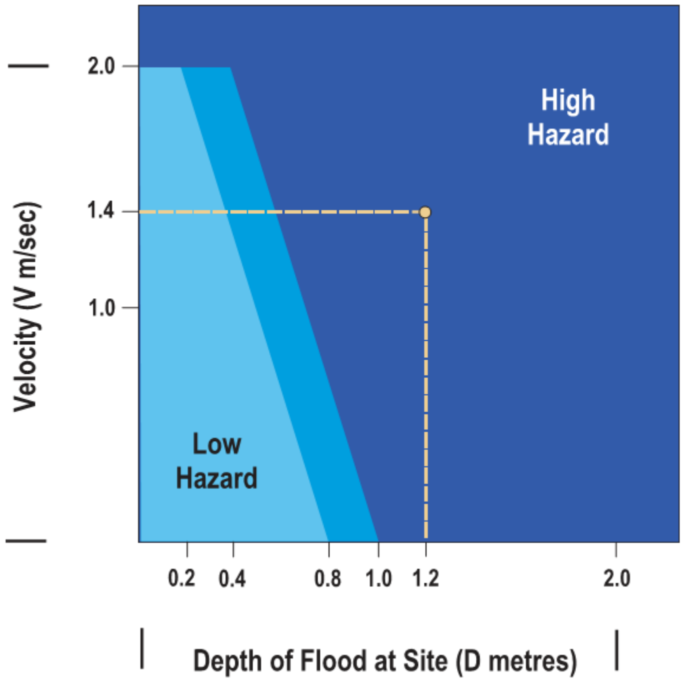


Figure 5-1 Provisional Hazard Categories (Source: NSW Government, 2005)

The provisional flood hazard assessment was undertaken and the categories mapped for the Narrabeen Lagoon floodplain for the 20%, 5% and 1% AEP flood events, and the PMF event as part of the Narrabeen Lagoon Flood Study (BMT WBM, 2013).

More recently an updated set of hazard thresholds has been proposed in the Technical Flood Risk Management Guideline: Flood Hazard (Australian Institute for Disaster Resilience, 2014) that focus in greater detail on the hydraulic scenarios where pedestrian, vehicle and building stability is at risk. Further guidance is provided in Australian Emergency Management (AEM) Handbook 7: Managing the floodplain: best practice in flood risk management in Australia (Australian Institute for Disaster Resilience, 2014) prepared by the National Flood Risk Advisory Group (NFRAG), working with the AEM Institute with a view to updating national best practice in flood risk management.

The flood hazard categories in the Technical Flood Risk Management Guideline: Flood Hazard (Australian Institute for Disaster Resilience, 2014) identify the thresholds where the stability is at risk for:

> Vehicles – hazard thresholds are identified for small vehicles (categories H2 and higher) and other types of vehicles (categories higher than H2);

> Pedestrians – hazard thresholds are identified for children and the elderly (categories H3 and higher), as well as all other types of pedestrians (categories higher than H3); and

> Buildings – hazard thresholds are identified for typically constructed buildings (categories lower than H5) as well as more stable, buildings with specific design features (categories lower than H6).

The resultant flood hazard curves are shown in **Figure 5-2** and the associated vulnerability thresholds are shown in **Table 5-1**.

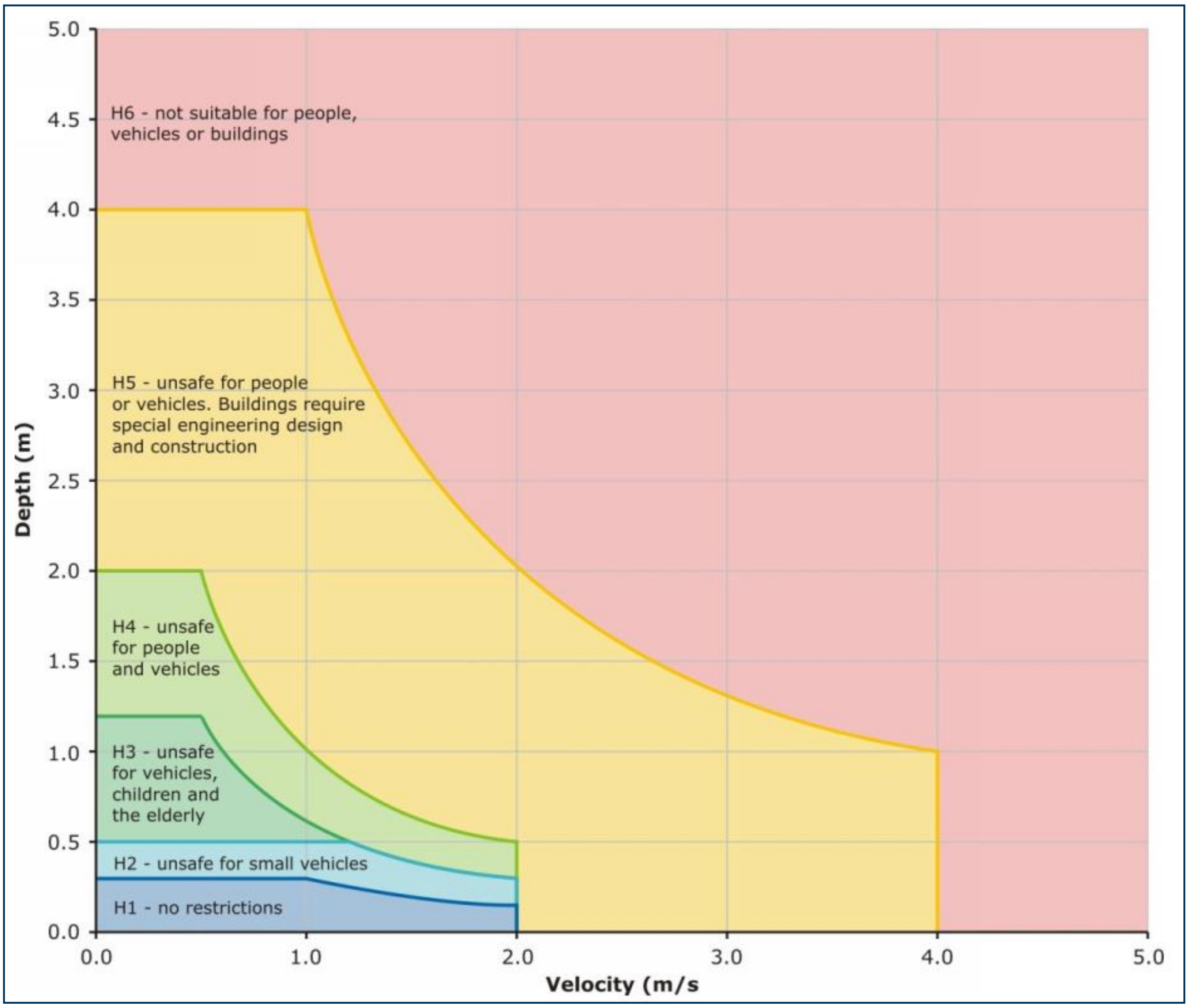


Figure 5-2 Combined Flood Hazard Curves (Source: Australian Institute for Disaster Resilience, 2014)

The curves in **Figure 5-2** represent the hydraulic category H2 at which vehicles will become mobilised, however pedestrian stability is not compromised until category H3. Hence, the increase in cumulative flood risk for people living or working in the floodplain is not expected to be significantly compromised at this hazard level. Therefore, hazard thresholds H1 and H2 have been grouped together into the lowest possible risk category for purposes of this assessment of flood risk to life.

Similarly, there is assumed to be a minimal increase in the cumulative flood risk to the population at the threshold between the H3 and H4 categories. The difference between the two hazard categories is that adult pedestrians are considered able to maintain stability (i.e. walk through floodwaters) at the H3 hydraulic category, but not in the H4 category; however, given it is assumed that children and the elderly will be unstable where the hydraulic characteristics correspond to the H3 category, it has been assumed for this assessment that the overall level of risk to pedestrians is similar. The two hazard groups have therefore been grouped together.

Table 5-1 Combined Hazard Thresholds

Hazard Categories	Description
H1 – H2	Relatively benign flow conditions. Unsafe for small vehicles.
H3 – H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. Buildings require special engineering design and construction.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

5.4.2 Design Flood Events

The above flood hazard categories can be mapped for each design flood event. For the more frequent flood events (such as the 20% AEP) the area of the floodplain mapped to the hazard categories will be smaller, and for the less frequent (or larger) flood events up to the PMF, the mapped areas will get progressively larger. That is, the more likely a flood event, the less likely it is to cause harm to people or property.

To determine the cumulative flood risk at any given location and accounting for all design flood events, it is necessary to adopt a single design flood event upon which to derive flood hazard category mapping.

The NSW Government's Floodplain Development Manual (2005) states the following:

> *"Response planning for the consequences of the PMF provides for effective management of smaller events, particularly those rarer than the flood event selected as the basis of the Flood Planning Level (FPL). For example, where 1% AEP flood is used as the basis for minimum floor levels or protection from a levee, a 0.5% AEP flood event will probably overwhelm these measures. This event, whilst smaller, but significantly more likely than the PMF, will have major consequences to people, property, and infrastructure and needs to be accounted for in emergency response planning."*
>
> *"An assessment of the full range of events therefore provides key information for flood response studies".*
>
> *"It is critical that relevant information on evacuation is provided on events up to the PMF".*

Based on the above, the PMF should be adopted as a design flood event when considering flood risk to life and property. As noted in the Manual, the Flood Planning Level is based on the 1% AEP event so the most significant costs to life and property occur in events falling between the PMF and the 1% AEP event.

A review of the literature was conducted, and their guidance on the selection of design flood events for consideration of flood risk is summarised below:

- Chapter 11 of Managing Flood Risk through Planning Opportunities – Guidance on Land Use Planning in Flood Prone Areas (HNFMSC, 2006) stresses the importance of considering flood emergency response for all events up to the PMF;
- The Flood Emergency Response Planning Classification of Communities Guideline (NSW Government, 2007) was prepared by the Department of Environment and Climate Change (now OEH) and the State Emergency Service (SES). The guideline provides a basis for emergency response categorisation of floodplain communities, and states that categories should be considered for the PMF event (as well as the 20 year and 100 year events);
- In 2013 the Australasian Fire and Emergency Service Authorities Council released its Guideline on Emergency Planning and Response to Protect Life in Flash Flood Events. The guideline reflects a consensus on best practice for managing flash flooding, focussing on risk to life. It advises that ideally buildings intended for shelter-in-place should have habitable floors that will be flood free in a PMF event;
- The Technical Flood Risk Management Guideline: Flood Hazard (Australian Institute for Disaster Resilience, 2014) recommends the national adoption of PMF as the design event for emergency response classifications, similar to the NSW Flood Emergency Response Planning guidelines.

5.4.3 Flood Hazard Category Mapping

The flood hazard categories for the Narrabeen Lagoon catchment were mapped in **Figures 5-3 and 5-4** for the PMF event based on the flood hazard classifications in **Section 5.4.1**.

As discussed in **Section 5.4.1**, the regions shown in **Figure 5-3** and **Figure 5-4** indicate the following.

> H1-H2: Green regions are areas where the flood risk is negligible for people, vehicles, and buildings;

> H3-H4: Yellow regions are areas where the majority of pedestrians and vehicles are unstable and there is risk of harm or loss of life of people; however, the majority of buildings are likely to be structurally stable;

> H5: Orange regions are areas where the majority of pedestrians and vehicles are unstable and harm or loss of life to people is likely. In addition, the majority of buildings are susceptible to failure unless they are specially designed to be stable under flood forces; and

> H6: Red regions are areas where the majority of pedestrians and vehicles are unstable and there is risk of harm or loss of life of people. In addition, the majority of buildings would be susceptible to failure, even if they have been specially designed to withstand flood forces.

The PMF hazard maps (**Figures 5-3 and 5-4**) show the full extent of flood risk, thus the use of these maps for emergency response will reduce the likelihood that people are placed at risk. However, noting that the intensity of a flood event is rarely known at the time it is occurring, hazard maps for the 1% AEP were also developed to gain an appreciation of the most at risk locations in the catchment (refer **Figure 5-5** and **Figure 5-6**).

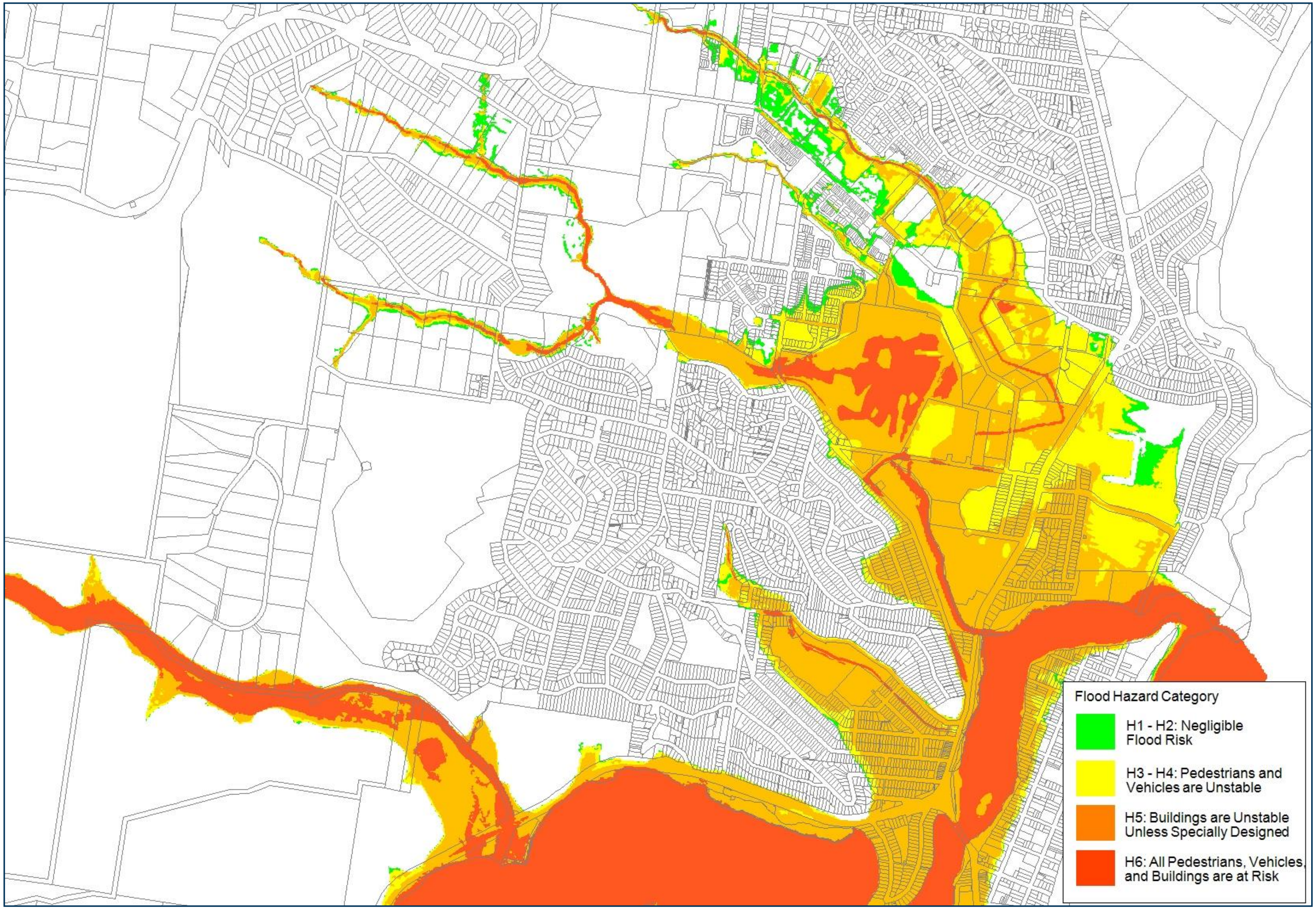


Figure 5-3 Flood Hazard Categories Northern lagoon catchment – PMF Event

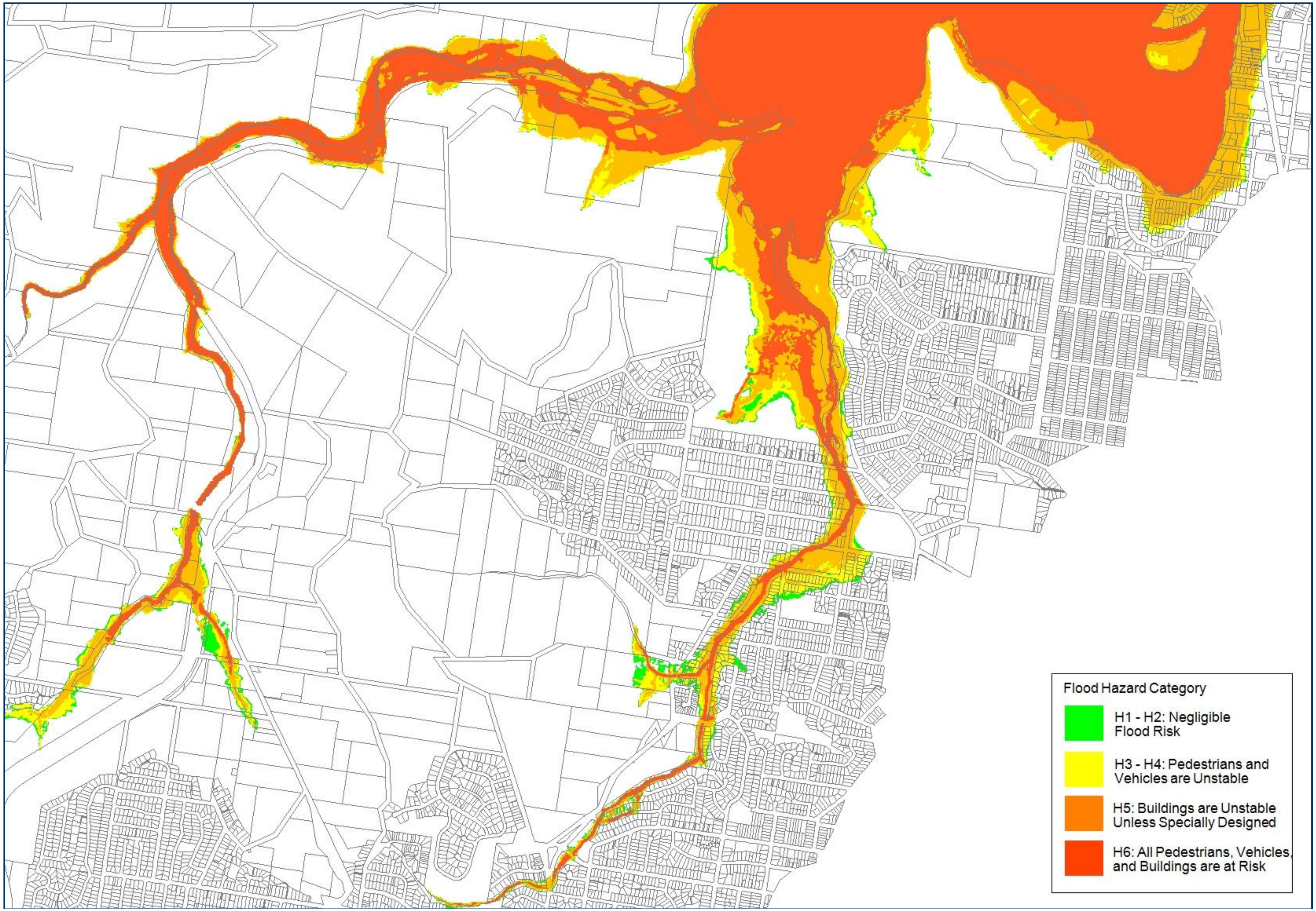


Figure 5-4 Flood Hazard Categories – Southern lagoon catchment – PMF Event

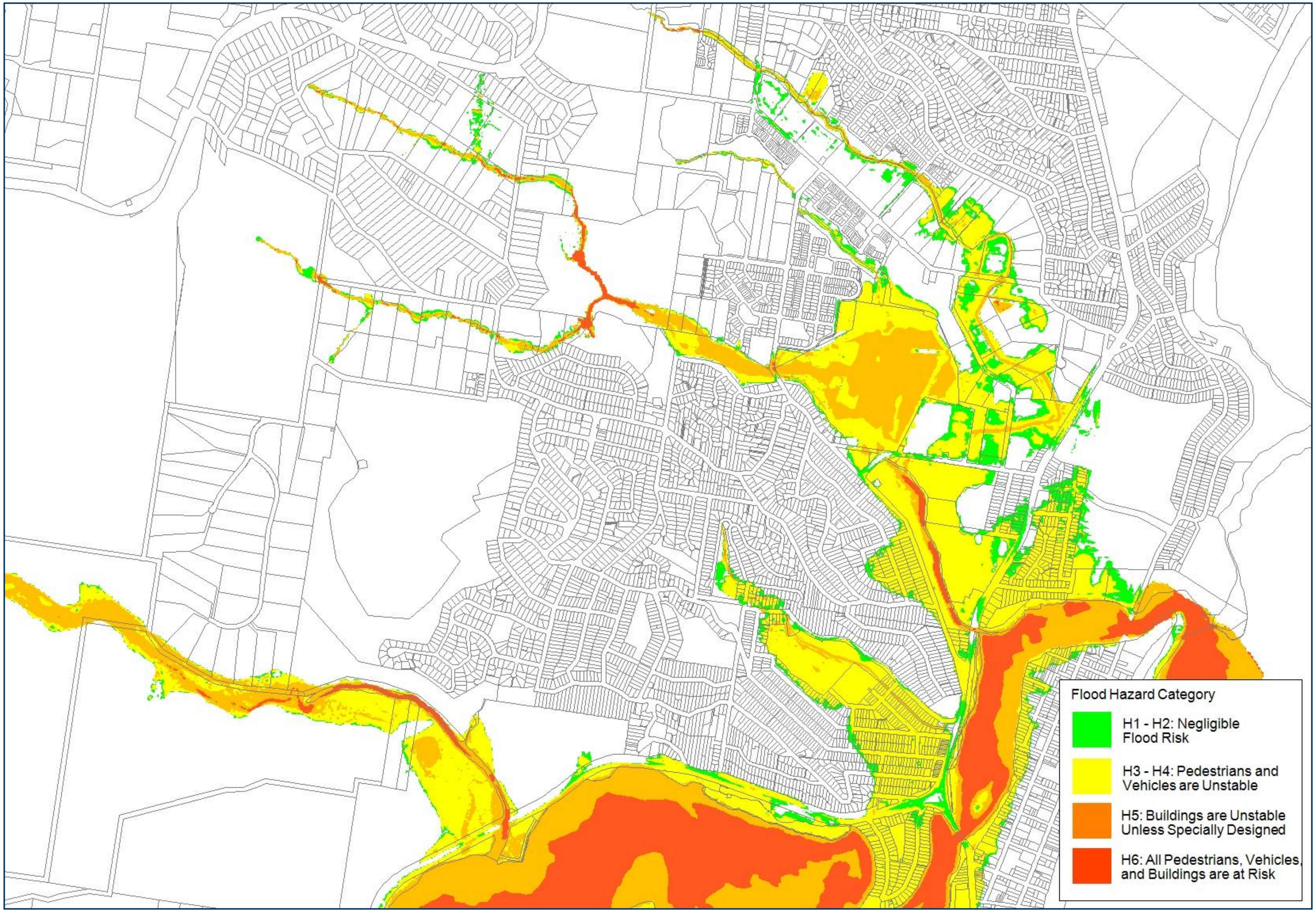


Figure 5-5 Flood Hazard Categories – Northern lagoon catchment – 1% AEP Event

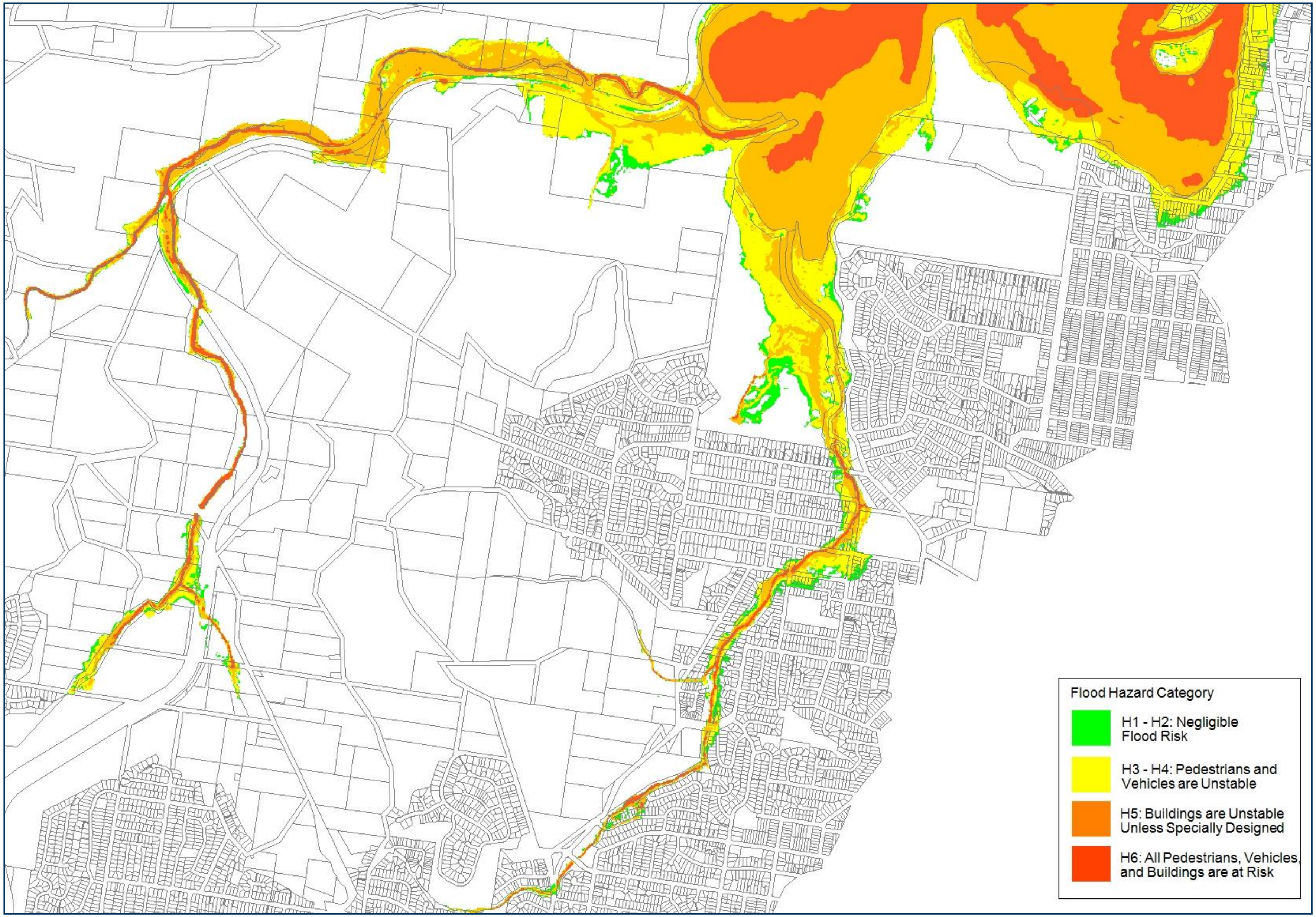


Figure 5-6 Flood Hazard Categories Southern lagoon catchment – 1% AEP Event

5.4.4 Property Flooding

The number of properties affected by flooding in the Narrabeen Lagoon Catchment for selected flood events is listed in **Table 5-2**. A total of 20,011 properties are present within the catchment.

Table 5-2 Properties Currently Affected by Flooding

Flood Event	Number of Flood Affected Properties	Number of Properties with Over floor Flooding
20% AEP	1,971	229
5% AEP	2,212	490
1% AEP	2,354	659
0.1% AEP	2,601	887
PMF	3,111	1,392

*Based on extents from the Narrabeen Lagoon Flood Study (BMT WBM, 2013). Note that units within an apartment block are considered to be individual properties.

5.4.5 Critical Infrastructure and Vulnerable Developments

During a flood certain public infrastructure becomes critical when considering flood risk for the following reasons:

> *Vulnerable development* – Relates to the increased risk of loss of life due to the concentration of vulnerable people such as children, the elderly and ill or disabled people associated with certain land use types. These types of people have a significantly greater risk to life when exposed to flood hazard. In addition, there may be increased risk to life to these people resulting from periods of isolation from medical emergency services due to pre-existing health conditions. Their generally lower levels of mobility are likely to reduce the effectiveness of an emergency response (e.g. they will be harder to evacuate). Vulnerable developments include:

- Schools;
- Childcare centres;
- Aged care facilities;
- Retirement villages; and
- Caravan parks.

> *Critical Infrastructure* – The infrastructure considered critical during a flood event include facilities that are either relied upon for emergency management or otherwise provide essential services. Critical infrastructure include:

- Hospitals;
- Sewerage facilities such as treatment plants;
- Electricity substations;
- Emergency services facilities such as ambulance stations, fire stations, and police stations; and
- NSW SES facilities.

The vulnerable developments and critical infrastructure located in the Narrabeen Lagoon study area have been mapped in **Figure 5-7**.

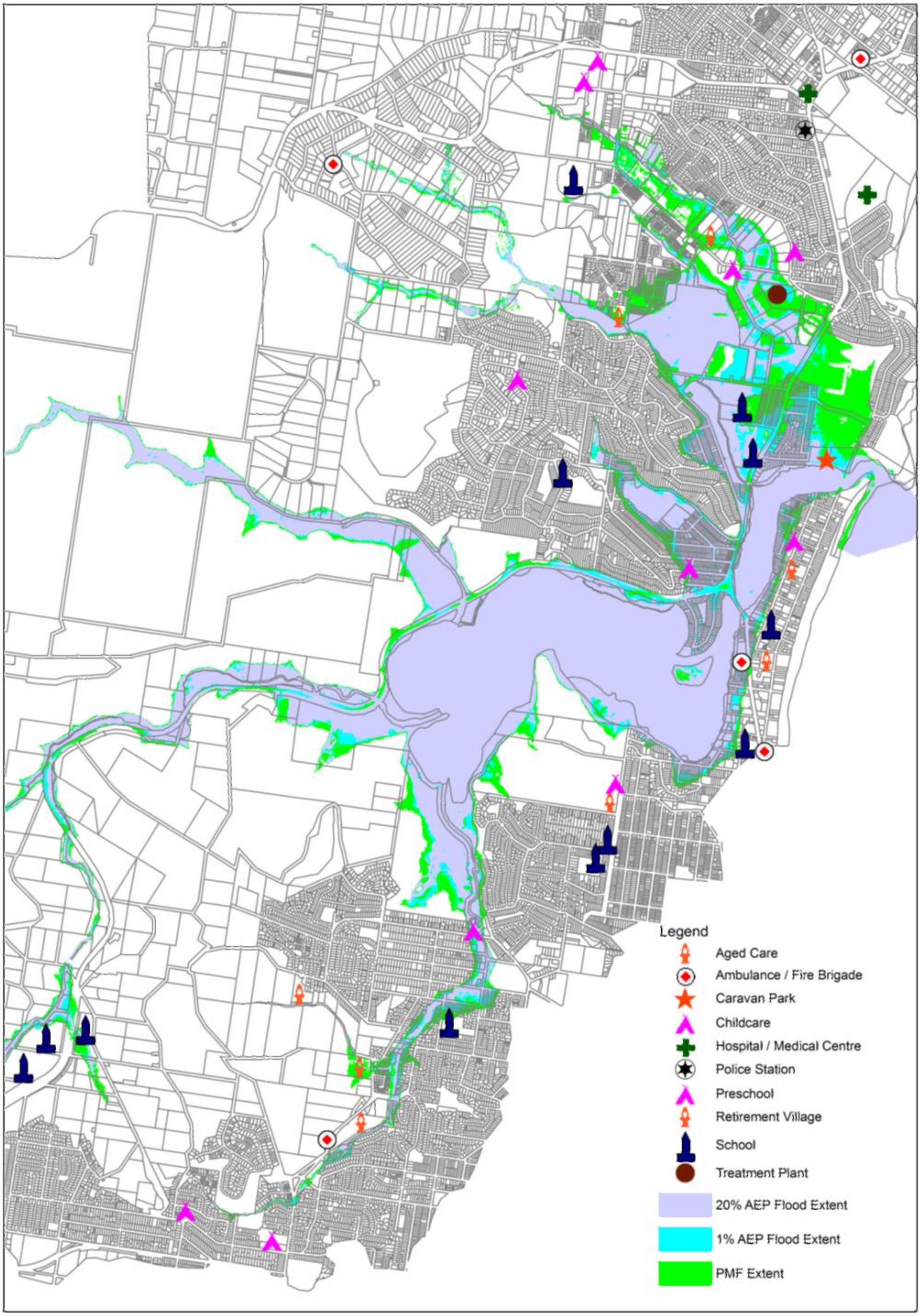


Figure 5-7 Critical Infrastructure and Vulnerable Land Uses

5.5 Coincident Flooding

As discussed in **Section 5.1**, flooding in the Narrabeen Lagoon catchment can occur as a result of catchment flows, elevated ocean water levels, or a combination of both. The Flood Study (BMT WBM, 2013) modelled three scenarios to define the 1% AEP flood event with various combinations of catchment flooding and elevated ocean levels. The design rainfall events adopted for the catchment flooding inputs were consistent with those outlined in AR&R 1987, and the ocean scenarios modelled as outlined in the Flood Risk Management: Incorporating sea level rise benchmarks in flood risk assessments (DECCW, 2010). The various combinations of 1% AEP events modelled were:

- 1% AEP catchment only flood event modelled with normal ocean levels (0.6 m AHD) for all rainfall event durations from 15 minute to 24 hours;
- Coincident 1% AEP catchment event with 5% AEP ocean levels (2.25 m AHD), only the 9 hour rainfall event was modelled; and
- Coincident 5% AEP catchment with 1% AEP ocean event (2.6 m AHD), only the 9 hour rainfall event was modelled.

The peak envelope of these three scenarios (i.e. the worst of these three scenarios) has been adopted as the design 1% AEP, consistent with the design envelope approach discussed within NSW Government Floodplain Risk Management Guide: Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways (NSW Government, 2015). The reason the “worst case” scenario was adopted using this envelope approach is that the coincident catchment rainfall and ocean events were not run for the full range of rainfall event durations. If they were, the coincident 1% AEP / 5% AEP event would be critical throughout the Narrabeen Lagoon floodplain as the catchment driven levels would be identical between the catchment only and the coincident 1% AEP / 5% AEP event

A note on the critical events across the Narrabeen Lagoon floodplain.

- The coincident 5% AEP catchment with 1% AEP ocean event is not critical anywhere within the floodplain for events where climate change is not a factor.
- The 1% AEP catchment only event is only critical in upper catchment locations where tailwater effects are negligible and where the 9 hour design event is not critical.
- The coincident 1% AEP rainfall with 5% AEP ocean is critical in tailwater affected locations and where the 9 hour duration is critical.

The coincident flooding event has peak water levels between 0.06 – 0.09 m higher than the catchment only event for the lower Narrabeen Lagoon floodplain; including lower South Creek, Nareen Creek and Warriewood floodplains.

5.6 Climate Change

5.6.1 Climate Change Modelling for Narrabeen Lagoon

Several climate change scenarios were modelled for the 1% AEP flood event as part of the Narrabeen Lagoon Flood Study (BMT WBM, 2013). Similar to the coincident elevated ocean scenarios, these were only modelled for the 9 hour duration storm. Two climate change scenarios were modelled:

- Sea level rise only, with two sub-scenarios - 0.4 m sea level rise corresponding to the 2050 planning horizon) and 0.9 m sea level rise corresponding to the 2100 planning horizon, as specified in the now repealed NSW Sea Level Rise Policy Statement (NSW Government, 2009); and
- Sea level rise and rainfall intensity increase – the two sea level rise scenarios above were also combined with projected rainfall intensity increases of 10%, 20% and 30%, as per the values in the Floodplain Risk Management Guideline: Practical Consideration of Climate Change (NSW Government, 2009).

A comparison of the peak water level results in Narrabeen Lagoon (and its surrounds) for the climate change scenarios described above is shown in **Section 5.5**.The worst case scenario for these climate change scenarios is the 0.9 m sea level rise combined with the 30% rainfall increase.

In all design events Narrabeen Lagoon and its surrounds (including the lower portions of the South Creek, Nareen Creek and Warriewood floodplains) has a consistent water level across a large area that covers the majority of flood-affected properties in the catchment.

Table 5-3 Comparison of Peak Flood Levels Across Narrabeen Lagoon for Design Flood Scenarios

Climate Scenario	Narrabeen Lagoon Peak Water Level (m AHD)	Compared to Current Climate 1% AEP Level (m)
Existing Climate Conditions	3.0	-
0.4 m Sea Level Rise Only	3.2	+0.2
0.9 m Sea Level Rise Only	3.5	+0.5
10% Rainfall Increase	3.1	+0.1
20% Rainfall Increase	3.2	+0.2
30% Rainfall Increase	3.3	+0.3
0.4 m Sea Level Rise and 10% Rainfall Increase	3.3	+0.3
0.4 m Sea Level Rise and 20% Rainfall Increase	3.4	+0.4
0.4 m Sea Level Rise and 30% Rainfall Increase	3.5	+0.5
0.9 m Sea Level Rise and 10% Rainfall Increase	3.6	+0.6
0.9 m Sea Level Rise and 20% Rainfall Increase	3.7	+0.7
0.9 m Sea Level Rise and 30% Rainfall Increase	3.8	+0.8

The results in **Table 5-3** show that the flood behaviour of the Narrabeen Lagoon floodplain is sensitive to 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.

5.6.2 Review of Modelled Sea Level Rise Scenarios

The modelled sea level rise values of 0.4 m by 2050 and 0.9 m by 2100 were based on previous guidance provided in the now repealed NSW Sea Level Rise Policy Statement (NSW Government, 2009). More recently, revised climate change projections have been released by the Intergovernmental Panel on Climate Change (IPCC, 2014). A graphical summary of projected sea level rise ranges are shown in **Figure 5-8** for four possible Representative Concentration Pathways (RCPs) that represent different future emissions scenarios.

RCP2.6 is a “best case” scenario for emissions reductions and RCP8.5 as a “worst case” scenario. For example, for RCP8.5, global mean sea level rise for 2081-2100 relative to 1986-2005 is projected to be in the range of 0.45 to 0.98 m.

The NSW Government (2009) 2050 and 2100 sea level rise benchmarks was reviewed in the context of the latest IPCC data for the local area as part of the Collaroy-Narrabeen Beach and Fishermans Beach CZMP (Haskoning, 2014). Haskoning (2014) determined the previous 2050 and 2100 benchmarks remain appropriate for adoption in light of the updated advice provided by the IPCC.

Therefore, future development should be appropriately accommodating projected sea level rise.

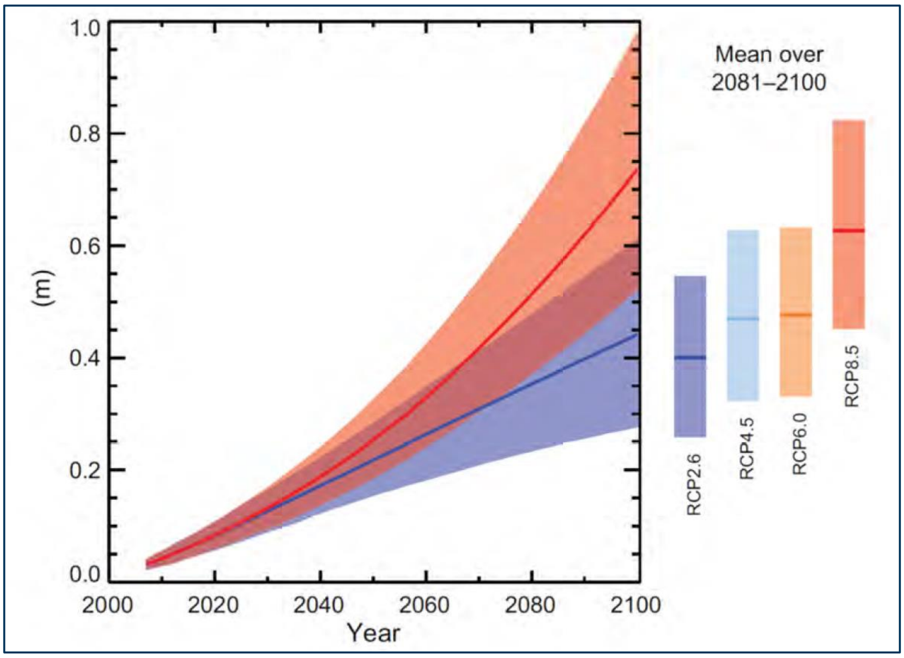


Figure 5-8 Global mean sea level rise predictions to 2100 relative to 1986-2005 for various RCPs (Source: IPCC, 2014)

5.6.3 Review of Modelled Rainfall Increases

Rainfall intensity is also predicted to change in the future, although the literature indicates less certainty around magnitude of change arising from climate change. The Floodplain Risk Management Guideline: Practical Consideration of Climate Change (NSW Government, 2009) recommends analysing a range of increases in rainfall between 10 and 30% for floodplain management assessments.

Recent reports suggest a 5% increase in rainfall intensity per degrees Celsius of global warming is likely (Engineers Australia, 2014). With a predicted mean temperature increase of 0.3 – 4.8 °C by 2100 (IPCC, 2014) based on the four RCPs modelled by the IPCC under a range of scenarios, this equates to an increase in intensity in the range 5 - 25%. Accordingly, the use of a maximum 30% increase in rainfall intensity is a reasonable approach to assess the potential impact of climate change on rainfall patterns.

In relation to rainfall changes associated with climate change, it is anticipated that updated Intensity-Frequency-Duration (IFD) information for climate change may become available as part of the Australian Rainfall and Runoff revision. In the meantime, however, the rainfall intensity increases adopted in this FRMS are seen as appropriate.

6 Economic Impact of Flooding

6.1 Background

In the past flooding in the Narrabeen Lagoon catchment has caused property damage, required evacuations, and blocked road access, or otherwise impacted a broad range of people in the local community.

The economic impact of flooding can be defined by what is commonly referred to as "flood damages". Flood damages are classified in different categories (refer **Table 6-1**).

Table 6-1 Flood Damages Categories

Type of Flood Damage		Description
Tangible	Direct	Building contents (internal) Structure (building repair and clean) External items (vehicles, contents of sheds etc.)
	Indirect	Clean-up (immediate removal of debris) Financial (loss of revenue, extra expenditure) Opportunity (non-provision of public services)
Intangible		Social – increased levels of insecurity, depression, stress General inconvenience in post-flood stage

Direct damages are just one component of the entire cost of a flood event (refer **Table 6-1**). There are also indirect costs. Both direct and indirect costs are referred to as 'tangible' costs. There are also intangible costs, such as social distress. The flood damage values discussed in this report are tangible damages only and do not include an assessment of the intangible costs, which are difficult to calculate in economic terms.

Flood damages can be assessed by several methods, including the use of computer programs such as FLDAMAGE or ANUFLOOD, or via more generic methods using spreadsheets. Generic spreadsheets and damage curves developed by the OEH have been used for this FRMS.

6.2 Floor Level and Property Survey

The floor level survey data used for the flood damages estimation includes the survey data provided by Council and the property and floor level survey obtained as part of this project (see **Section 3.2** and **Figure 3-1** and **Figure 3-2**). Levels for 2041 land parcels (including, where relevant, multiple unit floor levels within a land parcel) were used in this assessment. All floor levels for properties affected by the 1% AEP event are contained in the dataset, and an additional 170 properties that are affected by the PMF event only have had their floor levels estimated based on the average floor levels of adjacent buildings for which survey data was available.

The floor levels were used only to assess the annual average damage calculations in this report. The levels are not used by Council in determining which properties are flood affected. This approach is considered adequate as these locations are only affected in very rare events and do not contribute significantly to the average annual flood damages.

In some locations it was identified that while over floor flooding was predicted, local landforms shown in the model resulted in the particular location of the spot level within the model to be flood free. In these locations some minor adjustments were made to floor level locations to enable calculation of the flood damages. These adjustments involved slightly moving the recorded survey location so that the flood extent intersected the point.

6.3 Damage Analysis

A flood damage assessment for the existing catchment conditions was completed as part of this study. The assessment was based on damage curves that relate the depth of flooding on a property to the likely damages within that property. Ideally, the damage curves should be prepared for the particular catchment for which the study is being carried out. However, damage data in most catchments is not available, and therefore damage curves from other catchments and available research have been used as a substitute.

OEH has conducted research and prepared a draft methodology for the development damage curves based on state-wide historical data. This methodology is only for residential properties and does not cover industrial or commercial properties. The OEH methodology is only a recommendation, and there are currently no strict guidelines regarding the use of damage curves in NSW.

The following sections outline the method used for determination of flood damages in the Narrabeen Lagoon catchment.

6.3.1 Residential Damage Curves

Residential damage curves were created based on Floodplain Management Guideline No. 4 Residential Flood Damage Calculation (the then NSW Department of Natural Resources, now OEH). This guideline includes a template spreadsheet program that determines damage curves for three types of residential buildings, namely:

- Single story, slab on ground;
- Two story, slab on ground; and
- Single story, high set.

Damages are generally incurred on a property prior to any over floor flooding. The OEH curves allow for damages of $9,552 (June 2015 dollars) to be incurred when the water level reaches the base of the house, with the base of a slab-on-ground house assumed to be 0.3 m below the floor level. We have assumed that this remains constant until over floor flooding occurs. This may occur on steeper properties and larger properties where the garden and fences may be impacted, but the flood waters do not reach the house.

Several input parameters are required to use the OEH curves, such as floor area and level of flood awareness. The following parameters were adopted.

- A value of 150 m^2 was adopted as a conservative estimate of the floor area for residential dwellings in the floodplain. With a floor area of 150 m^2, the contents value is estimated at $53,465 (June 2015 dollars);
- The effective warning time has been assumed to be zero due to the nature of flooding and the difficulty in providing much flood warning in the catchment. A long effective warning time allows residents to prepare for flooding by moving valuable household contents and hence reducing the potential damages to household contents.

6.3.1.1 Average Weekly Earnings

The OEH curves were derived for late 2001 and have been updated to represent November 2014 dollars (**Table 6-2**). General recommendations by OEH are to adjust the values in residential damage curves by Average Weekly Earnings (AWE) rather than by the inflation rate measured by the Consumer Price Index (CPI). OEH proposes that AWE is a better representation of societal wealth, and hence an indirect measure of the building and contents value of a home. The most recent data from the Australian Bureau of Statistics at the time of this study was for November 2014. Therefore, all ordinates in the residential flood damage curves were updated to November 2014 dollars. In addition, all damage curves include Goods and Services Tax (GST) as per OEH recommendations.

The OEH guidelines were developed in November 2001, which allows us to use the November 2001 AWE statistics (issued quarterly) for comparison purposes. November 2014 AWE values were taken from the Australian Bureau of Statistics website. Consequently, damages have been increased by 68% when compared to 2001 values, which includes the increase due to GST.

Table 6-2 Average Weekly Earnings (AWE) Statistics for Residential Damage Curves

Month	Year	AWE
November	2001	$673.60
November	2014	$1,128.70*

*Source: Australian Bureau of Statistics (2014)

6.3.2 Commercial Damage Curves

Commercial damage curves were adopted from the FLDamage Manual (Water Studies Pty Ltd, 1992). FLDamage allows for three types of commercial properties:

> Low value commercial;
> Medium value commercial; and
> High value commercial.

In determining these damage curves, it has been assumed that the effective warning time is approximately zero, and the loss of trading days as a result of the flooding has been taken as 10.

These curves are determined based on the floor area of the property. Existing floor level surveys provide an estimate of the floor area of several individual commercial properties. When this data was not available, an indicative value of 150m^2 was adopted. The areas have been used to factor these curves.

The Consumer Price Index (CPI) was used to bring the 1990 data to June 2015 dollars (**Table 6-3**), using data from the Australian Bureau of Statistics (2015). It was assumed that the FLDamage data was in June 1990 dollars. Consequently, commercial damages have been increased by 88% and GST has been included compared to 1990 values.

Table 6-3 CPI Statistics for Commercial Damage Curves

Month	Year	CPI
June	1990	57.10
June	2015	107.5

6.4 Industrial Damage Curves

As part of the Allans Creek Floodplain Management Study, Cardno conducted a survey of industrial properties in 1998 for Wollongong City Council (Cardno Lawson Treloar, 2006). The damage curves derived from that survey are more recent than those presented in FLDamage and have been used in several previous studies. Therefore, these damage curves are considered the most appropriate for use in this study.

The curves were prepared for three categories:

> Low value industrial;
> Medium value industrial; and
> High value industrial.

The survey only accounted for structural and contents damage to the property. Clean-up costs and indirect financial costs were estimated based on the FLDamage Manual (Water Studies Pty Ltd, 1992). Actual internal damage could be estimated, along with potential internal damage, using various factors within FLDamage. Using both the actual and potential internal damages, estimation of both the clean-up costs and indirect financial costs could be made. The values were adjusted to June 2015 dollars using a CPI value of 67.4 compared to June 1998.

Consequently, damages have been increased by 59.5% and GST has been included, compared to 1998 values.

6.5 Adopted Damage Curves

The adopted damage curves are shown in **Figure 6-1** and **Figure 6-2**. For illustrative purposes the commercial and industrial damage curves are shown assuming a floor area of 150m^2, although the actual floor areas for each commercial or industrial property were used where available.

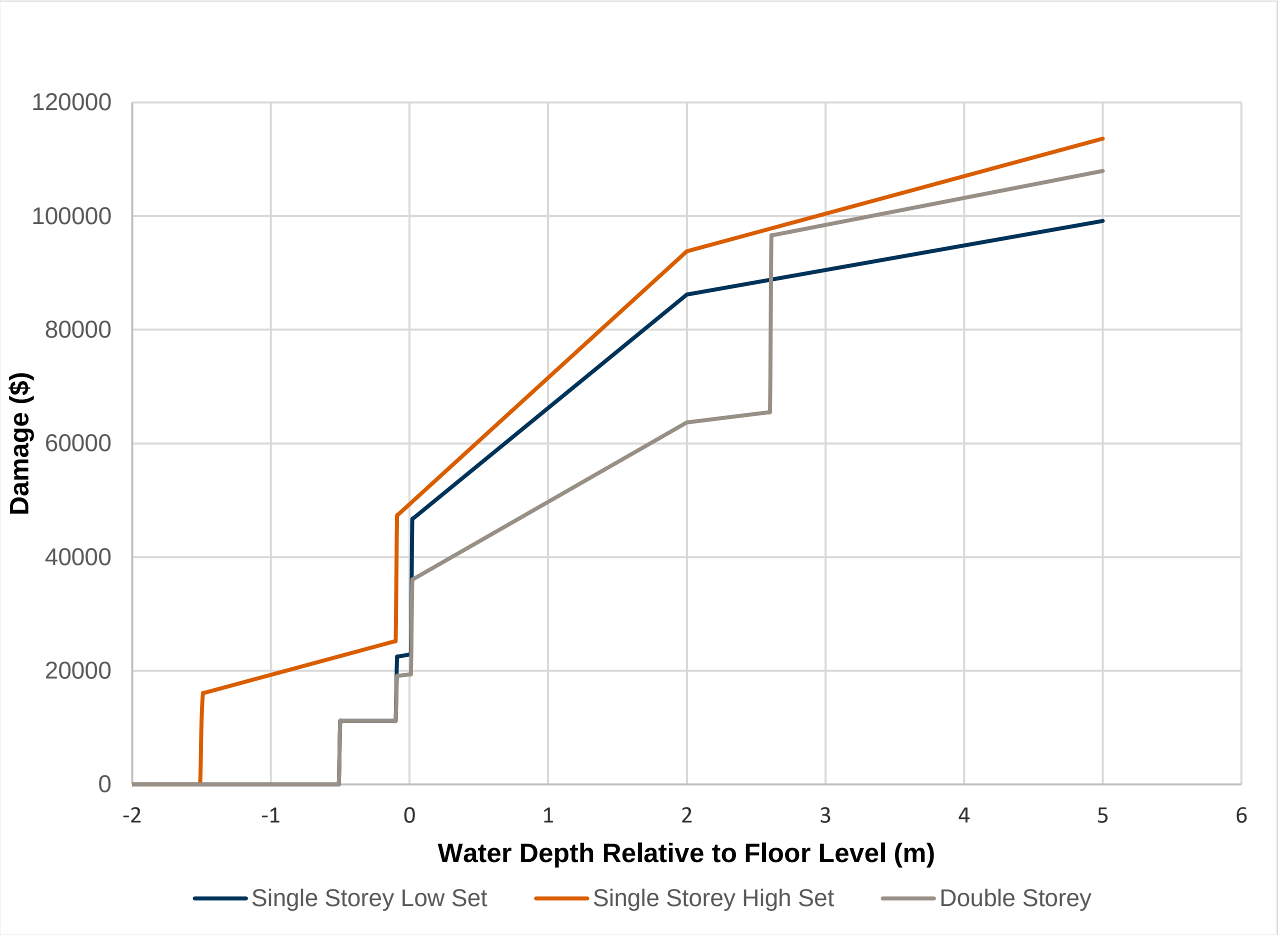


Figure 6-1 Residential Damage Curves

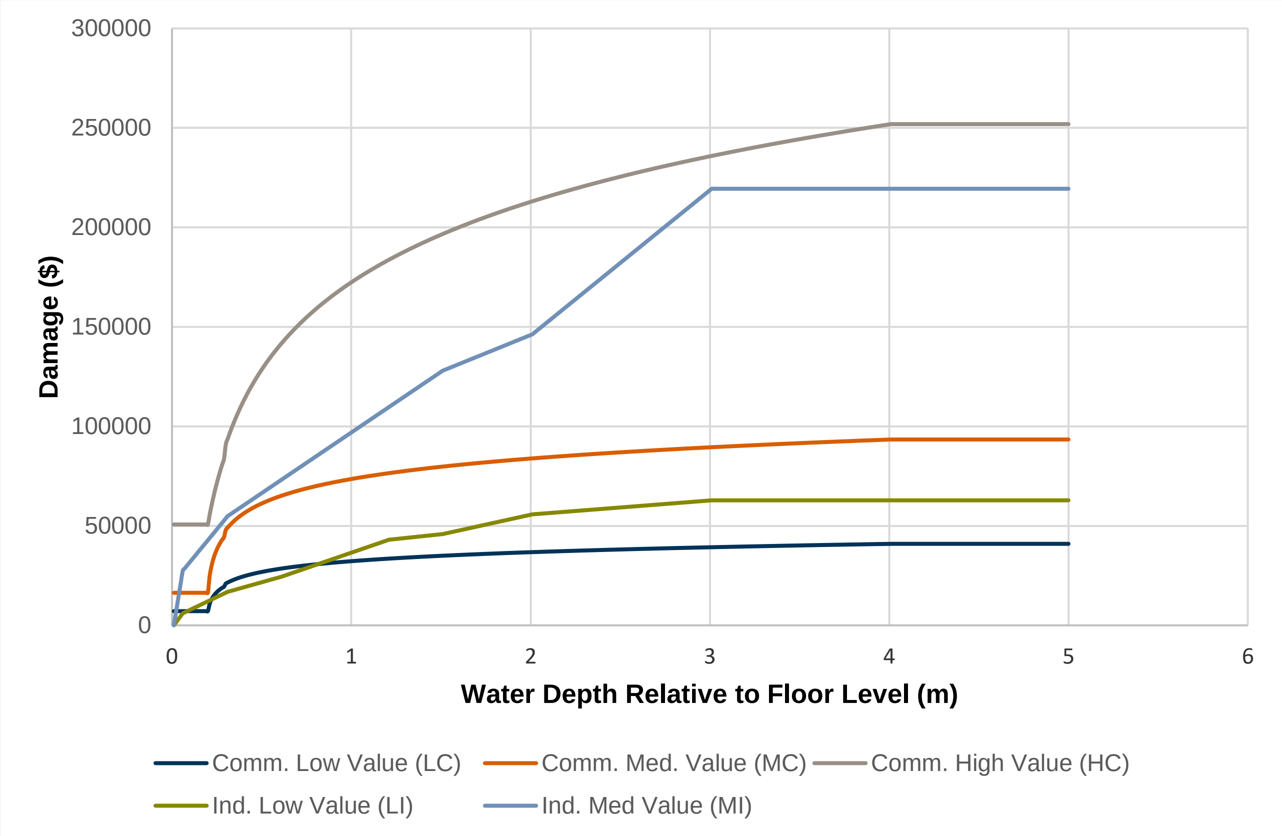


Figure 6-2 Industrial and Commercial Damage Curves

6.6 Total Damages

The total damage results from the damage analysis are shown in **Table 6-4**.

Table 6-4 Narrabeen Existing Damage Analysis Results

	Properties with over floor flooding	Average Over floor Flooding Depth (m)	Maximum Over floor Flooding Depth (m)	Properties with overground flooding*	Total Damages ($)
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

	Properties with over floor flooding	Average Over floor Flooding Depth (m)	Maximum Over floor Flooding Depth (m)	Properties with overground flooding*	Total Damages ($)
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

*Used for Garden Damages and Only Calculated on Residential Properties

6.7 Average Annual Damage

Average Annual Damages (AAD) are calculated using a probability approach based on the flood damages calculated for each design event.

Flood damages (for a design event) are calculated by using the damage curves described above. These damage curves attempt to define the damage experienced on a property for varying depths of flooding. The total damage for a design event is determined by adding all the individual property damages for that event.

The AAD value attempts to quantify the flood damage that a floodplain would receive on average during a single year. A probability curve is drawn based on the flood damages calculated for each design event. For example, the 1% AEP design event has a 1% chance of occurring in any given year, thus the 1% AEP flood damage is plotted at 0.01 on the AAD curve, and so on. AAD are then calculated by determining the area under the plotted curve. Further information of the calculation of AAD can be found in Appendix M of the Floodplain Development Manual (NSW Government, 2005).

Based on the analysis described above, the AAD for the Narrabeen Lagoon floodplain under existing conditions is $11,540,886. The contribution of the various design flood scenarios to AAD for Narrabeen Lagoon are shown graphically in **Figure 6-3**.

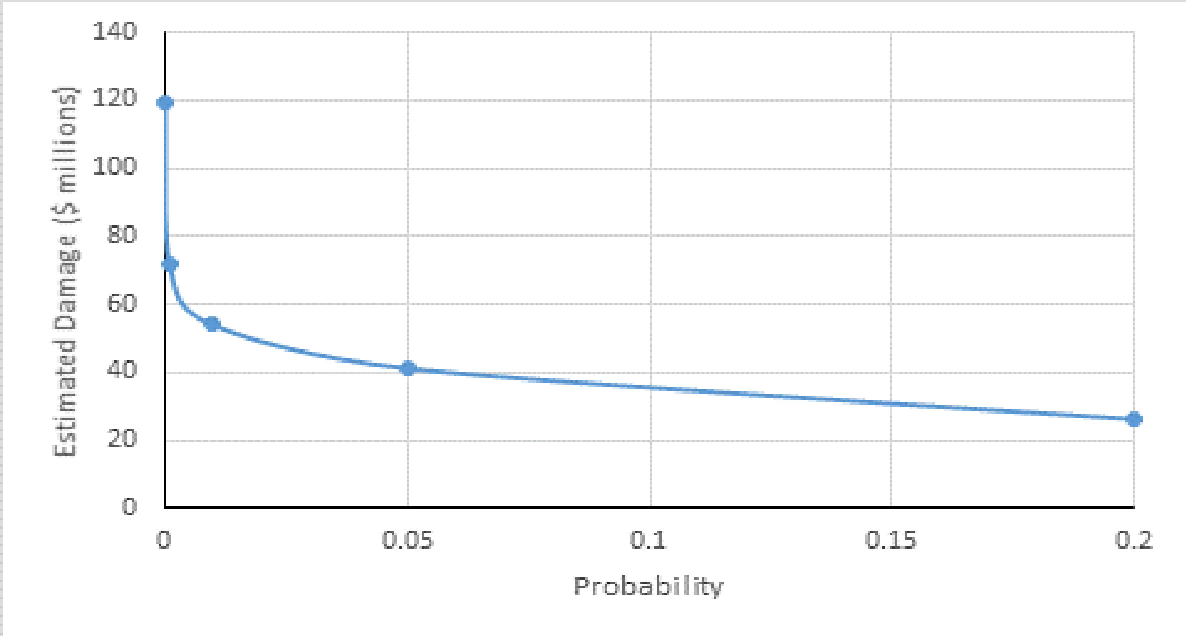


Figure 6-3 Annual Average Damage Curve for Narrabeen Lagoon Floodplain – Existing Scenario

7 Flood Emergency Response Assessment

7.1 Flood Emergency Response

Flooding in the Narrabeen Lagoon catchment generally occurs as flash flooding which results in a limited time period in which to provide a flood warning or to arrange for evacuations.

While flood behaviour is often defined in terms of flood hazard, the risk to life from flooding can often depend on the ability of people to respond and react to flooding and remove themselves from harm's way. This concept is referred to as the 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:

> 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 (or part of a building) that provides refuge on the site or near the site before their property becomes flood affected.

The following sections review the current emergency response systems in place for the Narrabeen Lagoon catchment, and the feasibility for flood evacuation based on:

> Critical infrastructure and vulnerable developments (Section 7.3),
> Key locations of road overtopping (Section 7.5);
> The evacuation timeline for the floodplain (Section 7.6),
> Shelter-in-place potential (Section 7.7); and
> Commentary on evacuation vs shelter-in-place for the Narrabeen Lagoon catchment (Section 7.8).

7.2 Flood Emergency Response Documentation

Flood emergency measures are an effective means of reducing the costs of flooding and managing the continuing and residual risks to the area. There are several documents relating to emergency preparedness and response for flood events, including:

> State Emergency Management Plan (EMPLAN) (NSW Government, 2012);
> State Flood Plan (SES, 2018);
> NSW SES Region Capability Plan Risk Matrix – this document can be used to identify the level of risk, potential hazards or property damage and help to prioritise any control measures;
> Guideline on Emergency Planning Response to Protect Life in the Event of Flash Floods (AFAC, 2013);
> Manly-Warringah-Pittwater Disaster Plan (DISPLAN) (MWPLEMC, 2005); and
> North West Metropolitan Emergency Management District DISPLAN (Interim) (NWMDEMC, 2011).

The Local Flood Plan for the Northern Beaches has not been finalised. Councils meet quarterly with the NSW SES to provide technical data determined through the Floodplain Risk Management process.

Current flood emergency response arrangements for flooding in the Narrabeen Lagoon Catchment are summarised below, with reference to these key documents.

7.2.1 <u>North West Metropolitan Emergency Management District Disaster Plan (DISPLAN)</u>

The North West Metropolitan Emergency Management District covers the Northern Beaches LGA and many other LGAs from the Blue Mountains, Hawkesbury, and Parramatta to the Northern Beaches. The aim of the North West Metropolitan Emergency Management District DISPLAN (2011) is to coordinate efficient management of the prevention, preparation, response and recovery arrangements for emergencies within the District. It describes the arrangements and agency responsibilities and provides policy direction for the preparation of supporting plans.

The primary hazards identified in this Floodplain Risk Management Study that could require district level response are listed in **Table 7-1**.

Table 7-1 Primary Hazards

Hazard	Threat level			Comments
	Likelihood	Consequence	Risk Rating	
Severe Storms	Likely	Major	High	General threat throughout the District.
Flash Flood	Likely	Major	High	General threat throughout the District.
Riverine Flood	Likely	Major	High	Refer to NSW State SES Flood Plan, as no local Flood Plan for this area.

The agencies, organisations and/or committees with responsibilities to facilitate prevention and mitigation measures in potential flood disaster situations are listed in **Table 7-2.**

Table 7-2 Agencies Responsible for Flood Prevention and Mitigation

Hazard	Agency Responsible	Mitigation / Prevention Strategies
Flood	Local Councils	▪ Regulate property development & building construction through LEPs & DCPs ▪ Development & maintenance of flood mitigation works. ▪ Preparation of floodplain management plans.
	NSW Department of Finance and Services and the EPA	▪ Preparation of mitigation schemes and floodplain management studies and plans.

Responsibility for the conduct and coordination of public education in relation to flooding and severe storm is with the NSW SES, as indicated in **Table 7-3.**

Table 7-3 Agencies Responsible for Public Education on Flooding

Hazard	Agency Responsible
Flooding	NSW SES is responsible for ensuring that residents are aware of the flood threat and how to protect themselves against it.
Severe Storm	NSW SES is responsible for ensuring that the residents of their divisions are aware of the likely effects of storm impact and how to protect themselves against it.

Responsibility for the provision of warnings to the community, participating organisations and other agencies in relation to flood hazards or threats are listed in **Table 7-4**.

Table 7-4 Agencies Responsible for Provision of Warnings for Flood Hazards

Hazard	Agency Responsible	Warning Provided
Flooding	NSW SES Region Controllers	▪ Local Flood Bulletins & Evacuation Warnings to: ▪ Flood affected communities via the electronic Media; ▪ The DEOCON; and ▪ Relevant Agencies and Functional Areas.
	Bureau of Meteorology	Local Flood Advice and Warnings.

Evacuation of persons or animals from an area of danger or potential danger is a possible strategy in combating a flood event. **Table 7-5** is an extract from the DISPLAN, and it lists some individuals and organisations that have authority to order an evacuation of persons or animals and under which circumstances they have that authority. Disseminating warnings and advice to the public is generally through electronic media, but if urgently required, evacuation warnings will be reinforced by public address systems fitted to emergency services vehicles and door knocks of affected areas by evacuation teams (emergency services personnel and others as necessary). The NSW State Flood Sub-Plan (SEMC, 2013) does not list locations in (or near) the catchment recommended for use as flood evacuation centres.

Table 7-5 The Standard Emergency Warning Signal (SEWS) is a nationally adopted distinctive sound which may be broadcast over radio or television immediately before an urgent public safety message. The SEWS is designed to attract the attention of the public to an urgent safety message. In addition, NSW emergency services are able to issue warnings by telephone (landline and mobile) to fixed areas to warn of flooding.Extract from DISPLAN (Evacuation Authority)

Individual / Organisation	Circumstances	Authority
A member of the Police Force	If satisfied that there are reasonable grounds for doing so for the purpose of protecting persons from injury or death.	The protection of persons from injury or death whether arising from criminal acts or in any other way (S.6 (3) (b) *Police Service Act 1990*).
A Police officer, and all other members of emergency service organisations	Emergency operation related to flood or storm or when directed by SEOCON.	Recognised authority of the Director-General NSW SES and emergency officers acting under the orders of the Director-General, division controller or local controller (S.21 - *State Emergency Services Act 1989*).
The Commissioner, NSW SES; or “Emergency Service Officer” (as defined) when authorised by the Commissioner	Emergency related to flood or storm; or when directed by SEOCON	Direct a person to leave premises and move out of an emergency area or part thereof, taking any persons in their care with them. Direct a person not to enter an emergency area or part thereof, including doing all such things as are reasonably necessary to ensure compliance, including use of reasonable force (S.22 - *State Emergency Service Act 1989*).

7.3 Emergency Response Guideline for Flash Flooding

In 2013 the Australasian Fire and Emergency Service Authorities Council (AFAC) released a guideline on emergency planning for flash flood events that provides useful insight into the position of the Emergency Services Authorities Council, of which NSW SES is a member. The guideline reflects a consensus on best practice for managing flash flooding, focussing on risk to life.

The guideline provides the following comments relating to appropriate emergency response in relation to flash flooding (which is applicable to Narrabeen Lagoon).

- The safest place to be in a flash flood is well away from the affected area. Accordingly, pre-event planning for flash floods should commence with an assumption that evacuation is the most effective strategy, provided evacuation can be safely implemented;
- Evacuating too late may be worse than not evacuating at all because of the dangers inherent in moving through flood waters. The timescale at which flash floods occur may limit the feasibility of evacuation as a response measure;
- A structurally suitable building means a building which is strong enough to withstand lateral flood flow, buoyancy, and suction effects and debris impact load;
- In the absence of a more detailed engineering-based code the following observations can be made regarding structural suitability for shelter-in-place buildings:
  - Single storey slab-on-ground dwellings, and relocatable homes and caravans are unlikely to be suitable,
  - Reinforced concrete or steel-framed multi-level buildings are more likely to be suitable, and
  - Ideally the building should have sufficient area of habitable floor that will be flood free in a Probable Maximum Flood (PMF) event to accommodate the likely number of occupants;

> The pre-incident planning of evacuation must include operational contingency plans for the rescue of individuals who do not evacuate in a timely manner'

> Due to the nature of flash flood catchments, flash flood warning systems based on detection of rainfall or water level generally yield short lead times (less than 30 minutes), and as a result provide limited prospects for using such systems to trigger planned and effective evacuation'

> The dangers to be considered in relation to evacuation include evacuees being overwhelmed by floodwaters, and exposure to adverse weather such as lightning, hail, heavy rain, strong winds, flying debris, or falling trees and power lines;

> The dangers to be considered for shelter-in-place include risks resulting from:
  - Their own decision making (drowning if they change their mind),
  - Their mobility (not being able to reach the highest part of the building),
  - Their personal safety within the building (fire and accident), and
  - Their health while isolated (pre-existing condition or sudden onset).

For these reasons, remaining in buildings likely to be affected by flash flooding is not low risk and should never be a default strategy for pre-incident planning. Where the available warning time and resources permit, evacuation should be the primary response strategy.

7.4 Flood Information Systems

In the Narrabeen Lagoon catchment the limited time to notify of, and respond to, an expected flood event limits the implementation of a flood warning system.

In the case of flash flood catchments the BoM provides general warning services including:

> Severe Thunderstorm Warnings;

> Severe Weather Warnings; and

> Flood Watches.

These services are typically issued for a much larger region, or catchment, of which the local flash flood site is often only a small part. For larger regional events, two to three days advanced notice may be available (e.g. where an East Coast Low develops off Sydney). At other times, however, it may only be possible to issue a flood warning a few hours in advance, if at all (e.g. thunderstorm or intense rainfall cells).

The Northern Beaches Flood Information Network is managed by Northern Beaches Council in collaboration with the OEH and the BoM. The five-year objective is to develop a basic flash flood information system for the region's community by strategic installation of rainfall, water level and flow gauges (Millener et al., 2013). A publicly accessible webpage hosted by Manly Hydraulics Laboratory (http://www.mhl.nsw.gov.au/users/NBFloodInfo/) is available to inform the public via real-time water level gauge data, advise of flood trigger levels, and to advise of where flooding may be occurring. Alarms and trigger levels on selected gauges will be used to send an SMS to relevant personnel in NSW SES and Councils.

7.5 Road Overtopping

Throughout the Narrabeen Lagoon floodplain there are various regional roads and important local roads that are affected by flooding. These access roads are important when considering evacuation as a flood emergency response. A total of 29 road overtopping locations have been identified in **Figure 7-1.** These key road locations are typically one of the following:

> Key regional routes providing access for entire regions, examples of this are Wakehurst Parkway (Points 27, 28, and 19), and Pittwater Road (Points 3, 6, and 13);

> Local roads that act as evacuation routes for entire suburbs that are isolated, examples include:
  - West Cromer is isolated during flooding of South Creek dependent on the following crossings; Toronto Ave (Point 23), Carcoola Road (Point 24), and Little Willandra Road (Point 30),

  - Elanora Heights is isolated during flooding dependent on the following crossings; Powderworks Road (Point 19), and Garden Street crossing Mullet Creek (Point 18), and
  - West Warriewood Valley is isolated during flooding dependent on the following crossings; Macpherson Street (Point 14), Ponderosa Parade (Point 15), and Garden Street crossing Fern Creek (Point 17);
- Neighbourhoods that are completely flood affected, examples include; Wimbledon Avenue (Point 2), eastern bank of Narrabeen Lagoon (Point 3), Nareen Creek floodplain (Point 4 and 5), and the Warriewood Valley floodplain (Point 8 and 9).

A summary of the flood affectation for key road locations is presented in **Table 7-6** and includes the peak depth of overtopping for the 20% AEP, 5% AEP, 2% AEP, 1% AEP flood events and the PMF. In addition, the 1% AEP peak velocity is provided to give an indication of hazard.

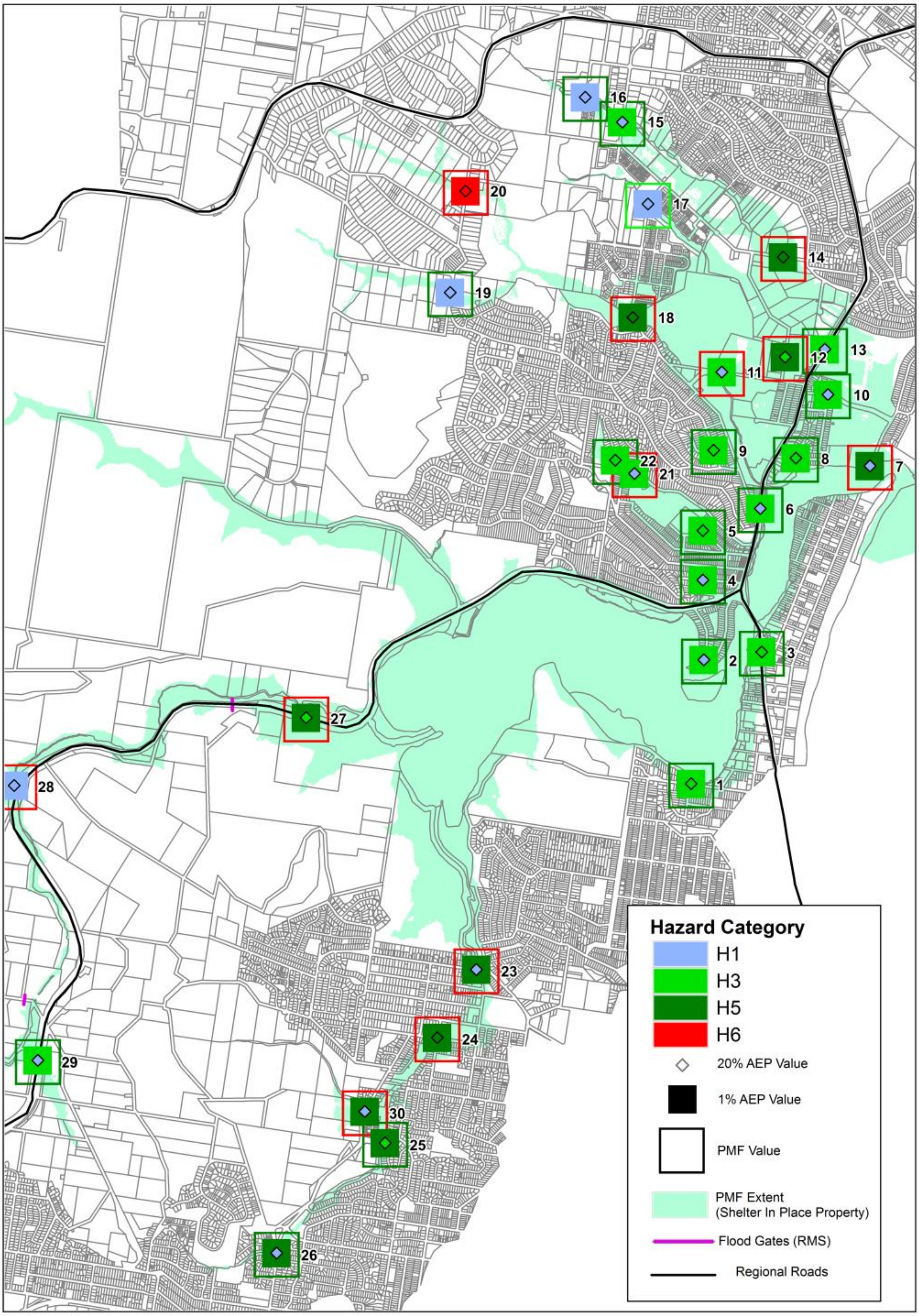


Figure 7-1 Key Road Locations within Narrabeen Lagoon Floodplain

Table 7-6 Summary of Flood Affectation for Road Locations

ID	Name	Road Level (m AHD)	Min AEP	20% AEP Depth metres	5% AEP Depth metres	2% AEP Depth metres	1% AEP Depth metres	PMF Depth metres	1% AEP Vel m / sec
1	Mactier Street	1.33	50%	1.11	1.38	1.54	1.66	3.69	0.27
2	Wimbledon Avenue	2.00	50%	0.44	0.71	0.86	0.98	2.99	0.21
3	Pittwater Road near Waterloo Street	1.98	50%	0.46	0.73	0.88	1.00	2.99	0.31
4	Windsor Parade	1.91	50%	0.52	0.78	0.89	1.05	3.00	0.58
5	Narroy Road	1.82	50%	0.61	0.86	0.99	1.13	3.08	0.32
6	Pittwater Road near Garden Street	2.40	10%	0.00	0.25	0.37	0.54	2.46	0.28
7	Ocean Street	2.41	2%	0.00	0.00	0.20	0.33	2.02	1.45
8	Lake Park Road	1.69	50%	0.72	0.96	1.10	1.25	3.17	0.67
9	Warraba Road	1.94	50%	0.49	0.74	0.86	1.02	2.93	0.17
10	Walsh Street	2.51	5%	0.00	0.14	0.26	0.43	2.33	0.33
11	Jacksons Road	2.46	10%	0.00	0.22	0.35	0.49	2.41	0.51
12	Boondah Road	2.00	50%	0.53	0.81	0.91	1.04	2.87	0.78
13	Pittwater Road near Narrabeen Creek	2.45	10%	0.00	0.37	0.48	0.60	2.42	0.36
14	Macpherson Street	4.16	1%	0.00	0.00	0.00	0.00	0.00	0.00
15	Ponderosa Parade	16.20	10%	0.00	0.22	0.28	0.31	0.60	1.70
16	Bert Close	19.81	0.50%	0.00	0.00	0.00	0.00	0.78	0.00
17	Garden Street cross Fern Creek	11.60	2%	0.00	0.00	0.03	0.11	0.48	1.08
18	Garden Street cross Mullet Creek	3.65	50%	0.22	0.38	0.46	0.54	1.23	2.78
19	Powderworks Road	99.60	10%	0.00	0.24	0.30	0.38	1.01	1.58
20	Ingleside Road	100.71	50%	0.32	0.43	0.59	0.52	1.23	5.33
21	Nareen Parade	2.31	50%	0.41	0.56	0.61	0.68	2.59	1.22
22	Tatiara Crescent	4.60	50%	0.48	0.66	0.72	0.80	1.33	0.87
23	Toronto Avenue	4.54	2%	0.00	0.00	0.14	0.28	1.01	1.55
24	Carcoola Road	5.40	50%	0.69	0.88	1.04	1.13	2.25	2.08
25	Willandra Road near Ara Crescent	12.47	50%	0.26	0.34	0.45	0.43	0.80	1.91
26	Willandra Road near McIntosh Road	86.87	10%	0.00	0.17	0.21	0.24	0.61	2.24
27	Wakehurst Pwy near Sports Field	2.15	50%	0.49	0.74	0.87	0.98	2.96	1.71
28	Wakehurst Pwy near Oxford Creek	9.89	0.50%	0.00	0.00	0.00	0.00	1.98	0.00
29	Wakehurst Pwy near Oxford Falls	70.52	50%	0.18	0.28	0.34	0.43	1.36	1.83
30	Little Willandra Road	10.83	5%	0	0	0.11	0.20	1.20	2.59

The following points summarise the outcomes of the flood affectation assessment:

> Of the 29 key road locations identified, 17 locations (58%) are overtopped in flood events as frequent as the 50% AEP event;

> Five of the 29 locations (17%) are flood free up to the 5% AEP, with only two of these remaining flood free up to the 1% AEP;

> Both major regional roads, Wakehurst Parkway and Pittwater Road, are flood affected in the 50% AEP making them unsuitable regional evacuation routes;

> Of the potentially isolated suburbs mentioned above:

- West Cromer has flood free access via Toronto Avenue (Point 23) up to the 2% AEP,
- Elanora Heights has flood free access via Powderworks Road (Point 19) up to the 10% AEP, and
- West Warriewood Valley has flood free access via Macpherson Street (Point 11) up to the 1% AEP;

> All of the flood affected neighbourhoods listed below are flood affected by events more frequent than the 50% AEP; Wimbledon Avenue (Point 2), eastern bank of Narrabeen Lagoon (Point 3), Nareen Creek floodplain (Point 4 and 5), and the Warriewood Valley floodplain (Point 8 and 9).

The above results show that the existing road network for the Narrabeen Lagoon floodplain is not suited for regional evacuation of residents in the event of flooding as most evacuation routes overtop in frequent flood events (less than 50% AEP in most cases).

7.6 Evacuation Timeline

7.6.1 Background

When considering flood evacuation, the most important areas are the flood affected neighbourhoods that are most at risk. This analysis therefore focusses on the key road locations (shown in **Figure 7-1**) that influence the flood affected neighbourhoods near Narrabeen Lagoon (i.e. Points 1 to 10).

The NSW SES Timeline Evacuation Model has been the de facto standard for evacuation calculations in NSW since it was first developed for evacuation planning in the Hawkesbury Nepean Valley. Though the guideline has not yet been released, the paper Technical Guideline for SES Timeline Evacuation Model was prepared by Molino et al. (2013) to brief the industry on the use of the guideline.

The timeline assessment of evacuation potential relates to the time required for regional evacuation of floodplains from door-knocking by SES volunteers through to the evacuation of all occupants from the region.

At the centre of the timeline methodology is the following concept:

Surplus Time = Time Available – Time Required

If surplus time is positive, then evacuation of all occupants is feasible, while a negative value implies evacuation of all occupants is not likely to be achieved. The determination of the two times; Time Available and Time Required, is summarised in the following sections.

7.6.2 Time Available

This variable is dependent on rate of rise of flood waters, meaning it varies for each evacuation scenario. All of the flood affected neighbourhoods (Points 1-10 shown in **Figure 7-1**) lie within the lower Narrabeen Lagoon floodplain. As the lower Narrabeen Lagoon floodplain, from lower South Creek to Warriewood Valley, is an inter-connected storage area the water level time series for the majority of the floodplain is nearly identical.

The water level time series for three flood events (20% AEP, 1% AEP, and PMF) are presented in **Figure 7-2**. The largest extent of flooding for this lower floodplain (the critical duration events) are long duration events; the 24 hour event for the 20% AEP and 1% AEP, and the 6 hour event for the PMF. When considering the fastest rate of rise of floodwaters, however, the short duration events are most important; the 2 hour storm for the 20% AEP and 1% AEP, and the 30 minute storm for the PMF event.

The times to reach inundation after the onset of rainfall for the flood affected neighbourhoods (Points 1 to 10) under these critical events are listed in **Table 7-7**. In summary:

> For the 20% AEP event the majority of sites have between 2 and 4 hours before flooding occurs, with the exception being the low-lying Mactier Street on the southern bank of Narrabeen Lagoon which is flooded within 30 minutes of rainfall commencing;

> For the 1% AEP the majority of sites have between 1.5 and 3 hours before flooding occurs; and

> For the PMF flood event all sites are flood affected in under 1.5 hours following the onset of rainfall.

It should be noted that theoretical flood events do not always match actual events and the time to reach inundation after the onset of rainfall may be shorter or longer than listed here.

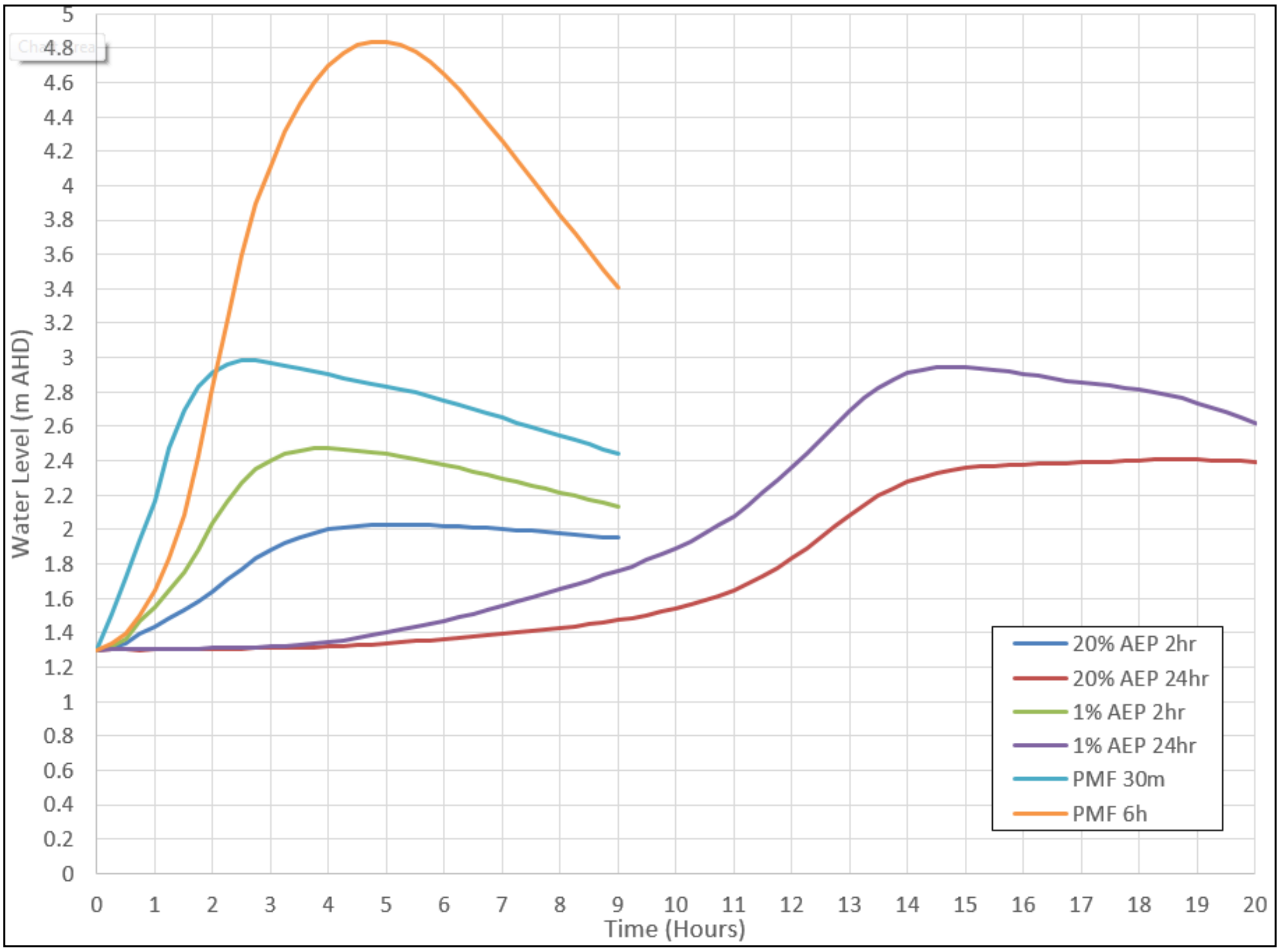


Figure 7-2 Water Level Time Series for the Narrabeen Lagoon at the Pittwater Road Bridge

Table 7-7 Time to Inundation after Onset of Rainfall - Key Locations in the Lower Narrabeen Floodplain

ID	Name	Road Level (m AHD)	Time to Flooding After Onset of Rainfall (hours)			
			20% 2hr	1% 2hr	PMF 30m	PMF 6h
1	Mactier Street	1.33	0.50	0.50	0.25	0.25
2	Wimbledon Avenue	2.00	4.25	2.00	1.00	1.50
3	Pittwater Road near Waterloo Street	1.98	4.00	2.00	1.00	1.50
4	Windsor Parade	1.91	3.25	2.00	0.75	1.50
5	Narroy Road	1.82	2.75	1.75	0.75	1.25
6	Pittwater Road near Garden Street	2.40	N/A*	3.00	1.25	1.75
7	Ocean Street	2.41	N/A*	3.25	1.25	1.75
8	Lake Park Road	1.69	2.25	1.50	0.50	1.25
9	Warraba Road	1.94	3.50	2.00	1.00	1.50
10	Walsh Street	2.51	N/A*	N/A*	1.50	2.00

*N/A – Road is not overtopped in this flood event

7.6.3 Time Required

The SES evacuation timeline model uses the following equation to calculate Time Required:

Time Required = Warning Acceptance Factor (WAF) + Warning Lag Time (WLT) + Travel Time (TT) + Travel Safety Factor (TSF)

Where the following values are recommended in the guideline:

WAF = 1 hour – accounts for the delay between occupants receiving the evacuation warning and acting upon it.

WLT = 1 hour – an allowance for the time taken by occupants to prepare for evacuation.

TT = Variable – the number of hours taken for the evacuation of all vehicles based on road capacity. NSW SES recommend a road lane capacity of 600 vehicles per hour. Since there are many evacuation routes to flood-free land across the Narrabeen Lagoon floodplain the Travel Time is assumed to be negligible (in the order of minutes, not hours).

TSF = Variable – added to travel time to account for any delays along the evacuation route, resulting from accidents for example, this value is a variable of TT between 1 hour and 3.5 hours.

Note that Time Required is calculated from the time that SES have mobilised and are ready to begin door knocking. Before this time there are two additional considerations.

> Forecast and actual rainfall monitoring – in the case of Narrabeen Lagoon, tools for flood forecasting to inform flood evacuation are inadequate. Actual rainfall monitoring is the only feasible warning system. The flood warning system that is in place is the Northern Beaches Flood warning system (MHL, 2014), which recommends response only after 3 hours of sustained heavy rainfall;

> Mobilisation – the time taken for SES to mobilise and travel to residences to commence doorknocking. There is no data available on mobilisation time for local SES services, so this has not been included in the evacuation timeline for Narrabeen Lagoon.

Based on the above contributors, the overall time required for evacuation of the Narrabeen Lagoon floodplain is a minimum of 5 hours (2 hours for WAF and WLT, 3 hours for actual rainfall monitoring). It should be noted that this is a low bound estimate, as various factors such as Travel Time, Travel Safety Factor and SES mobilisation have been disregarded.

7.6.4 Surplus Time

Based on available guidance, the PMF event is adopted as the design event for emergency response (**Section 5.4.2**). For all of the locations listed in **Table 7-7** the estimated Surplus Time is negative, because the time available (between 15 minutes and 90 minutes for the PMF 30 minute storm) is less than the time required to evacuate (minimum of 5 hours). Note that the Surplus Time is negative for all flood affected locations even when considering the 20% AEP instead of the PMF.

Under the current flood warning system and the existing provisions available, there is insufficient time to fully evacuate any of the flood affected neighbourhoods within the lower Narrabeen Lagoon floodplain based on SES doorknocking and assisted evacuation.

7.7 Shelter-in-Place Potential

Implementation of appropriate shelter-in-place strategies to reduce flood risk to life requires consideration of the following:

> Stability of the shelter-in-place structure;

> Feasibility of a flood free refuge area; and

> Duration of the isolation period in the refuge area.

The potential for shelter-in-place to be implemented for the Narrabeen Lagoon floodplain based on these three factors is discussed in the following sections.

7.7.1 Structural Stability

The collapse of a shelter-in-place refuge could result in loss of life and therefore is not acceptable under any flood event. Adopting the flood hazard categories presented in **Section 5.4.3,** it is possible to identify approximate levels of structural stability for the following structures:

> All normal structures are assumed to have structural stability up to and including Hazard Category H4; and

> All specially engineered structures are assumed to have structural stability up to and including Hazard Category H5.

Flood hazard category H6 only covers regions of the floodplain where structural stability of shelter-in-place refuges is not certain, and therefore shelter-in-place may not be feasible. These H6 hazard areas for the Narrabeen Lagoon floodplain are shown in **Figure 5-3** and **Figure 5-4.**

The H6 hazard categories are mostly limited to the lagoon water body itself and the floodways of the creeks and tributaries, with only very limited overlap with currently developed areas. For the vast majority of the floodplain, therefore, shelter-in-place is specially engineered structures is feasible based on consideration of structural stability.

7.7.2 Duration of Inundation

Duration of inundation relates to the length of isolation of any shelter-in-place refuges within the floodplain. Isolation results in the following sources of risk to life:

> Isolation from medical services – in the event of a medical emergency, a pre-existing condition, injury, or sudden onset event such as heart attack, medical services may not be accessible. This is a particularly high risk for vulnerable developments occupied by residents who are more likely to experience a medical emergency at any given time than other demographics; and

> Isolation from supplies – including drinking water, food, amenities, and communication lines. This becomes a particular concern when the period of isolation exceeds 24 hours.

The duration of inundation (the time period that the location is submerged) for the critical duration events for Narrabeen Lagoon (the 24 hour for the 20% AEP, and 1% AEP, and the 6 hour for the PMF) are listed in **Table 7-8**.

Table 7-8 Duration of Inundation – Key Locations in the Lower Narrabeen Floodplain

ID	Name	Road Level (m AHD)	Duration of Inundation (hours)		
			20% 24hr	1% 24hr	PMF 6h
1	Mactier Street	1.33	21.00	20.50	8.50
2	Wimbledon Avenue	2.00	12.50	11.75	7.50
3	Pittwater Road near Waterloo Street	1.98	13.00	12.00	7.50
4	Windsor Parade	1.91	15.00	12.75	7.75
5	Narroy Road	1.82	17.00	13.75	7.75
6	Pittwater Road near Garden Street	2.40	0.00	8.00	7.25
7	Ocean Street	2.41	0.00	7.75	7.25
8	Lake Park Road	1.69	18.00	15.25	7.75
9	Warraba Road	1.94	14.00	12.25	7.50
10	Walsh Street	2.51	0.00	6.75	7.25

The results show that the 20% AEP has the longest duration of inundation of between 16 and 18 hours at most low-lying locations. This is due to the behaviour of the berm at the lagoon entrance. In the 20% AEP the flood flows are not large enough to break through the berm and therefore the falling limb of the 20% AEP hydrograph drains the lagoon slowly. In larger flood events, such as the 1% AEP event, the berm is washed away by the flood flows and the lagoon drains more quickly.

The modelled 20% AEP flood event with no mechanical removal of the berm provides the longest duration of inundation as the water level behind the berm has lower driving head. This results in the berm eroding slower than in more intense rainfall events. It should be noted the Lagoon Entrance Management

Operational Management Standard (Warringah Council, 2012) instructs the mechanical removal of the berm opening when flood waters reach 1.0 to 1.3 m AHD The expected peak duration of inundation for flooding is therefore approximately 16-18 hours at most locations in the lower Narrabeen Lagoon floodplain. An exception is the low-lying Mactier Street, which has an expected duration of inundation of approximately 21 hours.

Since the duration of inundation is expected to be sub-daily for the majority of the floodplain, the flood risk to life associated with shelter-in-place isolation is expected to be manageable through provision of supplies and services to the refuge.

7.7.3 Flood Free Refuge

Flood hazard exposure is the main risk to life related to flooding. If shelter-in-place is implemented, where occupants will remain on site for the duration of the flooding event, it is essential that they are not exposed to any direct flood hazard (i.e. that the refuge is flood free).

This applies for all possible flood events, thus the PMF has been adopted as the applicable event. The peak flood depths in the PMF event for the Narrabeen Lagoon floodplain are shown in **Figure 7-3**. These flood depths show the minimum required height above approximate ground levels of any shelter-in-place refuge.

The PMF depth results show that for the majority of the flood affected neighbourhoods in the floodplain; Wimbledon Avenue, eastern bank of Narrabeen Lagoon, Nareen Creek floodplain, and the Warriewood Valley floodplain, the average depth is between 2-3 m. This suggests that to be flood free, shelter-in-place refuges will need to be elevated approximately 2-3 m above the existing ground level for the majority of the developed floodplain. This might be considered onerous for developers, but nonetheless feasible.

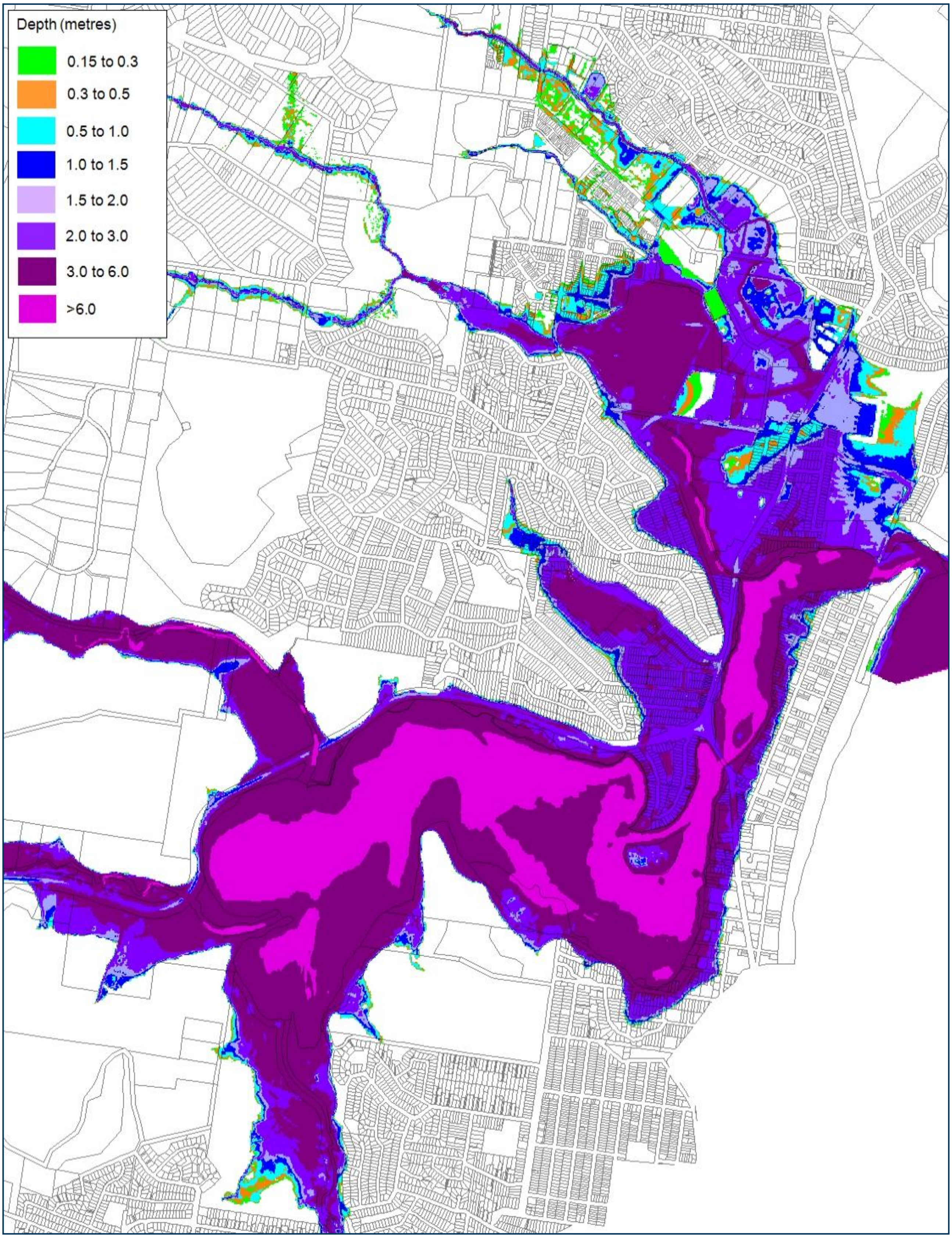


Figure 7-3 PMF Event Peak Depth Results – Lower Narrabeen Lagoon Floodplain

7.8 Evacuation vs Shelter-in-Place

7.8.1 Regional Evacuation

As discussed above, the regional evacuation potential of the lower Narrabeen Lagoon floodplain in the event of flooding is considered limited due to the following:

> 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; and

> The current Northern Beaches Flood Information Network records near real time water level, rainfall and flow gauge data. Due to the short warning times available, Council in partnership with Manly Hydraulics Laboratory have developed a Flood Intelligence Tool to provide predicted peak flood conditions up to 12 hours in advance. This will increase the potential warning time to implement regional evacuation with the NSW SES. However, this tool is only applicable for the lagoon foreshore areas, and even so some areas will still not have sufficient time to evacuate.

7.8.2 Local Evacuation

Residents can make a decision to evacuate themselves without the involvement of emergency services. This is called "local evacuation". A high level of flood awareness would be required for this strategy to be feasible.

Compared to the regional timeline above, local evacuation significantly reduces the time required to evacuate because:

> Rainfall forecasting and monitoring, as well as SES mobilisation, is not involved;

> Warning Acceptance Factor (WAF) for observed flooding is insignificant as occupants will be far more responsive to observed flooding compared to doorknocking by SES;

> Warning Lag Factor (WLF) for observed flooding is significantly reduced; instead of preparing the house for flooding, it is expected occupants may secure key items and possibly notify friends and family and then evacuate; and

> Travel Time (TT) and Travel Safety Factor (TSF) are minimal. This is where the localised concept is important, because long distance evacuation routes (in the scale of kilometres) will not be conducive to spontaneous pedestrian evacuation.

These reductions could feasibly result in localised evacuation being achieved in under an hour. Given the rate of rise of floodwaters summarised in **Section 7.6.2**, this timeframe means that 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 AFAC guideline, wherever possible, local evacuation should be the preferred emergency response for the Narrabeen Lagoon floodplain.

7.8.3 Shelter-in-Place

While not the preferred form of emergency response, as stated in **Section 7.7** shelter-in-place is a reasonable 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.

8 Policies and Planning

8.1 Review of Land Use Zoning

Several land uses are affected by flooding in the 1% AEP event (**Figure 8-1**). The area of each land use zone within the study area and the proportion of flood affected land is listed in **Table 8-1**.

Of the flood affected lands, defined as those below the 1% AEP level, the majority of land is either W1 natural waterways (35.4% of the floodplain), RE1 public recreation (17.6%), E2 environmental conservation (10.2%), SP2 infrastructure (8.7%), or R2 low density residential (8.1%).

The cumulative area of business, industrial, and residential land uses within the floodplain is 91.7 ha, or 13.5% of the 1% AEP floodplain area. The floodplain risk management options identified in **Section 11** focus on these areas. The remaining 86.4% of the floodplain is occupied by land uses where flood risk is seen as less critical, such as waterways, environmental protection areas, recreational areas, rural, and special purpose.

Table 8-1 Narrabeen Lagoon Land Uses – Area Breakdown

Type	Land Use	Study Area		1% AEP Flood Affected	
		Area (ha)	% of Total	Area (ha)	% of Area
Business	B1 Neighborhood Centre	5.6	0.1%	0.7	0.1%
	B2 Local Centre	18.2	0.3%	8.8	1.3%
	B6 Enterprise Corridor	1.6	0.0%	1.2	0.2%
	B7 Business Park	45.3	0.8%	Not in Floodplain	
Misc	DM Deferred Matter	1169.1	21.0%	1.3	0.2%
Env. Protection	E1 National Parks and Nature Reserves	977.7	17.6%	34.4	5.1%
	E2 Environmental Conservation	230.9	4.2%	68.7	10.2%
	E3 Environmental Management	30.8	0.6%	Not in Floodplain	
	E4 Environmental Living	175.2	3.2%	6.6	1.0%
Industrial	IN1 General Industrial	19.2	0.3%	Not in Floodplain	
	IN2 Light Industrial	21.8	0.4%	3.8	0.6%
Residential	R2 Low Density Residential	1024.7	18.4%	55.0	8.1%
	R3 Medium Density Residential	170.9	3.1%	18.9	2.8%
	R5 Large Lot Residential	82.3	1.5%	3.3	0.5%
Recreation	RE1 Public Recreation	505.2	9.1%	118.8	17.6%
	RE2 Private Recreation	186.7	3.4%	19.1	2.8%
Rural	RU2 Rural Landscape	255.2	4.6%	13.0	1.9%
Special Purpose	SP1 Special Activities	119.7	2.2%	19.2	2.8%
	SP2 Infrastructure	263.8	4.7%	58.6	8.7%
	SP3 Tourist	13.0	0.2%	5.0	0.7%
Waterways	W1 Natural Waterways	239.4	4.3%	239.1	35.4%

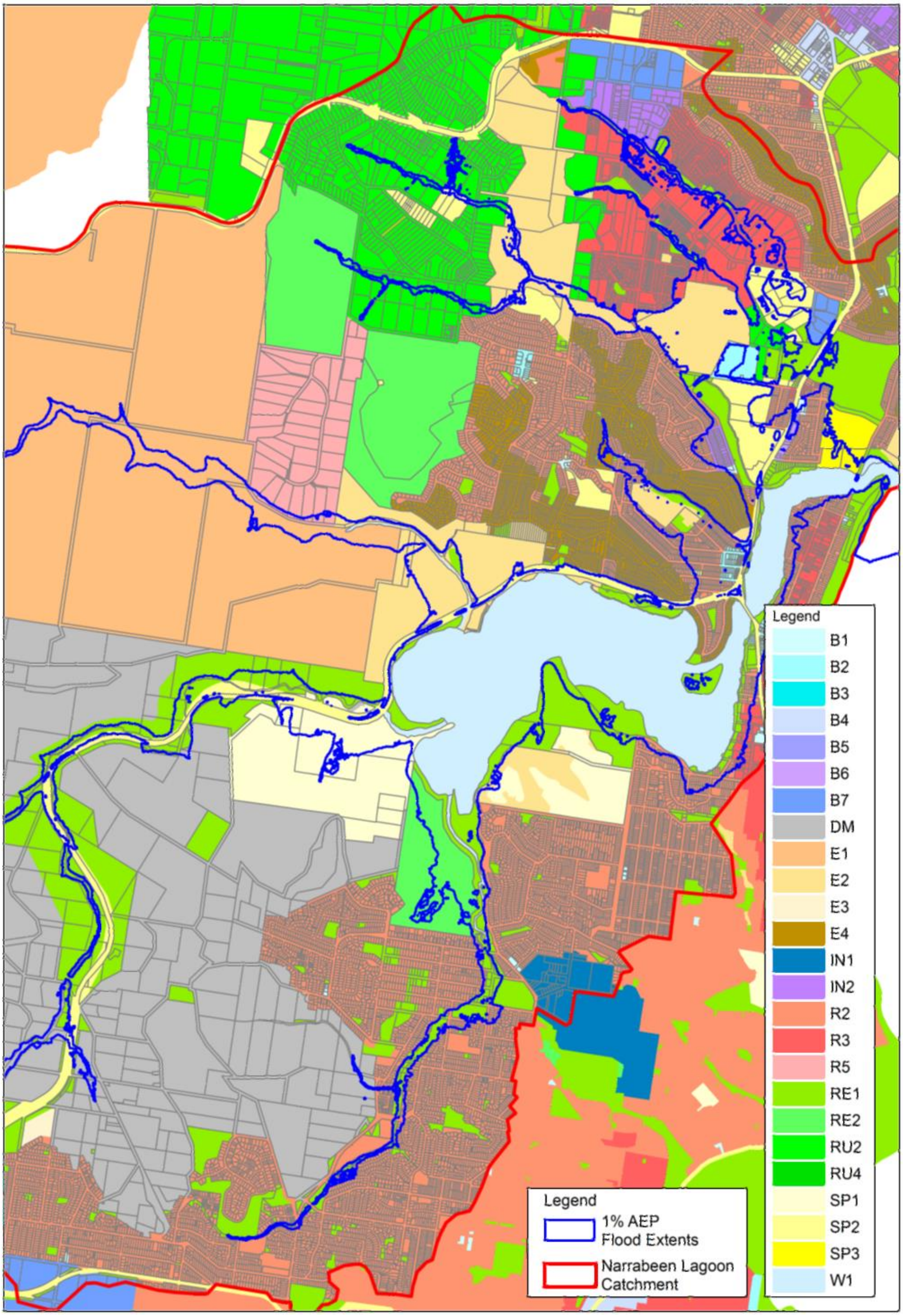


Figure 8-1 Land Use Zones for the Narrabeen Lagoon Floodplain

8.2 Flood Planning Levels

As stated within Appendix K of the Floodplain Development Manual (NSW Government, 2005):

> *Flood Planning Levels (FPLs) are an important tool in the management of flood risk. They are derived from a combination of a flood event, and a freeboard.*

The Flood Planning Level (FPL) for the majority of flood prone areas across New South Wales has traditionally been based on the 1% AEP flood level plus a freeboard that is generally set at 0.5 m.

For Narrabeen Lagoon the FPL has historically been the 1% AEP flood level plus a freeboard of 0.5 m for the majority of development types. This was true for both the former Warringah and former Pittwater Council portions of the floodplain.

8.2.1 Current Flood Planning Levels

8.2.1.1 Northern Beaches Council

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 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.

Development requirements for flood prone land depend on the type of development or land use, and which flood risk planning precinct the development lies within. They relate not just to setting the minimum floor level of new, habitable rooms, but also to building components and method, structural soundness, impact of development, emergency response, car storage, fencing and pools.

The categories of development or land use defined in the DCPs are:

> Critical Services;

> Vulnerable Uses;

> Subdivision;

> Residential;

> Business and industrial;

> Recreational and Environmental; and

> Concessional.

Northern Beaches Council has categorised flood prone land as being High, Medium or Low Risk, based on the hydraulic category and hazard classification defined in the NSW Floodplain Development Manual (NSW Government, 2005) and the Technical Flood Risk Management Guideline: Flood Hazard (Australian Institute for Disaster Resilience, 2014). The following provides an overview of each of the three flood risk categories:

> The High Risk Planning Precinct means all flood prone land (a) within the 1% AEP Flood Planning Area; and (b) is either subject to a high hydraulic hazard within the floodway, or subject to significant evacuation difficulties (H5 and or H6 Life Hazard Classification);

> The Medium Flood Risk Planning Precinct means all flood prone land that is (a) within the 1% AEP Flood Planning Area; and (b) is not within the high flood risk precinct; and

> The Low Flood Risk Planning Precinct means all flood prone land affected by the PMF but not identified within the High or Medium flood risk precincts.

Council may require an assessment of the level of flood risk associated with the land use and subsequent control measures to manage this risk. The detail and technical complexity of the flood risk assessment are to reflect the scale of the development. Council has technical guidelines that outline the requirements for the preparation of a Flood Risk Assessment and can provide advice on what flood information is already available for the development site and surrounding areas.

The following minimum floor level requirements apply.

> For new residential, business and industrial development:
  - High and medium risk precincts – minimum habitable floor levels are set at the FPL;
  - Low risk precinct – no minimum floor level requirement.
> For new critical and vulnerable development:
  - High, medium and low risk precincts – minimum habitable floor levels are set at either the FPL or PMF level, whichever is greater.

The DCP for the former Pittwater LGA, which affects the northern part of the Narrabeen Lagoon catchment, contains an additional two sections (B3.12 and B3.13):

> Section B3.12 requires that climate change (sea level rise and increased rainfall volume) is considered in the FPL for any "intensification of development". Intensification includes but is not limited to an increase in the number of dwellings (but excluding dual occupancies and secondary dwellings), and an increase in commercial or retail floor space; and
> Section B3.13 requires that if the Flood Life Hazard Category is H3 or above, the development is undertaken in a way that is reflective of the flood risk. This may include demonstration that the property can be safely evacuated, or that there is a suitable refuge area in the development to shelter in place during a flood event.

8.2.2 Review Compared to s117 Directive

In January 2007, the then NSW Department of Planning and Department of Natural Resources jointly released a new Guideline on development controls for low flood risk areas – Floodplain Development Manual. The Guideline was issued to provide additional guidance to Councils on matters dealt with in the Floodplain Development Manual (NSW Government, 2005), and should be read as part of the Floodplain Development Manual.

The Guideline refers to areas above the residential FPL but below the PMF and states the following:

The Guideline confirms that, unless there are exceptional circumstances, councils should adopt the 100 year flood as the FPL for residential development. In proposing a case for exceptional circumstances, a Council would need to demonstrate that a different FPL was required for the management of residential development due to local flood behaviour, flood history, associated flood hazards or a particular historic flood.

The Guideline also notes that, unless there are exceptional circumstances, councils should not impose flood related development controls on residential development on land above the residential FPL (low flood risk areas).

However, the Guideline does acknowledge that controls may need to apply to critical infrastructure (such as hospitals) and consideration given to evacuation routes and vulnerable developments (like nursing homes) in areas above the 100 year flood.

Reviewing the current Flood Planning Level and minimum floor level approaches for Narrabeen Lagoon against the 2007 s117 directive:

> The current Flood Planning Level based on the 1% AEP plus freeboard adopted by Northern Beaches Council is in accordance with the provisions set out in the s117 Directive;
> The application of a minimum floor level requirement to the PMF level for vulnerable developments and critical infrastructure is in accordance with the provisions set out in the s117 directive; and
> The requirement in high flood risk areas to submit a flood risk assessment to assess the risk to life and flood hazard is a measure in addition to the provisions of the Section 117 directive.

If Council needs to demonstrate that a FPL based on a flood other than the 1% AEP event is required for the management of residential development, Appendix K of the Floodplain Development Manual (NSW Government, 2005) outlines a range of issues relating to risk that may be considered, including: social factors, economic factors, environmental factors (including sea level rise), cultural factors and planning and governance.

8.2.3 Other Councils

To assist with benchmarking the current planning arrangements for Narrabeen Lagoon, a comparison of Flood Planning Level and minimum floor levels adopted by other selected Councils within the Sydney region and surrounds is listed in **Table 8-2**.

Table 8-2 FPL and Minimum Floor Level Approaches for Selected Councils in NSW (March 2015)

Council	FPL Design Event	FPL Freeboard	Minimum Floor Level			Consideration of Flood Risk / Hazard Category
			Residential	Commercial / Industrial	Vulnerable / Critical	
Northern Beaches (southern part of catchment)	1% AEP (with coincident 5% AEP ocean event)	0.5m (0.3m for shallow flow)	FPL	FPL	The greater of PMF/FPL	No
Northern Beaches (northern part of catchment)	1% AEP (with coincident 5% AEP ocean event)	0.5m (0.3m for shallow flow)	FPL (+ climate change for intensification)	FPL (+ climate change for intensification)	The greater of PMF/FPL (+ climate change for intensification)	Shelter in place refuge above PMF may be required if affected by H3-H6
City of Sydney	1% AEP	0.5m (0.3m min for OLF*)	FPL (1% AEP for non-habitable floors)	1% AEP minimum (merit based assessment)	PMF or FPL whichever is greater	No
Randwick	1% AEP	0.5m (0.3m min for OLF)	FPL	FPL (1% AEP for non-habitable floors)	PMF plus freeboard	No
Leichhardt	1% AEP	0.5m	FPL	FPL (1% AEP accepted where impractical)	PMF or FPL whichever is greater	For high hazard areas, floor underside to PMF or FPL whichever is greater
Gosford	1% AEP (inclusion of climate change dependent on catchment)	0.5m	FPL (300mm above ground level for non-habitable)	FPL (300mm above ground level for non-habitable)	PMF	"If consequences are high, then consider raising floor levels above the FPL"
Woollahra	1% AEP	0.5m (0.3m for non-habitable)	FPL	FPL	FPL	No vulnerable developments permitted in medium and high risk precincts
Hornsby	1% AEP (0.9m SLR for habitable, 0.4m SLR for non-habitable)	0.5m	FPL	FPL	FPL	No
Wollongong	1% AEP (5% AEP for open space / non-urban) (plus design blockage of structures)	0.5m	FPL	FPL	PMF plus 0.5m freeboard	No development in high flood risk areas

Council	FPL Design Event	FPL Freeboard	Minimum Floor Level Residential	Commercial / Industrial	Vulnerable / Critical	Consideration of Flood Risk / Hazard Category
Newcastle	1% AEP	0.5m	FPL (1% AEP for Garages)	FPL	FPL	No development in high risk areas
Parramatta	1% AEP (5% AEP for open space / non-urban)	0.5m	FPL	FPL	PMF plus 0.5m freeboard	No development in high flood risk areas
Wyong	1% AEP (all design events must consider mine subsidence)	0.5m	FPL (5% AEP for non-habitable)	FPL (5% AEP for non-habitable)	PMF	No development in high hazard areas

*OLF – Overland flow

From the comparison of selected Councils in **Table 8-2** the following observations are made:

> All adopt the 1% AEP as the design event for the FPL, with several adopting a secondary event of the 5% AEP for open space / non-urban / non-habitable;

> For those with lagoon systems similar to Narrabeen Lagoon, often a coincident event with flooding and ocean inundation has been adopted. Other variations to the 1% AEP event include consideration of climate change, design blockage of structures, and mine subsidence;

> All adopt a freeboard of 0.5 m for mainstream flooding, with several adopting a secondary value of 0.3 or 0.0 m for overland flow or for non-habitable floors;

> Most adopt the FPL for minimum floor level requirements for residential and commercial / industrial structures. Some Councils adopt lower values for non-habitable floors while only Leichhardt adopts the PMF for high risk areas;

> Only Northern Beaches Council (in the former Pittwater LGA when intensifying development) and Hornsby Council adopt a mandatory consideration of climate change in FPLs, and Gosford City Council has some catchment dependent requirements. It is expected that a number of other Councils would account for sea level rise impacts in estuary planning levels; and

> For vulnerable developments typically including hospitals, child care centres, schools, retirement homes etc, most councils adopt the PMF as the design flood, some adopting the PMF plus a freeboard of 0.5 m.

Utilising the above information as a benchmark Section 11.5 reviews potentially appropriate Flood Planning Level modifications.

8.2.4 Flood Planning Area

The Flood Planning Area (FPA) is generally defined as the area of land below the FPL. The FPA is a mapping extent used to identify properties that may have flood related development controls applied to them. This is usually reflected in the relevant notation upon a property's Section 149 certificate. The selection of the FPL is integral to identifying properties at risk from flooding and appropriately applying planning controls to manage that risk.

8.3 Warriewood Valley Water Management Specification

8.3.1 Summary

Urban development has long been planned for rural land areas surrounding the sensitive Warriewood Wetlands. Pittwater Council moved to develop an Integrated Water Cycle Management (IWCM) strategy in 1995 that set out management objectives and treatment targets to mitigate the impacts of the planned development.

The Warriewood Valley Water Management Specification (WMS) was prepared to supplement the IWCM strategy and provide development controls to protect existing water quality and prevent degradation to existing ecosystem conditions. The sensitivity of the receiving environment led to the planning controls requiring nil impact on water quality and quantity for urban development. A staged approach to the consideration of the water cycle assessments was presented relative to common steps in the planning process (rezoning, development application, construction certificate, construction and hand-over).

With respect to flood planning it is noted that flood planning levels and requirements of the flood modelling are outlined for inclusion in the Water Management Report at each stage of the development process. Aspects of the flood protection section require information on flood modelling methodology, plans showing flood levels, interim flood protection works and a flood evacuation plan. Consideration of design storm events include the 50%, 20%, 5%, 1% AEPs, together with the PMF.

It is noted that the Warriewood Valley Water Management Specification (Cardno Lawson Treloar, 2001) outlines stringent objectives aiming to limit the impact of urban development across all aspects of the water cycle and seeking to implement a zero net change approach to impact. Over the course of its application to development within the Warriewood Valley, the following issues have been identified.

- Setting local (sector-specific) requirements for on-site detention (site storage requirements and permissible site discharges) meant that applications could be more easily assessed against these pre-set requirements:
- JRPP determinations and Local Environment Court determinations for some developments within the land release area circumvented some of the detailed requirements laid out in the WMS (2001), and often these requirements were relaxed or reduced and did not allow for proper integration of the overall regional strategy; and
- Where a creek line corridor was shared and the creek was to be rehabilitated, constructing one-half of the creek line as part of a development was achievable, but presented challenges in the interim period prior to the development on the other side of the creek being constructed. Flood impact assessments also had to demonstrate that a half-creek construction did not result in short term flood impacts upstream or downstream.

Overall, the WMS provides an effective tool for reducing flood risk to property and life however the complexity of the document has resulting in several developments in the area requiring court decisions for determination. As such while effective, improvements to the usability and clarity of the document should be investigated.

8.4 Basement Carparking

8.4.1 Current Policy

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 flood risks associated with basement car parking can be more critical than flooding of other elements of a development. The reason for this is that basement car parks have the potential to accommodate a large number of occupants at any one time and are enclosed. They provide a limited number of evacuation points for occupants and it can be too dark to find the exit in the likely event of a power failure, are even more dangerous when vehicles become buoyant, and often offer a very small response time in the event of flooding as the basement fills with floodwaters quickly. Therefore, the flood risk to life is significant.

Additionally, the risk to property from basement car park flooding is excessive, because a large number of vehicles are exposed to significant depths and are likely to become buoyant as the carpark fills, leading to significant damage.

Due to this high level of risk, the ideal solution would be to elevate basement car park entry points above the PMF water level so that the basement is unlikely to ever flood. PMF depths for the majority of the Narrabeen Lagoon floodplain are in excess of 2-3 m (**Figure 7-3**), however, thus this proposal is not very feasible as the access ramps would need to grade upwards to a height of over 2 m before descending down to the basement level.

Most Councils set minimum basement car park entry levels at the Flood Planning Level. For the majority of the Narrabeen Lagoon including North Narrabeen and the foreshore area, the average depth of the 1% AEP event is between 0.8-1.0 m above existing ground. With freeboard added this means that under current requirements, basement entries need to be elevated by up to 1.5 m. This is not considered feasible for most sites within the Narrabeen Lagoon floodplain.

There are several potential solutions that could be further explored by Council and presented to developers as viable design alternatives to reduce the risk:

- 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.

9 Flood Risk for Future Development

9.1 Development Precincts

There are two types of development occurring in the Narrabeen Lagoon catchment; greenfield development where the previously undeveloped land is developed, or in-fill development where land within a built-up area is used for re-development. Greenfield development usually result in a significant increase in impervious area which produces increased runoff, while in-fill development typically results in a less significant increase because there is not as large a change in the impervious area (i.e. it is usually present on the site).

This section of the report aims to identify changes to flood risk in the catchment from future development, and in particular precincts that are likely to have significant development in the future. There are several key development precincts within the Narrabeen Lagoon catchment:

> Ingleside Land Release Area: The NSW Department of Planning and Environment is in the process of preparing planning material for the development of the mostly rural Ingleside development precinct which is located in the elevated upper areas of the Narrabeen Creek, Mullet Creek and Fern Creek catchments;

> Oxford Falls Area: The suburb of Oxford Falls, which lies on the elevated upper section of Middle Creek has a significant area of development potential;

> North Narrabeen Commercial Area: Council has prepared the North Narrabeen Masterplan outlining the development potential for the North Narrabeen commercial centre, which lies within the lower Nareen Creek floodplain; and

> Warriewood Valley Urban Release Area: While the majority of the Warriewood Valley is already developed, a Strategic Review by the former Pittwater Council identified several sites on the fringes of the floodplain within the Warriewood Valley, which have development potential.

These development precincts are shown in **Figure 9-1**. For purposes of this assessment it has been assumed that the developments are to be completed with no detention storage systems in place (which replicates the situation that occurs when storage is full prior to the start of a storm).

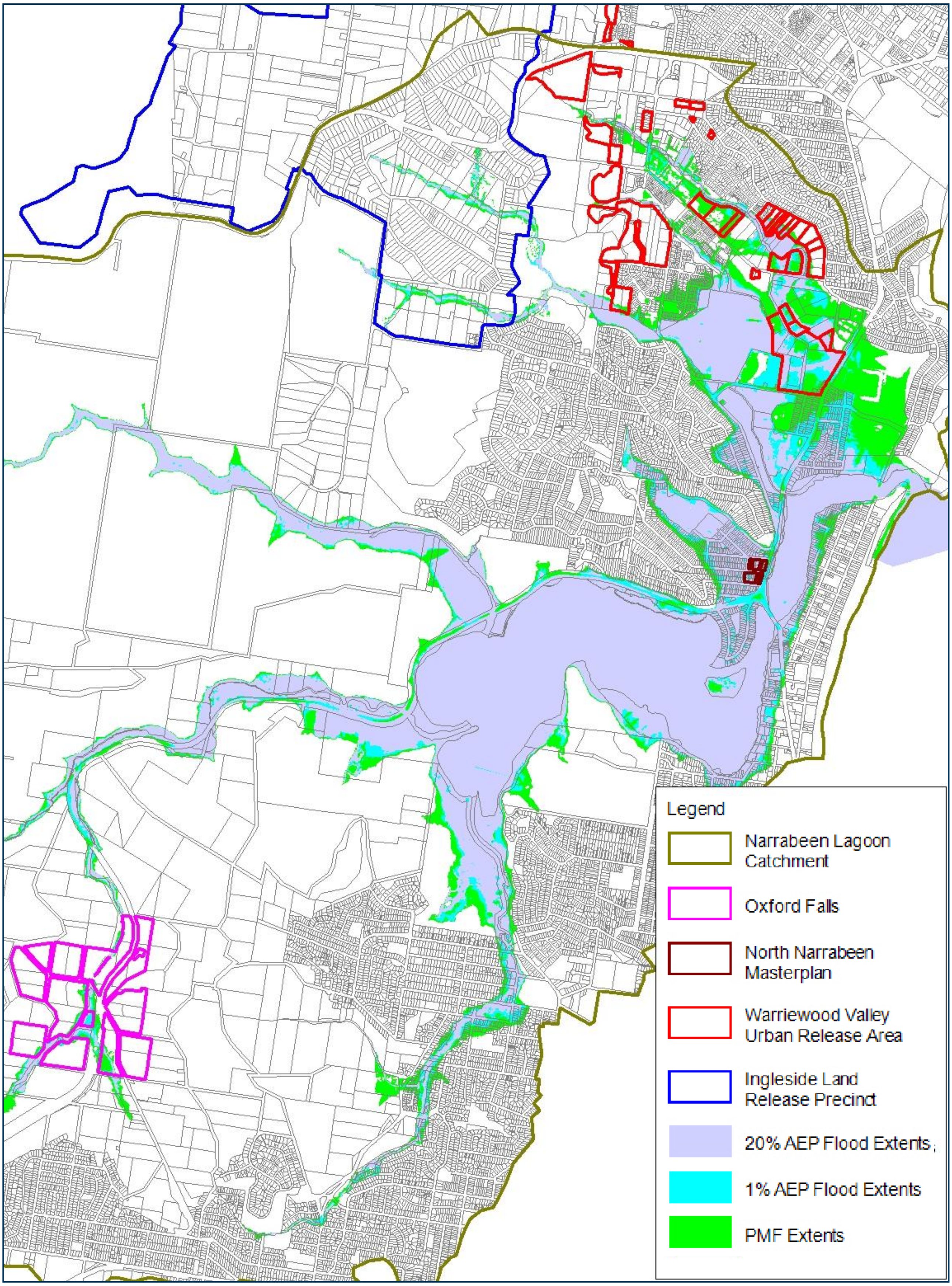


Figure 9-2 Narrabeen Lagoon Catchment - Development Precincts

9.2 Impact on Hydrology

9.2.1 Rainfall Losses

In the XP-RAFTS hydrology model, established as part of the Narrabeen Lagoon Flood Study (BMT WBM, 2013), the impacts of impervious surfaces on hydrology was accounted for in the adoption of varying initial and continuing rainfall losses. The adopted rainfall loss values for the impervious and pervious surfaces are listed in **Table 9-1**.

By analysing the rainfall losses for each surface it is possible to determine the total rainfall loss across a storm duration, which has been assessed for the 2 hour and 24 hour storm durations and is also listed in **Table 9-1**. These storms were chosen for assessment because the 24 hour duration is critical for the Lagoon floodplain and the 2 hour duration is critical for the majority of the upper catchment waterways.

As shown in **Table 9-1** it is possible to assess the rainfall losses as a percentage of the total rainfall depth, which for the 1% AEP 2 hour storm and 24 hour storm are 128.0 mm and 338.4 mm respectively.

Table 9-1 Analysis of Rainfall Losses for Surface Types

Surface Type	Initial Loss (mm)	Continuing Loss (mm / hr)	Total Rainfall Loss (mm)		Rainfall Loss as % of Total Rainfall Depth	
			2 hour storm	24 hour storm	1% AEP 2 hour storm	1% AEP 24 hour storm
Pervious	10	2.5	15.0	60.0	12%	18%
Impervious	2	0	2.0	2.0	2%	1%

The results presented in **Table 9-1** show that for the 1% AEP event the replacement of pervious areas with impervious surfaces results in a 10% and 17% increase in rainfall depth for the 2 hour and 24 hour storms respectively.

9.2.2 Impervious Percentage

For the majority of the development precinct areas listed in **Section 9.1,** a “low density residential” surface type was adopted in the Flood Study, which corresponds to an impervious percentage of 20%. For the purposes of this assessment it is assumed that following development of these precincts the land-use could be classed as “high density residential”. This land-use has an impervious percentage of 50% adopted in the XP-RAFTS model. The exception is the North Narrabeen Masterplan, which has been modelled as “high density residential” in the existing scenario and therefore no significant increase in impervious area is expected as a result of this development. An area summary of the development precincts is listed in **Table 9-2.**

Table 9-2 Impervious Area Assessment for Development Precincts

Development Precinct	Total Development Area in NL Catchment (ha)	Existing Scenario		Post-Development Scenario		Increase in Impervious Area (ha)
		Impervious %	Impervious Area (ha)	Impervious %	Impervious Area (ha)	
Ingleside	233.2	20%	46.6	50%	116.6	70.0
Oxford Falls	60.7	20%	12.1	50%	30.4	18.3
North Narrabeen	1.4	50%	0.7	50%	0.7	0.0
Warriewood Valley	72.0	20%	14.4	50%	36.0	21.6

The development of these precincts in the Narrabeen Lagoon catchment could result in a 110 ha increase in impervious area in the catchment. While this is a significant area of additional impervious surface, it equates to less than 2% of the total area of the Narrabeen Lagoon catchment, which is approximately 5,557 ha.

9.2.3 Water Level Impacts

As part of the Narrabeen Lagoon Flood Study (BMT WBM, 2013), sensitivity analysis runs were conducted for the hydraulic model to assess the impacts of rainfall increases of 10%, 20% and 30% across the entire catchment as part of the climate change assessment. Future development is likely to interact with changes in rainfall intensity from climate change, so it is important to consider how these two factors interact.

The modelling results showed that a rainfall increase of 10% across the entire catchment results in water level increases of 0.13 m for the lower Narrabeen Lagoon floodplain, with 0.24 m increases for a 20% rainfall increase.

Based on the review of the influence of loss rates within the catchment, to achieve a runoff increase in the order of 10 to 20% the entire Narrabeen Lagoon Catchment would have to experience an increase in impervious surface of 30%. Given the level of development present within the catchment, coupled with the national park regions in the upper catchment, it is highly unlikely development of this magnitude would occur.

The proposed developments result in an increase in impervious surface area of less than 2% of the total Narrabeen Lagoon Catchment and the modelling demonstrates that the worst impact that the developments may cause is a 0.026 m increase in water level.

Based on this outcome, these future developments are unlikely to significantly impact on floodplain behaviour in the Narrabeen Lagoon catchment overall, and certainly relative to the impact of changes in rainfall intensity.

9.3 Relevant Council Stormwater Detention Policy

The above assessment assumes that flows from additional impervious surfaces will not be stored in on-site or other detention structures. This is because flood modelling should consider the worst case scenario being that these systems are full (e.g. from rainfall a day earlier) and therefore cannot attenuate flood waters.

Notwithstanding this assumption in the modelling, it is still appropriate to try and minimise any increase in runoff from new development. Within the relevant stormwater planning controls for both the former Pittwater Council and former Warringah Council, all future 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 and Treloar, 2001) is applicable. The specification has the following development control relevant to stormwater attenuation:

> *On-site detention parameters are outlined for the various sectors of development in the valley in order for flows from development sites to be retarded so they do not exceed pre development conditions for the full range of durations and frequencies up to the 1% AEP. Replication of the base case hydrograph is required. This is to be achieved through both detention and retention of stormwater and a number of options to achieve this are identified (basins, ponds, OSD systems, seepage and re-use). Specific requirements for the hydrograph replication are noted as per below:*
>
> a. *Peak flow is +/-5% of pre-development condition;*
>
> b. *Pre and post development hydrographs are to be shown on one graph with tail cut at given storm duration; and*
>
> c. *The developed hydrograph is to be no more than +/-10% of pre-development at any location on rising/falling limbs.*

These requirements mean that not only are existing peak flows in the 1% AEP to be matched post-development, but that the flows throughout the flood hydrograph are expected to be comparable (+/-5%) to existing.

Therefore based on the above policies it is unlikely that the majority of development will occur without implementing appropriate detention to ensure that existing flows from the development site are matched.

10 Entrance Management

10.1 Introduction

As an intermittently closed and open lagoon (ICOLL), flooding within the Narrabeen Lagoon can be affected by the estuary entrance condition. Consequently Council, has operational protocols in place that govern how the entrance to the estuary is managed in the short-term (through emergency breakouts) and the long-term (large scale sand clearance projects).

As part of the FRMS, a review and assessment of management options for Narrabeen Lagoon Entrance has been undertaken, including:

> An assessment of how coastal processes over short, medium and long time frames are likely to impact management options;

> An assessment of the relative advantages and disadvantages associated with various strategies for sand clearance from the entrance (including the current clearance strategy). This assessment involved use of numerical modelling to quantitatively assess the efficacy of each strategy;

> An assessment of the trigger levels for Council's reactive mechanical opening of the closed entrance. This assessment included numerical modelling of a range of trigger level scenarios in order to provide a recommendation regarding the trigger level at which mechanical opening of the closed entrance should be undertaken, in both the short and long terms (under mean sea level rise).

This scope of this study is limited to the flooding implications and potential management options of the entrance shoal to limit the catchment flood extent. In addition to flood implications, other factors will need to be considered when developing the entrance strategy, some of which are:

1. Environmental implications. Significant and ongoing changes to the lake entrance will likely result in changes to the natural environment in the entrance. This needs to be investigated as part of the entrance management strategy;
2. Recreational use. Opening the entrance shoal will result in the lower part of the lagoon becoming tidal. This would result in the water level within the lagoon being maintained at a lower water level than typically occurring at present. Activities such as sailing and kayaking would be restricted in this case;
3. Long-term morphological processes. Permanently opening the lagoon entrance could significantly change the hydraulic regime of the lagoon. The bathymetry of the lagoon would naturally adapt to this. These potential morphological changes would need to be studied when developing the entrance management strategy.

It is also worth noting that the NSW government, through the Department of Primary Industry (DPI) have developed a set of guidelines and policies relating to the management of ICOLLs. The entrance management strategy would need to be developed in accordance with DPI's policies and guidelines.

10.2 Coastal Processes

In order to review and assess management options for Narrabeen Lagoon entrance, it is important to understand the physical coastal processes within the estuary. Narrabeen Lagoon entrance is situated at the northern end of the Narrabeen-Collaroy embayment, which is effectively a closed littoral cell with limited exchange of sediment with adjacent beach embayments.

Narrabeen Lagoon is classified as an ICOLL that is at an intermediate stage in its evolution over geologic timescales (which essentially refers to the degree of sediment infilling). Sediment transport within the estuary system is largely controlled by catchment inflows to the basin, and both tides and waves at the ocean entrance. A conceptual model depicting sediment transport processes in wave dominated barrier estuaries is presented in **Figure 10-1**. The ocean entrance is mostly open, with tidal exchange occurring through the entrance approximately 75% of the time between 1984 and 2010 (Morris, 2010). An important feature of the entrance channel is the presence of a natural rock weir that has a maximum crest level at approximately 0 m AHD (WBM, 2002). This controls the lowest water level at the entrance and therefore in the lagoon.

10.2.1 Present day morphodynamic behaviour of the entrance

10.2.1.1 Water levels through the lagoon entrance

Tide gauge records from inside the lagoon entrance (WBM, 2002) demonstrate that, during low catchment inflow following an entrance scour, the greatest dynamic range in water level inside the entrance is associated with both the semi-diurnal tidal period (12.42 hours) and spring-neap tidal period (15 days), though the range (of the order 0.2 m) is reduced significantly with respect to the ocean tide range. During partial entrance shoaling, the semi-diurnal tide range inside the entrance is further reduced and so the largest water level variation is then associated with the spring-neap tide cycle.

Tidal exchange of water through the lagoon entrance, even when scoured, is generally inefficient. Tidal energy losses through the entrance results in the water volume entering the lagoon on each rising tide not fully draining on each falling tide (i.e. the water levels in the lagoon can be “pumped up” by tidal inflows). This process results in a higher daily-averaged water level inside the lagoon compared to the mean sea level outside. This super-elevation varies over a fortnight and is typically 0.4 m AHD during springs and 0.2 m AHD during neaps (WBM Oceanics, 2002).

10.2.1.2 Currents and sediment transport through the lagoon entrance

The different water levels across the estuary entrance between high and low tide result in tidal lags. The typical lag between the ocean and lagoon tide is approximately 2 hours at high water and 3 hours at low water. This results in a shorter duration flood tide (i.e. incoming tide) with higher velocities and a longer duration ebb tide (i.e. outgoing tide) with lower velocities. This tidal asymmetry of a short flood phase with larger peak velocity compared to a long ebb phase with weaker peak velocity has an important influence on the net sediment transport direction in the entrance channel. The result is a net transport of sediment into the lagoon entrance.

The sediment entering the lagoon comes from the beach and surf zone immediately adjacent to the entrance, with waves playing an important role in the delivery of that sediment. Waves stir-up sediment at the seaward end of the entrance channel and in the adjacent surf zone, and mobilise sediment which is then transported into the estuary by tidal currents. Sediments can also migrate along the beach toward the entrance due to oblique wave run-up in the swash zone. Overtopping of the beach berm adjacent to the entrance channel can also sweep sediment into the channel. Once sediment is inside the channel its movement is controlled by the tide-related currents.

Other factors can oppose this sediment accumulation. Catchment floods act to scour the entrance and transport sediment seaward. Furthermore, the elevation of the lagoon water level described earlier, can increase the tidal ebb (outgoing) current and thus potentially increase the seaward transport of sediment. The higher the lagoon water level, the stronger the outflow current, and therefore the potential for transport and entrance scour.

While the transport of sediment through the Narrabeen Lagoon entrance channel is bi-directional, over time the net transport is clearly into the lagoon, otherwise the entrance wouldn’t continue to close and there wouldn’t be any requirement to dredge the accumulated sand. Presently, opening of the lagoon entrance usually occurs mechanically, triggered by a lagoon water level of about 1.3 m AHD. Most of the mechanical openings are for flood mitigation purposes. In addition there is larger-scale dredging of the entrance and flood tide delta approximately every 3-5 years.

10.2.1.3 Lagoon entrance morphodynamics

In the early stages following entrance scour (e.g. from a flooding event or after large scale sand clearance) the net sediment transport rate into the lagoon is much higher leading to rapid rates of sediment transport into and through the entrance channel to build the flood tide delta.

As the entrance area accumulates sand, the mean water level difference between the lagoon and the ocean increases. This adds to the hydraulic gradient on the outgoing tide and enhances the outgoing current velocity and sediment transport potential. This can result in a slowing down of the initial rapid rate of entrance infilling and tends to keep the entrance open for some time.

Whether the entrance remains heavily shoaled, but open, for a long period of time or closes off depends on a mixture of factors. These include the balance between sediment transport due to tidal differences versus floods and the elevated lagoon water level, the rate of sediment supply from wave-related processes, and the initial configuration of the entrance channel.

This pattern of rapid infilling initially following entrance scour and then a slower rate of infilling as the system approaches closure (or a subsequent scour) was observed by Morris (2010) and is consistent with a system in dynamic equilibrium that is restored by negative feedback after a disturbance.

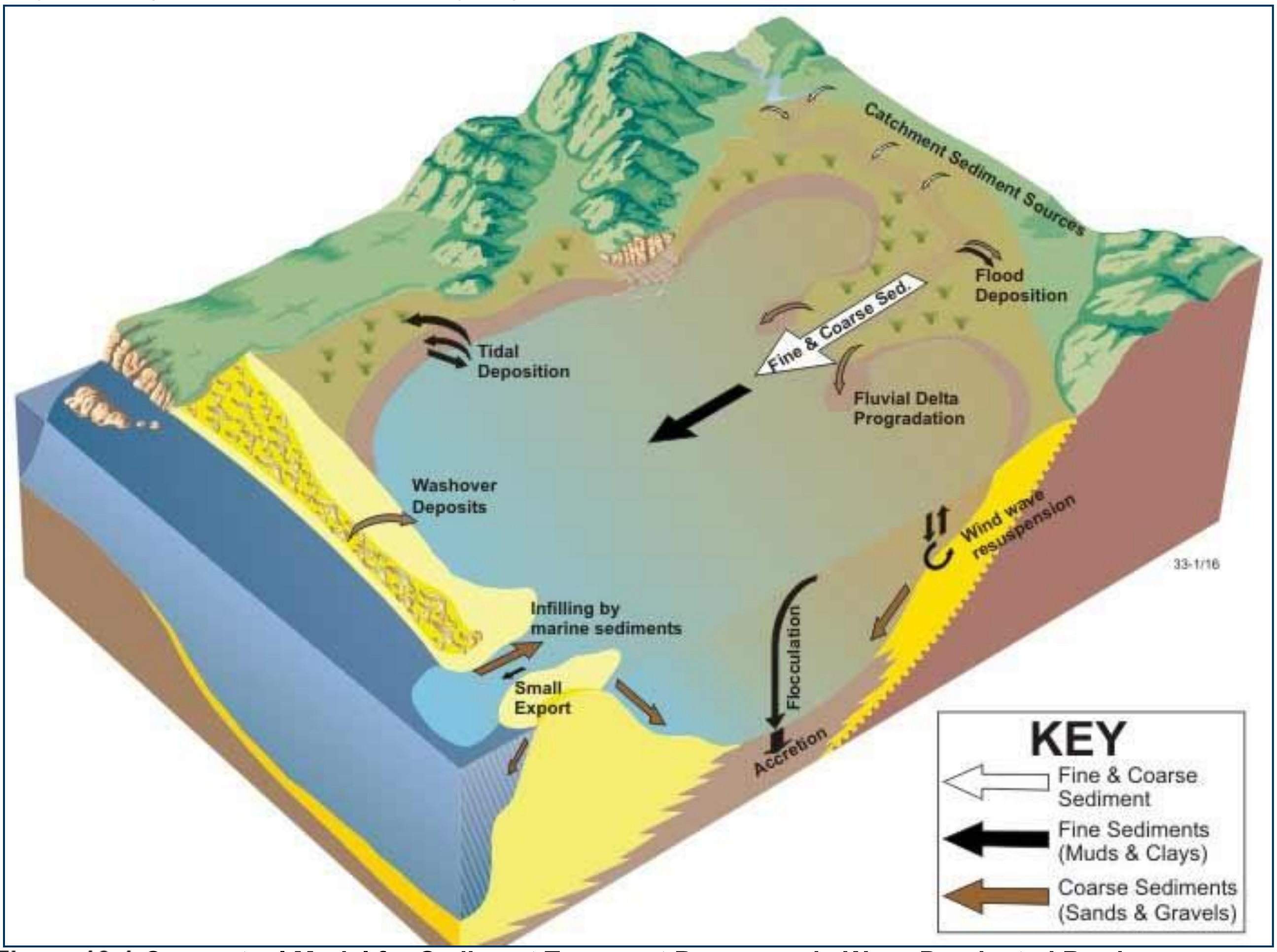


Figure 10-1 Conceptual Model for Sediment Transport Processes in Wave Dominated Barrier Estuaries (Source: www.ozcoasts.gov.au)

10.2.2 Expected morphodynamic response to climate change (sea level and storminess)

Haines and Thom (2007) reviewed the climate change variables that are expected to have an influence on NSW lagoon entrances in the coming decades. They are principally:

- Mean sea level;
- Wave climate; and
- Rainfall patterns.

Mean sea level on the Sydney coastline rose over much of the last century and is continuing to do so. The IPCC predictions for sea level into the future vary according to the carbon emissions scenario and the model uncertainty. Indicative values are 0.16 m to 0.19 m above 2015 mean sea level at 2050 and 0.38 m to 0.68 m above 2015 sea level at 2100 (IPCC, 2014).

The wave climate in NSW is expected to be influenced by an increase in Tasman lows during winter and a reduction in Tasman highs during summer with a net result that waves from the southeast will become more prevalent throughout the year (Hennessy *et al*., 2004).

Hennessy *et al.* (2004) predicted a decrease in average rainfall over the next century, particularly winter and spring rainfall, and an increased prevalence of droughts. While overall rainfall has been predicted to decrease, storm rainfall intensity is predicted to increase (Hennessy *et al.,* 2004; Walsh, 2004).

Considering these predictions for process drivers due to climate change collectively, Haines and Thom (2007) concluded that the combined effects could either compound or offset each other depending on the entrance setting and character of a lagoon.

Assuming that entrance berm levels increase with sea level, which is the conventional approach (Hanslow *et al.*, 2000), then future water levels in Narrabeen Lagoon will increase proportionately with sea level rise for both open and closed entrance conditions.

With an increased dominance of south-east waves, littoral sand transport will increase towards Narrabeen Lagoon entrance until the beach shoreline has rotated into an equilibrium planform. This will have the effect of widening the beach at the lagoon entrance. Opposing this effect will be the shoreline recession anticipated to result from sea level rise (i.e. the Bruun Rule). As the beach profile likely shifts landward and upward due to sea level rise there will be an increased tendency for accretion in the lagoon entrance, irrespective of the balance between shoreline recession and shoreline rotation.

While extended frequency of drought periods will tend to reduce the number of natural entrance openings, increased storm intensity will likely increase the amount of entrance scour when floods do occur, and potentially extend the time the lagoon is open. However, this potential influence will be limited by the presence of the rock weir in the entrance channel of Narrabeen Lagoon.

In summary, it is difficult to be definitive regarding the influence of climate change on the behaviour of Narrabeen Lagoon entrance. As Haines and Thom (2007) concluded for ICOLLs located at the northern end of beach embayments, the outcome will depend on the relative strength of the opposing effects involved, but the most likely scenario will be that the lagoon will have increased periods of closure, reduced frequency of entrance breakouts and consequently higher siltation rates.

10.2.3 Implications for entrance management options

There are two types of flood mitigation operations undertaken at the lagoon entrance: reactive mechanical opening and entrance clearance. The existing approach to each of the operations is detailed in the Lagoon Entrance Strategy OMS 455 (2013).

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 3-5 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, but the driving processes are not changed significantly from their existing regime and the system response is a dampened one directed toward re-establishing the equilibrium.

Any structural intervention intended to permanently increase the hydraulic efficiency of Narrabeen Lagoon entrance carries risk and would require detailed investigation. There is the potential for the system response to become self-forcing, and as a consequence to drive the system toward a new equilibrium condition that is associated with significant erosion of the natural sand delta and other intertidal areas around the broader lagoon foreshore. This occurred in Wallis Lake following the introduction of a second breakwater at its entrance (Gordon and Nielsen, 2001). In the case of Narrabeen Lagoon, the relaxation time required to re-equilibrate after such an intervention is likely to be shorter than that at Wallis Lake, but erosion issues could persist for a decade or more.

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. It would be appropriate to undertake significant further investigation to determine how Narrabeen Lagoon entrance behaviour can or should be modified which would need to include consideration of future climate change scenarios.

10.3 Entrance Clearance

10.3.1 Summary of existing and previously proposed clearance strategies

Over the past 40 years' several entrance clearance alternatives have been proposed in an attempt to manage the accretion of the flood tide delta and intermittent closure of Narrabeen Lagoon. A pictorial summary of approaches to dredging this type of environment, including some of their advantages and disadvantages, is presented in **Appendix E**.

Presently Northern Beaches Council, with the assistance of the NSW Government, undertake dredging of marine sands from the flood tide delta, typically between 40,000-50,000 m^3 every 3-5 years. The sand is loaded into trucks and transported to Collaroy Beach for placement. This approach promotes a medium-term increase in the duration of open entrance conditions by improving the hydraulic efficiency of the entrance channel.

The timing of clearance operations is based on the following factors: field observations and/or modelling that indicate the duration of the open entrance condition is decreasing, the volume of sand in the entrance area, peak usage periods and weather conditions. Works approvals are only granted under specific conditions. The Lagoon Entrance Strategy states that it is desirable for the entrance to be closed when conducting clearance works, with the entrance to be mechanically opened upon completion of the clearance works.

This approach, used very successfully by Council to manage the entrance since the 1970s, is also considered to have some limitations. Firstly, there is only a finite timeframe on the positive flow response experienced by the system upon clearing of the entrance – once the entrance is cleared it begins to fill again soon after (**Section 10.2.1.3**). There are also limitations associated with this approach regarding public safety and amenity concerns, with beach usage being impacted by heavy machinery, as well as costs associated with having to repeat the clearance works every 3-5 years. The timing of the works is also very difficult to forecast, and once closure has occurred due to large scale shoaling it takes around 6 months to implement a clearance operation. This forces Council to rely solely on emergency mechanical openings to mitigate flood risk. As discussed above, the morphology and hydrodynamics of the entrance make an opening difficult under water levels in the lagoon are super-elevated.

Following recommendations to investigate alternative methodologies for undertaking minor and major clearance operations, MHL (2009) examined the feasibility of six alternative options for the intermittent clearance of the entrance:

> Dry Earth Sand Winning with Directionally Drilled Pipeline;
> Dry Earth Sand Winning with Beach Cut and Cover Pipeline;
> Dry Earth Sand Winning with Pipeline on Beach;
> Dry Earth Sand Winning with Pipeline in Road Reserve;
> Slurrified Sand Winning with Pipeline on Beach; and
> Slurrified Sand Winning with Pipeline in Road Reserve.

These options envisaged mechanical pumping and placement of sand, in comparison to the existing clearance operation which involves excavation followed by loading, transport and delivery of sand to Collaroy-Narrabeen Beach via trucks.

In order to determine the most viable long-term clearance strategy, a preliminary long-term economic appraisal was conducted in the form of a cost effectiveness analysis, which considered five clearance campaigns from 2009 to 2021 assuming a removal of 40,000 m^3 of sediment each time. A range of constraints in the form of engineering, environmental, Aboriginal cultural heritage, social and community impacts, legislation, regulation and approvals and subsurface utilities were also considered as part of the feasibility.

A merit assessment of the current sand clearance approach and each alternative option was presented in MHL (2009). The advantages of the current approach were found to be a refined methodology from previous experience, known operational costs, minimal approvals, minimal impact on flora and fauna, no Aboriginal heritage issues, and no subsurface utilities. The disadvantages largely involved short-term impacts to the public, with beach access restrictions, noise of works, public safety concerns, truck traffic, as well as high mobilisation and demobilisation costs. The most favourable alternative to the present management strategy was considered to be Dry Earth Sand Winning with Beach Cut and Cover Pipeline.

Several other alternatives to mechanical clearance of entrance sand have also been explored. In 1991 MHL conducted a pilot study to assess the ability of a fluidisation system to simultaneously control the location of the southern bank and to form a sufficiently large sediment trap to accommodate the next flood tide sediment influx (MHL, 1991). In this case fluidisation involved the pumping of water into the bed sediment to increase pore pressure and ensure the sediment could be more easily moved by tidal flow.

The pilot study determined that fluidisation could be reliably achieved and was technically feasible as a management option. However the study highlighted several negative economic and social aspects of the proposed scheme, and it was therefore recommended the scheme be abandoned without further expenditure.

Once closed, the entrance relies on natural break-out via overtopping from the lagoon or mechanical breakout. The presence of a rock shelf with an elevation of 0 m AHD in the Narrabeen Lagoon entrance channel greatly limits the break-out processes (WBM, 2002). By changing the morphology at and surrounding the lagoon entrance, it may encourage more frequent natural break-outs that would minimise the build-up of sediment inside the entrance.

The possibility of bedrock removal was explored by MHL (1989) when they suggested a management strategy of “Excavated Rockshelf Entrance and Low Training Walls”. This strategy would involve the construction of an entrance excavated through the Narrabeen Headland rock shelf and bounded by rock training walls to establish a permanently open entrance.

Advantages of this strategy included no ‘entrance plug’ development due to the relocation of the entrance into moderately deep water, a reduction in sediment infill, expected low maintenance and water quality improvements. Disadvantages of this approach were the high capital cost, public safety due to higher velocities and slippery rock in the entrance channel. Additionally, the entrance would be very different aesthetically, and increased tidal influence in the lagoon may result in significant alterations to lagoon ecology, shoreline erosion issues, and impacts to the adjacent surf break.

10.3.2 Impact of Management Options on Flooding

Cardno has used numerical modelling to investigate the relative advantages and disadvantages of various strategies for sand clearance from the entrance for flood mitigation purposes. The specific strategies have been informed by the literature review, and discussed and agreed with Council. These flood mitigation measures are discussed further in **Section 11.2**, where they have been assigned identification codes. The strategies are:

> The current strategy of large-scale excavation of sand downstream and upstream of the Ocean St bridge every 3-5 years (referred to as FM4 in **Section 11.2**). Note that this is equivalent to the dry earth winning with cut and cover pipeline mentioned in MHL (2009);

> The use of dredging to remove sand from the flood tide delta upstream and downstream of the Ocean St bridge (referred to as Option FM5 in **Section 11.2**); and

> The removal of bed rock from the entrance via blasting or cutting, without the implementation of groynes (referred to as Option FM3 in **Section 11.2**).

The current strategy (FM4) was investigated in order to provide a quantitative measure of the impact of the strategy on flood levels, and to provide a baseline scenario to compare to the other two options.

The impact of dredging the flood tide delta upstream and downstream of the entrance bridge (FM5) was tested in conjunction with extending the Ocean Street bridge to remove the abutments. The rationale was that this would serve to reduce the hydraulic constriction that occurs around the entrance bridge, which would allow for a more rapid release of flood waters and reduction of flood levels (at least locally) during larger flood events.

The final option investigated involved lowering the underlying bedrock at the lagoon entrance (FM3), which presently limits entrance scour during flood events. This would require the use or combination of blasting, saws or other rock cutting equipment. The rationale was that without the bedrock acting as a limiting agent, the entrance could scour to a greater extent during a flood, thereby allowing a more rapid release of flood waters and reduction in flood levels.

Permanently opening the lagoon entrance with hard structural options (e.g. training walls, breakwaters, sea walls or groynes) was not assessed with detailed modelling due to poor community response (see **Table 4-1**), which would likely prevent their implementation regardless of positive outcomes. In order for the approach to be effective it would probably have to be accompanied by lowering of the bedrock underlying the entrance channel in order to permit scour to a level that reduced flood risk. The cost of these two activities combined would be considerable. Entrance structures would also significantly change the amenity of the lagoon entrance area. The area landward of the entrance channel confined by any hard structure would likely erode also, significantly impacting the present styles of recreational activity that take place in the area fronting the caravan park. As described earlier, experience at Wallis Lake suggests such a significant change to the entrance conditions could also result in considerable morphological adjustment (erosion and accretion) further into the lagoon proper. Removing the possibility for the bermed entrance to keep pace with sea level rise potentially introduces further negative effects by permanently opening the entrance. Hard structural options could possibly become more viable in the future when sea level rise starts to have more impact on flooding.

The three options were assessed using numerical modelling with the calibrated and verified Delft3D model of the estuary. Simulations were conducted for flood events of 20%, 5%, 1% and 0.1% AEP flood events. The efficacy of the options for flood mitigation were assessed by comparing results to the base cases used in the design flood modelling, which incorporated a fully shoaled and closed entrance. The impacts on water levels are listed in **Table 10-1,** and shown in **Figures 10-1 to 10-4**.

The results of the simulations show that the current entrance management strategy (Option FM4) is effective in its aim to reduce flood levels. Compared to a fully shoaled entrance, Option FM4 reduces flood levels throughout the lagoon by around 0.38 – 0.54 m or more for the more frequent floods of 20% and 5% AEP. The 1% AEP has reductions between 0.35 – 0.46 m AHD while the 0.1% AEP has reductions in the lagoon of between 0.27 – 0.37 m AHD. The effect is slightly more pronounced at the entrance than it is upstream around Deep Creek.

Dredging of the flood tide delta upstream and downstream of the Ocean Street bridge, and removal of the bridge abutments (Option FM5), also reduce flood levels. The effect of this option is minimal, however, for frequent flood events. Reductions in peak flood levels only become significant for the 1% AEP event or greater, where reductions of up to 0.03m m are observed. This is likely attributable to the fact that the entrance bridge abutments and upstream shoals generally only act as a hydraulic constriction for infrequent flood events where catchment inflows are greater relative to lagoon storage.

The simulations also indicated that the removal of the bed rock from the entrance reduces flood levels, with the impact increasing with the magnitude of the flood event. For 20% AEP events the impact of the bed rock removal reduces peak flood levels by around 0.03 to 0.04 m. However, as the magnitude of the flood event increases, so too does the magnitude of the entrance scour and therefore the impact of removing the bed rock. For 1% AEP flood events removal of the bed rock may reduce flood levels by around 0.08 m to 0.14 m in the upstream and downstream regions of the estuary respectively. The effect is significantly greater at the entrance than it is upstream around Deep Creek. An important finding is that the removal of the bedrock significantly reduces the flood duration, with the duration of flood levels above Council’s mechanical opening level (1.3 m AHD) reduced by 4-6 hours for most AEPs.

Table 10-1 Entrance Management Results - Modelling Results for 1% AEP Catchment Event

Design Event	Location	Closed & Shoaled Entrance (Existing)	Water Level Impacts (m) relative to Existing		
			FM4	FM5	FM3
20% AEP	US Ocean St Bridge	2.41	-0.54	-0.55	-0.04
	US Pittwater Rd Bridge	2.46	-0.47	-0.53	-0.03
	US Deep Creek Bridge	2.47	-0.46	-0.51	-0.03
5% AEP	US Ocean St Bridge	2.63	-0.49	-0.50	-0.08
	US Pittwater Rd Bridge	2.69	-0.41	-0.48	-0.05
	US Deep Creek Bridge	2.70	-0.38	-0.45	-0.04
1% AEP	US Ocean St Bridge	2.94	-0.46	-0.48	-0.14
	US Pittwater Rd Bridge	3.03	-0.36	-0.46	-0.09

Design Event	Location	Closed & Shoaled Entrance (Existing)	Water Level Impacts (m) relative to Existing		
			FM4	FM5	FM3
	US Deep Creek Bridge	3.04	-0.35	-0.43	-0.08
0.1% AEP	US Ocean St Bridge	3.41	-0.37	-0.42	-0.27
	US Pittwater Rd Bridge	3.50	-0.28	-0.39	-0.16
	US Deep Creek Bridge	3.52	-0.27	-0.37	-0.14

FM4: Shoal extraction upstream and downstream of the Ocean St bridge

FM5: Ocean St bridge extension as well as shoal extraction upstream and downstream of the Ocean St bridge

FM3: Entrance bed rock removal

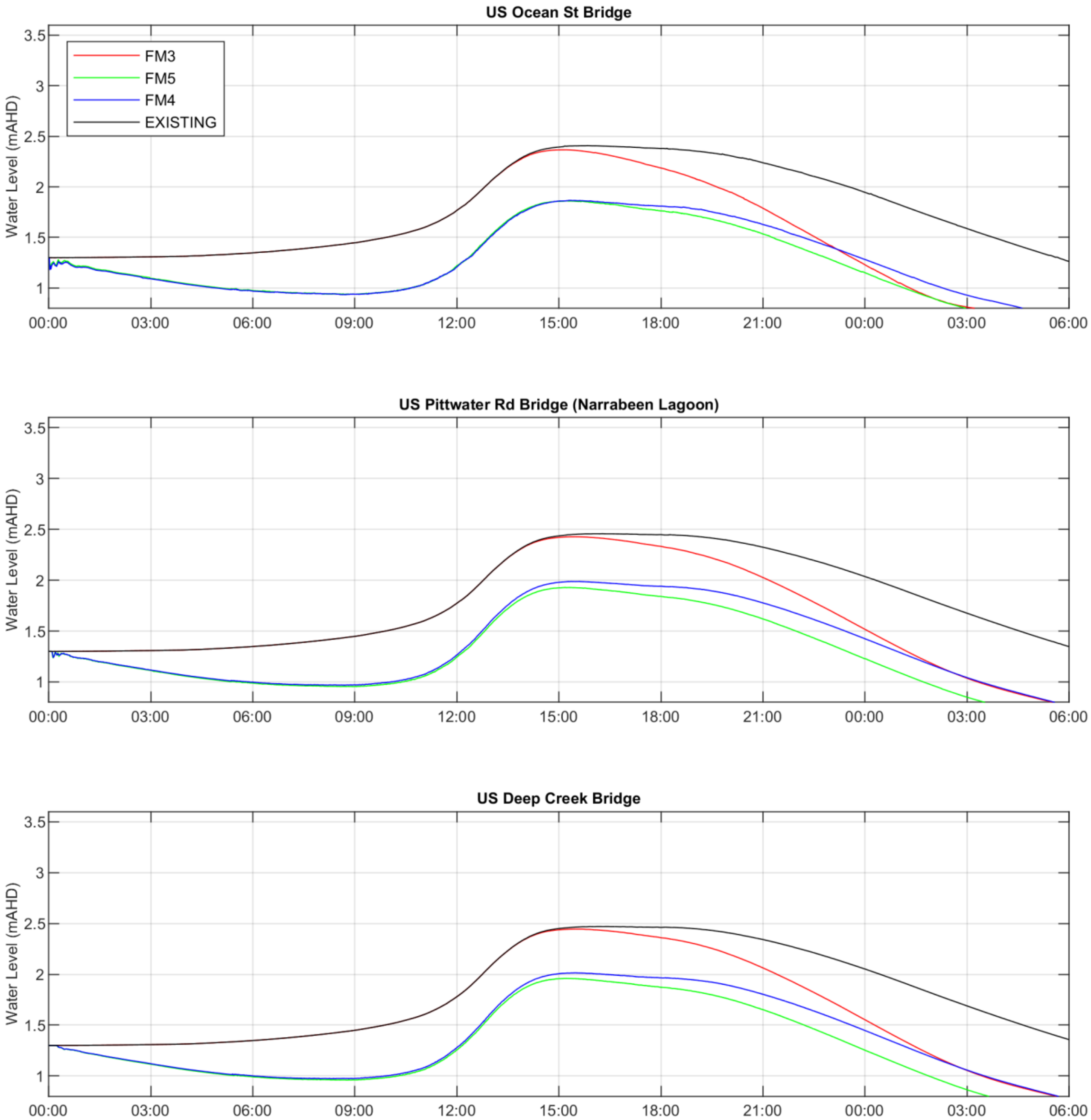


Figure 10-2 Entrance Management Options – Impact of Flood levels – 20% AEP

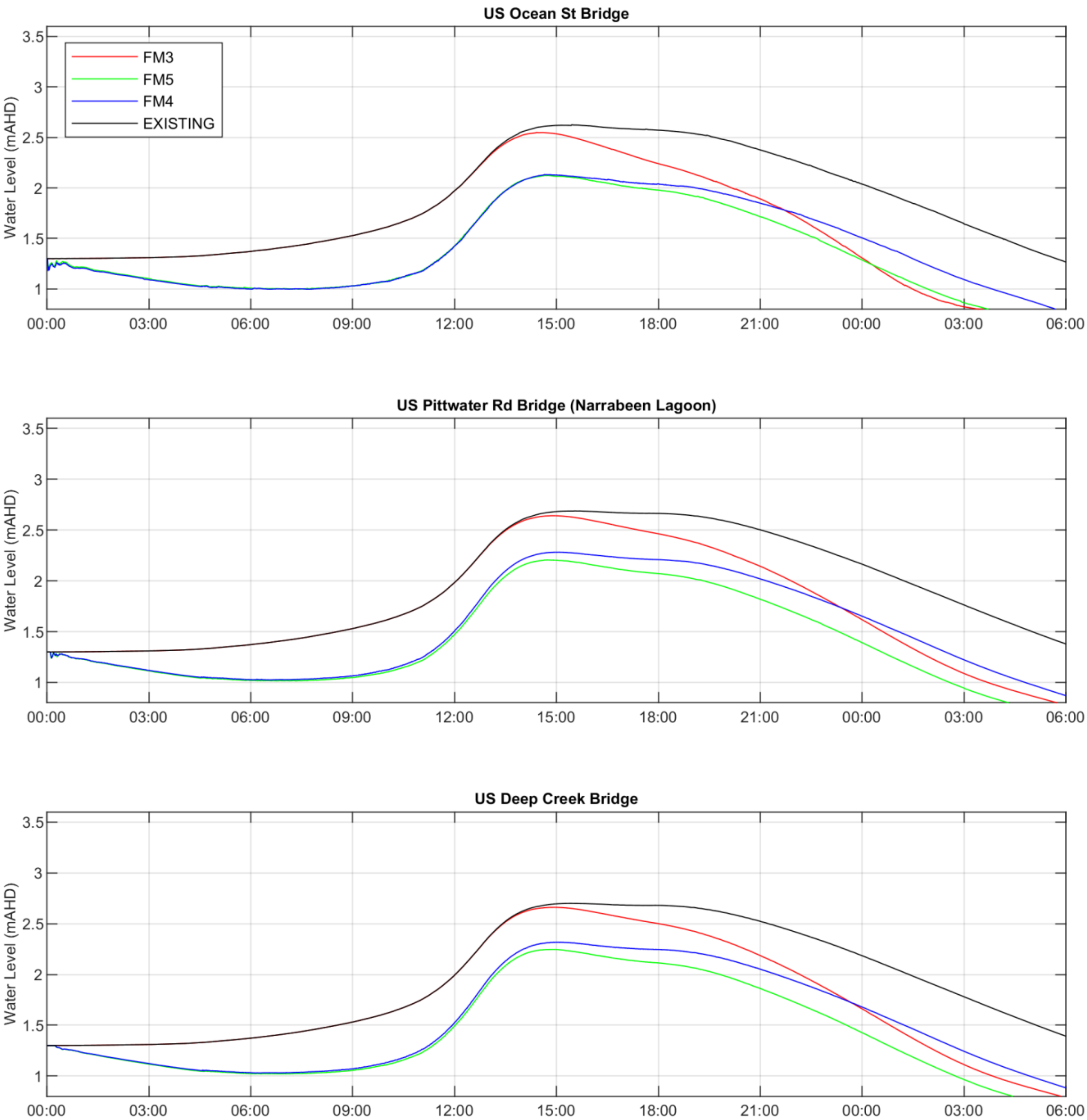


Figure 10-3 Entrance Management Options – Impact of Flood levels – 5% AEP

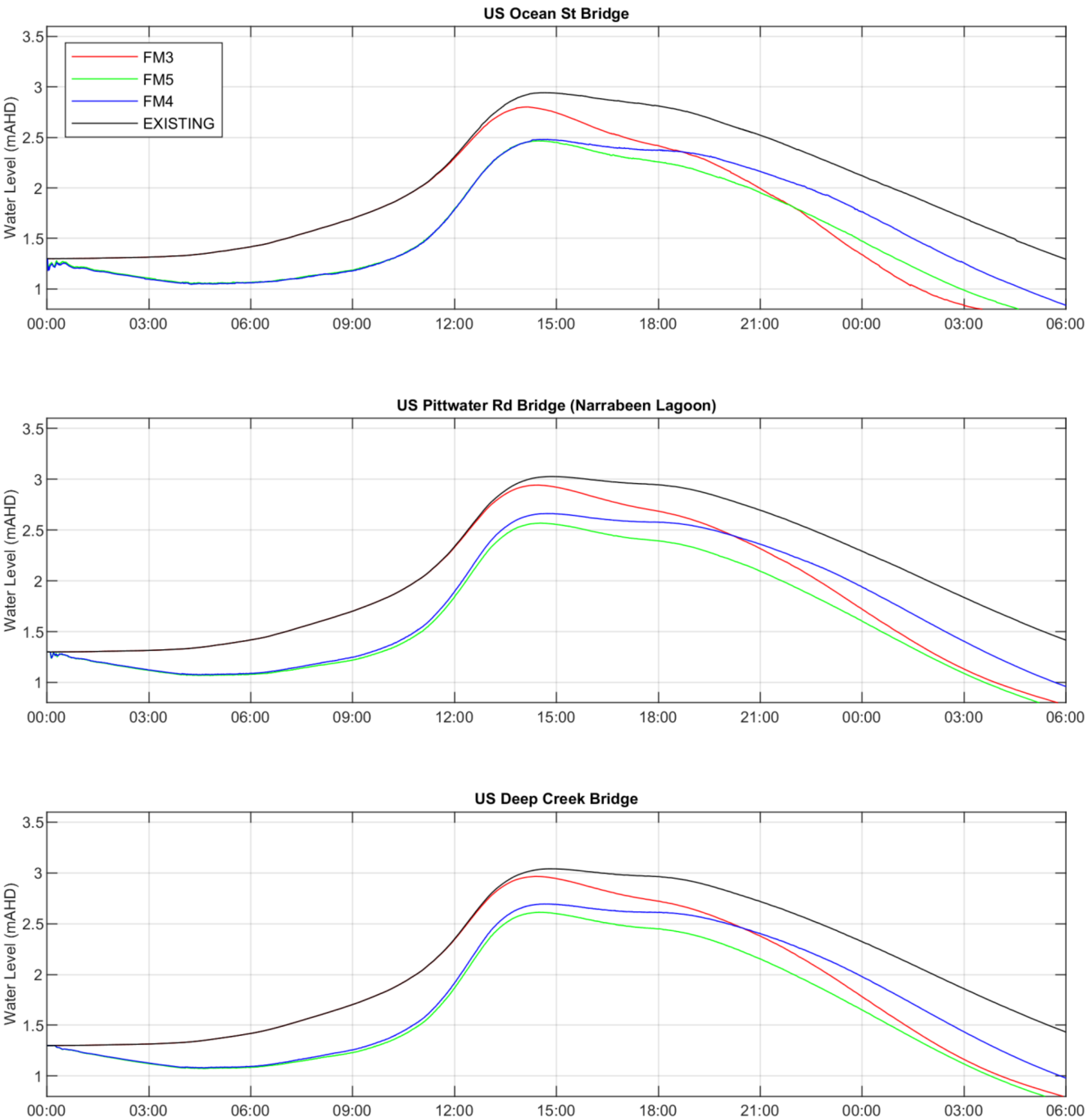


Figure 10-4 Entrance Management Options – Impact of Flood levels – 1% AEP

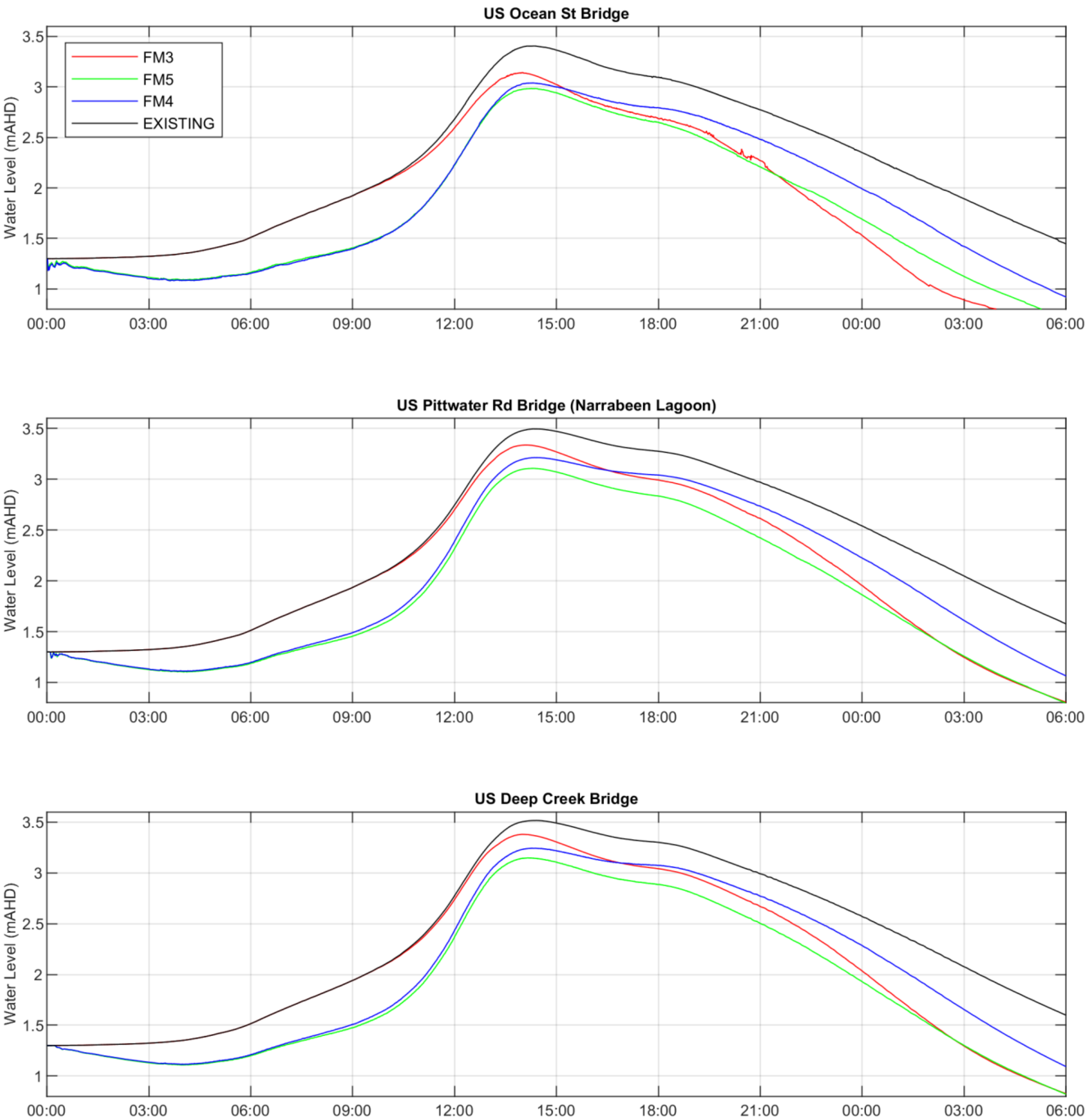


Figure 10-5 Entrance Management Options – Impact of Flood levels – 0.1% AEP

10.3.3 Discussion and Recommendation

The outcomes of the modelling have demonstrated that Council's current entrance management policy (FM4) is effective in mitigating flood risk compared to not mechanically opening the lagoon entrance. The results show that further benefits could be achieved by continuing the same strategy in conjunction with removing sand upstream of the Ocean Street Bridge and removing the constriction caused by the Ocean Street Bridge abutments.

The results have also shown that the removal of the bed rock at the entrance may reduce infrequent (1% AEP or less frequent) peak flood levels and durations compared to a shoaled entrance, however is far less effective than the other strategies assessed in this report. It is also noted that the removal of bedrock 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 not provide any flood mitigation compared to the existing adopted strategy, it is concluded that Council's present entrance management strategy is effective. Peak flood levels and durations could be further reduced by extending this program to include sand upstream of Ocean Street Bridge and removing its abutments. The alterations to the bridge are likely to be a considerable expense, and as such should be further investigated as part of the cost/benefit analysis.

10.4 Reactive Mechanical Opening

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

Currently, mechanical openings shall be undertaken when 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 – 1.3 m 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.

The OMS also notes that to achieve an opening in the 1.0 to 1.3 m AHD range the entrance should not be opened during king tides or large spring tides. These will promote the movement of sand back into the entrance channel before a stable outflow channel is established.

Narrabeen Lagoon drains slowly at a rate of approximately 0.01 m/hr when the entrance is well open, less when the channel cross-section area is small and less when the entrance is heavily shoaled upstream. The slow rate of drawdown means that it is important to ensure that the initial lagoon level is high enough to result in sufficient scour to widen out and establish the channel, and even then it can take several tidal cycles for the lagoon level to fall significantly.

In order to review the trigger level at which mechanical opening occurs, and assess the consequences of changing that trigger level, morphological modelling has been conducted for a range of different trigger level scenarios, which included lowering the trigger level to 1.1 m AHD, and raising it to 1.5 m AHD. The lower trigger levels were assessed in order to determine if earlier mechanical opening could significantly reduce the subsequent flood levels. The higher trigger level was assessed in order to determine if a management regime consisting of less frequent mechanical openings could be adopted without negatively affecting flood levels within the lagoon.

In order to encompass a reasonable range of trigger levels that Council might consider, the modelled lagoon trigger levels ranged from 1.1 m AHD to 1.5 m AHD (**Table 10-2)**. It is noted that trigger levels below 1.0m AHD are generally not considered to result in effective openings. Council experience indicates that opening the lagoon at a level of less than 1.0 m AHD without rainfall does not generally provide enough head to significantly scour out the entrance channel, resulting in the channel re-filling and even closing again shortly thereafter (usually within the range of days to weeks).

Morphological modelling was also conducted for 2050 and 2100 mean sea level rise scenarios, so that mechanical opening trigger levels could be assessed in the medium to long term. These scenarios consisted of increased ocean water levels and an accompanying increase in entrance berm levels and lagoon levels for 0.4 m and 0.9 m of mean sea level rise respectively (**Table 10-2**). The modelled storm event used to assess mechanical opening of the entrance was the 20% AEP catchment flooding scenario.

The results of the simulations are presented in **Table 10-3** and **Figures 10.6** to **10.8**. The results show that reducing the lagoon trigger level does reduce the subsequent flood level, and that reduction is fairly uniform throughout the lagoon system. However, the reduction is not 1:1, but rather is fractional. The reduction is fractional for two predominant reasons. The first is because the available flood storage in the system increases with elevation – and so for a lower initial water level, the volume of catchment flow entering the estuary is greater relative to the available storage. Secondly, flood levels within the system are also affected by the rate at which the estuary drains into the ocean, and this is affected by the magnitude and rate of entrance scour. The relatively narrow and shallow entrance acts to minimise the effect of reducing the trigger level, by acting as a flood constriction and controlling the rate of lagoon outflow.

For the present day mean sea level scenario, reducing the lagoon trigger level from 1.3 m AHD to 1.1 m AHD would reduce the 20% AEP flood levels in the lagoon by 7 cm, while increasing the lagoon trigger level to 1.5 m AHD would raise the 20% AEP flood levels by about 12 cm. Similar results are observed for future sea level scenarios (**Table 10-3**). The efficiency and effectiveness of mechanical entrance opening would be reduced with lower levels and may not be possible to achieve.

The reduction is fractional for two predominant reasons. The first is because the available flood storage in the system increases with elevation – and so for a lower initial water level, the volume of catchment flow entering the estuary is greater relative to the available storage. Secondly, flood levels within the system are also affected by the rate at which the estuary drains into the ocean, and this is affected by the magnitude and rate of entrance scour. The relatively narrow and shallow entrance acts to minimise the effect of reducing the trigger level, by acting as a flood constriction and controlling the rate of lagoon outflow. Converse results were observed when the trigger level was raised; lagoon flood levels increased but not by the fully equivalent amount. Raising the trigger level 0.2 m resulted in flood levels increasing by around 0.08 m.

It should be noted that a lower trigger level of 0.8 m AHD was also assessed for a less frequent, 1% AEP flooding scenario by Tulk and Beadle (2017). The results of this investigation showed that lowering the trigger level by 0.5 m to 0.8 m AHD resulted in reduced flood levels for the 1% AEP event by approximately 0.15 m, further highlighting the fractional and non-linear response to lowering the trigger level. Reductions in flood level for a 20% AEP scenario would likely be even less efficient.

Table 10-2 Mechanical Entrance Opening - Scenarios

Mean Sea Level Scenario	Lagoon Trigger Level
Present Day	1.1 m AHD 1.3 m AHD (existing policy – as a baseline for comparison) 1.5 m AHD
2050: Present Day + 0.4 m	1.5 m AHD 1.7 m AHD 1.9 m AHD
2100: Present Day + 0.9 m	2.0 m AHD 2.2 m AHD 2.4 m AHD

Table 10-3 Mechanical Entrance Opening - Modelling Results for 20% AEP Catchment Event

Mean Sea Level Scenario	Lagoon Trigger Level and Berm Level (mAHD)	US Ocean St Bridge		US Pittwater Rd Bridge		US Deep Creek Bridge	
		Flood Level (mAHD)	Difference to 1.3m Berm Scenario	Flood Level (mAHD)	Difference to 1.3m Berm Scenario	Flood Level (mAHD)	Difference to 1.3m Berm Scenario
Present Day	1.1	2.42	-0.07	2.48	-0.07	2.49	-0.06
	1.3	2.49	0.00	2.54	0.00	2.55	0.00
	1.5	2.61	0.12	2.66	0.12	2.67	0.12
2050: Present Day +0.4 m	1.5	2.69	0.20	2.73	0.19	2.74	0.18
	1.7	2.75	0.26	2.79	0.25	2.80	0.25
	1.9	2.91	0.43	2.95	0.41	2.96	0.40
2100: Present Day + 0.9 m	2	3.06	0.57	3.08	0.54	3.09	0.53
	2.2	3.14	0.65	3.17	0.63	3.18	0.62
	2.4	3.29	0.80	3.32	0.78	3.32	0.77

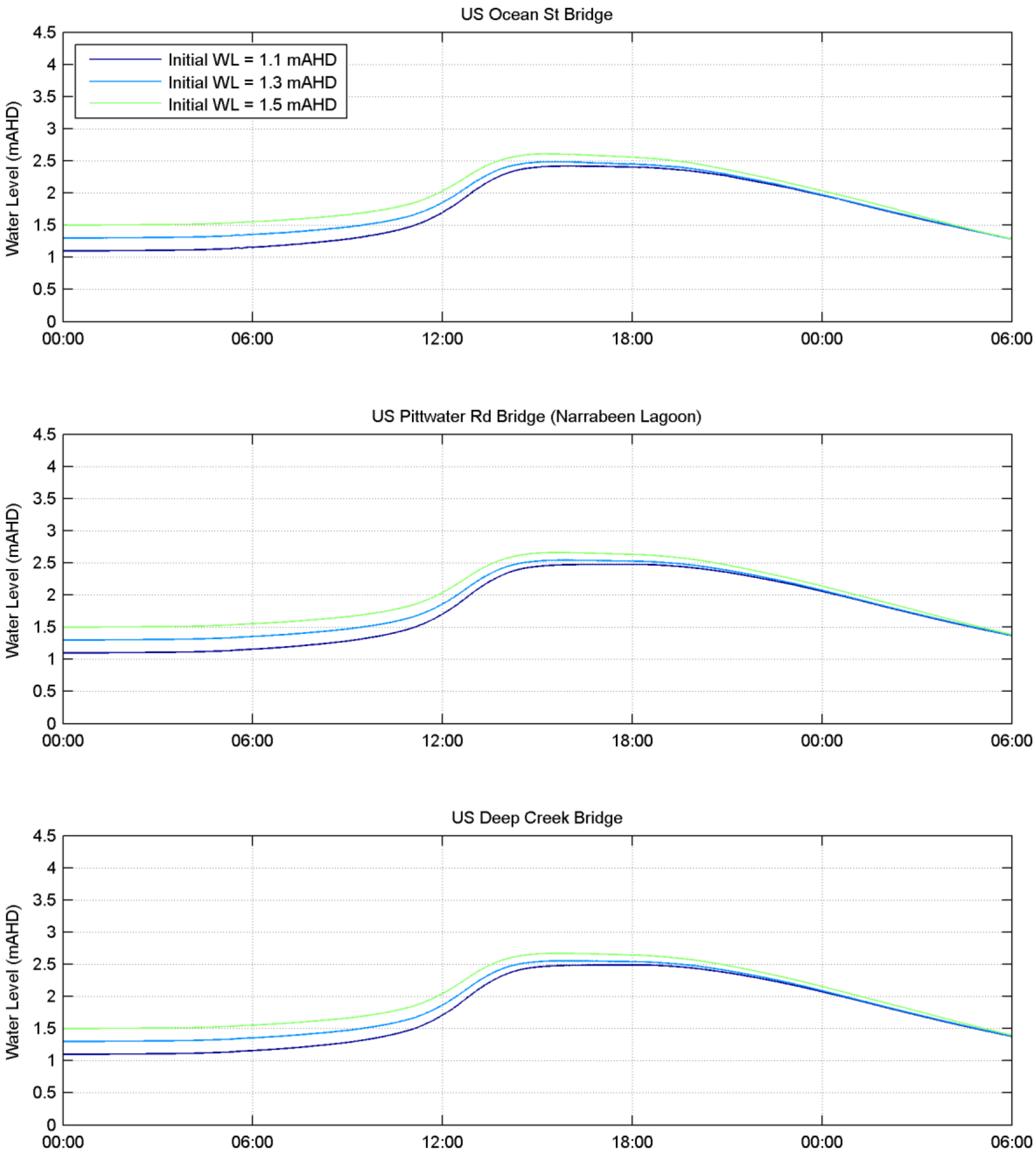


Figure 10-6 Mechanical Entrance Opening - Modelling Results for Present Day MSL

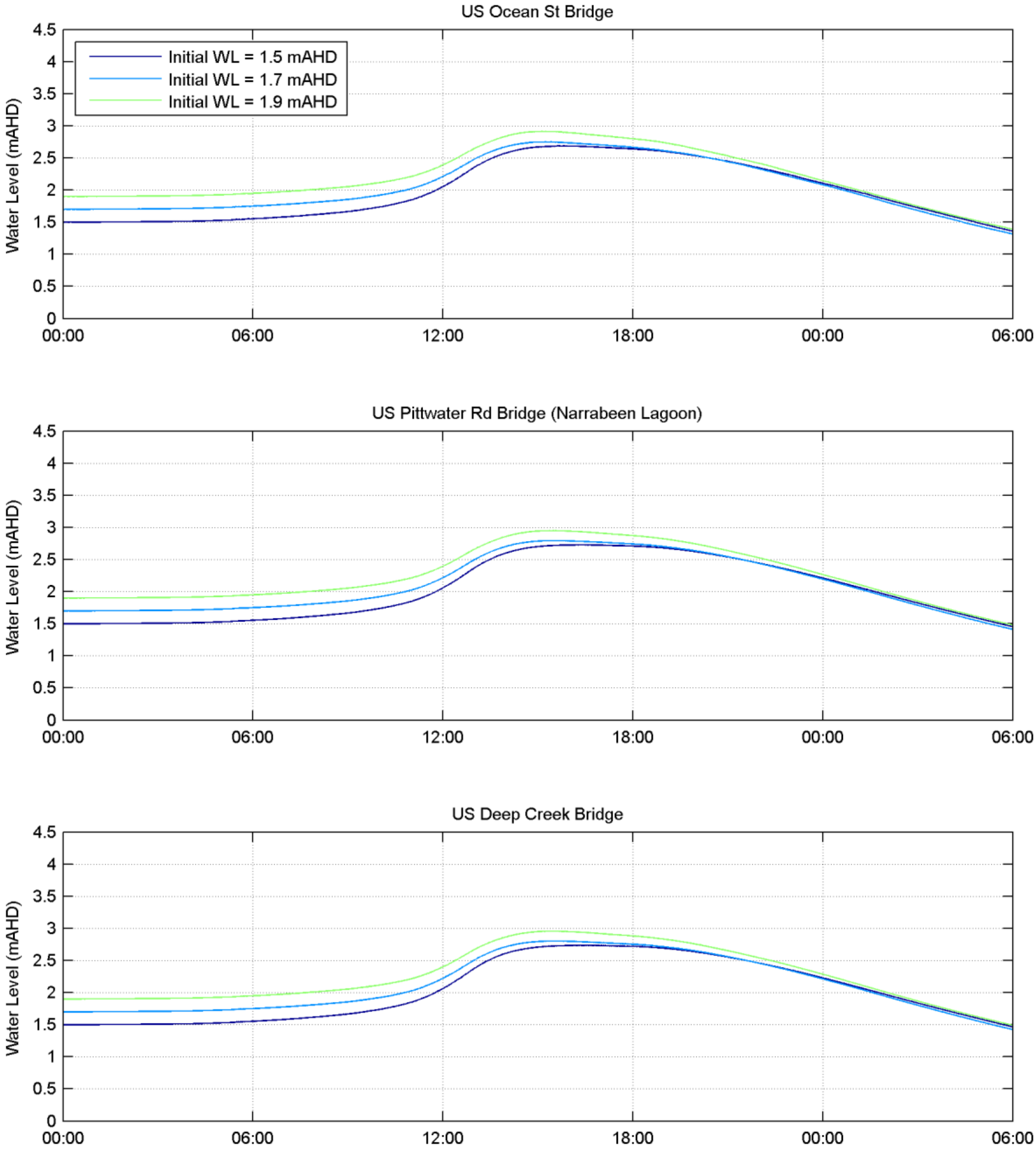


Figure 10-7 Mechanical Entrance Opening - Modelling Results for Present Day MSL + 0.4 m

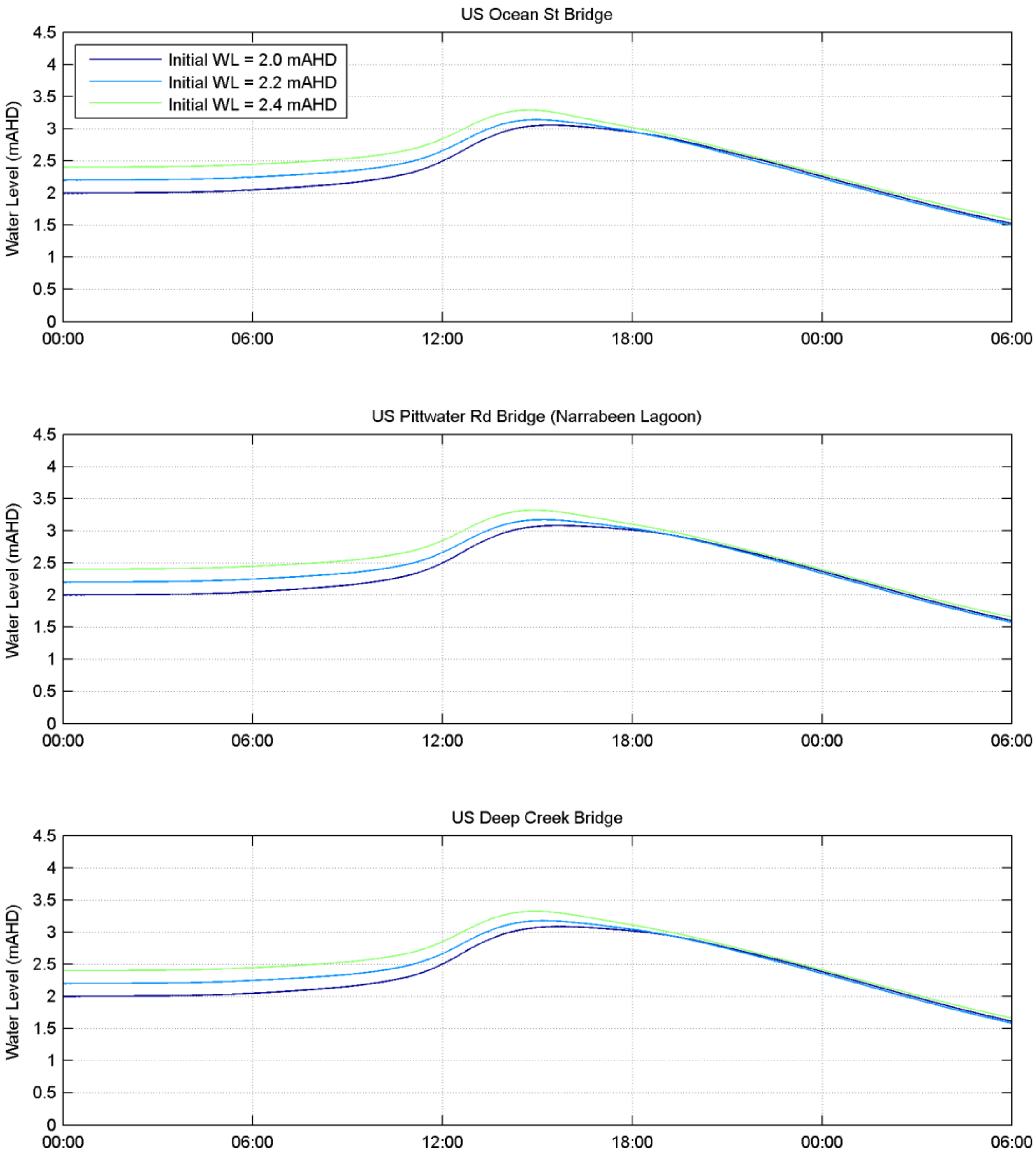


Figure 10-8 Mechanical Entrance Opening - Modelling Results for Present Day MSL + 0.9 m

10.4.1 Discussion and Recommendation

The selection of a mechanical entrance opening level is a trade-off between flood mitigation, entrance hydrodynamics and other practical and logistical issues such as available response time, and frequency of openings (lower trigger levels will result in more frequent openings and more intensive intervention to maintain it open long enough for water to drain from the lagoon).

The numerical modelling exercise has identified and quantified the non-linear response of flood levels to the change in trigger levels. While reducing the mechanical opening trigger level will reduce peak flood levels, the reductions are relatively modest due to the flood storage available at lower elevations and geometry of the entrance channel, which constricts the rate of lagoon outflow.

Consideration of the optimal mechanical entrance opening level requires consideration of flood mitigation requirements, but also other practical and logistical issues. Reducing the trigger level would allow more time to respond and perform the mechanical opening before flooding reaches critical levels. However, a reduction in the lagoon trigger level would also result in mechanical entrance openings occurring at a higher frequency, with an associated increase in costs and logistical requirements, while the flooding benefits would remain modest. Furthermore, the lowering the trigger level for entrance opening results in a lesser degree of entrance scour, and therefore a more rapid re-closing of the entrance.

Reducing the mechanical opening trigger level from 1.3 m AHD to 1.1 m AHD may be a viable alternative to the present practice, however reductions in the 20% AEP peak flood levels are relatively modest, at 7 cm. The efficiency and effectiveness of mechanical entrance opening would be reduced with lower levels and may not be possible to achieve.

Conversely, while increasing the lagoon trigger level may result in less frequent mechanical openings and more confidence in achieving a fully scoured entrance opening, the increase in flood level for a relatively common 20% AEP event (around 12 cm) is likely to be unacceptable to both Council and the local community. Therefore it is considered that Council’s current mechanical opening level of 1.3 m AHD is appropriate for present day mean sea level conditions.

The simulations summarised in **Table 10-3** indicate that for a +0.4 m sea level rise, a raised trigger level of 1.5 m AHD would limit the 20% AEP flood level at the Ocean St bridge to only 20 cm higher than the present day scenario. As mean sea level rises, implementation of mechanical opening will become increasingly impractical to apply for flood mitigation because spring high tides outside then entrance will begin to exceed the trigger value. As sea level rise continues over coming decades the flood mitigation value derived from mechanical entrance opening will diminish.

10.5 June 2016 Flood Event

During the development of this study a significant rainfall and storm tide event was experienced within the Narrabeen Lagoon Catchment. The flooding of Narrabeen Lagoon in June 2016 was due to a combination of heavy rainfall and large ocean conditions.

Over 200 mm of rainfall fell in a 24 hour period, which was combined with offshore ocean swells up to 12 m and a king tide cycle. This raised the downstream water levels at the lagoon entrance and hindered flood water escaping through the entrance of Narrabeen Lagoon.

On Friday 3 June 2016, in preparation for forecast rainfall and while lagoon levels were 0.9 m AHD (below the standard opening range), Council staff prepared a large channel through the berm as preparation for a quick opening the following day when the rainfall was forecast. A small plug was left at each of the upstream and downstream ends of the channel in order to preserve the channel from deterioration due to waves. Early on the morning of Saturday 4 June 2016, the lagoon was mechanically opened at 1.0 m AHD in accordance with the adopted Operational Management Standard for lagoon entrance management.

The majority of rain fell between the 4 and the 7 of June, however the elevated ocean conditions made it impossible for flood waters to escape. Peak water levels reached 2.10 m AHD at Ocean St Bridge which equates to slightly less than 5% AEP design event. The Narrabeen Lagoon Flood Study (2013) predicts that flooding would occur with the rainfall and ocean conditions experienced.

11 Floodplain Risk Management Options

11.1 Managing Flood Risk

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. Such buildings and developments would be exposed to a flood risk when they are built; and

> Residual Flood Risk – buildings and development that would be at risk if a flood were to exceed management measures already in place. In general mitigation options aim to reduce and or remove flooding for a design AEP event (for instance the 1% AEP). For events greater than the design AEP event risk of flooding is still present and must be considered.

The various approaches to managing risk are outlined in **Table 11-1**.

Table 11-1 Flood Risk Management Alternatives (SCARM, 2000)

Alternative	Examples
Preventing / Avoiding risk	Appropriate development within the flood extent, setting suitable planning levels.
Reducing likelihood of risk	Structural measures to reduce flooding risk such as drainage augmentation, levees, and detention.
Reducing consequences of risk	Development controls to ensure structures are built to withstand flooding.
Transferring risk	Via insurance – may be applicable in some areas depending on insurer.
Financing risk	Natural disaster funding.
Accepting risk	Accepting the risk of flooding as a consequence of having the structure where it is.

Measures available for the management of flood risk can be categorised according to the way in which the risk is managed. There are four broad categories:

> Flood modification measures;

> Emergency response modification measures;

> Property modification measures; and

> Planning policy modification measures.

These four option categories have been discussed further in the following sections.

11.2 Flood Modification Measures

Flood modification measures are options aimed at preventing, avoiding or reducing the likelihood of flood risks. These measures reduce the risk through modification of the flood behaviour in the catchment. For the Narrabeen Lagoon study area there are two types of modification measures.

> <u>Regional flood modification measures</u> – these seek to lower flood levels within the lagoon. While these measures are unlikely to completely remove flood risk at any locations, they attempt to alleviate flooding across a large area. Two types of regional measures have been considered:

  o Lagoon entrance management options to manage way in which flood waters are discharged through a lagoon entrance, and

  o Bridge upgrades to alter major flow constrictions at bridge crossings;

> <u>Local flood modification measures</u> – these target specific flood affected development areas and attempt to remove, or significantly reduce the flood affectation in a specific location. Assessment of

these options must guarantee that the options do not have adverse impacts on other parts of the floodplain not targeted by the option. The types of local options considered for Narrabeen Lagoon were:

- Levees – to create barriers to flood waters,
- Drainage upgrades and channel works – to improve conveyance in channels and lower flood levels in the area, or divert floodwaters away from existing development,
- Road raising – and often improving flows under roadways to limit road overtopping, which can often divert floodwaters into adjoining properties, and
- Detention basins – that detain creek floodwaters to reduce the amount of flood affectation downstream.

An additional proposed option, to raise the berm height in order to achieve a larger water depth in the lagoon and facilitate recreational activities such as boating, was also considered. This option was ruled out, on the basis of the results from the Narrabeen Lagoon Flood Study (BMT WBM, 2013). The immediate consequence of raising the berm height and permitting a higher water level is a reduction in the already small flood buffering capacity of the lagoon. If an increased lagoon water level is desired for recreational purposes, then presumably the intent would be to also maintain the entrance closed for most of the time. This would have significant ecological impacts in addition to the flood-related concerns. The alternative to raising the berm and lagoon water level to achieve suitable depths for recreational boating is to dredge the central lagoon area.

From the list of preliminary options above, a final list of measures was compiled to be assessed through detailed modelling. A summary of the final flood modification measures is presented in the following sections and includes:

> Details of the flood modification option including the existing flooding problem and dimensions and indicative scope of works involved;

> Whether the option has been proposed in any of the previous FRMSs for the area (see **Section 3.1** for details of these previous studies);

> Likely constraints and issues that may limit the feasibility of the flood modification options including ecological concerns, issues of constructability, acknowledgement of likely costs, and likely social disruption; and

> A brief summary of the hydraulic modelling results for the flood modification option including the impacts on flood behaviour and water levels, particularly any adverse impacts on adjoining properties.

The locations of the final flood modification options are shown in **Figure 11-1**. 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).

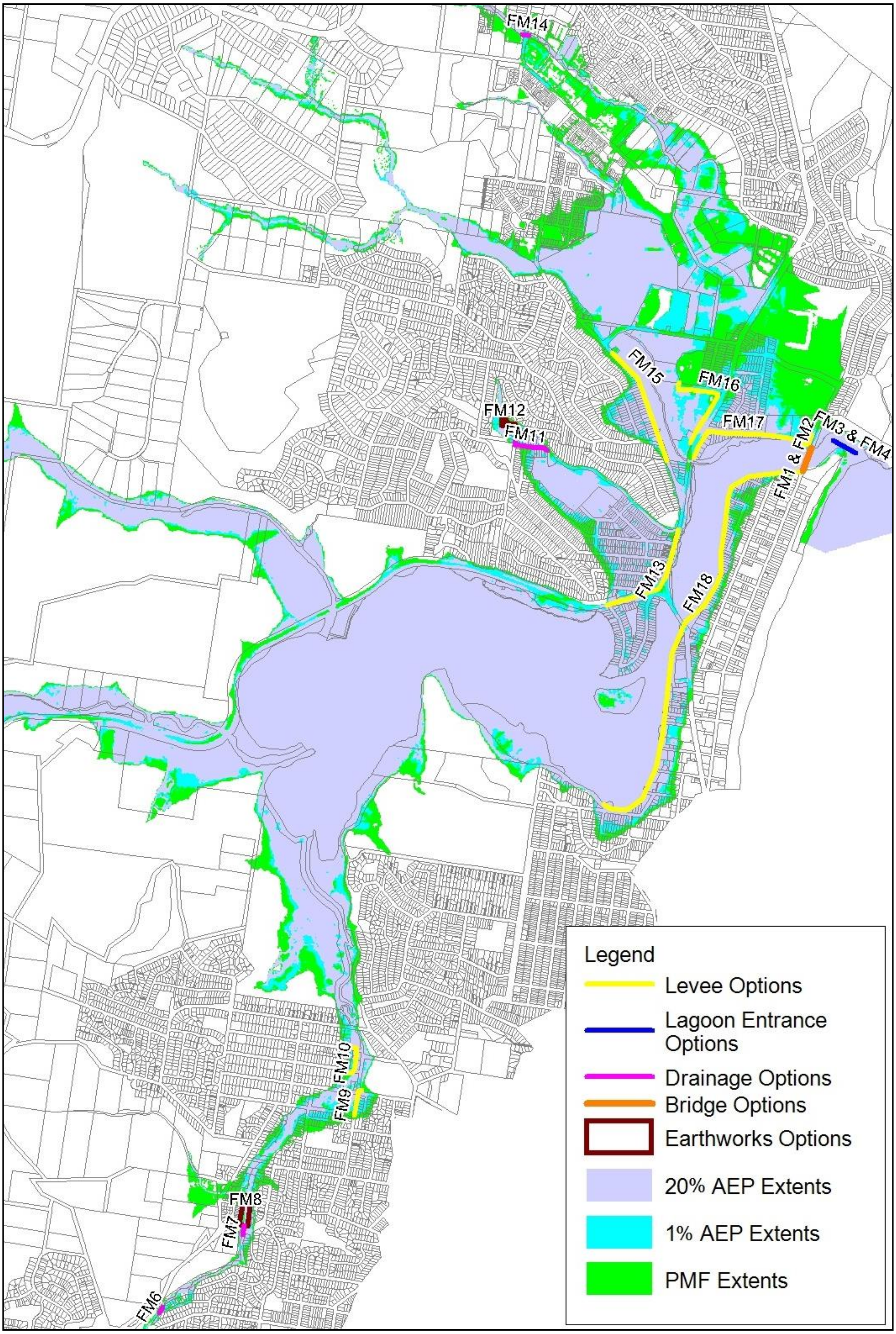


Figure 11-1 Location of Flood Modification Measures for Narrabeen Lagoon

11.2.2 FM1 – Ocean Street Bridge Extension

Description

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.

Potential Constraints

The location of the bridge embankment is within an area of ASS Class 1 / 3, as well as an area where four threatened species have been identified. In addition the scale of works involved would be expensive, and during construction a key regional road would be inaccessible. The feasibility of the bridge extension would require a review of the existing structure. In addition, any alteration to the area surrounding the entrance should be subject to a sediment transport assessment to ensure no unexpected changes to the sediment transport system are encountered.

Modelling Results

The Figures for Option FM1 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The option manages to reduce the level within the Lagoon by 0.01 to 0.03 m. The effects of this reduction are experienced upstream to Pittwater Road where the control at this location minimises any further reductions. **Table 11-2** summarises the water level differences within the lagoon due to the implementation of this option.

In general this option does provide some protection for the catchment and some minor hazard reductions around the lagoon area.

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

Description

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.

Potential Constraints

This option will likely be prohibitively expensive. The removal of this constraint may result in marginal water level reductions depending on how much additional throttling occurs at the lagoon entrance. In addition, any alteration to the area surrounding the entrance should be subject to a sediment transport assessment to ensure no unexpected changes to the sediment transport system are encountered.

Modelling Results

The Figures for Option FM2 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The option manages to reduce flood levels by around 0.01 m to 0.03 m throughout the lagoon by removing the obstruction of flood waters. **Table 11-2** summarises the water level differences within the lagoon due to the implementation of this option.

11.2.4 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.

Potential Constraints

This option is likely to be very expensive. Additionally, if the bedrock at the entrance were to be removed by blasting, that would require an extensive environmental impact assessment process prior to approval. Additionally thorough and detailed entrance modelling of the approach under a range of climate conditions would need to be undertaken to ensure no adverse or unexpected impacts are presented.

The entrance would continue to fill with sand after the bedrock is removed. At times when the channel is at its deepest, however, the improved hydraulic conveyance will lead to greater penetration of tide and storm surge levels into the lagoon potentially exacerbating flooding of the lagoon foreshores. It will also potentially result in lower low tide levels, with deleterious impacts on seagrass and other benthic species.

Modelling Results

The Figures for Option FM3 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The results of the simulations indicate that the removal of the bedrock from the entrance also reduces flood levels, with the impact increasing with the magnitude of the flood event. For the 20% AEP event the impact of the bedrock removal reduces peak flood levels by around 0.03 to 0.05 m. The magnitude of the entrance scour and therefore the improvement in flood reduction achieved from removing the bedrock increases with the magnitude of the flood event.

For the 1% AEP event this option may reduce flood levels by around 0.08 m to 0.15 m in the upstream and downstream regions of the estuary respectively. The effect is significantly more pronounced at the entrance than it is upstream around Deep Creek. An important finding is that the removal of the bedrock significantly reduces the flood duration; the duration of flood levels above council's mechanical opening level (1.3 m AHD) can be reduced by 4-6 hours for most AEPs. **Table 11-2** summarises the water level differences within the lagoon due to the implementation of this option.

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

Description

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.

Potential Constraints

This option needs to be undertaken frequently to maintain its effectiveness. The entrance shoals will begin to form immediately after dredging, and hence the impact will be reduced unless dredging is undertaken shortly before flooding. The extraction of sand from this location may have unforeseen impacts on the lagoon habitat and will require an extensive environmental impact assessment prior to approval, which could leave the lagoon entrance closed for significant periods of time, potentially with elevated water levels.

Modelling Results

The Figures for Option FM4 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The results of the simulations show that Option FM4 is effective in its aim to reduce flood levels. Compared to a fully shoaled entrance, Option FM4 reduces flood levels throughout the lagoon by around 0.4 – 0.5 m for the more frequent floods of 20% and 5% AEP. The 1% AEP has reductions between 0.36 – 0.46 m AHD while the 0.1% AEP has reductions in the lagoon of between 0.27 – 0.37 m AHD.

The effect is slightly more pronounced at the entrance than it is upstream around Deep Creek. This result indicates that the entrance shoals have a major impact on flooding, and that dredging of the shoals upstream and downstream of the Ocean St bridge is an effective flood mitigation option. **Table 11-2** summarises the water level differences within the lagoon due to the implementation of this option.

11.2.6 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 was 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 mechanical excavators would be used to dredge the flood tide delta and costs estimated accordingly (MHL, 2009).

Description

This option entails utilising a mechanical excavator to remove the sand. This sand is then placed in a hopper and turned into a slurry 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 and may significantly reduce the lead time for action compared to FM4 which requires new regulatory approvals each time.

Potential Constraints

The infrastructure associated with this option may be subject to storm damage, particularly due to the relatively unprotected nature of the pipeline. Storm damage risk will increase under climate change scenarios, even if the pipe is buried where possible. This option would also require an extensive environmental impact assessment process prior to approval.

Modelling Results

The modelling results for this option are as discussed in **Section 11.2.5** for Option FM4. As the options are designed to provide the same outcome no additional modelling was undertaken for this option.

11.2.7 FM5 - Ocean Street Bridge Extension, Upstream & Downstream Shoal Extraction

Description

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.

Potential Constraints

This option needs to be undertaken frequently to maintain its effectiveness. The entrance shoals will begin to form immediately after dredging, and hence the impact will be reduced unless dredging is undertaken shortly before flooding. The extraction of sand from this location may have unforeseen impacts on the lagoon habitat and will require an extensive environmental impact assessment process and prior to approval.

Modelling Results

The Figures for Option FM5 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The results of the simulations indicate that Option FM5 achieves a minor reduction in flood levels, however, the effect of this option is limited for the more frequent AEP events. Reductions in peak flood levels are generally of the order of 0.01 m for 5% to 20% AEP events, and 0.02 to 0.03 m for 1% to 0.1% AEP events. The results for this option are very similar to Option FM1, indicating that the extension of the bridge is the primary reason for the reduction in flood levels and the shoals upstream of the entrance bridge have only minimal impact on flooding. **Table 11-2** summarises the water level differences within the lagoon due to the implementation of this option.

11.2.8 FM6 - Alkira Circuit Drainage Upgrade

Description

Upgrading the current culvert network (three 1350 mm pipes and one 1500 mm pipe) under the low-lying Alkira Circuit crossing (road level is only 2.3 m 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).

Potential Constraints

The existing road surface is quite low lying which means that cover from the road level to the 1500mm pipe obvert is 0.8 m, meaning there is limited cover available for increases in culvert height. It is not known what services run under Alkira Circuit. Removal of the existing pipe network and replacement could be expensive, and during construction the local road will be inaccessible. Raising of Alkira Circuit road surface is also a possibility that could be further explored.

Modelling Results

The Figures for Option FM6 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The results highlight that under the proposed culvert arrangement the overland flow conveyed down the road can be contained within the channel. This in turn reduces the amount of affected properties on the north side of the road. While increasing the culvert size results in some higher water levels within the channel these increases do not adversely affect properties in the area.

11.2.9 FM7 - Willandra Road Reserve Lowering

Description

The public reserve on the western bank downstream of Willandra Road is elevated (approximately 12 m AHD), while the eastern bank which has flood affected residential properties is lower (approximately 11 m 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.

Potential Constraints

This section of creek line is River Flat Eucalypt Forest, an identified threatened ecological community. Although the proposed modifications are in an ASS Class 5 area requiring minimal treatment, the depth to bedrock is unknown in this area, thus channel lowering could be difficult if shallow bedrock is encountered.

Modelling Results

The Figures for Option FM8 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The results indicate that while this option provides some protection in regards to properties, the option does not completely remove flood affectation of these properties. Locally water level reductions of up to 0.3 m are achieved for adjacent properties.

11.2.10 FM8 - Willandra Road Culvert Upgrade and Channel Vegetation Clearing

Description

There are two 3.0W x 1.55H RCBCs 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 overtops the road reserve diverting flood waters onto several low-lying residential properties downstream.

In order to improve conveyance through the roadway, a 3.0W x 1.55H RCBC through the road has been considered. To cater for the increased culvert conveyance, vegetation clearance has been considered within the model 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).

Potential Constraints

The existing cover from the road level to the culvert obverts is 0.4 m, thus there is limited cover available for increases in culvert height. This section of creek line is River Flat Eucalypt Forest, an identified threatened ecological community. During construction a key local road would be inaccessible.

Modelling Results

The Figures for Option FM8 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The introduction of the culvert dramatically lowers the water level over the roadway. This results in a marked reduction in water levels on the (up to 500 mm) northern side of the roadway. The improvement in conveyance downstream of the culvert also alleviates some impacts, resulting in an option which provides good protection to the local properties.

11.2.11 FM9 - Waroon Road Levee

Description

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.

Potential Constraints

Adjacent to the levee site is River Flat Eucalypt Forest, an identified threatened ecological community. A site visit to the area identified that this constraint is unlikely to affect the option, because there is sufficient space between the required vegetation removal line and the forest. This option may provide opportunity for the removal of introduced species and potentially improve the River Flat Eucalypt Forest.

Modelling Results

The Figures for Option FM9 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The Waroon Road levee successfully mitigates the impacts of flooding on the properties behind the levee. The levee results in a minor increase in water level within the creek extents (approx. 0.02 m) however this does not encroach significantly on adjacent properties. It is likely the small impacts present could be offset with minor drainage alignment works or protection on the opposite side of the creek channel.

11.2.12 FM10 - Wabash Avenue Levee

Description

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 1.7 m above the existing surface, and a length of approximately 210 m. This option may result in the removal of flooding on four residential properties for the 1% AEP event. This option was previously considered as part of South Creek FRMS (2008).

Potential Constraints

Adjacent to the levee site is River Flat Eucalypt Forest, an identified threatened ecological community. A site visit to the area identified that this constraint is unlikely to affect the potential of the option as the forest is not located along the edge of the vegetation in the area. This option may allow opportunity for the removal of introduced species and potentially improve the River Flat Eucalypt Forest.

Modelling Results

The Figures for Option FM10 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The Wabash Avenue levee successfully mitigates the impacts of flooding on the properties behind the levee. The levee results in a minor increase in water level within the creek extents however this does not encroach significantly on adjacent properties. It is likely the small impacts present could be offset with minor drainage alignment works or protection on the opposite side of the creek channel. Further improvements may be available if a vegetation management plan is established for the area. This scenario should be investigated if the option is considered viable in the future.

11.2.13 FM11 - Tatiara By-pass Overland Flow path

Description

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 m over a distance of 200 m.

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.

Potential Constraints

ASS Class 2 / 3 exists in this area and depth to bedrock is unknown so cutting may be difficult, however there are no ecological constraints. Two key local roads would be out of service during construction and costs could be significant. The grading requires significant surface works which may interfere with access to properties and underground services.

Modelling Results

The Figures for Option FM11 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The bypass through this section improves the flood levels across the region significantly. In the 1% AEP reductions of up to 0.5 m are expected on the properties downstream of the by-pass.

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

Description

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.

Potential Constraints

The land involved is in private ownership and using/acquiring it may present financial and other challenges. Other issues are similar to those outlined for Option FM11.

Modelling Results

The Figures for Option FM12 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The bypass through this section improves the flood levels through the region significantly. In the 1% AEP reductions of up to 0.4 m are expected on the properties downstream of the by-pass. While this option results in less depth reduction than FM11 it also protects properties upstream of Tatiara Crescent, thus it is considered a more effective flood mitigation option.

11.2.15 FM13 - Pittwater Road & Wakehurst Parkway Raising / Levee

Description

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.

Potential Constraints

There are ASS Class 2 / 3 present in this area thus excavated soils will likely require treatment. The potential environmental impacts of the option on Nareen wetland are not anticipated to be significant since the impacts on frequent flooding and low flow scenarios is expected to be negligible. The option is only expected to significantly affect rare flooding events. Two key regional roads would be out of service during construction, and the costs of fill sourcing and road design and construction would be significant. These roads are NSW RMS assets and so the road upgrades would need to be conducted by the State Government.

This option only addresses lagoon backwater flooding and not Nareen Creek flooding and so low-lying residential sites near the creek may still be affected.

Modelling Results

The results show that Option FM13 provides effective protection up to the 1% AEP design event for properties landward of the levee. For the 0.1% AEP event, however, the flood waters begin to overtop the levee and trap some water behind. More regionally, the addition of the levee would reduce the overall amount of flood storage for the lagoon, and therefore may increase flood levels elsewhere. **Table 11-2** shows that the implementation of FM13 could raise flood levels by around 0.01 to 0.02 m elsewhere in the lagoon.

11.2.16 FM14 – Ponderosa Parade Drainage Upgrade

Description

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 m 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 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.

Potential Constraints

The existing cover from the road level to the 1800mm pipe obvert is 0.3 m, meaning there is limited cover available for increases in culvert height. It is not known what services run under Ponderosa Parade. Removal of the existing pipe network and replacement could be expensive, and during construction the local road will be inaccessible. There are no ASS constraints (ASS Class 5) or ecological concerns for the site.

Modelling Results

The Figures for Option FM14 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The increased culvert capacity does not have sufficient capacity to remove all overland flow from the surface of the road, however, the levels are dropped by up to 0.15 m. This lowers the peak depth on the road in the 1% AEP to approximately 0.45 m. Due to the capacity of the downstream system any further increase in culvert size would need to be accommodated with additional channel works to improve both the conveyance capacity and storage capacity of the channel. Any channel upgrades would be difficult with existing development on both banks of the creek restricting the space available to increase channel size.

11.2.17 FM15 – Garden Street Levee

Description

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)

Potential Constraints

There are ASS Class 2 / 3 in this area and so disturbed soils will likely require treatment. There is a section of Swamp Oak Floodplain Forest immediately adjacent to Garden Street, which is considered a threatened ecological community. There is also a risk of overland flow from the local catchment being trapped behind the levee. There is only 25 m from Mullet Creek top of banks to the edge of the road reserve available for the levee.

Modelling Results

The Figures for Option FM15 in **Appendix B** show the performance of the mitigation option for the 1% AEP event. The results show that Option FM15 provides effective protection up to the 1% AEP design event for properties west of Garden Street (59 properties protected). The results also indicate that the addition of the levee has minimal impact on the overall flood storage of the lagoon, and so negligible impact on flood levels elsewhere in the lagoon (<0.01 m).

11.2.18 FM16 - Pittwater Road / Narrabeen Sports High Levee Bank

Description

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 was modelled 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 m over a distance of 590 m. 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.

Potential Constraints

There are ASS Class 2 / 3 in this area and so disturbed soils will likely require treatment. There is also a risk that overland flow from the local catchment is trapped behind levee. The levee will not protect Narrabeen Sports High from flooding, and the majority of the levee will need to be constructed on school land requiring agreement and likely acquisition costs.

Modelling Results

The results show that the combination of Option FM16 and FM17 provides effective protection up to the 1% AEP design event for Pittwater Road and the surrounding residential properties. The results also indicate that the addition of the levee may have some minor impact on the overall flood storage of the lagoon, with flood levels elsewhere in the lagoon increasing by 0.01 m to 0.03 m. **Table 11-2** shows that the implementation of FM16 and FM17 would raise flood levels by around 1-3 cm elsewhere in the lagoon.

11.2.19 FM17 - Lakeside Levee and Pittwater Road / Narrabeen Sports High Levee Bank

Description

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 m 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.

Potential Constraints

There are ASS Class 2 / 3 in this area and so disturbed soils will likely require treatment. There is also a risk of overland flow from the local catchment being trapped behind the levee. A portion of the levee will need to be constructed on caravan park land requiring their agreement and likely acquisition costs, however, the proposed levee area seems to align with an existing internal road in the caravan park.

Modelling Results

Since this option is dependent on the presence of option FM16 for its effectiveness, the results for this option are described in **Section 11.2.18** (Option FM16).

11.2.20 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 m over a length of 2400 m.

Potential Constraints

There are ASS Class 2 / 3 in this area and so disturbed soils will likely require treatment. There is a small area of Swamp Oak Floodplain Forest along this bank, which is identified as a threatened ecological community, and one area of identified threatened fauna species.

There is also a risk of overland flow from the local catchment being trapped behind the levee. The majority of the levee's length will need to be constructed on private land with associated complications. It should be noted that the proposed levee would be quite high; potentially removing existing lagoon views and requiring a significant width of land for construction.

Modelling Results

The results show that Option FM18 provides effective protection up to the 1% AEP design event for properties landward of the levee. However for the 0.1% AEP event the flood waters begin to overtop the levee and trap some water in behind. More regionally, the addition of the levee would reduce the overall amount of flood storage for the lagoon, and therefore may increase flood levels elsewhere.
Table 11-2 shows that the implementation of FM18 would raise flood levels by around 1-3 cm elsewhere in the lagoon.

Table 11-2 Impacts of Options on Lagoon Flooding

AEP	LOCATION	Existing (mAHD)	Water Level Impacts (metres)								
			FM1	FM2	FM3	FM4	FM5	FM13	FM15	FM16 and FM17	FM18
20%	US Ocean St Bridge	2.41	0	0	-0.04	-0.54	-0.54	0	0	0	0.01
	US Pittwater Rd Bridge	2.46	-0.01	-0.01	-0.03	-0.47	-0.47	0	0	0	0.01
	US Deep Creek Bridge	2.47	-0.01	-0.01	-0.03	-0.46	-0.46	0.01	0	0.01	0.02
5%	US Ocean St Bridge	2.63	0	0.01	-0.08	-0.49	-0.49	0.01	0	0.01	0.02
	US Pittwater Rd Bridge	2.69	-0.01	-0.01	-0.05	-0.41	-0.41	0.01	0	0.01	0.02
	US Deep Creek Bridge	2.70	-0.01	-0.01	-0.04	-0.38	-0.38	0.02	0	0.01	0.03
1%	US Ocean St Bridge	2.94	0	-0.01	-0.14	-0.46	-0.46	0.01	0.01	0.02	0.01
	US Pittwater Rd Bridge	3.03	-0.03	-0.04	-0.09	-0.36	-0.36	0	0	0.02	0.01
	US Deep Creek Bridge	3.04	-0.02	-0.03	-0.08	-0.35	-0.35	0.01	0	0.03	0.02
0.1%	US Ocean St Bridge	3.41	-0.02	-0.02	-0.27	-0.37	-0.37	0	-0.01	0.01	0.01
	US Pittwater Rd Bridge	3.50	-0.04	-0.04	-0.16	-0.28	-0.28	0	-0.01	0.02	0.01
	US Deep Creek Bridge	3.52	-0.04	-0.04	-0.14	-0.27	-0.27	0	-0.01	0.02	0.01

11.2.21 Entrance Management Strategy

The technical studies and options investigated as part of this Study have identified a number of opportunities to reduce flood impacts both regionally and locally. In terms of the strongest influence on regional flood behaviour, it is clear that the management of sand shoaling and the opening of the entrance itself has the greatest impact (FM4).

Although the excavation of sand shoals upstream and downstream of Ocean Street (FM4) has been consistently undertaken every 4-5 years, at the time of writing this report, the entrance has shoaled more rapidly than previous projects and needs to be evaluated to determine if this reflects a more likely occurrence in the future. In addition, a closed and shoaled entrance and subsequent heightened water levels can cause concern in the community about flood levels and increases Council's reliance on emergency breakout procedures.

Managing these issues is very complex and includes sand transport, coastal processes, public amenity and recreational use, various benefits and dis-benefits of works/actions, capital vs ongoing costs, size of impacts, environmental impacts, the possible climate change impacts, emergency response strategies, the history of entrance modification and lastly the interaction with ocean conditions.

It is not possible in the context of an overarching FRMS to cover off all these various complexities, however it is clear that a fit-for-purpose technical investigation is required to assess the efficacy and appropriateness of long term entrance management options and strategies.

This strategy will investigate all aspects of entrance management, including sediment transport, flood impacts, entrance efficiency and dynamics and the long-term costs and sustainability of entrance specific options.

11.3 Emergency Response Modification Measures

Emergency response modification measures aim to reduce the consequences of flood risks generally by modifying the behaviour of people during a flood event. Improved emergency response, warning measures and increased community awareness are specific outcomes. The following emergency response options are discussed further in the sections below.

- 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 of 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; and
- 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.

11.3.1 EM1 - Local Evacuation Measures

The currently adopted flood evacuation procedures involve SES door-knocking and assisted evacuation of residents. The review of the evacuation timeline for Narrabeen Lagoon (**Section 7.8.1**) concluded that none of the flood affected neighbourhoods can be fully evacuated (with full confidence of a successful evacuation) using regional evacuation processes. If a more localised evacuation strategy can be implemented then evacuation may still be possible for some flood affected neighbourhoods.

While these areas could potentially be evacuated to higher ground, the lack of understanding of local overland flow paths and other hazards make a reliable recommendation on the feasibility impossible. Consequently, based on currently available information it is recommended that a shelter in place policy is retained for all suitable dwellings within the Narrabeen Lagoon Catchment.

A review of potential local flood evacuation options was undertaken for the following locations.

> Wimbledon Avenue – includes a residential neighbourhood located on a peninsula on the north bank of Narrabeen Lagoon, south of Wakehurst Parkway. The minimum surface elevation of the area is approximately 2 m AHD. The shortest pedestrian evacuation route to flood free land is across Wakehurst Parkway and to the north along Bristol Lane before directing west up Woorarra Road, a total distance of 900 m;

> Narrabeen Sports High School – on the northern bank of Narrabeen Creek in lower Warriewood Valley has a minimum surface elevation of approximately 2 m AHD. The shortest and most elevated pedestrian evacuation route to flood free ground is north along Pittwater Road, then east along Walsh Road, and then north on Narrabeen Park Parade; a total distance of 1,200 m;

> East Bank of Narrabeen Lagoon – from Mactier Street in the south to Malcolm Street in the north is low lying, with a minimum surface elevation of 1.5 m AHD. However along this east bank there is a steep grade in an easterly direction, which makes this developed area suited for evacuation. The maximum evacuation distance is approximately 300 m; and

> Garden Street – includes a low-lying group of properties bounded by Garden Street to the west, Pittwater Road to the east and Mullet Creek to the north, including a service station. The shortest pedestrian evacuation route to flood free land is west along Garden Street before directing west up Powderworks Road, a total distance of 600 m.

11.3.2 EM2 - Public Awareness and Education

Flood awareness is an essential component of flood risk management for people living in the floodplain. The affected community must be made aware of, and remain aware of, their role in the overall floodplain management strategy for their area. This includes preparations to reduce the risk of damage, the defence of their property and their evacuation (if required) during a flood event.

Flood awareness campaigns need to be an ongoing process and require the continuous effort of relevant organisations (e.g. Council and NSW SES). A major factor determining the degree of awareness within the community is the frequency of moderate to large floods in the recent history of the area. For effective flood emergency planning, it is important to maintain an adequate level of flood awareness during the extended periods when flooding does not occur. A continuous awareness program needs to be undertaken to ensure new residents are informed, awareness among long-term residents is maintained, and to allow for changing flood behaviour and new developments.

In May 2012 a community survey was undertaken by the Councils and NSW SES to determine the level of understanding and awareness of flood preparedness, and response to flooding and coastal erosion on the Northern Beaches. It was found that there is a very low level of concern regarding flooding by the Northern Beaches community (Micromex, 2012).

NSW SES and the former Manly, Warringah and Pittwater Councils developed the Northern Beaches Flood and Coastal Storms Education Strategy in 2012. The strategy has been developed to identify programs that will be undertaken by Northern Beaches Council to raise awareness of the mechanisms and potential impacts of natural hazards and encourage appropriate emergency response behaviours. It aims to improve community knowledge, attitudes and actions towards flooding and coastal storms on the Northern Beaches by implementing a participatory, tailored and ongoing education program that builds disaster resilience within the Northern Beaches community.

The current programs identified in the Strategy encourage an opportunistic approach to education. For example, attendance at events and distribution of material where available being examples of two such programs. An alternative approach may be to develop a more targeted education campaign that is rigorously planned and identifies required resources (both staff and financial) for implementation, as well as defining objectives and how the education campaign will be evaluated against those objectives. The Micromex (2012) survey, which was undertaken prior to the development of the Strategy, identified hazard 'appetite' through awareness of various parameters. Future surveys need to be designed to include questions that assess baseline scenarios so that follow up surveys can objectively assess the results of the education campaign.

The Northern Beaches Flood and Coastal Storm Education Strategy complements the Northern Beaches Flood Warning Network (**Section 10.5.2**) by identifying actions to regularly promote the MHL webpage. These include:

> NSW SES Flash Flood Guide for Pittwater LGA (and shortly Manly LGA);
> Links on each Council webpage;
> Regular social media updates by each Council to the webpage, especially during large rain events;
> Council newsletters;
> Presentations by NSW SES in schools;
> Local newspaper (i.e. the Manly Daily);
> Attendance by NSW SES at festivals and events; and
> Provision of information to local businesses through the Chamber of Commerce.

Review of the demographic characteristics of the catchment (**Section 2.3**) identified that the study will need to consider platforms that may be effective across several different languages, particularly those prevalent in the community.

It is recommended that webpages on Council's website dedicated to awareness of flooding are developed and promoted. The use of local and social media and other means to reinforce flood awareness when it is most within the public consciousness, following significant flood events, may also be valuable.

11.3.3 EM3 - School Education Programs

There is one childcare facility in the South Creek floodplain, Goodstart Cromer; one in the Nareen Creek floodplain, Narrabeen Community Kindergarten; and two schools in the lower Warriewood Valley, Narrabeen Sports High School and Narrabeen North Public School (**Section 5.4.5**). There are also several other childcare facilities and schools located just outside the floodplain. While these centres and schools are an obvious focus for targeted education programs, all schools in the LGA should provide education to children about flood risk. It should also be an intention to reach parents and carers through education of children attending the schools.

The SES has developed a tailored program for school children in primary schools. The program includes teacher's resources, newsletters, activities and games, and is designed to deliver knowledge and awareness of floods to young children. SES personnel are also available to visit schools to talk about flooding and flood response. Further details of these programs are available on the SES StormSafe website.

Education of parents and carers on the flood affectation of the school and the emergency response procedures in place to ensure the safety of their children could be provided directly or through children in the form of brochures etc.

In addition to the StormSafe initiative undertaken by the SES, the former Pittwater and Warringah Councils implemented a program that aimed to inform the employees of organisations that work with young children. This program, entitled "Get Ready", provided information on the following topics

> What is the role of emergency services during an event?
> How can our service better prepare our premises?
> How can we prepare for events which happen very quickly?
> How are we responsible to staff, parents and children during an event?
> How can we communicate our plan to staff, parents and children?
> Are there issues specific to our service type or location we should consider?

The course runs for a single day and is aimed at informing the attendants not just on flooding, but all natural disasters that may occur within the region.

In the future it may be feasible to modify this program to inform the parents / carers of the hazards present in the region and discuss their role in emergency preparedness.

11.3.4 EM4 - Flood Markers and Signage

Flood warning signs are commonly installed in locations that are periodically inundated and present a traffic or pedestrian hazard. Several public places and roads in the catchment experience high hazard flooding in the 20% AEP event. It is therefore important that appropriate flood warning signs are posted at these locations. These signs may contain information on flooding issues, or be depth gauges to inform residents of the flooding depth over roads and paths.

Potential locations for flood warning signs (based on the existing 20% AEP extent) include:

> For Lagoon Flooding:
  - Mactier Street
  - Wimbledon Avenue
  - Pittwater Road near Waterloo Street
  - Windsor Parade - Lagoon Flooding
  - Narroy Road - Lagoon Flooding
  - Lake Park Road - Lagoon Flooding
  - Warraba Road - Lagoon Flooding

> For Creek Flooding
  - Macpherson Street crossing Narrabeen Creek
  - Nareen Parade crossing Nareen Creek
  - Tatiara Crescent crossing Nareen Creek
  - Carcoola Road crossing South Creek
  - Wakehurst Parkway near Sydney Academy of Sport and Recreation crossing Middle Creek

In less frequent events high hazard flow conditions for pedestrians and drivers are predicted in more locations, some of which may benefit from provision of warning signs depending on the potential risk and effectiveness. Systems of this nature are beneficial to both local residents of the catchment and visitors to the region who may not be aware of the flood risk present.

11.3.5 EM5 – Flood Warning Systems

There may be opportunity to provide improved flood warning to residents within the floodplain through SMS alerts of pending storm events. Council could potentially run an SMS alert system for flood warnings for particular areas of the floodplain.

Alternatively, the Australian Emergency Alert System could be used by the SES to disseminate SMS flood warnings. This may be the most suitable mechanism to provide flood warnings in the Narrabeen Lagoon catchment, because in addition to calling landlines in the affected area it also captures the following mobile phone users:

> those with a registered service address that falls within the area of interest; and

> those where the last known location of their handset at the time of emergency was in the area of interest.

In this way the Alert System captures people visiting or travelling in the local area as well as residents. SMS alerts would provide a more immediate notification method than the current Northern Beaches Flood Information Network website.

11.4 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 properties so that there is a reduction in flood risk.

The following four property modification measures have been assessed for Narrabeen Lagoon:

> House raising;

> Voluntary purchase;

> Land swap; and

> Council re-development.

11.4.1 PM1 - House Raising

House raising is a measure designed to reduce the incidence of over-floor flooding of existing buildings through works funded by Council, and with assistance from the OEH. The Guidelines for voluntary house raising schemes (OEH, 2013a) sets out ineligibility criteria for house raising under the Voluntary House Raising (VHR) scheme and include the following.

> Properties which are already benefiting substantially from other floodplain mitigation measures, such as houses already protected by a levee, and those that will be under future plans.

> Properties that would not achieve a positive benefit through damage reduction relative to cost (i.e. benefit-cost ratio less than 1). Consideration may be given to lower benefit-cost ratios where there are substantial social and community benefits, or where the VHR is compensatory work for the adverse impacts of other mitigation works.

The scheme should involve raising residential properties above a minimum design level, generally the council's FPL, and comply with the council's relevant development control requirements.

The costs involved are estimated to be approximately $40,000 for a standard residential house, thus the benefit-cost ratio is a key constraint to feasibility of the action. There are several additional obstacles to consider.

> There are difficulties in raising some houses, such as slab on ground buildings. For some slab on ground houses it may be possible to install a false floor, although this is limited by ceiling heights;

> There is no reduction in the potential damage to items on a property other than the raised dwelling (e.g. garden sheds, garages);

> Unless a dwelling is raised above the level of the PMF, the potential for over-floor flooding still exists (i.e. there will still be a residual risk). The average PMF peak depth across the Narrabeen Lagoon floodplain is 2-3 m above the existing ground surface (**Figure 7-3**), which may be onerous in most situations.

> The new footings or piers must be designed to withstand flood-related forces; and

> There is potential for conflict, with height restrictions imposed for a specific zone or locality within the LGA.

> There are potential heritage constraints.

In consideration of the above factors, as well as the likely costs involved with any house raising works, it is assumed that house raising is not a viable option for the Narrabeen Lagoon catchment.

11.4.2 PM2 – Voluntary Purchase

The voluntary purchase of existing flood affected properties is an alternative to the construction of flood modification measures for properties where house raising is not possible. It would free both residents and emergency services personnel from the hazard of future floods by removing the risk, and is achieved by the purchase of properties and the removal and demolition of buildings. Properties could be purchased by Council at an equitable price and only when voluntarily offered. Such areas would then need to be re-zoned under the LEP to a flood compatible use, such as recreation or parkland, or possibly redeveloped in a manner that is consistent with the flood hazard.

Due to the significant expense associated with purchase of properties in the study area, this measure should be considered only after other more practical measures have been investigated and exhausted.

The OEH has prepared Guidelines for voluntary purchase schemes (OEH, 2013b), which describes the objectives, eligibility criteria, funding and implementation procedures for such an action. The stated eligibility criteria for voluntary purchase includes:

> Location of property in the high hazard zone for the 1% AEP flood event;

> Occurrence of over-floor flooding in the 20% AEP flood event; and

> Economic value of damages for the property as comparable to the property market value.

There are no residential properties that experience over-floor flooding in the 20% AEP event (or the PMF) and that result in property damages greater than $160,000. No properties have therefore been identified for voluntary purchase in the catchment. Since the OEH budget for acquisition of land is $1 million annually, it is unlikely that any blocks of land could be purchased either, considering the higher than average property prices in the area.

11.4.3 PM3 - Land Swap

An alternative to voluntary purchase is the consideration of 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. After the land swap, Council would then arrange for demolition of the building and have the land re-zoned under the LEP to open space.

It is expected that the land swap scheme would have similar financial constraints to those for voluntary purchase, and therefore no properties within Narrabeen Lagoon catchment are viable for a land swap. Note that land swap could also raise several issues relating to transfer of ownership of existing public open space, which would be contentious, and is therefore not advised.

11.4.4 PM4 – Council Redevelopment

This option also provides an alternative to the Voluntary Purchase scheme. While Council would still purchase the worst affected properties, it would redevelop these properties in a flood compatible manner and re-sell them with a break even objective.

Since no properties were identified as suitable for voluntary purchase, this option is not considered viable for the Narrabeen Lagoon catchment.

11.5 Flood Planning Level Revision

11.5.1 Introduction

Based on a review of the current FPL policies used by Northern Beaches Council, potential alterations to the existing FPL have been identified.

The options discussed in the following sections have been considered within the Multi-Criteria Assessment (MCA) (**Section 13**). Due to the nature of the options and the limited opportunity to evaluate the potential benefits and impacts without significant investigation, however, the results of the MCA should be used with discretion.

11.5.2 FPL Recommendations

The Flood Risk Management Policy (2017) makes note of the risks posed by climate change and states that Council will implement changes to climate change policy or practice on an iterative basis to reflect current best advice/information. Currently however, FPLs adopted by Northern Beaches Council do not cater for the risks associated with climate change impacts.

There are two methods of incorporating climate change into FPLs that may be suitable for this catchment:

> Including climate change in the freeboard allowance; and
> Including climate change in the design flood event that forms the base of the FPL.

11.5.2.1 Incorporation of Climate Change in Freeboard Allowance

Under this approach the existing 1% AEP event is used as the base for the FPL, and an amount for climate change is included in the freeboard allowance. This would result in different freeboards being applied, depending on the proposed use and expected lifecycle of the development proposed for a site.

A potential issue with using freeboard to account for climate change is that climate change impacts vary significantly across the catchment. In the 2100 scenario, climate change impacts range from 0.1 m to 1.2 m at different locations within the study area.

If future climate change were to be managed through increasing the freeboard, either:

- The freeboard for the full study area would be required to be set at 1.2 m (0.9 m for climate change and 0.3 m for other uncertainties) in order to ensure that the largest climate change impacts are covered by the freeboard allowance; or
- Freeboards would need to be determined for each individual property, which would increase the complexity for residents, developers and Council in preparing and assessing planning applications.

Furthermore, this approach results in the freeboard being reduced over time, which may reduce its ability to manage other uncertainties such as modelling accuracy, wind and wave action and local blockages, as climate change impacts consume increasing amounts of the freeboard allowance.

An alternative approach to incorporating future flood conditions in the FPL is to apply changes arising from climate change to the design event.

11.5.2.2 Incorporation of Climate Change in Base Design Event

This approach accounts for climate change within the design event base flood levels, with a constant freeboard applied as per the current manner. Climate change is incorporated into the base flood levels by using the predicted higher sea level as the downstream ocean boundary during computer modelling, rather than by adding the predicted increase in sea level across the entire floodplain.

This approach means that:

- A consistent freeboard is applied to all developments, simplifying development and planning requirements;
- The freeboard is kept to the minimum that is able to manage flood uncertainty arising from modelling accuracy, and the actions of wind, waves and local obstructions. This keeps floor levels lower in regions that are subjected to minor impacts due to climate change. This reduces development costs and improves visual amenity. Review of the standard 0.5 m freeboard against sensitivity analysis results for Narrabeen Lagoon found that this was an appropriate freeboard in this regard;
- The FPL can be altered in the future by Council for varying scales of risk. For example short-term developments can adopt a projected 2050 design flood scenario while long term developments can adopt projected 2100 design flood scenarios;
- The approach of incorporating climate change in the 1% AEP flood, rather than the freeboard, also ensures that Councils FPL is consistent with S117 Directive Guideline on development controls for low flood risk areas – Floodplain Development Manual, which requires:
  - Councils to adopt an FPL of the 1% AEP +0.5m unless extraordinary circumstances can be demonstrated,
  - The communication of these exceptional circumstances to the Department of Natural Resources (now OEH) and the Department of Planning and Environment for review,
  - Acceptance of the exceptional circumstances from the Department of Natural Resources (now OEH) and the Department of Planning and Environment.

11.5.2.3 Recommendation

Given the above, it is recommended that climate change be incorporated into planning levels through revising the 1% AEP flood event, rather than incorporating it in the freeboard. Two climate change scenarios have been adopted for Narrabeen Lagoon (refer to **Section 5.6** for further details):

- 2050 (36 year climate horizon, at time of reporting); and
- 2100 (86 year climate horizon, at time of reporting).

Given the planning timeframes and design lifetimes of various developments, the following recommendations are made.

- An FPL of 1% AEP (existing climate horizon) +0.5 m be adopted for renovations and minor extensions. The extent of allowance extensions would be determined in consultation with Council officers (for example, less than 35m^2).
- An FPL of 1% AEP (35 year climate horizon) +0.5 m be adopted for large extensions and minor subdivisions.

- An FPL of 1% AEP (85 year climate horizon) +0.5 m be adopted for long term strategic planning, large scale subdivisions and major developments.

The levels for each climate horizon should be consistent with Council's current sea level rise and rainfall intensity policies. These FPLs would be incorporated into the planning matrices set out in Section E11 of the Warringah DCP.

The proposed scheme may encounter the following limitations or issues in implementation.

- The selection of an appropriate FPL also has implications for the definition of the Flood Planning Area (FPA) (**Section 8.2.4**). The FPA is used to identify properties within the floodplain that may have flood related controls applied to them. A FPL which varies dependent on the development type proposed means that development controls may be applied on properties containing ground levels below the FPL based upon 1% AEP (85 year climate horizon) +0.5 m. Therefore, the FPA may need to be set at land at or below this level.
- Due to the fact that flooding in some portions of the Narrabeen Lagoon Floodplain are impacted by coastal storm surge, rather than purely catchment flooding, the Planning Circular on coastal hazard notations should also be considered within the context of FPL and FPA. The Department of Planning released a draft Planning Circular (PS 14-003 November 2014) regarding notations on s149 certificates in respect to coastal hazards. Specifically, the circular stated that where a relevant policy or development control does relate to the land and the policy or development control arises due to a coastal hazard, then notations should:
  - Clearly identify the type of hazard(s); and
  - For each hazard identified, classify whether that hazard is a current or future hazard.

This recommendation will be subject to thorough economic and feasibility review in addition to a comprehensive community engagement program to assess future implementation.

12 Economic Assessment of Options

12.1 Preliminary Costing of Options

Preliminary cost estimates have been prepared for those flood modification measures that allow for an economic assessment. These are then compared with the potential associated reduction in flood damages (**Table 12-1**). For measures that do not allow for any easy economic evaluation, costs were estimated only on the basis of cost to implement, and were done for the purpose of comparison in the multi-criteria assessments (**Section 12.2**). Since Option FM13 resulted in negative impacts within the catchment the option was not progressed past the preliminary modelling stage. All cost estimates exclude GST, and include a contingency of 50%. This contingency contains allowances for unknowns, such as geotechnical information and detailed design considerations.

Prior to a measure proceeding it is recommended that, in addition to detailed analysis and design of the measure, these costs be refined in detail to achieve a more accurate assessment for overall budget estimates. Detailed rates and quantities will also be required at the detailed design phase. A cost breakdown is provided in **Appendix C**.

12.1.1 Lagoon Levee Costing

It is difficult to quantify the costs (and other constraints) associated with land acquisition on a scale required for the lagoon levee options (Option FM15, FM16 and FM17, and FM18). A unit land acquisition cost of $1,000 per square metre has been applied for all relevant options, meaning it will be consistent for comparison between options but may vary with the actual cost should that option be selected.

The costs estimated below for the construction of levees assumes private land acquisition and construction of the entire length of all levees. An alternative is for Council to construct the sections of the levees on public land where public property (including roads) is being protected, and levee works on private land to protect private property would be either partially or fully the responsibility of private land owners (i.e. a beneficiary pays model). This could be facilitated through appropriate development controls and guidelines that provide private landowners with the information required to construct and maintain structures in accordance with the desired flood protection outcomes.

Where the levee is part of a continuous levee bank to provide regional benefits, the funding arrangements between public and private sources would need further evaluation. The disadvantage to this approach is that where a continuous levee is required to achieve flood protection, the flood benefits will not be achieved until all sections of the levee have been completed, and private property owners may not wish to implement a solution at the same time.

Table 12-1 Cost Estimates for Quantitatively Assessed Measures

Option No.	Description	Capital Cost (Excl. GST)	Ongoing (Annual) Costs (Excl. GST)
FM1	Ocean Street Bridge Extension	$5,070,000	$25,000
FM2	Reconstruction of Ocean Street Bridge to be above the 1% AEP Flood Level	$20,505,000	$25,000
FM3	Entrance Bedrock Removal	$17,259,000	$50,000
FM4	Extraction of Entrance Shoals Upstream and Downstream of Ocean Street Bridge	$1,160,000	$290,000
FM4a*	Dry Earth Sand Winning with Beach Cut and Cover Pipeline	$3,939,000	$131,250
FM5	Ocean Street Bridge Extension & Downstream Shoal Dredging	$6,519,000	$175,000
FM6	Alkira Circuit Drainage Upgrade	$484,000	$1,000

Option No.	Description	Capital Cost (Excl. GST)	Ongoing (Annual) Costs (Excl. GST)
FM7	Willandra Road Reserve Culvert Upgrade and Lowering / Detention Basin	$536,000	$2,000
FM8	Willandra Road Culvert Upgrade and Vegetation Removal	$948,000	$3,500
FM9	Waroon Road Levee	$185,000	$1,500
FM10	Wabash Avenue Levee	$309,000	$2,100
FM11	Tatiara By-pass Overland Flow path	$679,000	$2,680
FM12	Basin at Narrabeen RSL, Pipe Diversion along Tatiara Cres and Nareen Parade to Open Channel	$6,595,000	$12,700
FM13	Pittwater Road & Wakehurst Parkway Raising / Levee	$11,281,000	$4,500
FM14	Ponderosa Parade Drainage Upgrade	$874,000	$1,000
FM15	Garden Street Levee	$3,057,000	$7,000
FM16 and FM17	Pittwater Road Levee Bank and Lakeside Levee	$18,665,000	$14,100
FM18	East Bank Levee	$56,642,000	$25,400

* FM4a Cost has been taken from *"Alternative Management Strategies for Clearing Narrabeen Lagoon Entrance"* (MHL, 2009) and updated to match current value prices.

12.2 Annual Average Damages Assessment

An assessment of AAD for the existing condition was presented in **Section 6.7**. Where flood management options predominantly reduce local flood impacts, the local reduction in damages has been considered (rather than catchment scale reductions and damages values). The results (all excl. GST) are summarised in **Table 12-2**, noting that the overall AAD under existing conditions is $11,540,886 (excl. GST).

It is noted that both Options FM4 and FM4a are implemented every 3 – 4 years and during that time sand is re-deposited gradually. This means that under these schemes the lagoon at any one time is somewhere between the modelled post-dredge scenario and the pre-dredge scenario, so the reductions in damages will be between zero and the post-dredge conditions depending on the time that flooding occurs. The regressive nature of these dredge scenarios has been accounted for in the damages by applying 50% of the AAD reductions.

Table 12-2 Reduction in Damages Associated with Each Option

Option No.	Description	Reduction in Damages for 1% AEP	Total Reduction in AAD
FM1	Ocean Street Bridge Extension	$937,000	$251,000
FM2	Reconstruction of Ocean Street Bridge to be above the 1% AEP Flood Level	$1,186,000	$257,000
FM3	Entrance Bed Rock Removal	$3,018,000	$709,000
FM4	Extraction of Entrance Shoals Upstream & Downstream of the entrance bridge	$11,515,140	$2,403,000*
FM4a	Dry Earth Sand Winning with Beach Cut and Cover Pipeline	$11,515,140	$2,403,000*
FM5	Ocean Street Bridge Extension & Upstream Shoal Dredging	$16,983,045	$2,602,163*
FM6	Alkira Circuit Drainage Upgrade	$277,000	$28,000

Option No.	Description	Reduction in Damages for 1% AEP	Total Reduction in AAD
FM7	Willandra Road Reserve Culvert Upgrade and Lowering / Detention Basin	$77,000	$8,000
FM8	Willandra Road Culvert Upgrade and Vegetation Removal	$155,000	$17,000
FM9	Waroon Road Levee	$448,000	$58,000
FM10	Wabash Avenue Levee	$261,000	$45,000
FM11	Tatiara By-pass Overland Flow path	$360,000	$105,000
FM12	Basin at Narrabeen RSL, Pipe Diversion along Tatiara Cres and Nareen Parade to Open Channel	$447,000	$196,000
FM13	Pittwater Road & Wakehurst Parkway Raising / Levee	-$168,000	-$862,000
FM14	Ponderosa Parade Drainage Upgrade	$410,000	$62,000
FM15	Garden Street Levee	$2,782,000	$726,000
FM16 and FM17	Pittwater Road Levee Bank and Lakeside Levee	$2,519,000	$937,000
FM18	East Bank Levee	$9,659,000	$1,865,000

*Total AAD Reduction in Damages for Option FM4 is $4,806,606 but a 50% factor has been applied to combined AAD for this option due to the regressive nature of the solution.

Please note the above assessment is under existing climatic conditions.

12.3 Benefit to Cost Ratio of Options

The economic evaluation of each modelled option was performed by considering the reduction in the amount of flood damages incurred for the design events and then comparing this value with the cost of implementing the option.

The existing condition (current conditions assuming no entrance management) was used as the base case to compare the performance of modelled options (FM1-FM18). Inputs for the assessment include those data derived from the floor levels and property survey along with damage curves for other similar areas. The flood extents for all the design events were considered for this evaluation. The preliminary costs of each measure were used to undertake a benefit-cost analysis on a purely economic basis.

Table 12-3 summarises the results of the economic assessment of each of the flood management options. The indicator adopted to rank these measures on economic merit is the benefit-cost ratio (B/C), which is based on the net present worth (NPW) of the benefits (reduction in AAD) and the costs (of implementation), adopting a 7% discount rate and an implementation period of 50 years.

The benefit-cost ratio provides an insight into how the damage savings from a measure relate to its cost of construction and maintenance:

> Where the benefit-cost ratio is greater than 1 the economic benefits are greater than the cost of implementing the measure;

> Where the benefit-cost is less than 1 but greater than 0 there is still an economic benefit from implementing the measure, but the cost of implementing the measure is greater than the economic benefit;

> Where the benefit-cost is equal to zero, there is no economic benefit from implementing the measure; and

> Where the benefit-cost is less than zero, there is a negative economic impact of implementing the measure.

Table 12-3 Summary of Economic Assessment of Flood Management Options

Option No.	NPW of Reduction in AAD (excl. GST)	NPW of Cost of Implementation (excl. GST)	B/C Ratio	Economic Ranking
FM1	$3,707,000	$5,440,000	0.68	11
FM2	$3,796,000	$20,875,000	0.18	17
FM3	$10,470,000	$17,998,000	0.58	12
FM4	$35,485,000	$5,443,000	6.52	1
FM4a	$35,485,000	$5,878,000	6.04	2
FM5	$38,426,000	$9,104,000	4.22	3
FM6	$414,000	$499,000	0.83	9
FM7	$119,000	$566,000	0.21	16
FM8	$252,000	$1,000,000	0.25	15
FM9	$857,000	$208,000	4.12	4
FM10	$665,000	$341,000	1.95	7
FM11	$1,551,000	$719,000	2.16	6
FM12	$2,895,000	$6,783,000	0.43	14
FM13	-$12,729,000	$11,348,000	-1.12	18
FM14	$916,000	$889,000	1.03	8
FM15	$10,721,000	$3,161,000	3.39	5
FM16 and FM17	$13,837,000	$18,874,000	0.73	10
FM18	$27,541,000	$57,018,000	0.48	13

The highest economic ranking flood management options are Option FM4 / FM4a - extraction of entrance shoals upstream and downstream of the Ocean Street Bridge which have high flood damage reductions (over $35 million) due to the significant reduction in flood levels for the lower floodplain. Comparatively the capital costs and ongoing costs of both options are significantly less than the damage reduction resulting in high benefit-cost ratios (4.84 and 6.04 for Option FM4 and FM4a respectively). While the alternative approach of constructing a pipeline to discharge dredge material has a higher capital cost, the lower ongoing costs for this option mean its overall cost over a 50 year period is lower than the current sand dredging and placement scheme, meaning it has slightly better economic performance than the current approach. Option FM5 provides a similar level of improvement however due to a higher cost associated with the roadworks the benefit-cost-ratio is slightly reduced.

The option with the next best economic performance is Option FM9 Waroon Road levee, which has the lowest cost of implementation over a 50 year period (NPW of $208,000) and significant reduction in flood damages through the protection of several residential properties up to the 1% AEP event. These two factors contribute to a high benefit-cost ratio of 4.12. Similarly the other local levee option on South Creek, FM10 – Wabash Avenue levee, is relatively low cost with significant damage reductions resulting in a benefit-cost ratio of 1.95.

FM15 - Garden Street levee is one of several large-scale levees proposed within the lower floodplain (FM16, FM17, and FM18 are other examples), however it is the only one of these options with a benefit-cost ratio greater than 1 (economic benefits outweigh costs). The Garden Street levee has strong economic performance through a reduced capital cost, which is a result of the levee being proposed on an existing open space reserve adjoining Narrabeen Creek, meaning that land acquisition costs are negligible.

The other two flood modification options with a benefit-cost ratio greater than 1 (economic benefits outweigh costs) are:

> FM11 – Tatiara By-pass Overland Flow path (benefit-cost ratio of 2.16); and

> FM14 - Ponderosa Parade Drainage Upgrade (benefit-cost ratio of 1.03).

The above ranking and positive cost-benefit does not reflect any potential adverse impacts associated with options, such as levees potentially transferring flooding, or the long term sustainability of particular entrance management options.

12.4 Climate Change Implications

The assessment undertaken is based on the current climate conditions as defined within the Narrabeen Lagoon Flood Study (BMT WBM, 2013). As highlighted in this report, under climate change conditions the levels within the lagoon will increase due to higher mean sea levels, and so too will flood levels.

Under a 0.4 m sea level rise projection, the anticipated water level within the lagoon in the 1% AEP event is 0.3 m higher than the current 1% AEP flood level. If a similar order of magnitude of water level increase is experienced for the 5% AEP event in 2050, that water level will be consistent with the current 1% AEP flood level. To put it another way, the present 1% AEP flood level will become the more frequent 20% AEP level in 2050.

The levee options proposed within this report are not currently feasible when considering both the cost-benefit analysis and level of community support. In coming years, if climate predictions start to eventuate, it is possible that the large-scale levee options proposed here will be the only suitable means to reduce flood risk within the Narrabeen Lagoon Catchment to acceptable levels.

13 Multi-Criteria Assessment

A multi-criteria assessment (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).

This approach does not provide an absolute "right" answer as to what should be included in the plan and what should be omitted. Rather, it provides a method by which stakeholders can re-examine options and, if necessary, debate the relative scoring assigned.

Each option is given a score according to how well the option meets specific considerations. In order to keep the scoring simple a system was developed for each criterion as shown in **Table 13-1**.

13.1 Scoring System

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 are shown in **Table 13-1** and include:

<u>Economic</u>	Benefit cost ratio
	Capital and operating costs
	Reduction in risk to property
	Feasibility
	Protection of Vulnerable Developments and Critical Infrastructure
<u>Social</u>	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
<u>Environmental</u>	Compatibility with surface water quality objectives
	Fauna / Flora impacts
	Acid sulfate soils

The assignment of a score for each criterion for each option is shown in the completed matrix in **Appendix D**. The total score of each option was calculated by equally weighting criteria and summing the total.

Each of the options was then ranked against each other based on the total scores, allowing identification of the preferred options, namely those that provide the greatest benefit to the community. These total scores and rankings are also shown in **Appendix D**.

The rankings are proposed as the basis for selecting management options for inclusion in the FRMP, and for prioritising their implementation.

It is noted that both structural (flood modification) and non-structural (property modification and emergency response) options have been considered separately. It is difficult to directly compare these two types of measures. Furthermore, funding sources and implementation timeframes for the two different types of measures are typically different.

Table 13-1 Multi-Criteria Assessment – Scoring System

Category	Criteria	Description of Criteria Assessment	Score -2	Score -1	Score 0	Score 1	Score 2
Economic	Benefit Cost Ratio	The cost effectiveness of the scheme, i.e. the tangible return on investment	0 to 0.2	0.2 to 1	1	1 to 1.5	>1.5
	Capital and Operating Costs	Consideration of the initial capital costs and ongoing operation costs to Council	Extreme >$10 million	High $2 million - $10 million	Medium $500,000 - $2,000,000	Low $200,000 - $500,000	Very Low < $200,000
	Reduction in Risk to Property	Based on reduction in AAD, it establishes the tangible benefit of an option	Major increase in AAD (>$20,000)	Slight increase in AAD (<$20,000)	No Improvement	Slight decrease in AAD (<$20,000)	Major decrease in AAD ($>20,000)
	Feasibility	Establishes the feasibility of options based on constructability, and bureaucratic difficulties such as land acquisition and agreements with external agencies	Very unlikely to be feasible	Unlikely to be feasible	May or may not be feasible	Likely to be feasible	Very likely to be feasible
	Protection of Vulnerable Development and Critical Infrastructure	Assesses the flood risk implications for existing vulnerable developments and critical infrastructure in the floodplain (as identified in **Section 5.4.5**)	High negative impact	Slight negative impact	No impact	Some benefit	Considerable benefit
Social	Reduction in Risk to Life in PMF	The impact on risk to life for the most extreme flood event, which is the design event for emergency response	Widespread or significant increase in risk to life	Localise or slight increase in risk to life	No change in risk to life	Localised or slight reduction of risk to life	Widespread or significant reduction of risk to life
	Reduction in Risk to Life in 1% AEP event	The impact on risk to life for the flood planning event, which is the design event for most structural options	Widespread or significant increase in risk to life	Localise or slight increase in risk to life	No change in risk to life	Localised or slight reduction of risk to life	Widespread or significant reduction of risk to life
	Reduction in Social Disruption	Social disruption of flooding has been based on reduction in road overtopping, with emphasis on regional roads, and access roads for isolated communities (as outlined in **Section 7.5**)	Major increase in social disruption (road overtopping increased by >0.2m)	Slight increase in social disruption (road overtopping increased by <0.2m)	No change to social disruption	Slight reduction of social disruption (road overtopping reduced by <0.2m)	Major reduction of social disruption (road overtopping reduced by >0.2m)
	Community Support	Guided by option ranking outcomes from the community questionnaire (**Table 4-1**)	Very unlikely to be supported	Unlikely to be supported	Neutral	Likely to be supported	Very likely to be supported
	Compatible with Policies and Plans	The compatibility with both former Warringah Council's and Pittwater Council's policies and plans	Amendment required to either Council's current policies or plans	Slightly incompatible with Council's current policies or plans	Slightly incompatible with Council's current policies or plans, but could be grounds for reviewing policies or plans	Compatible with both Council's policies and plans	In line with and supported by Council's current policies or plans
Environment	Compatibility with Surface Water Quality Objectives	Impacts to quality of catchment inflows or reduction in water exchange with ocean and freshwater inputs	High negative impact	Slight negative impact	No impact	Some benefit	Considerable benefit
	Fauna/Flora Impact	Likely impacts on Threatened Ecological Communities and Threatened Species based on recorded locations identified in **Section 2.5**	High negative impact	Slight negative impact	No impact	Some benefit	Considerable benefit
	Acid Sulfate Soils	The likely disturbance of the range of classes of Acid Sulfate Soils as identified in **Section 2.4.3**, with emphasis on earthworks, particularly excavation.	Any work within Class 1 ASS area. Any excavation work within Class 2. Excavation >1m within Class 3. Excavation >2m within Class 4.	Surface works within Class 2 ASS. Excavation <1m or surface works within Class 3. Excavation <2m or surface works within Class 4.	Works not within areas identified as PASS	N/A	N/A

13.2 Summary of Options Assessment Outcomes

Table 13-2 provides a ranked list of management options for consideration for inclusion in the FRMP. The options selected for inclusion should be based on both their likely benefits and the likely funding available from Council and the State Government.

Table 13-2 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
FM18	East Bank Levee	0.27	21	S-15
FM3	Entrance Bed Rock Removal	-0.20	23	S-17

The highest ranked option is Option FM4 representing the current practice for Narrabeen Lagoon entrance management of mechanical dredging of the shoals upstream and downstream of Ocean Street. In terms of economic performance this option was one of the best two options, with the other being the alternative dredging approach of constructing a pipeline for placement of dredged material (Option FM4a). While the economic benefits were slightly higher for the Option FM4a alternative the social and economic scores for the current approach were far higher, because the historical implementation of this scheme since 1978 meant that community support was expected to be high and the environmental impacts were well understood. Comparatively, the alternative dredging approach scored worse in the social and environmental criteria resulting in an overall ranking of 16th.

The four options ranked 2nd to 5th highest are all small scale structural works proposed within the lagoon tributaries in the upper catchment to protect residential properties in the local area up to the 1% AEP design event. These options are:

- FM9 - Waroon Road Levee (South Creek);
- FM10 – Wabash Avenue Levee (South Creek);
- FM6 – Alkira Circuit Drainage Upgrade (Narrabeen Creek); and
- FM14 - Ponderosa Parade Drainage Upgrade (South Creek).

These options all have reasonably good economic performance; as the scope of works involved is relatively minor, the cost of implementation is low, and the reduction in flood damages up to the 1% AEP is significant. These options are expected to have good community support due to their low cost and the tangible benefits they provide to the community in the local area. The relatively minor scope of works means that limited social disruption is anticipated and the expected environmental impacts are expected to be minor.

The five emergency management options all score well, with all five ranking between 6th and 11th based on the outcomes of the MCA. Though these options produce negligible reductions in flood damages and therefore tangible economic benefits, these options score well due to significant reduction in risk to life, low costs, ease of implementation, and strong community support.

Given the importance of options FM4 and FM4a in flood levels, risk to life and avoided damages, it is accepted that these options should be progressed and that an Entrance Management Strategy is the most appropriate way of undertaking this. So while those two options are included in the Multi-Criteria analysis, an Entrance Management Strategy is not because it is simply the mechanism used to progress these two options rather than an option in its own right.

The Entrance Management Strategy is considered a high priority item and should be progressed as soon as practicable. It will be important in ensuring community support for Council's approach to implementing FM4 and FM4a.

13.3 Potential Funding Sources

The NSW Government has established the Floodplain Management Program to provide financial support to Local Government for the implementation of the Flood Prone Land Policy, as described in the Floodplain Development Manual (NSW Government, 2005). The primary objective is "to reduce the impacts of flooding and flood liability on communities as well as the private and public losses resulting from floods, using ecologically positive methods wherever possible".

Floodplain management grants from the NSW Government are available for implementing actions listed in approved FRMPs, which include (but are not limited to) the following types of actions:

- structural works such as levees, detention basins, flood gates and improved flow conveyance;
- flood warning systems;
- evacuation management; and
- voluntary house purchase or house raising.

This grant program is administered by OEH.

14 Conclusions and Recommendations

This FRMS of the Narrabeen Lagoon catchment follows on from the Flood Study prepared in 2013. The early sections of this report provide context through a description of the social and economic character of the catchment (**Section 2**), review of the data available for the study area (**Section 3**), and outline of the community consultation process undertaken as part of this study (**Section 4**).

Further assessment of the existing flood behaviour has been undertaken, including an assessment of flood hazard and a review of climate change impacts (**Section 5**). In addition, current average annual flood damage for the Narrabeen Lagoon floodplain has been estimated to be approximately $11,540,886 for the properties examined (**Section 6**).

A review of existing emergency management (**Section 7**), current flood policies (**Section 8**), impacts of future development (**Section 9**), and lagoon entrance management (**Section 10**) was used to develop a range of flood mitigation options (**Section 11**). A detailed economic assessment of the options' costs and benefits has been conducted (**Section 12**); informing a multi-criteria assessment and review of the feasibility of the options (**Section 13**). The MCA scores of the emergency management and flood modification options have been combined to produce rankings of options and an implementation preference list (**Table 13-2**).

The review and analysis undertaken as part of this FRMS has identified that the most effective structural option for the Narrabeen Lagoon floodplain is the continuation of the sand clearance from above and below Ocean Street bridge, the currently implemented lagoon entrance strategy since 1978.

The other structural options that scored well in the MCA relate to controlling flood risk in the upper portions of tributaries. Four of the top five ranked options relate to drainage upgrades or levees at locations along South Creek or Narrabeen Creek.

All five emergency management options are ranked highly based on MCA scores with the other non-structural option, Floor Planning Level revisions, also recommended for implementation. These options all rank well in that they provide significant improvements to flood risk for the floodplain without the same level of capital investment required for the majority of structural options.

The preparation of an Entrance Management Strategy which was not scored through the MCA process is considered a strategic priority. The dynamics and management of Narrabeen Lagoon entrance is complex and a study which investigates the coastal and flood processes at the entrance and investigates long term management options under current and future climatic conditions will enable a best-practice approach.

All other options are recommended should be further considered in the next stage of the process, the Floodplain Risk Management Plan (FRMP), even though they did not perform as well in the MCA scoring. Feedback during the consultation process for the Draft Study may lead to altered rankings. The outcomes of this FRMS will be used to develop the FRMP that details how flood prone land within the study area will be managed.

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Narrabeen Lagoon Floodplain Risk Management Study and Plan

APPENDIX

A

COMMUNITY CONSULTATION MATERIAL

Cardno
Shaping the Future

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Local Resident / Business Owner Survey | April 2015

Local knowledge and personal experiences of flooding are an invaluable source of data. Council would like to hear about your experiences, concerns and suggestions on how to manage flooding around Narrabeen Lagoon in this short survey.

Cardno, on behalf of Warringah Council and Pittwater Council, is preparing a Floodplain Risk Management Study and Plan of the Narrabeen Lagoon catchment, located across the Warringah and Pittwater Local Government Areas.

The Floodplain Risk Management Study aims to help Councils make informed decisions on how to manage flood risks in the future.

Please return the survey to Council by 25 May 2015 via the reply paid address.
Alternatively, please complete this survey online, via the following link:
https://extranet.cardno.com/NarrabeenLagoonFRMSP

WARRINGAH COUNCIL | PITTWATER COUNCIL | NSW GOVERNMENT Office of Environment & Heritage | Cardno Shaping the Future

Figure: The Study Area

If you have any further comments that relate to the Narrabeen Lagoon Floodplain Risk Management Study and Plan, please provide them in the space below (or attach any additional pages if necessary).

If you have any photos from the recent storm event, identifying any major problems or showing how high the water level rose, please send copies to either of the Council email addresses below.

Thank you for providing the above information.

Contact Us
If you have any queries, please contact us.

YOUR PERSONAL INFORMATION WILL REMAIN CONFIDENTIAL

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Project Website: https://extranet.cardno.com/NarrabeenLagoonFRMSP

This project is supported by the NSW Government's Floodplain Management Program.

WARRINGAH COUNCIL | PITTWATER COUNCIL | NSW GOVERNMENT Office of Environment & Heritage | Cardno Shaping the Future

Q1. Could you please provide us with the following details, to locate specifically where your comments and responses relate to? This information will not be shared without your consent. Alternatively the survey can be filled in anonymously.

Name: ....

Address: ....

....

Daytime Ph: ....

Email: ....

Q 2. Do you give permission for someone from Cardno or Council to contact you to discuss some of the information you have provided us? ☐ Yes ☐ No

Flood Risk

Q 3. a. Do you think your property could be flood affected? If describing a business premises or location other than the address provided in Q1, please indicate the alternative address.

- ☐ No.
- ☐ Yes, but only a small part of my yard.
- ☐ Yes, most of my yard/outdoor areas could be flooded.
- ☐ Yes, my house/office/business could flood over the floor.

Alternative address if applicable: ....

b. If yes, for what reasons do you think your property is flood effected (e.g. personal experience, Council has advised you of the fact)? ....

c. Have you looked for information about flooding on your property?

- ☐ Council's customer service centre.
- ☐ Other information from Council (specify).

....

- ☐ Viewed a Property Planning (Section 149) Certificate.
- ☐ Information from a real estate agent.
- ☐ Information from relatives, friends, neighbours, or the previous owner.
- ☐ Other information (specify).

....

- ☐ Council's website.
- ☐ No information has been sought.

d. Are you concerned about the flood risk to your property? ☐ Yes ☐ No

Q 4. Are you concerned about flood risk in your area (apart from your private property or place of business)?

☐ Yes ☐ No

If yes, can you provide some examples (e.g. flooding of roads, footpaths, open space areas etc)?

- ☐ Overland flow through properties located on steep slopes or hills.
- ☐ Flooding from Narrabeen Lagoon (i.e. lagoon water levels overtopping the foreshore areas).
- ☐ Blockage of stormwater drains.
- ☐ Other (please describe). ....

Q 5. What do you believe to be the main cause of flooding in your area?

- ☐ Elevated ocean water levels and waves during coastal storms.
- ☐ Local creeks overtopping their banks.
- ☐ Lack of capacity in the stormwater network causing drainage systems to surcharge.
- ☐ Other (please describe).

....

The Uncertainty of the Climate

Q 6. Are you concerned about the uncertainty of future climates and the possible impacts on flooding in your area? ☐ Yes ☐ No

If yes, can you provide some examples of your concerns?

....

Q 7. Under an uncertain future there is potential for impacts on flooding due to possible increases in sea levels and rainfall intensities. The Narrabeen Lagoon Floodplain Risk Management Study will be looking at measures to reduce the flood impact as a result of existing and future climate conditions.

a. Do you believe the climate is changing?

☐ Not at all ☐ Yes, but the effects won't be significant ☐ Yes, it will have significant effects

b. Are you concerned about the impact of an uncertain climate on future flooding in Narrabeen Lagoon?

☐ Yes ☐ Somewhat ☐ No

c. Should Council be addressing the impacts of an uncertain future climate on flooding?

☐ Yes ☐ No

If yes, how would you like to see Council address these impacts (e.g. development controls on potentially affected properties, structural protection works)?

....

Flood Planning Level

Q 8. A Flood Planning Level is a flood level derived from a predicted flood event, plus a freeboard*, and may include an allowance for sea level rise. Flood Planning Levels are used in the planning of developments to ensure they are built in a flood compatible manner.

a. Have you heard of Flood Planning Levels before? ☐ Yes ☐ No

b. Do you feel that Flood Planning Levels are necessary for the protection of property and life? ☐ Yes ☐ No ☐ Yes, to some degree

c. Do you understand what a freeboard is and why it is included in Flood Planning Levels? ☐ Yes ☐ No ☐ Yes, to some degree

d. Do you think the uncertain future climate should be taken into account in Flood Planning Levels? ☐ Yes ☐ No ☐ Yes, to some degree

*Freeboard: A factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc, expressed as the difference between the actual flood level, and the adopted Flood PLanning Level.

Flood Related Development Controls

Q 9. What level of control do you consider Council should place on new development to minimise flood-related risks?

☐ Stop all new development only in the most dangerous areas of the floodplain.

☐ Place restrictions on development (e.g. minimum floor levels and/or the use of flood compatible building materials)

☐ Advise people of flood risks, and allow individuals to choose how they would reduce flood damage.

☐ Stop all new development on land with any potential to flood.

☐ There should be no control on development in flood affected areas.

Q 10 The following management options have been used in other locations, and some may not be suitable or cost effective for Narrabeen Lagoon catchment. Please rate the options (where 1 = most preferred, 5 = least preferred) and provide comments as to the location where you think the option might be suitable.

Proposed Option	Preference (please tick) Most preferred > Least preferred	Location / Other Comments
Continue the existing program of lagoon entrance clearance every 4 years.	1 2 3 4 5	
Maintain the beach height at the entrance at a specified level and allow to open 'naturally' when the height is exceeded.	1 2 3 4 5	
Mechanically open the lagoon entrance when a specific water level is reached.	1 2 3 4 5	
Permanently open the lagoon entrance with hard structural measures (e.g. training walls, breakwaters, sea walls or groynes)	1 2 3 4 5	
Install pipes at the lagoon entrance	1 2 3 4 5	
Levee banks	1 2 3 4 5	
Increase the size of the bridge openings	1 2 3 4 5	
Improve drainage, such as upgrades to stormwater pits and pipes to improve capacity	1 2 3 4 5	
Improve creek channels (including removal of weeds and bank stabilisation)	1 2 3 4 5	
Detention basins (depressions in the land to allow slow draining of stormwater)	1 2 3 4 5	
Voluntary house raising subsidies to assist property owners to raise existing floor levels for flood protection	1 2 3 4 5	
Voluntary house purchase of the worst affected properties.	1 2 3 4 5	
Planning and flood related development controls to ensure future development does not add to the existing flood risk	1 2 3 4 5	
Education of the community, providing greater awareness of the potential hazards	1 2 3 4 5	
Flood forecasting, flood warning, evacuation planning and emergency response such as early warning systems, improved local SES capabilities/ resources or improved radio and phone communications	1 2 3 4 5	
Other (please specify any options you believe are suitable). Please attach extra pages for other suggestions	1 2 3 4 5	

Consultation

The Councils recognise the important role that community consultation will have in the Floodplain Risk Management Study. The Councils' goals for community consultation are to inform the community about the Study, identify community concerns and attitudes, gather information from the community, and develop and maintain community confidence in the Study results.

In addition to the attached /online survey you will have further opportunities to comment on the direction of the project during the public exhibition periods of the Draft Management Study and Plan. These will include community workshops conducted by Pittwater Council, Warringah Council and Cardno.

Any comments received during the public exhibition period and workshops will be taken into account before finalisation of the Study and Plan.

Contact Us
If you have any queries, please contact us.

YOUR PERSONAL INFORMATION WILL REMAIN CONFIDENTIAL

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Project Website: https://extranet.cardno.com/NarrabeenLagoonFRMSP

This project is supported by the NSW Government's Floodplain Management Program.

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Information Brochure | April 2015

Many people who live, work or own property in the Narrabeen Lagoon catchment may be vulnerable to the risk of flooding. This risk may increase over time due to the uncertainty of possible future climate changes.

Warringah Council, in partnership with Pittwater Council, has engaged flooding consultants, Cardno, to assist with the preparation of the Narrabeen Lagoon Floodplain Risk Management Study and Plan. This follows on from the Flood Study, adopted in 2013 by Warringah and Pittwater Councils. The Management Study and Plan will identify and recommend appropriate actions to manage flood risks in the Narrabeen Lagoon catchment.

This brochure provides an introduction to the Management Study and Plan and its objectives. The outcomes of the Floodplain Risk Management Study will be adopted in the Plan to prioritise the recommended management options.

Study Area

The Narrabeen Lagoon catchment occupies a total area of approximately 55km^2 and drains to the Tasman Sea through a narrow channel at the lagoon entrance at North Narrabeen Beach. Narrabeen Lagoon is the largest coastal lagoon located in the Sydney metropolitan region, with a waterway area of 2.2km^2. The catchment can be separated into a number of 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 Flooding Issues

The Probable Maximum Flood (PMF) extent for the Narrabeen Lagoon catchment is shown in Figure 1. This demonstrates the most extreme flood that could ever be expected to occur.

The Uncertainty of the Climate

It is possible that potential future climate changes may have adverse impacts upon sea levels and rainfall intensities, both of which may have significant influence on flood behaviour at specific locations.

These possible climate changes and the associated ramifications upon the vulnerability of floodplain risk management options and development decisions could be significant and therefore cannot be ignored in decision making today.

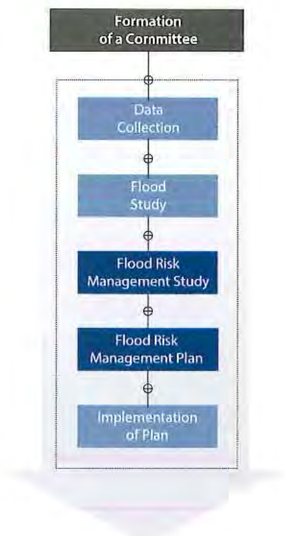
Flooding in the Narrabeen Lagoon catchment is influenced by both ocean levels and rainfall. As such, the Floodplain Risk Management Study will need to consider the possible impacts of both sea level rise scenarios and increases in rainfall intensity.

Narrabeen Lagoon Entrance

The Narrabeen Lagoon entrance closes naturally due to the movement of sand along Narrabeen Beach and into the entrance channel as a result of wave, current and wind processes. The volume of sand moved into the entrance exceeds the volume of sand flushed out by the outgoing tide.

Prior to 1970 the Lagoon was predominantly closed. However, due to growing community concerns regarding potential flooding within the catchment and water quality within the lagoon, the Councils have acted to keep the entrance predominantly open since then, and mechanically open the entrance if it is closed and there is a threat of flooding. The Councils have undertaken large scale sand clearances approximately every four years since 1975. Entrance clearance works have a significant ongoing cost, which may not be sustainable in the long term.

The Floodplain Risk Management Process



Floodplain Risk Management Process

The Narrabeen Lagoon Floodplain Risk Management Working Group (the Working Group) oversees the Floodplain Management process. The Working Group meets regularly and includes representatives from Council, Office of Environment and Heritage (OEH), State Emergency Service (SES), NSW Department of Primary Industries (DPI), and representatives of the local community. The principal aim of the Working Group is to bring together the expertise and diverse community knowledge needed to address floodplain risk management matters relating to the Narrabeen Lagoon catchment.

Figure 1: The Study Area

Floodplain Risk Management Study and Plan Objectives

The Floodplain Risk Management Study will identify an appropriate mix of actions to effectively manage the full range of flood risks in accordance with the NSW Government Floodplain Development Manual (2005). The community will be involved through community consultation. The information from this Study, together with community feedback, will enable the Councils to formulate a Floodplain Risk Management Plan for the study area.

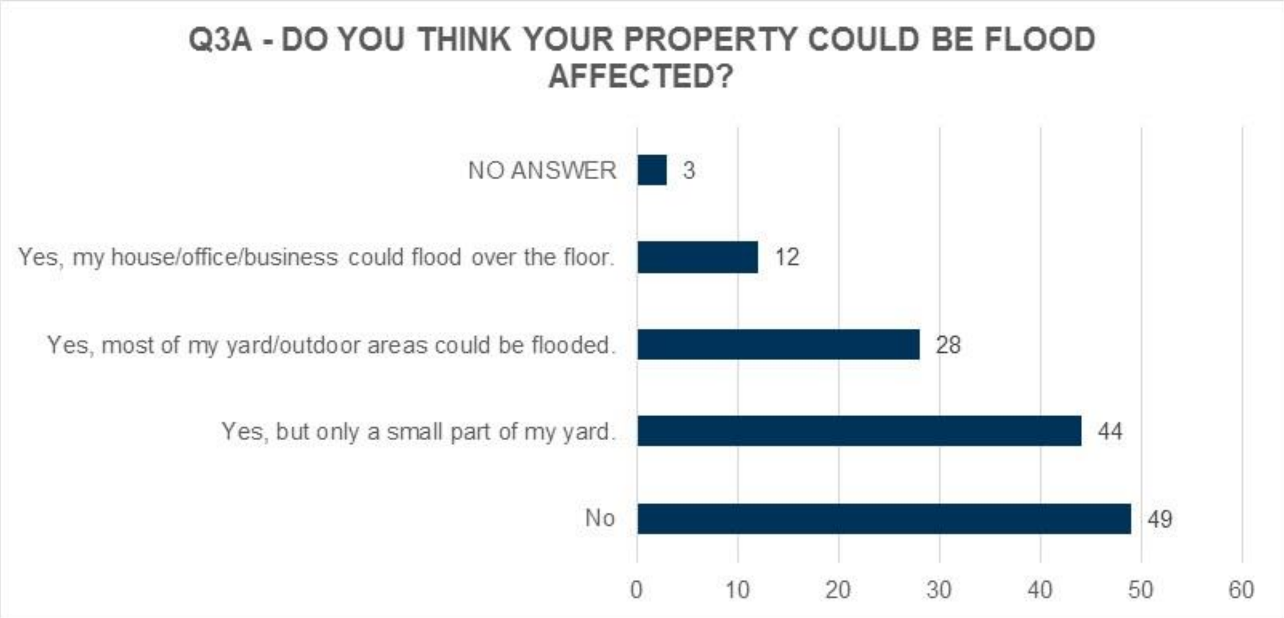
The Floodplain Risk Management Plan will set out a cost-effective program of action for the study area based on the findings of the Floodplain Risk Management Study. The Plan will detail how the existing and future flood risk within the study area will be managed.

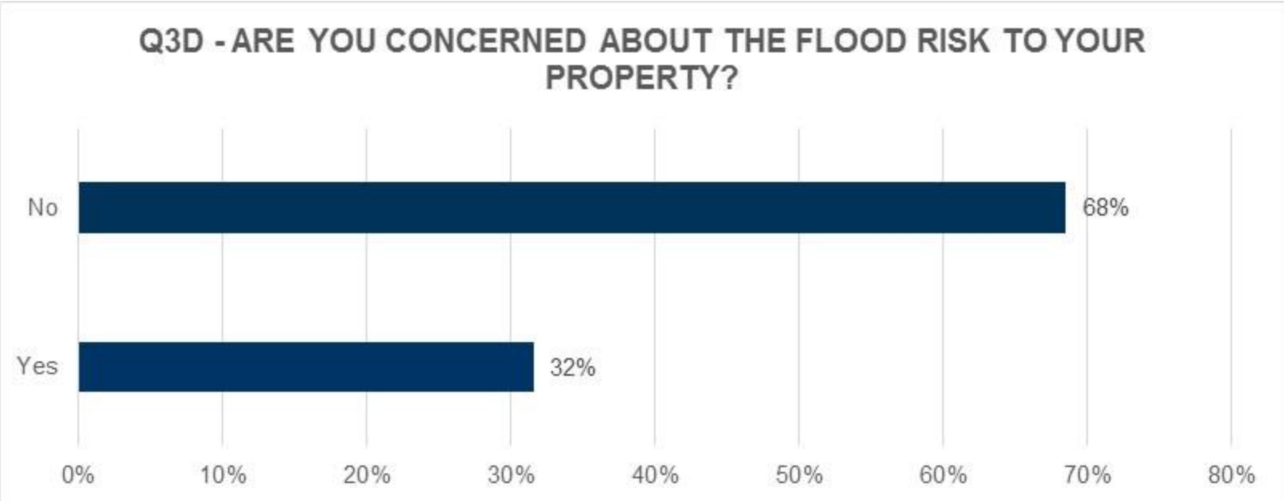
Floodplain Risk Management Options

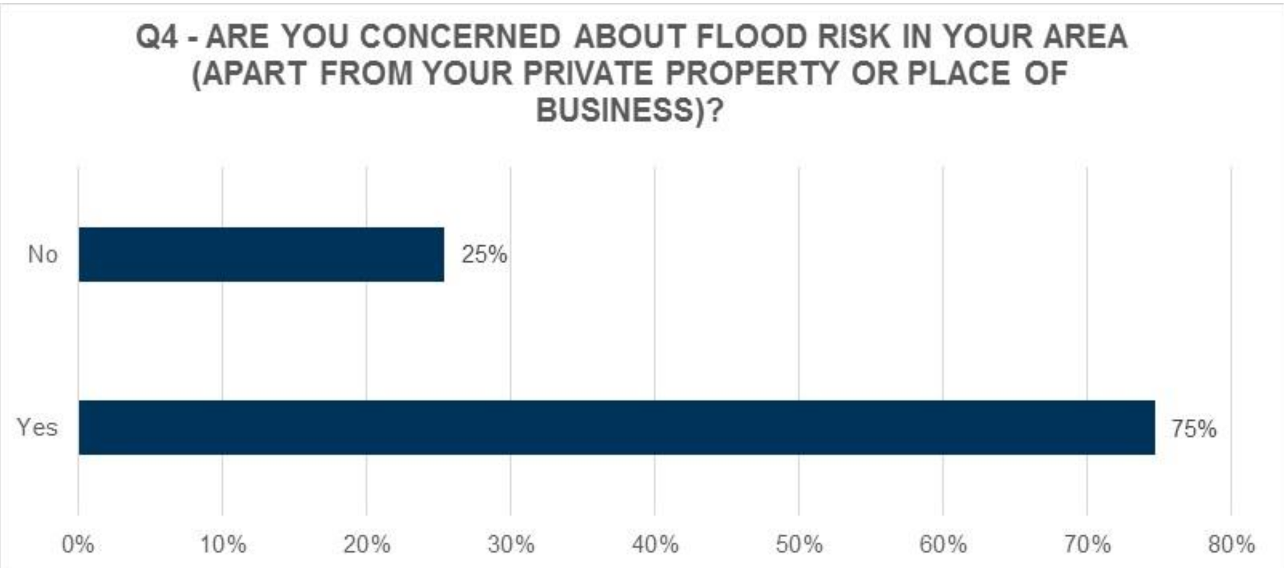
The primary ways of managing flood risk to reduce flood losses is by modifying:

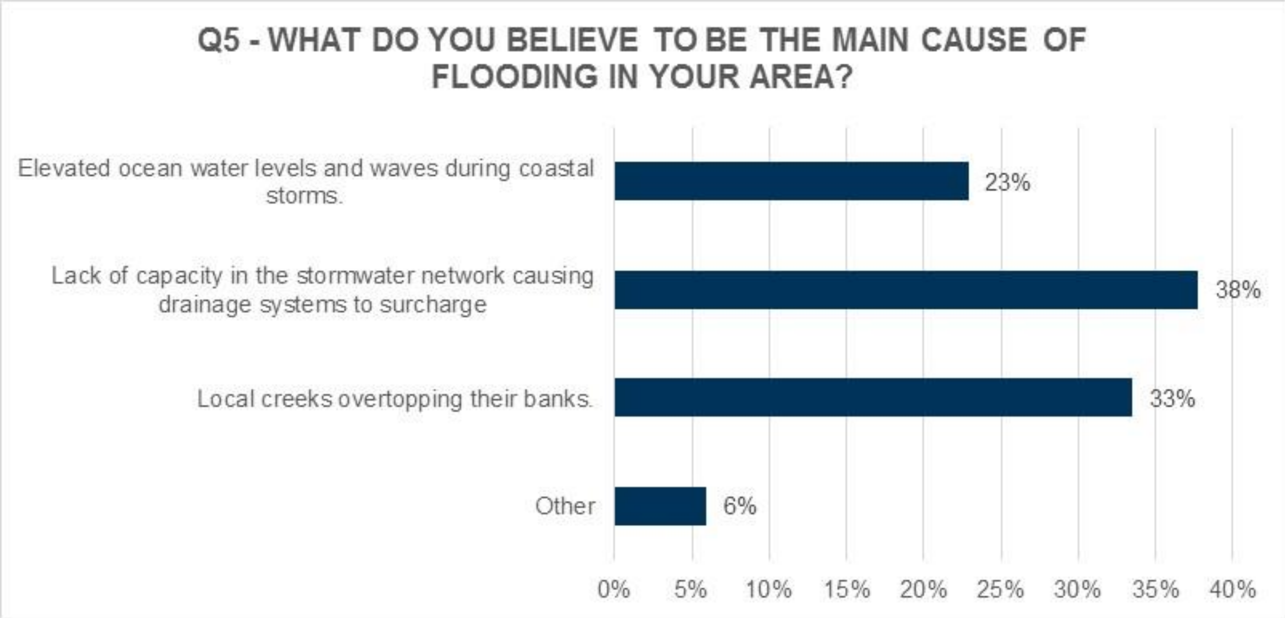
- Existing properties (e.g. house raising) and / or by imposing controls on development
- The response of the people at risk to enable them to better cope with a flood event (e.g. flood warning systems)
- The behaviour of the flood itself (e.g. levees, entrance management).

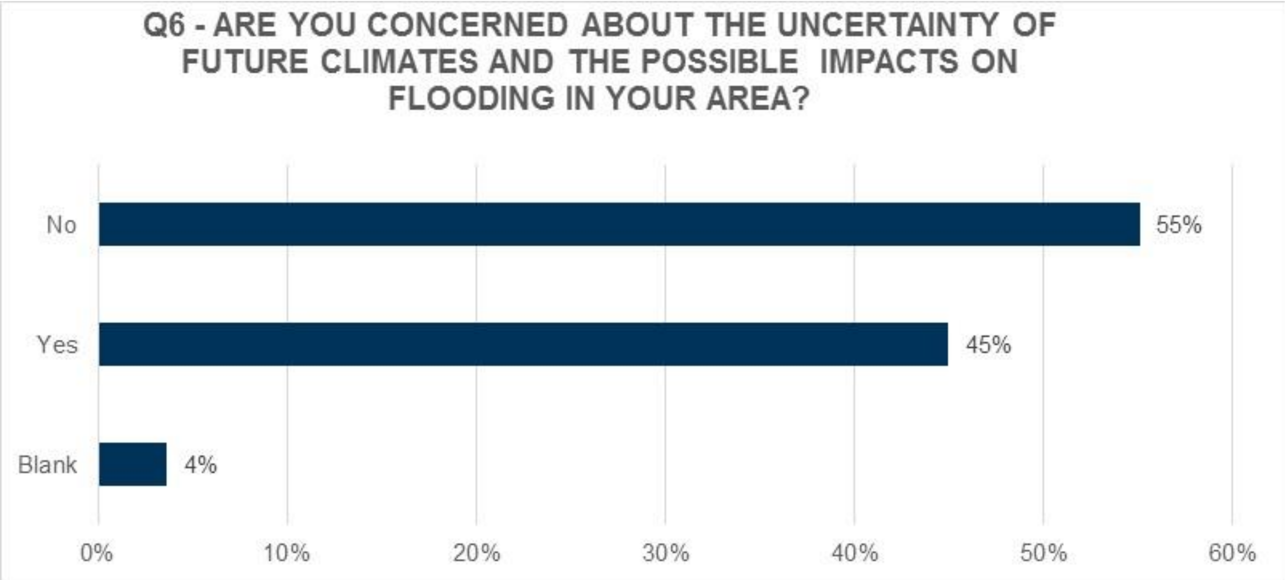
The Management Study will investigate potential flood risk management options, assessing the reduction in flood risk and losses, and the cost of implementing the options. All options will also be assessed for their social and environmental benefits or impacts. The outcome will be a prioritised list of options recommended for implementation in the catchment.

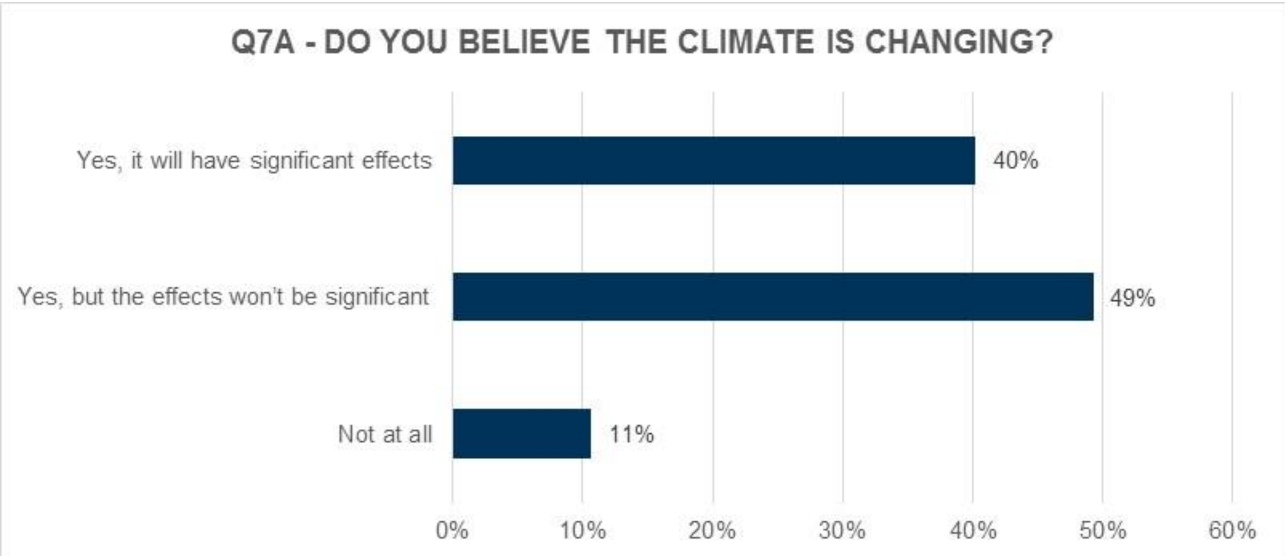

Q3A - DO YOU THINK YOUR PROPERTY COULD BE FLOOD AFFECTED?
NO ANSWER
3
Yes, my house/office/business could flood over the floor.
12
Yes, most of my yard/outdoor areas could be flooded.
28
Yes, but only a small part of my yard.
44
No
49
0
10
20
30
40
50
60

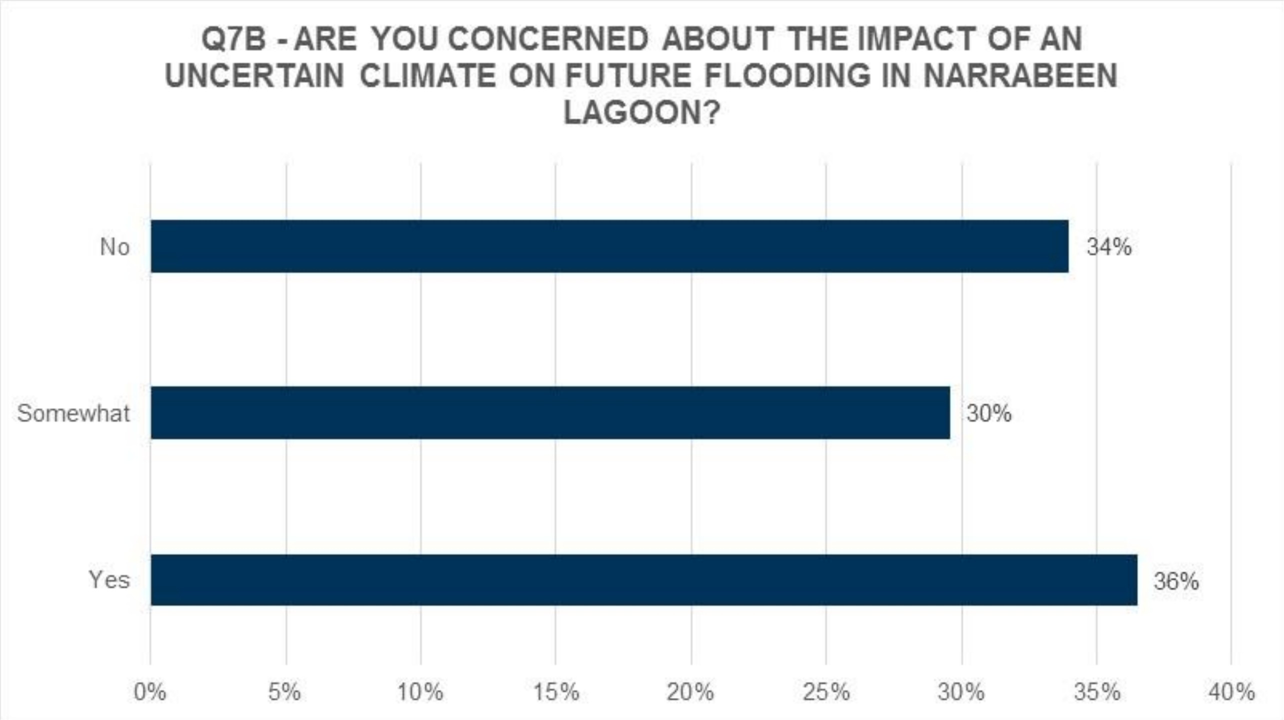

Q3D - ARE YOU CONCERNED ABOUT THE FLOOD RISK TO YOUR PROPERTY?
No
68%
Yes
32%
0%
10%
20%
30%
40%
50%
60%
70%
80%

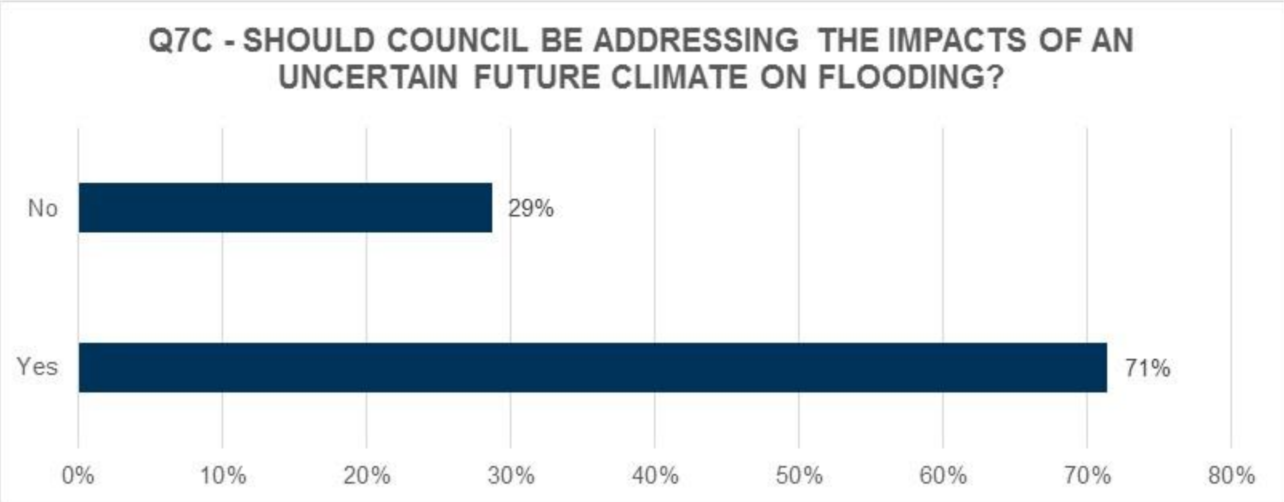

Q4 - ARE YOU CONCERNED ABOUT FLOOD RISK IN YOUR AREA (APART FROM YOUR PRIVATE PROPERTY OR PLACE OF BUSINESS)?
No
25%
Yes
75%
0%
10%
20%
30%
40%
50%
60%
70%
80%

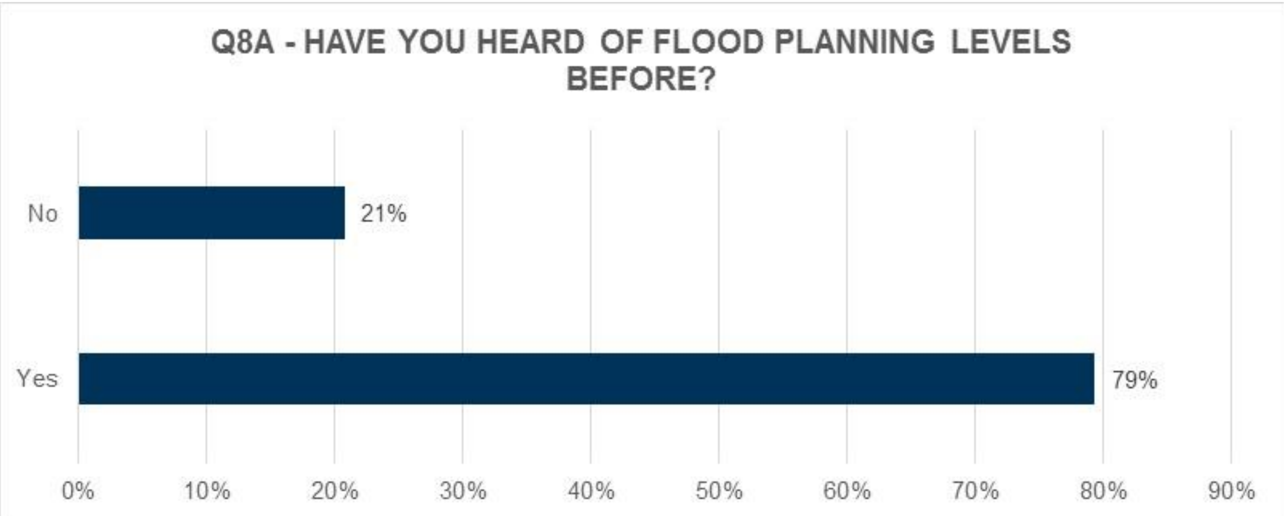

Q5 - WHAT DO YOU BELIEVE TO BE THE MAIN CAUSE OF FLOODING IN YOUR AREA?
Elevated ocean water levels and waves during coastal storms.
23%
Lack of capacity in the stormwater network causing drainage systems to surcharge
38%
Local creeks overtopping their banks.
33%
Other
6%
0% 5% 10% 15% 20% 25% 30% 35% 40%

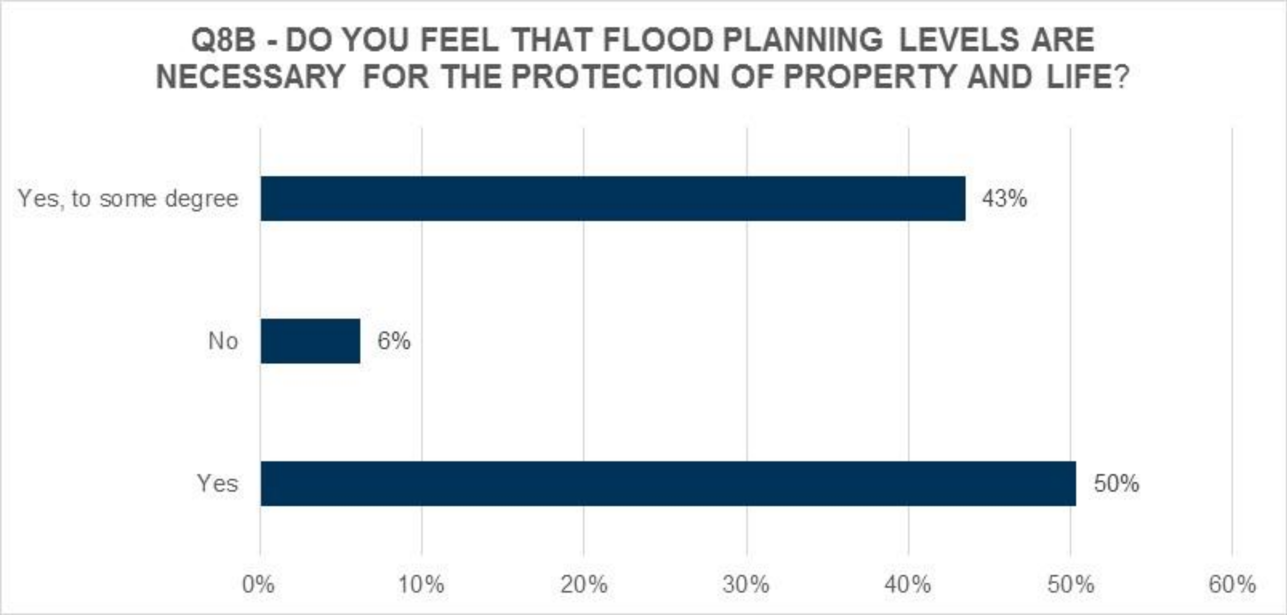

Q6 - ARE YOU CONCERNED ABOUT THE UNCERTAINTY OF FUTURE CLIMATES AND THE POSSIBLE IMPACTS ON FLOODING IN YOUR AREA?
No
55%
Yes
45%
Blank
4%
0% 10% 20% 30% 40% 50% 60%

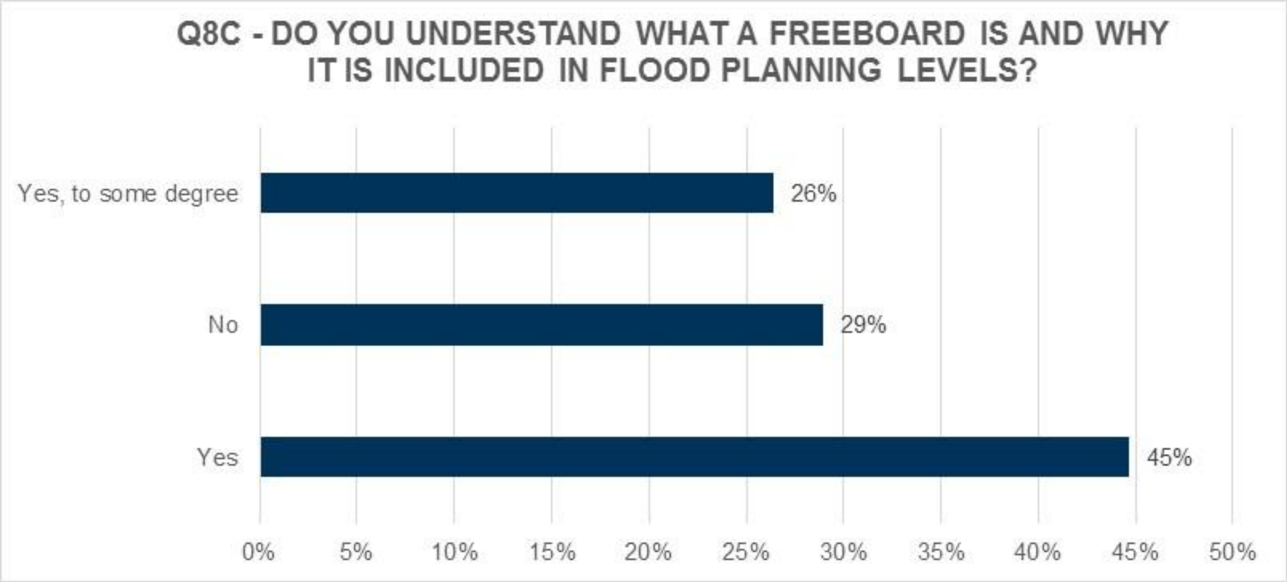

Q7A - DO YOU BELIEVE THE CLIMATE IS CHANGING?
Yes, it will have significant effects
40%
Yes, but the effects won't be significant
49%
Not at all
11%
0% 10% 20% 30% 40% 50% 60%

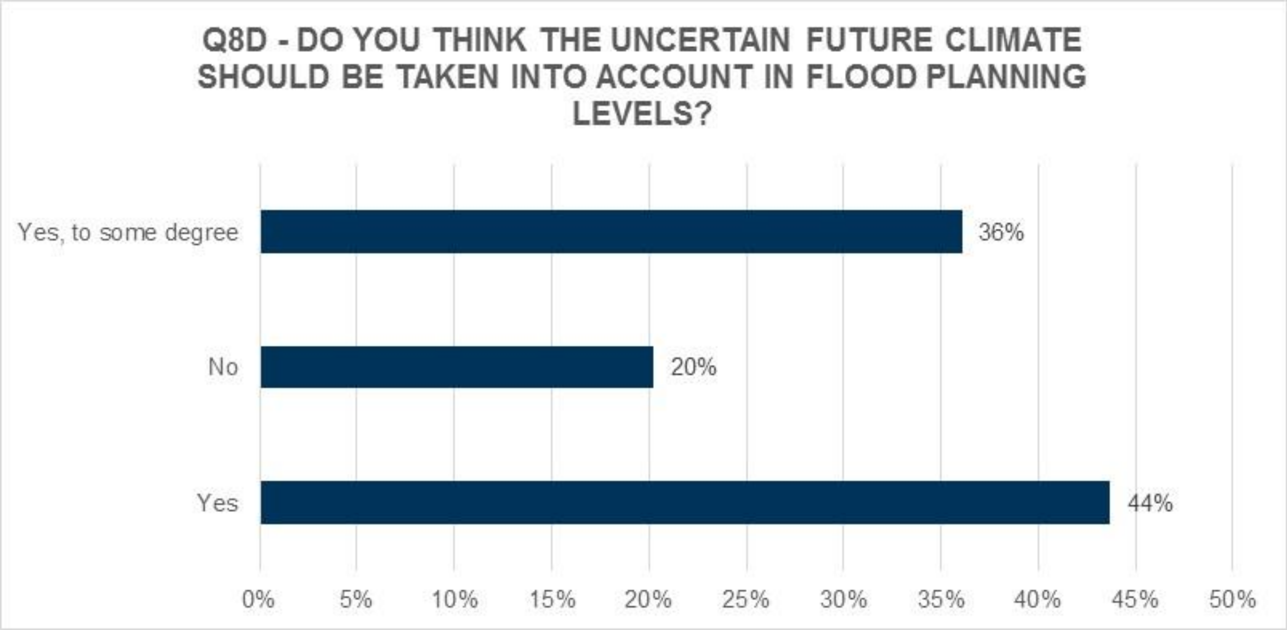

Q7B - ARE YOU CONCERNED ABOUT THE IMPACT OF AN UNCERTAIN CLIMATE ON FUTURE FLOODING IN NARRABEEN LAGOON?
No
34%
Somewhat
30%
Yes
36%
0%
5%
10%
15%
20%
25%
30%
35%
40%


Q7C - SHOULD COUNCIL BE ADDRESSING THE IMPACTS OF AN UNCERTAIN FUTURE CLIMATE ON FLOODING?
No
29%
Yes
71%
0%
10%
20%
30%
40%
50%
60%
70%
80%


Q8A - HAVE YOU HEARD OF FLOOD PLANNING LEVELS BEFORE?
No
21%
Yes
79%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%


Q8B - DO YOU FEEL THAT FLOOD PLANNING LEVELS ARE NECESSARY FOR THE PROTECTION OF PROPERTY AND LIFE?
Yes, to some degree
43%
No
6%
Yes
50%
0%
10%
20%
30%
40%
50%
60%


Q8C - DO YOU UNDERSTAND WHAT A FREEBOARD IS AND WHY IT IS INCLUDED IN FLOOD PLANNING LEVELS?
Yes, to some degree
26%
No
29%
Yes
45%
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%


Q8D - DO YOU THINK THE UNCERTAIN FUTURE CLIMATE SHOULD BE TAKEN INTO ACCOUNT IN FLOOD PLANNING LEVELS?
Yes, to some degree
36%
No
20%
Yes
44%
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%

Narrabeen Lagoon Floodplain Risk Management Study and Plan

APPENDIX

B

MITIGATION OPTION FIGURES

Cardno
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Cardno
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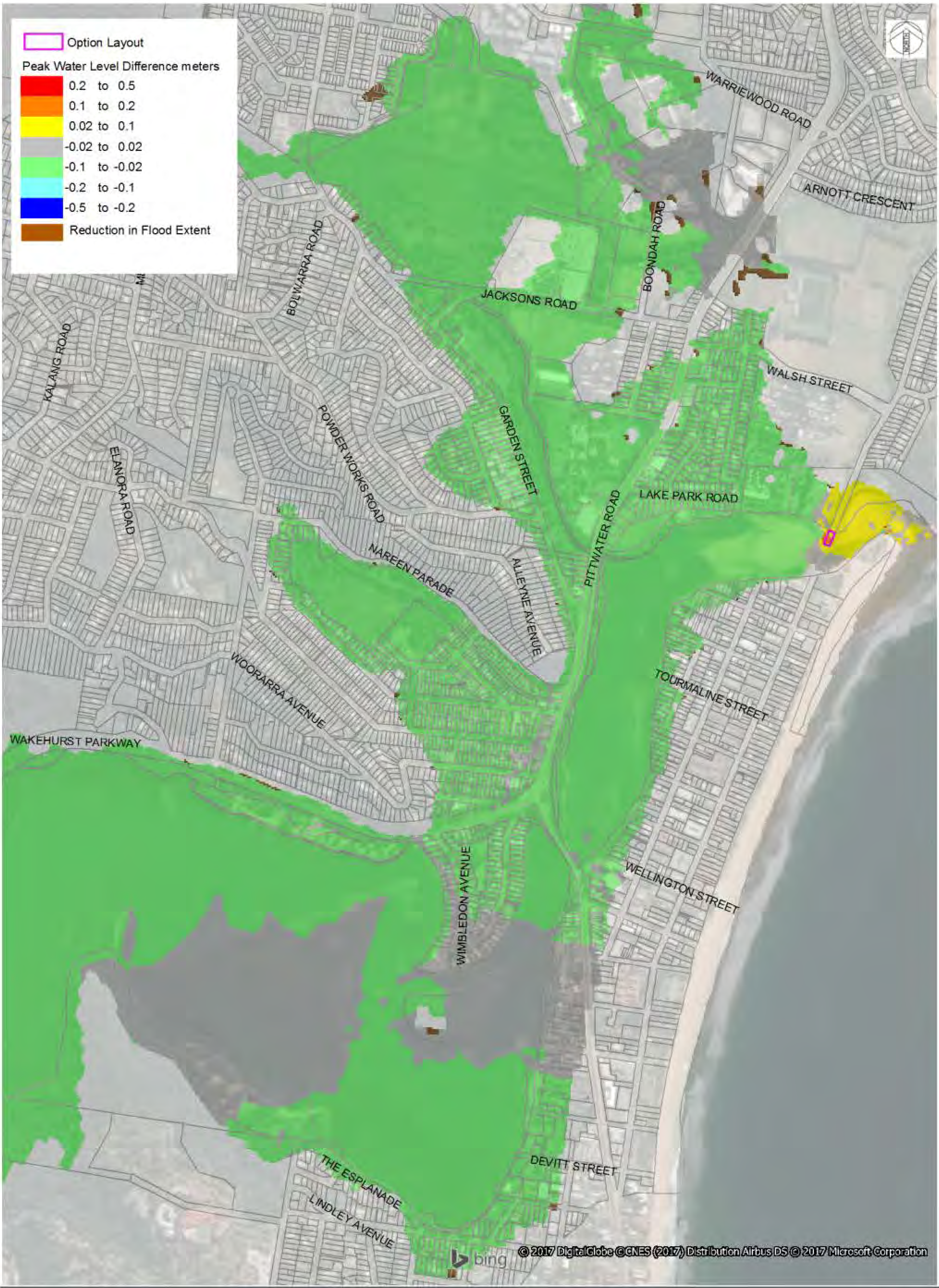
Date
November 2017

Size
A3

Scale 0 250 metres

Figure B1a
Option FM1 - Ocean Street Bridge Extension Layout
Narrabeen Lagoon Floodplain Risk Management Study and Plan
Figure_B1a.wor R2



Cardno
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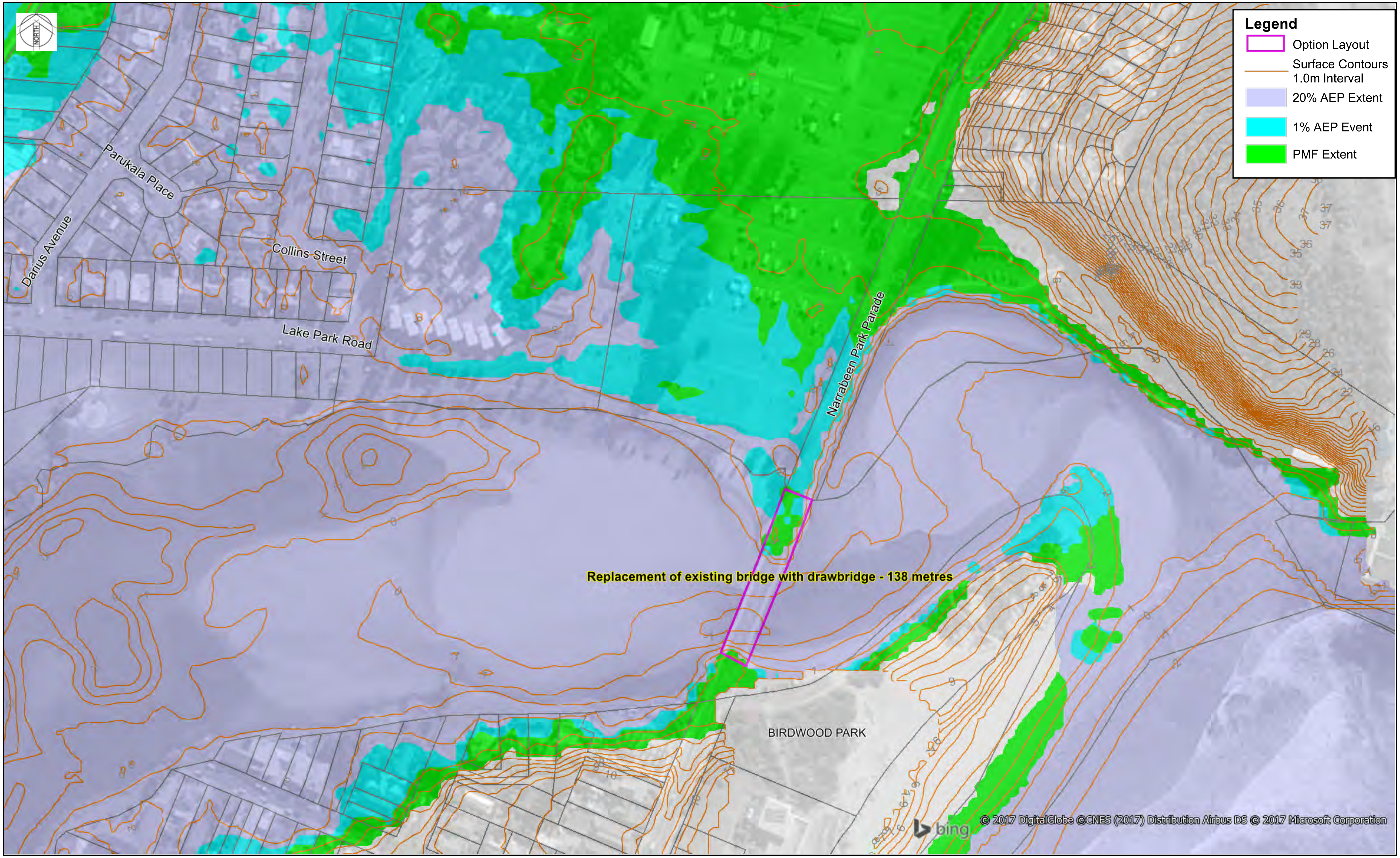
Date
November 2017

Size
A3

Scale 0 250 metres

Figure B1b
Option FM1 - Ocean Street Bridge Extension
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
Figure_B1b.wor R2



Cardno
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Date
November 2017

Size
A3

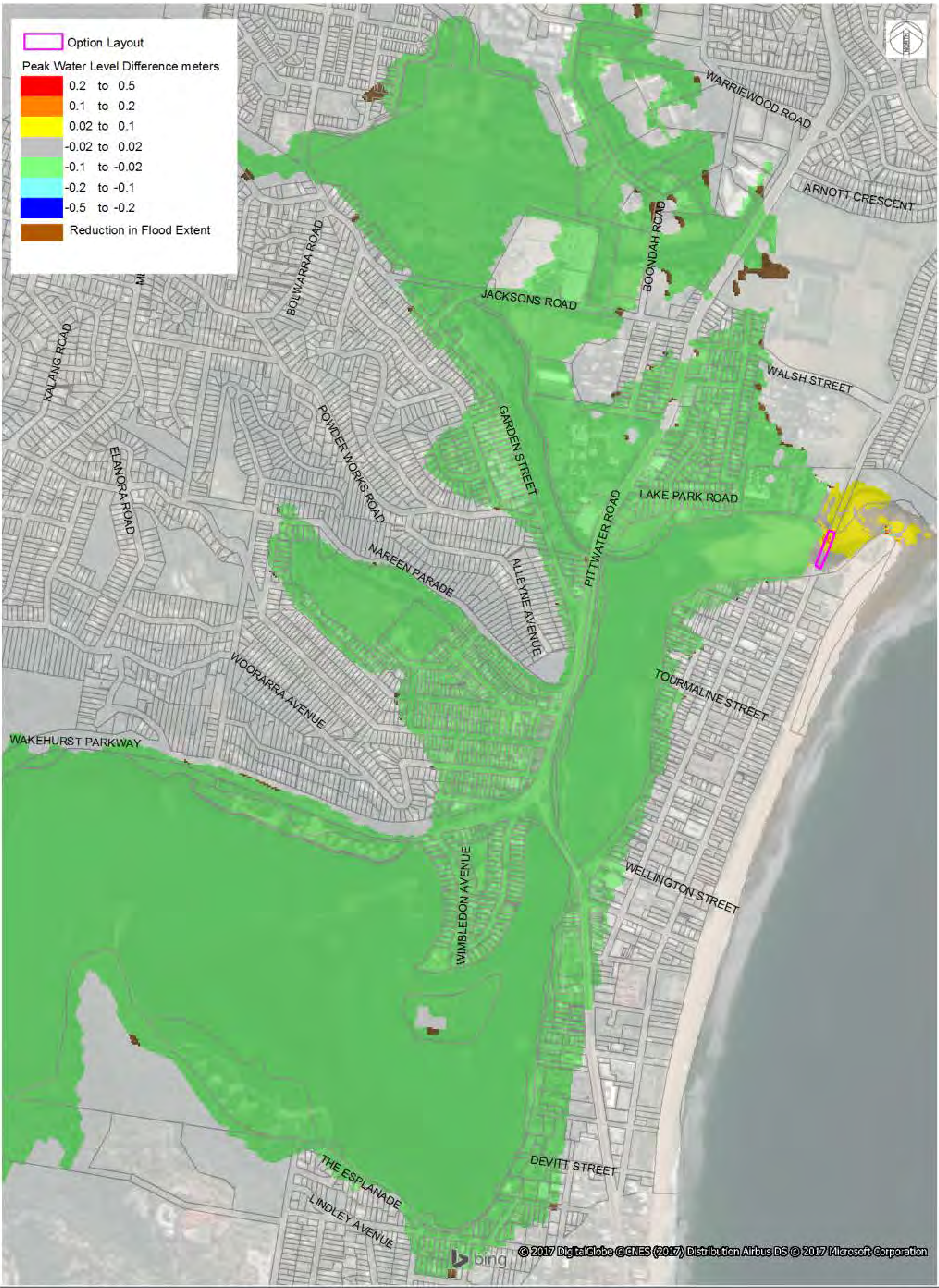
Scale 0 100 metres

Figure B2a

Option FM2 - Reconstruction of Ocean Street Bridge Layout

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Figure_B2a.wor R2



Cardno Shaping the Future

Date
November 2017

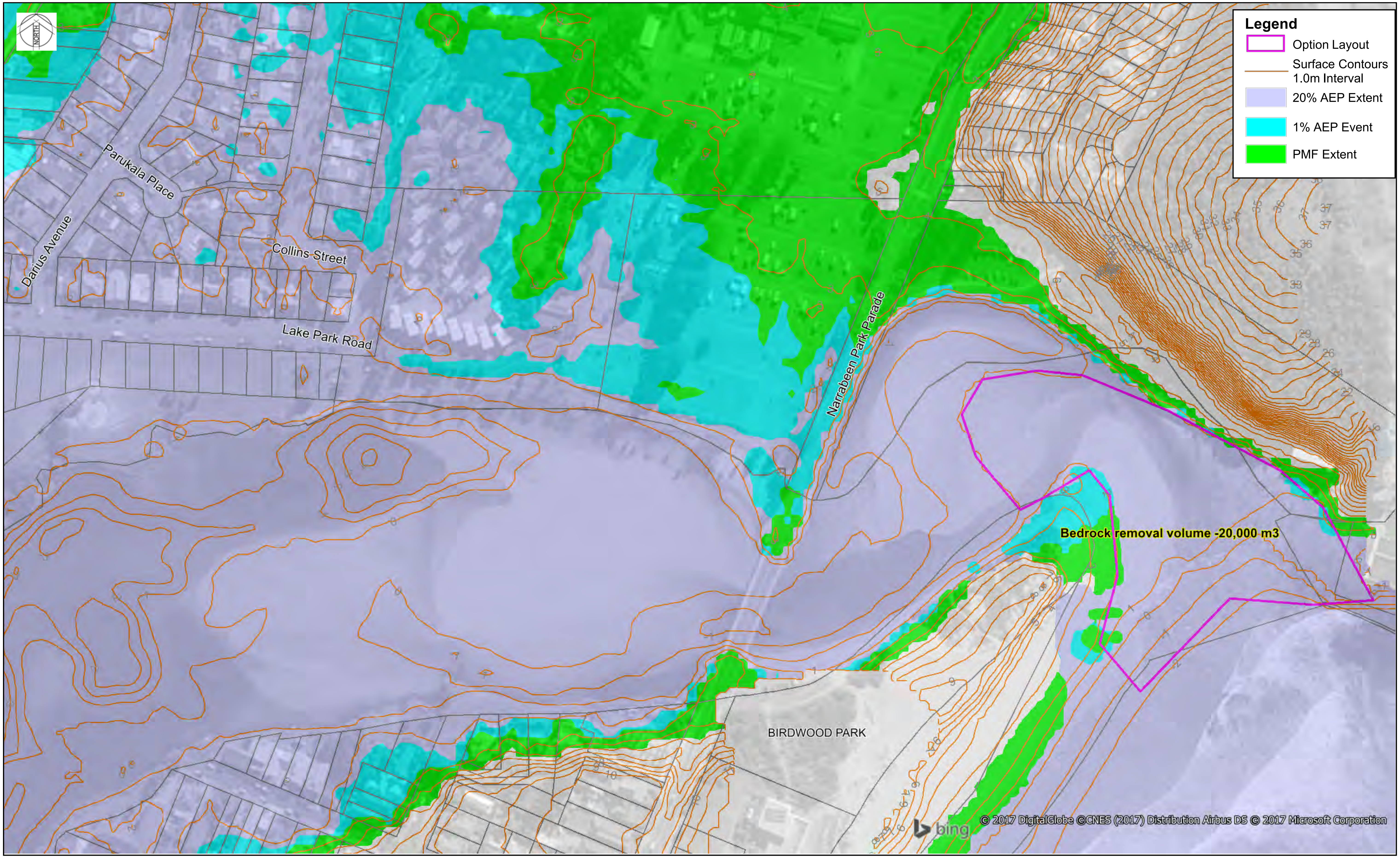
Size
A3

Scale 0 250 metres

Figure B2b

Option FM2 - Reconstruction of Ocean Street Bridge
1% AEP Mitigation Difference Plot

Narrabeen Lagoon Floodplain Risk Management Study and Plan
Figure_B2b.wor R2



Cardno
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Date
November 2017

Size
A3

Scale 0 100 metres

Figure B3a

Option FM3 - Entrance Bed Rock Removal Layout

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Figure_B3a.wor R2

Cardno
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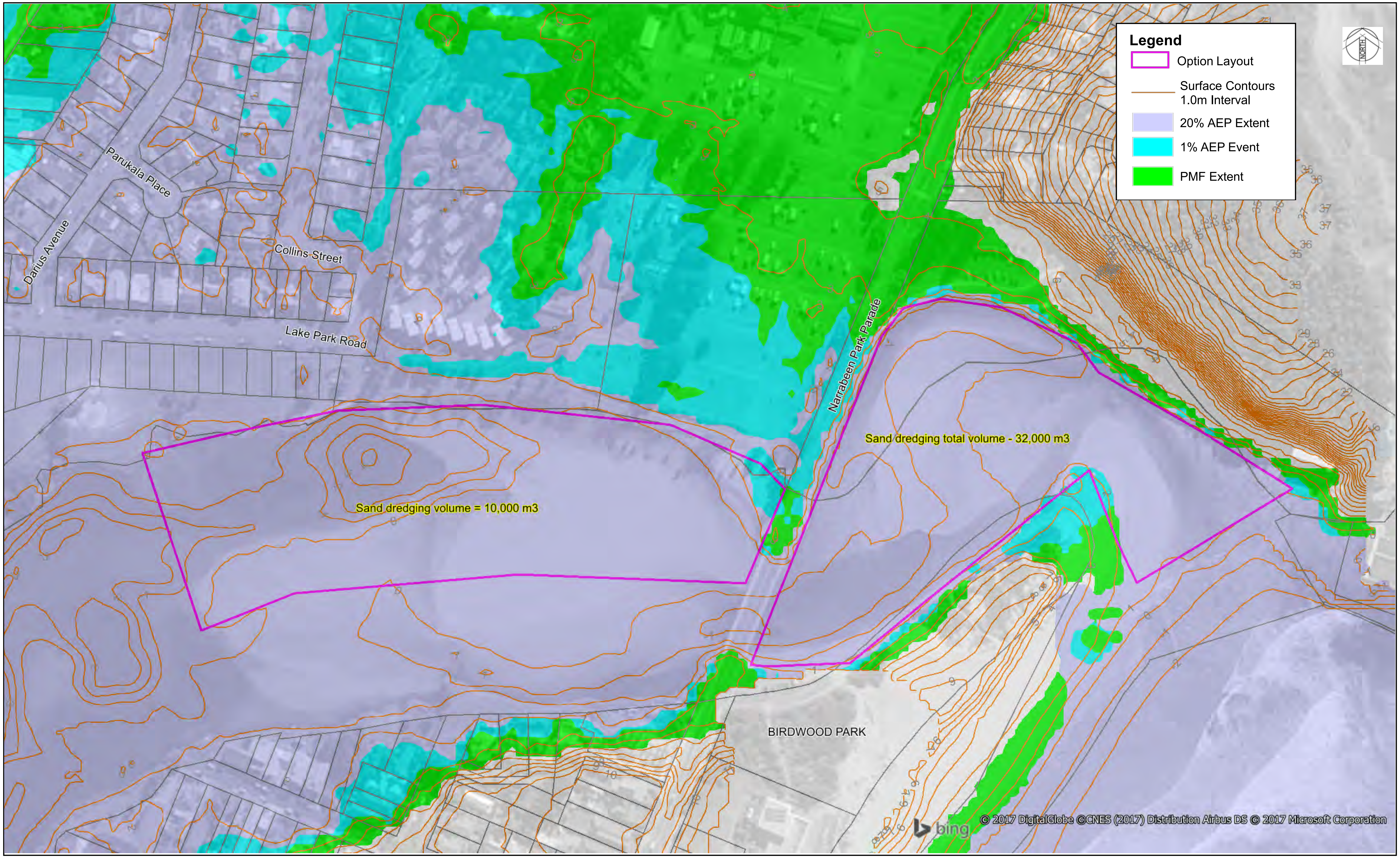
Date
November 2017

Size
A3

Scale 0 250 metres

Figure B3b
Option FM3 - Entrance Bed Rock Removal
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
Figure_B3b.wor R2



Cardno
Shaping the Future

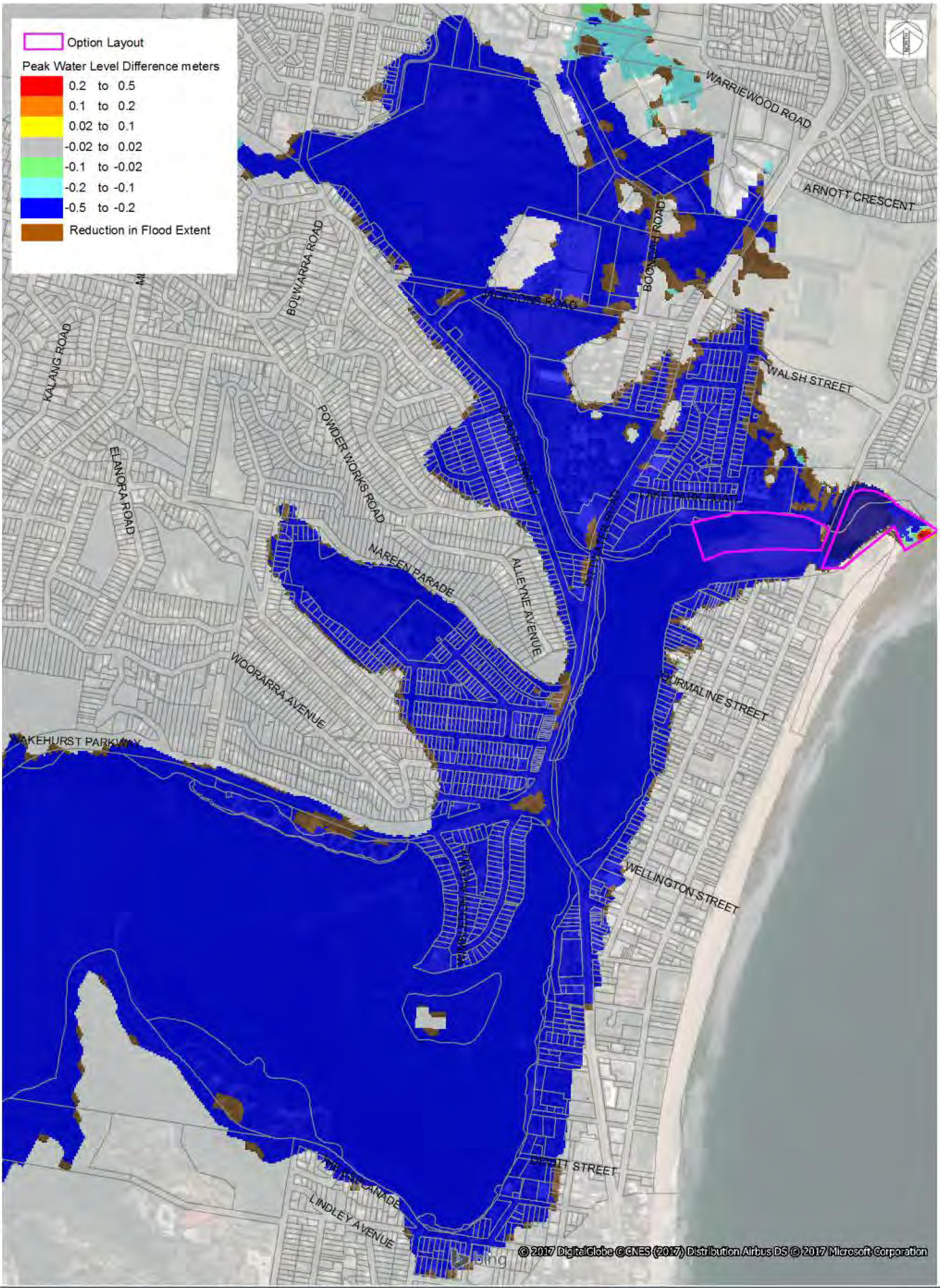
Date
November 2017

Size
A3

Scale 0 100 metres

Figure B4a
Option FM4 - Extraction of Entrance Shoals
Layout

Narrabeen Lagoon Floodplain Risk Management Study and Plan
Figure_B4a.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 250 metres

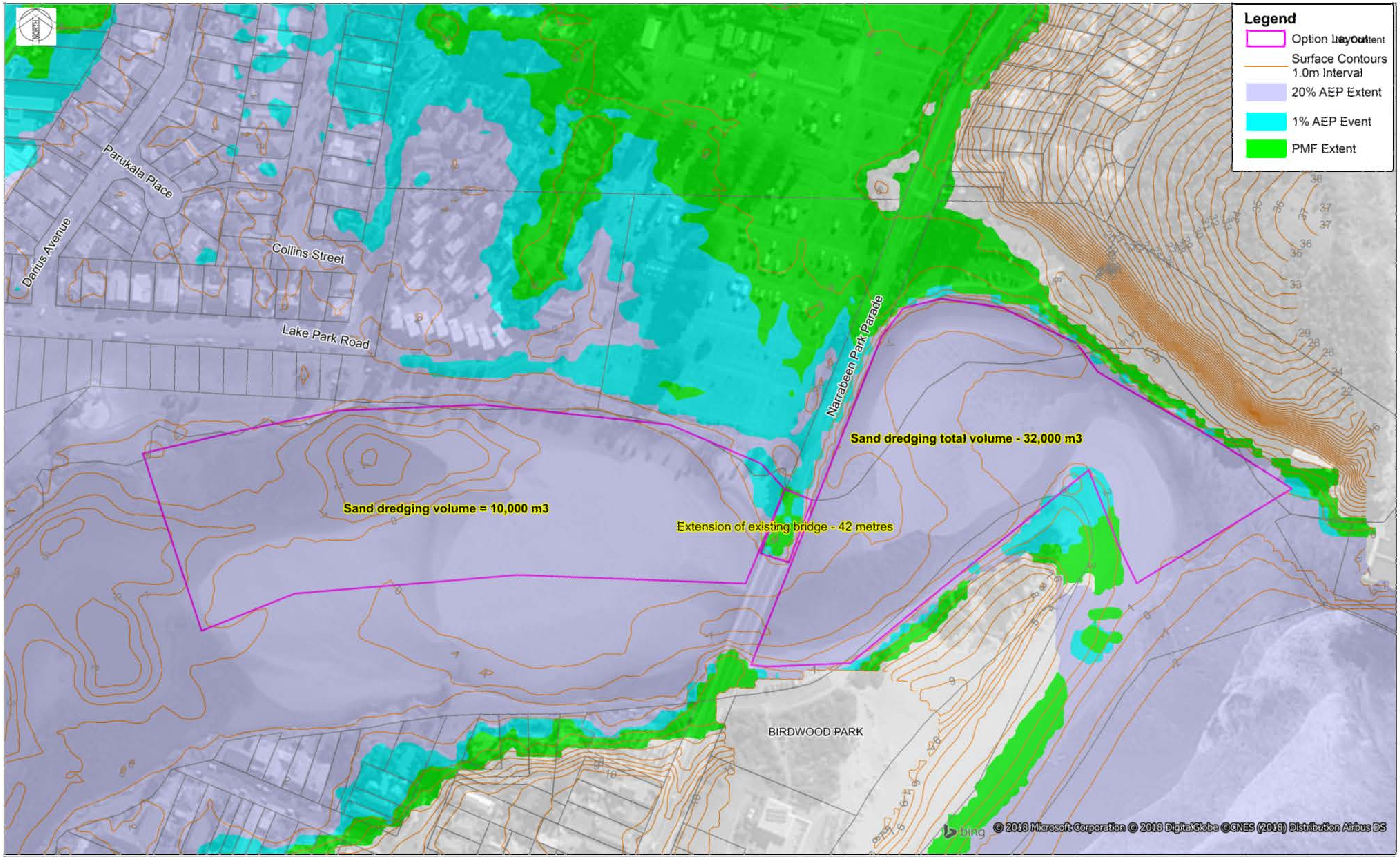
Figure B4b

Option FM4 - Extraction of Entrance Shoals

1% AEP Mitigation Difference Plot

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Figure_B4b.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

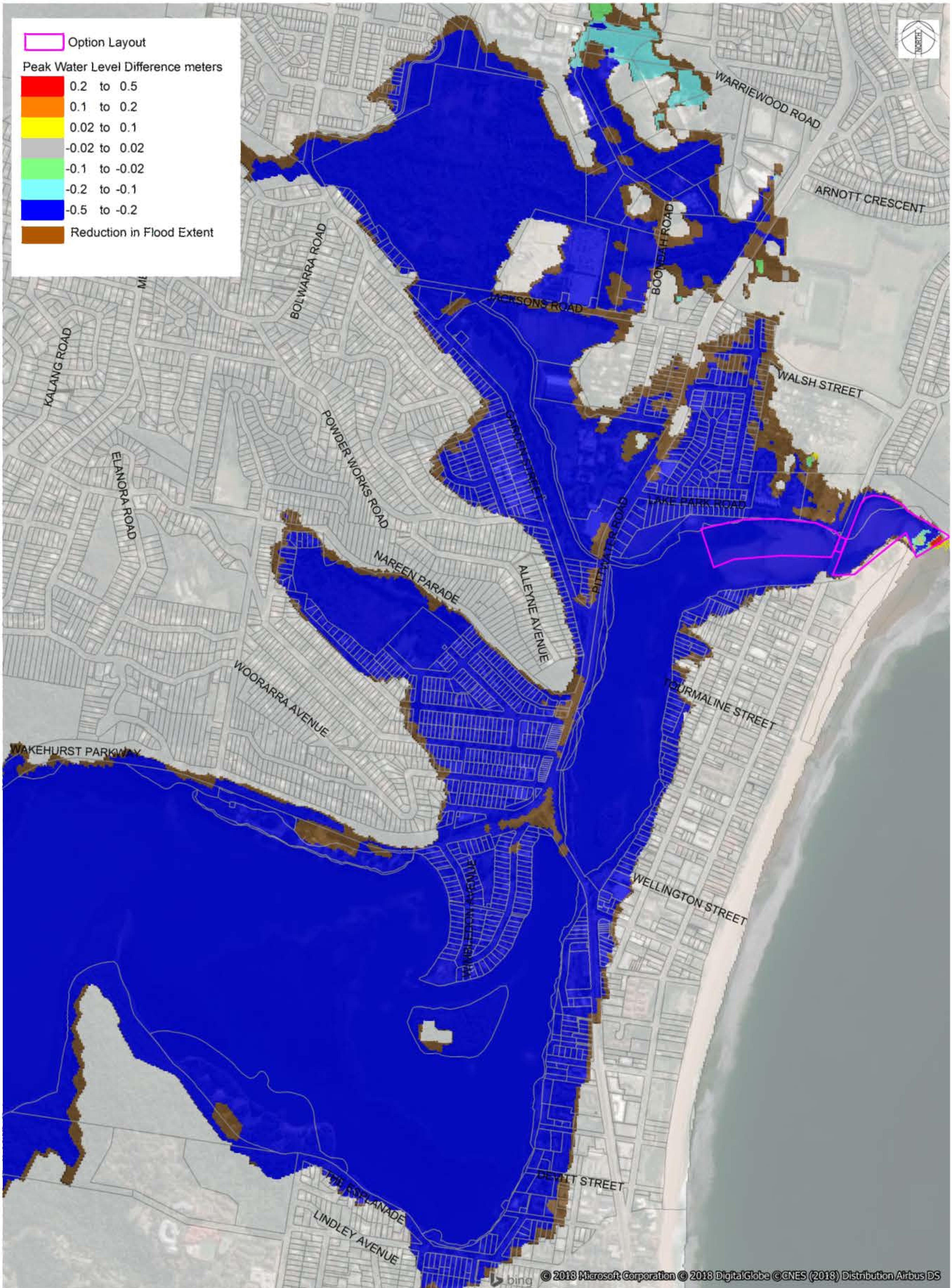
Scale 0 100 metres

Figure B5a

Option FM5 - Bridge Extension & Upstream and Downstream Shoals

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Figure_B5a.wor R2



Cardno
Shaping the Future

Date
November 2017

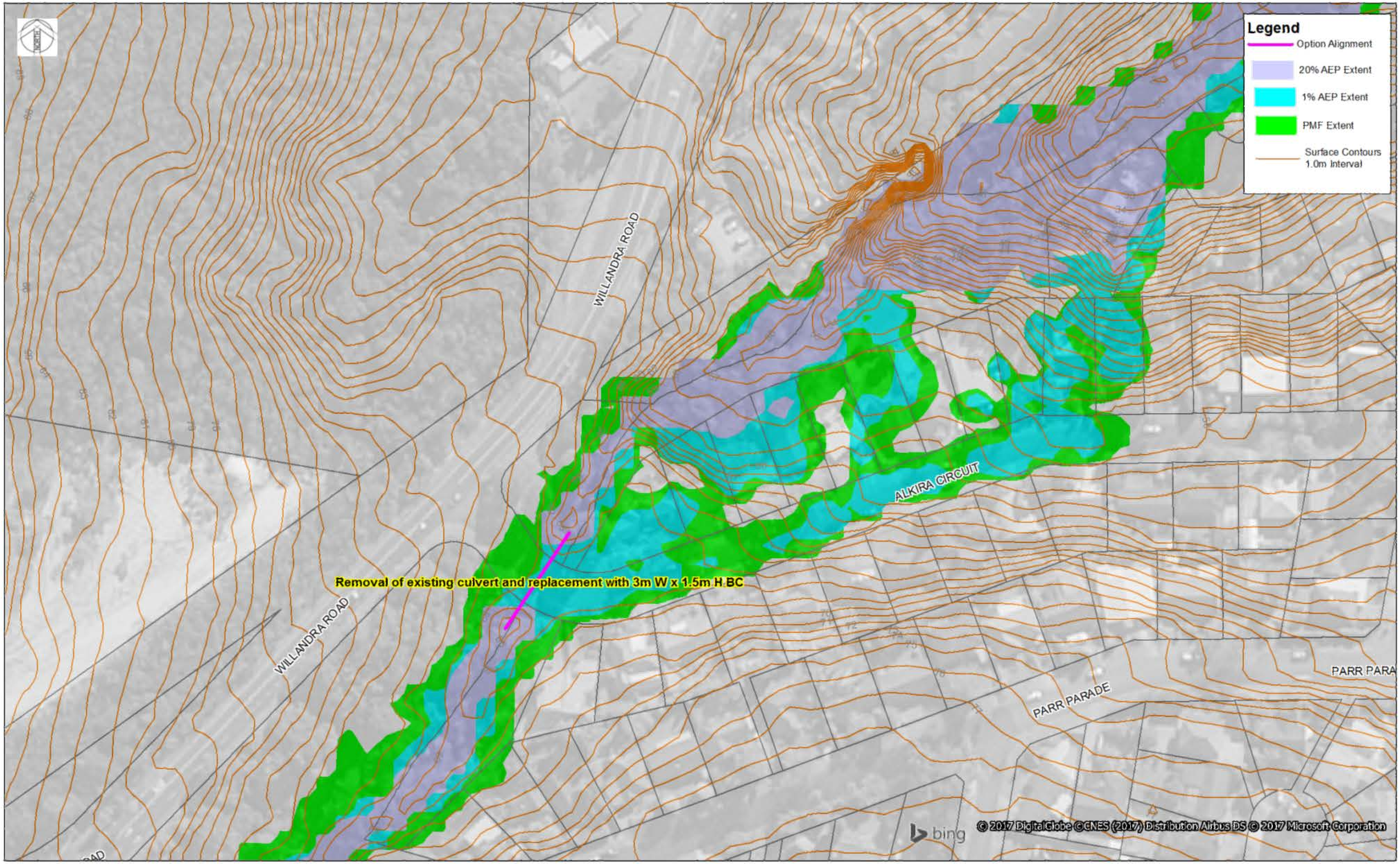
Size
A3

Scale 0 250 metres

Figure B5b

Option FM5 - Bridge Extension & Upstream
1% AEP Mitigation Difference Plot

Narrabeen Lagoon Floodplain Risk Management Study and Plan
Figure_B5b.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

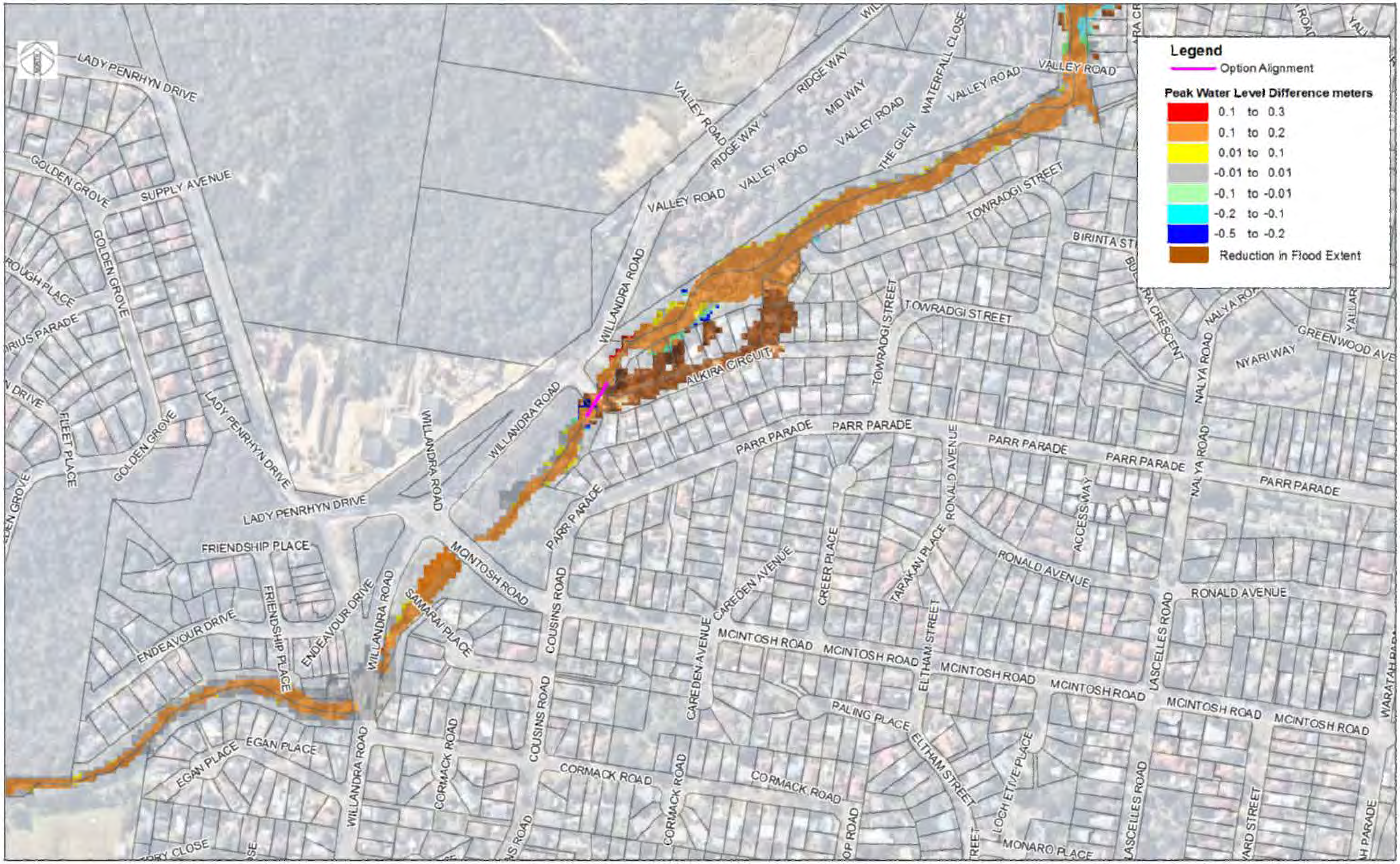
Scale 0 50 metres

Figure B6a

Option FM6 - Alkira Circuit Drainage Upgrade

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Figure_B6a.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

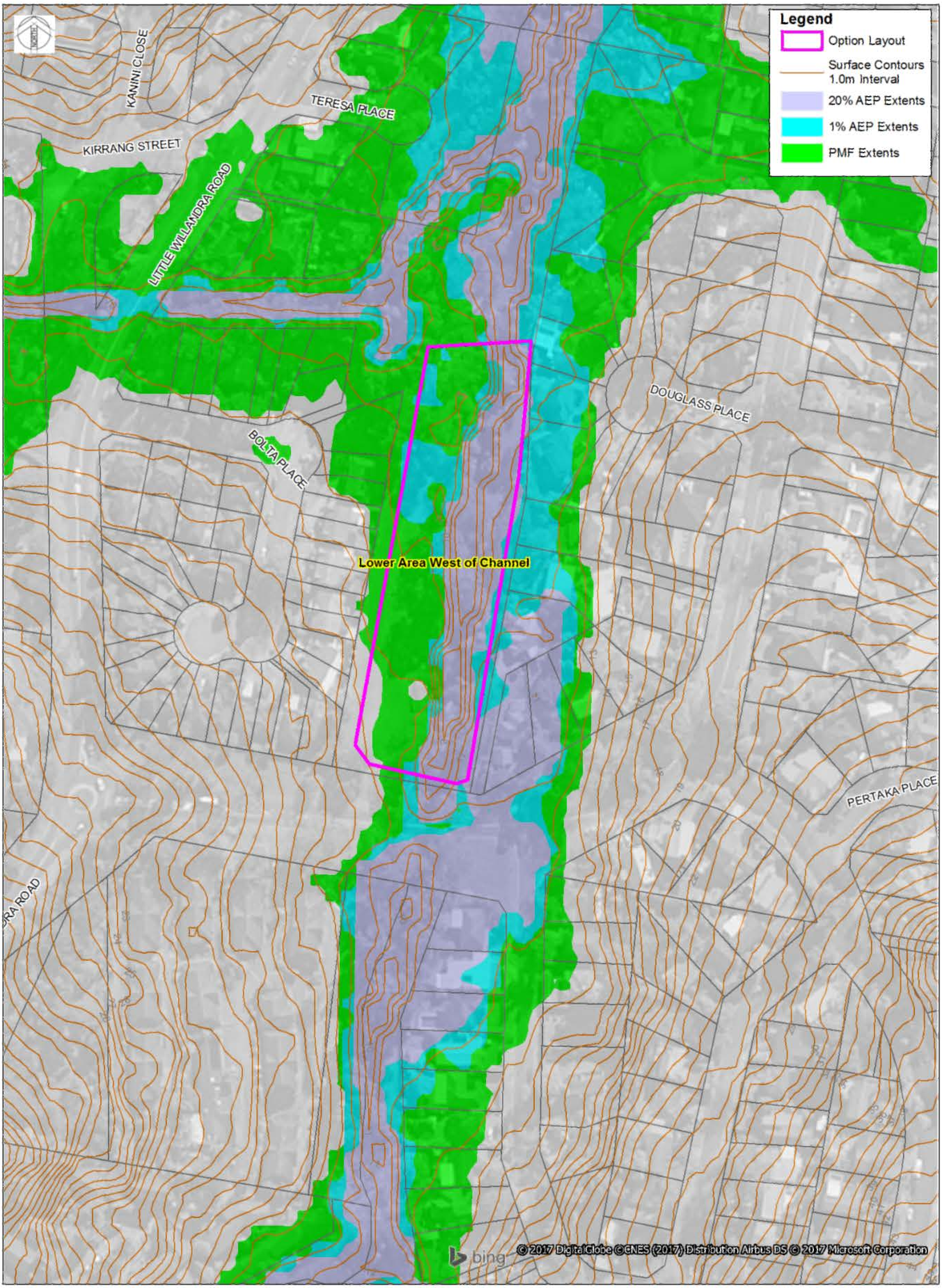
Scale 0 152.6 metres

Figure B6a

Option FM6 - Alkira Circuit Drainage Upgrade

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Figure_B6a.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

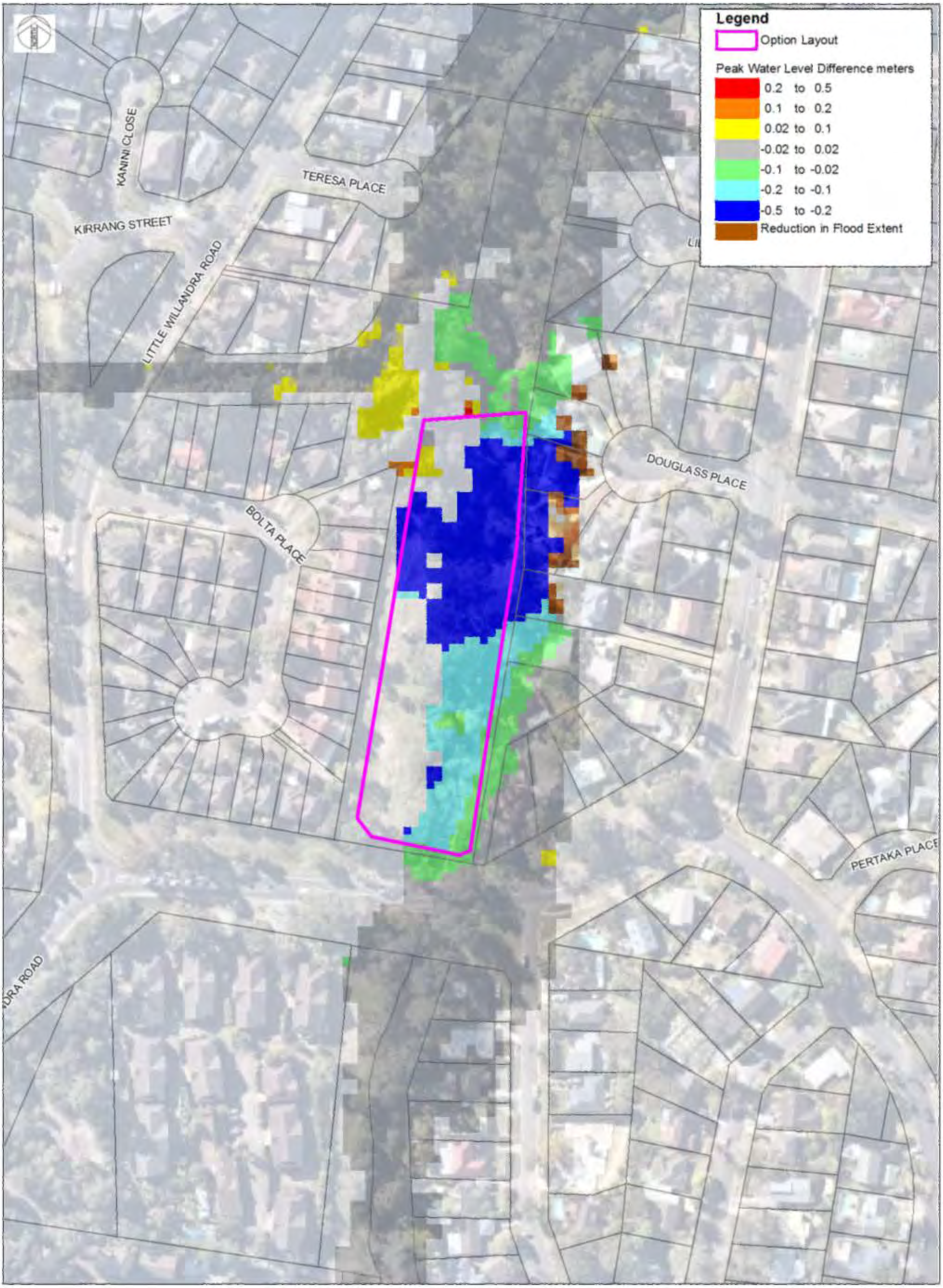
Scale
0 50
metres

Figure B7a

Option FM7 - Willandra Rd Reserve Lowering Layout

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Figure_B7a.wor R2



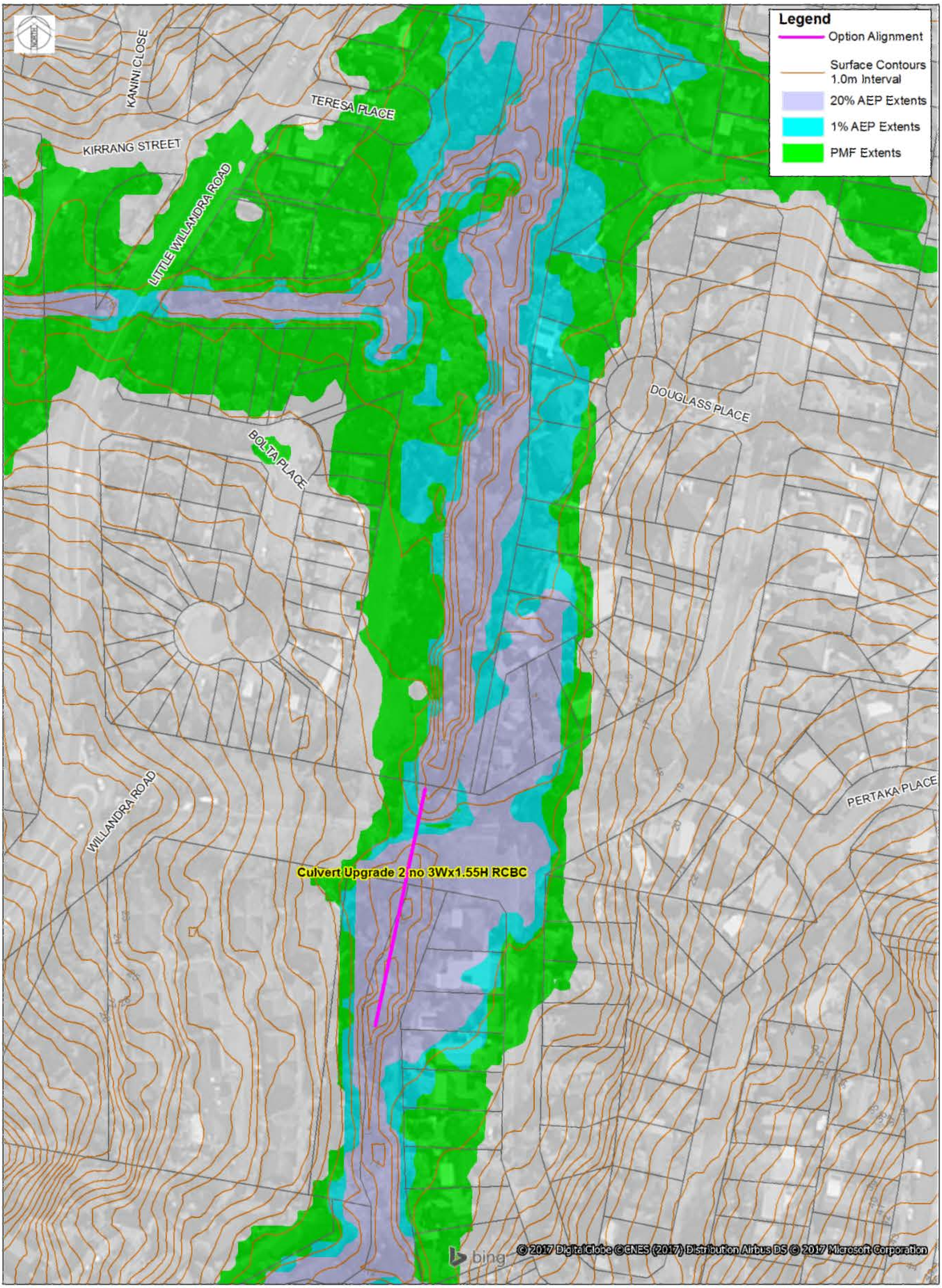
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 50 metres

Figure B7b
Option FM7 - Willandra Rd Reserve Lowering
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
Figure_B7b.wor R2



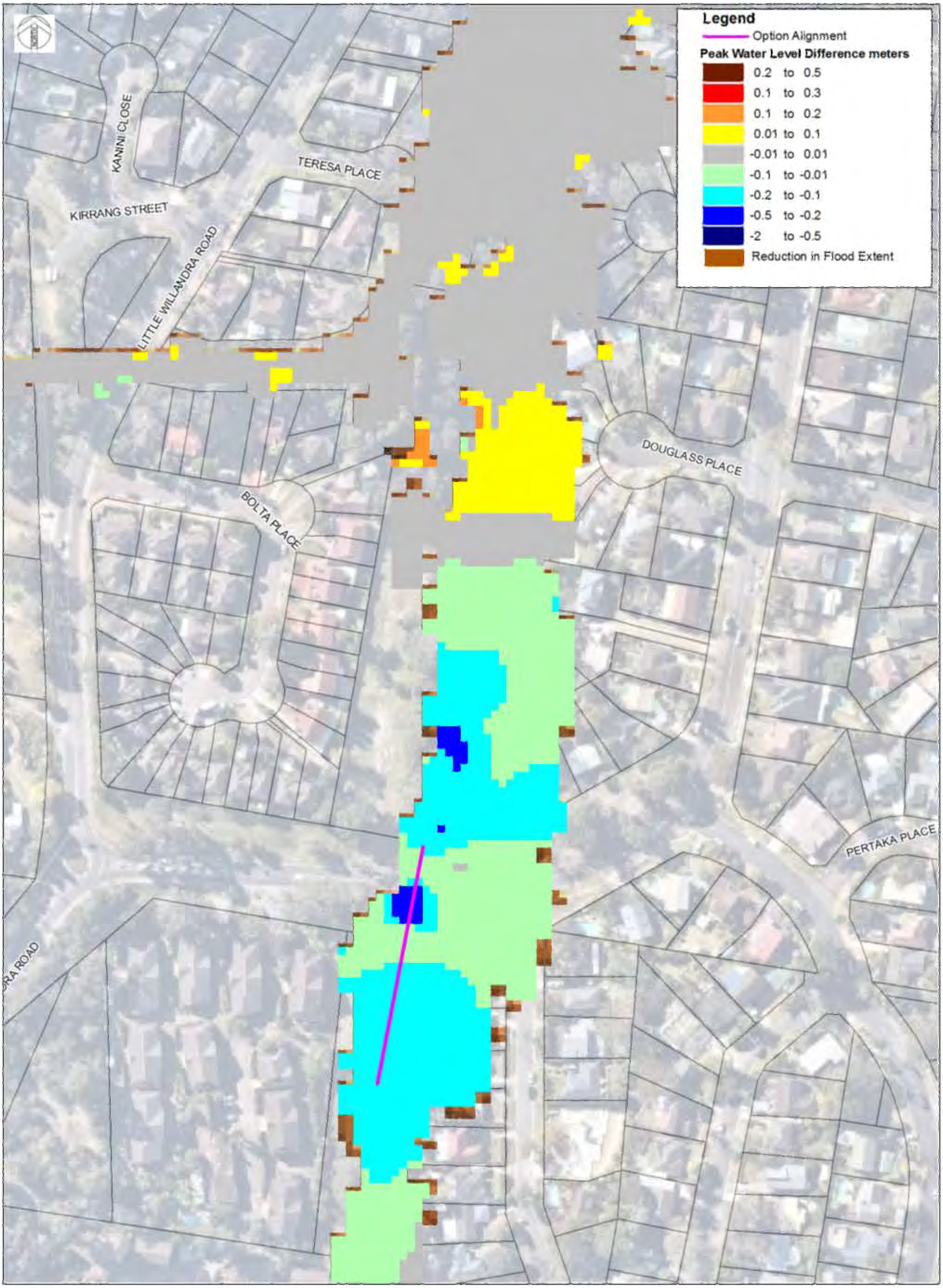
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 50 metres

Figure B8a
Option FM8 - Willandra Rd Culvert
Layout
Narrabeen Lagoon Floodplain Risk Management Study and Plan
Figure_B8a.wor R2



Date
November 2017

Size
A3

Scale
0 50
metres

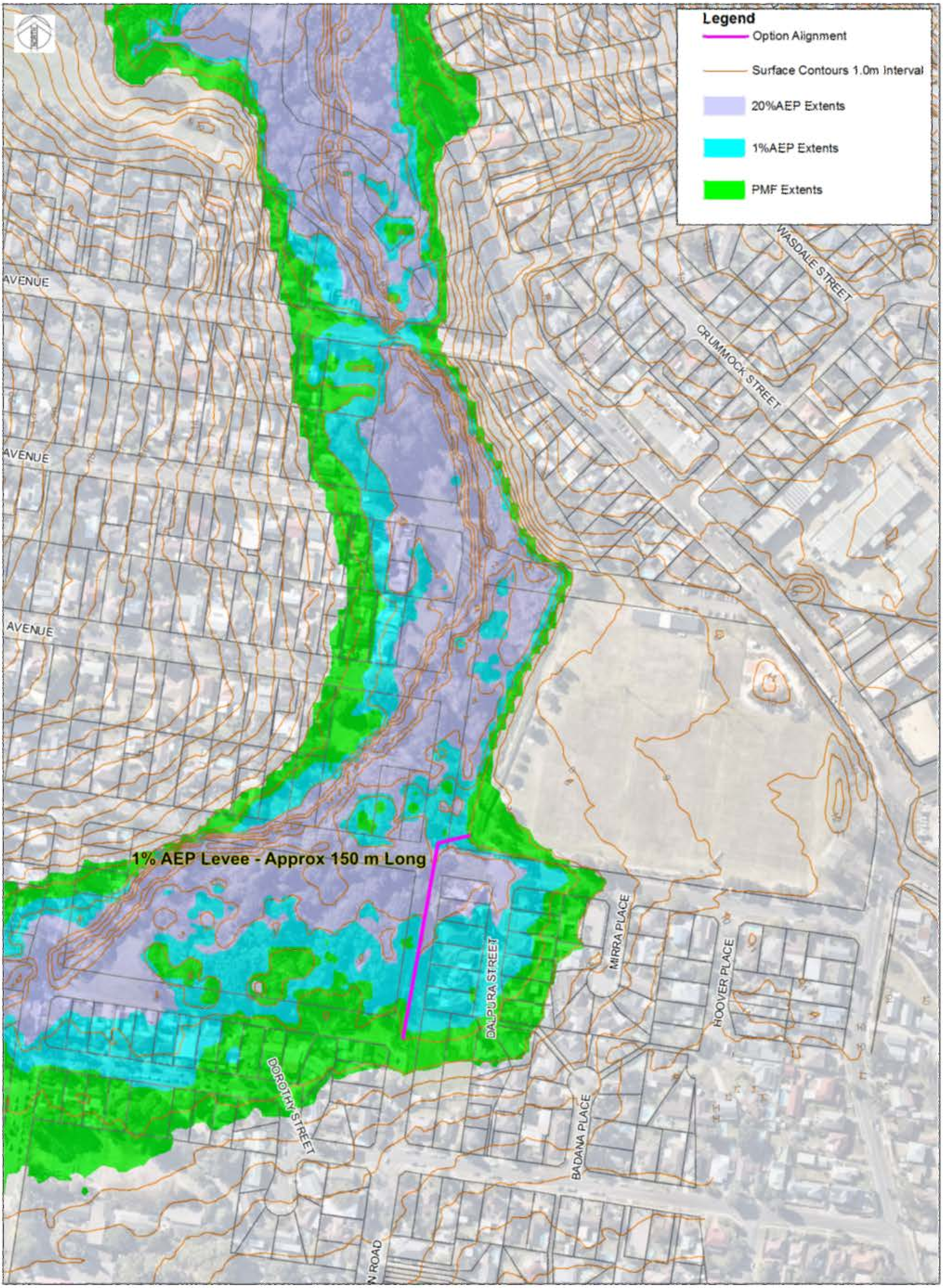
Figure B8b

Option FM8 - Willandra Rd Culvert

1% AEP Mitigation Difference Plot

Narrabeen Lagoon Floodplain Risk Management Study and Plan

Figure_B8b.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

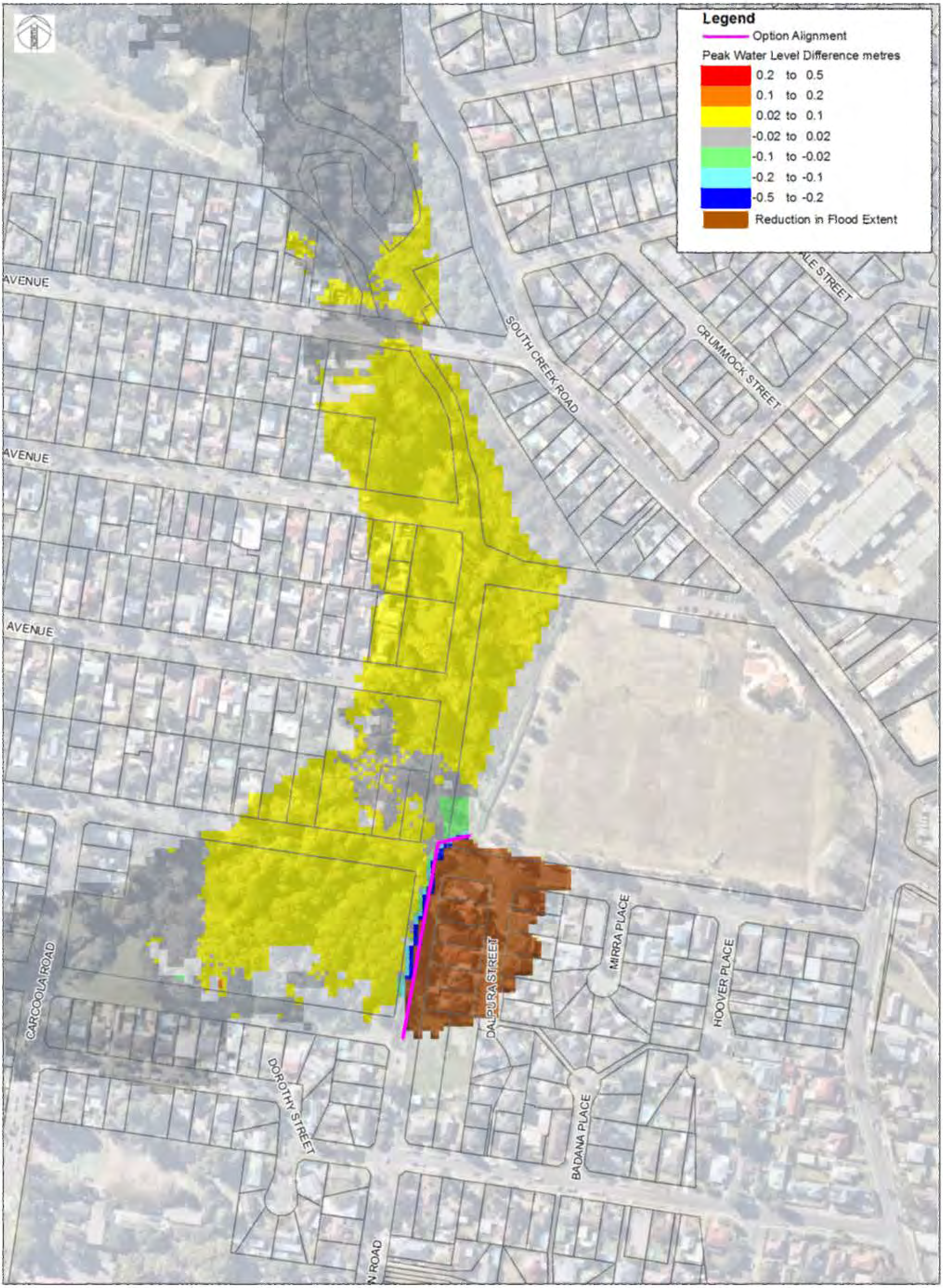
Scale

Figure B9a

Option FM9 - Waroon Road Levee Layout

Narrabeen Lagoon Floodplain Risk Management Study and Plan

FigureB9a.wor R2



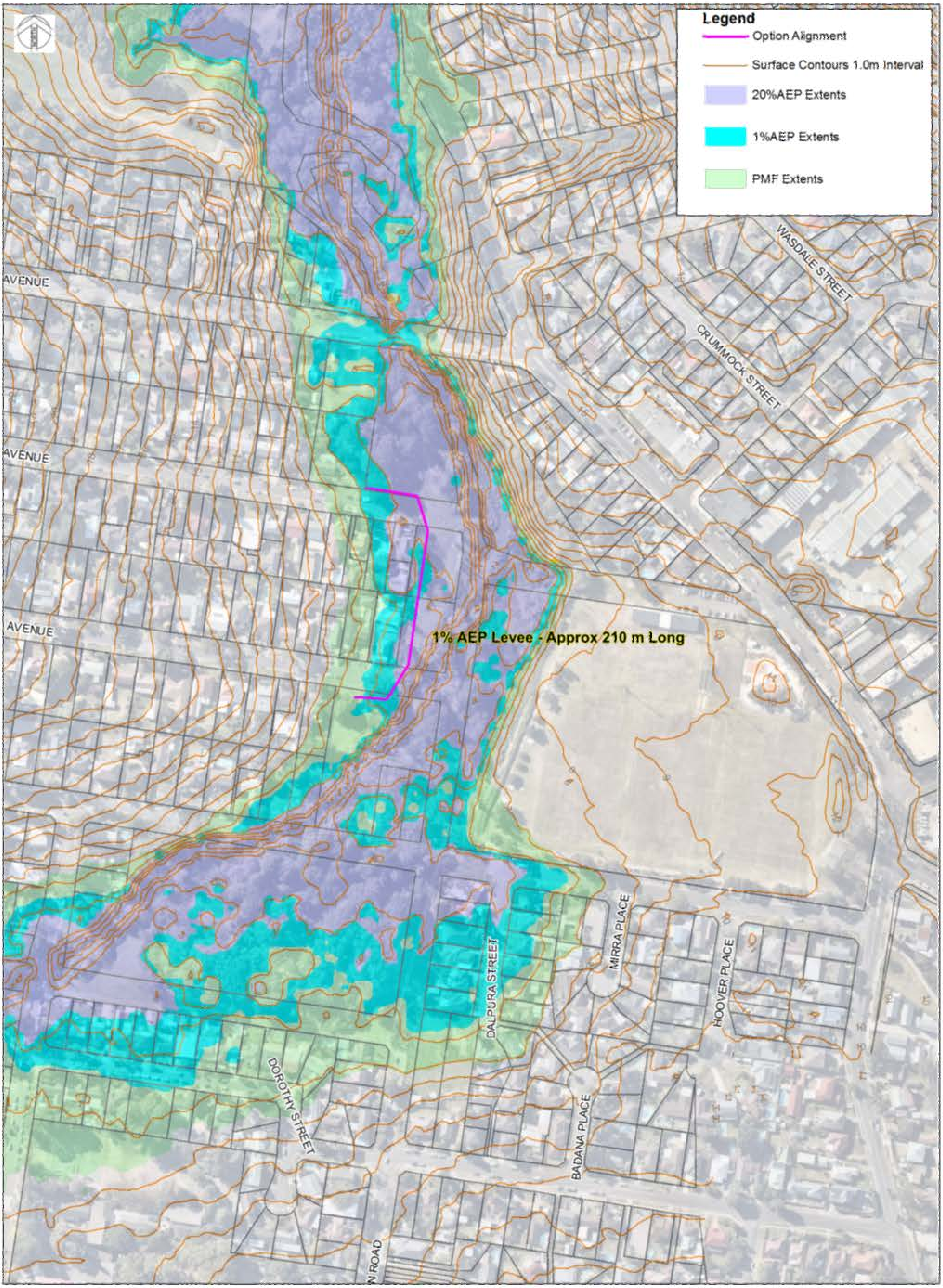
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale
0 100
metres

Figure B9b
Option FM9 - Waroon Road Levee
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB9bb.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

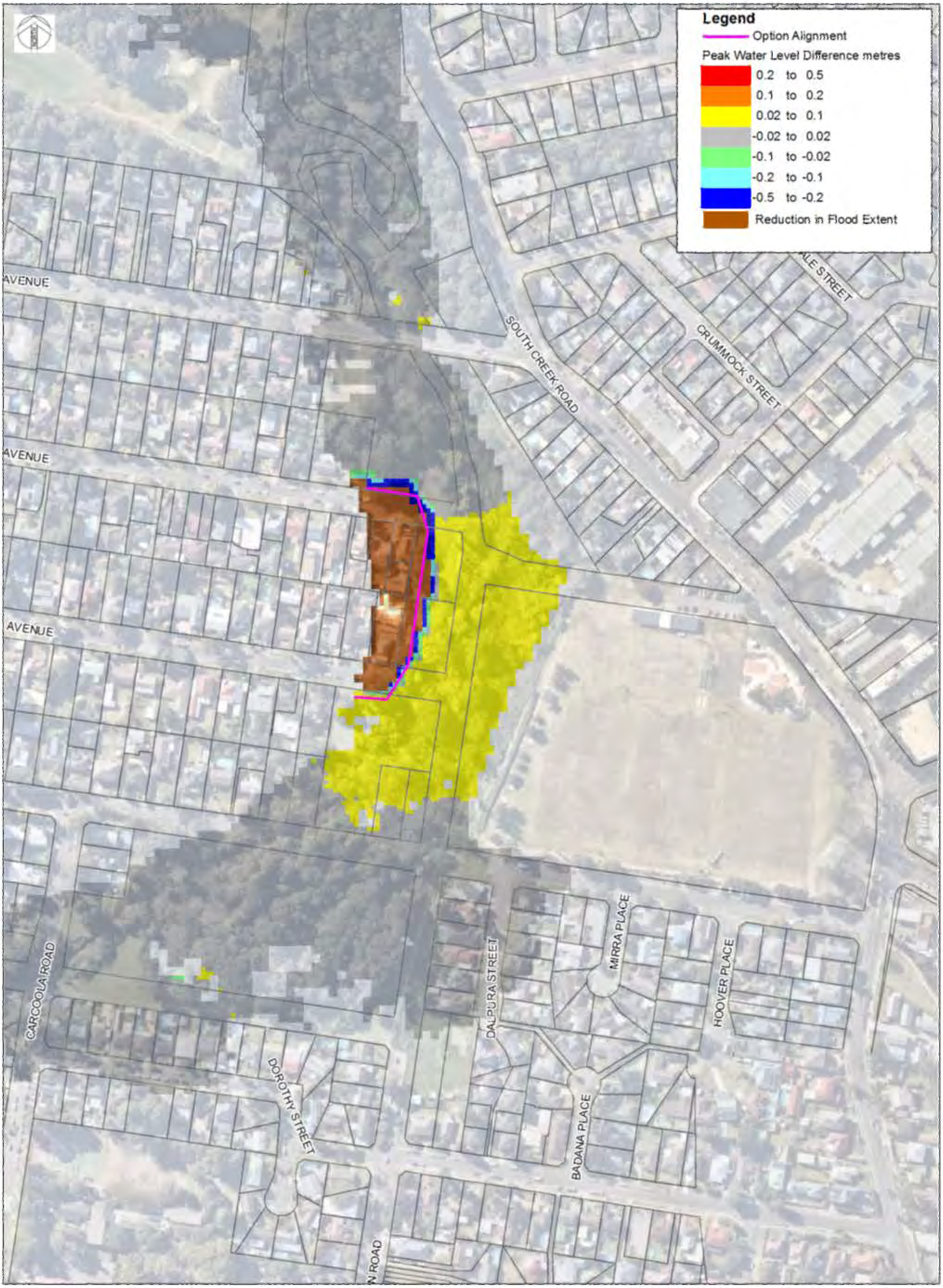
Scale 0 100 metres

Figure B10a

Option FM10 - Wabash Ave Levee Layout

Narrabeen Lagoon Floodplain Risk Management Study and Plan

FigureB10a.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 100 metres

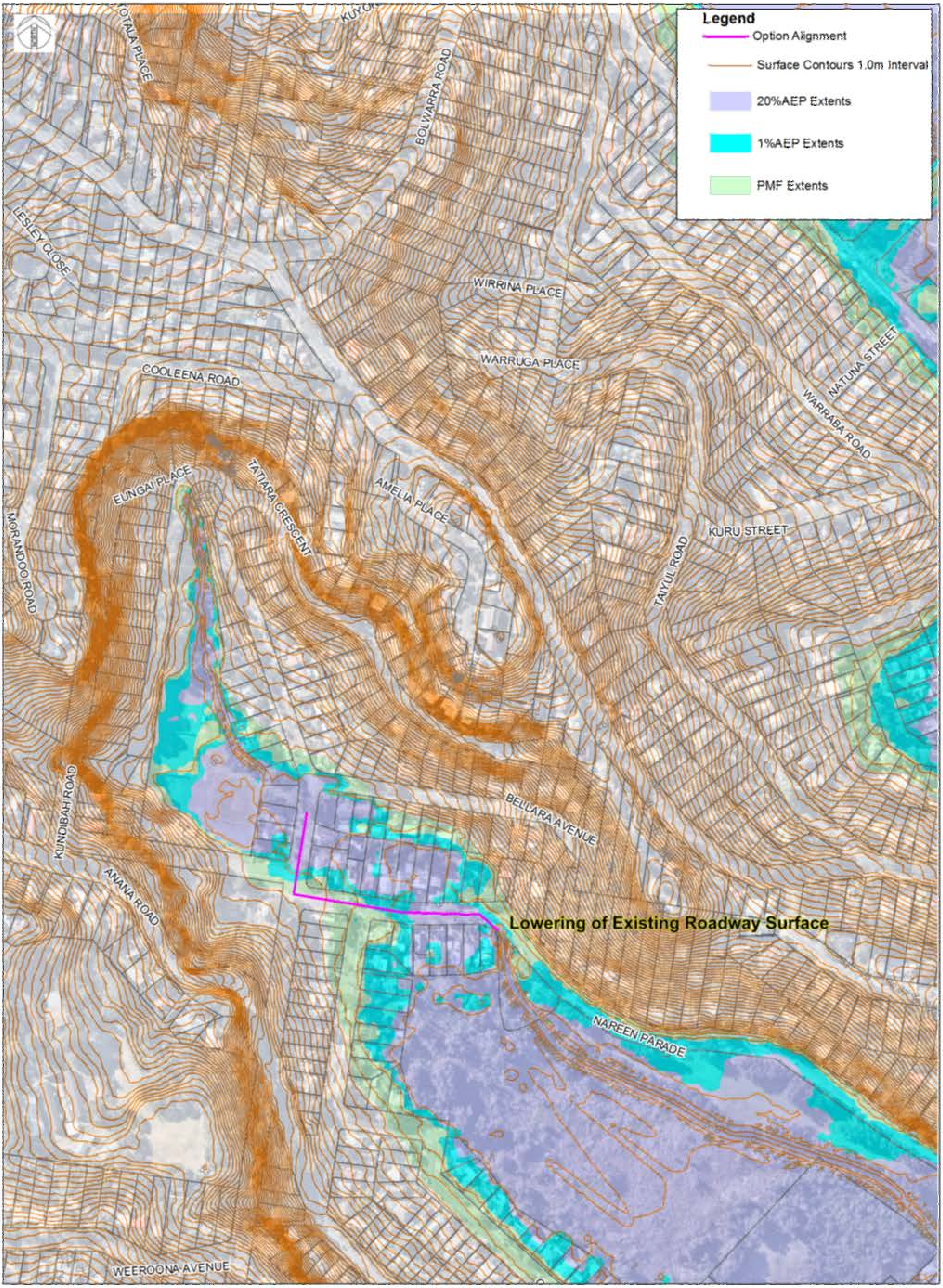
Figure B10b

Option FM10 - Wabash Ave Levee

1% AEP Mitigation Difference Plot

Narrabeen Lagoon Floodplain Risk Management Study and Plan

FigureB10b.wor R2

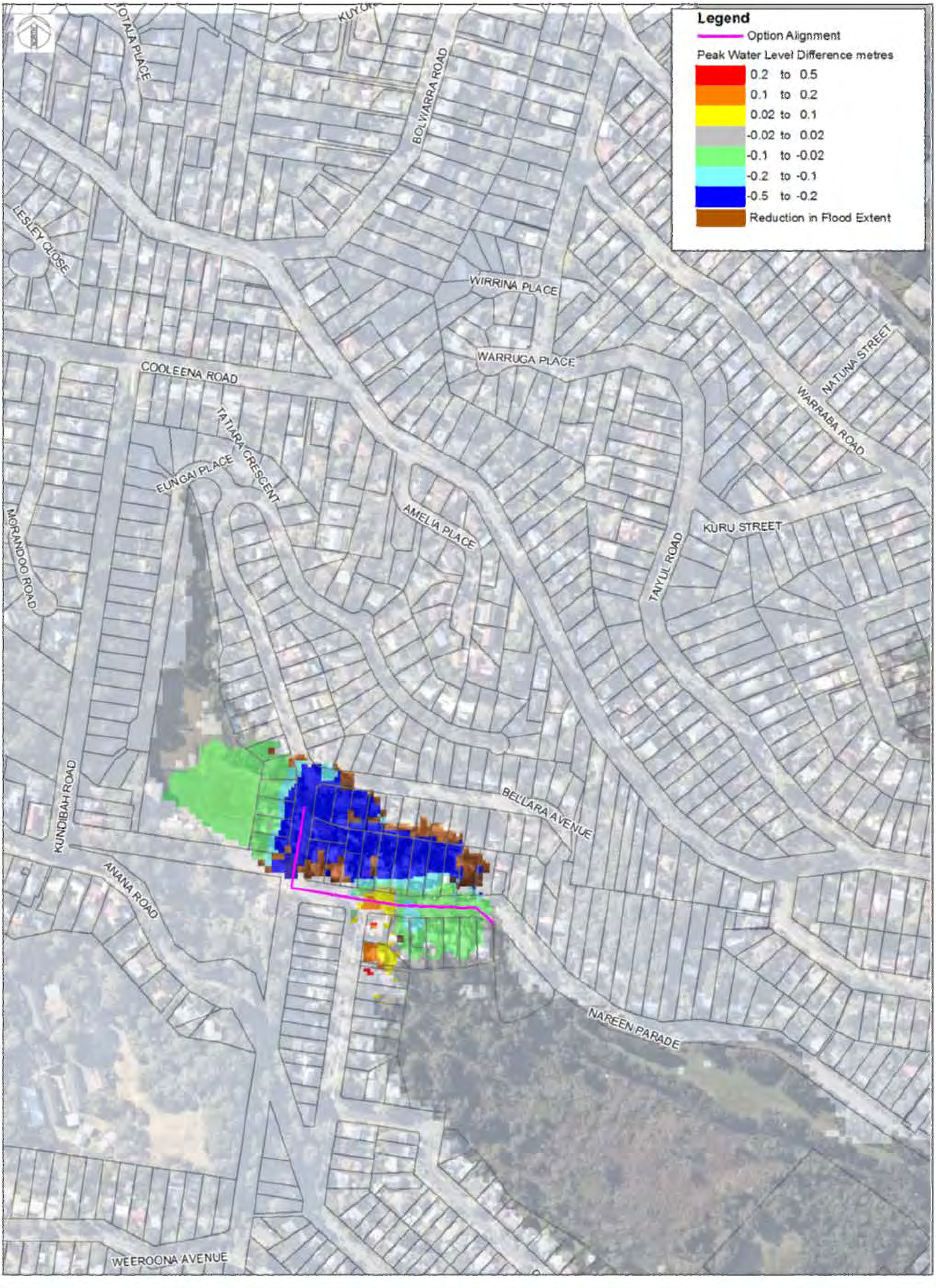


Date
November 2017

Size
A3

Scale 0 100 metres

Figure B11a
Option FM11 - Tatiara By-Pass
Layout
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB11a.wor R2



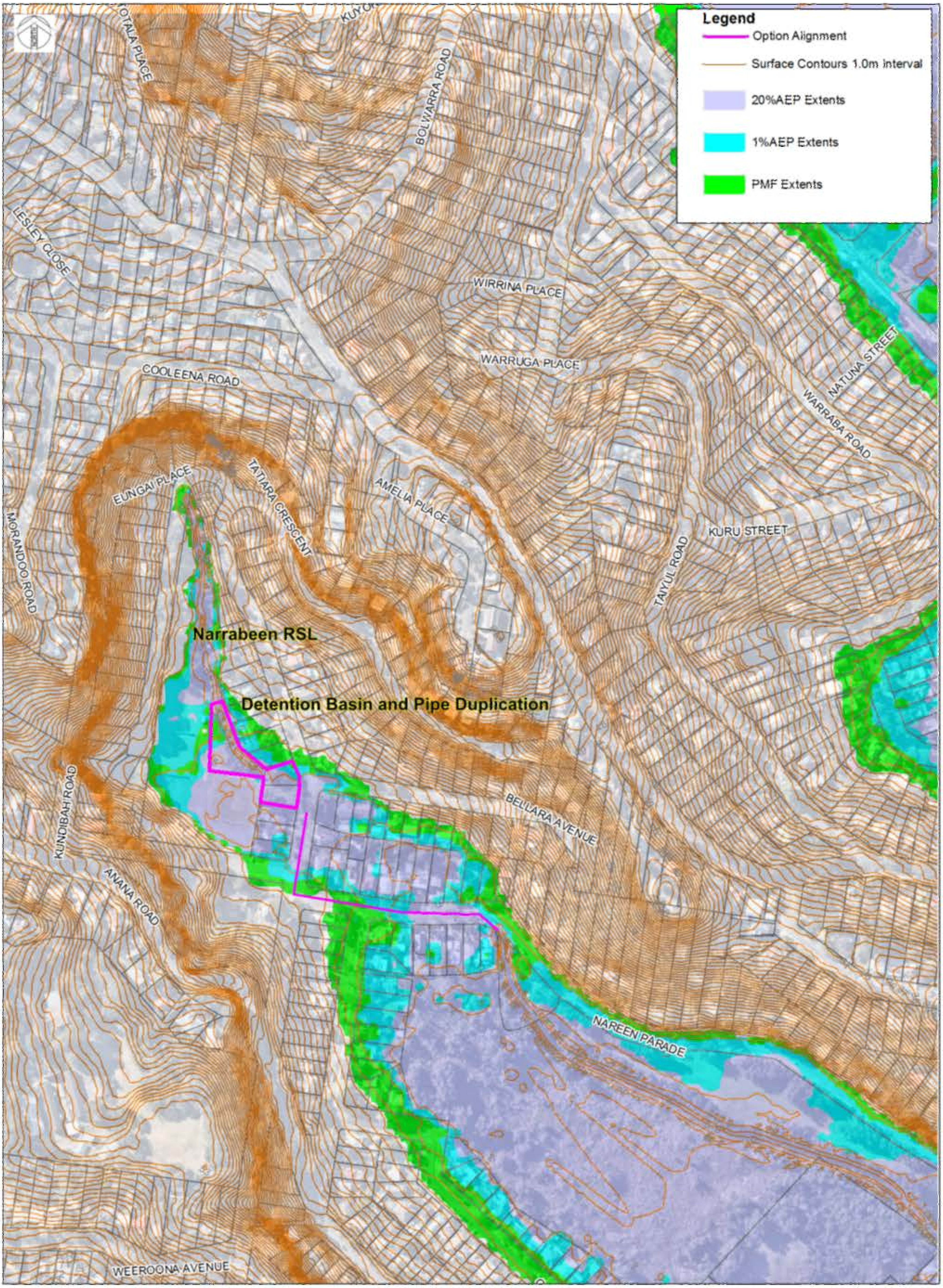
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 100 metres

Figure B11b
Option FM11 - Tatiara By-Pass
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB11b.wor R2



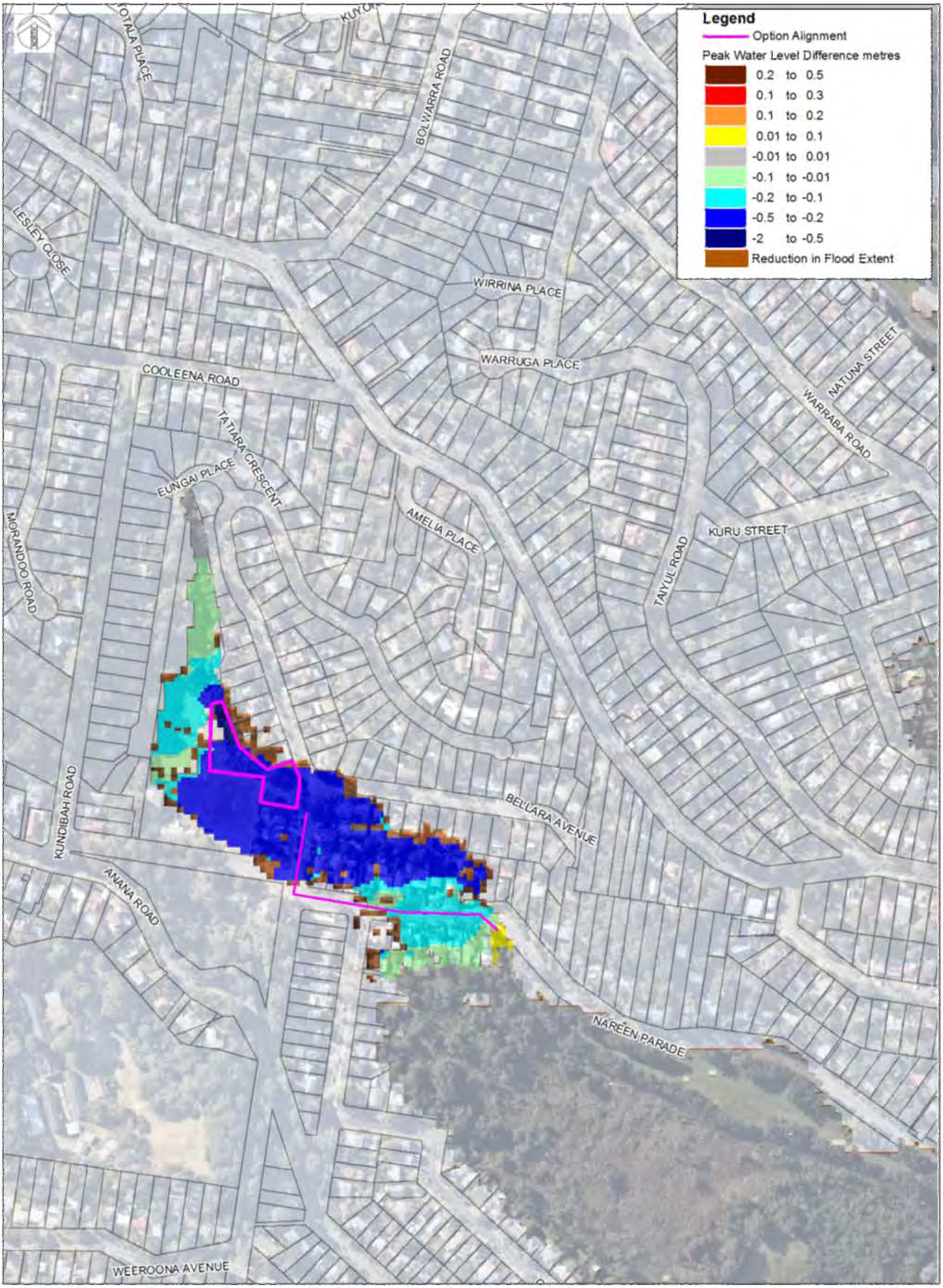
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale
0 100
metres

Figure B12a
Option FM12 - Basin at Narrabeen RSL
Layout
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB12a.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale
0 100
metres

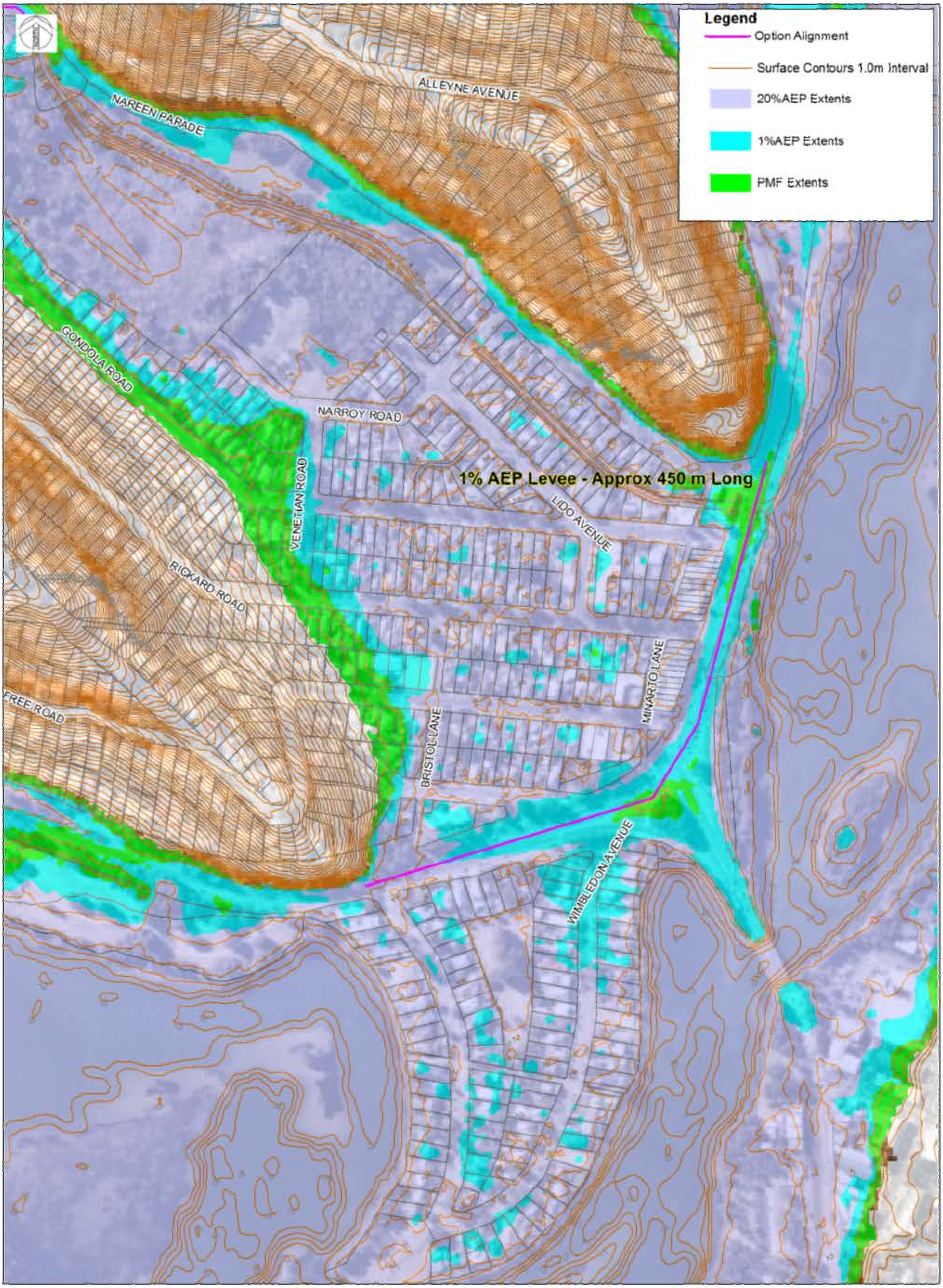
Figure B12b

Option FM12 - Basin at Narrabeen RSL

1% AEP Mitigation Difference Plot

Narrabeen Lagoon Floodplain Risk Management Study and Plan

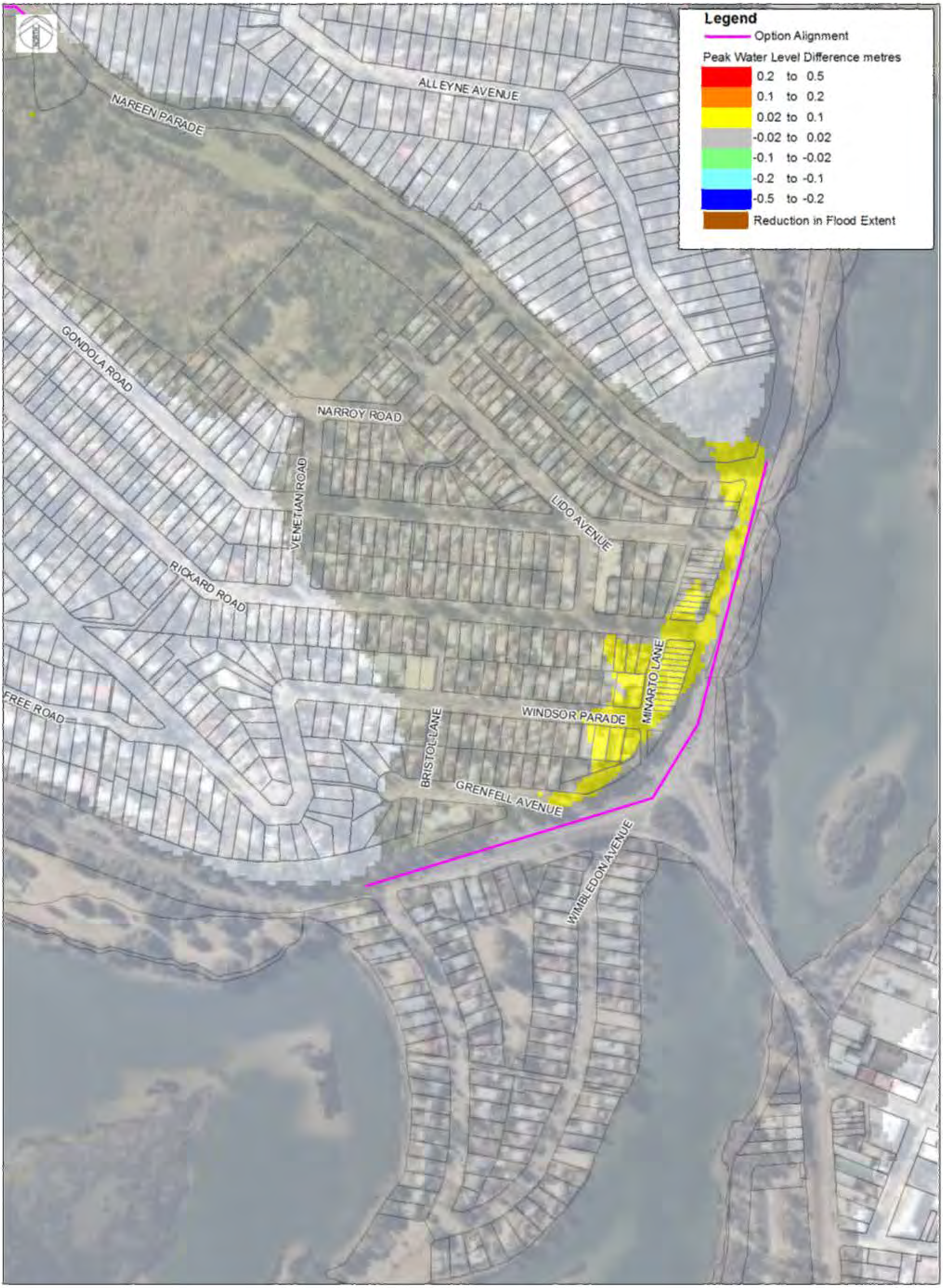
FigureB12b.wor R2



Cardno
Shaping the Future

Date
November 2017
Size
A3
Scale
0 100
metres

Figure B13a
Option FM13 - Pitwater Rd Levee
Layout
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB13a.wor R2



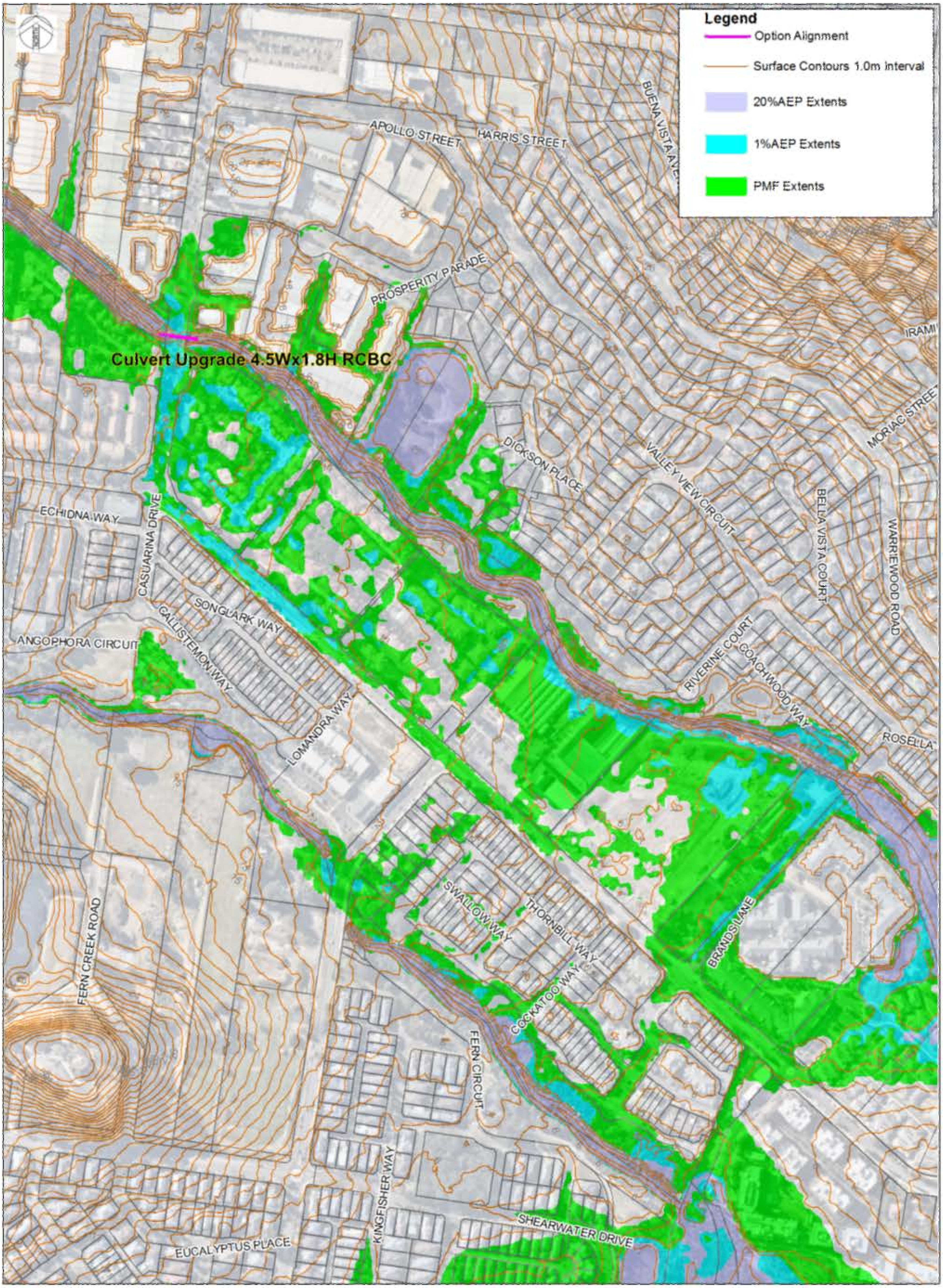
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 100 metres

Figure B13b
Option FM13 - Pitwater Rd Levee
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB13b.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

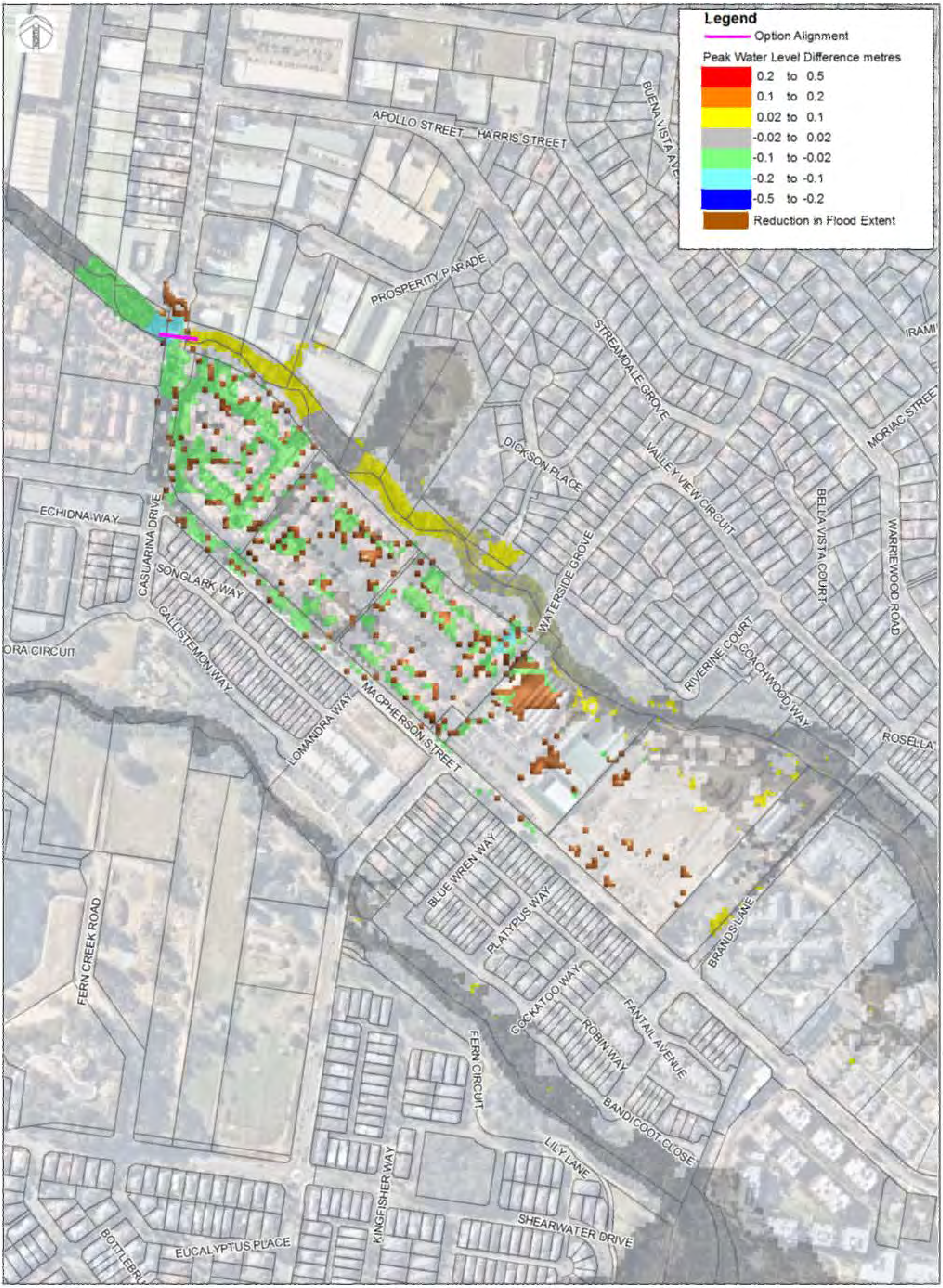
Scale 0 100 metres

Figure B14a

Option FM14 - Ponderose Pde Drainage Layout

Narrabeen Lagoon Floodplain Risk Management Study and Plan

FigureB14a.wor R2



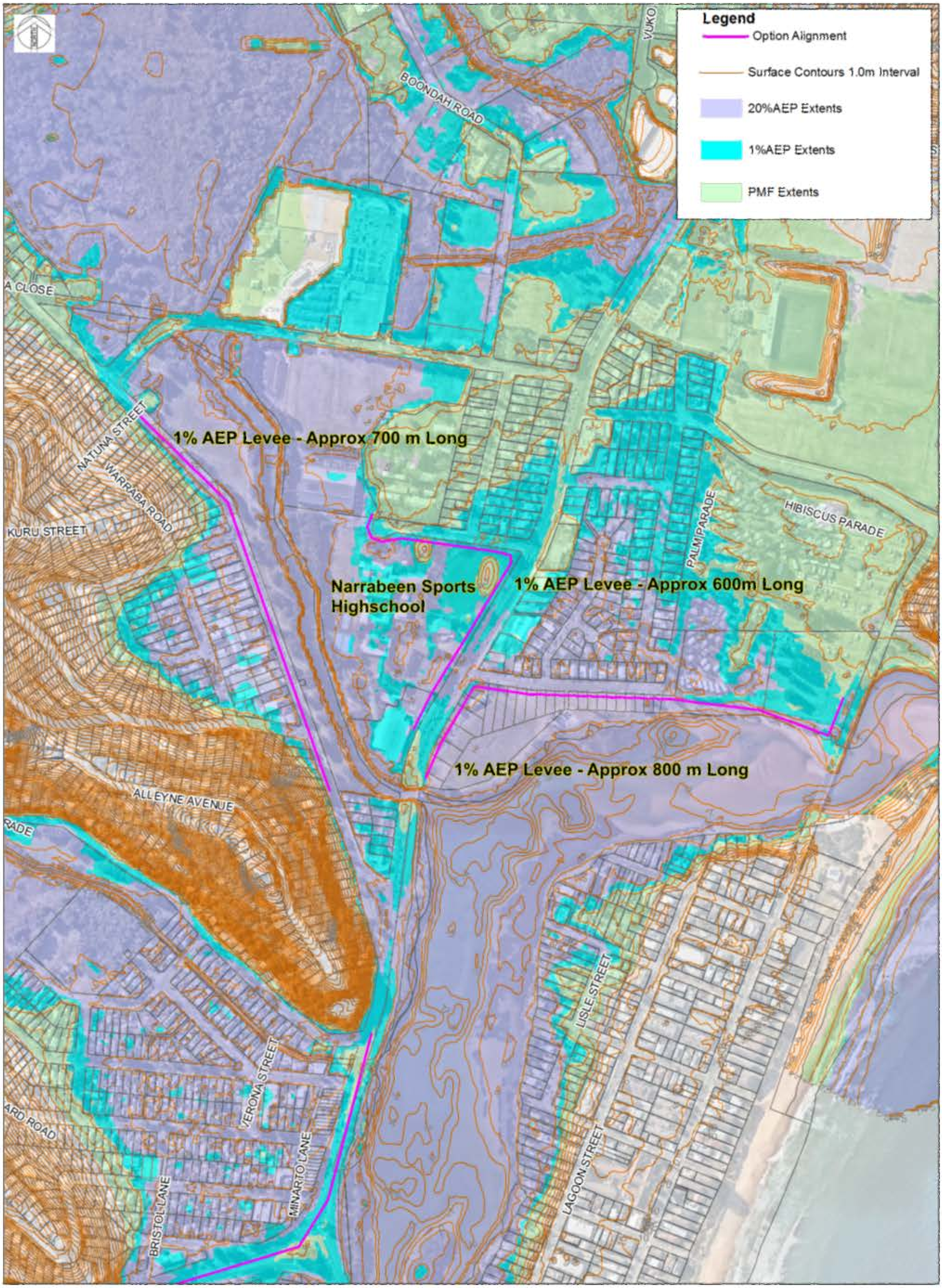
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 100
metres

Figure B14b
Option FM14 - Ponderose Pde Drainage
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB14b.wor R2



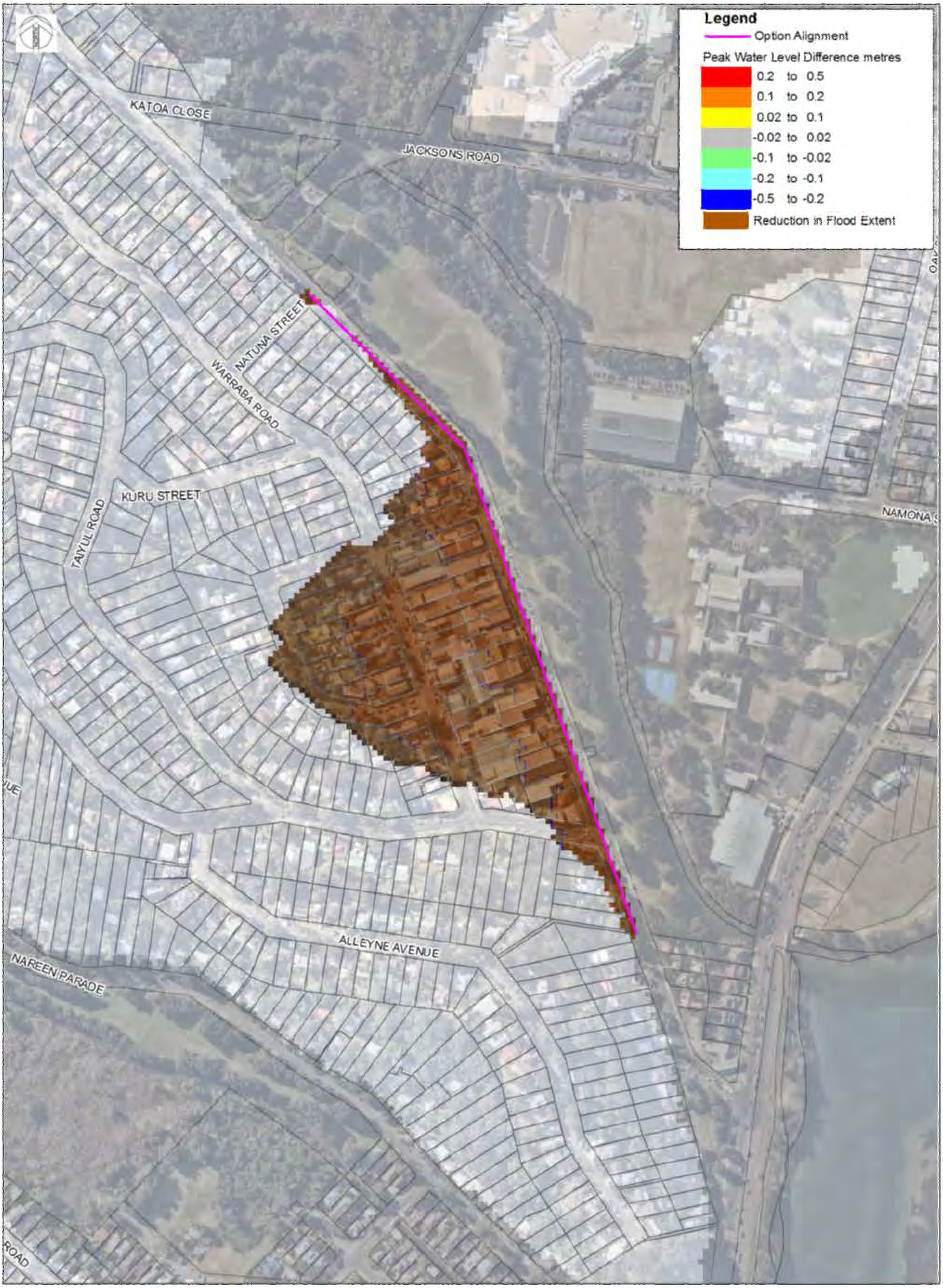
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale
0 150
metres

Figure B15a
Options FM15, FM16 & FM17
Layout
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB15a.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 100 metres

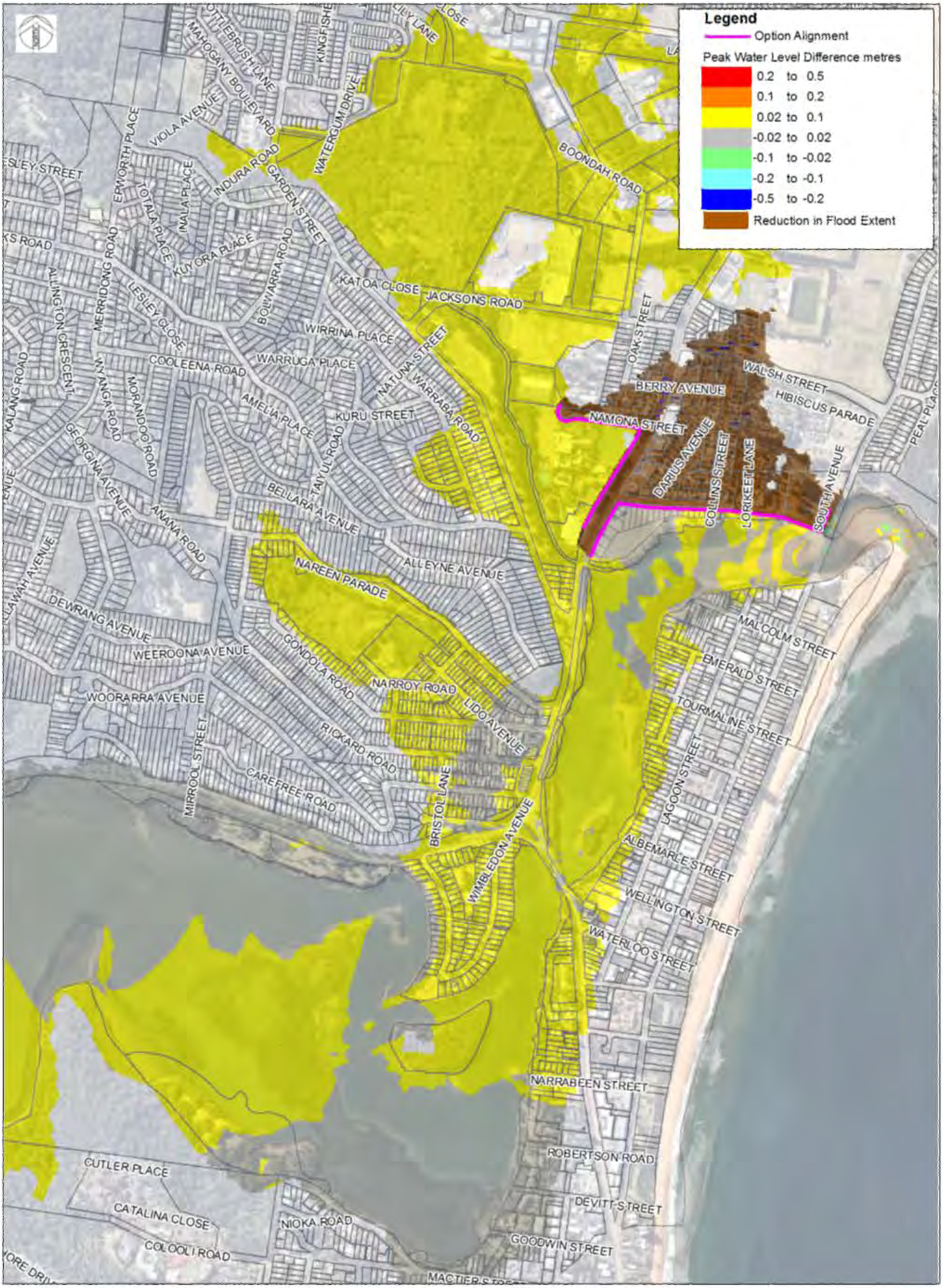
Figure B15b

Option FM15 - Garden Street Levee

1% AEP Mitigation Difference Plot

Narrabeen Lagoon Floodplain Risk Management Study and Plan

FigureB15b.wor R2



Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 300 metres

Figure B15c
Options FM16 & FM17
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB15c.wor R2

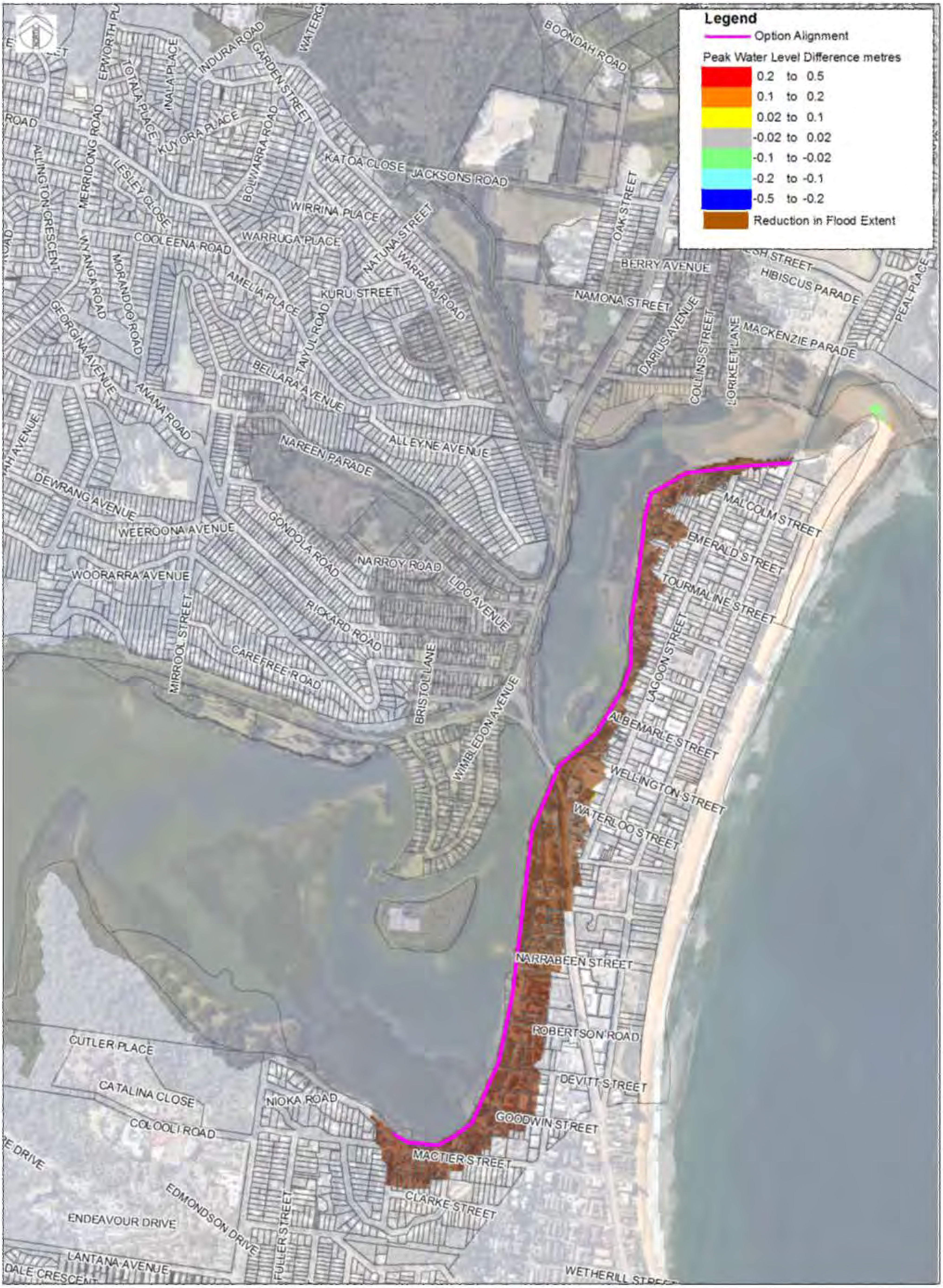
Cardno
Shaping the Future

Date
November 2017

Size
A3

Scale 0 300 metres

Figure B16a
Option FM18 - East Bank Levee
Layout
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB16a.wor R2



Cardno Shaping the Future

Date
November 2017

Size
A3

Scale 0 300 metres

Figure B16b
Option FM18 - East Bank Levee
1% AEP Mitigation Difference Plot
Narrabeen Lagoon Floodplain Risk Management Study and Plan
FigureB16b.wor R2

Narrabeen Lagoon Floodplain Risk Management Study and Plan

APPENDIX

C

COST BREAKDOWN

59915102 ‑ Narrabeen Lagoon FRMSP

FM1 ‑ Extension of the Existing Ocean Street Bridge to Edge of Lagoon
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**440,900**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	500	sq. m	10	5,000
2.2	Strip topsoil & stockpile for re‑use (assuming 150mm depth)	80	cu. m	25	2,000
2.3	Dispose of excess topsoil (nominal 10% allowance)	8	cu. m	60	480
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	460	sq.m	50	23,000
	SUBTOTAL				**30,480**
3.0	**EARTHWORKS**				
3.1	Removal and disposal of existing bridge abutment material	1	item	10000	10,000
3.2	Excavate embankment , including disposal / provision of cut	3900	cu. m	20	78,000
	SUBTOTAL				**88,000**
4.0	**BRIDGE CONSTRUCTION**				
4.1	Extend bridge with 42m span, single carriage bridge. Includes transitions to existing road, pedestrian footpath, railings, bridge abutments, erosion protection	630	sq. m	3500	2,205,000
4.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	110250	110,250
4.3	Relocation of services for major road	1	item	500000	500,000
	SUBTOTAL				**2,815,250**
5.0	**MINOR LANDSCAPING**				
5.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	500	sq. m	10	5,000
	SUBTOTAL				**5,000**
	CONSTRUCTION SUB‑TOTAL				**3,379,630**
6.0	**CONTINGENCIES**				
6.1	50% construction cost				**1,689,800**
	TOTAL, excluding GST				**5,069,430**
	TOTAL, rounded				**5,070,000**
	GST				**507,000**
	TOTAL, including GST				**5,577,000**

DISCLAIMER:

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NOTES:

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2. Nominal allowance for movement of existing services allowed under any disturbed roads
3. Estimate / rates in 2015 dollars

59915102 - Narrabeen Lagoon FRMSP

FM2 - Reconstruction of Ocean Street Bridge to be above the 1% AEP Flood Level
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**1,783,000**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	500	sq. m	10	5,000
2.2	Strip topsoil & stockpile for re-use (assuming 150mm depth)	80	cu. m	25	2,000
2.3	Dispose of excess topsoil (nominal 10% allowance)	8	cu. m	60	480
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	2070	sq. m	50	103,500
	SUBTOTAL				**110,980**
3.0	**EARTHWORKS**				
3.1	Remove existing bridge, including disposal	630	sq. m	500	315,000
3.2	Removal and disposal of existing bridge abutment material	1	item	10000	10,000
3.3	Excavate embankment , including disposal / provision of cut	3900	cu. m	20	78,000
	SUBTOTAL				**403,000**
4.0	**BRIDGE CONSTRUCTION**				
4.1	Provide 138m long, single carriage drawbridge. Includes transitions to existing road, pedestrian footpath, railings, bridge abutments, erosion protection	2070	sq. m	5000	10,350,000
4.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	517500	517,500
4.3	Relocation of services for major road	1	item	500000	500,000
	SUBTOTAL				**11,367,500**
5.0	**MINOR LANDSCAPING**				
5.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	500	sq. m	10	5,000
	SUBTOTAL				**5,000**
	CONSTRUCTION SUB-TOTAL				**13,669,480**
6.0	**CONTINGENCIES**				
6.1	50% construction cost				**6,834,740**
	TOTAL, excluding GST				**20,504,220**
	TOTAL, rounded				**20,505,000**
	GST				**2,050,500**
	TOTAL, including GST				**22,555,500**

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NOTES:

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3. Estimate / rates in 2015 dollars

59915102 - Narrabeen Lagoon FRMSP

FM3 - Entrance Bed Rock Removal
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**1,500,800**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Bed rock removal (blasting) and disposal of blasted material	20,000	cu. m	500	10,000,000
	SUBTOTAL				**10,000,000**
3.0	**MINOR LANDSCAPING**				
3.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	500	sq. m	10	5,000
	SUBTOTAL				**5,000**
	CONSTRUCTION SUB-TOTAL				**11,505,800**
4.0	**CONTINGENCIES**				
4.1	50% construction cost				**5,752,900**
	TOTAL, excluding GST				**17,258,700**
	TOTAL, rounded				**17,259,000**
	GST				**1,725,900**
	TOTAL, including GST				**18,984,900**

DISCLAIMER:
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NOTES:
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2. Nominal allowance for movement of existing services allowed under any disturbed roads
3. Estimate / rates in 2015 dollars

59915102 - Narrabeen Lagoon FRMSP

FM4 - Dredging of entrance shoals upstream and downstream of the entrance bridge
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**126,000**
2.0	**DREDGING WORKS**				
2.1	Dredge tidal delta shoals and relocate to deposition area	42000	cu. m	20	840,000
	SUBTOTAL				**840,000**
	CONSTRUCTION SUB-TOTAL				**966,000**
3.0	**CONTINGENCIES**				
3.1	20% construction cost - Costs well understood based on previous works				**193,200**
	TOTAL, excluding GST				**1,159,200**
	TOTAL, rounded				**1,160,000**
	GST				**116,000**
	TOTAL, including GST				**1,276,000**

DISCLAIMER:
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NOTES:
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2. Nominal allowance for movement of existing services allowed under any disturbed roads
3. Estimate / rates in 2015 dollars

59915102 ‑ Narrabeen Lagoon FRMSP

FM4a ‑ Dry Earth Sand Winning with Beach Cut and Cover Pipeline
Cost Estimate ‑ Based on MHL Report Updated for CPI

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**Dry Earth Sand Winning with Beach Cut and Cover Pipeline**				
1.1	Dry Earth Sand Winning with Beach Cut and Cover Pipeline	1	item	1467900	1,467,900
1.2	Hopper and Sled	1	item	174750	174,750
1.3	Site Establishment	1	item	17475	17,475
1.4	Set Out	1	item	5825	5,825
1.5	Environmental Management	1	item	17475	17,475
1.6	Pumping Stations	1	item	291250	291,250
1.7	Sand Winning and Pumping	1	item	152615	152,615
1.8	Sand Placement	1	item	76890	76,890
1.9	Compliance Surveys	1	item	5825	5,825
1.10	Site Disestablishment	1	item	17475	17,475
1.11	Additional Costs (Design, DA Prep, Contract Admin Etc)	1	item	398430	398,430
					2,625,910
	CONSTRUCTION SUB‑TOTAL				**2,625,910**
2.0	**CONTINGENCIES**				
2.1	50% construction cost				**1,312,955**
	TOTAL, excluding GST				**3,938,865**
	TOTAL, rounded				**3,939,000**
	GST				**393,900**
	TOTAL, including GST				**4,332,900**

DISCLAIMER:

1. This estimate of cost is provided in good faith using information available at this stage. This estimate of cost is not guaranteed. Cardno (NSW) will not accept liability in the event that actual costs exceed the estimate.

NOTES:

1. Nominal allowance for movement of existing services allowed under any disturbed roads
2. Estimate / rates in 2015 dollars

59915102 - Narrabeen Lagoon FRMSP

FM5 - Ocean Street Bridge Extension and Dredging of Upstream and Downstream Shoals
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**470,900**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	500	sq. m	10	5,000
2.2	Strip topsoil & stockpile for re-use (assuming 150mm depth)	80	cu. m	25	2,000
2.3	Dispose of excess topsoil (nominal 10% allowance)	8	cu. m	60	480
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	460	sq.m	50	23,000
	SUBTOTAL				**30,480**
3.0	**EARTHWORKS**				
3.1	Removal and disposal of existing bridge abutment material	1	item	10000	10,000
3.2	Excavate embankment , including disposal / provision of cut	3900	cu. m	20	78,000
3.3	Dredge tidal delta shoals west of entrance bridge	10000	cu. m	20	200,000
	SUBTOTAL				**288,000**
4.0	**BRIDGE CONSTRUCTION**				
4.1	Extend bridge with 42m span, single carriage bridge. Includes transitions to existing road, pedestrian footpath, railings, bridge abutments, erosion protection	630	sq. m	3500	2,205,000
4.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	110250	110,250
4.3	Relocation of services for major road	1	item	500000	500,000
	SUBTOTAL				**2,815,250**
5.0	**MINOR LANDSCAPING**				
5.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	500	sq. m	10	5,000
	SUBTOTAL				**5,000**
	CONSTRUCTION SUB-TOTAL				**3,609,630**
6.0	**CONTINGENCIES**				
6.1	50% construction cost				**1,804,815**
	TOTAL, excluding GST				**5,414,445**
	TOTAL, rounded				**5,415,000**
	GST				**541,500**
	TOTAL, including GST				**5,956,500**

DISCLAIMER:

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NOTES:

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2. Nominal allowance for movement of existing services allowed under any disturbed roads
3. Estimate / rates in 2015 dollars

59915102 ř Narrabeen Lagoon FRMSP

FM6 ř South Creek ř Alkira Circuit Drainage Upgrade
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**42,100**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	100	sq. m	10	1,000
2.2	Strip topsoil & stockpile for re-use (assuming 150mm depth)	15	cu. m	25	375
2.3	Dispose of excess topsoil (nominal 10% allowance)	1.5	cu. m	60	90
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	55	sq.m	50	2,750
2.5	Removal of existing culvert system	2	Item	5000	10,000
	SUBTOTAL				**14,215**
3.0	**DRAINAGE**				
3.1	Supply, excavate, bed, lay, joint, backfill and provide connections for 3.0m x 1.5m culvert	27	lin.m	5720	154,440
	SUBTOTAL				**154,440**
4.0	**MINOR LANDSCAPING**				
4.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	100	sq. m	10	1,000
	SUBTOTAL				**1,000**
5.0	**PAVEMENTS**				
5.1	Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing	55	sq. m	50	2,750
5.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	7859.5	7,860
5.3	Relocation of services for minor road	1	item	100000	100,000
	SUBTOTAL				**110,610**
	CONSTRUCTION SUB-TOTAL				**322,365**
7.0	**CONTINGENCIES**				
7.1	50% construction cost				**161,182**
	TOTAL, excluding GST				**483,547**
	TOTAL, rounded				**484,000**
	GST				**48,400**
	TOTAL, including GST				**532,400**

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NOTES:

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2. Nominal allowance for movement of existing services allowed under any disturbed roads
3. Estimate / rates in 2015 dollars

59915102 ĩ Narrabeen Lagoon FRMSP

FM7 ĩ South Creek ĩ Willandra Road Reserve Lowering
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**46,600**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	4,800	sq. m	10	48,000
2.2	Strip topsoil & stockpile for re2use (assuming 150mm depth)	720	cu. m	25	18,000
2.3	Dispose of excess topsoil (nominal 10% allowance)	72	cu. m	60	4,320
	SUBTOTAL				**70,320**
3.0	**EARTHWORKS**				
3.1	Excavate reserve 2cut / fill & regrade to suit new design levels, including disposal / provision of cut / fill	9600	cu. m	20	192,000
	SUBTOTAL				**192,000**
5.0	**MINOR LANDSCAPING**				
5.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	4,800	sq. m	10	48,000
	SUBTOTAL				**48,000**
	CONSTRUCTION SUBĩTOTAL				**356,920**
7.0	**CONTINGENCIES**				
7.1	50% construction cost				**178,460**
	TOTAL, excluding GST				**535,380**
	TOTAL, rounded				**536,000**
	GST				**53,600**
	TOTAL, including GST				**589,600**

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NOTES:

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3. Estimate / rates in 2015 dollars

59915102 – Narrabeen Lagoon FRMSP

FM8 – South Creek – Willandra Road Channel Vegetation Clearing and Drainage Upgrade
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**82,400**
2.0	**DEMOLITION, CLEARING AND WEEDING**				
2.1	Clearing & grubbing	680	sq. m	10	6,800
2.2	Strip topsoil & stockpile for re-use (assuming 150mm depth)	102	cu. m	25	2,550
2.3	Dispose of excess topsoil (nominal 10% allowance)	10.2	cu. m	60	612
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	165	sq.m	50	8,250
2.5	Removal of trees and debris from within channel (nominal cost)	1	item	25,000	25,000
2.6	Weeding / clearing of channel sections with overgrown banks or invasive / exotic species.	3400	sq.m	30	102,000
	SUBTOTAL				**145,212**
4.0	**DRAINAGE**				
4.1	Supply, excavate, bed, lay, joint, backfill and provide connections for 3.0m x 1.5m culvert	48	lin.m	5720	274,560
	SUBTOTAL				**274,560**
5.0	**MINOR LANDSCAPING**				
5.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	680	sq. m	10	6,800
	SUBTOTAL				**6,800**
6.0	**PAVEMENTS**				
6.1	Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing	165	sq. m	50	8,250
6.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	14140.5	14,141
6.3	Relocation of services for minor road	1	item	100000	100,000
	SUBTOTAL				**122,391**
	CONSTRUCTION SUB-TOTAL				**631,363**
5.0	**CONTINGENCIES**				
5.1	50% construction cost				**315,681**
	TOTAL, excluding GST				**947,044**
	TOTAL, rounded				**948,000**
	GST				**94,800**
	TOTAL, including GST				**1,042,800**

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NOTES:

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3. Estimate / rates in 2015 dollars

59915102 – Narrabeen Lagoon FRMSP

FM9 – South Creek – Waroon Road Levee
Cost Estimate

Cardno
Shaping the Future

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**16,100**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	2,560	sq. m	10	25,600
2.2	Strip topsoil & stockpile for re-use (assuming 150mm depth)	384	cu. m	25	9,600
2.3	Dispose of excess topsoil (nominal 10% allowance)	38.4	cu. m	60	2,304
	SUBTOTAL				**37,504**
3.0	**EARTHWORKS**				
3.1	Import, prepare and compact fill material	2190	cu. m	20	43,800
	SUBTOTAL				**43,800**
4.0	**MINOR LANDSCAPING**				
4.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	2,560	sq. m	10	25,600
	SUBTOTAL				**25,600**
	CONSTRUCTION SUB-TOTAL				**123,004**
5.0	**CONTINGENCIES**				
5.1	50% construction cost				**61,502**
	TOTAL, excluding GST				**184,506**
	TOTAL, rounded				**185,000**
	GST				**18,500**
	TOTAL, including GST				**203,500**

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3. Estimate / rates in 2015 dollars

59915102 ĩ Narrabeen Lagoon FRMSP

FM10 ĩ South Creek ĩ Wabash Avenue Levee
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**26,900**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	4,090	sq. m	10	40,900
2.2	Strip topsoil & stockpile for re2use (assuming 150mm depth)	613.5	cu. m	25	15,338
2.3	Dispose of excess topsoil (nominal 10% allowance)	61.35	cu. m	60	3,681
	SUBTOTAL				**59,919**
3.0	**EARTHWORKS**				
3.1	Import, prepare and compact fill material	3900	cu. m	20	78,000
	SUBTOTAL				**78,000**
4.0	**MINOR LANDSCAPING**				
4.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	4,090	sq. m	10	40,900
	SUBTOTAL				**40,900**
	CONSTRUCTION SUBĩTOTAL				**205,719**
5.0	**CONTINGENCIES**				
5.1	50% construction cost				**102,859**
	TOTAL, excluding GST				**308,578**
	TOTAL, rounded				**309,000**
	GST				**30,900**
	TOTAL, including GST				**339,900**

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3. Estimate / rates in 2015 dollars

59915102 – Narrabeen Lagoon FRMSP

FM11 – Nareen Creek – Tatiara By-pass Overland Flowpath
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**59,000**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	2080	sq.m	50	104,000
	SUBTOTAL				**104,000**
3.0	**EARTHWORKS**				
3.1	Excavate reserve 3cut / fill & regrade to suit new design levels, including disposal / provision of cut / fill	4000	cu. m	20	80,000
	SUBTOTAL				**80,000**
4.0	**PAVEMENTS**				
4.1	Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing	2,080	sq. m	50	104,000
4.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	5200	5,200
4.3	Relocation of services for minor road	1	item	100000	100,000
	SUBTOTAL				**209,200**
	CONSTRUCTION SUB-TOTAL				**452,200**
6.0	**CONTINGENCIES**				
6.1	50% construction cost				**226,100**
	TOTAL, excluding GST				**678,300**
	TOTAL, rounded				**679,000**
	GST				**67,900**
	TOTAL, including GST				**746,900**

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3. Estimate / rates in 2015 dollars

59915102 ř Narrabeen Lagoon FRMSP

FM12 ř Nareen Creek ř Basin at Narrabeen RSL, Pipe Diversion along Tatiara Cres and Nareen Parade
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**300,400**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	3,140	sq. m	10	31,400
2.2	Strip topsoil & stockpile for re-use (assuming 150mm depth)	480	cu. m	25	12,000
2.3	Dispose of excess topsoil (nominal 10% allowance)	48	cu. m	60	2,880
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	945	sq.m	50	47,250
	SUBTOTAL				**93,530**
3.0	**EARTHWORKS**				
3.1	Excavate basin - cut / fill & regrade to suit new design levels, including disposal / provision of cut / fill	4320	cu. m	20	86,400
	SUBTOTAL				**86,400**
4.0	**DETENTION BASIN DRAINAGE**				
4.1	Instal entry and exit weirs, construct drainage and connect to existing network (nominal cost)	4	item	5000	20,000
	SUBTOTAL				**20,000**
5.0	**DRAINAGE**				
5.1	Supply, excavate, bed, lay, joint, backfill and provide connections for 3.0m x 1.5m culvert	270	lin.m	5720	1,544,400
	SUBTOTAL				**1,544,400**
6.0	**PAVEMENTS/LANDSCAPING**				
6.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	3,140	sq. m	10	31,400
6.2	Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing	945	sq. m	50	47,250
6.3	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	79582.5	79,583
6.4	Relocation of services for minor road	1	item	100000	100,000
	SUBTOTAL				**258,233**
	CONSTRUCTION SUB-TOTAL				**2,302,963**
7.0	**CONTINGENCIES**				
7.1	50% construction cost				1,151,481
5.2	Acquisition of land for basin	3,140	sq. m	1000	3,140,000
	SUBTOTAL				**4,291,481**
	TOTAL, excluding GST				**6,594,444**
	TOTAL, rounded				**6,595,000**
	GST				**659,500**
	TOTAL, including GST				**7,254,500**

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3. Estimate / rates in 2015 dollars

59915102 ř Narrabeen Lagoon FRMSP

FM13 ř Nareen Creek ř Pittwater Road & Wakehurst Parkway Raising / Levee
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**320,100**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	4,500	sq. m	10	45,000
2.2	Strip topsoil & stockpile for re1use (assuming 150mm depth)	675	cu. m	25	16,875
2.3	Dispose of excess topsoil (nominal 10% allowance)	67.5	cu. m	60	4,050
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	10800	sq.m	50	540,000
	SUBTOTAL				**605,925**
3.0	**EARTHWORKS**				
3.1	Import, prepare and compact fill material for road base	7920	cu. m	50	396,000
	SUBTOTAL				**396,000**
4.0	**PAVEMENTS**				
4.1	Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing	10,800	sq. m	50	540,000
4.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	46800	46,800
4.3	Relocation of services for major road	1	item	500000	500,000
	SUBTOTAL				**1,086,800**
5.0	**MINOR LANDSCAPING**				
5.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	4,500	sq. m	10	45,000
	SUBTOTAL				**45,000**
	CONSTRUCTION SUBřTOTAL				**2,453,825**
7.0	**CONTINGENCIES**				
7.1	50% construction cost				1,226,913
7.2	Modify property to ensure connectivity with raised road level while preserving visual amenity	38	per lot	200000	7,600,000
	SUBTOTAL				**8,826,913**
	TOTAL, excluding GST				**11,280,738**
	TOTAL, rounded				**11,281,000**
	GST				**1,128,100**
	TOTAL, including GST				**12,409,100**

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3. Estimate / rates in 2015 dollars

59915102 ‑ Narrabeen Lagoon FRMSP

FM14 ‑ Warriewood Valley ‑ Ponderosa Parade Drainage Upgrade
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**76,000**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	100	sq. m	10	1,000
2.2	Strip topsoil & stockpile for re‑use (assuming 150mm depth)	15	cu. m	25	375
2.3	Dispose of excess topsoil (nominal 10% allowance)	1.5	cu. m	60	90
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	77	sq.m	50	3,850
2.5	Removal of existing culvert system	1	Item	5000	5,000
	SUBTOTAL				**10,315**
3.0	**DRAINAGE**				
3.1	Supply, excavate, bed, lay, joint, backfill and provide connections for 4.5m x 1.8m culvert	25	lin.m	14900	372,500
	SUBTOTAL				**372,500**
4.0	**MINOR LANDSCAPING**				
4.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	100	sq. m	10	1,000
	SUBTOTAL				**1,000**
5.0	**PAVEMENTS**				
5.1	Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing	77	sq. m	50	3,850
5.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	18817.5	18,818
5.3	Relocation of services for minor road	1	item	100000	100,000
	SUBTOTAL				**122,668**
	CONSTRUCTION SUB‑TOTAL				**582,483**
6.0	**CONTINGENCIES**				
6.1	50% construction cost				**291,241**
	TOTAL, excluding GST				**873,724**
	TOTAL, rounded				**874,000**
	GST				**87,400**
	TOTAL, including GST				**961,400**

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3. Estimate / rates in 2015 dollars

59915102 ř Narrabeen Lagoon FRMSP

FM15 ř Warriewood Valley ř Garden Street Levee
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**126,700**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	13,620	sq. m	10	136,200
2.2	Strip topsoil & stockpile for re2use (assuming 150mm depth)	2043	cu. m	25	51,075
2.3	Dispose of excess topsoil (nominal 10% allowance)	204.3	cu. m	60	12,258
2.4	Pull up and dispose existing road surface (assuming 500mm depth)	1320	sq.m	50	66,000
	SUBTOTAL				**265,533**
3.0	**EARTHWORKS**				
3.1	Import, prepare and compact fill material	13000	cu. m	20	260,000
	SUBTOTAL				**260,000**
4.0	**PAVEMENTS**				
4.1	Reinstate disturbed road pavement, including demolition and disposal of additional material to provide good jointing	1,320	sq. m	50	66,000
4.2	Traffic control for duration of works (assumed 5% of roadworks cost)	1	item	16300	16,300
4.3	Relocation of services for minor road	1	item	100000	100,000
	SUBTOTAL				**182,300**
5.0	**MINOR LANDSCAPING**				
5.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	13,620	sq. m	10	136,200
	SUBTOTAL				**136,200**
	CONSTRUCTION SUBřTOTAL				**970,733**
6.0	**CONTINGENCIES**				
6.1	50% construction cost				485,367
6.2	Modify property to ensure connectivity with raised road level while preserving visual amenity	8	per lot	200000	1,600,000
	SUBTOTAL				**2,085,367**
	TOTAL, excluding GST				**3,056,100**
	TOTAL, rounded				**3,057,000**
	GST				**305,700**
	TOTAL, including GST				**3,362,700**

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3. Estimate / rates in 2015 dollars

59915102 ř Narrabeen Lagoon FRMSP

FM16 & FM17 ř Warriewood Valley ř Lakeside and Pittwater Road Levees
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**101,300**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	17,500	sq. m	10	175,000
2.2	Strip topsoil & stockpile for re2use (assuming 150mm depth)	2,625	cu. m	25	65,625
2.3	Dispose of excess topsoil (nominal 10% allowance)	263	cu. m	60	15,750
	SUBTOTAL				**256,375**
3.0	**EARTHWORKS**				
3.1	Import, prepare and compact fill material	12,190	cu. m	20	243,800
	SUBTOTAL				**243,800**
4.0	**MINOR LANDSCAPING**				
4.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	17,500	sq. m	10	175,000
	SUBTOTAL				**175,000**
	CONSTRUCTION SUBřTOTAL				**776,475**
5.0	**CONTINGENCIES**				
5.1	50% construction cost				388,288
5.2	Acquisition of land for levee	17,500	sq. m	1000	17,500,000
	SUBTOTAL				**17,888,288**
	TOTAL, excluding GST				**18,664,763**
	TOTAL, rounded				**18,665,000**
	GST				**1,866,500**
	TOTAL, including GST				**20,531,500**

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3. Estimate / rates in 2015 dollars

59915102 ř Narrabeen Lagoon FRMSP

Cardno
Shaping the Future

FM18 ř Narrabeen Lagoon ř East Bank Levee
Cost Estimate

v1

ITEM NO.	DESCRIPTION OF WORK	QUANTITY	UNIT	RATE	COST
1.0	**GENERAL AND PRELIMINARIES**				
1.1	Site establishment, security fencing, facilities & disestablishment	1	item		
1.2	Provision of sediment & erosion control	1	item		
1.3	Construction setout & survey	1	item		
1.4	Work as executed survey & documentation	1	item		
1.5	Geotechnical supervision, testing & certification	1	item		
	SUBTOTAL (Assumed as 15% of works cost)				**359,200**
2.0	**DEMOLITION, CLEARING AND GRUBBING**				
2.1	Clearing & grubbing	53,500	sq. m	10	535,000
2.2	Strip topsoil & stockpile for re1use (assuming 150mm depth)	8025	cu. m	25	200,625
2.3	Dispose of excess topsoil (nominal 10% allowance)	802.5	cu. m	60	48,150
	SUBTOTAL				**783,775**
3.0	**EARTHWORKS**				
3.1	Import, prepare and compact fill material	53780	cu. m	20	1,075,600
	SUBTOTAL				**1,075,600**
4.0	**MINOR LANDSCAPING**				
4.1	Repair disturbed bank areas in accordance with landscape architects requirements (nominal allowance)	53,500	sq. m	10	535,000
	SUBTOTAL				**535,000**
	CONSTRUCTION SUBřTOTAL				**2,753,575**
6.0	**CONTINGENCIES**				
5.1	50% construction cost				388,288
5.2	Acquisition of land for levee	53,500	sq. m	1000	53,500,000
	SUBTOTAL				**53,888,288**
	TOTAL, excluding GST				**56,641,863**
	TOTAL, rounded				**56,642,000**
	GST				**5,664,200**
	TOTAL, including GST				**62,306,200**

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3. Estimate / rates in 2015 dollars

APPENDIX

D

MULTI CRITERIA ASSESSMENT SUMMARY

ID	Description	Economic					Social					Environment			Score	Rank	Structral / Non-structural Rank
		Benefit Cost Ratio	Capital and Operating Costs	Reduction in Risk to Property	Feasibility	Protection of Vulnerable Development and Critical Infrastructure	Reduction in Risk to Life in PMF	Reduction in Risk to Life in 1% AEP Event	Reduction in Social Disruption	Community Support	Compatibility with Policies and Plans	Impact on Water Quality and Flows	Impact on Fauna/Flora	Disturbance of Acid Sulfate Soils			
FM1	Ocean Street Bridge Extension	-1	-1	2	0	1	0	1	1	0	1	0	0	1	1.13	13	S-8
FM2	Reconstruction of Ocean Street Bridge to be above the 1% AEP Flood Level	-2	-2	2	1	1	1	1	2	0	1	0	0	1	1.33	12	S-7
FM3	Entrance Bed Rock Removal	-1	-2	2	0	1	0	2	1	-2	-2	0	0	0	-0.20	23	S-17
FM4	Extraction of entrance shoals downstream of the entrance bridge	2	-1	2	2	2	0	2	2	2	2	0	0	0	3.00	1	S-1
FM4a	Dry Earth Sand Winning with Beach Cut and Cover Pipeline	2	-1	2	0	2	0	2	2	-2	0	-1	-1	0	0.73	17	S-11
FM5	Ocean Street Bridge Extension & Upstream Shoal Dredging	-1	-1	2	0	1	0	1	1	-2	-2	0	0	1	0.13	22	S-16
FM6	Alkira Circuit Drainage Upgrade	-1	1	1	2	1	1	1	2	2	2	0	0	0	2.40	4	S-4
FM7	Willandra Road Reserve Culvert Upgrade and Lowering / Detention Basin	-1	0	1	1	0	0	1	2	1	1	0	-1	-1	0.53	18	S-12
FM8	Willandra Road Culvert Upgrade and Vegetation Removal	-1	0	1	1	0	0	1	2	1	1	0	-1	-1	0.53	18	S-12
FM9	Waroon Road Levee	2	1	1	2	0	0	1	1	1	2	0	2	0	2.87	2	S-2
FM10	Wabash Avenue Levee	2	1	1	2	0	0	1	1	1	2	0	2	0	2.87	2	S-2
FM11	Taitara By-pass Overland Flowpath	2	0	2	1	0	0	1	2	1	1	0	0	-1	1.67	9	S-6
FM12	Basin at Narrabeen RSL, Pipe Diversion along Tatiara Cres and Nareen Parade to Open Channel	-1	-1	2	1	0	0	1	2	1	1	0	0	-1	0.87	16	S-10
FM13	Pittwater Road & Wakehurst Parkway Raising / Levee	-2	-2	-2	-2	0	-1	-1	-1	-2	-1	0	0	0	-2.80	24	S-18
FM14	Ponderosa Parade Drainage Upgrade	1	0	1	2	0	0	1	2	2	2	0	0	0	2.20	5	S-5
FM15	Garden Street Levee	2	-1	2	1	2	0	2	2	-2	-1	0	0	-1	1.07	14	S-9
FM16 and FM17	Pittwater Road Levee Bank and Lakeside Levee	-1	-2	2	1	2	0	2	2	-2	-1	0	0	-1	0.27	20	S-14
FM18	East Bank Levee	-1	-2	2	1	2	0	2	2	-2	-1	0	0	-1	0.27	20	S-14
EM1	Local Evacuation Measures	0	2	0	2	0	1	1	0	2	2	0	0	0	2.00	6	NS-1
EM2	Public awareness and education	0	2	0	2	0	1	1	0	2	2	0	0	0	2.00	6	NS-1
EM3	School Education Programs	0	2	0	2	0	1	1	0	1	1	0	0	0	1.60	10	NS-4
EM4	Flood Markers and Signage	0	2	0	2	0	1	1	0	0	1	0	0	0	1.40	11	NS-5
EM5	Flood Warning Systems	0	2	0	2	0	1	1	0	1	2	0	0	0	1.80	8	NS-3
FPL1	Flood Planning Level Revision	0	2	0	1	1	1	2	0	0	-2	0	0	0	1.00	15	NS-6

Narrabeen Lagoon Floodplain Risk Management Study and Plan

APPENDIX

E

ENTRANCE CLEARANCE OPTIONS

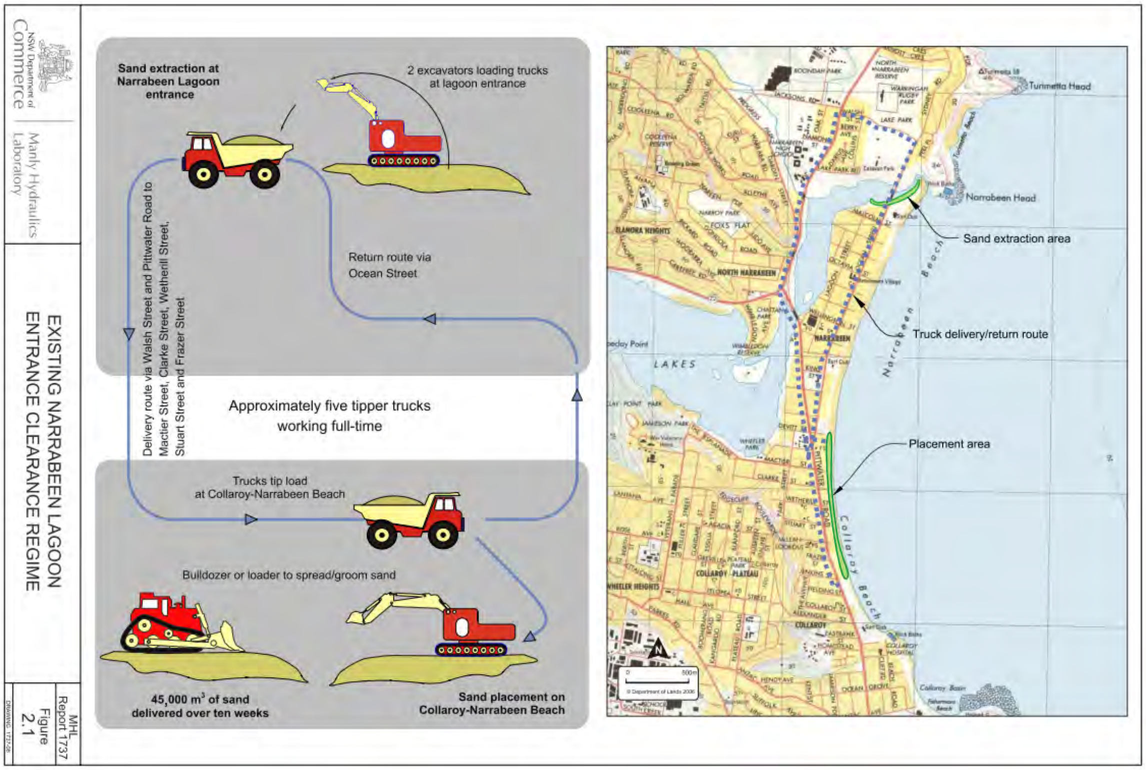
Cardno
Shaping the Future

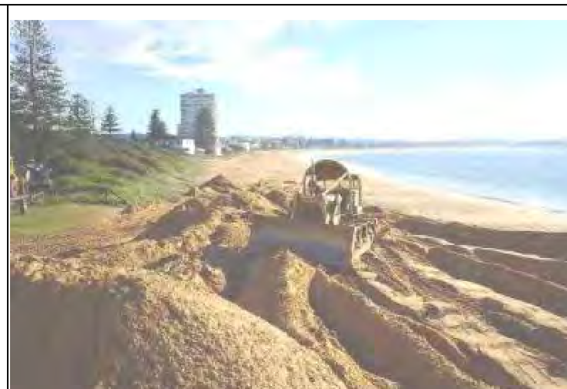
ENTRANCE CLEARANCE OPTIONS

Most of the material presented in this appendix was extracted from the investigation by MHL (2009) *Alternative Management Strategies for Clearing Narrabeen Lagoon Entrance*. That report examined the feasibility of six alternative options for the intermittent clearance of the entrance. Example photos and diagrams of some of the identified options and techniques in practice have been provided to assist in demonstrating what is involved with each option assessed.

> *Existing Clearance/Replenishment Method – Excavation and Trucking*

The existing clearance operation involves excavation via conventional earthmoving machinery followed by loading, transport and delivery of sand to Collaroy-Narrabeen beach via trucks. The sand is then placed and spread on Collaroy- Narrabeen Beach.



	
Sand extraction and transport via excavators and tip trucks	*Placement and spreading of sand at Collaroy-Narrabeen Beach*

Advantages and disadvantages of the existing operations undertaken to clear the entrance are listed in the table below.

ADVANTAGES	DISADVANTAGES
- Refined methods - Appreciation and knowledge of costs - Minimal approvals - Minimal impact/issues o Flora and fauna o Aboriginal Heritage o Subsurface Utilities	- Impacts to the public o beach access restrictions o noise of works o public safety o truck traffic, traffic disruption - High mobilisation and demobilisation costs

Six alternative options for management of the entrance were assessed by MHL (2009). These options utilised variations of mechanical pumping and placement, and transporting the sand via a pipeline. This is achieved by creating a sand-water slurry that can be pumped to Collaroy-Narrabeen Beach where it is redistributed with excavators.

The six alternative options for the intermittent clearance of the entrance were:

> Dry Earth Sand Winning with Directionally Drilled Pipeline;
> Dry Earth Sand Winning with Beach Cut and Cover Pipeline;
> Dry Earth Sand Winning with Pipeline on Beach;
> Dry Earth Sand Winning with Pipeline in Road Reserve;
> Slurrified Sand Winning with Pipeline on Beach; and
> Slurrified Sand Winning with Pipeline in Road Reserve.

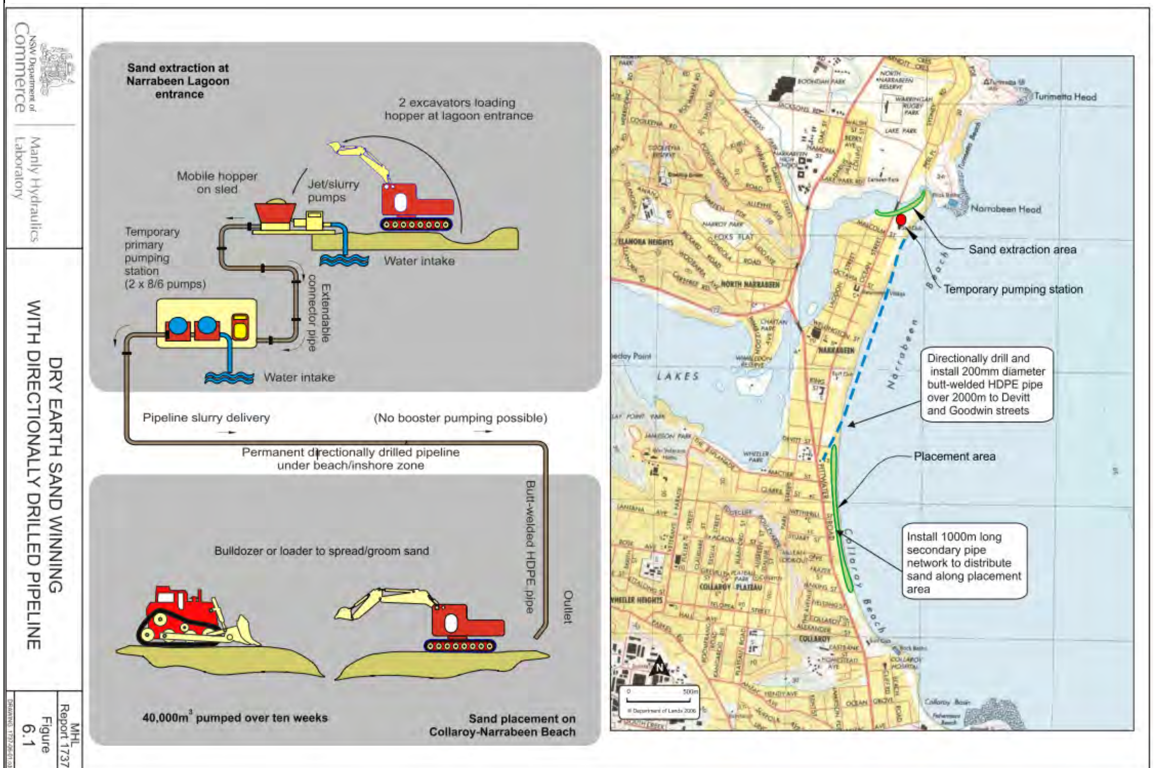
MHL considered the most favourable alternative to the present management strategy to be *Dry Earth Sand Winning with Beach Cut and Cover Pipeline.* The advantages and disadvantages of this option are listed in the following table.

ADVANTAGES	DISADVANTAGES
- Minimal impact/issues o Flora and fauna o Subsurface Utilities - No known Aboriginal Heritage issues	- Impacts to the public during construction and operation o beach access restrictions o noise of pump operations o public safety o truck traffic, traffic disruption - Pipeline exposure to storm damage - Aboriginal Heritage assessment required

> *Dry Earth Sand Winning with Directionally Drilled Pipeline*

This option for sand extraction and fluidisation process utilises dry earth sand winning, where a mobile hopper is filled via conventional earthmoving equipment such as excavators and diggers. The sand material is combined with water to form a slurry which is transported via a pipeline.

For this option, the delivery pipeline would be positioned underground in the beach/inshore, using horizontal drilling techniques to drill through bedrock.

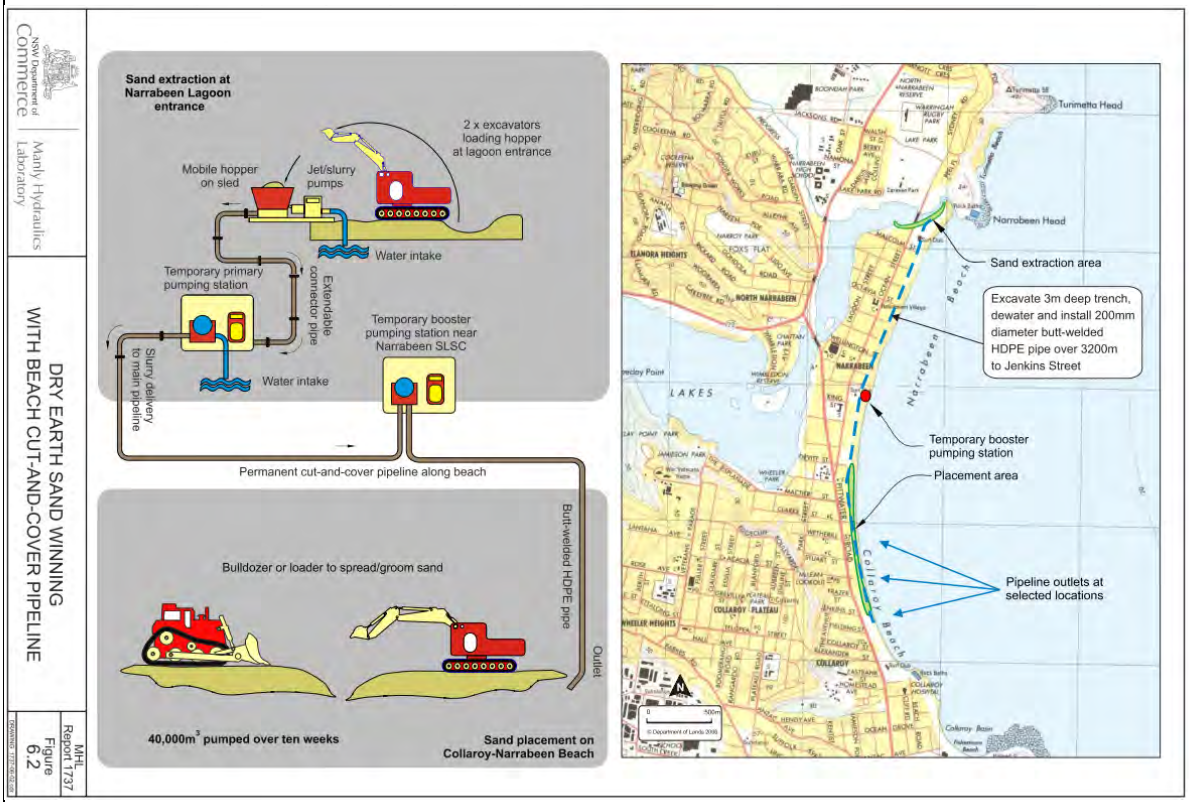


*An example of **Dry Earth Sand Winning**, where a tracked mobile hopper (Slurrytrak) is filled via conventional earthmoving equipment such as excavators and diggers. (Dawesville, Western Australia)*

> *Dry Earth Sand Winning with Beach Cut-and-Cover Pipeline*

This option for sand extraction and fluidisation process utilises dry earth sand winning, where a mobile hopper is filled via conventional earthmoving equipment such as excavators and diggers. The sand material is combined with water to form a slurry that is transported via a pipeline.

For this option, the delivery pipeline would be a permanent structure, positioned underground on the beach, using a cut-and cover method. This method involves cutting or digging a trench, laying the pipe and then covering the pipeline using the excavated material.

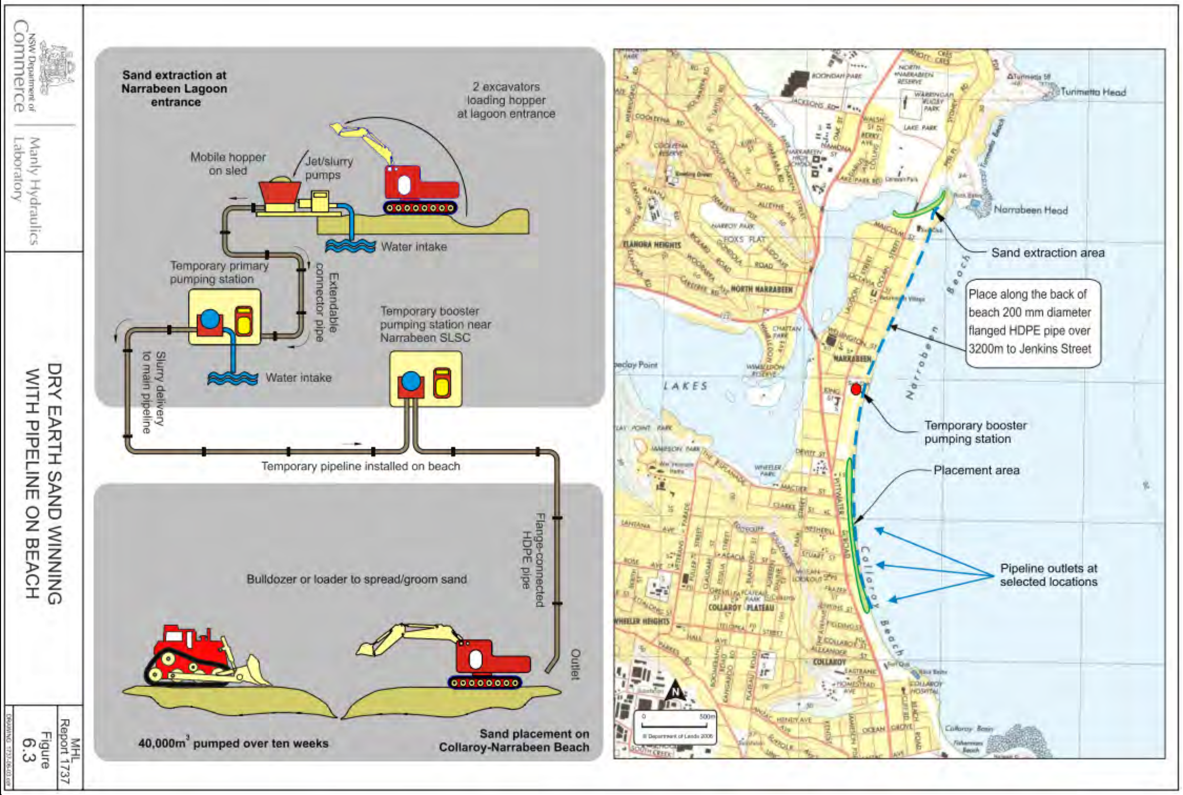


Construction of permanent sand transfer system with buried pipeline, at Jimmy's Beach, NSW (Photos from ABC News website)

> *Dry Earth Sand Winning with Pipeline on Beach*

This option for sand extraction and fluidisation process utilises dry earth sand winning, where a mobile hopper is filled via conventional earthmoving equipment such as excavators and diggers. The sand material is then combined with water to form a slurry that is transported via a pipeline

For this option, the temporary delivery pipeline would be positioned above ground, to discharge on the Collaroy- Narrabeen Beach. Additional booster pumps would be positioned along this pipeline route.



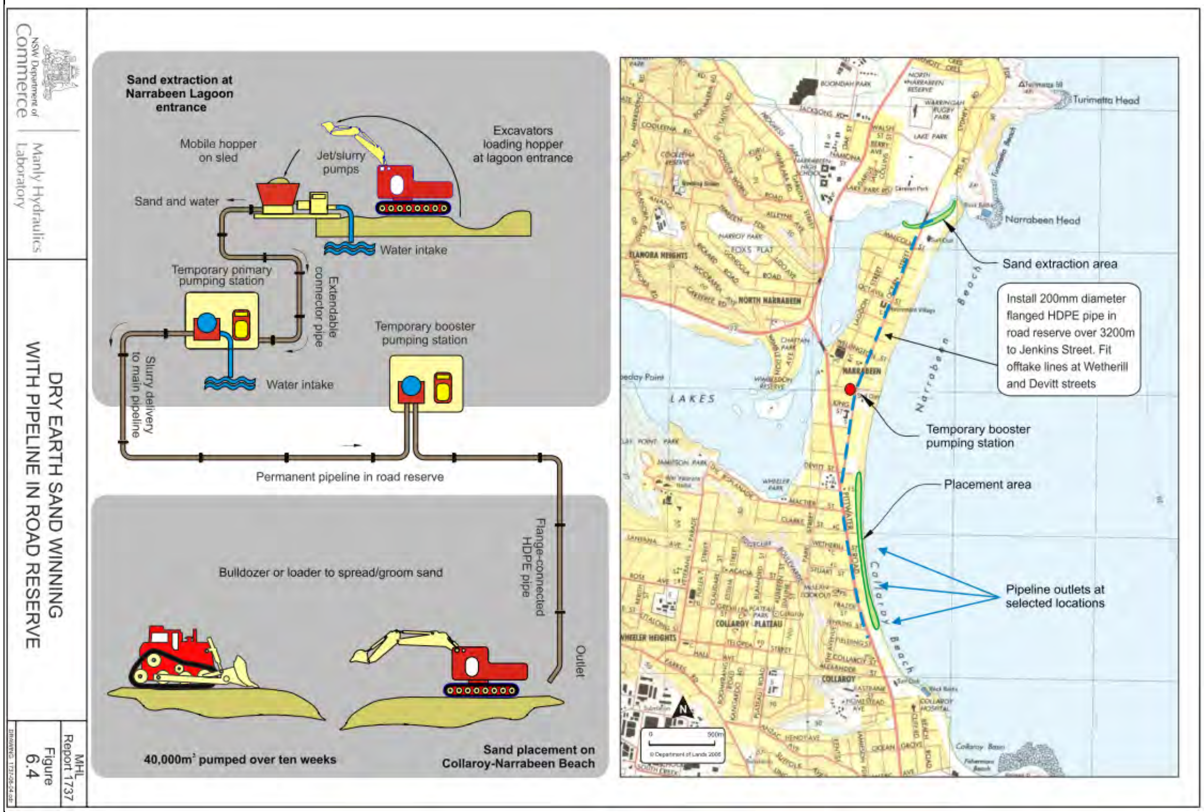
	
Sand being pumped along temporary pipe on beach, Burleigh, Qld Australia. (Image obtained from SMEC Jimmy's Beach Review of Management Options, March 2015)	*Sand is loaded in tracked mobile hopper and pumped, via temporary pipeline on beach surface, Dawesville WA*

> *Dry Earth Sand Winning with Pipeline in Road Reserve*

This option for sand extraction and fluidisation process utilises dry earth sand winning, where a mobile hopper is filled via conventional earthmoving equipment such as excavators and diggers. The sand material is combined with water to form a slurry which is transported via a pipeline.

For this option, the temporary delivery pipeline would be positioned in a shallow, buried trench in the road reserve. Additional booster pumps would be positioned approximately halfway along this pipeline route.

Since this pipe is located in the road reserve, this particular option has a higher risk for Aboriginal heritage concerns and potential for utility damage.

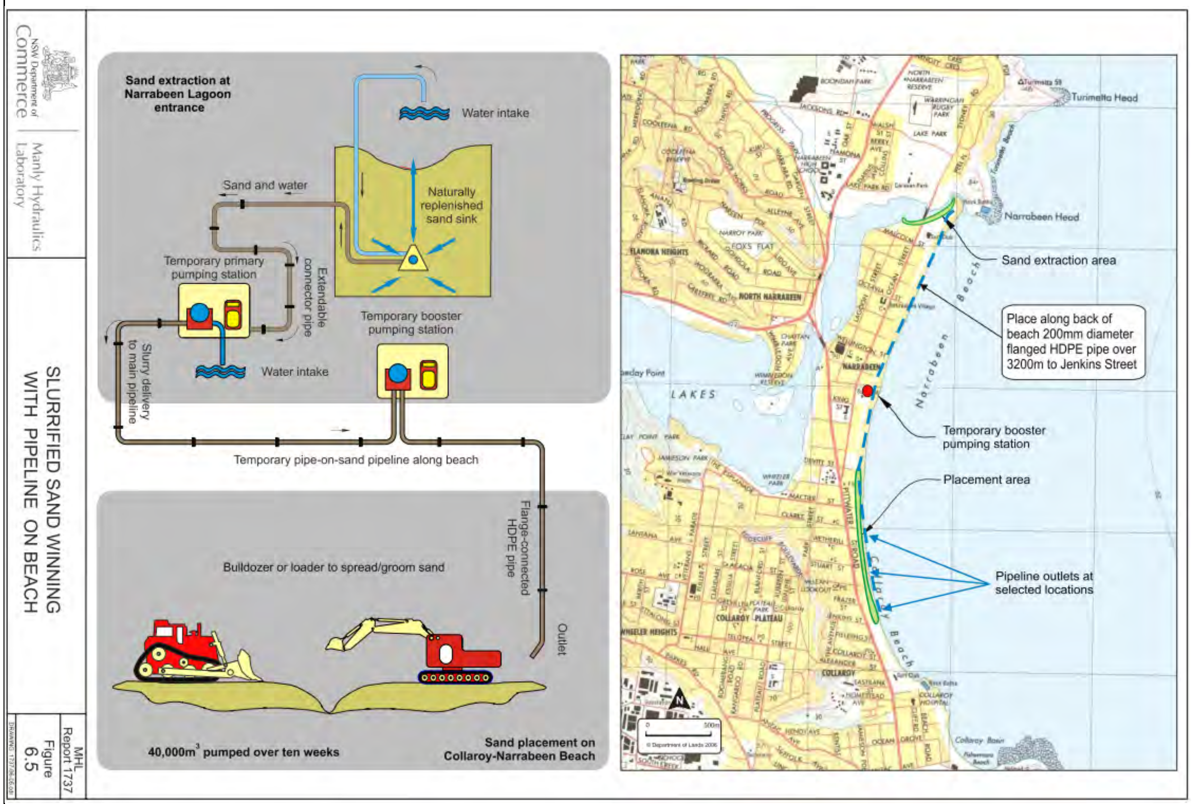


An example pump station as part of operations. Insulated in a shipping container to reduce noise emissions. Photo at Blairgowire, Vic

> *Slurrified Sand Winning with Pipeline on Beach*

This option utilises slurrified sand winning, where a submerged sand pump, in the form of a self-burying submarine Sand Shifter unit, would intercept the sand moving into the entrance. Screens are used to remove oversize material from the slurry, before it is pumped via a temporary pipeline placed on the beach. This system, developed by Slurry Systems Marine Pty Ltd, has been successfully used in various locations around Australia.

The slurrified sand would be distributed and groomed using a dozer or excavator.



Sand Shifter Unit Configuration (Slurry Systems Marine)

Noosa trial Sand Shifter in operation (unit buried). (Slurry Systems Marine)

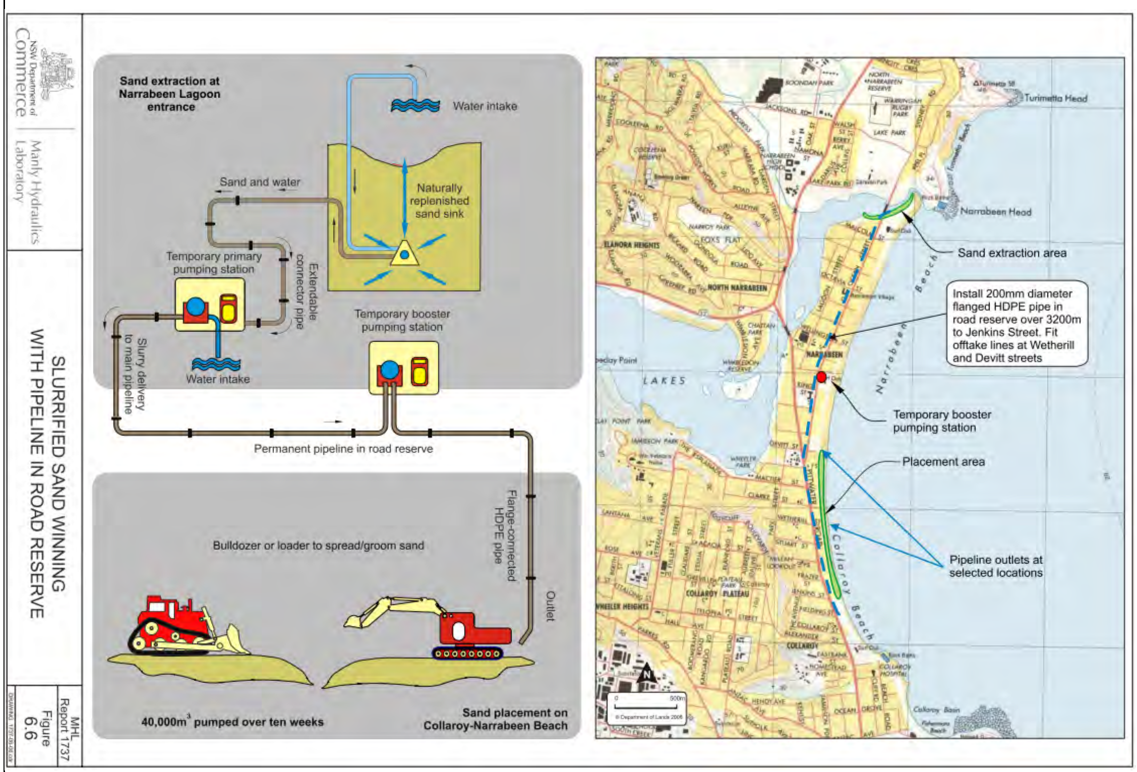

Onshore booster pumps and pipework (Slurry Systems Marine)

> ***Slurrified Sand Winning with Pipeline in Road Reserve.***

This option utilises slurrified sand winning, where a submerged sand pump, in the form of a self-burying submarine Sand Shifter unit, would intercept the sand moving into the entrance. Screens are used to remove oversize material from the slurry before it is pumped via a permanent pipeline within the road reserve. This system, developed by Slurry Systems Marine Pty Ltd, has been successfully used in various locations around Australia.

The slurrified sand would be distributed and groomed using a dozer or excavator.

Since this pipe is located in the road reserve, this particular option has a higher risk for Aboriginal heritage concerns and potential for utility damage.



Slurry discharge pumped from pipeline following fluidisation by the Sand Shifter unit, Noosa. (Slurry Systems Marine)

The following table provides an overview of some advantages and disadvantages of these final five options involving pipeline transfer systems to move the material from the entrance to Collaroy-Narrabeen Beach.

ADVANTAGES	***DISADVANTAGES***
- Able to move sand long distances for lower operation costs. - Sand slurry can be controlled to be a consistent density. - Reliably measure sand volume. - Coarse material, debris can be separated via screening processes. - Ability for permanent infrastructure that would minimise establishment time and cost for entrance clearance. - Lower safety issues than the current excavation and trucking methods. - Permanent infrastructure could obtain ongoing approval avoiding EIAs and other required approvals for each clearance operation	- Noise from pumps and booster stations. - Cost of installation of infrastructure for the system, both temporary and permanent. - Pipeline and equipment infrastructure along this section of beach may be exposed to storm damage. Vulnerability will increase with sea level rise. - Sand slurry impacts beach amenity during operations. - Temporarily restricted beach access during installation.