Manly Council

Attachments

Ordinary Meeting

Notice is hereby given that an Ordinary Meeting of Council will be held at Council Chambers, 1 Belgrave Street, Manly, on:

Monday 12 December 2011

Commencing at 7:30 PM for the purpose of considering items included on the Agenda.

Persons in the gallery are advised that the proceedings of the meeting are being taped. However, under the Local Government Act 1993, no other tape recording is permitted without the authority of the Council or Committee. Tape recording includes a video camera and any electronic device capable of recording speech.

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Water Research Laboratory

Identification of Coastal Hazard Risk Areas to Projected Sea Level Rise for the Manly Local Government Area

FINAL DRAFT

WRL Technical Report 2011/19
November 2011

by
A Mariani, J T Carley, D B Lord and T D Shand

UNSW
THE UNIVERSITY OF NEW SOUTH WALES

Water Research Laboratory
University of New South Wales
School of Civil and Environmental Engineering

Identification of Coastal Hazard Risk Areas to Projected Sea Level Rise for the Manly Local Government Area

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EXECUTIVE SUMMARY

ES1. Overview

The following tasks have been undertaken for Manly Council by the Water Research Laboratory of the University of New South Wales.

- **Field survey** of existing coastal protection works;
- Definition of **coastal erosion hazard lines** for present day conditions, 2050 and 2100 planning periods;
- Definition of **coastal inundation** levels for the 1, 50 and 100 year average recurrence interval storm events, for present day, 2050 and 2100 planning periods;
- **Vulnerability assessment** of existing assets to erosion and inundation;
- Recommendations for coastal risk **management options**.

ES2. Field Survey

The site inspection focused on the visual assessment and engineering characterisation of coastal protection works (seawalls). The survey output was used for the subsequent analysis of erosion and inundation hazards. No detailed stability assessment was undertaken. Considering the early 1900s construction for most of the seawalls, they were found to be in reasonable condition. The atmospheric and ocean weathering evidenced was as expected. However, these seawalls will come under increasing pressure as sea level rises and will need to be regularly monitored to ensure their stability during storm events.

ES3. Beach Erosion and Recession

The majority of the sandy beaches along the Manly coastline are backed by seawalls. Therefore, the landward limit of the coastal erosion and recession hazard line is limited to the seawall face. Should the seawalls fail, modelling showed that erosion will progress inland and potentially impact a large number of private and public properties and infrastructure.

ES4. Coastal Inundation

The inundation study was based on the current shoreline location including allowance for the NSW Government sea level rise benchmarks. Inundation due to elevated water levels (including storm surge and wave setup) will potentially affect areas located away from the foreshore as well as beachfront properties. Inundation by wave overtopping will potentially affect beachfront dwellings, pedestrians and vehicles.

ES5. Vulnerability Assessment of Private/Public Assets

With the seawalls in place, the areas most impacted by the erosion and recession hazard for the 2100 planning horizon are Clontarf and Forty Baskets. In the case of seawall failure, Manly Ocean Beach, Manly Cove East and Clontarf will be the most impacted by 2100. Within the harbour beaches, properties in Clontarf and Manly Cove East are most likely to be affected by inundation. On Manly Ocean Beaches and Fairy Bower Beach, wave overtopping during storm events is likely to represent hazard to property and public safety.

ES6. Management Options

Future sea level rise is likely to challenge the public expectation that the line separating the beach and the land will remain at that alignment. The mapping of erosion and inundation indicates the importance of seawalls in preserving existing development and assets at their present locations. In many locations these seawalls will require substantial upgrading or replacement. Other management measures may also be preferred.

1. Introduction

The Water Research Laboratory (WRL) of the University of New South Wales was engaged by Manly Council to undertake the study: *"Identification of Coastal Hazard Risk Areas to Projected Sea Level Rise for the Manly Local Government Area (LGA)"*.

Sandy beaches along the Manly coastline are distributed in three main geographically distinct sections (as shown in Figure 1.1):

- Middle Harbour *(the Spit to Clontarf Point)*;
- North Harbour *(Forty Baskets Beach to the Sydney Harbour National Park boundary including Fairlight, Manly Cove and Little Manly Cove)*; and
- Manly Ocean Beach *(Queenscliff to Manly Stretch, Fairy Bower and Shelly Beach)*.

The methodology applied in this report for the assessment of Coastal Risks Areas within the Manly LGA conforms to the following documents:

- NSW Coastal Planning Guideline: Adapting to Sea Level Rise (DoP, 2010);
- Coastal Risk Management Guide (DECCW, 2010);
- NSW Sea Level Rise Policy Statement (DECCW, 2009); and
- NSW Coastline Management Manual (NSW PWD, 1990).

The scope of this report includes the following tasks:

1. **Field Survey** of existing coastal protection works;
2. Definition of **coastal erosion hazard lines** for present day conditions, 2050 and 2100 planning periods;
3. Definition of **coastal inundation** levels for the 1, 50 and 100 year ARI (average recurrence interval) storm events, for present day, 2050 and 2100 planning periods;
4. **Vulnerability assessment** of existing private/public assets to erosion and inundation;
5. Recommendations for coastal risk **management options**.

These tasks are addressed throughout the report as listed below:

- **Section 2** summarises the data used in the preparation of this report;
- **Section 3** describes the survey of existing seawalls within the Manly LGA;
- **Section 4** of this report outlines the coastal processes relevant to this study;
- **Section 5** presents the coastal erosion (and recession) hazard lines;
- **Section 6** presents the coastal inundation zones and the wave overtopping (and runup);
- **Section 7** lists the assets vulnerable to coastal risk;
- **Section 8** provides coastal management options to address the identified risks; and
- **Section 9** describes the assumptions and limitations of the study.

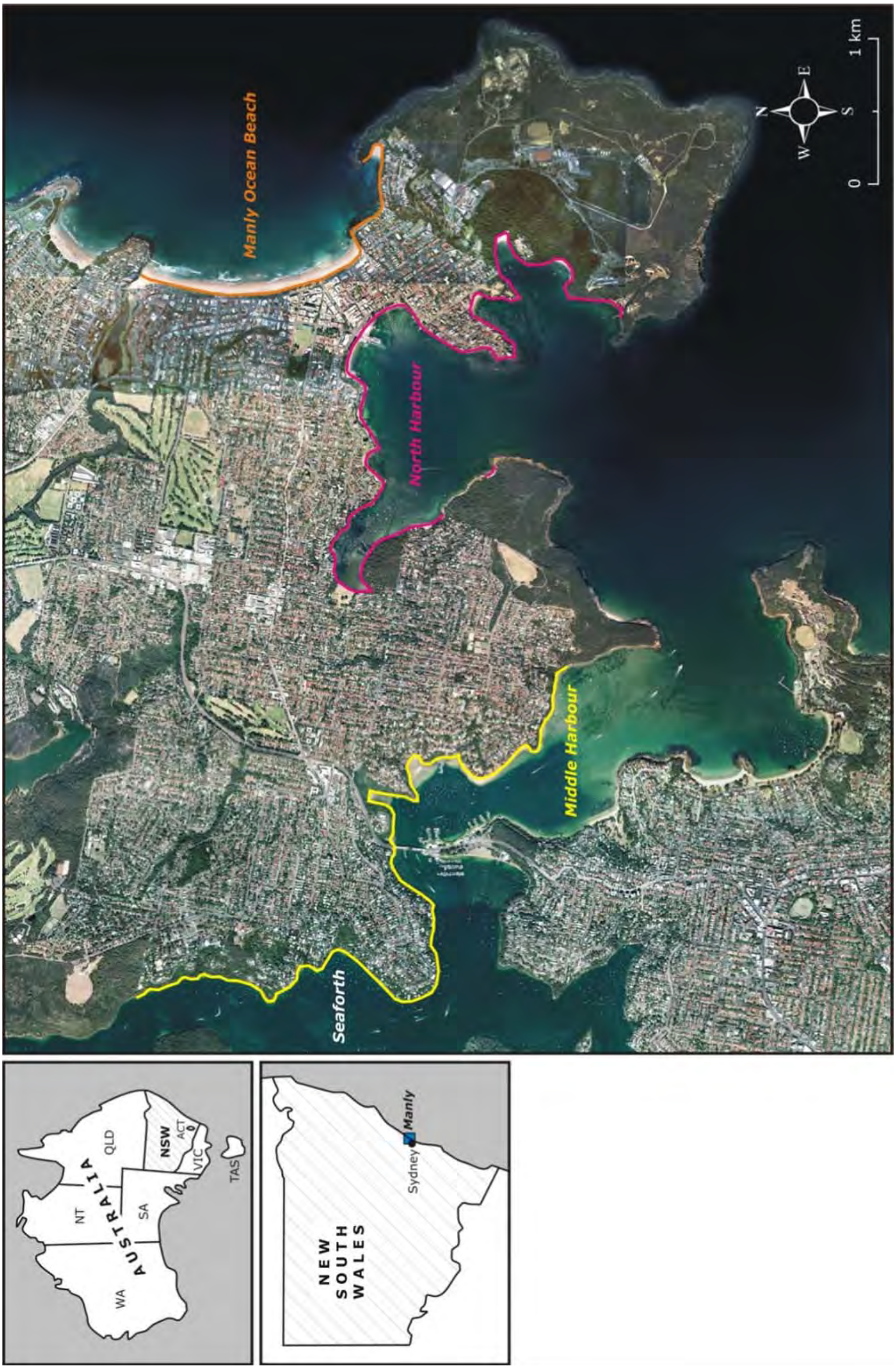


Figure 1.1 Location Plan

2. Data Compilation

2.1 Literature Review

A substantial body of literature in the form of consultant and council technical and management reports exists for the Manly coastline. All the relevant literature addressing coastal processes, coastal protection works and coastal management within the Manly LGA was consulted with the most important in relation to the current studies listed below. Brief summaries of each study are presented in Section 9.

2.1.1 Coastal Hazard Definition Studies

A series of coastal hazard definition reports was prepared by Patterson Britton and Partners. The reports provided information on the coastal hazards relevant to the Ocean Beach and North Harbour sections of the Manly coastline in particular in terms of coastal erosion and coastal recession due to sediment loss and sea level rise. The reports also included the assessment of seawall and rocky cliff stability and related geotechnical investigations. The reports consulted for the current study are listed below.

- Patterson Britton & Partners (2003), *Manly Ocean Beach and Cabbage Tree Bay Coastline Hazard Definition Study*, Issue No. 2, May, Manly Council;
- Patterson, Britton & Partners (2003), *Forty Baskets Coastline Hazard Definition Study*, Issue No. 2, May, Manly Council;
- Patterson, Britton & Partners (2003), *Little Manly Coastline Hazard Definition Study*, Issue No. 2, May, Manly Council;
- Patterson, Britton & Partners (2004), *Davis Marina to Manly Point Coastline Hazard Definition Study*, for Manly Council.

2.1.2 Coastal Processes Studies

Cardno Lawson Treloar prepared two reports addressing sediment transport processes in the Middle Harbour area from Clontarf Point to the Spit. A stability assessment of the seawalls along this section of coastline was presented in the reports. The reports consulted for this study are listed below.

- Cardno Lawson Treloar (2009), *Clontarf Sedimentary Processes and Foreshore Stability Study, Sedimentary Processes Report*, Manly Council;
- Cardno Lawson Treloar (2009), *Clontarf Sedimentary Processes and Foreshore Stability Study, Foreshore Stability Report*, Manly Council.

Manly Hydraulics Laboratory (MHL) NSW Department of Public Works carried out two studies regarding coastal processes and remedial options in East Manly Cove:

- MHL (1997), *East Manly Cove Coastal Engineering Study,* Report MHL863;
- MHL (1997), *East Manly Cove Coastal Engineering Study, Stage Two,* Report MHL894.

2.1.3 Coastline Management Studies

The following coastal management study reports were issued by the Manly Council, Worley Parsons and MHL:

- Manly Council (Final Report February 2009), *North Harbour Coastline Management Study*;
- Manly Council (Final Draft June 2011), *Manly Cove Coastal Zone Management Plan*;
- Manly Council (Final Draft September 2011), *Ellery's Punt Reserve Landscape Masterplan*;

- Worley Parsons (2008), *Manly Ocean Beach Coastline Management Plan,* Issue No. 4;
- MHL (2002), East Manly Cove Beach Management Options Scoping Study, Draft Report MHL1194.

2.1.4 Coastal Protection Works Studies

The Water Research Laboratory prepared a report for Manly Council addressing the stability of Manly Ocean Beach seawall and providing a risk assessment and management options. The report reviewed was:

- Water Research Laboratory (2003), *Manly Ocean Beach Seawall and Beach Amenity Risk Assessment and Remedial Options*.

2.2 Photogrammetry Data

Photogrammetry data was provided by the New South Wales Office of Environment and Heritage (NSW OEH). The analysis of the photogrammetry data, including profile plotting and volumetric analysis, allowed the determination of storm erosion demand and long term recession rate and the validation of these when assessed in previous reports. The data analysed are summarised for every beach in Table 2.1.

Table 2.1 Summary of Photogrammetric Data (source NSW OEH)

Location	Year
Manly Beach	1930, 1951, 1961, 1965, 1970, 1975, 1976, 1978, 1993, 1999, 2001, 2008
Fairy Bower	1930,1961, 1965, 1972, 1974, 1978, 1985, 1993, 2001
Shelly Beach	1930, 1961, 1965, 1972, 1974, 1978, 1993, 2001
Collins Beach	1956, 1965, 1972, 1974, 1978
Little Manly Cove	1961, 1972, 1974, 1978, 1999, 2001
Manly Cove	1930,1974, 1978, 1986, 1990, 1996, 2001
Delwood Beach	1930,1956, 1965, 1972, 1975, 1978, 1998
Fairlight Beach	1930, 1956, 1965, 1972, 1978, 1998
Forty Baskets	1961, 1972, 1975, 1978, 1998
Reef Beach	1930, 1956, 1965, 1972, 1978, 1998
Clontarf	1961, 1970, 1978, 1982, 1986, 1993, 1999, 2006

2.3 Bathymetric and Topographic Data

Bathymetric and topographic sources are listed in Table 2.2.

Table 2.2 Summary of Bathymetric and Topographic Data Sources

Dataset	Data Source	Grid Reference System	Datum
Sydney Region Bathymetry and Seabed Mapping	NSW Office of Environment and Heritage	MGA Zone56 GDA94	Fort Denison Tide Gauge
Sydney Harbour 1m Contours	Sydney Metro CMA derived from soundings from NSW Maritime	MGA Zone56 GDA94	AHD
Offshore Contours	Geoscience Australia 9 arc second Bathy and Topo Grid ausbath_09_v4	GCS_WGS_1984	AHD
Manly LIDAR 2008	Manly Council	MGA Zone56 GDA94	AHD
Inner Sydney 2m Topographic Contours	Department of Lands (NSW)	MGA Zone56 GDA94	AHD

3. Field Survey

3.1 Overview

Formal site inspections took place during the weeks from 25 – 29 July and from 8 – 12 August and were performed by Mr A Mariani, Mr D Lord and Mr J Carley though all three team members have previously visited the study area on numerous occasions. The site inspection focused on the visual assessment of coastal protection works (seawalls and revetments) in regards to location, extent and engineering characterisation i.e. crest level, construction, present condition etc. Several points along the seawall crest were surveyed using a RTK-GPS survey system and the surveyed data were used as input for the subsequent modelling of wave overtopping of the seawalls.

The area inspected comprises three geographical zones (refer to Figure 1.1):

- Middle Harbour;
- North Harbour; and
- Manly Ocean Beaches.

Middle Harbour is framed by Dobroyd Point and Middle Head and narrows through the Spit. Within the Manly LGA (Local Government Area), it comprises four sandy beaches occupying a total of 1.0 km (15%) of the predominantly rocky shore:

- Castle Rock Beach;
- Clontarf Beach;
- Sandy Bay; and
- Fisher Bay.

The North Harbour area has 12 km of shoreline with a total of 13 beaches occupying 1.5 km (13%) of the predominantly rocky shore (Short, 2007) including:

- Quarantine Beach;
- Store Beach;
- Collins Beach (Spring Cove);
- Little Manly Cove;
- Manly Cove (east and west);
- Delwood Beach;
- Fairlight Beach;
- Esplanade Beach;
- North Harbour Reserve;
- Silver Beach;
- Forty Baskets Beach;
- Reef Beach; and
- Washaway Beach.

The Manly Ocean Beaches area extends from the rocky headland of Queenscliff to North Head at the entrance of Sydney Harbour. Sandy beaches occupy 26% (1.7 km) of the shore, the rest being sheer cliffs and rocks. This area includes the following beaches:

- Queenscliff to Manly stretch;
- Fairy Bower; and
- Shelly Beach.

The majority of the beaches are backed by seawalls. Figure 3.1 presents the main seawall locations along Manly LGA coastline. Table 3.1 lists the inspected seawalls and depicts the date(s) of construction, construction type and total length. For Manly Ocean Beach, up to 16 wall types were identified from the Drawing Manly Council Plan No. 1-468. For the purpose of this investigation these seawalls have been regrouped in 4 representative wall types.

Table 3.1 Summary of Inspected Seawalls

Area	#	Location	Construction	Year	Length (m)
[2]Middle Harbour	1	Ellery's Punt Seawall	Vertical/near-vertical sandstone blocks set in mortar or loosely stacked, concrete construction in places; concrete and basalt capping	late 1800s	120
	2	Clontarf #1 between Sandy Bay and the Marina	Vertical and steep-sloping sandstone blocks set in mortar, concrete capping	early 1950s	200
	3	Clontarf #2 at culvert	Vertical sandstone blocks set in mortar, concrete capping, protection for stormwater culvert	?	15
	4	Clontarf #3 at pool	Vertical concrete landscaping wall	?	60
	5	Clontarf #4 at private properties	Vertical and near-vertical sandstone blocks set in mortar, concrete, rendered brick	?	260
	6	Clontarf #5 public access from Monash Cres.	Sloping rock seawall (1H:1V)	?	5
North Harbour	7	Forty Baskets Seawall	Vertical sandstone blocks set in mortar (South) and concrete construction (North)	early-mid 1900s	100
	8	North Harbour Reserve Rock Revetment	Sloping sandstone rubble 0.5 to 2 tonnes on layer of geo-fabric	?	158
	9	Fairlight Beach	Vertical concrete, façade of sandstone rocks on western end	early 1900s	90
	10	Manly Cove West	Vertical sandstone masonry faced with cement render	1900	230
	11	Manly Cove East	Vertical sandstone set in mortar masonry construction	late 1800s	270
	12	Little Manly Beach	Vertical concrete (reinforced) construction	mid 1900s	120
	13	Gas Works Quay	Vertical concrete and sandstone set in mortar construction	late 1800s	230
	14	Quarantine Station	Vertical concrete	?	35
Manly Ocean Beaches	15	Manly Ocean Beach South: Manly LSC to Corso (*ch. 0 - 360 m*)[1]	Vertical/near-vertical sandstone masonry with concrete facing and capping	1890s on	360
	16	[3]Manly Ocean Beach Middle: Corso to Pacific St (*ch. 360 - 1282 m*) [1]	Near-vertical masonry; 1:4 batter at some locations; sloping (1:1.5) concrete blocks (*ch. 900 - 1015 m)*	early 1900s	922
	17	Manly Ocean Beach North: Pacific St to Queenscliff boatshed *(ch. 1282-1522)* [1]	Sloping (1:1.5) precast concrete blocks, masonry capping	mid 1900s	240
	18	Marine Parade Seawall	Vertical masonry, founded and fronted by exposed reef except Fairy Bower beach	1890s	650

Notes: (1) chainage from Manly LSC
(2) timber landscaping walls are also present which do not provide coastal protection
(3) from ch. 900 – 1015 m the seawall is constructed of sloping concrete blocks

Figure 3.1 Seawall Locations

Table 3.2 Seawall Characteristics and Present Condition

Area	#	Location	Crest Level (m AHD)	[(1)]Toe Level (m AHD)	Ave. Sand Level (m AHD)	Present Condition
[(2)]Middle Harbour	1	Ellery's Punt Seawall	1.5	?	na	Serious erosion of concrete, sandstone and mortar; undermining
	2	Clontarf #1 between Sandy Bay and the Marina	1.5	-0.4	0.0	Generally reasonable condition, localised erosion of sandstone and mortar, isolated cracks, settling and rotation
	3	Clontarf #2 at culvert	1.4	<-0.4	0.6	Good condition, minor weathering
	4	Clontarf #3 at pool	1.4	<0.3	1.1	Reasonable condition, isolated forward leaning and corrosion of reinforcing steel
	5	Clontarf #4 at private properties	1.6-2.5	?	-	Reasonable condition
	6	Clontarf #5 access from Monash Cres.	1.9	?	-	Reasonable condition, weathering of mortar
North Harbour	7	40 Baskets Seawall	1.6	on bedrock	na	Concrete section in poor condition, wedges of concrete broken, erosion of render, undermining of toe, high weathering
	8	North Harbour Reserve	1.5	0.0	na	Good condition, smaller rocks displaced at some locations at the crest and geofabric exposed
	9	Fairlight Beach	3.3 middle 2-2.5 at E+W ends	1.4-2.4	1.0	Reasonable conditions, vertical crack, weathering of render, exposure of aggregates
	10	Manly Cove West	2.9-3.5	0.8-1.2	2.0	General good condition, render spalled off, horizontal crack along 10 m top of seawall
	11	Manly Cove East	2.2-3.2	?	1.8(E) &1.0 W	Reasonable condition, some sandstone blocks and mortar weathered
	12	Little Manly Beach	2.4-3.5	2.0	2.8	Fair condition overall but localised deep vertical cracking and movement of rotation outwards, no drainage
	13	Gas Works Quay	2.9&5.8	?	na	General weathering and erosion of concrete, aggregates visible, corrosion of reinforcement steel, large cracks
	14	Quarantine Station	-	?	?	General weathering and erosion of concrete, aggregates visible, corrosion of reinforcement steel, large cracks
Manly Ocean Beaches	15	Manly LSC to Corso	3.5(S)-4.0(N)	?	2.7	Minor cracking, transverse and horizontal
	16	[(2)]Corso to Pacific st	4.5(S)-6.0(N)	?	3.6	Issues with stability for scour, solved now?
	17	Pacific st to Queenscliff boatshed	5.0	?	3.5	Minimal weathering
	18	Marine Parade Seawall	2.8 at Fairy Bower	?	1.3	Concrete strip undermined, sandstone joint in N Fairy Bower

Notes: (1) as determined by previous geotechnical investigations
(2) toe protection works were recently undertaken in the Pine to Pacific St section

Table 3.2 shows the range of measured crest elevation, the toe level (when determined by previous geotechnical investigations), the average sand level against the seawall (inferred from photogrammetric analysis) and the present condition. Crest level data were complemented by photogrammetric analysis.

In Appendix A, Figures A.1 to A.18 present the seawall locations with overview photos illustrating the main features.

While a detailed stability assessment was not part of the scope of works, the visual assessment of the seawalls allowed general and qualitative observations of the seawall present conditions. Considering the early 1900s construction for most of the seawalls, these were found to be in reasonable condition with the expected atmospheric and ocean weathering such as erosion of sandstone and mortar, corrosion of reinforcement steel, localised settlement etc. In addition to the information presented in Table 3.1 and 3.2, the inspected seawalls and their beach location are briefly described below.

A variety of private seawalls connected to private boatsheds were observed along the rocky coastline of Seaforth, west of the Spit Bridge. These seawalls are generally approximately 10 metres in length and of different construction such as grouted sandstone blocks, brick and concrete. A small seawall made of sandstone blocks set in mortar forms part of the causeway leading to the Northbridge Sailing Club (Seaforth Moth Club, down from Sangrado Street in Seaforth).

3.2 Ellery's Punt Reserve

The Ellery's Punt reserve is located adjacent and to the east of the Spit Bridge. In the late 1800s, prior to the construction of the bridge, a punt service was operated from this reserve. A continuous section (80 metres length) of seawall runs from west of the Spit Bridge to an unprotected embankment. This embankment is adjacent to the original punt ramp and platform and a stormwater outlet discharges at this location. The seawall is made mostly of vertical/near vertical sandstone blocks set in mortar, while a concrete toe beam was constructed to reinforce a section of the seawall. Some sections of the seawall are made of un-grouted stacked sandstone blocks.

Figure 3.2 Ellery's Punt Reserve Photos of Present Condition

The seawall presents serious erosion of the mortar with several pockets of erosion where the sandstone blocks are detached from the seawall (see Figure 3.2). Moreover, serious undermining of the toe was observed along this seawall.

A 40 metre long seawall connects the eastern end of the punt platform to the western rocky end of the reserve. The seawall is made of sandstone blocks with minimal grouting and concrete (and basalt) capping. A 10 metre section of the seawall is made of concrete construction and is backed by a grassed embankment. The concrete is in poor condition and the leeward embankment suffers from erosion which is probably caused by wave overtopping of the seawall (see Figure 3.2). This area is also subject to high volumes of boat traffic therefore boat wakes. Several sandstone boulders of approximately 1 tonne have been placed at this location to protect the embankment from erosion. The crest levels of the seawalls vary between 1 m AHD and 1.5 m AHD.

3.3 Clontarf

The Clontarf foreshore includes the sandy foreshore from Sandy Bay 500 metres east of the Spit Bridge fronting Sandy Bay Road, Holmes Avenue and Monash Crescent. It is bounded to the east by the rocky headland of Clontarf Point at the end of Monash Crescent. The foreshore includes the Clontarf Marina, the netted swimming reserve and Clontarf Reserve.

There are a number of discrete seawall sections along the Clontarf section of coastline and these are detailed in Tables 3.1 and 3.2. There is a continuous section of seawall running from the western end of Sandy Bay to the Marina. This section of wall is of generally sloping construction and constructed of dressed or cut sandstone blocks. At the back of Sandy Bay, the wall is buried and appears to have been in part excavated and removed. Telecommunication cables are exposed at the ground surface across the beach in this location.

From Sandy Bay to the marina, much of this wall has a poured concrete capping. While of early construction (1950s) it is generally in good condition. The section to the west of the Marina appears to be of earlier construction or has been rebuilt and is “bulging” seaward. No information is available detailing the precise construction of the wall. It appears to be performing adequately at the present time.

To the east of the Marina , the seawall is not visible, possibly buried by the accreted dune and garden. It remerges as a dressed sandstone wall either side of the stormwater outlet on the western side of Clontarf Reserve. From the stormwater outlet, along the western side of Clontarf Reserve to the southern side of the swimming enclosure, the sandstone wall is replaced by a vertical concrete wall of unknown cross section and depth. This section of the wall is generally in poor condition showing cracking and rotation. Exposed reinforcing steel is rusting. The sections of wall east of the swimming enclosure and within Sandy Bay have a crest level generally at 1.4 m AHD to 1.5 m AHD.

From the southern side of the swimming enclosure to the start of the private properties along Monash Crescent, Clontarf Reserve is separated from the beach by a simple treated pine retaining wall which in sections is suspended above the current sand level. This timber wall is for landscaping purposes, providing no role as a seawall or retaining wall if subject to wave and tidal action.

The properties along Monash Crescent are all fronted by seawalls of varying design and alignment. They vary from sloping to vertical with varying crest levels. Materials used include timber, brick, cement rendered blocks and dressed sandstone. It would appear that the majority of these walls are not designed as a seawall but rather have been constructed "as required" with landscaping priorities. The crest levels of the walls in front of these properties vary from 1.6 m AHD to 2.5 m AHD.

3.4 Forty Baskets

Forty Baskets beach is on the northern side of the Sydney Harbour National Park and is accessed by a pathway from Beatty Street. The beach is approximately 250 metres in length and oriented to the north-east. The south-eastern section of the beach comprises a rocky shoreline and the north-western end, which is approximately 160 metres long, is sandy. The northern 70 metres of the beach is backed by a vertical concrete seawall. At the northern end is a netted swimming enclosure. The beach is backed by a grassy reserve with residential development set back approximately 20 metres from the back of the beach, on the steeply rising slopes of the headland.

Figure 3.3 Forty Baskets Seawall Photos of Present Condition

The existing seawall at the northern end is a vertical concrete wall of poor construction. The wall appears to be founded on the rock shelf and in some sections the toe is exposed and undermined. The wall is retaining up to 1.5 metres of fill which forms the grassed reserve seaward of the private properties. The crest level of the wall is approximately 1.6 m AHD. The condition of the wall is poor with degradation of the concrete, cracking of the wall and rotation of the crest seaward (see Figure 3.3). Some patches acting as concrete buttresses have been poured at the northern end to try and delay the failure of the wall. The structure needs to be removed and replaced as it is approaching the end of its serviceable life.

3.5 North Harbour Reserve

North Harbour Reserve is a deeply embayed foreshore park on a reclaimed creek outlet. The beach is approximately 250 metres in length and oriented to the east-south-east. The grassed reserve is reclaimed land, fronted by an engineered rock armoured wall with a low crest level. There is no sandy beach seaward of the rock revetment. The original creek channel has been piped and discharges through the rock wall at the northern end. Residential development and a childcare centre are located on the north-west side of the reserve, well back from the foreshore.

The seawall along the reserve is a sloping wall with sandstone armour of 0.5 tonne to 2.0 tonne visible (estimated). The wall incorporates a geotextile filter that is visible near the crest. The crest level of the wall is at 1.5 m AHD and the toe level is estimated at 0.0 m AHD. The wall generally appears to be in good condition with a concrete pathway immediately landward of the crest. At the northern end, the stormwater pipe exits through the seawall via a concrete headwall. There is minor cracking visible in the head wall.

3.6 Fairlight

Fairlight Beach is oriented to the south and located on the rocky foreshores approximately 500 metres west of Manly Cove. The beach is approximately 90 metres in length and contained by bedrock headlands at both ends. Bedrock is also visible on the bed across the mouth of the bay. The sandy area is backed by a low retaining wall and there is a grassed reserve and concrete foot path separating the residential development from the beach. The property boundaries vary from 10 metres to 20 metres from the back of the beach. The eastern end of the beach and the eastern headland incorporate a concrete walled ocean pool. The beach is directly exposed to the mouth of Sydney Harbour and waves approaching from the south-east. The beach experiences higher than average wave conditions within the harbour when offshore waves approach from the south-east and is known as a location that can be surfed during large storm events.

The seawall at the back of the beach is a low vertical concrete retaining wall which appears in part to be founded on bedrock, shallowly underlying the northern and southern ends of the beach. Along the northern half of the beach this seawall encases a stormwater line that discharges across the beach towards the western end. This wall, while in poor condition along some sections, remains serviceable, but will need to be upgraded. The southern shoreline of the bay is protected from erosion by the vertical concrete walls of the ocean baths. The crest of the wall varies from 2.0 m AHD at the middle of the beach to 3.3 m AHD across the rock shelf.

3.7 Manly Cove West

Manly Cove West is the western portion of Manly Cove occupying the harbour side of the Manly sand spit, 450 metres from the southern end of Manly Ocean Beach. The west part of the beach occupies the 280 metres of sandy beach between the Sydney Ferry terminal and the Ocean Aquarium and Gallery. The beach is separated from West Esplanade by a grassed reserve with Norfolk Island pines, varying in width from 30 metres at the western end to about 10 metres at the wharf. The beach is backed by a sandstone seawall and is oriented to the south-south-west.

The beach is backed by a vertical sandstone wall which is concrete rendered on the seaward face. This seawall has is generally in sound condition showing little cracking or distress. The crest level of the wall varies from 2.9 m AHD to 3.5 m AHD. The toe level is reported (Patterson Britton, 2004) at 0.8 m AHD to 1.2 m AHD. The wall is around 100 years old and still serviceable. It will come under increasing pressure as sea level rises.

3.8 Manly Cove East

Manly Cove East is the 250 metres of sandy beach within Manly Cove and located to the east of the Sydney ferry terminal. It is backed by a sandstone seawall and a grass reserve 15 to 20 metres wide separates the beach from East Esplanade. The sandy beach has experienced erosion at the western end adjacent to the ferry terminal where the low tide washes against the seawall. At the eastern end of the beach is a large stormwater outlet. The southern headland of the beach includes the Manly Sailing Club and the Manly 16 foot Skiff Club. The eastern headland is protected along its full length by vertical seawalls and there is no sandy beach along this shore. South-west of the skiff club is occupied by residential development, protected by vertical seawalls and with no public access to the foreshore.

The beach is backed by a vertical sandstone wall, which is concrete rendered on the seaward face. This seawall is generally in sound condition showing little cracking or distress. The crest level of the wall varies from 2.2 m AHD to 3.2 m AHD. The wall is around 100 years old and still serviceable, but will come under increasing pressure as sea level rises.

3.9 Little Manly

Little Manly Beach is located on the harbour side of North head. It is a short, sandy beach 150 metres in length deeply embayed between bedrock headlands and oriented to the west-south-west. There is a boat launching ramp at the western end of the beach and a netted swimming enclosure at the eastern end. The beach is backed by a low concrete retaining wall and there is some development immediately adjacent to the retaining wall.

Figure 3.4 Little Manly Seawall Photos of Present Condition

The seawall behind the beach comprises a vertical concrete retaining wall that was probably constructed with little consideration of the potential for wave attack. The crest of the wall is at 2.4 m AHD to 3.5 m AHD and the reported toe level (Patterson Britton, 2004) at 2.0 m AHD. Despite being in reasonable condition overall, the Little Manly seawall showed signs of settlement with forward movement evident from vertical cracks (10-30 mm) across the entire height of the seawall and a general misalignment of seawall sections. No drainage provisions were evident along the seawall which could lead to a build-up of water pressure at the back of the seawall during heavy rainfall events. This, coupled to the erosion of sand in front of the seawall during storm events, could potentially worsen the forward leaning of the seawall.

3.10 Quarantine Beach

Quarantine Beach is just within Sydney Harbour on the western side of North Head within the National Park. It is approximately 120 metres in length and oriented to the north-west. At the southern end of the beach is the Quarantine Station jetty and behind the beach are a group of buildings of high heritage value. The southern end of the beach is protected by a low retaining wall.

The short length of seawall is adjacent to the wharf and acting as a headwall for an old stormwater outlet. The wall is of vertical construction and in poor condition, exhibiting cracking and rusting reinforcement. The crest level is very low and provides little protection from overtopping by storms.

3.11 Shelly Beach

Shelly Beach is located on the open ocean on the northern side of North head. The small sandy beach is approximately 70 metres long and is oriented almost due west. There is no seawall at the back of the wide beach which fronts the grassed and timbered reserve of Shelly Park. At the southern end of the beach is a kiosk and commercial restaurant. Along the southern headland to the beach is a walkway linking Shelly Beach to Fairy Bower and Manly Beach. The foreshore along this southern headland is protected by a vertical seawall, constructed on the exposed bedrock. This is an easterly continuation of the seawall at Fairy Bower and the foreshore from Shelly Beach to Manly Lagoon entrance is all protected by a continuous seawall of varying construction.

3.12 Fairy Bower (Marine Parade Seawall)

Fairy Bower is located on the northern rocky headland of North head, between South Steyne to the west and Shelley Beach to the east. Fairy Bower is the 140 metres length of low lying rock shelf immediately to the west of the ocean pool. This beach used to be covered with a veneer of sand, the last of which was eroded during the May-June 1974 storms. It has not been replaced, leaving a low, rock shelf shoreline with a protective seawall above. The base of the seawall contains the sewer and stormwater lines servicing the development on the headland behind and to the east. At the lowest section adjacent to Bower Lane, the private development is located within a few metres of the seawall crest which is regularly overtopped during storms at present.

Figure 3.5 Fairy Bower Seawall Photos of Present Condition

The seawall along the foreshore at Fairy Bower is an old, dressed sandstone wall, constructed across the bedrock shelf at the shoreline, and appears to be generally sound. At the toe of the wall is a concrete encased sewerage line that forms a step at the base of the wall. This concrete strip was found to be significantly undermined (Figure 3.5) with sand being eroded by the constant action of waves.

Along the low sections of the wall adjacent to Bower Lane, the sandstone wall has been topped with a parapet wall, approximately 0.75 metres high, to reduce the wave overtopping. This wall appears to be constructed of blocks with a cement render facing. The parapet wall is discontinuous with openings and stairs to allow access to the beach. Horizontal and vertical cracks running all along the parapet were observed (Figure 3.5).

3.13 Manly Ocean Beach

3.13.1 Manly LSC to Raglan Street

The southern section of Manly Beach extends approximately 500 metres from the Manly LSC at the southern end to Raglan Street, just north of The Corso. This section of the beach is oriented to the east-north-east. The beach is backed by a seawall and is separated from South Steyne by a narrow reserve approximately 20 metres to 35 metres in width. The reserve is mostly paved, with some grassed areas, iconic Norfolk Island Pines, shelter areas and seating.

The structure of the seawall along south Manly Beach is already well described through previous studies specifically addressing the remediation and upgrading of the various sections of the wall (see Sections 2 and 8). The crest level along this more sheltered section of the beach is approximately 4.2 m AHD. The significance of the wall in protecting the foreshore reserve, the roadways and development sited west of the road is already well accepted through these previous studies.

3.13.2 Manly Beach (Raglan Street to Pine Street)

This section of the beach, which extends from Raglan Street in the south to Pine Street and the North Steyne SLSC in the north, is approximately 570 metres in length and is oriented east-north-east. It is backed by a seawall and a narrow grassed reserve approximately 15 metres to 35 metres wide, which separates the beach from North Steyne.

The structure of the seawall along the central section of Manly Beach is already well described through previous studies specifically addressing the remediation and upgrading of the various sections of the wall (see Sections 2 and 8). The crest level along this more exposed section of the beach is approximately 6.0 m AHD. The significance of the wall in protecting the foreshore reserve, the roadways and development sited west of the road is already well accepted through these previous studies.

3.13.1 Manly Beach (Pine St to Queenscliff SLSC boatshed)

The northern section of Manly Beach extends approximately 540 metres from the North Steyne SLSC at Pine Street in the south to the Manly Lagoon entrance in the north. This end of the beach is oriented to the east and is backed by a seawall. At the northern end of the beach is the Queenscliff SLSC and the bridge across the Manly Lagoon entrance. The beach is separated from North Steyne by a narrow grassed reserve approximately 20 metres to 40 metres in width.

The structure of the seawall along the northern section of Manly Beach is already well described through previous studies specifically addressing the remediation and upgrading of the various sections of the wall (see Sections 2 and 8). The crest level along this exposed section of the beach is approximately 6.0 m AHD. The significance of the wall in protecting the foreshore reserve, the roadways and development sited west of the road is already well accepted through these previous studies.

4. Coastal Processes

4.1 Overview

Prior to assessing the coastal hazards, it was necessary to understand the coastal processes relevant to the study area. Coastal hazards are a direct consequence of coastal processes, which may affect the built environment and the safety of people.

The coastal processes listed below are most relevant for this investigation and are assessed in the following sections.

- Water levels;
- Swells and local wind waves;
- Wave setup;
- Wave runup and overtopping;
- Storm demand and long-term shoreline recession.

The information presented in the following sections was acquired from the review of previous coastal processes reports as well as from analysis and modelling undertaken specifically for this study.

4.2 Water Levels

Coastal inundation is caused by elevated water levels coupled to extreme waves impacting the coast. Elevated water levels consist of (predictable) tides, which are forced by the sun, moon and planets (astronomical tides), and a tidal anomaly. Tidal anomalies primarily result from factors such as wind setup (or setdown) and barometric effects, which are often combined as "storm surge". Water levels within the surf zone are also subject to wave setup and wave runup. Figure 4.1 diagrammatically represents the different components contributing to coastal inundation.

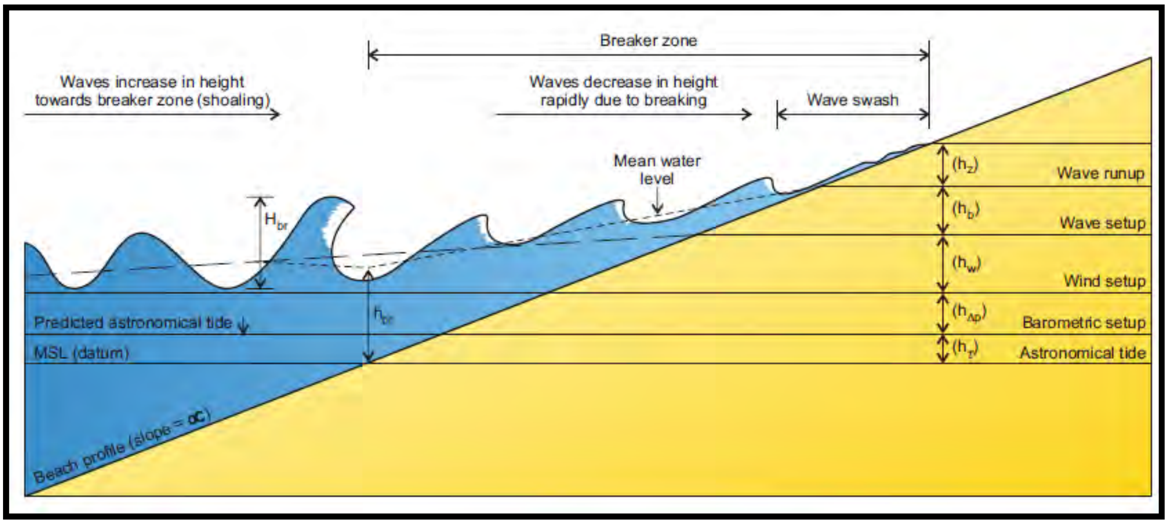


Figure 4.1 Components Elevated Water Levels

The design elevated water levels for the range of average recurrence intervals (ARI) considered in this investigation are presented in Table 4.1 and conform to the recommendations contained in the Coastal Risk Management Guide (DECCW, 2010). While these design water levels incorporate allowance for tides, barometric setup and wind setup (i.e. storm surge), wave setup and wave runup are excluded and needed to be accurately determined through data and/or modelling. Wave setup and runup are intrinsically dependent on the determination of the nearshore wave conditions and were calculated separately for individual locations along the Manly coastline as explained in Section 4.3.

Table 4.1 Design Water Levels Tide +Storm Surge (source DECCW, 2010)

Average Recurrence Interval ARI (yr)	**Water Level Excl. Wave Setup and Runup** (m AHD)
1	1.24
10	1.35
50	1.41
100	1.44

The sea level rise projections for the 2050 and 2100 planning periods adopted in this study were derived from the NSW Sea Level Rise Policy Statement (DECCW, 2009) and are shown in Table 4.2. These benchmarks were established considering the most recent international (Intergovernmental Panel on Climate Change, IPCC, 2007) and national (McInnes, 2007) projections. A revision by the Government is expected to occur following the release of the next IPCC report in 2014.

Table 4.2 Sea Level Rise Projections (source DECCW, 2010)

Planning Period (year)	**(1)Sea Level Rise** (m)
2050	0.40
2100	0.90

Notes: (1) increase above 1990 Mean Sea Level

4.3 Ocean Swell and Local Wind Waves

The Manly LGA coastline is subject to waves originating from offshore storms (swell) or produced locally (wind waves) within Sydney Harbour and the nearshore coastal zone. Swell waves reaching the coast may be modified by the processes of refraction, diffraction, wave-wave interaction and dissipation by bed friction and wave breaking. Locally generated waves undergo generation processes as well as the aforementioned propagation and dissipation processes.

The model SWAN (Simulating WAves Nearshore Delft Hydraulics, version 40.85) was used to quantify the change in wave conditions from a deepwater boundary into the Manly LGA coastline and to model the generation of local wind-waves within Sydney Harbour. Detailed information on the wave modelling is presented in Appendix B.

Model scenarios corresponding to 1, 10, 50 and 100 year ARI events from all directions between north clockwise to north-west were simulated. Directions between north-east and south included an offshore wave component as well as a local wind field, while directions from south-west to north are forced by local winds only. Figure 4.2 shows contours of predicted significant wave heights locally generated by the 100 yr ARI south-westerly wind field.

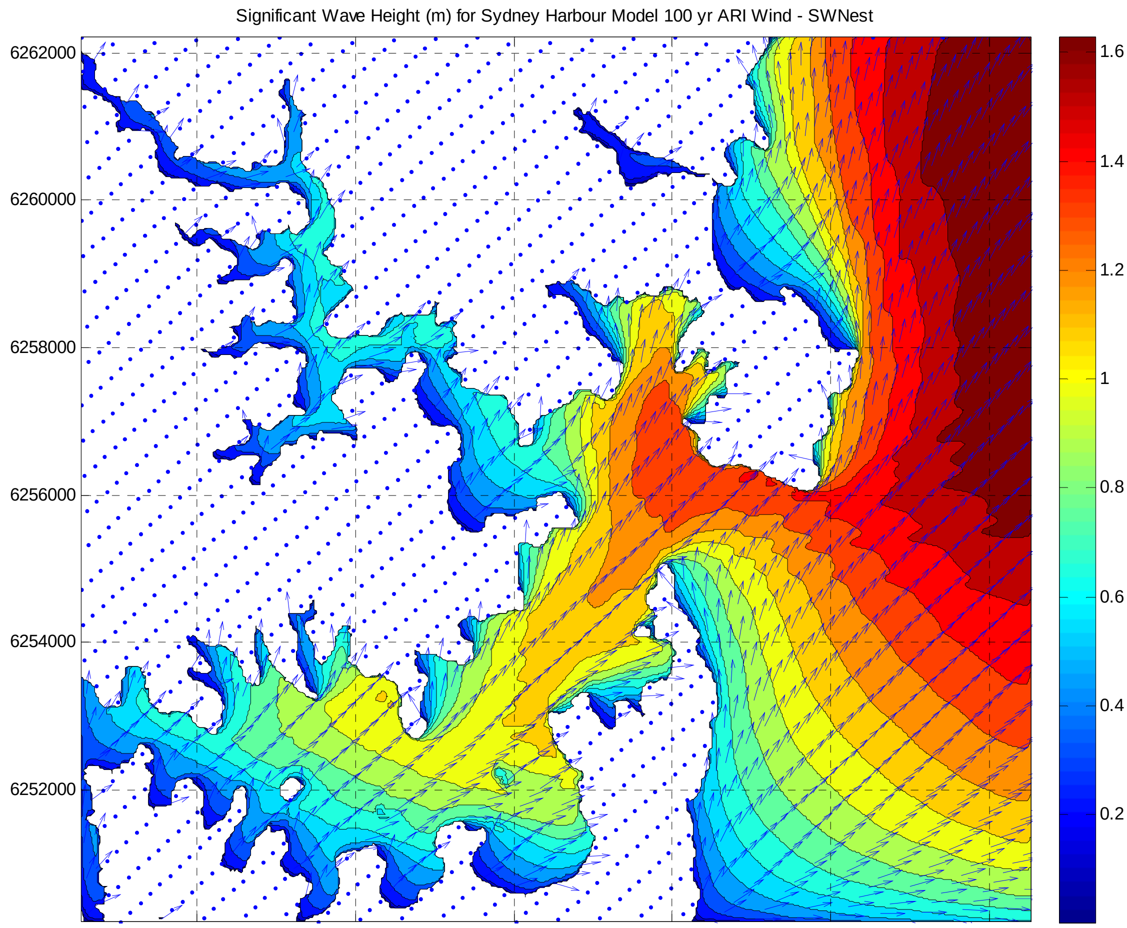


Figure 4.2 SWAN Model Results 100 yr ARI SW Wind Only

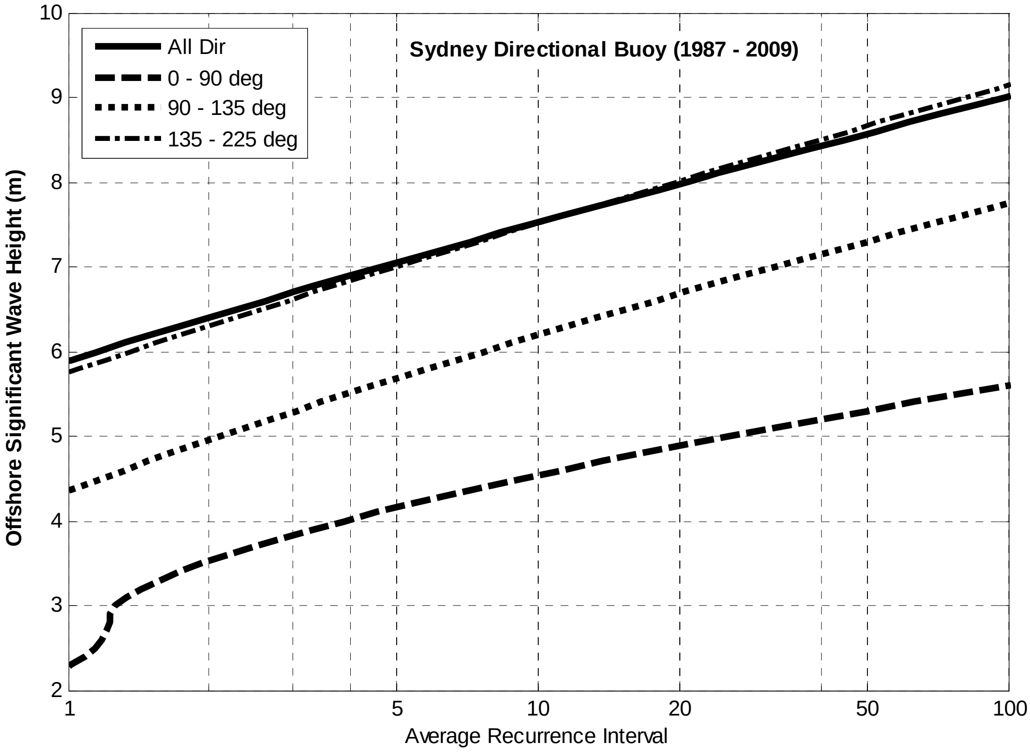


Figure 4.3 Summary of Sydney Directional Extreme Wave Climate (Shand 2010)

Figure 4.3 shows significant wave height for events between 1 and 100 year ARIs from different offshore directions at the Sydney directional wave buoy. Offshore conditions adopted within the present study are depicted in Table 4.3.

Table 4.3 Adopted Directional Extreme Wave Conditions for the Sydney Offshore Wave Buoy (Shand, 2010)

Direction	1 yr ARI		10 yr ARI		50 yr ARI		100 yr ARI	
	H_s (m)	T_p (s)	H_s (m)	T_p (s)	H_s (m)	T_p (s)	H_s (m)	T_p (s)
North-east	3.0	11.0	4.5	12.1	5.4	12.7	5.7	13.0
East	4.4	11.0	6.2	12.1	7.4	12.7	7.8	13.0
South-east	5.9	11.0	7.5	12.1	8.6	12.7	9.0	13.0
South-south-east	5.9	11.0	7.5	12.1	8.6	12.7	9.0	13.0
South	4.4	11.0	6.2	12.1	7.4	12.7	7.8	13.0

Design wind velocities adopted in this study were derived from the Australian Standard AS/NZS 1170.2:2002 *Structural Design Actions Part 2: Wind Actions* and are presented in Table 4.4. This provides wind speeds for 3 second gusts. Equivalent sustained one hour wind speeds were calculated using the approach set out in Figure II-2-1 of Part II of the USACE Coastal Engineering Manual (CEM, 2003).

For the purpose of the subsequent modelling of coastal inundation and wave overtopping of seawalls, detailed information including significant wave height, mean and peak period and direction was extrapolated for 25 coastal locations of interest within the Manly coastline. These representative locations are presented Figure 4.4.

Table 4.4 Adopted Extreme Wind Conditions for the Sydney Coastal Area (source: ASNZS1170)

Direction	Multiplier	1 Hour Average (ms^{-1})			
		1 yr ARI	**10 yr ARI**	**50 yr ARI**	**100 yr ARI**
North-east	0.80	13.8	18.0	20.8	21.7
East	0.80	13.8	18.0	20.8	21.7
South-east	0.95	16.4	21.4	24.7	25.8
South	0.90	15.5	20.3	23.4	24.4
South-west	0.95	16.4	21.4	24.7	25.8
West	1.00	17.2	22.5	26.0	27.2
North-west	0.95	16.4	21.4	24.7	25.8
North	0.80	13.8	18.0	20.8	21.7

Figure 4.4 Wave Modelling Output Locations

4.4 Wave Setup

Wave setup is defined as the local quasi-steady increase in water level inside a surf zone due to transfer of wave momentum. The numerical surfzone model of Dally, Dean and Dalrymple (1984) was implemented using SWAN wave modelling output to calculate local wave setup at each representative location along the Manly coastline.

4.5 Wave Runup and Overtopping

The majority of beaches within the Manly coastline are backed by seawalls. During storm events, waves frequently impact these seawalls and overtopping of the crests occurs in the form of bores of water being discharged inland or splashes of water being projected upwards and eventually transported inland by onshore winds. Wave overtopping can cause serious structural damage to the seawall crest and to properties immediately behind the seawall. Figure 4.5 shows a photo of the North Steyne seawall collapsed in front of Pacific St due to wave overtopping.

Figure 4.5 North Steyne Seawall Collapsed in front of Pacific St (25/05/1943)

Overtopping also constitutes a direct hazard to pedestrians and vehicles transiting in the proximity of the seawall during storm events. Figure 4.6 depicts waves overtopping at Fairy Bower and Manly LSC.

Wave runup is defined as the extreme level of the water reached on a structure slope by wave action. Unlike wave setup, wave runup is highly fluctuating and dynamic phenomenon and it is commonly described using the runup parameter $R_{u2\%}$ which is the runup level exceeded by 2% of the waves. For vertical or near vertical seawalls, overtopping is typically characterised by up-rushing jets of water and wave runup is not addressed as it is not considered a measure of physical importance for this class of structures (Eurotop, 2007).

Figure 4.6 ***Top Photos*** **Wave Overtopping at Fairy Bower;** ***Bottom Photos*** **Wave Runup at Manly LSC Boat Ramp and Manly Beach Stairs at Victoria Pde (26/06/2003 Photos James Carley, WRL)**

Wave overtopping depends on the:

- hydraulic parameters such as water level, wave height and period; and
- structural parameters such as the seawall construction (sandstone masonry, precast concrete blocks, rock revetments etc.), slope (vertical, battered, sloping) and crest levels.

Wave overtopping was calculated for fourteen representative locations along the Manly coastline based on:

- the extreme water levels incorporating storm surge and wave setup;
- the nearshore wave parameters (significant wave height and peak wave period) as derived from SWAN numerical wave modelling; and
- the seawall structural features (crest level, slope etc.) as derived from the field survey.

The representative locations were chosen taking into consideration the local wave and water level conditions and the seawall characteristics.

Wave overtopping was calculated for the 1, 50 and 100 yr ARI storm events for present day conditions and for the 2050 and 2100 planning horizons. Wave overtopping was reported as the volume of water discharged above the crest level on average over the duration of the storm, and expressed in *L/s per m*. In this form, wave overtopping could be related to published tolerable rates (CEM, 2003, Eurotop, 2007) in regards to structural and people safety.

4.6 Beach Erosion and Shoreline Recession

The beach erosion process relates to the erosion of the beach by a single extreme storm event or from several storm events in close succession (DECCW, 2010). The amount of sand (above 0 m AHD) transported offshore by wave action is referred to as “storm demand” and expressed as a volume of sand per metre length of beach *(m^3/m)*. Figure 4.7 shows a photo of the eroded beach after a storm in front of the Manly LSC with the seawall rock apron left exposed.

Figure 4.7 Photo of Eroded Beach near Manly LSC (06/02/2008)

Along the Manly coastline, storm demand varies depending on several factors such as exposure of the beach, wave conditions (i.e. wave height, period and direction relative to the beach alignment), water levels and state of the beach prior the storm. Design storm demands for the Manly Ocean and Harbour beaches were provided by previous Coastal Hazard Definition Studies (Patterson Britton, 2003 and 2004) and are presented for each beach in Table 4.5.

These values were re-assessed and verified through analysis of the historical beach profiles (photogrammetric analysis) and SBEACH numerical modelling (Larson, 1989, Larson, 1990, Carley and Cox, 2003). Storm demand volumes of 250 to 320 m^3/m have been observed on more exposed beaches in NSW (NSW Government, 1990). Note that these volumes may not eventuate where a functioning seawall prevents the full extent of erosion occurring.

Shoreline recession is the progressive onshore shift of the long term average land-sea boundary which may result from sediment loss and/or increasing water levels. It is expressed in terms of change over years in volume of sand within the beach fronting the seawalls *($m^3/m/yr$)* and/or corresponding landward shoreline movement *(m/yr)*.

Recession rates due to sediment loss along the Manly Ocean and Harbour beaches were derived from the review of previous Manly coastal studies (Patterson Britton, 2003 and 2004, Cardno, 2009) and verified though the analysis of long term changes in sand volumes (photogrammetric analysis). A summary of the values adopted for this study are presented in Table 4.5.

Table 4.5 Summary of Adopted Storm Demands and Recession Rates For Manly LGA Beaches

Location	Volume of Storm Demand (m^3/m)	Ongoing Underlying Recession Rate due to Sediment Loss	
		(m3/m/yr)	(m/yr)
Queenscliff SLSC	180	0.00	0.00
North Steyne SLSC	160	0.00	0.00
Corso and Raglan St	130	0.00	0.00
Victoria Pde	100	0.00	0.00
Fairy Bower Beach	80	0.25	0.13
Shelly Beach	40	0.00	0.00
Fairlight Beach	40	0.10	0.04
Delwood Beach	40	0.00	0.00
Manly Cove East	20	0.11	0.05
Manly Cove West	30	0.00	0.02
40 Baskets Beach	15	0.08	0.06
Little Manly	25	0.27	0.10
Collins Beach	10	0.00	0.00
Store Beach	10	0.00	0.00
Quarantine	10	0.00	0.00
Clontarf North	10	0.00	0.00
Clontarf Pool	10	0.00	0.00
Clontarf South	10	-	0.10

It is expected that open coast beaches will recede under conditions of accelerated sea level rise (SLR). Recession rates due to SLR can be estimated using the *Bruun Rule* (Bruun, 1962, 1988) as the rate of sea level rise divided by the average slope ("Bruun Factor") of the active beach profile. This rule is based on the concept that the existing beach profile is in equilibrium with the incident wave climate and existing average water level and it assumes that the beach system is two-dimensional and that there is no interference with the equilibrium profile by headlands and offshore reefs.

Figure 4.8 shows photos of Fairy Bower beach in 1924 and present day. Fairy Bower Beach has been receding at an average rate of 0.1 m/yr since 1930.

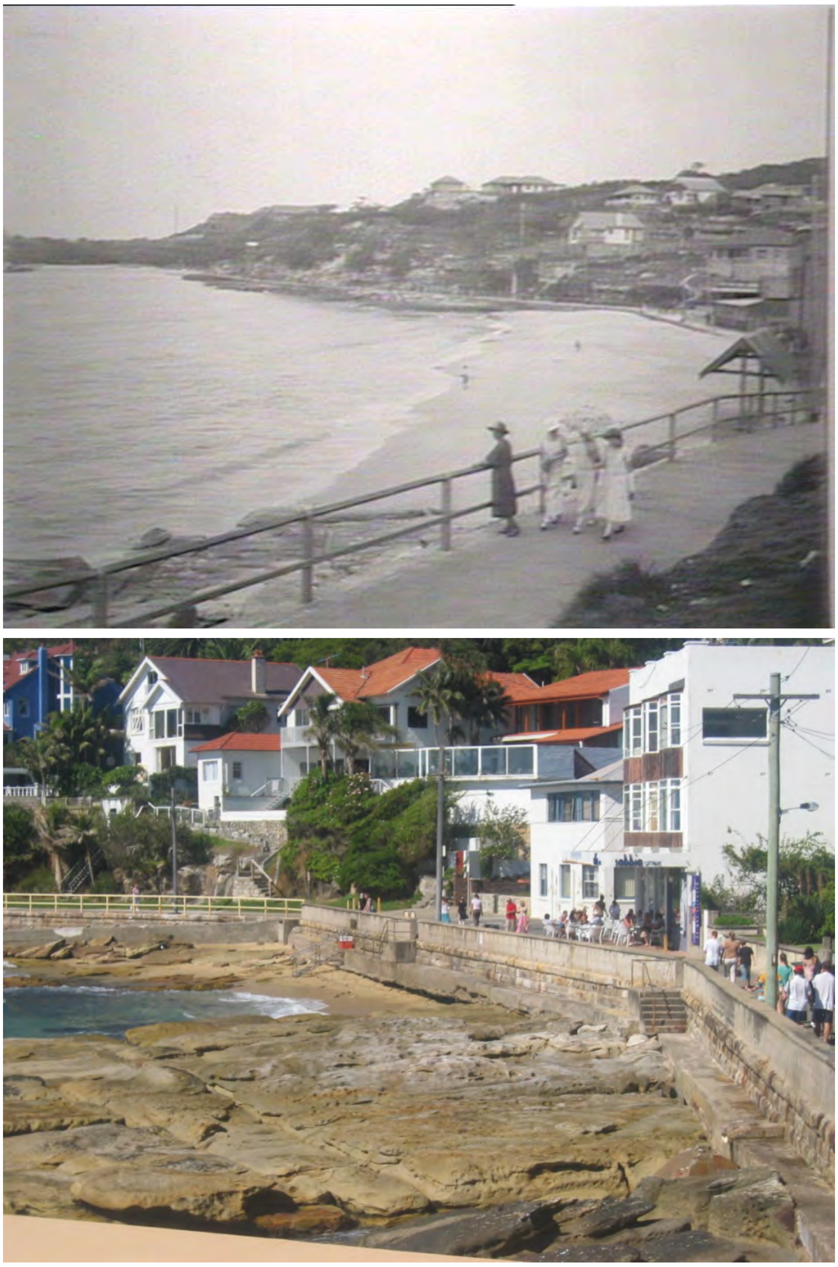


Figure 4.8 Fairy Bower Beach in 1924 and Present Day (18/04/2005)

5. Coastal Hazard Lines Determination

5.1 Overview of Coastal Hazards

The NSW Government (1990) “Coastline Management Manual” identifies seven separate coastal hazards, namely:

- Beach erosion;
- Shoreline recession;
- Coastal entrance behaviour;
- Sand (aeolian) drift;
- Coastal inundation;
- Slope and cliff instability; and
- Stormwater erosion.

The dominant coastal hazards within the Manly coastline are the hazards of beach erosion and shoreline recession (due to ongoing underlying processes and future sea level rise) which are combined into a “coastline hazard line” for various planning periods. The coastal inundation hazard also relevant for the study area is discussed in Section 6. The assessment of the coastal hazards in this section draws widely from the coastal process assessment described in Section 4.

Coastal entrance behaviour and aeolian sand drift present only minor hazards within the Manly coastline. The Manly LGA has no major estuaries or inlets and most of the beaches are backed by seawalls and grassed berms which prevent major sand loss for the beach compartment by wind action. Stormwater erosion can cause local scouring of sand in the proximity of the stormwater outlets when these discharge directly onto the beach. Rocky cliff instability and potential geotechnical hazards were not considered in this study as these would involve a geotechnical and geological assessment, which was beyond the present scope of works.

5.2 Coastal Erosion Hazard Lines

In accordance with the recommendations within the Coastal Risk Management Guide (DECCW, 2010), coastal hazard lines were identified for the present condition and for the 2050 and 2100 planning horizons including sea level rise projections (0.4 m and 0.9 m for 2050 and 2100 respectively).

Figure 5.1 presents the method for estimation of immediate and future position of the coastal hazard lines diagrammatically. The landward limit of the coastline hazard zone corresponds to the estimated position of the backshore erosion scarp for the particular planning period. The immediate hazard line position was obtained considering the erosion hazard due to storm demand and allowing for slope instability. The future hazard line (for the 2050 and 2100 planning horizon) was estimated adding the underlying shoreline recession and the sea level rise induced shoreline recession.

Four key components of coastal setback were defined in this study and incorporated into the hazard line, namely:

- S1: Allowance for short term storm erosion (storm demand);
- S2: Allowance for dune stability (Zone of Reduced Foundation Capacity – ZRFC as defined by Nielsen et al., 1992);
- S3: Allowance for ongoing underlying recession; and
- S4: Allowance for recession due to future sea level rise (SLR).

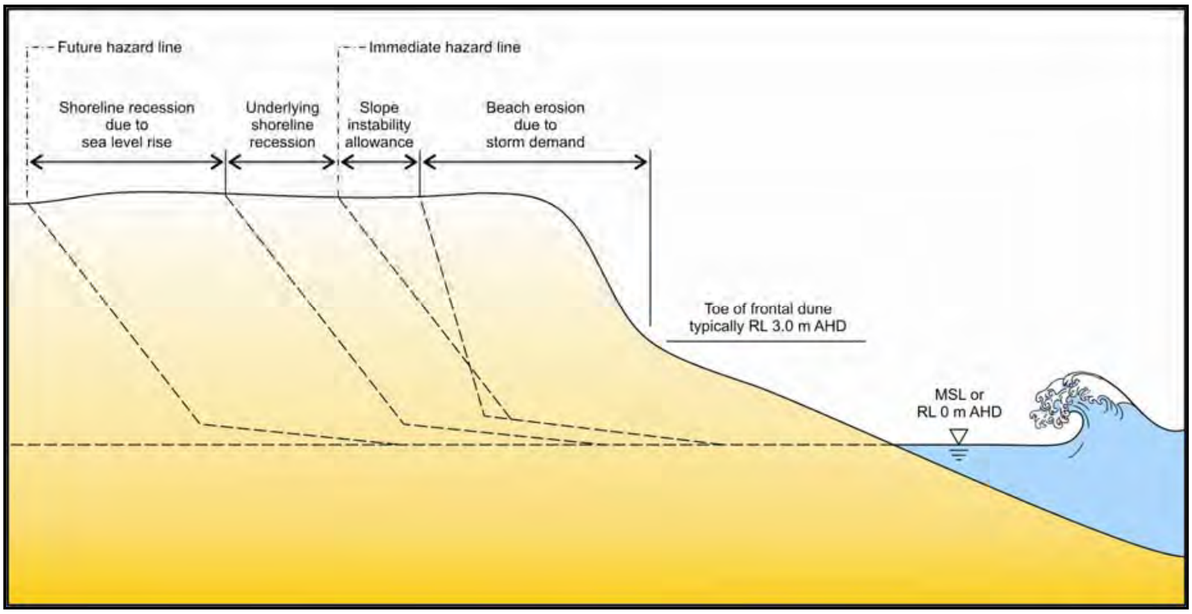


Figure 5.1 Estimation of Coastal Hazard Lines

The total design setback (S) for three planning horizons comprises:

- Present day: S = S1 + S2;
- 2050: S = S1 + S2 + S3*(2050)* + S4*(2050)*; and
- 2100: S = S1 + S2 + S3*(2100)* + S4*(2100)*.

Most of the sandy beaches within the Manly Council LGA are backed by seawalls. Therefore, assuming the seawalls will not fail during an extreme storm event, the erosion hazard lines will coincide with the seawall locations.

Coastal erosion hazard lines with the seawall in place are shown for every beach within the Manly LGA in Appendix C Figures C.1 to C.12. In the event of seawall failure, erosion will progress inland and allowances for this scenario were calculated and shown for each location in Appendix C Figures C.13 to C.21.

Figure 5.2 shows a photo of North Steyne seawall collapsed and progression of erosion beyond the seawall position. Figure 5.3 presents estimated erosion hazard lines for North Steyne in case of seawall failure.

Figure 5.2 North Steyne Collapsed Seawall 27/06/1950

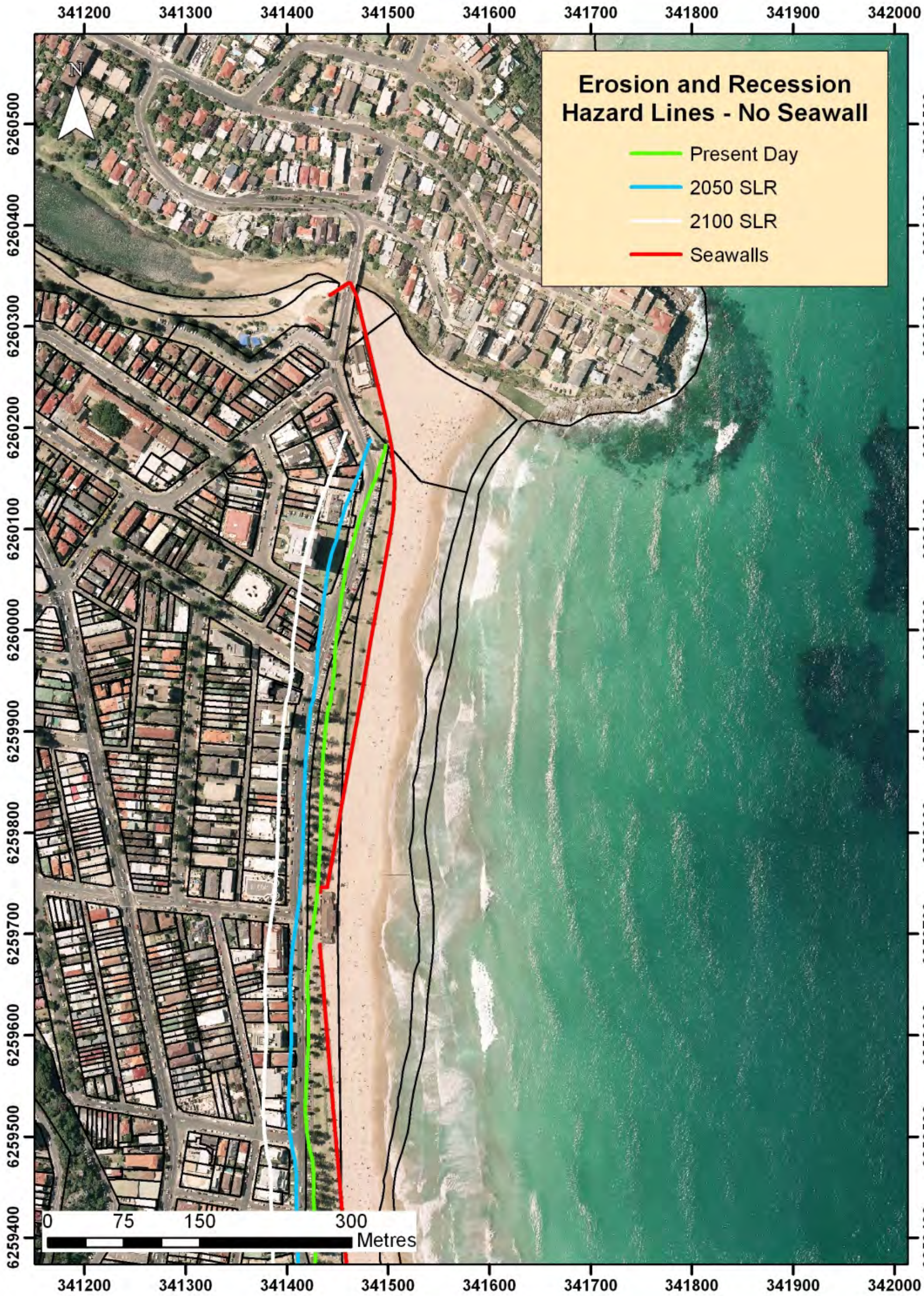


Figure 5.3 Predicted Coastal Erosion Hazards Line (No Seawall)

The allowances for short term storm erosion and dune stability (S1 and S2) are shown in Table 5.1. Table 5.1 also summarises the present day horizontal setback distances from the 2008 (relative to LIDAR topographic dataset obtained Manly Council) +1 m AHD contour level for the harbour beaches and +2 m AHD contour level for the ocean beaches.

Due to no photogrammetric data being available, no formal analysis could be undertaken for the section of beach located in Ellery's Punt reserve. Moreover, the presence of underlying bedrock at that location will alter the progression of the erosion and recession. As a qualitative estimate only, the total present day setback S was predicted to be approximately 14 m from the present position of the embankment scarp (assuming a volume of storm demand of 5 m^3/m and an average ground level behind the beach of 2.2 m AHD).

The allowances for ongoing underlying (S3) and SLR (S4) recession for the 2050 and 2100 planning horizon are described in Table 5.2. While Table 5.3 summarises 2050 and 2100 horizontal setback distances from the 2008 (relative to DEM obtained Manly Council) +1 m AHD contour level for the harbour beaches and +2 m AHD contour level for the ocean beaches.

Table 5.1 Allowances for short term storm erosion, dune stability and present day horizontal setback distances (from 2008 +1 m AHD and +2 m AHD contour levels)

		S1			S2	S = S1+S2
	Representative Profile Location	**Storm demand** (m3/m)	**Average ground level behind beach** (m AHD)	**[1]Equivalent horizontal distance relative to 2008 +2 m (or +1 m) AHD contour** (m)	**Indicative width of ZRFC** (m)	**Present day horizontal setback [1]** (m)
Harbour Beaches	[2]Sandy Bay	10	1.8	na	6.4	7
	Clontarf North	10	2.3	9	7.1	16
	Clontarf Pool	10	2.0	6	6.7	13
	Clontarf South	10	2.5	8	7.4	15
	40 Baskets Beach	15	2.0	11	6.7	17
	[3]Fairlight Beach	40	4.1	20	9.8	30
	[4]Delwood Beach	40	na	na	na	na
	Manly Cove West	30	3.5	20	8.9	29
	Manly Cove East	20	0.0	9	8.2	18
	Little Manly Cove	25	3.5	17	8.9	26
	Collins Beach	10	1.3	5	5.6	11
	Store beach	10	1.9	9	6.5	16
	Quarantine	10	1.5	7	5.9	13
Ocean Beaches	Queenscliff SLSC	180	6.0	45	12.6	58
	North Steyne SLSC	160	6.0	41	12.6	54
	Corso and Raglan St	130	4.8	43	10.8	54
	Victoria Pde	100	3.7	26	9.2	35
	[4]Fairy Bower Beach	80	na	na	na	na
	Shelly Beach	40	2.1	5	6.8	11

Notes:

(1a) Horizontal distance is subject to ground level and volume

(1b) Horizontal distance relative to 2008 +1 m AHD contour for harbour beaches and +2 m AHD contour for ocean beaches

(2) Erosion hazard line seaward of +1 m AHD contour

(3) The presence of underlying rock may alter the hazard line location

(4) These are beaches formed by a shallow veneer of sand over rock platforms. Erosion is not expected to progress once the rock platform is uncovered.

Table 5.2 Allowances for underlying and SLR recession

		S3			S4		
	Representative Profile Location	**[1]Underlying recession** (m/yr)	**2050** (m)	**2100** (m)	**Bruun factor (active slope)** (-)	**2050** (m)	**2100** (m)
Harbour Beaches	Sandy Bay	0.00	0.0	0.0	11	4	9
	Clontarf North	0.00	0.0	0.0	11	4	9
	Clontarf Pool	0.00	0.0	0.0	11	4	9
	Clontarf South	0.10	4.0	9.0	11	4	9
	40 Baskets Beach	0.06	2.4	5.4	15	5	13
	[2]Fairlight Beach	0.04	1.6	3.6	18	6	15
	[2]Delwood Beach	0.00	0.0	0.0	8	3	7
	Manly Cove West	0.02	0.8	1.8	16	5	13
	Manly Cove East	0.05	2.0	4.5	33	11	28
	Little Manly Cove	0.10	4.0	9.0	15	5	13
	Collins Beach	0.00	0.0	0.0	15	5	13
	Store beach	0.00	0.0	0.0	15	5	13
	Quarantine	0.00	0.0	0.0	15	5	13
Ocean Beaches	Queenscliff SLSC	0.00	0.0	0.0	50	17	42
	North Steyne SLSC	0.00	0.0	0.0	50	17	42
	Corso and Raglan St	0.00	0.0	0.0	50	17	42
	Victoria Pde	0.00	0.0	0.0	50	17	42
	Fairy Bower Beach[2]	0.13	5.2	11.7	50	17	42
	Shelly Beach	0.00	0.0	0.0	50	17	42

Notes:

(1) For beaches accreting, recession was conservatively considered nil

(2) The presence of underlying rock may alter the hazard line location

Table 5.3 2050 and 2100 Horizontal Setback Distances (from 2008 DEM contours)

		S = S1+S2+S3+S4 (1)Total horizontal setback from +1 m AHD (+2 m AHD) contour (from 2008)	
	Representative Profile Location	**2050** (m)	**2100** (m)
Harbour Beaches	Sandy Bay	11	16
	Clontarf North	19	25
	Clontarf Pool	17	22
	Clontarf South	23	34
	40 Baskets Beach	25	35
	Fairlight Beach	38	49
	Delwood Beach(2)	na	na
	Manly Cove West	35	44
	Manly Cove East	31	50
	Little Manly Cove	35	48
	Collins Beach	16	23
	Store beach	21	28
	Quarantine	18	25
Ocean Beaches	Queenscliff SLSC	75	100
	North Steyne LSC	71	96
	Corso and Raglan St	71	96
	Victoria Pde	52	77
	Fairy Bower Beach(2)	na	na
	Shelly Beach	28	53

Notes:

(1) Horizontal distance relative to 2008 +1 m AHD contour for harbour beaches and +2 m AHD contour for ocean beaches

(2) The presence of underlying rock may alter the hazard line location

6. Coastal Inundation Determination

6.1 Overview

Coastal inundation is the flooding of coastal areas by ocean waters. It is due to elevated water levels coupled to extreme waves impacting the coast. Consequently, inundation levels along the coast are characterised by two components:

- a "quasi-static" component, which includes the effects of elevated water levels due to tide, storm surge and wave setup; and
- a "dynamic" component, which includes the effects of wave runup and wave overtopping caused by the direct impact of waves on the coastal structures.

The "quasi-static" inundation level is the most representative inundation level for areas located away from direct impact of the overtopping waves (generally those properties which are not in the front row facing the water). Wave runup and overtopping are a predictor of the wave impacts beachfront structures are likely to suffer during extreme storm events.

6.2 Coastal Inundation Zones

Design water levels incorporating tide and storm surge were presented in Section 4.2 (Table 4.1) and derived from the Coastal Risk Management Guide (DECCW, 2010). Wave setup varies along the Manly beaches as it is intrinsically dependent on the wave conditions at each beach. For instance, harbour beaches will present a lower wave setup compared to the ocean beaches due to the typically lower incident wave conditions.

Wave setup was calculated by implementing the Dean, Dally Darlymple surfzone model (1984) locally at every representative location within the Manly coastline using the nearshore wave modelling outputs (refer to Section 4.3 and 4.4). "Quasi-static" inundation levels were then derived by adding the calculated wave setup to the design water levels.

Predicted inundation levels incorporating astronomical tide, barometric setup, wind setup and wave setup for present day conditions are presented in Table 6.1. Inundation levels for the 2050 and 2100 planning horizons are presented in Table 6.2. Based on these inundation levels, mapping of inundation was undertaken using the 2008 LIDAR topographic data (provided by the Manly Council) and GIS modelling. Inundation zones along the Manly coastline for the 100 yr ARI present day and 2050 and 2100 planning horizons are shown in Appendix D Figures D.1 to D.16.

Table 6.1 Summary of Present Day Inundation Levels (excluding wave runup and overtopping)

	Representative Profile Location	Present Inundation Level (m AHD)			
		100yr ARI	**50yr ARI**	**10yr ARI**	**1yr ARI**
		1% AEP	**2% AEP**	**9% AEP**	**63% AEP**
Harbour Beaches	Seaforth	1.5	1.5	1.4	1.3
	Sandy Bay	1.5	1.5	1.4	1.3
	Clontarf North	1.5	1.5	1.4	1.3
	Clontarf Pool	1.5	1.5	1.4	1.3
	Clontarf South	1.5	1.5	1.4	1.3
	Washaway	2.2	2.1	1.9	1.8
	Reef Beach	1.6	1.6	1.5	1.4
	40 Baskets	1.6	1.5	1.5	1.3
	N. Harbour Res.	1.5	1.5	1.4	1.3
	Fairlight Beach	1.9	1.8	1.7	1.6
	Delwood	1.8	1.7	1.6	1.5
	Manly Cove W.	1.7	1.7	1.6	1.4
	Manly Cove E.	1.6	1.6	1.5	1.4
	Little Manly	1.7	1.6	1.5	1.4
	Collins Beach	1.6	1.5	1.4	1.3
	Store beach	1.5	1.5	1.4	1.3
	Quarantine	1.5	1.5	1.4	1.3
Ocean Beaches	Queenscliff	2.6	2.5	2.3	2.1
	North Steyne	2.6	2.5	2.3	2.1
	Corso and Raglan St	2.2	2.2	2.1	1.8
	Victoria Parade	2.2	2.2	2.0	1.8
	Fairy Bower	1.6	1.6	1.5	1.4
	Shelly Beach	1.8	1.8	1.7	1.6

Table 6.2 Summary of Inundation Levels for the 2050 and 2100 Planning Period (excluding wave runup and overtopping)

	Representative Profile Location	2050 Inundation Level (m AHD)				2100 Inundation Level (m AHD)			
	ARI	**100yr**	**50yr**	**10yr**	**1yr**	**100yr**	**50yr**	**10yr**	**1yr**
	AEP	**1%**	**2%**	**9%**	**63%**	**1%**	**2%**	**9%**	**63%**
Harbour Beaches	Seaforth	1.9	1.9	1.8	1.7	2.4	2.4	2.3	2.2
	Sandy Bay	1.9	1.9	1.8	1.7	2.4	2.4	2.3	2.2
	Clontarf North	1.9	1.9	1.8	1.7	2.4	2.4	2.3	2.2
	Clontarf Pool	1.9	1.9	1.8	1.7	2.4	2.4	2.3	2.2
	Clontarf South	1.9	1.9	1.8	1.7	2.4	2.4	2.3	2.2
	Washaway	2.6	2.5	2.3	2.2	3.1	3.0	2.8	2.7
	Reef Beach	2.0	2.0	1.9	1.8	2.5	2.5	2.4	2.3
	40 Baskets	2.0	1.9	1.9	1.7	2.5	2.4	2.4	2.2
	N. Harbour Res.	1.9	1.9	1.8	1.7	2.4	2.4	2.3	2.2
	Fairlight Beach	2.3	2.2	2.1	2.0	2.8	2.7	2.6	2.5
	Delwood	2.2	2.1	2.0	1.9	2.7	2.6	2.5	2.4
	Manly Cove W.	2.1	2.1	2.0	1.8	2.6	2.6	2.5	2.3
	Manly Cove E.	2.0	2.0	1.9	1.8	2.5	2.5	2.4	2.3
	Little Manly	2.1	2.0	1.9	1.8	2.6	2.5	2.4	2.3
	Collins Beach	2.0	1.9	1.8	1.7	2.5	2.4	2.3	2.2
	Store beach	1.9	1.9	1.8	1.7	2.4	2.4	2.3	2.2
	Quarantine	1.9	1.9	1.8	1.7	2.4	2.4	2.3	2.2
Ocean Beaches	Queenscliff	3.0	2.9	2.7	2.5	3.5	3.4	3.2	3.0
	North Steyne	3.0	2.9	2.7	2.5	3.5	3.4	3.2	3.0
	North of Corso	2.6	2.6	2.5	2.2	3.1	3.1	3.0	2.7
	Victoria Parade	2.6	2.6	2.4	2.2	3.1	3.1	2.9	2.7
	Fairy Bower	2.0	2.0	1.9	1.8	2.5	2.5	2.4	2.3
	Shelly Beach	2.2	2.2	2.1	2.0	2.7	2.7	2.6	2.5

6.3 Wave Overtopping of Seawalls

The majority of sandy beaches within the Manly LGA are backed by vertical or near vertical seawalls. Wave runup at this class of structure is not well defined and typically not considered, as overtopping is characterised by up-rushing jets of water being thrown upwards (Eurotop, 2007). Overtopping was quantified in terms of volume of water being discharged above the seawall crest and expressed in *L/s* per metre length of crest.

Wave overtopping was quantified for each structure taking into account the following factors:

- structural characteristics of the seawalls (construction type, crest level, slope etc.) derived from the site inspection and complemented by the review of previous technical reports;
- nearshore wave conditions i.e. wave height and period as derived from the wave modelling exercise. Typically depth limited conditions dominated at the ocean beach seawalls while non-breaking wave conditions dominated at the harbour seawalls;
- elevated water levels calculated by at each representative location incorporating tides, storm surge and wave setup;

Best practice empirical prediction methods based on the most current published literature (Eurotop, 2007) were applied to estimate wave overtopping and runup levels at the structures. The estimated overtopping rates refer to the zone immediately behind the structure crest and can be related to the published tolerable rates (CEM, 2003, EurOtop, 2007) in regards to structural and people safety. Range of mean tolerable overtopping rates for hazards relevant to the study area are presented in Table 6.3 (Eurotop, 2007).

Table 6.3 Limits for Tolerable Mean Wave Overtopping Discharges (Eurotop 2007)

Hazard type	**Mean Overtopping Discharge** (L/s per m)
Aware pedestrian and or trained staff expecting to get wet	0.1 to 10
Damage to paved promenade behind seawall	200
Damage to grassed promenade behind seawall	50
Structural damage to seawall crest	200
Structural damage to building	1 (1)

Notes: (1) this limit relates to the effective overtopping defined at the building

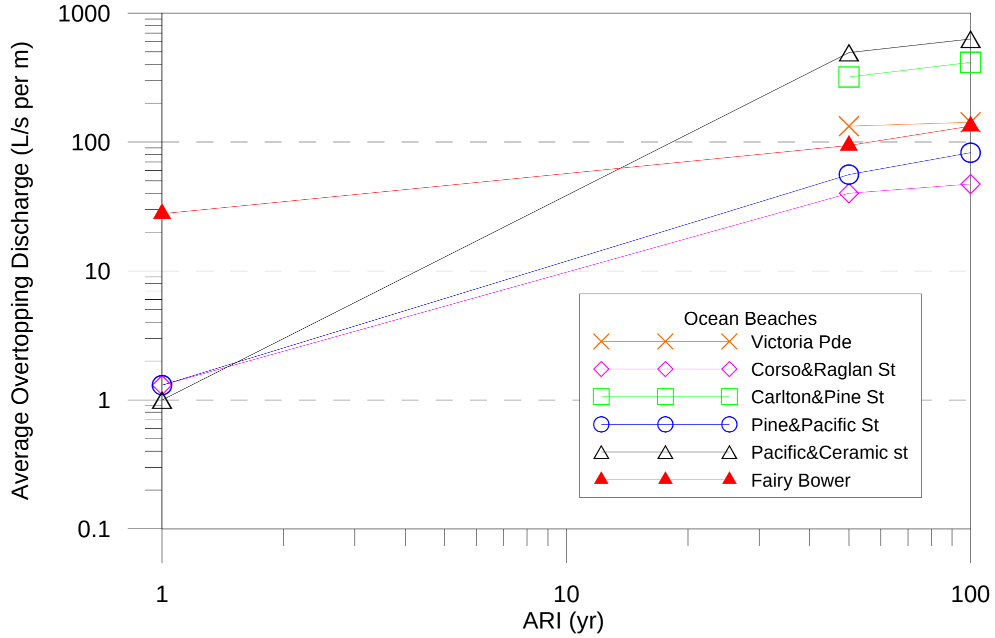
For the purpose of estimating the hazard from wave overtopping for buildings, infrastructure and pedestrians located at a certain distance inland from the seawall crest, the propagation distance of the bore landwards of the crest was estimated based on the methodology presented in FEMA guidelines (FEMA, 2000). The approach used is a simplistic approach and the estimated distance of bore propagation needs to be considered as an estimate of the order of magnitude only.

Present day predicted overtopping discharges for the ocean and harbour beaches are diagrammatically summarised in Figures 6.1. Corresponding overland bore propagation distances are shown in Figure 6.2. Overtopping discharges and related overland propagation distances for present day conditions are tabulated in Tables 6.4 and 6.5 respectively.

On the ocean beaches, Fairy Bower seawall was predicted to be the most heavily overtopped (28 L/s per m) for the present day 1 yr ARI storm event. During this event, the overtopping water bores were predicted to travel inland for distances of the order of 10 m. Considered that the setback distance of the buildings at this location is approximately 3.5 m, it is expected the buildings behind the seawall to be significantly impacted by wave overtopping starting from the 1 in 1 yr ARI event. Based on the tolerable limits presented in Table 6.3, wave overtopping at this location is likely to cause hazard both for pedestrian safety and structural integrity of buildings.

On the harbour beaches, overtopping rates for the present day 1 yr ARI storm event were predicted to be highest (211 L/s per m) at the Forty Baskets seawall. The seawall is backed by a grassed area with the properties at a setback distance of 25 metres. Based on the predictions, it is not expected that the properties will be impacted by overtopping bores during the 1 yr ARI. Nevertheless, based on the tolerable limits presented in Table 6.3, wave overtopping during the 1 yr ARI storm event at this location is likely to constitute hazard for pedestrians in proximity of the seawall, erosion of the grassed area and structural damage to the seawall crest.

Overtopping discharges and overland propagation distances estimated for the 2050 planning horizon are presented in Tables 6.6 and 6.7 respectively. Overtopping discharges and related overland propagation distances for 2100 planning horizon are tabulated in Tables 6.8 and 6.9 respectively.



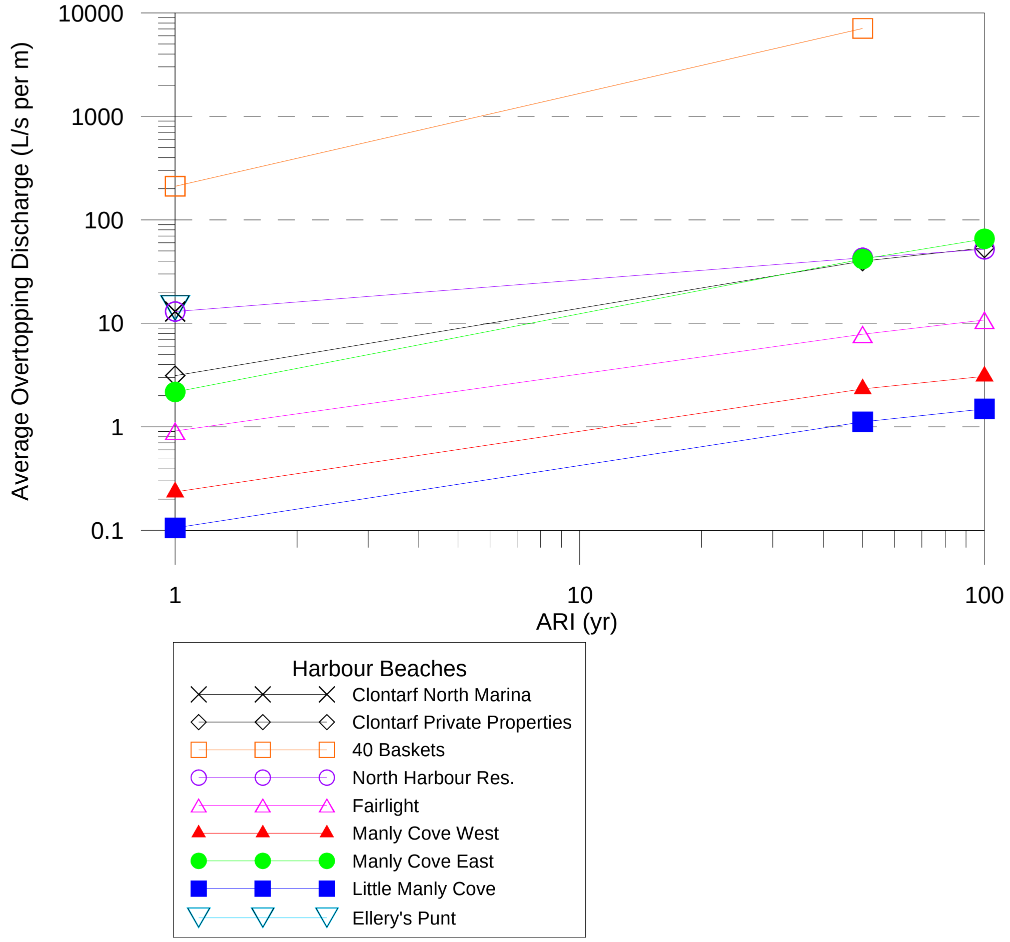


Figure 6.1 Plot of Present Day Predicted Overtopping Discharges

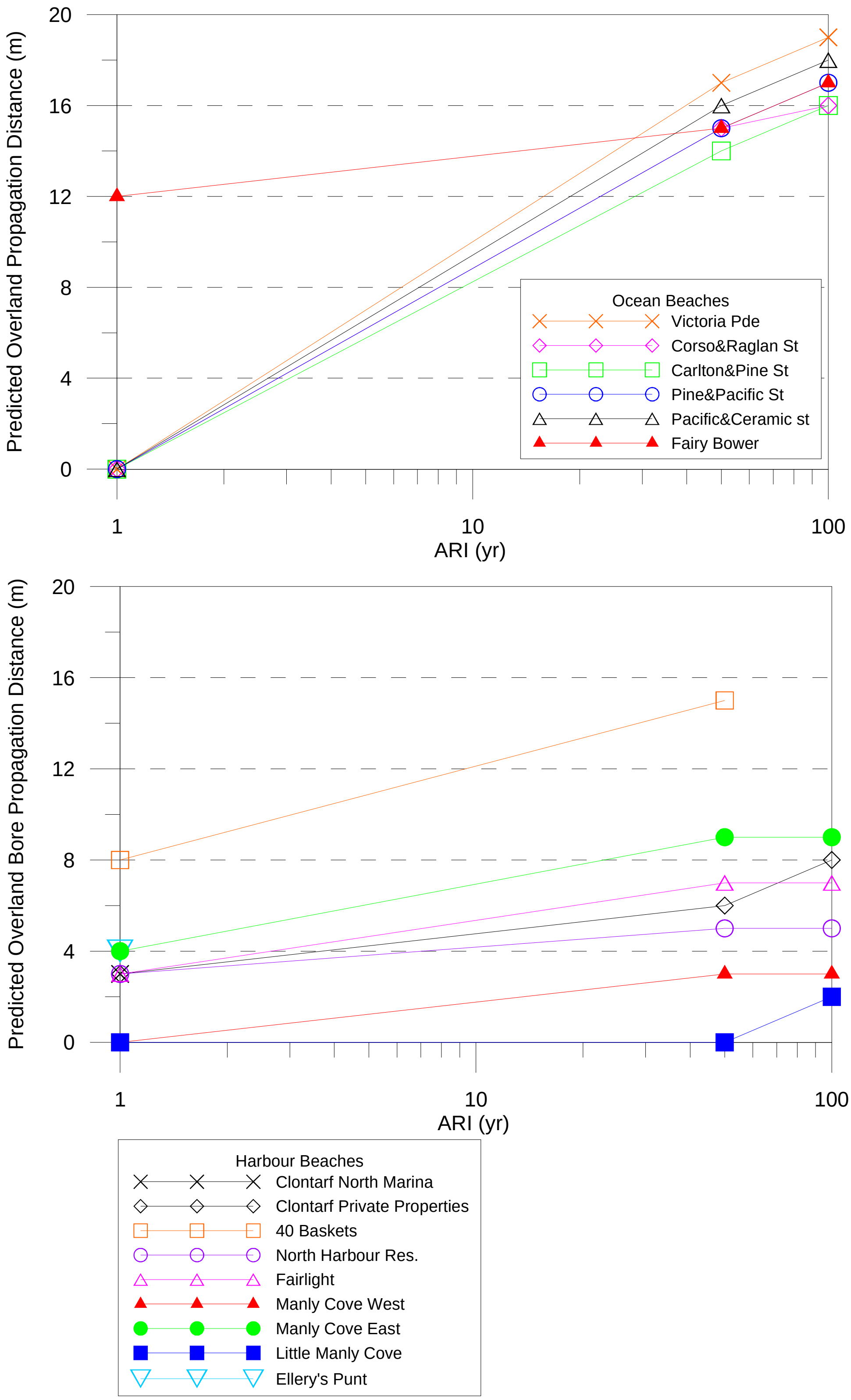


Figure 6.2 Plot of Present Day Overland Overtopping Propagation Distances

Table 6.4 Present Day Predicted Wave Overtopping Discharge

Location	Construction	(2)Crest Level	Mean Overtopping Discharge (L/s per m)		
		(m AHD)	100 yr ARI	50 yr ARI	1 yr ARI
Ellery's Punt	Vertical	1.5	(1)t.i.	(1)t.i.	14
Clontarf Sandy Bay	Sloping	1.8	173	152	7
Clontarf btw Sandy Bay and Marina	Sloping	1.5	(1)t.i.	(1)t.i.	13
Clontarf at private properties	Vertical	2.2 (1.6-2.5)	53	40	3
40 Baskets Seawall	Vertical	1.6	(1)t.i.	7,073	211
North Harbour Reserve	Sloping Rocks	1.6	52	43	13
Fairlight Beach	Vertical	2.7 (2.2–3.3)	11	8	1
Manly Cove West	Vertical	3.3 (2.9–3.5)	3	2	0
Manly Cove East	Vertical	2.2 (2.2-3.2)	66	42	2
Little Manly Beach	Vertical	3.5 (2.4-3.5)	1	1	0
Manly Victoria Parade	Vertical	3.4 (3.4-4.0)	142	133	0
Manly btw Corso and Raglan St	Vertical	4.7 (4.5–6.0)	47	40	1
Manly N. Steyne btw Carlton and Pine St	Sloping concrete blocks	5.9 (4.5-6.0)	415	319	0
Manly N. Steyne btw Pine St and Pacific St	Vertical battered	5.7 (4.5-6.0)	83	56	1
Manly Queenscliff btw Pacific St and Ceramic Lane	Sloping concrete blocks	5.0	629	493	1
Manly Parade Seawall Fairy Bower	Vertical	2.8	132	94	28

Notes: (1) totally inundated: crest level equal or below water level (2) crest level range provided if available

Table 6.5 Present Day Predicted Overland Bore Propagation

Location	Construction	(1)Crest Level	Overtopping Bore Propagation Distance (m)		
		(m AHD)	100 yr ARI	50 yr ARI	1 yr ARI
Ellery's Punt	Vertical	1.5	na	na	4
Clontarf Sandy Bay	Sloping	1.8	7	7	1
Clontarf btw Sandy Bay and Marina	Sloping	1.5	na	na	3
Clontarf at private properties	Vertical	2.2 (1.6-2.5)	8	6	3
40 Baskets Seawall	Vertical	1.6	na	15	8
North Harbour Reserve	Sloping Rocks	1.6	5	5	3
Fairlight Beach	Vertical	2.7 (2.2–3.3)	7	7	3
Manly Cove West	Vertical	3.3 (2.9–3.5)	3	3	0
Manly Cove East	Vertical	2.2 (2.2-3.2)	9	9	4
Little Manly Beach	Vertical	3.5 (2.4-3.5)	2	0	0
Manly Victoria Parade	Vertical	3.4 (3.4-4.0)	19	17	0
Manly btw Corso and Raglan St	Vertical	4.7 (4.5–6.0)	16	15	0
Manly N. Steyne btw Carlton and Pine St	Sloping concrete blocks	5.9 (4.5-6.0)	16	14	0
Manly N. Steyne btw Pine St and Pacific St	Vertical battered	5.7 (4.5-6.0)	17	15	0
Manly Queenscliff btw Pacific St and Ceramic Lane	Sloping concrete blocks	5.0	18	16	0
Manly Parade Seawall Fairy Bower	Vertical	2.8	17	15	12

Notes: (1) crest level range is provided when available

Table 6.6 2050 Predicted Wave Overtopping Discharge

Location	Construction	[2]Crest Level	Mean Overtopping Discharge (L/s per m)		
		(m AHD)	100 yr ARI	50 yr ARI	1 yr ARI
Ellery's Punt	Vertical	1.5	[1]t.i.	[1]t.i.	[1]t.i.
Clontarf Sandy Bay	Sloping	1.8	[1]t.i.	[1]t.i.	99
Clontarf btw Sandy Bay and Marina	Sloping	1.5	[1]t.i.	[1]t.i.	[1]t.i.
Clontarf at private properties	Vertical	2.2 (1.6-2.5)	571	336	10
40 Baskets Seawall	Vertical	1.6	[1]t.i.	[1]t.i.	[1]t.i.
North Harbour Reserve	Sloping Rocks	1.6	[1]t.i.	[1]t.i.	[1]t.i.
Fairlight Beach	Vertical	2.7 (2.2–3.3)	233	160	19
Manly Cove West	Vertical	3.3 (2.9–3.5)	100	82	5
Manly Cove East	Vertical	2.2 (2.2-3.2)	2,107	874	13
Little Manly Beach	Vertical	3.5 (2.4-3.5)	14	11	1
Manly Victoria Parade	Vertical	3.4 (3.4-4.0)	1,191	1,128	6
Manly btw Corso and Raglan St	Vertical	4.7 (4.5–6.0)	223	188	78
Manly N. Steyne btw Carlton and Pine St	Sloping concrete blocks	5.9 (4.5-6.0)	1,669	1,505	7
Manly N. Steyne btw Pine St and Pacific St	Vertical battered	5.7 (4.5-6.0)	304	208	78
Manly Queenscliff btw Pacific St and Ceramic Lane	Sloping concrete blocks	5.0	2,291	2,078	26
Manly Parade Seawall Fairy Bower	Vertical	2.8	1,142	758	177

Notes: (1) totally inundated (2) crest level range is provided when available

Table 6.7 2050 Predicted Overland Bore Propagation

Location	Construction	[1]Crest Level	Overtopping Bore Propagation Distance (m)		
		(m AHD)	100 yr ARI	100 yr ARI	100 yr ARI
Ellery's Punt	Vertical	1.5	na	na	na
Clontarf Sandy Bay	Sloping	1.8	10	7	5
Clontarf btw Sandy Bay and Marina	Sloping	1.5	na	na	na
Clontarf at private properties	Vertical	2.2 (1.6-2.5)	na	na	na
40 Baskets Seawall	Vertical	1.6	13	13	9
North Harbour Reserve	Sloping Rocks	1.6	11	11	5
Fairlight Beach	Vertical	2.7 (2.2–3.3)	14	12	6
Manly Cove West	Vertical	3.3 (2.9–3.5)	7	7	3
Manly Cove East	Vertical	2.2 (2.2-3.2)	23	20	8
Little Manly Beach	Vertical	3.5 (2.4-3.5)	21	19	9
Manly Victoria Parade	Vertical	3.4 (3.4-4.0)	20	18	7
Manly btw Corso and Raglan St	Vertical	4.7 (4.5–6.0)	22	19	14
Manly N. Steyne btw Carlton and Pine St	Sloping concrete blocks	5.9 (4.5-6.0)	22	19	9
Manly N. Steyne btw Pine St and Pacific St	Vertical battered	5.7 (4.5-6.0)	22	19	15
Manly Queenscliff btw Pacific St and Ceramic Lane	Sloping concrete blocks	5.0	10	7	5
Manly Parade Seawall Fairy Bower	Vertical	2.8	na	na	na

Notes: (1) crest level range is provided when available

Table 6.8 2100 Predicted Wave Overtopping Discharge

Location	Construction	[2]Crest Level (m AHD)	Mean Overtopping Discharge (L/s per m)		
			100 yr ARI	50 yr ARI	1 yr ARI
Ellery's Punt	Vertical	1.5	[1]t.i.	[1]t.i.	[1]t.i.
Clontarf Sandy Bay	Sloping	1.8	[1]t.i.	[1]t.i.	[1]t.i.
Clontarf btw Sandy Bay and Marina	Sloping	1.5	[1]t.i.	[1]t.i.	[1]t.i.
Clontarf at private properties	Vertical	2.2 (1.6-2.5)	[1]t.i.	[1]t.i.	[1]t.i.
40 Baskets Seawall	Vertical	1.6	[1]t.i.	[1]t.i.	[1]t.i.
North Harbour Reserve	Sloping Rocks	1.6	[1]t.i.	[1]t.i.	[1]t.i.
Fairlight Beach	Vertical	2.7 (2.2–3.3)	[1]t.i.	[1]t.i.	1,706
Manly Cove West	Vertical	3.3 (2.9–3.5)	384	289	12
Manly Cove East	Vertical	2.2 (2.2-3.2)	[1]t.i.	[1]t.i.	[1]t.i.
Little Manly Beach	Vertical	3.5 (2.4-3.5)	36	26	2
Manly Victoria Parade	Vertical	3.4 (3.4-4.0)	43,889	38,130	266
Manly btw Corso and Raglan St	Vertical	4.7 (4.5–6.0)	1,446	1,227	97
Manly N. Steyne btw Carlton and Pine St	Sloping concrete blocks	5.9 (4.5-6.0)	4,122	3,882	1,015
Manly N. Steyne btw Pine St and Pacific St	Vertical battered	5.7 (4.5-6.0)	1,434	980	97
Manly Queenscliff btw Pacific St and Ceramic Lane	Sloping concrete blocks	5.0	5,300	5,010	1,471
Manly Parade Seawall Fairy Bower	Vertical	2.8	218,320	189,673	4,566

Notes: (1) totally inundated (2) crest level range is provided when available

Table 6.9 2100 Predicted Overland Bore Propagation

Location	Construction	[1]Crest Level (m AHD)	Overtopping Bore Propagation Distance (m)		
			100 yr ARI	100 yr ARI	100 yr ARI
Ellery's Punt	Vertical	1.5	na	na	na
Clontarf Sandy Bay	Sloping	1.8	na	na	na
Clontarf btw Sandy Bay and Marina	Sloping	1.5	na	na	na
Clontarf at private properties	Vertical	2.2 (1.6-2.5)	na	na	na
40 Baskets Seawall	Vertical	1.6	na	na	15
North Harbour Reserve	Sloping Rocks	1.6	14	14	9
Fairlight Beach	Vertical	2.7 (2.2–3.3)	na	na	na
Manly Cove West	Vertical	3.3 (2.9–3.5)	10	10	5
Manly Cove East	Vertical	2.2 (2.2-3.2)	28	24	15
Little Manly Beach	Vertical	3.5 (2.4-3.5)	25	23	15
Manly Victoria Parade	Vertical	3.4 (3.4-4.0)	25	22	15
Manly btw Corso and Raglan St	Vertical	4.7 (4.5–6.0)	26	23	16
Manly N. Steyne btw Carlton and Pine St	Sloping concrete blocks	5.9 (4.5-6.0)	26	23	15
Manly N. Steyne btw Pine St and Pacific St	Vertical battered	5.7 (4.5-6.0)	30	28	22
Manly Queenscliff btw Pacific St and Ceramic Lane	Sloping concrete blocks	5.0	na	na	na
Manly Parade Seawall Fairy Bower	Vertical	2.8	na	na	na

Notes: (1) crest level range is provided when available

7. Assessment of Assets Impacted by Coastal Hazards

7.1 Risk Areas for Coastal Erosion and Recession Hazards

The erosion and recession hazard lines were estimated following the methodology presented in Section 5. Predicted hazard lines are shown in Appendix C, Figures C.1 to C.21 for each area for a 100 year ARI (1% AEP) erosion event with present day conditions and also for the 2050 and 2100 planning horizons. Both the scenarios with seawall in place and seawall failure were considered. Detailed assessment for individual properties may generate slightly different hazard line locations.

An estimate of the number of houses affected by the erosion and recession hazard lines is shown in Table 7.1. This is an approximate estimate only, and does not consider the building type or any specific protection works. These buildings would only be lost if adaptation was not undertaken, emergency action was not taken and if the sea level rise and coastal change projections in this report eventuate.

Roads and other infrastructure such as swimming pools, sewer and stormwater lines, water mains and pumping stations were also considered in the assessment.

Table 7.1 Indicative Assets Potentially Impacted by Erosion and Recession

Area	Asset	Seawall			No Seawall		
		Present	2050	2100	Present	2050	2100
Clontarf	Houses/Buildings	0	0	3	18	18	20
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	yes	yes	yes	yes	yes	yes
	Water Mains	no	no	no	no	no	no
	Stormwater lines	yes	yes	yes	yes	yes	yes
	Pools/Encl.	yes	yes	yes	yes	yes	yes
	Roads	yes	yes	yes	yes	yes	yes
Forty Baskets	Houses/Buildings	0	0	3	0	0	3
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	no	no	yes	no	no	yes
	Water Mains	no	no	no	no	no	no
	Stormwater lines	yes	yes	yes	yes	yes	yes
	Pools/Encl.	yes	yes	yes	yes	yes	yes
	Roads	no	no	no	no	no	no
North Harbour Res.	Houses/Buildings	0	0	0	0	na	na
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	no	no	no	no	no	no
	Water Mains	no	no	no	no	no	no
	Stormwater lines	no	no	no	na	na	na
	Pools/Encl.	no	no	no	no	no	no
	Roads	no	no	no	na	na	na
*Fairlight	Houses/Buildings	0	0	0	3	3	3
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	no	no	no	yes	yes	yes
	Water Mains	no	no	no	no	no	no
	Stormwater lines	no	no	no	yes	yes	yes
	Pools/Encl.	no	no	no	no	no	no
	Roads	no	no	no	no	no	no

Area	Asset	Seawall			No Seawall		
		Present	2050	2100	Present	2050	2100
Manly Cove West	Houses/Buildings	0	0	0	1	1	1
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	yes	yes	yes	yes	yes	yes
	Water Mains	no	no	no	no	no	yes
	Stormwater lines	yes	yes	yes	yes	yes	yes
	Pools/Encl.	yes	yes	yes	yes	yes	yes
	Roads	no	no	no	no	no	yes
Manly Cove East	Houses/Buildings	0	0	0	0	0	11
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	no	no	no	yes	yes	yes
	Water Mains	no	no	no	no	yes	yes
	Stormwater lines	no	no	no	yes	yes	yes
	Pools/Encl.	no	no	no	no	no	no
	Roads	no	no	no	no	yes	yes
Little Manly	Houses/Buildings	0	0	0	1	3	5
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	no	no	no	yes	yes	yes
	Water Mains	no	no	no	no	no	no
	Stormwater lines	yes	yes	yes	yes	yes	yes
	Pools/Encl.	yes	yes	yes	yes	yes	yes
	Roads	no	no	no	yes	yes	yes
Quarantine	Houses/Buildings	0	1	2	1	2	3
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	na	na	na	na	na	na
	Water Mains	na	na	na	na	na	na
	Stormwater lines	na	na	na	na	na	na
	Pools/Encl.	no	no	no	no	no	no
	Roads	no	no	no	no	yes	yes
Shelly	Houses/Buildings	na	na	na	0	1	1
	Pumping Station	na	na	na	0	0	0
	Sewer Mains	na	na	na	yes	yes	yes
	Water Mains	na	na	na	no	no	no
	Stormwater lines	na	na	na	yes	yes	yes
	Pools/Encl.	na	na	na	no	no	no
	Roads	na	na	na	no	no	no
***Fairy Bower**	Houses/Buildings	0	0	0	na	na	na
	Pumping Station	0	0	0	na	na	na
	Sewer Mains	yes	yes	yes	na	na	na
	Water Mains	no	no	no	na	na	na
	Stormwater lines	yes	yes	yes	na	na	na
	Pools/Encl.	yes	yes	yes	na	na	na
	Roads	no	no	no	na	na	na
Manly LSC to Raglan St	Houses/Buildings	0	0	0	3	13-15	26
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	no	no	no	yes	yes	yes
	Water Mains	no	no	no	no	yes	yes
	Stormwater lines	yes	yes	yes	yes	yes	yes
	Pools/Encl.	no	no	no	no	no	no
	Roads	no	no	no	yes	yes	yes

Area	Asset	Seawall			No Seawall		
		Present	2050	2100	Present	2050	2100
Manly Raglan St to Pine st	Houses/Buildings	1	1	1	1	5	22
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	no	no	no	yes	yes	yes
	Water Mains	no	no	no	no	yes	yes
	Stormwater lines	yes	yes	yes	yes	yes	yes
	Pools/Encl.	no	no	no	no	no	no
	Roads	no	no	no	yes	yes	yes
Manly Pine St to Queenscliff st boatshed	Houses/Buildings	0	0	0	1	5	25
	Pumping Station	0	0	0	0	0	0
	Sewer Mains	no	no	no	no	no	yes
	Water Mains	no	no	no	no	yes	yes
	Stormwater lines	yes	yes	yes	yes	yes	yes
	Pools/Encl.	no	no	no	no	no	no
	Roads	no	no	no	yes	yes	yes
TOTAL	Houses/Buildings	***1***	***2***	***9***	***29***	***38***	***120***

Notes: * likely presence of rock may preclude/protect properties from erosion and recession, however, this has not been quantified. Such properties may also be vulnerable to wave impacts. Rock level needs to be mapped. Higher values cannot be excluded until this is undertaken.

7.2 Risk Areas for Coastal Inundation

The ground areas subject to inundation under 100 year ARI (1% AEP) conditions are shown in Appendix D Figures D.1 to D.16 with present day conditions and for the 2050 and 2100 planning horizons. Consideration of individual house floor levels is beyond the scope of this study. The inundation level does not include direct wave impacts, which may occur for the first row of beachfront houses. Furthermore, inundation from the ocean side may be prevented if a continuous dune/seawall of sufficient height and sand volume protects the land behind it. The inundation areas presented would eventuate if the dunes/seawall are breached/overtopped. The inundation areas are mapped based on ground elevation (the “bare earth” LIDAR layer) and do not consider flow paths and velocities.

The potential for inundation does not necessarily preclude new development, but such inundation potential must be considered in the design of buildings and infrastructure, and in emergency planning. The peak of inundation events would persist for approximately 2 hours with the peak of the tide. However, subject to topography, substantial ponding may remain in some areas well after the peak.

Indicative numbers of houses at risk due to inundation are shown in Table 7.2. It is acknowledged that other infrastructure is also at risk, however, most of this infrastructure services the houses which are also inundated. Subject to the floor level and construction type, the occurrence of inundation of the ground surrounding a house may not result in any damage to the house.

In regards to the Manly Lagoon area, inundation levels were derived from ocean inundation levels excluding any coincident flooding and/or hydrodynamic modelling within the lagoon.

Table 7.2 Indicative Assets Potentially Impacted by Inundation

Area	Asset	100 yr ARI (1% AEP)			50 yr ARI (2% AEP)			1 yr ARI (63% AEP)		
		Present	**2050**	**2100**	**Present**	**2050**	**2100**	**Present**	**2050**	**2100**
(4)Seaforth	Properties	3	5	5	3	5	5	0	1	1
Clontarf	Properties	2	16	40	2	16	40	0	8	33
(1)Forty Baskets	Properties	0	0	2	0	0	2	0	0	0
North Harbour Res.	Properties	0	2	5	0	2	5	0	0	2
Fairlight	Properties	0	0	0	0	0	0	0	0	0
Manly Cove West	Properties	0	0	0	0	0	0	0	0	0
Manly Cove East	Properties	1	8	13	1	8	13	1	3	12
Little Manly	Properties	0	0	0	0	0	0	0	0	0
Quarantine	Properties	0	0	1	0	0	1	0	0	0
Shelly	Properties	0	0	0	0	0	0	0	0	0
(1)Fairy Bower	Properties	0	0	0	0	0	0	0	0	0
Manly Ocean Beach	Properties	0	0	0	0	0	0	0	0	0
(2)Manly Lagoon Area	Properties	138	175	223	138	175	223	5	50	150
(3)TOTAL	Properties	***6***	***31***	***66***	***6***	***31***	***66***	***1***	***12***	***48***

Notes: (1) assessment does not include direct wave impacts which may occur for the first row of houses
(2) analysis excludes any flooding/hydrodynamic consideration
(3) excluding properties within the Manly Lagoon area
(4) several private boatsheds will potentially be impacted by inundation

8. Vulnerability Assessment and Coastal Management Options

8.1 Objectives of Vulnerability Assessment

This section presents a review of the currently identified strategies included in the recently undertaken management plans and planning instruments to ascertain their continued suitability over the three identified planning timeframes (present day, 2050 and 2100). The hazards and subsequent risks as quantified through this study over the various timescales are then applied to assess the suitability of these approaches and to assist Council in prioritising their future responses. The individual steps in this process are as follows:

1. *Identification of existing significant assets and infrastructure on any affected parcel of land for each planning time scale (present day, 2050, 2100).* The modelling and hazard mapping information have been analysed in Section 7 to identify significant impacts over the three defined time intervals. Detailed site inspection was undertaken and an inventory of existing protection structures prepared for each location (refer to Section 2).
2. *Re-assessment of the risk to significant development, infrastructure and land use/zonings, consistent with the current sea level rise benchmarks and planning approach.* The assets landward of the existing shoreline were identified and assessed in terms of the likely hazard (based on the hazard lines determined in Section 5) and the likely consequences of that hazard being realised (likely damage) in accordance with the risk based approach recommended in the planning guideline. For sandy beaches where a protective seawall exists, the seawall and no seawall case has been assessed.
3. *Review of the suitability of existing protection structures over each planning horizon and as appropriate to identify potential upgrade options and when they are likely to be required.* Many of the existing individual coastal protection structures are not adequate to accommodate a sea level rise of 0.9 m in 2100. It is not necessary that those structures be replaced immediately and as practical, opportunities to upgrade/replace those structures at some future time have been identified on a beach by beach basis. The existing protection structures identified have been assessed in terms of their likely durability and performance over time. Where modifications can be readily made to these structures, these are identified. Key triggers (in terms of time, erosion or sea level) are identified where the modifications should be undertaken. The impacts of upgrading the structures is discussed in qualitative terms.
4. *Review the applicability of previously adopted management measures (planning and engineering).* The current strategies and protection measures at each location have been reviewed in the light of the hazards as now identified through this study. Final selection and implementation of suitable options by Council will be subject to a further detailed assessment, detailed design and costing.
5. *Provision of clear recommendations.* At each location, the hazard determined and subsequent risk to existing development and assets are identified. As appropriate, problems affecting the future coastal management at each location are identified and discussed. Clear recommendations are provided on the preferred option for each locality and what further studies are required before these could progress.

8.2 Review of Existing Studies

The relevant literature listed in Section 2 was reviewed in regards to the undertaking of the vulnerability assessment and the formulation of coastal management options. A brief summary of each study is presented below.

- **Clontarf Sedimentary Processes and Foreshore Stability Study – Sedimentary Processes Report (February 2009**). This report was prepared by Cardno for Manly Council. It specifically assesses the sedimentary processes within Clontarf/Bantry Bay to assist with a concurrent assessment of the stability of foreshore structures through the area. The report concludes that sand movement driven by swell waves around Clontarf point is approximately 300 m^3/yr to 450 m^3/yr. To the west of Clontarf Point the alongshore transport rate is 400 to 450 m^3/yr to Clontarf Spit. Clontarf Spit acts as a deposition area with approximately 100 m^3/yr being transported through the spit with low volumes of sediment transported into the area around Clontarf Marina, Sandy Bay and Fisher Bay.

- **Clontarf Sedimentary Processes and Foreshore Stability Study - Foreshore Stability Report (March 2009**). This report was prepared by Cardno for Manly Council. It specifically presents an assessment of the various sections of the seawalls extending from Sandy Bay to the southern end of Clontarf Reserve. The assessment included site inspection and geotechnical assessment. Some of the (timber) structures are identified as landscaping structures only. The remaining seawalls are described as adequate and achieving their primary functions. The older structures are recognised as being unlikely to be designed to present standards and at risk of damage during a severe storm. The recommended strategy was for monitoring of the structures.

- **Clontarf Pool Maintenance Dredging – Review of Environmental Factors (July 2010).** This report was prepared by Cardno for Manly Council to assess the environmental effects of a proposal to dredge the Clontarf swimming enclosure. The pool was shown to be infilling at rates of 150 m^3/yr to 250 m^3/yr due to alongshore sand movement driven by swell waves from the south. The proposal solution was to move the dredged sand to nourish the beaches fronting Monash Crescent to the west of Clontarf point.

- **Forty Baskets Coastline Hazard Definition Study - Issue No 2 (May 2003).** This report was prepared by Patterson Britton & Partners for Manly Council. This study recognised a low rate of sand loss from Forty Baskets Beach as a result of storm erosion and advises that this trend is likely to continue in the future with sea level rise. The existing seawall along the beach were assessed and in particular the concrete wall at the north end of the beach was described as "*in poor condition and should be monitored. The need for future stabilisation or reconstruction of this section of seawall is likely*".

- **North Harbour Coastline Management Study - Final Report (February 2009).** This report was prepared by Manly Council as "baseline condition" report for the North Harbour area. It includes the beaches of North Harbour Reserve and Fairlight. The report includes a suite of strategic management options to enhance understanding and achieve ecologically sustainable management of the harbour, foreshores and hinterland.

- **East Manly Cove Beach Management Options – Scoping Study - Draft Report (June 2002**). This report undertaken by Manly Hydraulics Laboratory (MHL) investigated options to address the erosion of the western end of East Manly Cove adjacent to the Wharf. The report drew on earlier reports by MHL in 1997 and updated the survey analysis of beach stability. The report concludes that the beach is relatively stable under the current wharf configuration. Changes since the 1880s were noted as being minimal and the beach volumes east of the wharf were shown to be consistent from 1997 to 2004. Recommended strategies to address the issues identified included limited beach scraping to move small volumes of sand from east to west along the beach and the reconstruction of the steps on the eastern side of the wharf to remove the drop from the steps to the water.

- **Foreshore Safety and Beach Rehabilitation Manly Cove East (May 2003**). This report was prepared by Lawson and Treloar for the Waterways Authority. It addresses safety issues associated with the erosion of the western end of East Manly Cove, adjacent to the ferry terminal. It also recommends extension of the current groyne attached to the terminal if sand nourishment of the western end of the beach is to be undertaken.

- **Manly Cove Coastal Management Plan - Final Draft (June 2011**). This draft plan has been prepared by Manly Council. It covers the foreshores and harbour between Federation Point to the west and Manly Point to the south-east. It covers an area of 50.9 Ha and puts forward 65 management strategies, 14 of which are directly relevant to this study, addressing hazards and climate change. Specifically, those recommendations under heading CH.1 aim to "*reduce to an acceptable level, the risk to property and infrastructure resulting from Sea Level Rise*". They include Ch.1.1 to "*establish coastal risk areas using NSW's planning and sea level rise benchmarks*", which is a key output from this study.

- **Little Manly Coastline Hazard Definition Study (May 2003).** This report was prepared by Patterson Britton & Partners for Manly Council. The objective of the report was to assess the beach stability and the stability of the seawall at the back of the beach. The report concludes that Little Manly Cove beach is susceptible to erosion during storms and is experiencing a small long term loss of sand, mainly due to losses offshore. This was expected to continue over time with sea level rise. While the existing seawall was considered to be in fair condition, some cracking and rotation of the seawall was cited and concerns expressed regarding the long term stability of the wall during storms as sea levels rises.

- **Manly Ocean Beach Seawall and Beach Amenity Risk Assessment and Remedial Options (April 2003).** This report was prepared by the Water Research Laboratory (WRL) for Manly Council. It addresses the long term stability of Manly Beach, recognising that an ongoing loss of sand from the beach is occurring and will increase in future as sea level rises. The report addresses the need for beach nourishment into the future and provides an estimate of the necessary sand volumes over a fifty year period. The report also recognises the need to upgrade the toe protection to the seawall, particularly south of the Corso where the current rock protection of the toe is being removed by Council as and when it is exposed. The report advises that this ongoing strategy is not sustainable in the long term and additional toe protection is required and/or beach nourishment to increase the beach volumes in front of the wall. The report also advises the risk from wave overtopping that will increasingly threaten and damage the wall, together with a rising groundwater level behind the wall. Ongoing monitoring is recommended.

- **Manly Ocean Beach Coastline Management Plan - Issue No 4 (March 2008**). This report was prepared by Worley Parsons for Manly Council. It presents a comprehensive plan for the whole of Manly Ocean Beach which outlines a suit of recommended management options to address the identified erosion history of the beach and to manage the foreshores while retaining beach amenity as sea level rises in the future. The strategy is based on maintaining the seawall in its present location. This would include structural measures to stabilise the toe of the existing seawall and possible measures to raise the level of the wall crest (coping) should inundation become unacceptable. The maintenance of the wall must be accompanied by ongoing beach nourishment (preferably from an offshore source) to maintain the beach amenity and provide some protection to the wall as sea level rises and the beach width decreases. An integral component of the strategy is ongoing monitoring of the beach including sand volumes, groundwater levels and overtopping to facilitate appropriate improvements to the overall beach protection.

- **Manly Ocean Beach Emergency Action Plan for Coastal Erosion - Issue No 6 (March 2008).** This report was prepared by Worley Parsons for Manly Council. The report draws on existing studies that show over a period of 107 years to the mid-1990s, sections of the seawall were damaged on average every 10 to 15 years. The report concludes that beach erosion will continue to threaten the seawall and other foreshore assets along Manly Ocean Beach into the future. The volume of sand available on the beach is not sufficient to accommodate the magnitude of sand losses in severe storms. The level of future threat would increase as sea levels rise and the foreshore continues to recede. This would be expected to cause a narrowing of the beach over time. The report puts forward a management strategy and identifies who is responsible for initiating responses when a coastal erosion emergency occurs.

- **Climate Change Actions for Manly LGA 2008 to 2038.** This report was prepared by Cardno for Manly Council to identify an action list for adaptation measures to assist Council in addressing future climate change. The objective of the report was to assist Council in seeking a levy funded schedule of works in response to predicted climate change impacts. It included static inundation modelling of the harbour and ocean foreshores.

8.3 Discussion of Risk Based Assessment

8.3.1 Risk Management Concept

Since the 1970s, coastal management in NSW has been based on the delineation of coastal hazards (erosion, recession, inundation) where the likely extent of the hazards at the coast and their encroachment on the adjacent land are defined for a set time period and design condition. This hazard assessment was then used to prepare hazard maps typically for the current, 50 year and 100 year time periods (NSW Coastline Management Manual 1990) which show the extent of lands typically affected by coastal erosion/recession, slope instability or inundation.

This information was then applied to coastal management by addressing the locations where the impacts of the coastal hazards were likely to be greatest at present or at some foreseeable time into the future. Typically this assessment was based on judgment and determined by a balanced (merits based) approach, depending on:

- the monetary value of assets at risk;
- the likely consequences of their loss (infrastructure);
- consideration of conservation and ecological issues;
- recreational values; and
- shoreline access.

In metropolitan areas, the threat to assets and the recreational/access issues tended to dominate considerations.

In risk management terms, a risk is defined as the likelihood of an event occurring, and the consequent impact of the event upon an asset or value (Risk=Hazard X Consequences). The Australian Standard AS/NZS 4360:2004 (now ISO 31000: 2009) outlines the process to be used in undertaking a risk based assessment. This process is to be applied to manage risks where there is a level of uncertainty and is therefore directly applicable to coastal zone management, particularly incorporating sea level rise.

The approach is an iterative process of continued improvement to manage or adapt to the risks over time and can be summarised in the following steps (modified from AS 2004) which are monitored and reviewed continuously:

- Establish the context;
- Identify the risks;
- Analyse the risks;
- Evaluate the risks; and
- Treat the risks.

Risk Management is a process familiar to Local Government in NSW and is incorporated in the on-going management of Council assets and delivery of various Council activities and services. In addressing the coastal hazards, the treatment of the risk is either through measures to reduce the risk (protect/accommodate) or to avoid the risk (retreat) until such time as the overall risk profile remaining is acceptable. Often these measures are not required at present but the ongoing rise in sea level and the consequent damage and /or loss of recreational amenity over time will require measures to be taken.

Through amendments to the NSW Coastal Protection Act in 2010, the NSW Government has implemented benchmarks to be considered for sea level rise to 2050 and to 2100. These allow for an increase in sea level of 0.4 m to 2050 and 0.9 m to 2100 above current levels. The recently released Guidelines for Preparing Coastal Zone Management Plans require the delineation of hazard lines for coastal recession and coastal inundation to 2050 and 2100 incorporating these benchmark increases. This effectively provides certainty to the likelihood of these hazards at each timeframe. The guideline recommends a risk based approach to managing risks from coastal hazards, outlining the methodology to be used in assessing and mapping the hazard lines for each time period.

For the study area these hazard lines are presented for each beach location in Section 5 and plotted on figures incorporated in Appendix C.

8.3.2 Likelihood of Coastal Hazards

The uncertainty of the likelihood of a coastal hazard extent occurring at any future timeframe (probability of occurrence) has been addressed by the NSW Government through the sea level rise benchmarks which remove this uncertainty from what is as yet a process based on projections rather than predictions. This allows the numerical computation of hazard extent to be undertaken with some certainty.

In practice, it is likely that both the numerical modelling techniques applied to computation of the foreshore relocation and the level and extent of inundation during a severe storm event at some future time will combine a range of uncertain computations and outcomes. The rate at which for example sea level rises, will vary from the current benchmark figures, at any intermediate time possibly increasing faster or slower than the allowances dictate.

Similarly, the potential for climate change impacting wind and wave conditions is not yet understood. Sediment supplies will change and the effects of as yet non-existent works and measures will further alter outcomes. The definition of the future hazard extent using these fixed timeframes and sea level allowances reduces this uncertainty to a usable outcome and for risk management purposes they are accepted as the most likely outcome.

8.3.3 Consequence of Coastal Hazards.

The consequence of coastal hazards if left untreated in developed metropolitan areas is substantial. The likely extent of the erosion hazards for example have been assessed and are presented in Table 7.1. This assessment was based on field inspection and the examination of detailed cadastral mapping with the identified coastal erosion hazards for each time period superimposed. This assessment was undertaken for three cases, (present, 2050 and 2100) and with the assumptions of existing seawalls in place and no seawalls. The implications are discussed for each beach section in Section 8.5.

Coastal locations are highly prized within communities and those properties with proximity to the water and/or coastal views generally attract the highest development value. For the open coast beaches and the harbour front beaches in the Manly Council area, those private properties closest to the foreshores are typically valued in millions of dollars, with the more desirable properties attracting prices in excess of $3M.

8.4 Assessment of Beach Areas

8.4.1 Defining the Hazards

The assessment of the individual beach areas in this section is restricted to those sandy beach locations within the study area (Figure 1.1) that are currently protected by a seawall/revetment. At these locations the currently adopted option for securing development behind the beach is to restrict the landward fluctuation of the erosion processes and to limit the risk of wave inundation during storms.

Details of the existing seawalls at each location were determined through site inspection and limited survey to determine the length and type of structure, the crest level and toe level (where possible), the type of construction and the current condition of the structure. This information is presented in Tables 3.1 and 3.2.

The available information is limited as at many locations the details of the construction, including the toe level and design, the likely existence of under layers/additional armouring behind the wall, drainage etc. are not visible. At many locations it is likely that the toe of the revetment is constructed on or near to bedrock and/or that bedrock may be exposed at a high level landward of the structure so as to influence future beach movements should the wall fail.

No detailed geotechnical assessment has been undertaken and this would be required to assist in determining the suitability of each structure for future (raised sea levels and/or eroded beach) conditions. The information presented here is a starting point for those more detailed, site specific assessments. As described in Sections 5 and 6, detailed assessment and mapping of the potential hazards of:

- foreshore recession/erosion;
- static (ocean storm level) inundation; and
- dynamic inundation (wave run-up and bore propagation)

has been determined for the current, 2050 and 2100 time periods.

The erosion/recession hazard mapping has also been undertaken for the two cases where a seawall is maintained at the current location and where the seawall is assumed to have failed providing no relief from erosion of the beach. For the first case, the landward limit of the coastal recession hazard line is limited to the face of the seawall. For the second case where the recession of the beach has occurred beyond the seawall it is assumed that the erosion is occurring into unconsolidated, sandy substrate.

This assumption is conservative, particularly for many of the harbour beaches and Fairy Bower where visible rock exposed behind the beach and at the end of many of the seawalls would suggest that the likely landward movement of the shoreline, if allowed to occur would most likely be modified by the presence of bedrock.

It should also be recognised that the landward extent of the erosion/recession in the absence of the seawalls is defined by the landward limit of the Zone of Reduced Foundation Capacity (ZRFC) as required in the NSW Government Coastal Risk Management Guide (2010). This zone as defined (Nielsen et al., 1992) incorporates an allowance landward of the erosion escarpment within which surface footings for development may not be able to develop their full design strength.

Existing development seaward of this line would not necessarily be lost or damaged should such an event occur. Rather, the identification of this line allows the opportunity for any new development sited seaward (such as extensions to existing dwellings or services) to incorporate development controls that may prolong the design life (such as piered or piled foundations, suspended floors etc.). In determining the width of this zone of reduced foundation capacity, it was assumed that the back beach is unconsolidated sand and the width of the zone is therefore a function of the surface elevation.

The static and dynamic inundation is based on the current shoreline location but includes allowance for the NSW Government benchmark sea level rise and the likely change in the beach and nearshore profile seaward of the existing seawall (through modelling). It does not include any allowance for the landward translation of the beach face beyond the seawall and assumes both that the crest level of the seawall and the shape of the land surface landward of the seawall remain as they are today. By 2050 or 2100 both of these assumptions may not remain as they are today. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

8.4.2 Issues for Consideration by Council

The construction of a seawall at the back of the beach is generally undertaken in response to the uncertainty introduced by the landward intrusion of the coastal processes during storm events at some time in the past. The existence of such walls creates, within the community, an expectation that the line separating the beach and the land will remain at that alignment. This expectation is likely to be challenged by future sea level rise and the mapping of the erosion and inundation hazard lines well landward of the existing seawall location indicates the importance of these protection structures in preserving existing development and assets at their present locations. In many locations they will require substantial upgrading or replacement. Other management measures may also be preferred.

At many locations it is not necessary for Council to proceed with upgrading existing structures and/or implementation of an alternative management strategy immediately. The extent of the assessed 2050 and 2100 hazards is dependent on the projected sea level rise benchmarks levels occurring and such expenditure may not be necessary for 50 years or more. However, given the likely extent of the hazards now identified and the risk to existing development and infrastructure at present and into the future, it is necessary for Council to consider what the longer term strategy will be (protect/adapt or relocate). Once this decision has been taken, it is possible for individual property owners to manage and utilise their land appropriately. Asset managers similarly can accommodate these projected future changes into the maintenance and upgrading of existing infrastructure and the design life and siting of future infrastructure and facilities with some understanding of the extent of likely risk.

While the management of the foreshores is generally seen as the responsibility of Council, this is not always so clearly defined. Along much of the harbour foreshores, the freehold property boundaries are defined by the surveyed location of the mean high water mark at some time (MHWM Titles). Where the development is located on bedrock, this may not be so much of an issue as the potential for erosion of this foreshores with rising sea levels is low and the steep foreshore slopes may only result in a small and gradual landward movement of the mean high water mark.

However, on sandy shorelines where the properties directly front the harbour, this issue becomes significant. The scientific consensus of rising sea levels with dwindling sand supply will in most cases where action is not taken to prevent it, result in the landward movement of the mean high water mark over time. The Coastal Protection Act advises that the "doctrine of erosion and accretion" is applied to the waters and foreshores of Sydney Harbour, allowing a redetermination of the property boundary resulting from the slow and permanent change in the location of the MHWM.

However, historically such redeterminations affecting private property have only occurred when the MHWM has moved further seaward due to beach accretion, providing the property owner with a larger usable property. It has not been used to reduce the size of private property as a result of beach erosion. To the contrary, the location of the boundary is usually fixed by the landowner constructing protection works in the form of a seawall or the like.

For example along the Clontarf shoreline (Figure 8.1), seaward of Monash Crescent, Council advises that there are approximately 18 waterfront properties with MHWM boundaries, as well as access ways and adjacent reserves under the control of Council. At present each of these properties are "protected" by a seawall, individually constructed to different (and usually unknown) designs, utilising different materials and many on slightly different alignments to their neighbours, possibly reflecting different MHWM boundary determinations.

It will be the expectation of these and similar foreshore property owners that they may defend their boundary as required by upgrading the existing structures. For this to be successful, Council would need to provide a similar level of protection to their sections of the foreshore and possibly to adjacent reserves to limit inundation threats in the future. This issue needs to be resolved.

Figure 8.1 Clontarf Seawall Fronting Private Properties

At many locations potentially affected by sea level rise causing increased erosion and inundation, there are significant public assets at risk. Often these infrastructure assets are not within the direct care and control of Council. For example along the seaward toe of the Fairy Bower seawall there is a major sewerage line encased in concrete. Intertwined with this is the stormwater infrastructure servicing the adjacent suburban development to the ridge crest and which passes through and seaward of the existing seawall.

Similarly, sewerage and drainage infrastructure runs along the entire Manly Beach foreshore immediately landward of the seawall (see Figure 8.2). This foreshore infrastructure services much more than the immediate beachfront residents, providing facilities to the broader community including sewerage, water supply, drainage, telecommunications, public jetties and road access. So the decision on how and when to manage the identified coastal hazards goes well beyond the responsibility of the Local Council alone.

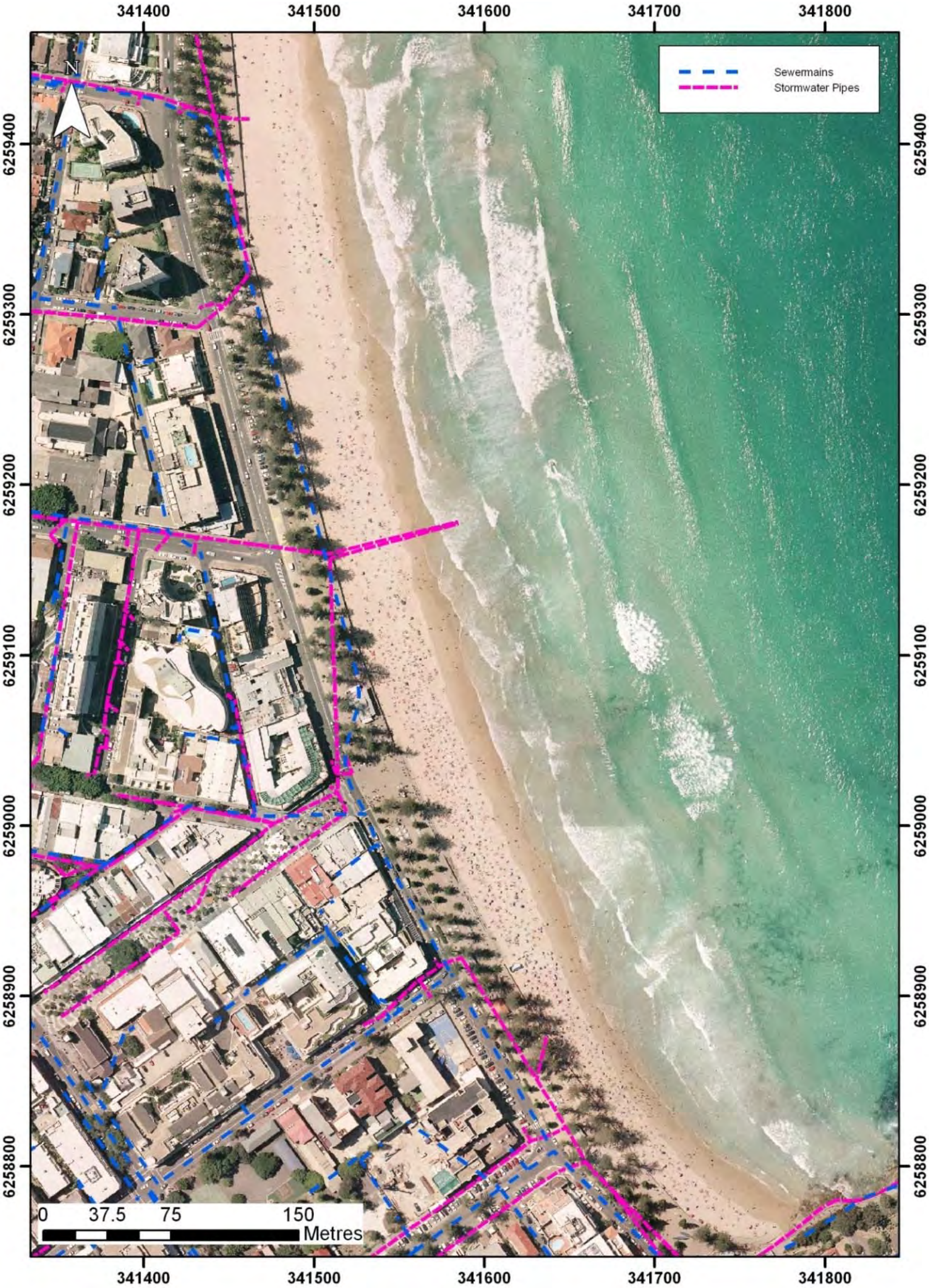


Figure 8.2 Location of Sewer Mains and Stormwater Pipes Manly Ocean Beach

Various other government instrumentalities are affected at different locations and need to be engaged in the process of developing and implementing future managements measures. For example the cost associated with relocating the major sewerage lines, pump stations and services may well exceed the cost of the upgrading of existing protection works. Other stakeholders such as Sydney Water Corporation need to be engaged in the management process as their requirements may dictate the preferred management strategy at some locations.

The future management of coastal hazards is undertaken through the coastal zone management planning process, prepared and implemented by the Local Council. Once certified by the Minister and gazetted in accordance with the Coastal Protection Act, the coastal zone management plan provides some certainty as to the way in which the foreshore is to be managed.

Prior to the recent amendments of the Coastal Protection Act, the waters of Sydney Harbour and their adjacent lands were not included in the Coastal Zone and therefore, could not be covered by a gazetted Coastal Zone Management Plan. Section 55B of the Act relating to the Requirements for Coastal Zone Management Plans now states (sub clause (9)) that "*In this section, coastal zone includes land that adjoins the tidal waters of the Hawkesbury River, Sydney Harbour and Botany Bay, and their tributaries*".

This would appear to cover the waters and foreshore areas of Manly fronting Sydney Harbour. However, the NSW Office of Environment and Heritage have provided advice that under Section 4A and 4B of the Act and that under 4A(3)(e) which describes the process for mapping the coastal zone, "*the boundary is to exclude (i) those parts of the local government areas of ...Manly...that are not, and are not likely to be, affected by and that do not, and are not likely to, affect coastal processes, including coastal wave and wind action, and (ii) the water of Sydney Harbour and Botany Bay*."

In providing this advice the OEH draw attention to the current maps showing the coastal zone for the greater metropolitan region that were gazetted on the 18th November 2005. In particular they draw attention to the map showing the coastal zone for the Manly LGA as not including the land adjoining the waters of Sydney Harbour. Their advice clearly states that "*the Manly Harbour shoreline is not included within the coastal zone, irrespective of the reference under Section 55B above, as the land was not included in the gazetted coastal zone map.*"

This advice raises significant issues for Manly Council that need to be resolved by Council before proceeding with plans for management of the harbour foreshores. In particular under the advice provided by OEH, Council cannot prepare, certify and gazette a coastal zone management plan for any of the Council lands fronting Sydney Harbour. While this does not prevent Council undertaking measures to manage the foreshores as they have always done, it does extinguish their access to certain powers rights and responsibilities that would be conferred on a gazetted plan. These include:

- The legislative certainty that no one can undertake works or measures that contravene a gazetted plan;
- The power and penalties that can be applied under the Act to control illegal or unapproved coastal protection works;
- The opportunities provided under the Act for Council to raise funding through a levy on private lands being protected at the request and with the agreement of the property owners;
- The liability protection provided to the Council through preparing and implementing a gazetted plan, etc.

The options for Council to clarify this advice include:

- Seek and obtain legal advice as to the inclusion or otherwise of the harbour foreshores in the NSW coastal zone under the Coastal Protection Act;
- Undertake mapping of the harbour foreshores in the Manly Council area that front Sydney Harbour and which are likely to affect or be affected by coastal processes. The hazard mapping provided in this report provides a definition of those lands. These maps would then need to be gazetted;
- Raise the issue broadly with Government and request that government undertake the task of mapping and gazetting maps of the Manly Council foreshores in accordance with the intent of the Act. This approach could be raised through a group, such as the Sydney Coastal Councils Group, that represents most affected Councils with lands fronting Sydney Harbour, Botany Bay and the Hawkesbury River.

8.5 Assessment of Individual Beaches

The individual beach assessment has been developed on the basis of the erosion projections and the table of assets provided in Section 7. The assessment does not include discussion of the assets affected by inundation. The occurrence of inundation may result in no damage, or range from nuisance flooding for some properties to major damage. The location and photographic records of each individual beach are presented in Appendix A.

8.5.1 Ellery's Punt Reserve

The existing seawall is in poor condition with severe erosion of the sandstone mortar and concrete. Undermining of the toe is also evident as well as erosion of the backfill due to wave overtopping. Based on the erosion analysis, a portion of the reserve may be under threat. No residential development is located within the reserve, however, the location has historical significance for the presence of the original punt ramp and platform.

8.5.2 Clontarf

Based on the assessment of assets at risk from coastal erosion/recession (Table 7.1), provided the seawalls are maintained, there is limited threat to existing residential development. With the seawalls in place no residential development is considered at risk at present or to 2050 and only 3 residential properties are likely to be affected by 2100. However, without the seawalls, 18 properties along Monash Crescent are potentially affected at present and a further 2 properties will be affected by 2100. Sewer access covers (manholes) are located along the beach seaward of the existing seawall alignment and in the longer term, these may need to be addressed along with the stormwater outlets, the swimming pool enclosure and some sections of the roadway as sea level rises.

8.5.3 Forty Baskets

The existing seawall at the northern end is a vertical concrete wall of poor construction. The condition of the wall is poor with degradation of the concrete, cracking of the wall and rotation of the crest seaward. Some patches acting as concrete buttresses have been poured at the northern end to try and delay the failure of the wall. The structure needs to be removed and replaced as it is approaching the end of its serviceable life.

The function of the wall is essentially to retain the fill along the northern end of the reserve. The assessment of assets (Table 7.1) indicates that, irrespective of whether the seawall is retained or removed, no residential properties landward of the beach are at risk at present or to 2050. Only three properties behind the beach and to the south of the seawall are at risk to 2100. The existing stormwater lines, swimming enclosure and sewer mains may need to be addressed as sea level rises.

8.5.4 North Harbour Reserve

North Harbour Reserve is a deeply embayed foreshore park on a reclaimed creek outlet. A sloping rock seawall retains the reserve behind and the assessment of assets (Table 7.1) shows no residential development or infrastructure within the reserve at risk either with or without the wall in place, to 2100. At this location a significant stormwater drain services a large catchment to the east of the reserve. The performance of this drainage system may need to be reviewed as sea levels increase.

8.5.5 Fairlight

With the seawall in place there is no risk to residential properties or infrastructure to 2100. Without the seawall, there is a low risk to three residential properties at present that would continue to increase as sea level rises. The stormwater line behind the seawall and the sewerage servicing the amenities block at the east end of the beach would be at risk also. Further geotechnical investigation may show that this risk is lower than assessed if bedrock outcropping on the beach is shown to be extensive. The performance and management of the ocean pool will need to be assessed as seal level rises.

8.5.6 Manly Cove West

The assessment of assets at risk from erosion and recession indicates that the function of the seawall at this location is the protection of the reserve separating West Esplanade from the beach. With the seawall in place no buildings are at risk from erosion/recession to 2100. Should the seawall be removed, then the art gallery/museum building would be at risk at present, with increasing risk to 2100. A small section of the West Esplanade near the ferry terminal may also be at risk by 2100. Sewerage and stormwater infrastructure located seaward of the seawall may need to be addressed as sea level increases.

8.5.7 Manly Cove East

The assessment of assets at risk from erosion and recession (Table 7.1) indicates that there are no properties or infrastructure at risk, provided the seawall at this location is maintained. The function of the wall is the protection of the reserve separating East Esplanade from the beach. Should the seawall be removed, then sewer mains and stormwater lines are immediately at risk with East Esplanade and 11 properties at increasing risk to 2100.

8.5.8 Little Manly

With the seawall at this location in place there is no risk to properties sited behind the beach although stormwater infrastructure and the ocean pool may need to be addressed as sea level rises. If the seawall was to be removed then one property is considered at immediate risk together with the road and sewerage services located behind the beach. This risk would continue to increase with a further two properties at risk by 2050 and five properties to 2100.

8.5.9 Quarantine Beach

A short section of seawall is present at this location providing little protection from overtopping by storms due to its low crest level. If the section of seawall was removed there would be an increasing risk to buildings over time with one building considered at immediate risk, two further building at risk by 2050 and a total of three buildings affected by 2100. These building are all heritage structures. Sections of the access road at the wharf would be increasingly affected also.

8.5.10 Shelly Beach

There is no seawall at the back of this wide beach which fronts the grassed and timbered reserve of Shelly Park. However, along the southern headland to the beach is a walkway linking Shelly Beach to Fairy Bower and Manly Beach. The foreshore along this southern headland is protected by a vertical seawall, constructed on the exposed bedrock. The removal of the seawall from the southern end of the beach would expose the sewer and stormwater lines along the southern side of the bay to increasing risk from the present to 2100. The Kiosk/café located at the southern end of the beach would be at risk by 2050.

8.5.11 Fairy Bower

With the wall in place there is no erosion risk to development or infrastructure. If the wall was removed then the stormwater and sewerage infrastructure would need to be addressed. No erosion of the back beach area would occur as the foreshore is natural sandstone. The current existing problem resulting from wave overtopping would be further exacerbated.

8.5.12 Manly Beach (Manly LSC to Raglan Street)

Along this southern section of Manly Beach, with the wall in place, there are no properties identified as being at risk from coastal erosion/recession. Stormwater infrastructure seaward of the wall may need to be addressed as sea levels rise. If the seawall was removed then sewerage, stormwater and water supply infrastructure landward of the wall would be immediately at risk and this risk would continue to increase to 2100. Sections of South Steyne would be immediately at risk and this risk would increase continually until 2100. Three buildings along the reserve would be at immediate risk and by 2050, 13 to 15 properties would be at risk while by 2100 the number of properties at risk would increase to 26.

8.5.13 Manly Beach (Raglan Street to Pine Street)

Along this central section of Manly Beach, with the wall in place, only the North Steyne SLSC is in a location considered at risk from coastal erosion/recession. Stormwater infrastructure seaward of the wall may need to be addressed as sea levels rise. If the seawall was removed then sewerage, stormwater and water supply infrastructure landward of the wall would be immediately at risk and this risk would continue to increase to 2100. Sections of North Steyne would be immediately at risk and this risk would increase continually until 2100. The Surf Club would be at immediate risk and by 2050, 5 properties would be at risk while by 2100 the number of properties at risk would increase to 22.

8.5.14 Manly Beach (Pine Street to Queenscliff SLSC boatshed)

Along this exposed northern section of Manly Beach, with the wall in place, no properties are considered at risk from coastal erosion/recession. Stormwater infrastructure seaward of the wall may need to be addressed as sea levels rise. If the seawall was removed then stormwater and water supply infrastructure landward of the wall would be immediately at risk and this risk would continue to increase to 2100. The sewerage infrastructure behind the beach may be affected by 2100. Sections of North Steyne would be immediately at risk and this risk would increase continually until 2100. One building would be immediately at risk and by 2050, 5 properties would be at risk while by 2100 the number of properties at risk would increase to 25.

9. Assumptions and Limitations

The methodology applied in this report for the assessment of Coastal Risk Areas within the Manly LGA was developed in consultation with the Manly Council and the NSW Office of Environment and Heritage (NSW OEH), and conforms to the following documents:

- NSW Coastal Planning Guideline: Adapting to Sea Level Rise (DoP, 2010);
- Coastal Risk Management Guide (DECCW, 2010);
- NSW Sea Level Rise Policy Statement (DECCW, 2009); and
- NSW Coastline Management Manual (NSW PWD, 1990).

The assumptions and limitations applicable to the analysis and the data used in this study are described below.

9.1 Field Survey

A visual assessment of the seawalls allowed general and qualitative observations of the seawall present conditions. A detailed stability assessment was not part of the scope of works and no geotechnical investigation was undertaken for this study. Representative crest levels and foreshore geometry were chosen by experienced coastal engineers, however, in some locations these vary along the seawall.

9.2 Sea Level Rise

The sea level rise (SLR) projections adopted in this investigation were based on the Coastal Risk Management Guide (DECCW, 2010). No further reassessment of these benchmarks was undertaken by WRL. The SLR benchmarks are based on projections and actual SLR may be higher or lower than these benchmarks over the planning period. The IPCC reviews and revises SLR projections at 5-7 years intervals, with the most recent revision being in 2007.

9.3 Wave Climate

The nearshore wave climate along Manly LGA ocean and harbour beaches was determined using a numerical wave propagation model (SWAN version 40.85). The model inputs were offshore boundary conditions and bathymetric data. Offshore boundary conditions relied on extreme wave statistics analysis recently undertaken by WRL (Shand et al., 2010) for the Australian Climate Change Adaptation Research Network for Settlements and Infrastructure (ACCARNSI). Bathymetric data was obtained from Manly Council and the OEH. Data collection and analysis was undertaken by reputable organisations, however, minor survey errors are likely.

9.4 Wave Runup and Overtopping

Best practice empirical prediction methods based on the most current published literature (Eurotop, 2007) were applied to estimate wave overtopping and runup levels at the structures. Statistical and data uncertainties related to these methodologies are discussed in the referenced literature (Eurotop, 2007). The effect of wind on overtopping rates was not considered. Site specific physical modelling is the only available method offering greater certainty than the methods used.

9.5 Beach Erosion and Recession

The volumes of storm erosion and rates of recession adopted in this study ultimately relied on the analysis of temporal data sets of beach profile fluctuations. These were obtained using photogrammetric data made available by the NSW OEH. The accuracy of this information rests with OEH, however, photogrammetric analysis is undertaken to best current practice by skilled and experienced staff. The temporal resolution of the dataset limits the accuracy and reliability of the estimates.

Future shoreline recession as a result of sea level rise were estimated using the Bruun rule and the NSW Government policy (NSW, 2009). The limitations of this methodology are well recognised (Ranasinghe et al., 2007) and were taken into consideration. However, no robust and scientifically recognised alternative currently exists and the application of the Bruun rule is currently supported by State Government Policy (DECCW, 2010). Where known or obvious, the presence of underlying bedrock shelves was taken into account in this study. However, there may be bedrock present in other areas where it is not visible.

9.6 Mapping of Coastal Hazard Lines

Mapping of coastal hazard lines was produced to provide general guidance for coastal planning and to identify areas prone to coastal hazards. Mapping was undertaken using state-of-the-art and government endorsed methodologies. Mapping was based on the discretisation of the coastline into mean profiles which were obtained from the photogrammetric analysis. The limitations of the temporal and spatial resolution of the available data applies to the mapping as well, and site specific investigations and surveys are encouraged to overcome such limitations.

9.7 Mapping of Coastal Inundation Zones

Mapping of coastal hazard lines was produced to provide general guidance for coastal planning and to identify areas prone to coastal inundation. Mapping was undertaken using state-of-the-art and government endorsed methodologies. Mapping of inundation was based on the current shoreline location and did not include any allowance for future landward recession. Mapping assumed that both seawall crest levels and topography remain as they were from the LIDAR 2008 data provided by the Manly Council. WRL is not responsible for the accuracy of the LIDAR data.

9.8 Risk Assessment

The risk assessment undertaken is preliminary as it relies on the spatial accuracy of the mapping data available (LIDAR data provided by Manly Council) and on the accuracy of the coastal hazard mapping. Site specific analysis should be undertaken to obtain a detailed risk assessment.

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APPENDIX A - Photographic Record of Seawall Inspection

Ellery's Punt Seawall

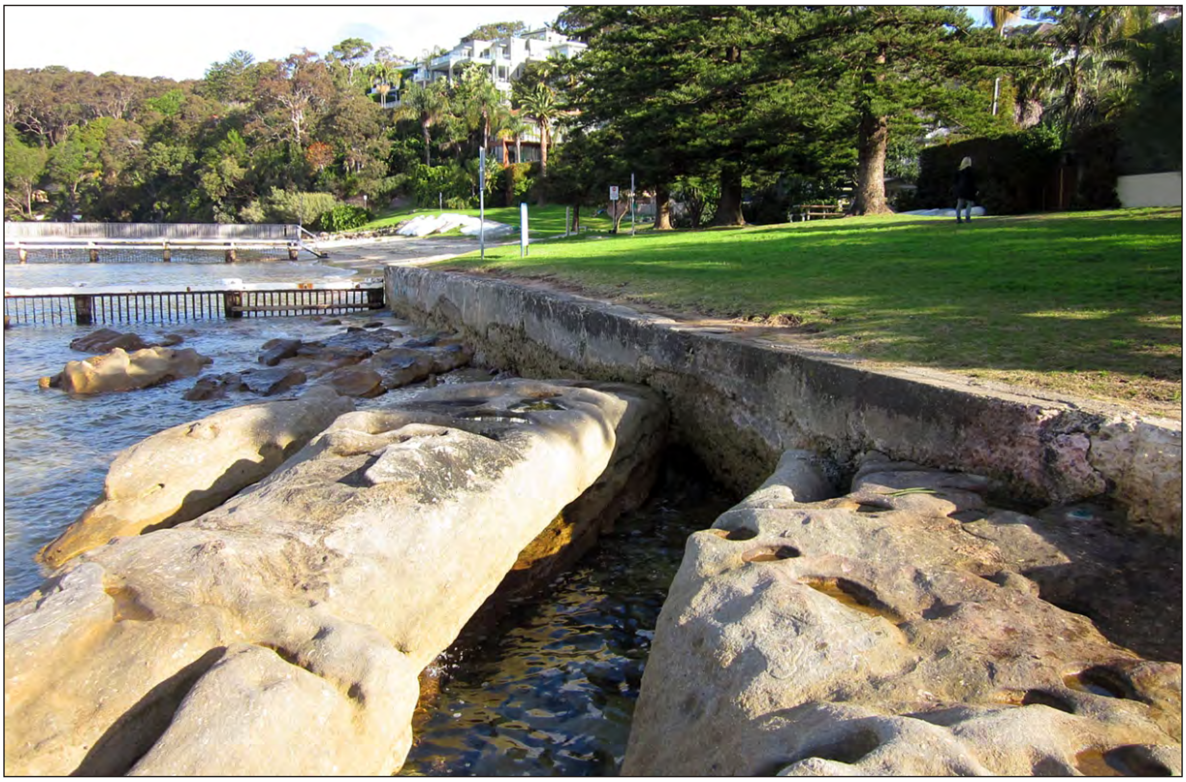
Clontarf #1 Seawall between Sandy Bay and the Marina

Clontarf #2 Seawall at Culvert

Clontarf #3 Seawall at Pool

Clontarf #4 Seawall at Private Properties

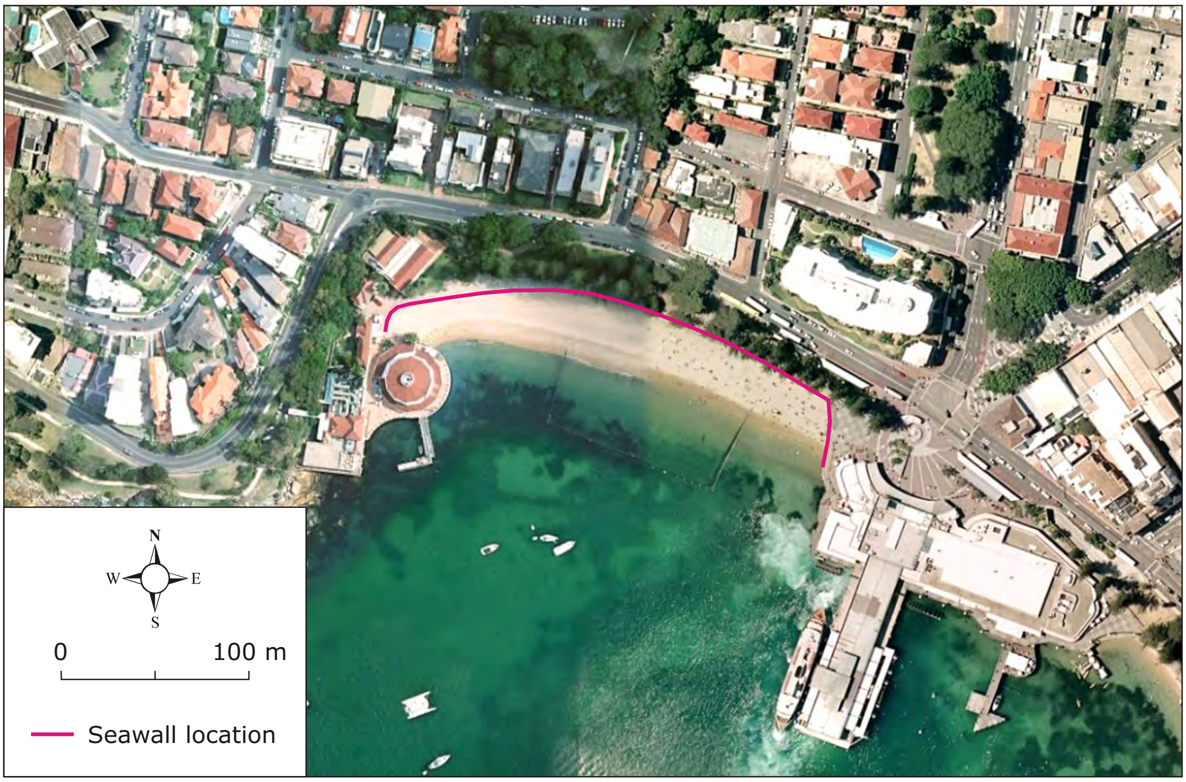
Clontarf #5 Seawall at Public Access from Monash Cresent

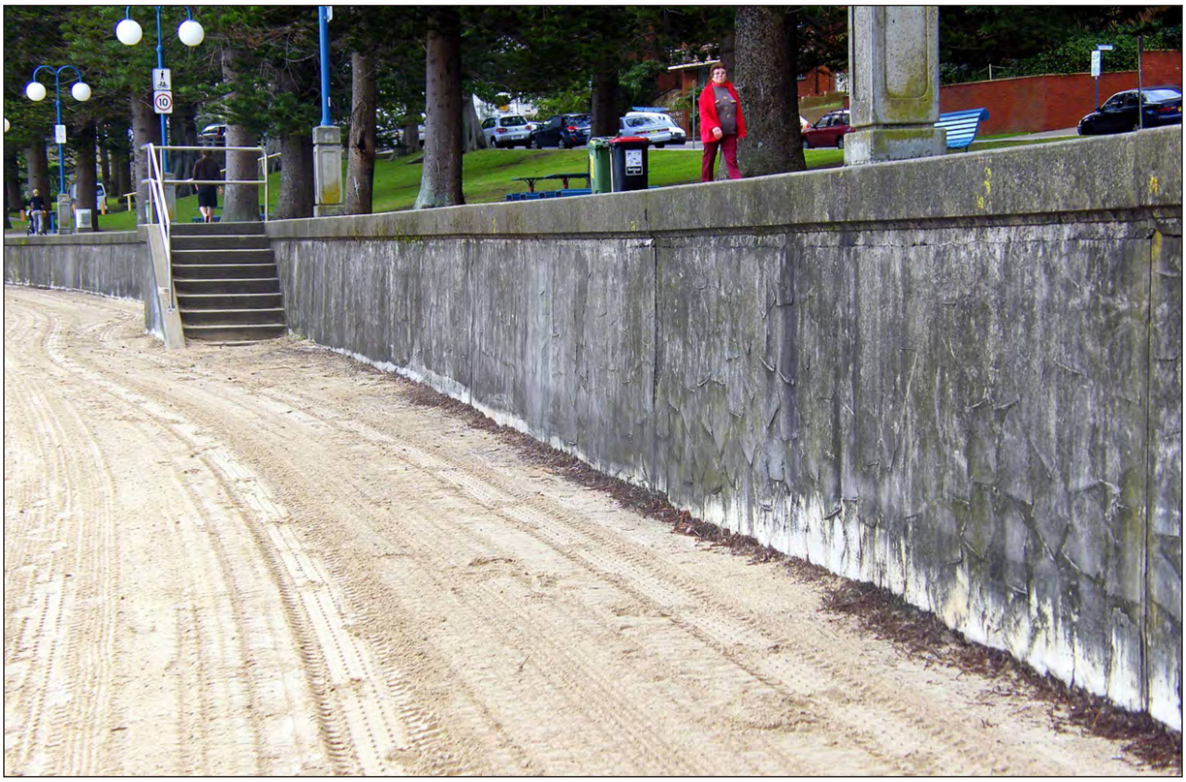


Forty Baskets Seawall

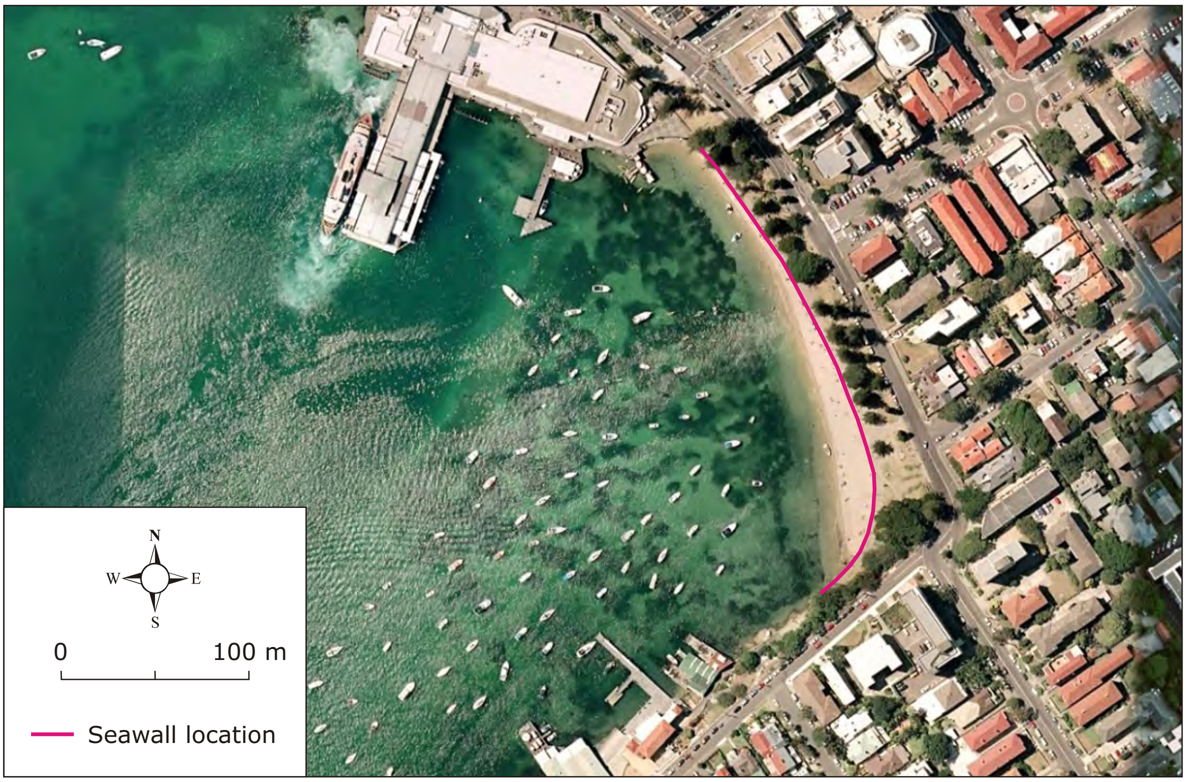
North Harbour Reserve Rock Revetment

Fairlight Beach Seawall



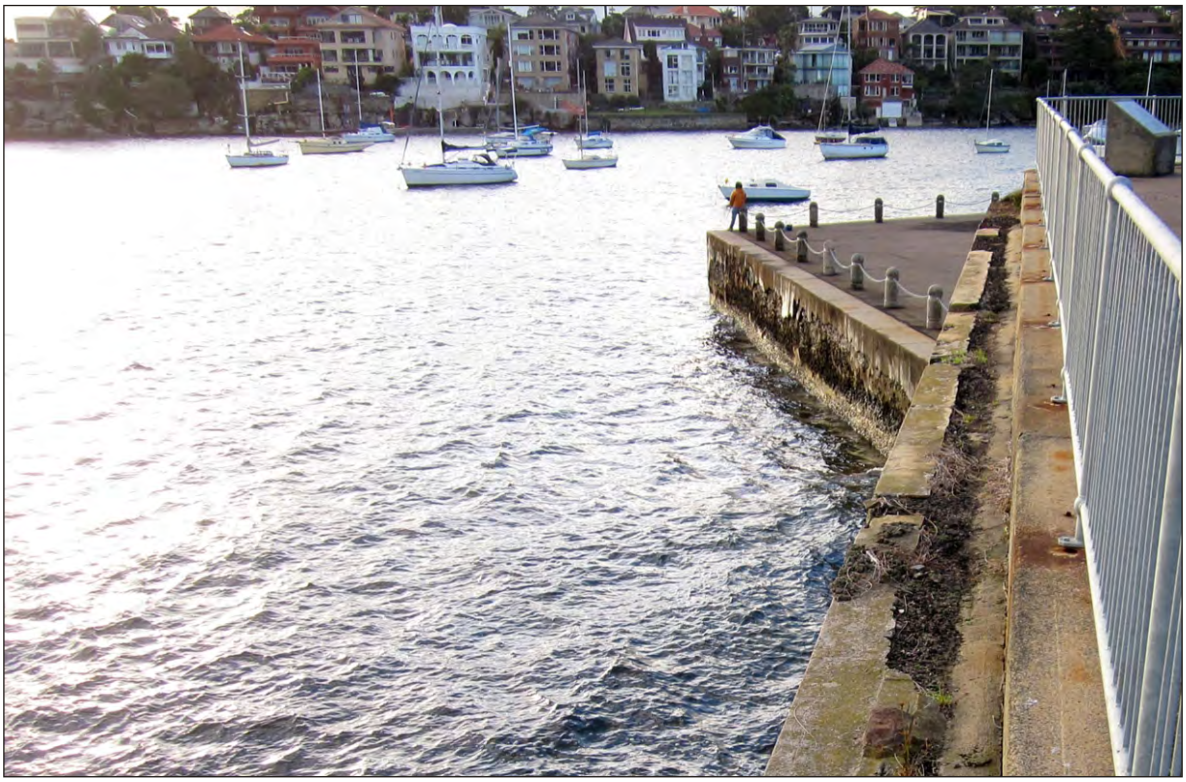


Manly Cove West Seawall



Manly Cove East Seawall

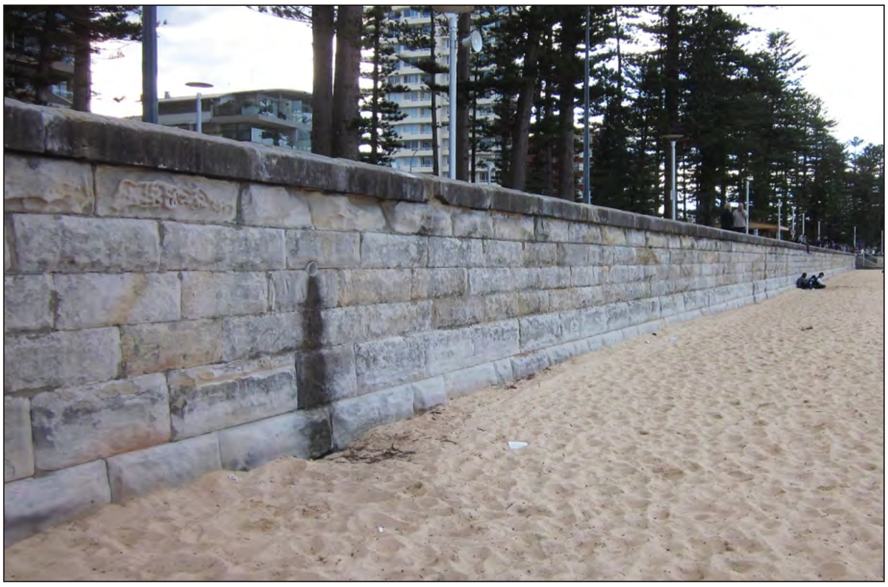
Little Manly Beach Seawall



Gas Works Quay

Quarantine Station

Manly Ocean Beach South: Manly LSC to Corso
(Chainage from Manly LSC = 0 m - 360 m)



Manly Ocean Beach Middle: Corso to Pacific St
(Chainage from Manly LSC = 360 m - 1,282 m)

Manly Ocean Beach North: Pacific St to Queenscliff Boatshed
(Chainage from Manly LSC = 1,282 m - 1,522 m)

Marine Parade Seawall

APPENDIX B – Wave Modelling

APPENDIX B. Wave Modelling

The Manly LGA coastline is subject to extreme waves originating from offshore storms or produced locally within Sydney Harbour. Swell waves reaching the coast may be modified by the processes of refraction, diffraction, wave-wave interaction and dissipation by bed friction and wave breaking. Waves generated locally within Sydney Harbour undergo generation processes as well as the aforementioned propagation and dissipation processes. The model SWAN (Simulating WAves Nearshore) was used to quantify the change in wave conditions from a deepwater boundary into the Manly LGA coastline and to model the generation of local wind-waves within Sydney Harbour. Details of SWAN can be found in Booij et al (1999a, 1999b) and is described in brief below.

1.1 SWAN Wave Model

SWAN (version 40.85) is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. The SWAN model is based on the wave action balance equation with sources and sinks and accommodates the process of wind generation, white capping, bottom friction, quadruplet wave-wave interactions, triad wave-wave interactions and depth induced breaking (Ris et al., 1994).

The formulation of the SWAN wave model imposes a number of restrictions which should be acknowledged. While the model may be used on domains of any scale, its use in oceanic scale domains is not recommended for reasons of computation efficiency compared to models such as WAM and WaveWatchIII. Additionally, the spectral formulation of the model limits its ability to accurately model wave diffraction and some surf zone processes such as wave setup (in a two-dimensional simulation).

Despite these limitations, the SWAN model is considered an industry-standard spectral wave generation and propagation model and, with appropriate acknowledgment and allowance for such limitations, provides accurate and robust values.

1.1 Computational Domain

Correct representation of natural bathymetry within the model computational domain is critical to simulating representative wave propagation and transformation processes.

1.1.1 Data Sources

Sources of bathymetric and topographic data of the Sydney Coastal and Harbour region used within this study are presented within Table B-1. Individual data sets are adjusted to a project co-ordinate system (MGA Zone56 GDA94) and reduced level (AHD) and combined to derived a comprehensive digital elevation model for the Sydney Coastal and Harbour region (i.e. Figure B-1).

Table B-1 Sources of bathymetric and topographic data used to construct the SWAN computational domain

Dataset	Data Source	Grid Reference System	Datum
Sydney Region Bathymetry and Seabed Mapping	NSW Office of Environment and Heritage	MGA Zone56 GDA94	Fort Denison Tide Gauge
Sydney Harbour 1m Contours	Sydney Metro CMA derived from soundings obtained from NSW Maritime	MGA Zone56 GDA94	AHD
Offshore Contours	Geoscience Australia 9 arc second Bathy and Topo Grid ausbath_09_v4	GCS_WGS_1984	AHD
Manly LIDAR	Manly Council	MGA Zone56 GDA94	AHD
Inner Sydney 2m Topographic Contours	Department of Lands (for NSW)	MGA Zone56 GDA94	AHD

1.1.2 Model Domains

Two model domains were constructed to represent different scales of the Sydney Coastal and Harbour region. These domain extents are shown within Figure B-2 and included a Sydney Coastal domain and a Sydney Harbour domain.

The Sydney Coastal domain extended 36 km along the Sydney coastline from Mona Vale in the north to Malabar in the south and 15 km offshore to ensure that model boundary effects did not influence wave characteristics reaching the Manly LGA area. This model domain had a resolution of 100 m and was primarily used as a transformation model to simulate wave propagation from an offshore location to the nearshore Sydney Harbour domain.

This Sydney Harbour domain was constructed at a finer 25 m resolution and extended from approximately 4 km offshore of Manly Beach to the western extent of the Manly LGA. The model was used to simulate local wind-wave growth within Sydney Harbour and to simulate wave propagation from offshore into Manly Beach and into Sydney Harbour.

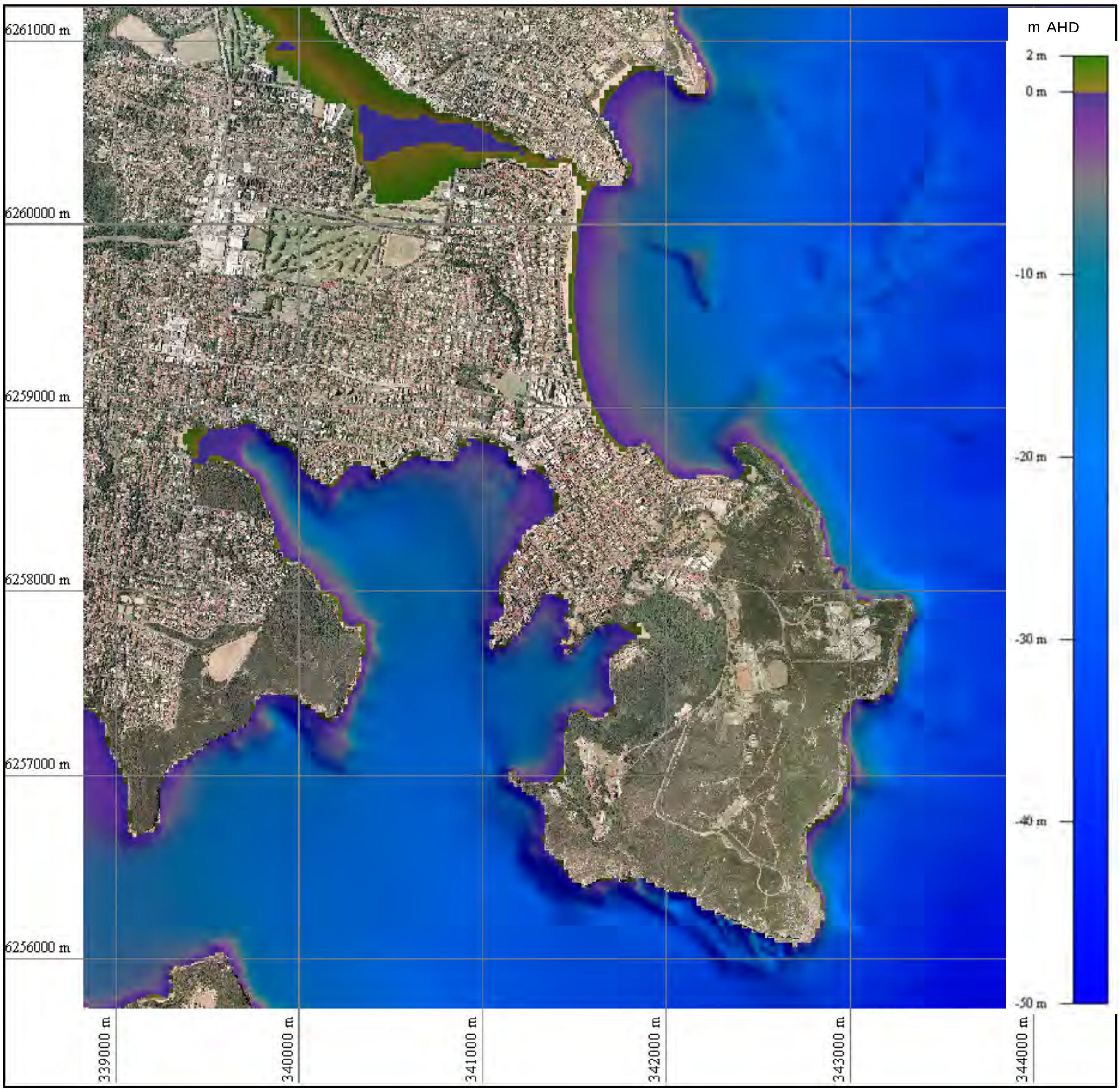


Figure B-1 Example of the digital elevation model used in SWAN simulations. Levels given in terms of m AHD.

Table B-2 Model Domain Parameters

Sydney Coastal	**Easting**	**Northing**
Lower Left Corner	338350	6237300
Size	20000	36000
Resolution	100	100
No Cells	200	360
Sydney Harbour	**Easting**	**Northing**
Lower Left Corner	333525	6250225
Size	12000	12000
Resolution	25	25
No Cells	480	480

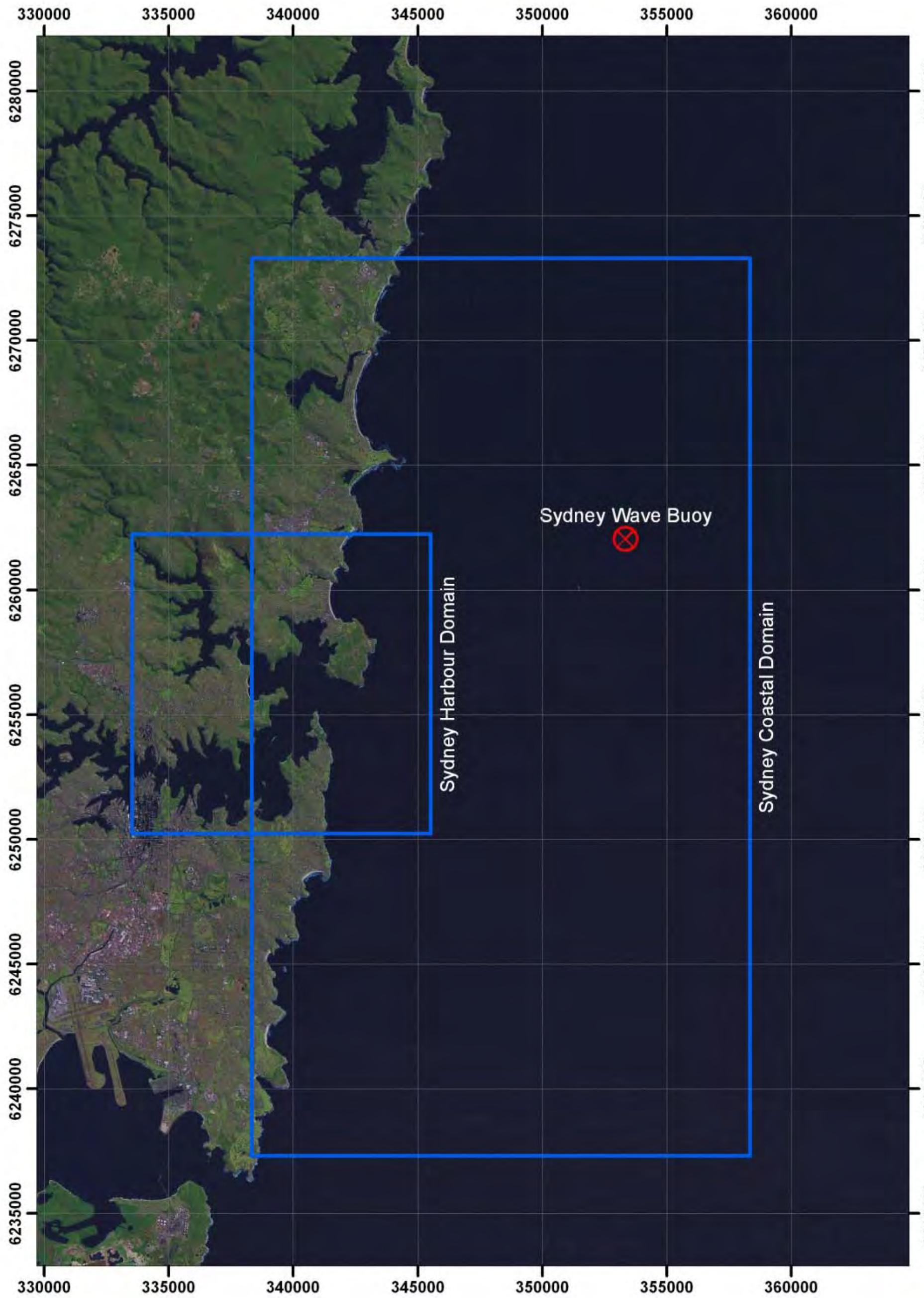


Figure B-2 SWAN model domains

1.1.3 Output Locations

For each model simulation, spatial maps of wave height, period and direction have been generated for the Sydney Coastal and Sydney Harbour regions. More detailed information including significant wave height, mean and peak period and direction, wave breaking fraction, water elevation, depth and wave setup have also been provided for 25 coastal locations of interest within the Manly LGA. These locations are presented within Table B-3 and Figure B-3.

Rather than specify a single point offshore of a coastal location, information is extracted along transect lines from pre-breaking to the shoreline. This is due to the significant amount of wave transformation which occurs immediately prior to breaking. When an arbitrary output point is specified, the location may be well offshore of the surf zone and will not include final, nearshore transformation or may be inside the surf zone where some loss of spectral wave height through offshore breaking of larger waves has already occurred. By extracting information along a transect, wave conditions at the outer edge of the surf zone may be extracted using the wave breaking fraction. The outer edge of the surf zone is assumed to occur when the wave breaking fraction reaches 1% and wave conditions are extracted and output for that location.

Table B-3 SWAN coastal output transects

Output Location	Offshore Transect End		Interval (m)	Onshore Transect End	
	Easting	Northing		Easting	Northing
Manly 4	342388	6259869	25	341481	6259998
Manly 3	342403	6259668	25	341433	6259700
Manly 2	342229	6259388	25	341532	6259089
Manly 1	342315	6259275	25	341671	6258823
Shelly Beach	342116	6258791	25	342463	6258643
Bower Beach	342279	6259019	25	342033	6258623
Quarantine Beach	341046	6257229	25	341438	6256992
Store Beach	341365	6257519	25	341710	6257352
Collins Beach	341439	6257596	25	341879	6257812
Little Manly Cove	341220	6257577	25	341434	6257981
Manly Cove East	341069	6258359	25	341363	6258576
Manly Cove West	340910	6258419	25	341039	6258824
Delwood	340686	6258455	25	340618	6258754
Fairlight	340296	6258404	25	340313	6258711
Nth Harbour Reserve	339896	6258676	25	339319	6258867
Forty Baskets	340303	6258318	25	339853	6258318
Reef Beach	340420	6257994	25	340233	6257825
Washway Beach	339728	6256778	25	339254	6256982
Clontarf South	338117	6257509	25	338268	6257682
Clontarf Spit	338048	6257868	25	338147	6257878
Clontarf North	338054	6258065	25	338277	6258165
Sandy Bay	337911	6258306	25	338023	6258616
Seaforth South	337019	6257974	25	337017	6258196
Seaforth Middle	336579	6258830	25	336959	6258805
Seaforth North	336606	6259701	25	336780	6259734

Figure B-3 Location of SWAN output transects

1.2 Environmental Conditions

Environmental conditions adopted for model scenario runs including extreme offshore wave conditions, local wind speeds and water levels are described below.

1.2.1 Offshore Waves

The NSW coast spans the southern Coral Sea to the Southern Tasman Sea across the sub-tropical to mid-latitude zone. Extreme wave energy is mainly generated within the Coral Sea and Tasman Sea window, but can also be generated from outside this zone: in the South – West Pacific tropics; and, in the Southern Ocean in the extra-tropics. Following a series of intense and damaging storms in 1974, a network of wave buoys was incrementally established along the NSW coast by the NSW Department of Public Works. Data from this wave buoy network was analysed by Shand et al. (2010) to derive extreme wave characteristics for the NSW coastline. The 100 year average recurrence interval (ARI) wave height for Sydney was found to be 9.0 m (with 90% confidence intervals of ± 0.5 m).

Variation in extreme characteristics as a function of direction was assessed f where directional wave data was available. Figure B-4 shows significant wave height for events between 1 and 100 years ARI from different offshore directions at the Sydney directional wave buoy. While limits in data availability, particularly for large events from the Northeast quarter, restricts the directional resolution of derived extreme values, results show waves from North to East to be substantially smaller than the those from the Southeast quarter.

Offshore conditions adopted within the present study are based on these extreme values. Boundary conditions are calibrated by modifying waves at the offshore boundary of the Coastal Model until wave height, period and direction at the Sydney wave buoy location (Figure B-2) match those presented within Table B-4.

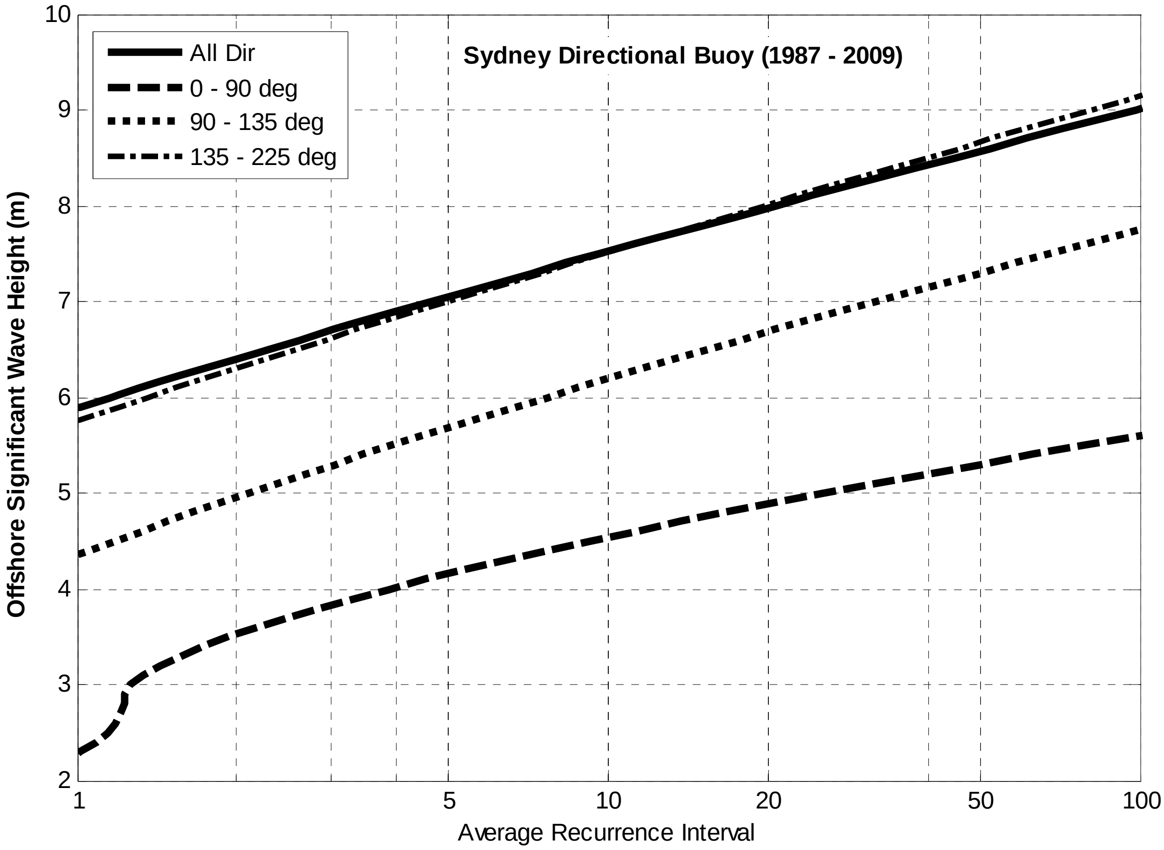


Figure B-4 Summary of Sydney Directional Extreme Wave Climate (Source: Shand et al. 2010)

Table B-4 Adopted directional extreme wave conditions for the Sydney offshore wave buoy (source: Shand et al. 2010)

	1 yr ARI		10 yr ARI		50 yr ARI		100 yr ARI	
Direction	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
Northeast	3.0	11.0	4.5	12.1	5.4	12.7	5.7	13.0
East	4.4	11.0	6.2	12.1	7.4	12.7	7.8	13.0
Southeast	5.9	11.0	7.5	12.1	8.6	12.7	9.0	13.0
South-southeast	5.9	11.0	7.5	12.1	8.6	12.7	9.0	13.0
South	4.4	11.0	6.2	12.1	7.4	12.7	7.8	13.0

1.2.2 Local Winds

Australian Standard AS/NZS 1170.2:2002 *Structural Design Actions Part 2: Wind Actions* gives design wind velocities for Australia excluding tornadoes. Design wind velocities (3 second gust, 10 m elevation, Terrain Category 2) applicable to coastal engineering assessments are given for average recurrence intervals of 1 to 1000 years. Site wind speeds (V_{sit}), are calculated according to Eqn. 1-1 using multipliers for direction (M_d), terrain ($M_{z,cat}$), shielding (M_s) and topography (M_t).

$$V_{sit} = V_R M_d (M_{z,cat} M_s M_t) \tag{1-1}$$

The Manly LGA coastline falls within Region A2 (Standards Australia, 2002) and corresponding wind speed multipliers are adopted. A Category 2 terrain multiplier is suggested for water surfaces at wind speeds higher than serviceability wind speeds (AS1170.2:2002, S4.2.1). No further shielding or topography multipliers have been applied.

Waves generated by winds blowing across Sydney Harbour are the result of sustained winds rather than extreme gusts. Equivalent sustained one hour wind speeds are therefore calculated using the approach set out in Figure II-2-1 of Part II of the USACE Coastal Engineering Manual (2003). A 1 hour duration has been selected based on the mean time of wave generation and propagation from south to north within Sydney Harbour. Sustained (1 hour) wind speeds for annual recurrence intervals of 1 to 100 years for directions of North to Northwest are presented within Table B-5.

Table B-5 Adopted extreme wind conditions for the Sydney coastal area (source: ASNZS1170)

		1 hour average (ms^{-1})			
Direction	Multiplier	1 yr ARI	10 yr ARI	50 yr ARI	100 yr ARI
Northeast	0.80	13.8	18.0	20.8	21.7
East	0.80	13.8	18.0	20.8	21.7
Southeast	0.95	16.4	21.4	24.7	25.8
South	0.90	15.5	20.3	23.4	24.4
Southwest	0.95	16.4	21.4	24.7	25.8
West	1.00	17.2	22.5	26.0	27.2
Northwest	0.95	16.4	21.4	24.7	25.8
North	0.80	13.8	18.0	20.8	21.7

1.2.3 Water Levels

Water levels corresponding to annual recurrence intervals of 1 to 100 years have been adopted based on those presented within the Coastal Risk Management Guide (ref). These water levels include astronomical tide and tidal residual components and are presented within Table B-6.

Table B-6 Adopted extreme water levels for the Sydney coastal area

ARI	Water Level (m AHD)
1 yr	1.24
10 yr	1.35
50 yr	1.41
100 yr	1.44

1.3 SWAN Wave Simulations

1.3.1 Parameters

SWAN modelling was undertaken using the model parameters and coefficients shown in Table B-7. Some sensitivity tests were undertaken on some coefficients and , with some determined based on past experience of WRL staff on wave modelling.

Table B-7 SWAN Modelling Setup and Parameters

Model Physics	
Physics mode (generation)	3rd
Wave growth formulation	Komen et al. (1984)
Triad wave-wave interaction	On
Nonlinear quadruplet wave interaction	On
Whitecapping	On
Wave breaking model	Battjes and Janssen
A	1
H_{max}/d (γ)	0.73
Bottom friction (JONSWAP)	0.067 (default)
Model Numerics	
Model Run Mode	Stationary, Two dimensional
Iterations	30
Spectral Parameters	
Spectral Shape at Boundary	JONSWAP
Peak Enhancement Factor	3.3 (default)
Period	Peak
Standard Deviation of Directional Spreading	30 º
Diffraction	Off (recommended)
Directional Space Parameters	
Directional Range	360 º
Directional Resolution	10 º
Frequency Space Parameters	
No. Frequency Bins	32
Min. Frequency	0.05
Max. Frequency	1

1.3.2 Scenarios

Model scenarios corresponding to 1, 10, 50 and 100 year ARI events from directions between north and northwest have been simulated. Directions between northeast and south include an offshore wave component as well a local wind field while directions from southwest to north are forced by local winds only.

While event directions have generally been at 45° increments, an additional scenario from the SSE direction (157.5°) was undertaken to maximise wave penetration into the Manly LGA coastline within Sydney Harbour. A summary of scenarios is presented within Table B-8.

Table B-8 SWAN model scenarios and environmental forcing conditions

Scenario	ARI	Water Level (m AHD)	Conditions at Sydney Offshore Wave Buoy			Domain Wind Conditions	
			Hs (m)	Tp (s)	Dp (°)	V (m/s)	Dir (°)
NE	1	1.24	3.0	11.0	45	13.78	45
	10	1.35	4.5	12.1		18.02	
	50	1.41	5.4	12.7		20.83	
	100	1.44	5.7	13.0		21.73	
E	1	1.24	4.4	11.0	90	13.78	90
	10	1.35	6.2	12.1		18.02	
	50	1.41	7.4	12.7		20.83	
	100	1.44	7.8	13.0		21.73	
SE	1	1.24	5.9	11.0	135	16.36	135
	10	1.35	7.5	12.1		21.40	
	50	1.41	8.6	12.7		24.74	
	100	1.44	9.0	13.0		25.81	
SSE	1	1.24	5.9	11.0	157.5	16.36	157.5
	10	1.35	7.5	12.1		21.40	
	50	1.41	8.6	12.7		24.74	
	100	1.44	9.0	13.0		25.81	
S	1	1.24	4.4	11.0	180	15.50	180
	10	1.35	6.2	12.1		20.27	
	50	1.41	7.4	12.7		23.43	
	100	1.44	7.8	13.0		24.45	
SW	1	1.24	-	-	-	16.36	225
	10	1.35	-	-	-	21.40	
	50	1.41	-	-	-	24.74	
	100	1.44	-	-	-	25.81	
W	1	1.24	-	-	-	17.23	270
	10	1.35	-	-	-	22.53	
	50	1.41	-	-	-	26.04	
	100	1.44	-	-	-	27.16	
NW	1	1.24	-	-	-	16.36	315
	10	1.35	-	-	-	21.40	
	50	1.41	-	-	-	24.74	
	100	1.44	-	-	-	25.81	
N	1	1.24	-	-	-	13.78	0
	10	1.35	-	-	-	18.02	
	50	1.41	-	-	-	20.83	
	100	1.44	-	-	-	21.73	

1.4 Results

Examples of 100 year ARI events from the southwest (local wind only) and from the south-southeast (offshore wave + local wind) are shown within Figure B0-5 and Figure B-6.

For each output location, wave conditions for each direction scenario are evaluated and maximum conditions (at outer breakpoint) are summarised in Table B-9 for the offshore swell + local wind forcing conditions and in Table B-10 for local wind forcing only.

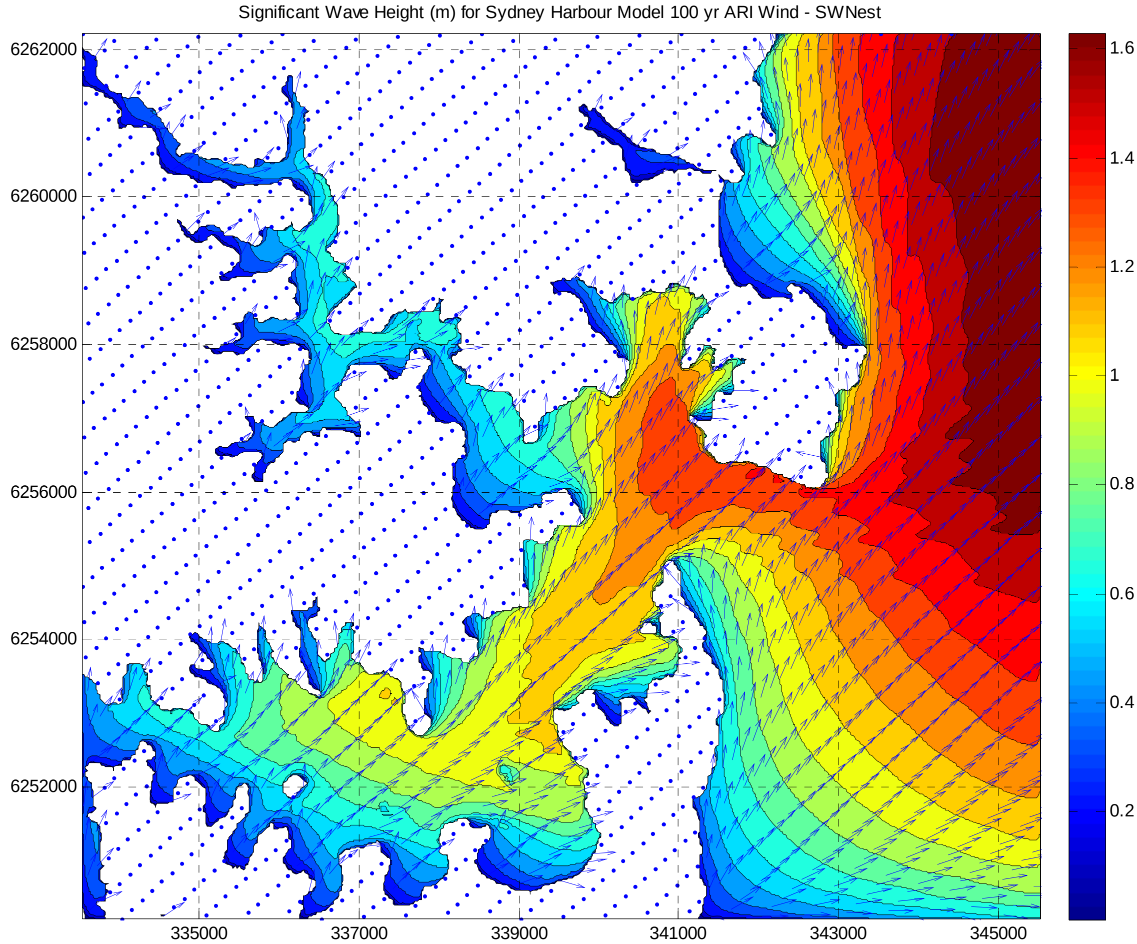


Figure B0-5 Example of a 100 year ARI southwest wind event for the Sydney Harbour model

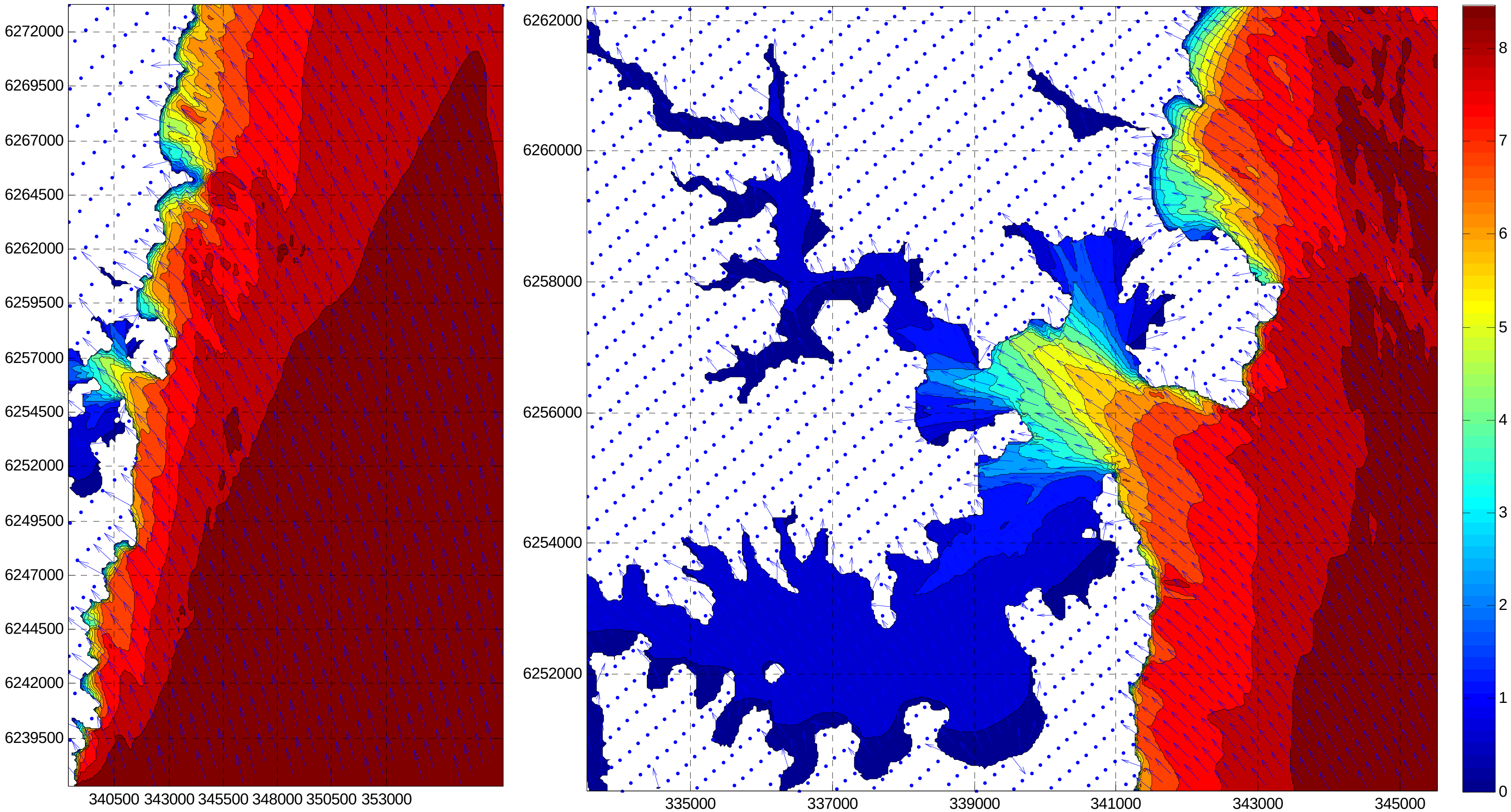


Figure B-6 Example of a 100 year ARI event from the South-southeast for the Sydney Coastal Model (A) and nested Harbour Model (B)

Table B-9 Resultant maximum wave height characteristics for Manly LGA output points as a result of Offshore Swell and Local Wind Forcing

	Hs (m)				Tp (s)				Dp (°)			
Point	100yr ARI	50yr ARI	10yr ARI	1yr ARI	100yr ARI	50yr ARI	10yr ARI	1yr ARI	100yr ARI	50yr ARI	10yr ARI	1yr ARI
Manly4	7.30	7.04	6.18	5.04	13.6	12.3	12.3	11.2	115	115	115	85
Manly3	7.31	7.02	5.90	5.12	13.6	12.3	12.3	11.2	115	115	115	115
Manly2	4.80	5.11	4.40	3.52	13.6	12.3	12.3	11.2	95	85	85	75
Manly1	4.84	5.14	4.06	3.23	13.6	12.3	12.3	11.2	85	75	75	65
Shelly	1.15	1.12	1.04	0.87	13.6	12.3	12.3	11.2	305	305	305	305
Bower	2.52	2.44	2.25	2.00	13.6	12.3	12.3	11.2	35	35	35	35
Quarintine	0.36	0.34	0.29	0.25	13.6	13.6	12.3	11.2	295	295	295	295
Collins	0.42	0.40	0.32	0.25	2.9	12.3	12.3	11.2	235	235	235	235
LilManCove	0.87	0.83	0.69	0.53	12.3	12.3	12.3	11.2	205	205	205	205
ManCoveE	0.69	0.65	0.53	0.42	12.3	12.3	12.3	11.2	225	225	225	225
ManCoveW	1.07	1.03	0.87	0.71	12.3	12.3	12.3	11.2	195	195	195	195
Delwood	1.30	1.24	1.06	0.88	12.3	12.3	12.3	11.2	175	175	175	175
Fairlight	1.57	1.52	1.36	1.19	12.3	12.3	12.3	11.2	165	165	165	165
NthHarRes	0.29	0.28	0.23	0.27	2.9	2.9	2.6	2.4	105	105	105	105
FortyBask	0.80	0.77	0.65	0.54	12.3	12.3	12.3	11.2	95	95	95	95
ReefBeach	1.18	1.13	0.97	0.85	12.3	12.3	12.3	11.2	85	85	85	85
Washway	4.45	4.20	3.60	3.19	13.6	12.3	12.3	11.2	125	125	115	115
ClontarfS	0.61	0.58	0.50	0.36	13.6	12.3	12.3	11.2	175	175	175	215
ClontarfSpit	0.60	0.57	0.47	0.30	2.4	2.9	2.9	11.2	165	165	165	175
ClontarfN	0.41	0.39	0.32	0.23	2.2	2.2	2.0	1.6	215	215	215	215
SandyBay	0.51	0.49	0.30	0.22	2.4	2.2	2.0	1.8	185	185	185	185
SeaforthS	0.64	0.60	0.50	0.36	2.2	2.2	2.0	1.8	105	105	105	105
SeaforthM	0.36	0.34	0.27	0.20	2.2	2.2	2.0	1.6	225	225	225	225
SeaforthN	0.48	0.46	0.38	0.28	2.4	2.4	2.2	2.0	195	195	195	205
Store	0.30	0.28	0.21	0.16	12.3	12.3	12.3	11.2	285	285	285	285

Table B-10 Resultant maximum wave height characteristics for Manly LGA output points as a result of Local Wind Forcing Only

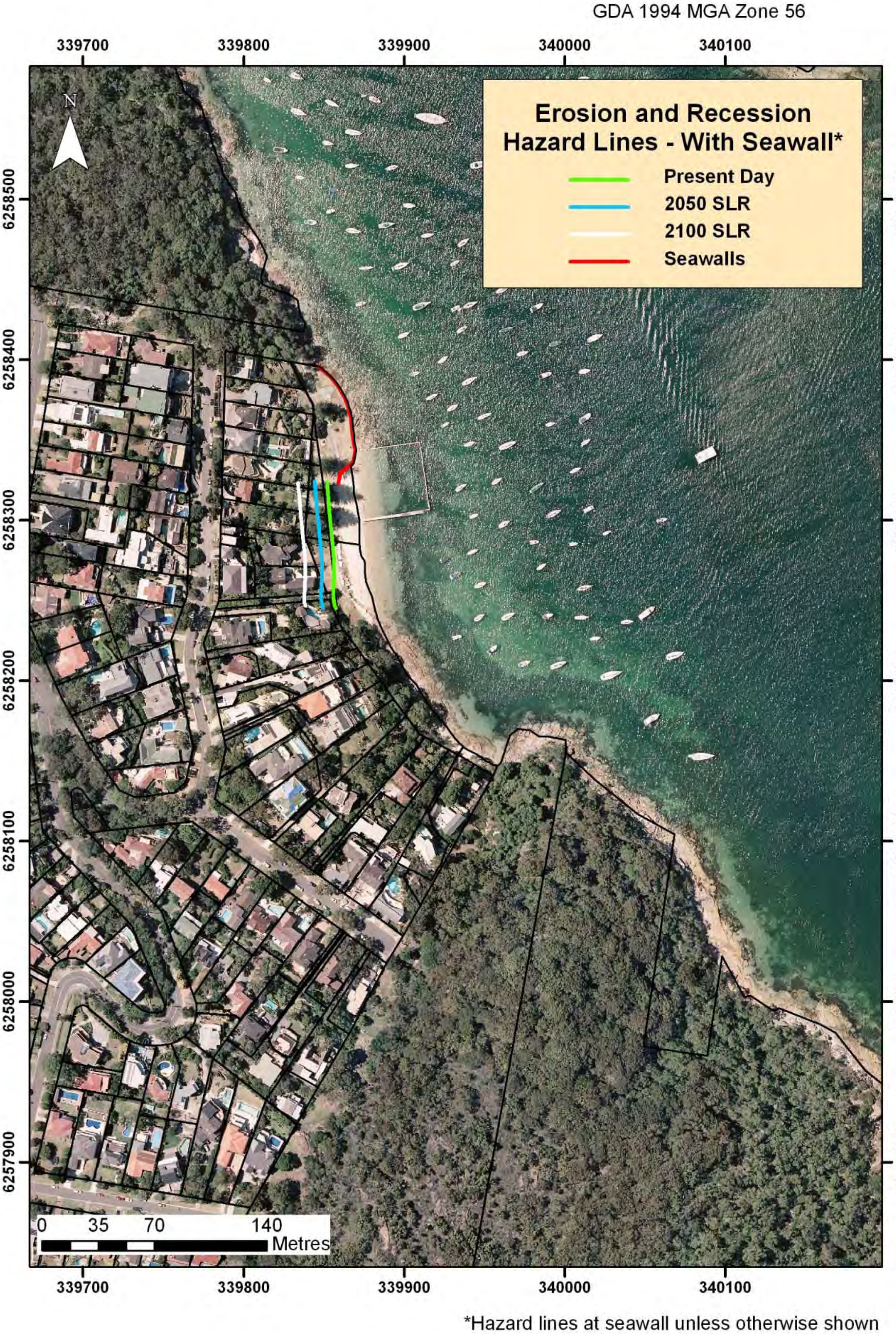
Point	Hs (m)				Tp (s)				Dp (°)			
	100yr ARI	50yr ARI	10yr ARI	1yr ARI	100yr ARI	50yr ARI	10yr ARI	1yr ARI	100yr ARI	50yr ARI	10yr ARI	1yr ARI
Manly4	-	-	-	-	-	-	-	-	-	-	-	-
Manly3	-	-	-	-	-	-	-	-	-	-	-	-
Manly2	-	-	-	-	-	-	-	-	-	-	-	-
Manly1	-	-	-	-	-	-	-	-	-	-	-	-
Shelly	0.51	0.48	0.40	0.29	2.9	2.6	2.4	2.2	315	315	315	315
Bower	0.90	0.86	0.71	0.53	3.5	3.2	3.2	2.6	35	35	35	25
Quarantine	0.64	0.61	0.52	0.38	2.9	2.6	2.6	2.4	315	315	315	315
Collins	0.56	0.54	0.47	0.35	3.5	3.5	3.2	2.9	235	235	235	235
LilManCove	0.89	0.85	0.75	0.54	3.9	3.5	3.5	3.2	205	205	205	205
ManCoveE	0.78	0.74	0.64	0.47	2.9	2.9	2.6	2.4	225	225	225	225
ManCoveW	0.95	0.91	0.80	0.57	4.3	3.5	3.2	3.2	195	195	195	195
Delwood	1.05	1.01	0.87	0.62	3.9	3.9	3.5	3.2	175	175	175	175
Fairlight	0.83	0.80	0.68	0.52	4.3	4.3	3.9	3.5	165	165	165	165
NthHarRes	0.27	0.26	0.22	0.27	2.9	2.9	2.6	2.4	105	105	105	105
FortyBask	0.66	0.63	0.54	0.41	2.6	2.6	2.4	2.2	115	115	125	125
ReefBeach	0.52	0.49	0.41	0.31	2.4	2.2	2.0	1.8	35	35	35	35
Washway	1.34	1.27	1.09	0.79	4.7	4.3	3.9	3.5	125	125	125	125
ClontarfS	0.44	0.43	0.36	0.27	2.9	2.2	2.6	2.2	175	175	175	175
ClontarfSpit	0.58	0.56	0.46	0.31	2.6	2.6	2.4	2.0	285	275	275	285
ClontarfN	0.69	0.65	0.55	0.41	2.9	2.9	2.6	2.2	265	265	265	265
SandyBay	0.51	0.49	0.40	0.23	2.6	2.4	2.2	2.0	185	185	185	185
SeaforthS	0.64	0.61	0.51	0.37	2.6	2.6	2.4	2.0	205	205	205	205
SeaforthM	0.68	0.65	0.54	0.38	2.4	2.4	2.2	2.0	295	295	295	235
SeaforthN	0.59	0.60	0.50	0.37	2.4	2.6	2.4	2.0	245	215	215	215
Store	0.66	0.62	0.52	0.37	2.9	2.9	2.6	2.2	275	275	275	295

APPENDIX C – Mapping of Coastal Erosion Hazard Lines

Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Clontarf Coastal Erosion Hazard Lines With Seawall



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Forty Baskets Coastal Erosion Hazard Lines With Seawall

Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Fairlight Beach Coastal Erosion Hazard Lines With Seawall

Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Manly Cove West Coastal Erosion Hazard Lines With Seawall

Notes:

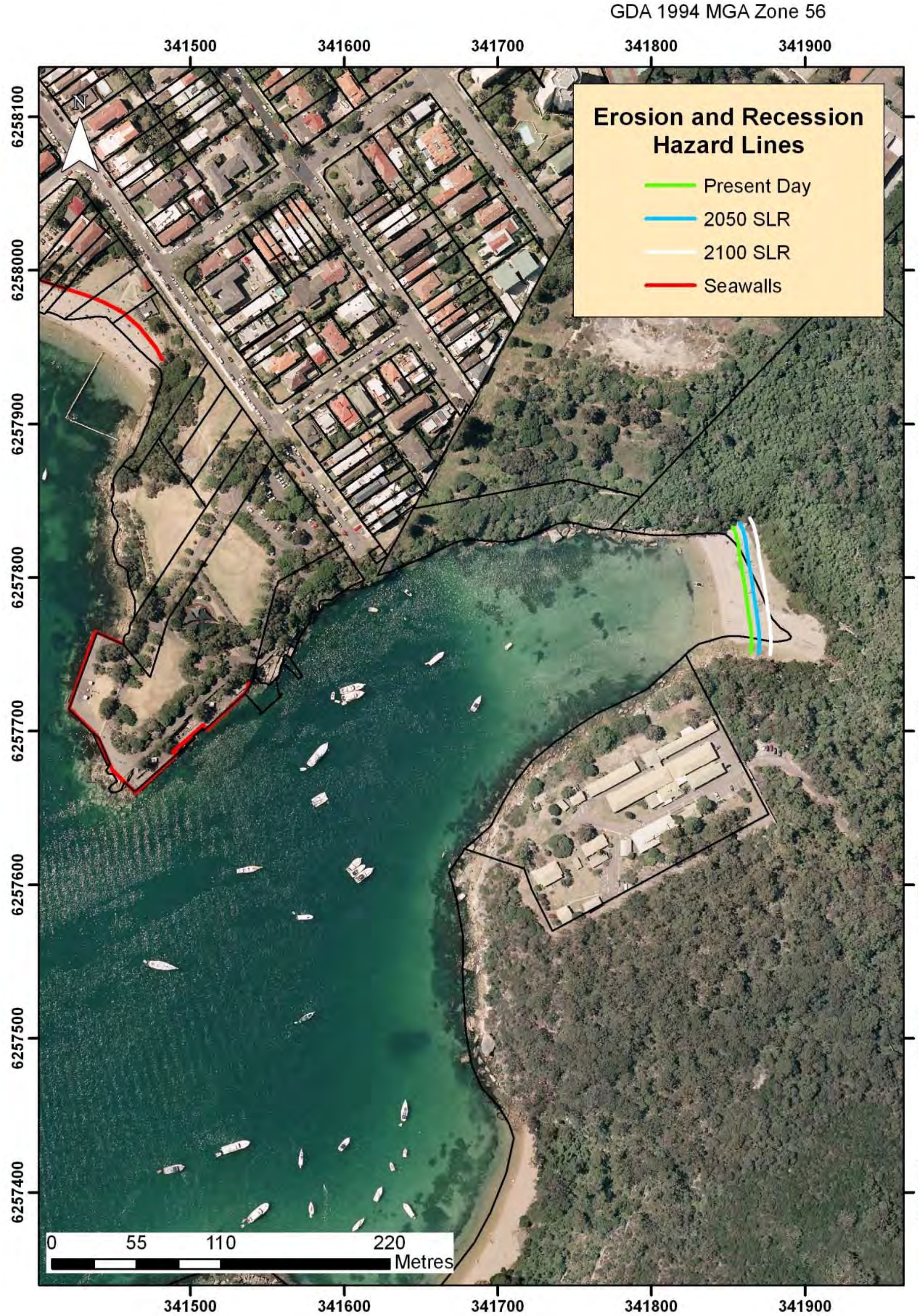
(1) Landward movement of the shoreline could be modified by the presence of bedrock

Manly Cove East Coastal Erosion Hazard Lines With Seawall

Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

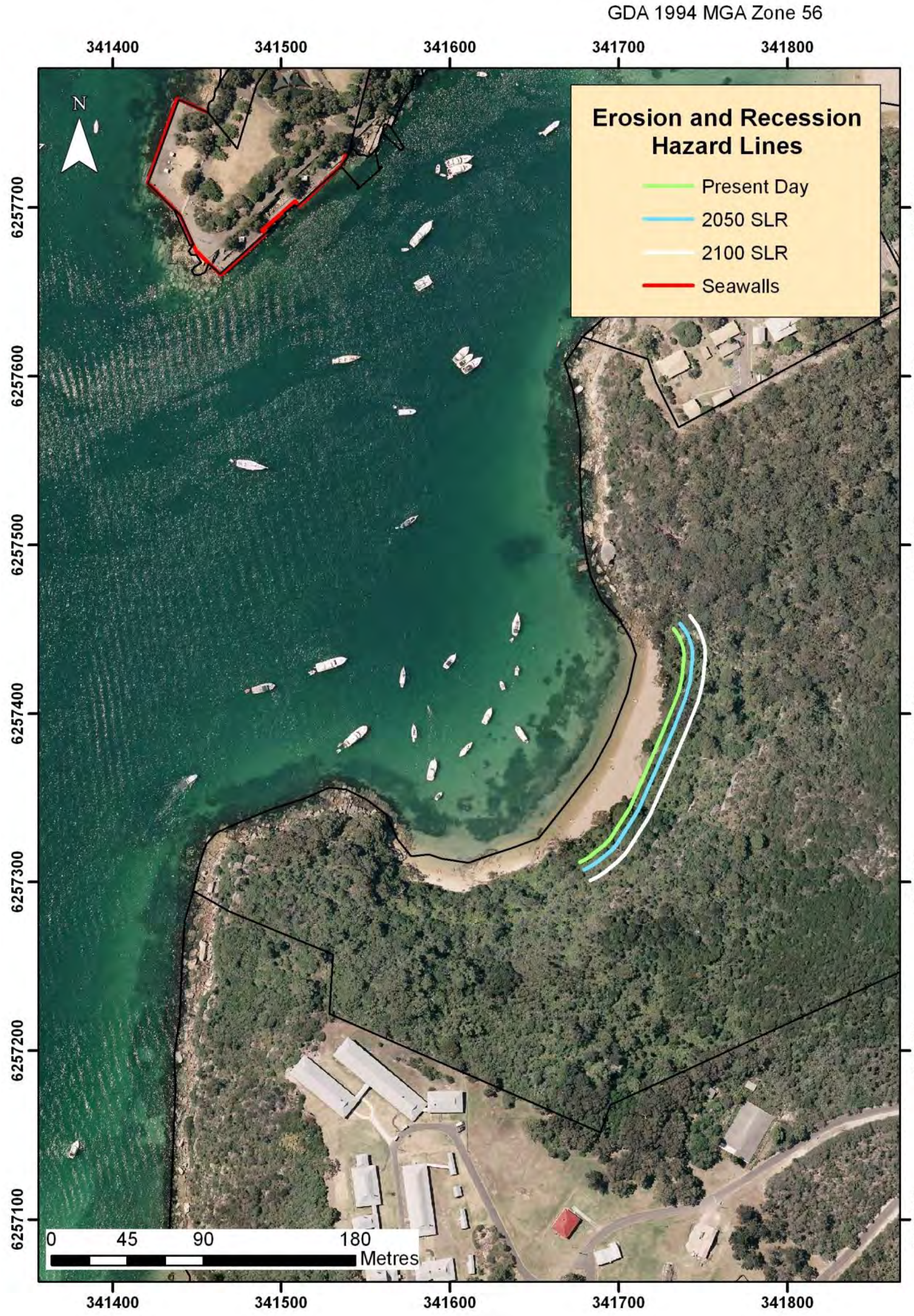
Little Manly Cove Coastal Erosion Hazard Lines With Seawall



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

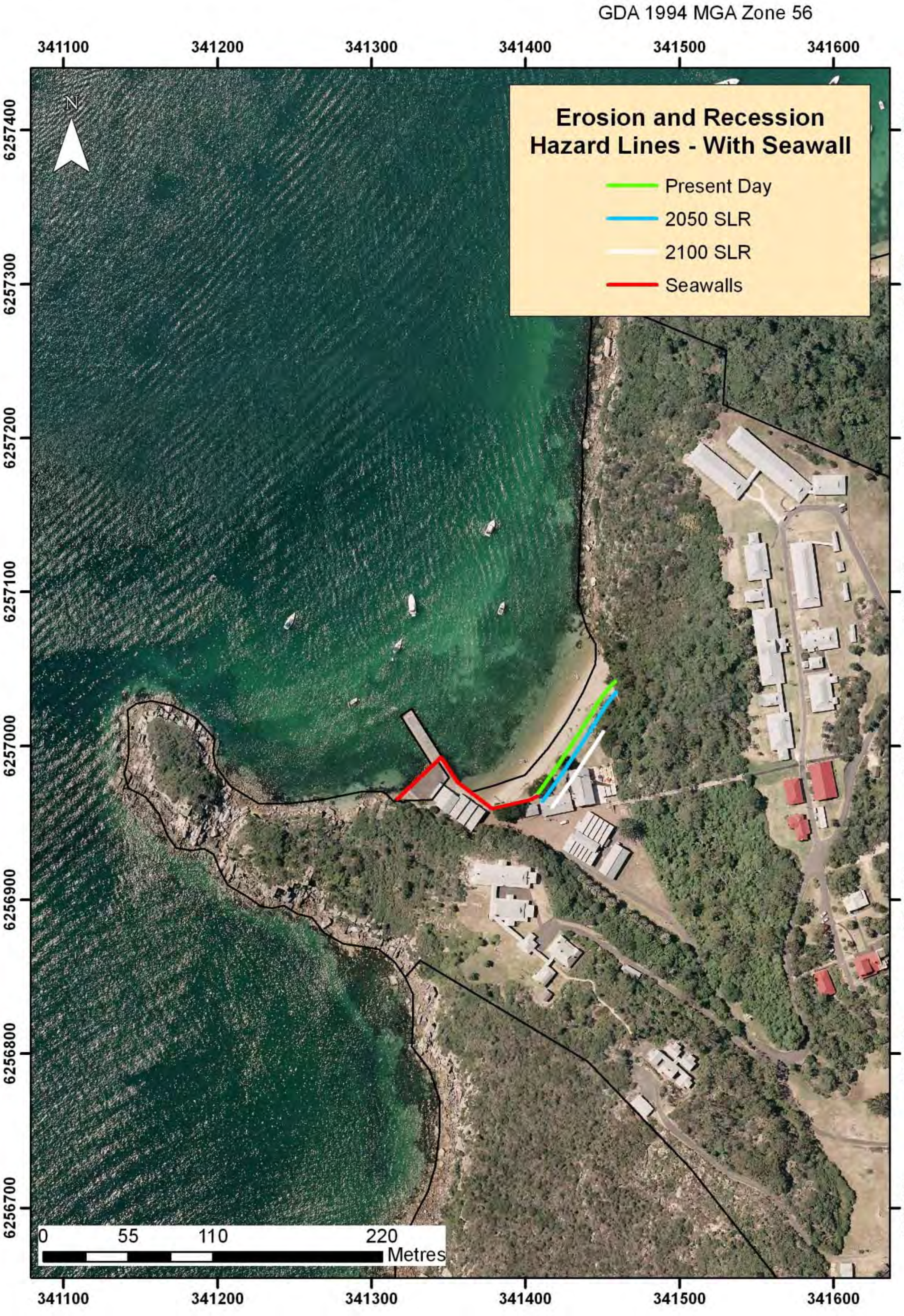
Collins Beach Coastal Erosion Hazard Lines



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

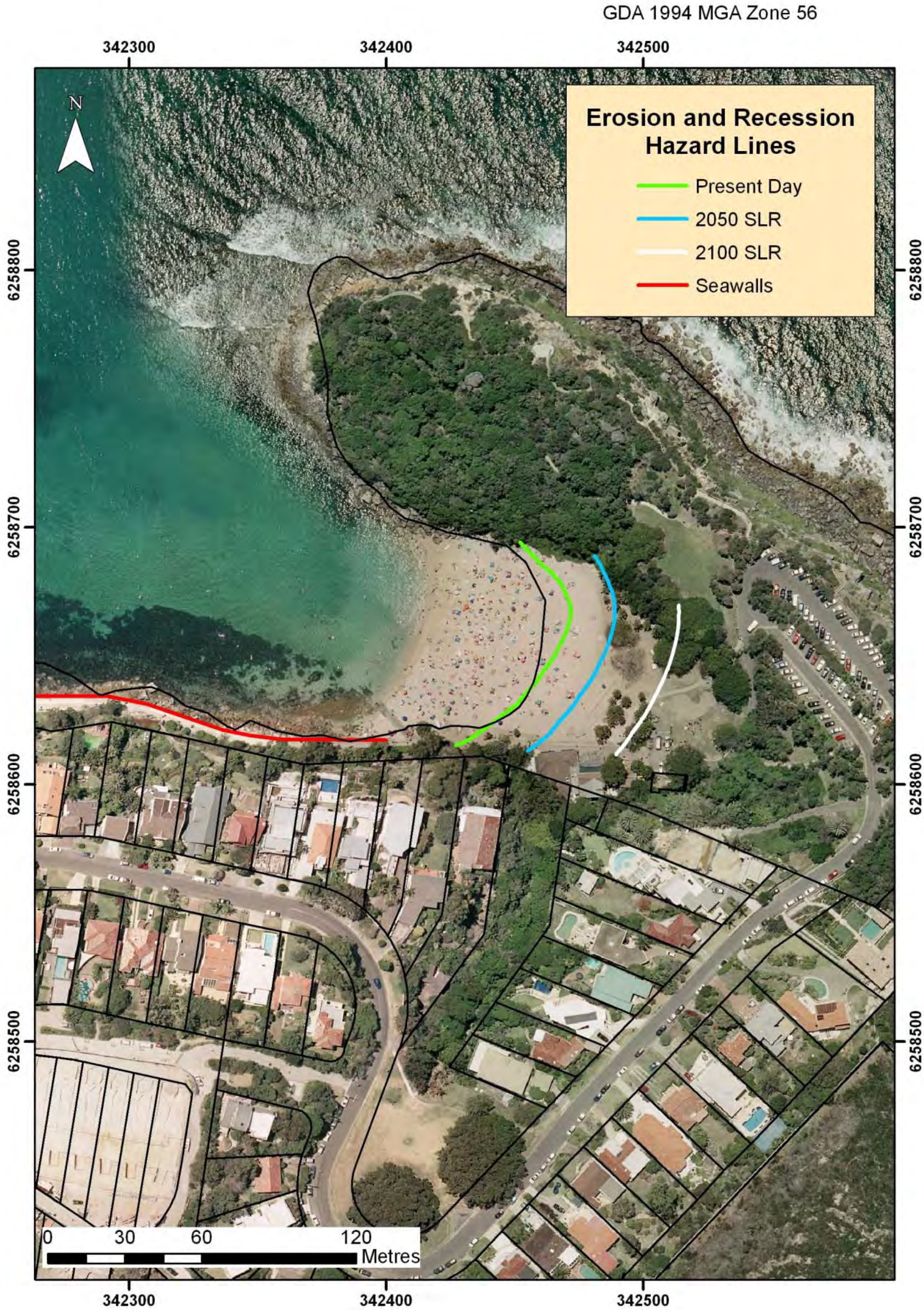
Store Beach Coastal Erosion Hazard Lines



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

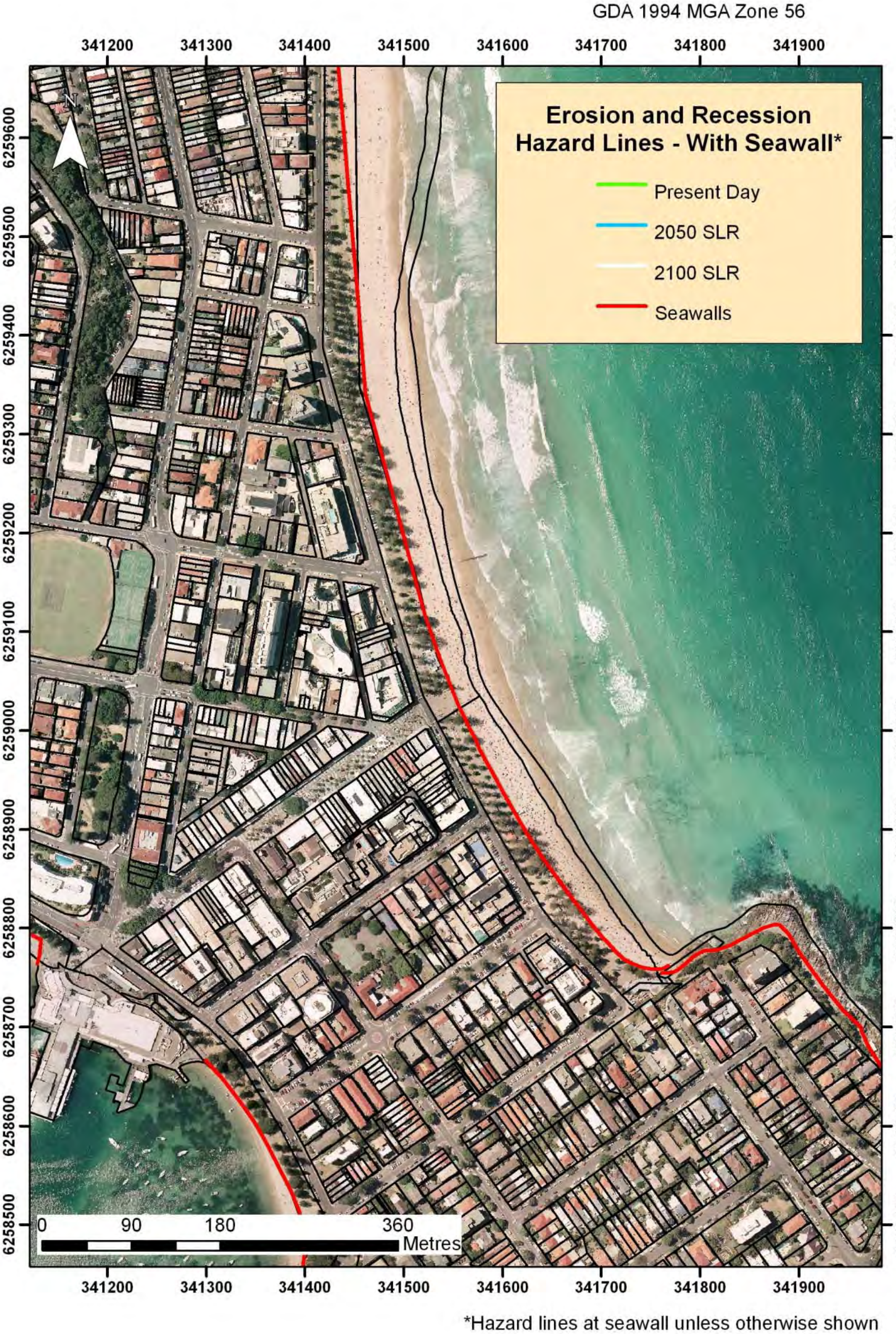
Quarantine Beach Coastal Erosion Hazard Lines With Seawall



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

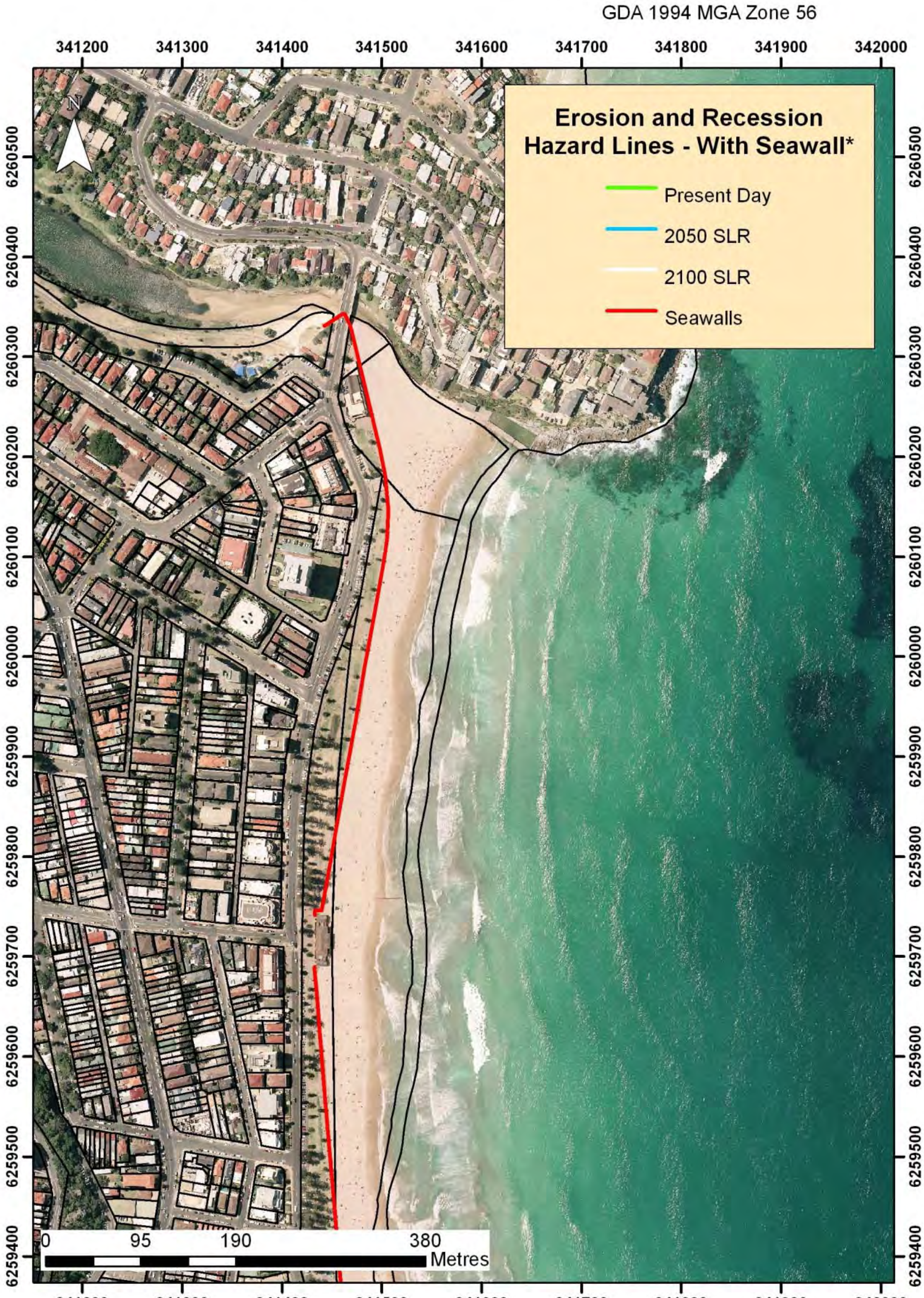
Shelly Beach Coastal Erosion Hazard Lines



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Manly Ocean Beach (South) Coastal Erosion Hazard Lines With Seawall

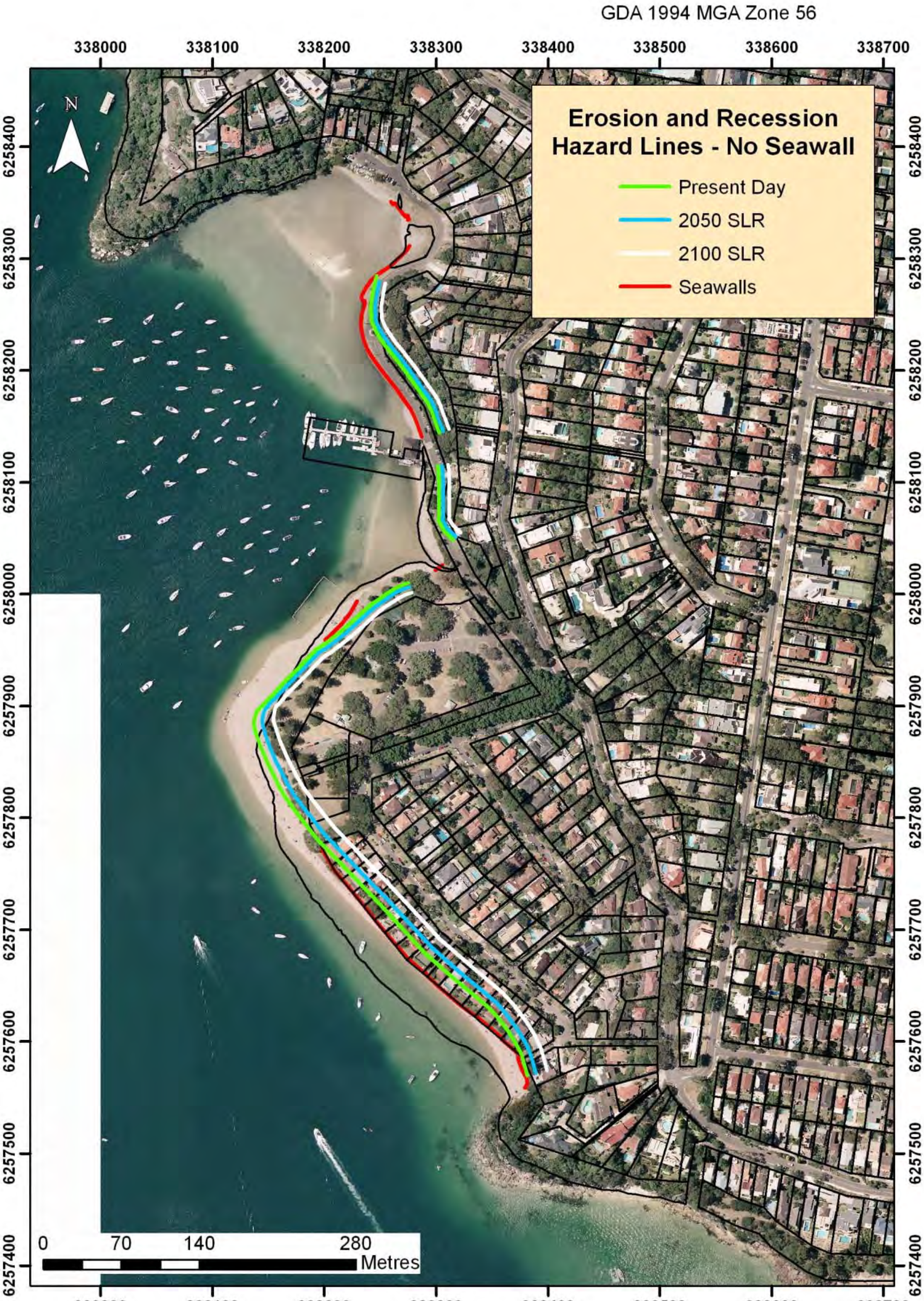


*Hazard lines at seawall unless otherwise shown

Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

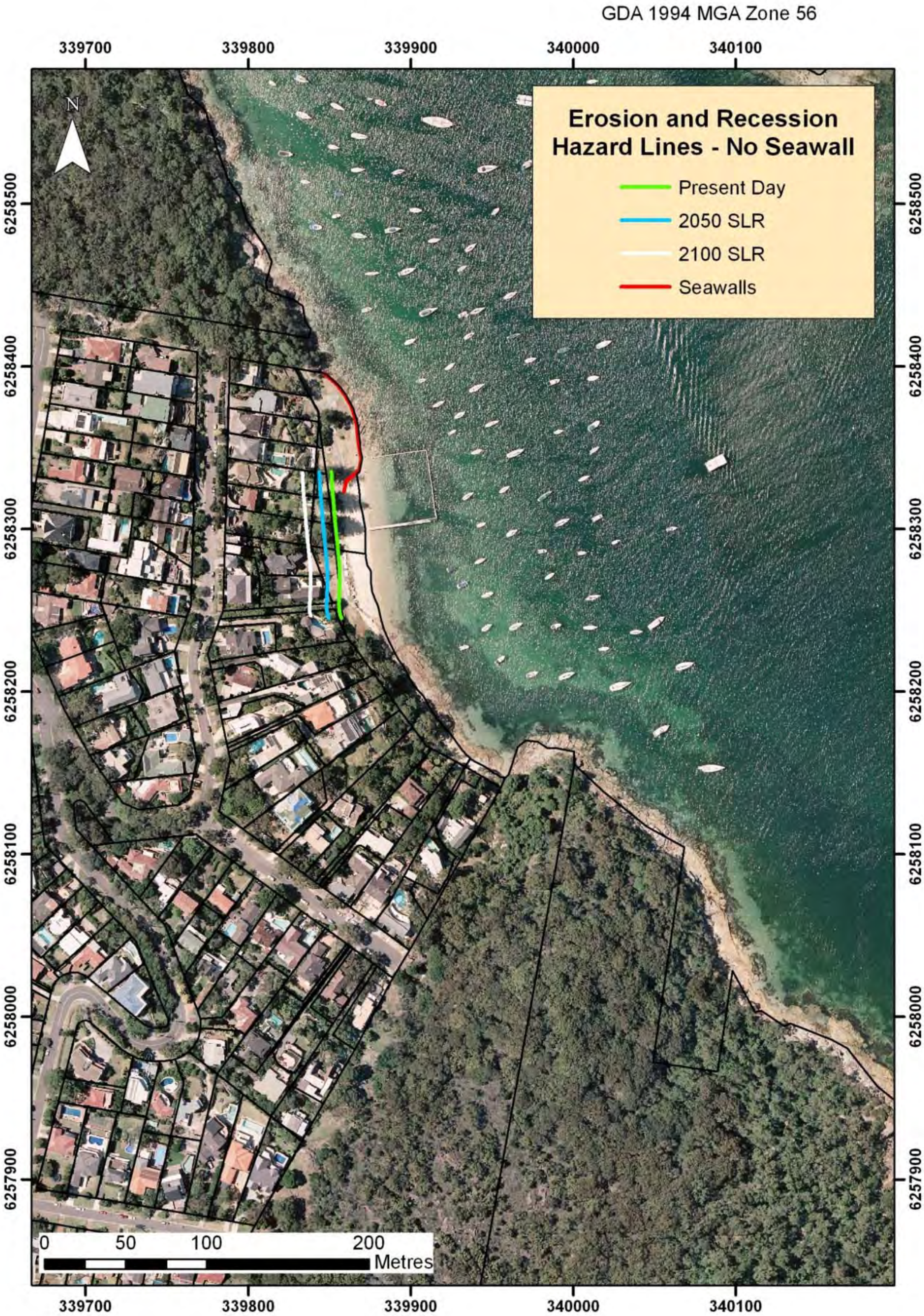
Manly Ocean Beach (North) Coastal Erosion Hazard Lines With Seawall



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Clontarf Coastal Erosion Hazard Lines No Seawall



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Forty Baskets Coastal Erosion Hazard Lines No Seawall

Notes:

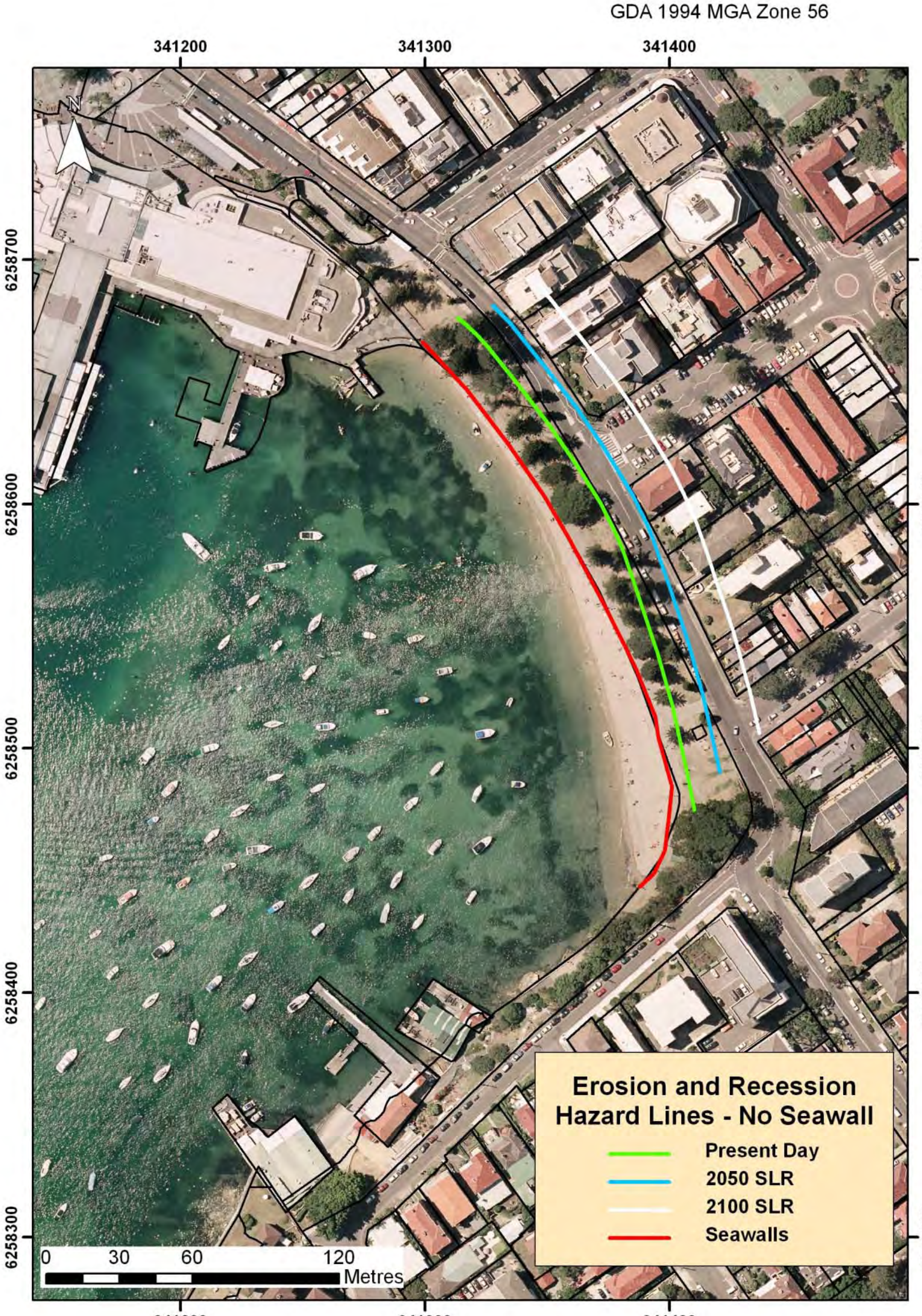
(1) Landward movement of the shoreline could be modified by the presence of bedrock

Fairlight Beach Coastal Erosion Hazard Lines No Seawall

Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Manly Cove West Coastal Erosion Hazard Lines No Seawall



Notes:

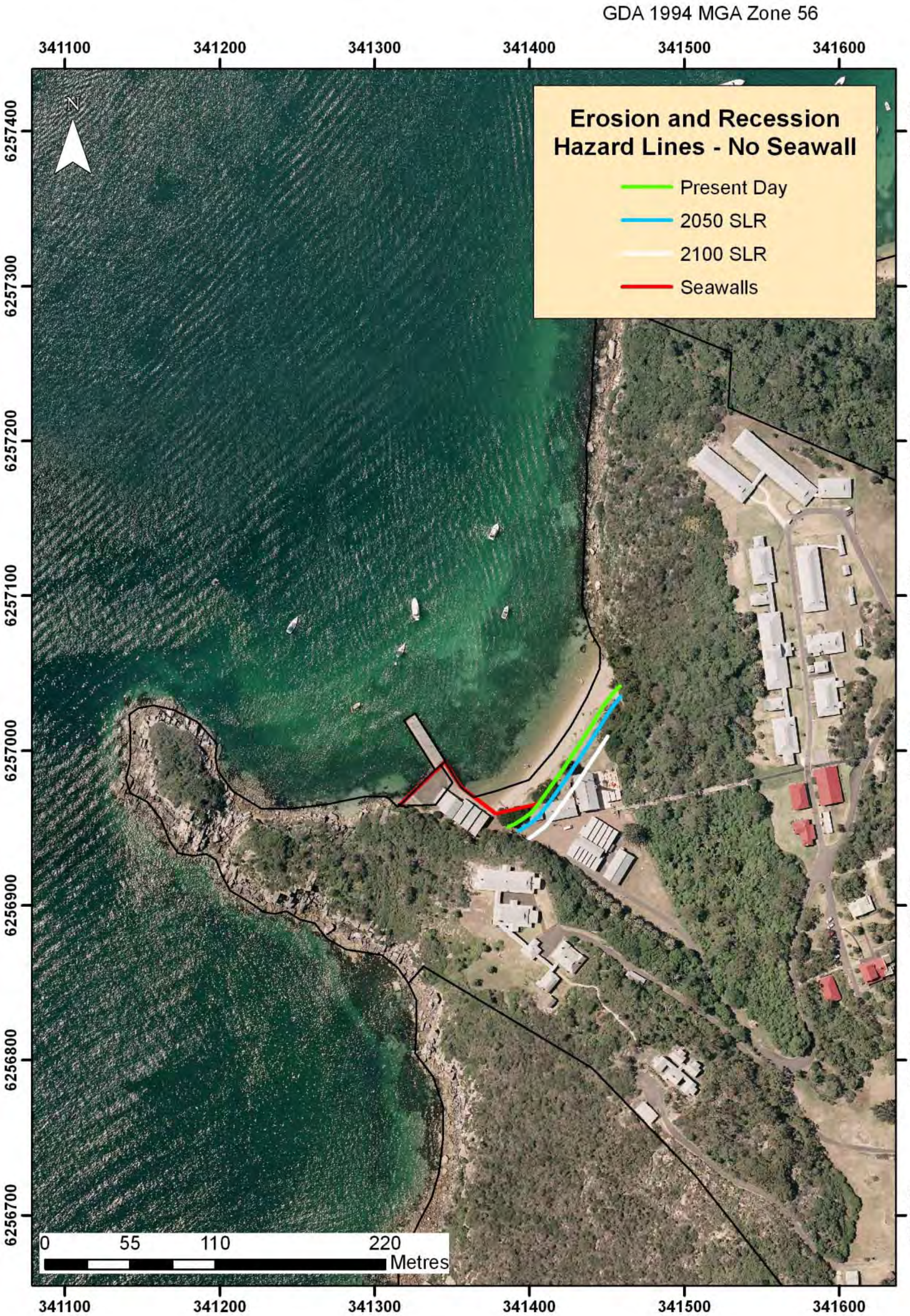
(1) Landward movement of the shoreline could be modified by the presence of bedrock

Manly Cove East Coastal Erosion Hazard Lines No Seawall

Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

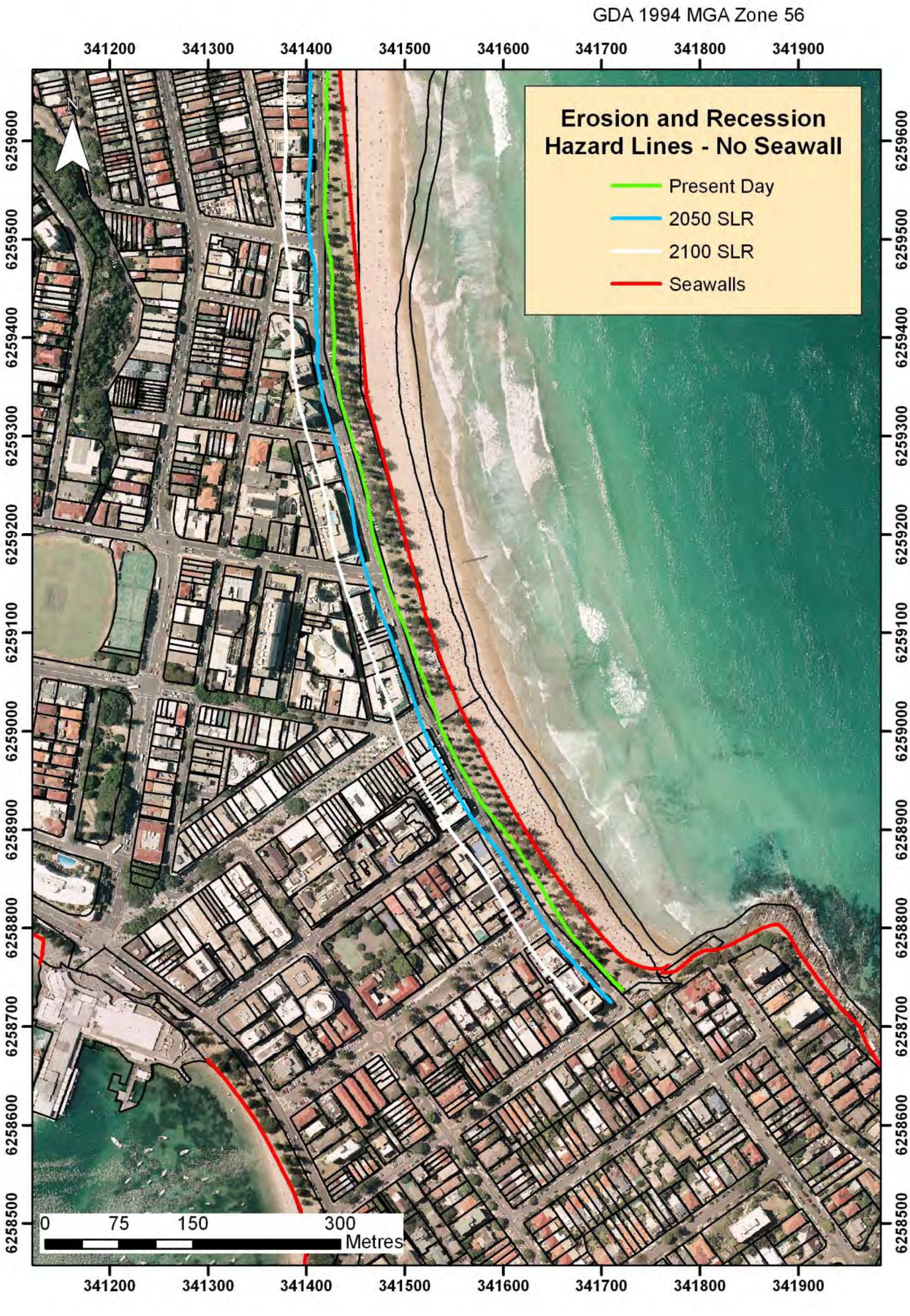
Little Manly Cove Coastal Erosion Hazard Lines No Seawall



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

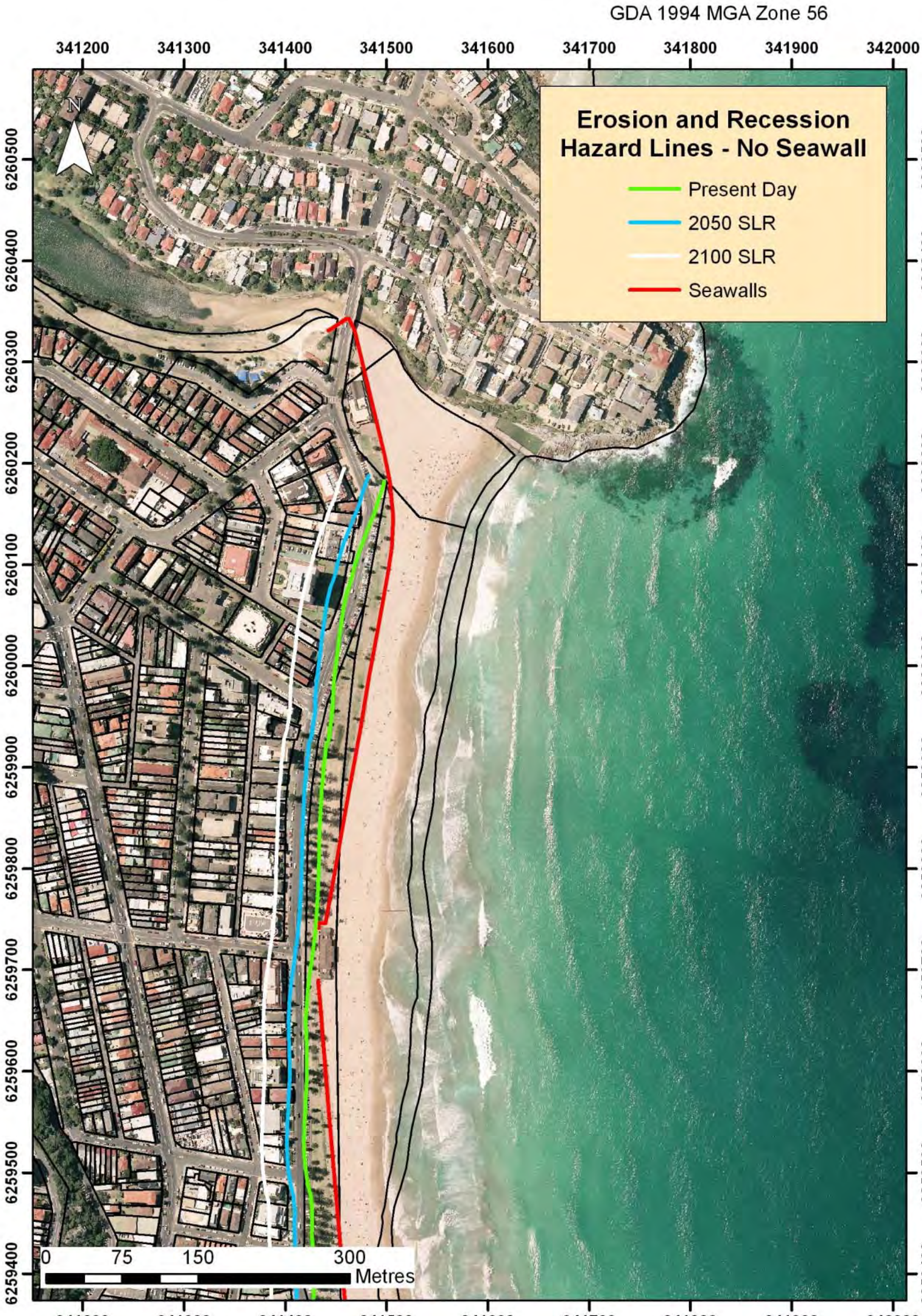
Quarantine Beach Coastal Erosion Hazard Lines No Seawall



Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

Manly Ocean Beach (South) Coastal Erosion Hazard Lines No Seawall

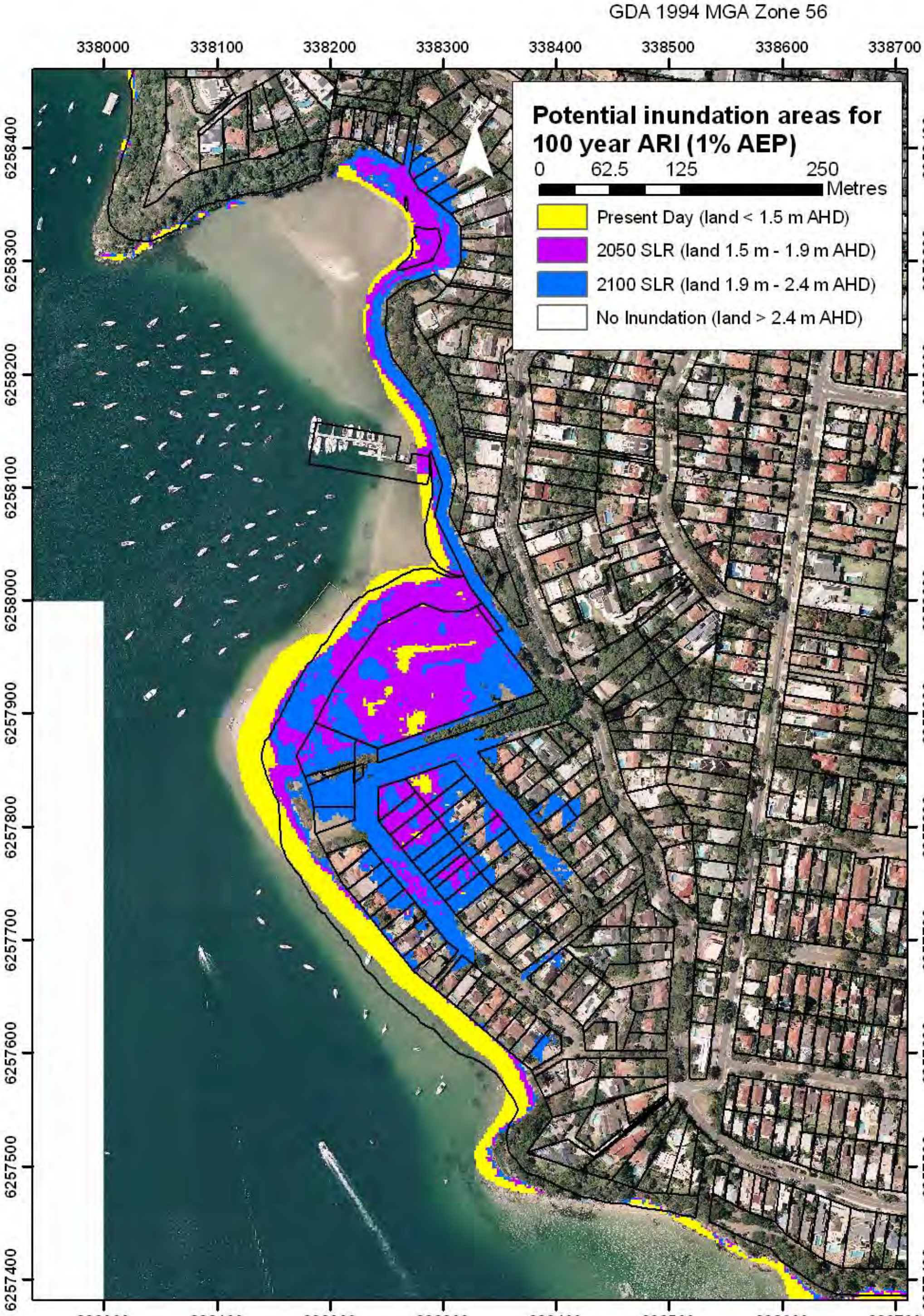


Notes:

(1) Landward movement of the shoreline could be modified by the presence of bedrock

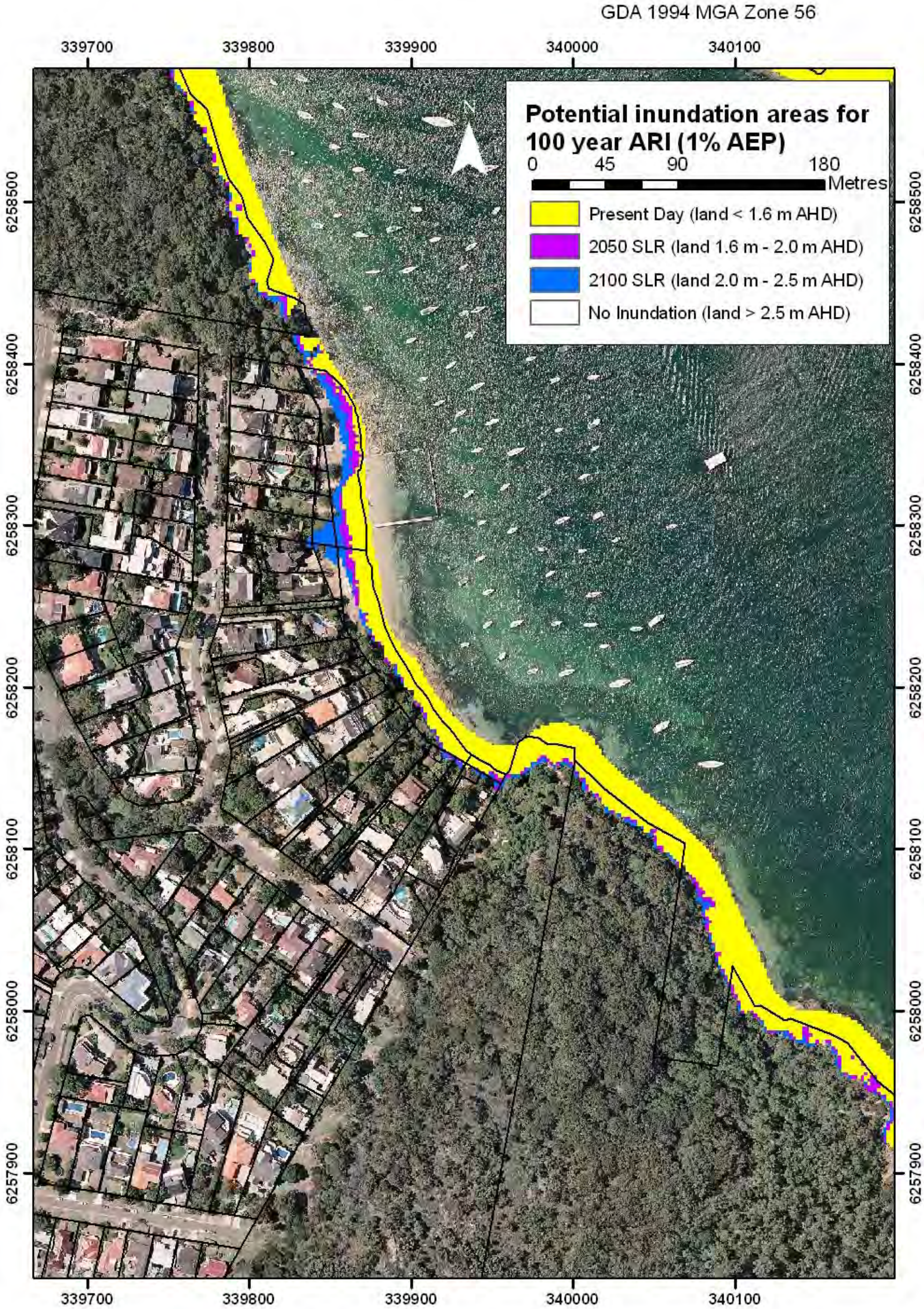
Manly Ocean Beach (North) Coastal Erosion Hazard Lines No Seawall

APPENDIX D – Mapping of Inundation Zones



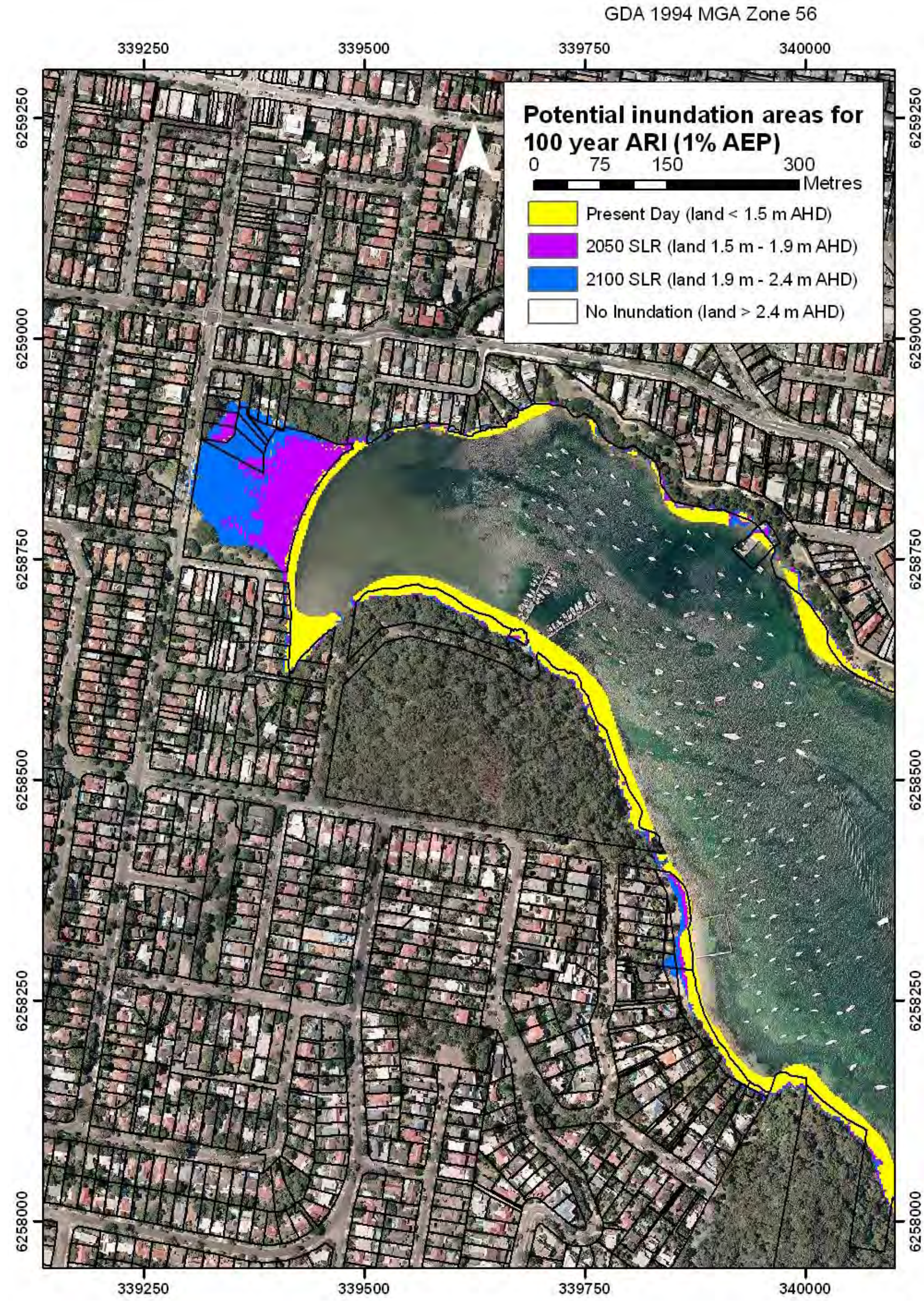
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Clontarf Coastal Inundation Zones (incl. wave and wind setup)



Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Forty Baskets Coastal Inundation Zones (incl. wave and wind setup)

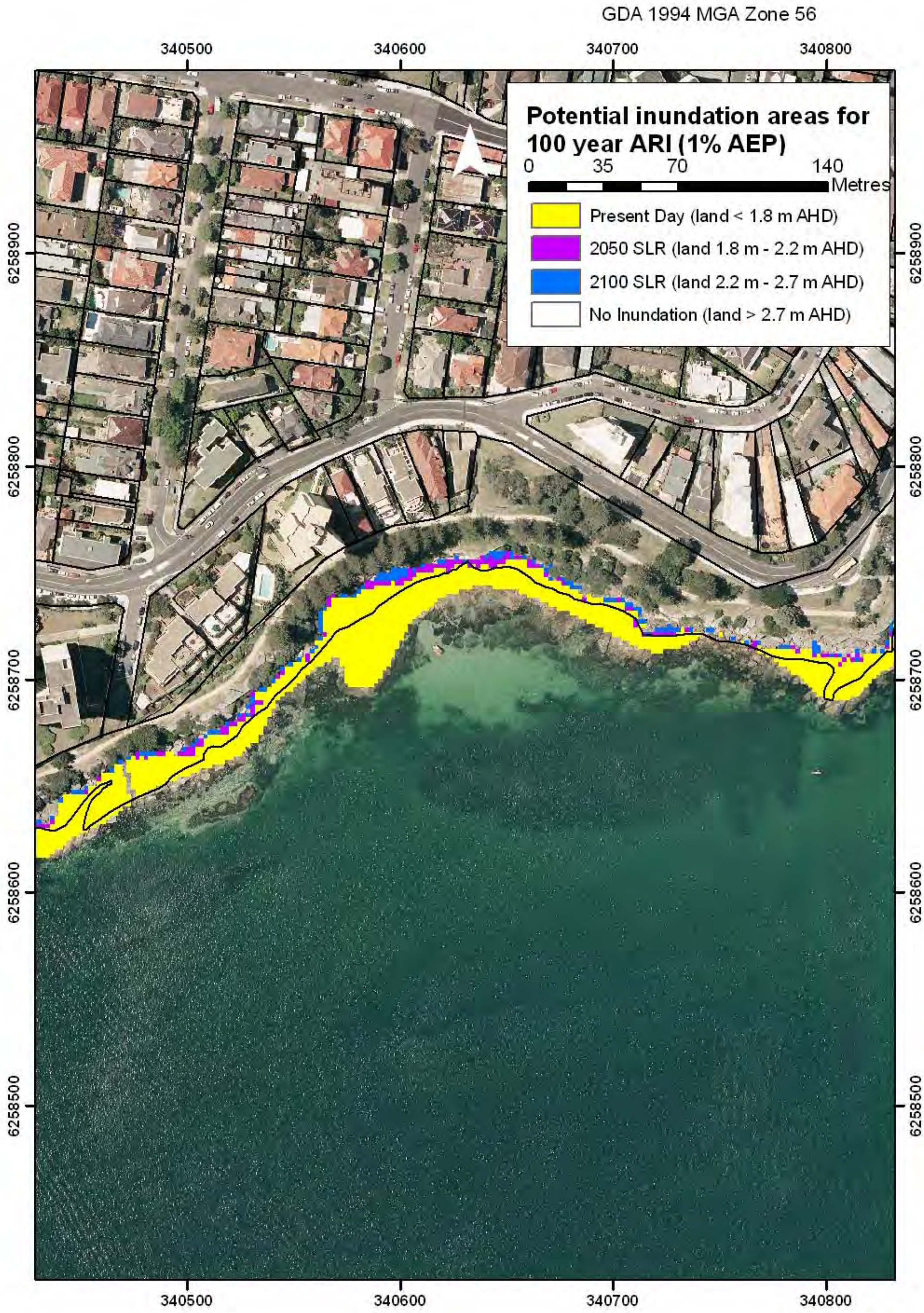


Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

North Harbour Reserve Coastal Inundation Zones (incl. wave and wind setup)

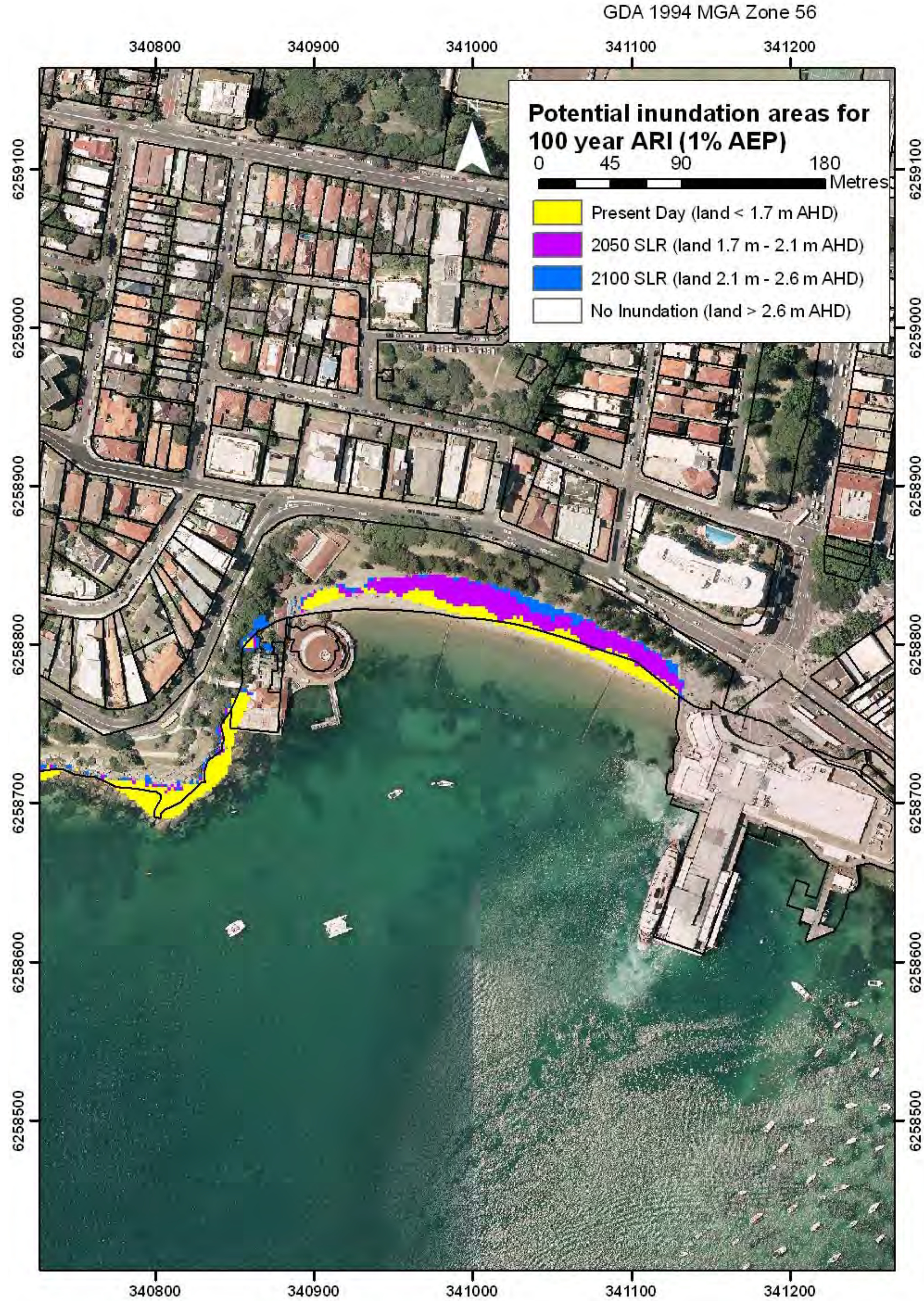
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Fairlight Beach Coastal Inundation Zones (incl. wave and wind setup)



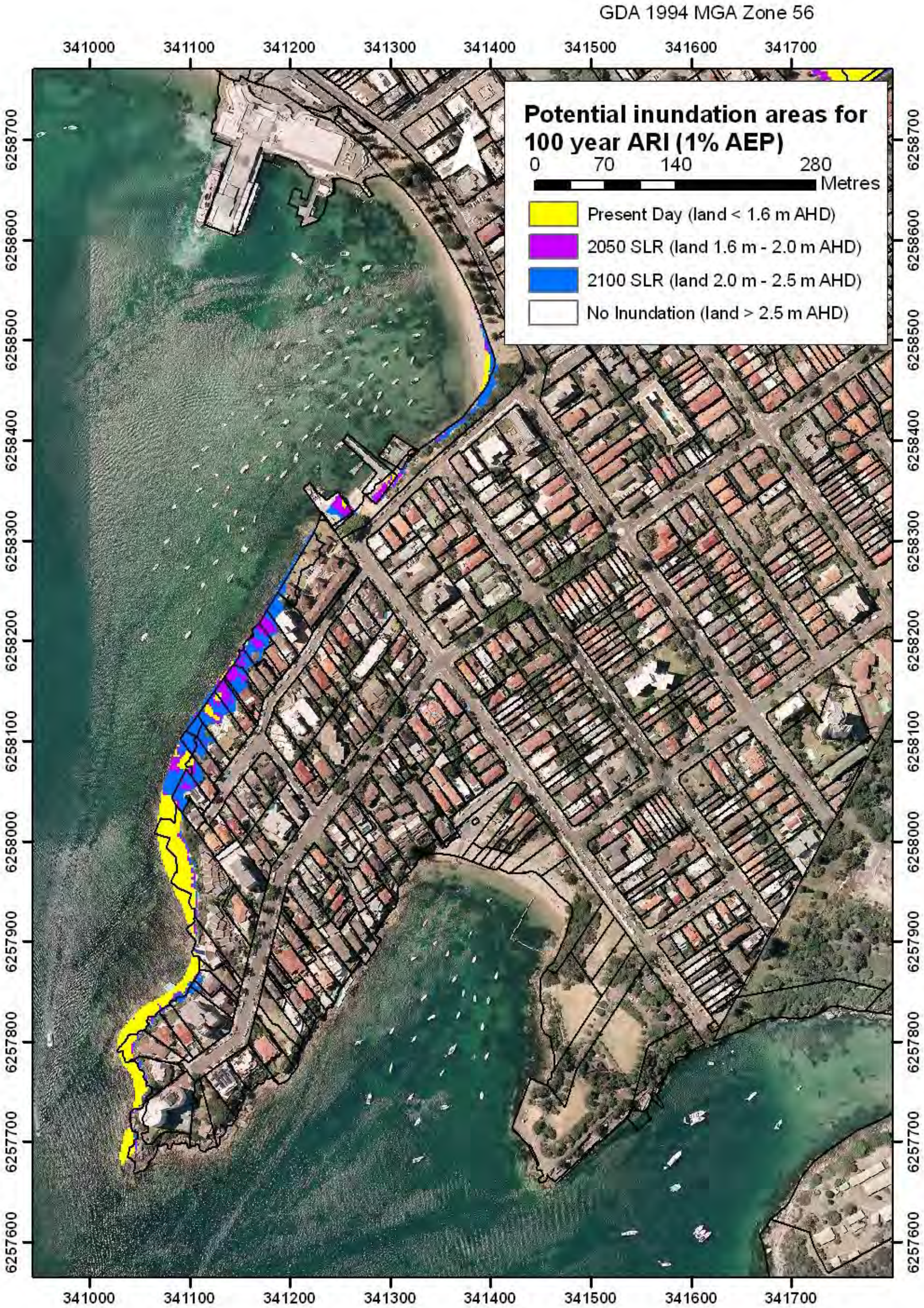
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Delwood Beach Coastal Inundation Zones (incl. wave and wind setup)



Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Manly Cove West Coastal Inundation Zones (incl. wave and wind setup)

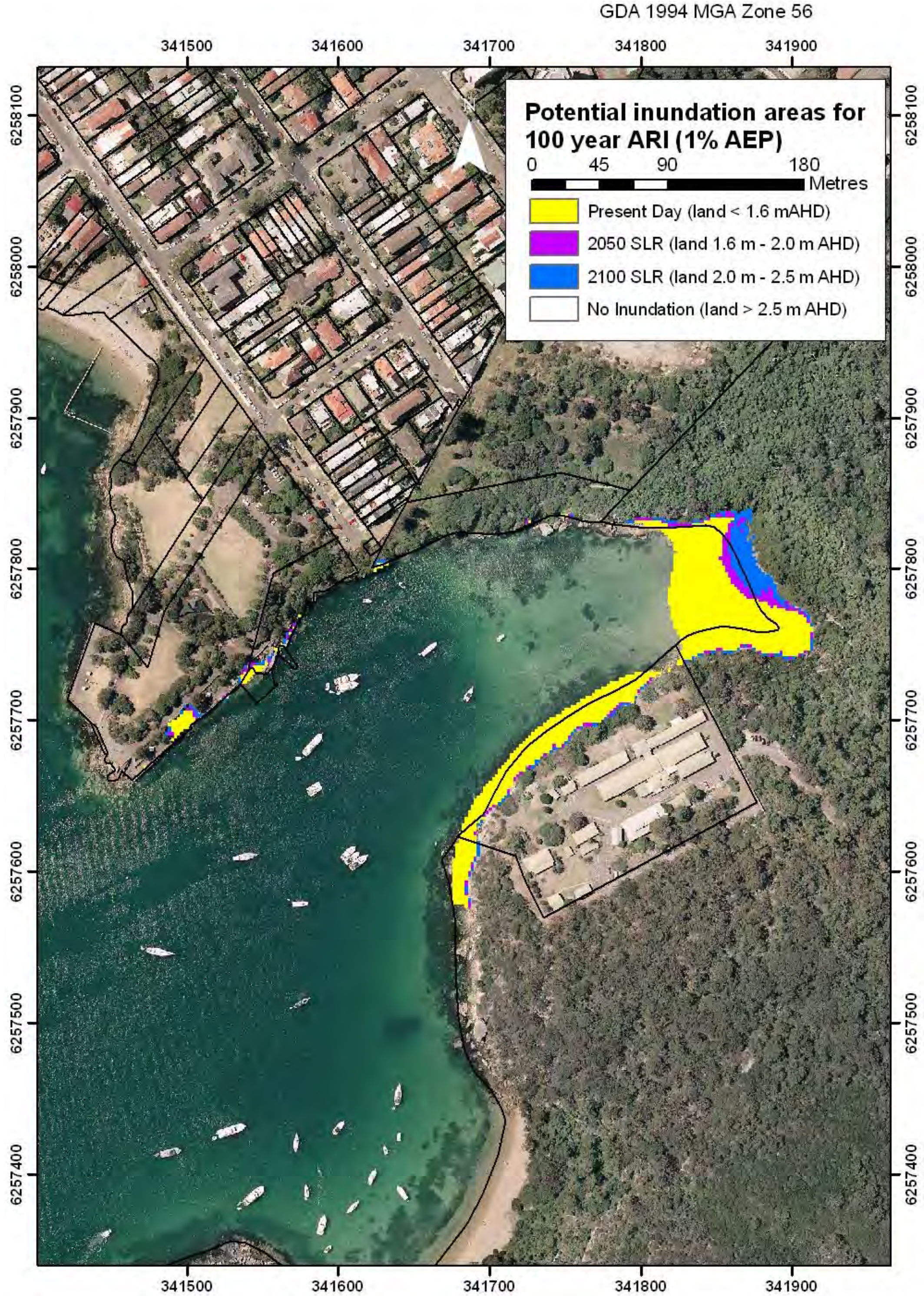


Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Manly Cove East Coastal Inundation Zones (incl. wave and wind setup)

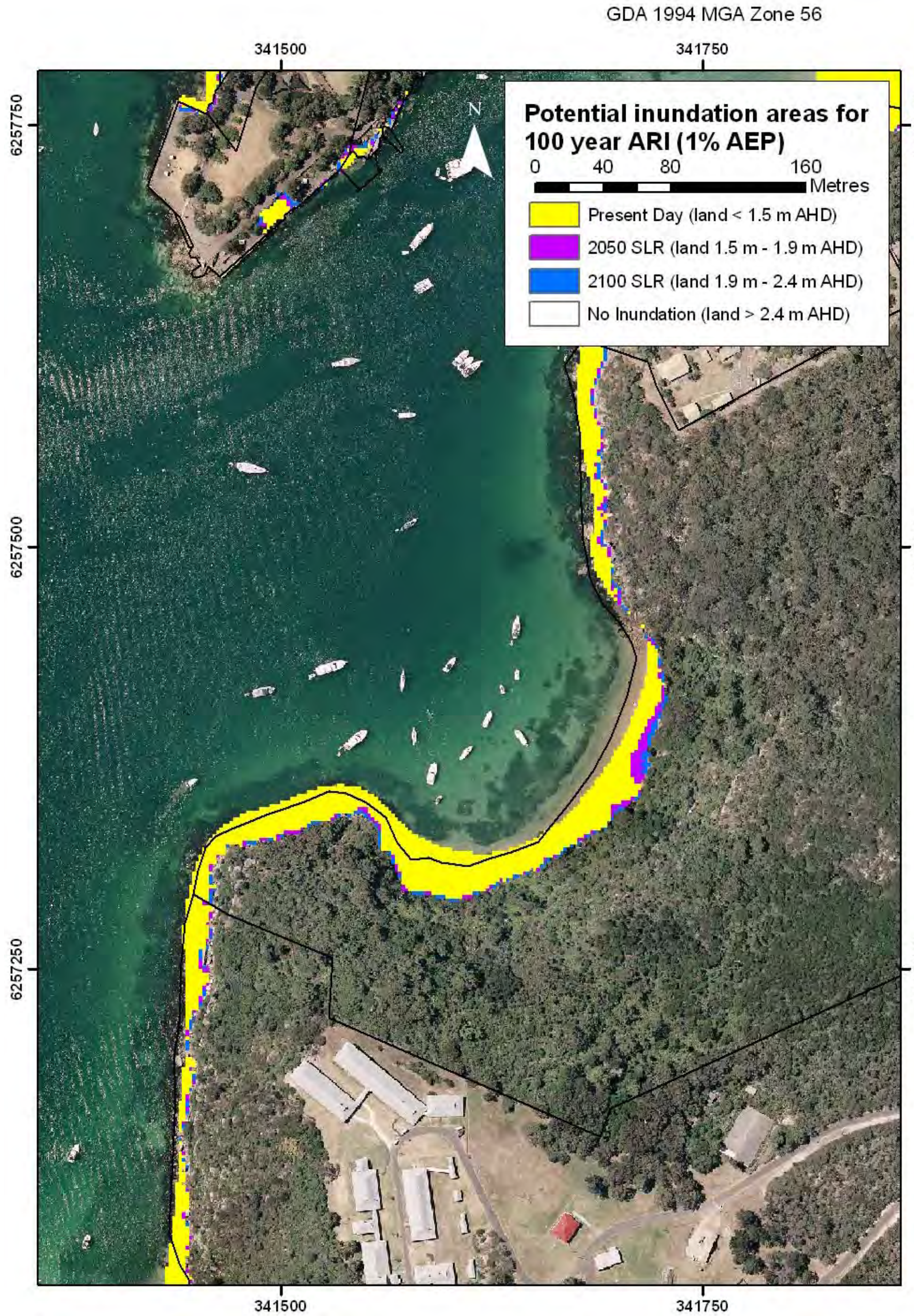
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Little Manly Cove Coastal Inundation Zones (incl. wave and wind setup)



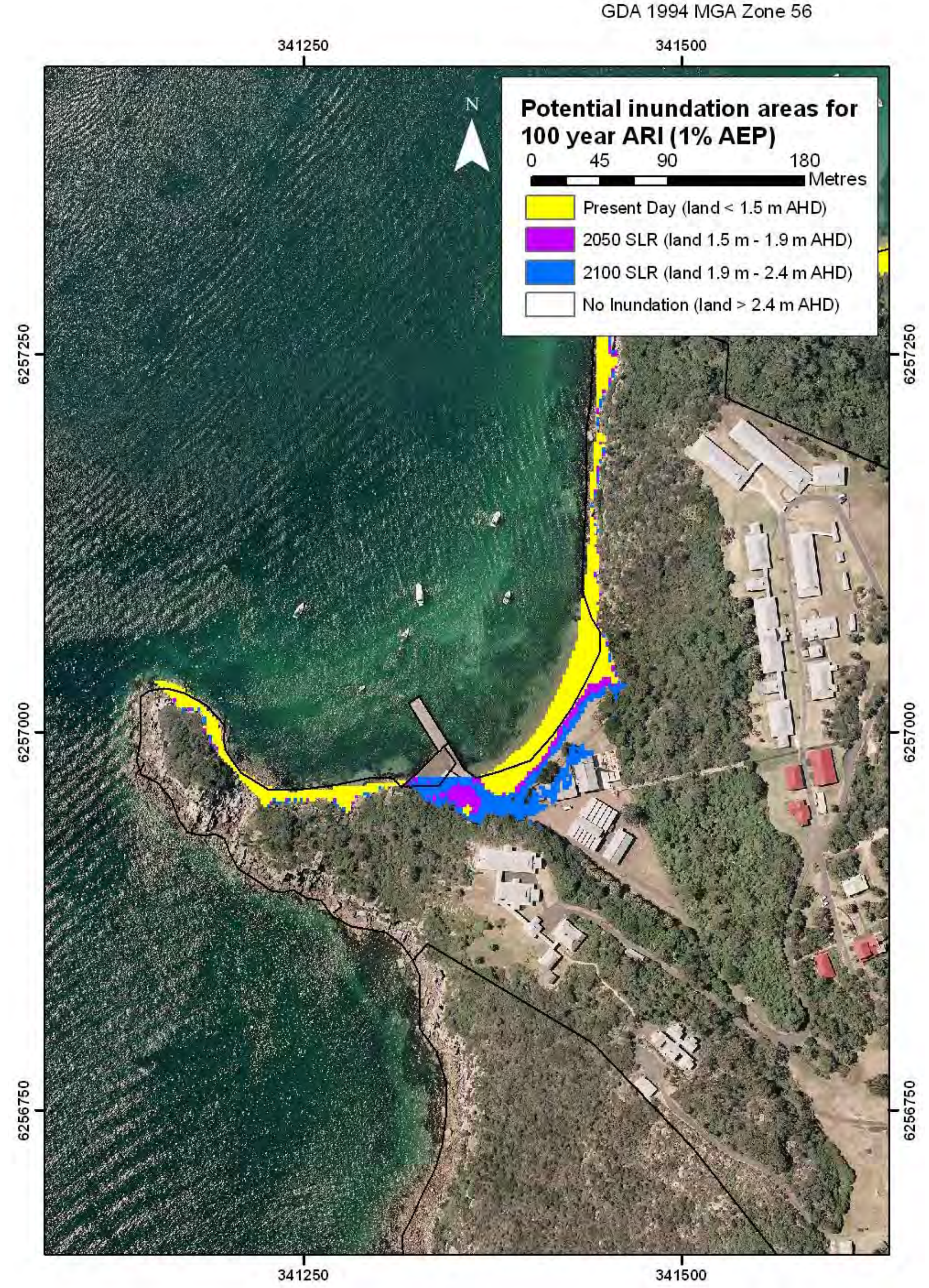
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Collins Beach Coastal Inundation Zones (incl. wave and wind setup)



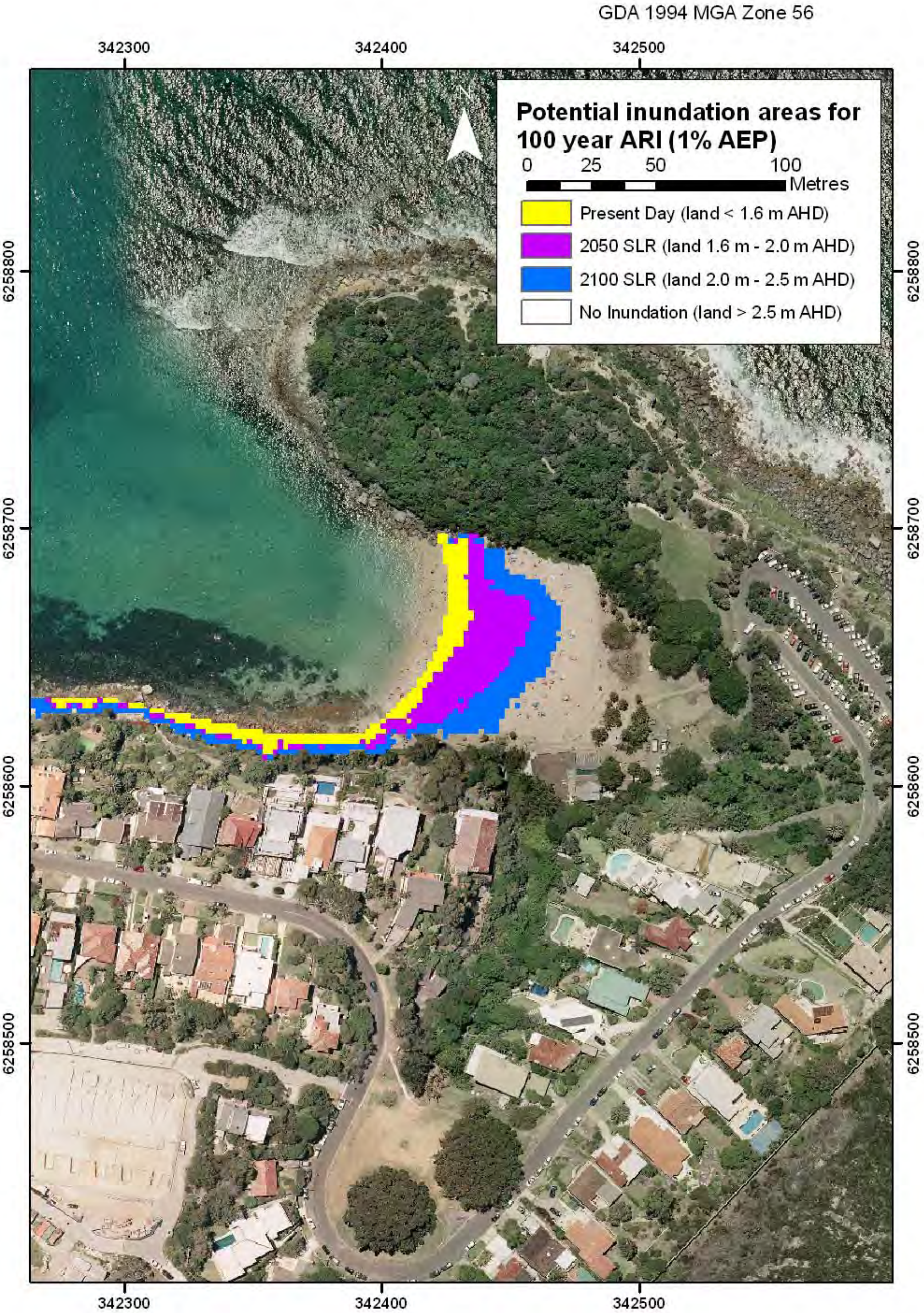
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Store Beach Coastal Inundation Zones (incl. wave and wind setup)



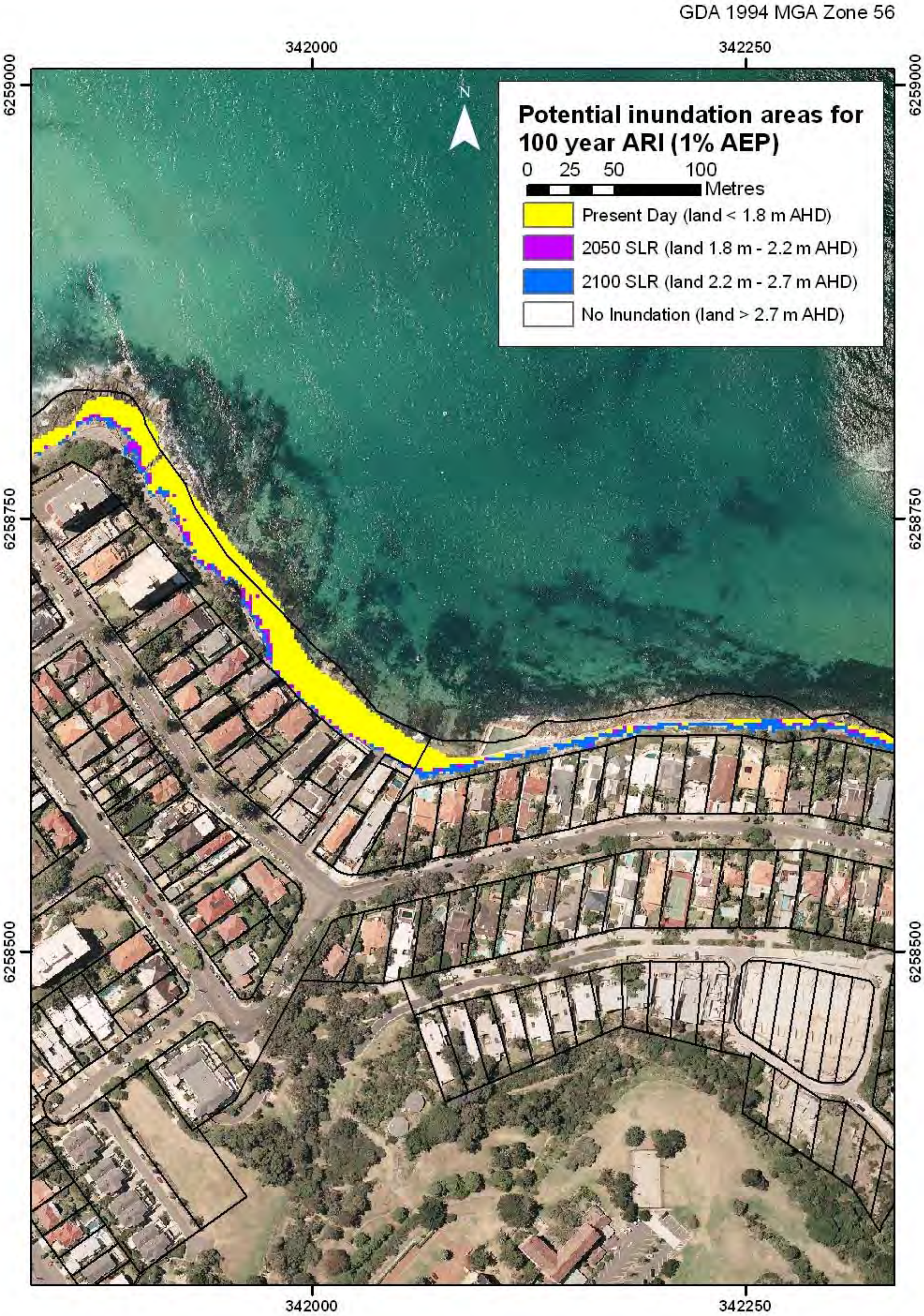
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Quarantine Coastal Inundation Zones (incl. wave and wind setup)



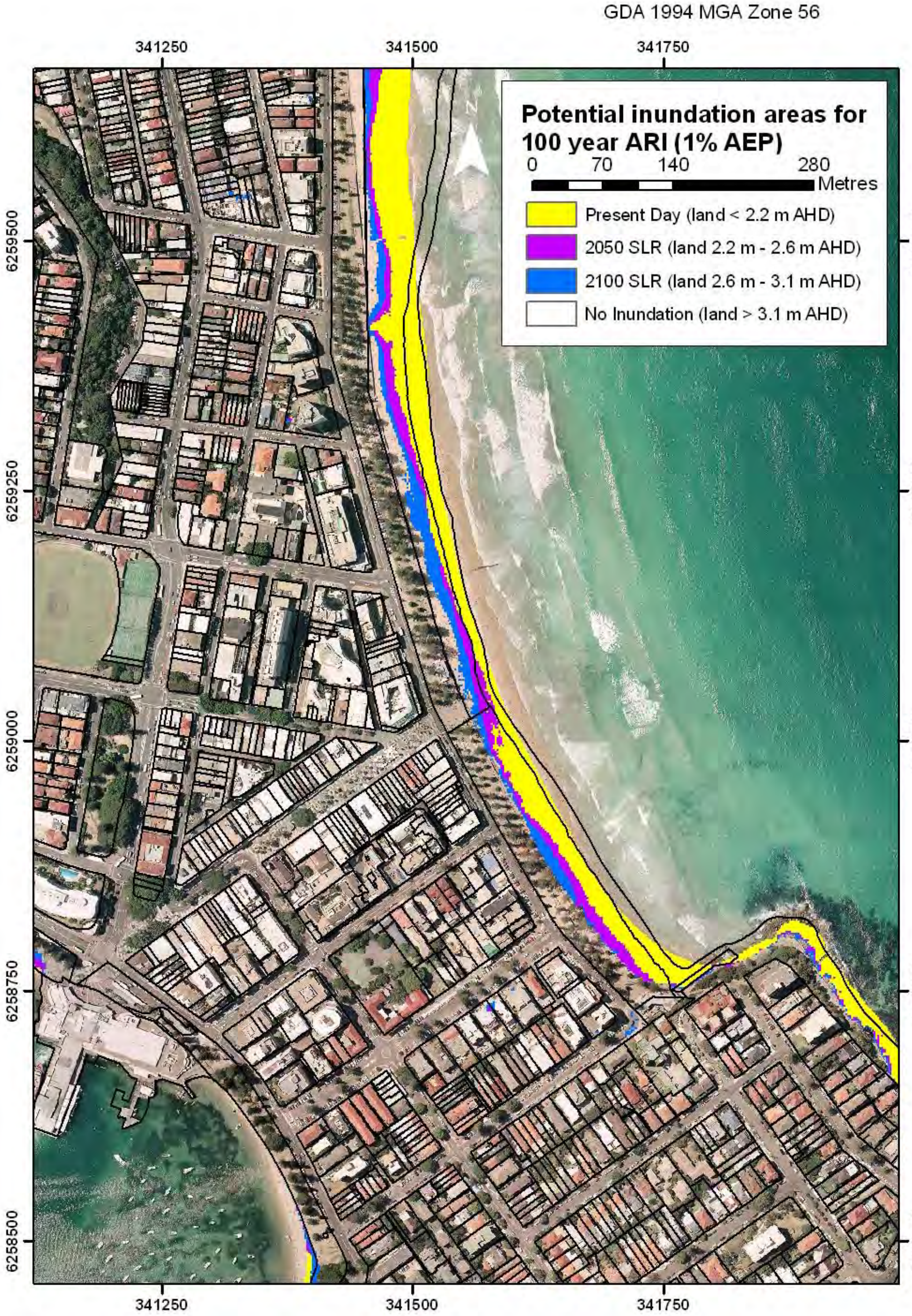
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Shelley Beach Coastal Inundation Zones (incl. wave and wind setup)



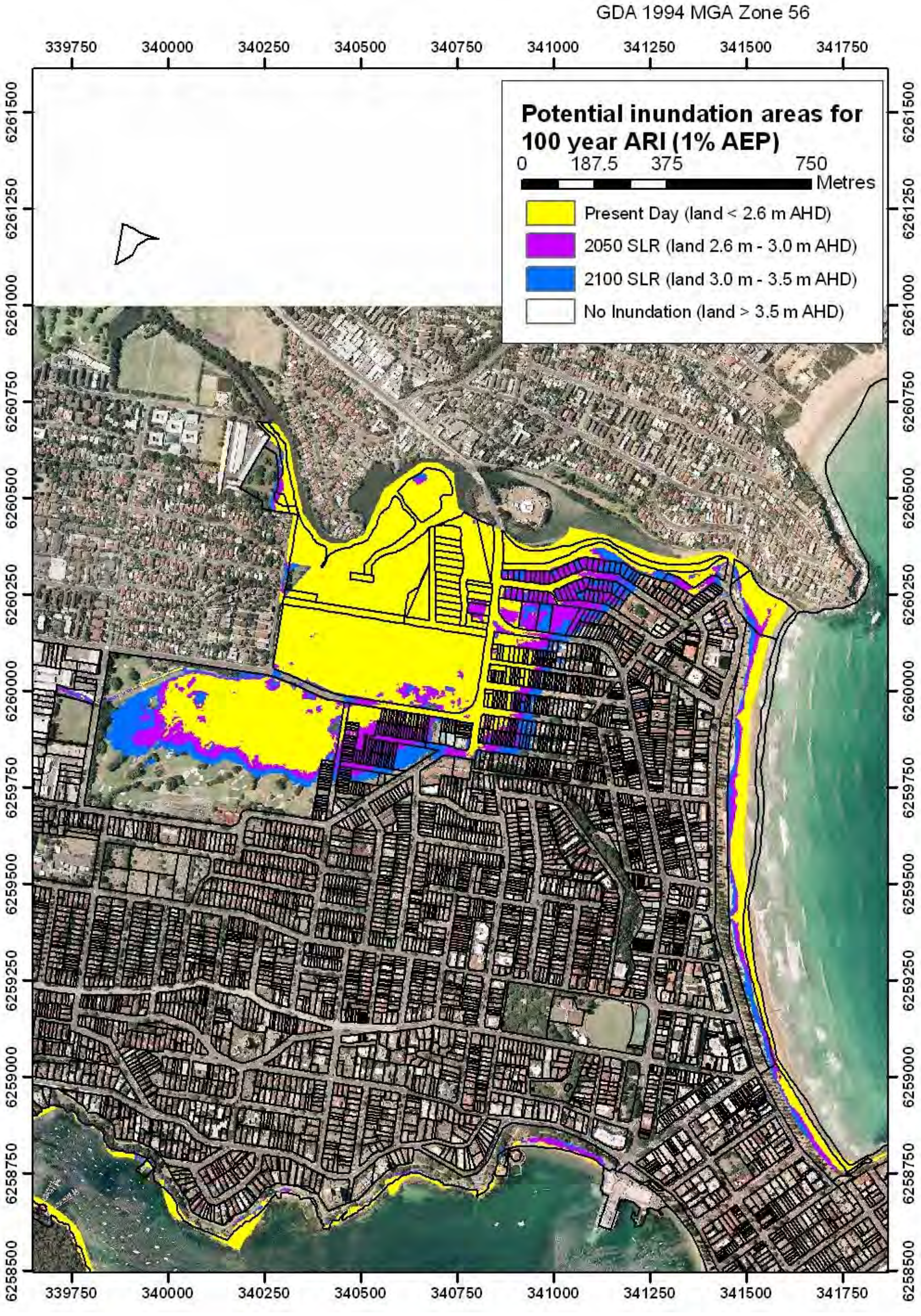
Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Fairy Bower Coastal Inundation Zones (incl. wave and wind setup)



Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

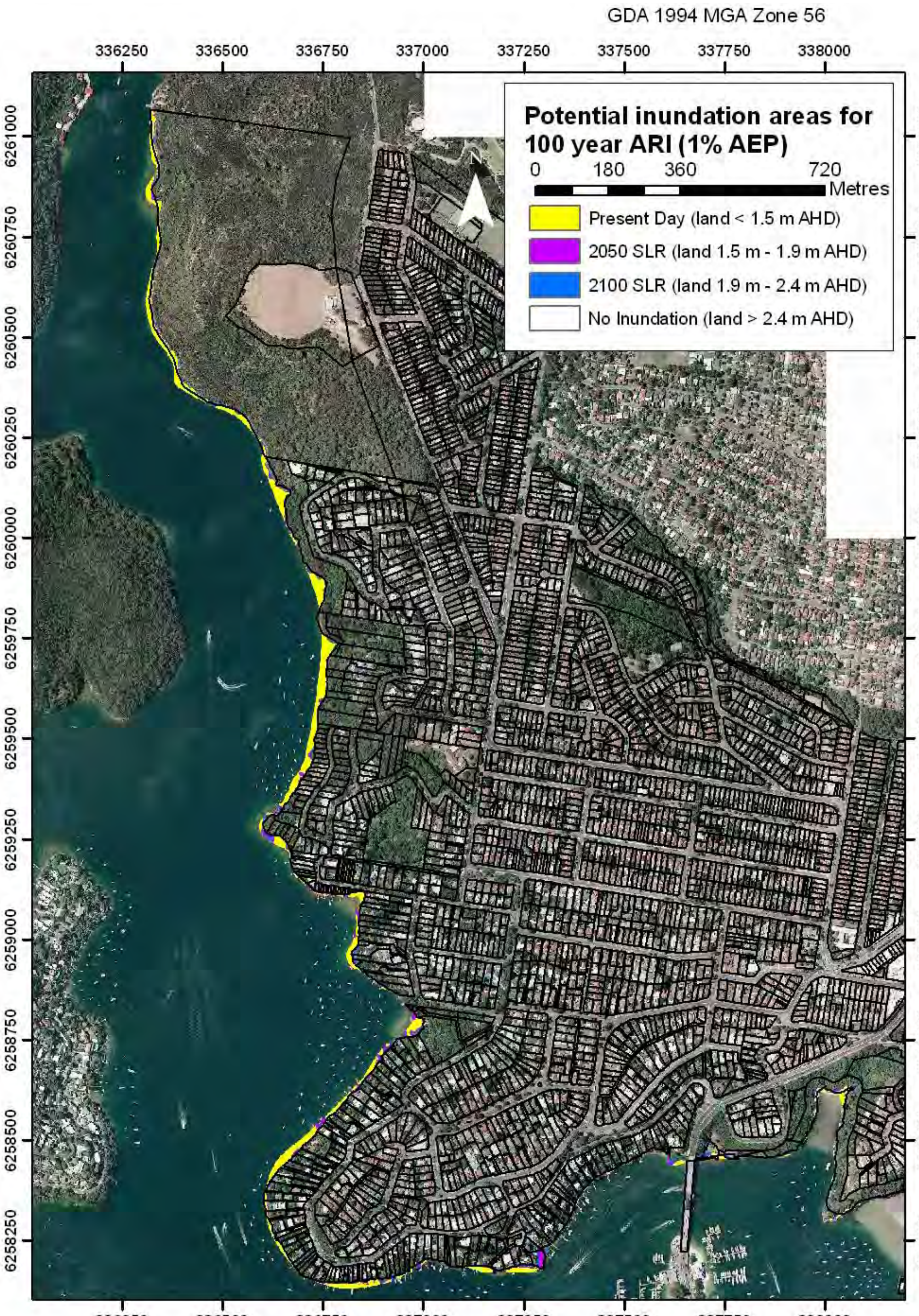
Manly Ocean Beach (South) Coastal Inundation Zones (incl. wave and wind setup)



Note: (1)Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

(2)The inundation of the Manly Lagoon area does not include any hydrodynamic/flooding consideration/analysis.

Manly Ocean Beach (North) and Lagoon Area Coastal Inundation Zones (incl. wave and wind setup)



Note: Inundation is based on the current shoreline location and includes allowance for the NSW Government benchmark sea level rise. It does not include any allowance for future landward recession of the beach face and assumes both that the crest level of the seawall (if present) and the topography remain as they were from the 2008 LIDAR survey. By 2050 or 2100 both of these assumptions may not be valid. Should the seawalls be allowed to fail then the landward extent of inundation may increase.

Seaforth Coastal Inundation Zones (incl. wave and wind setup)