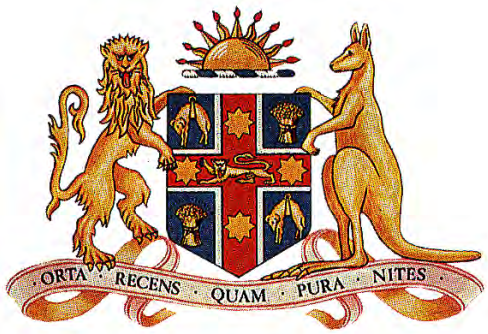


Government Gazette

of the State of

New South Wales

Number 11
Friday, 2 February 2018

The New South Wales Government Gazette is the permanent public record of official notices issued by the New South Wales Government. It also contains local council and other notices and private advertisements.

The Gazette is compiled by the Parliamentary Counsel's Office and published on the NSW legislation website (www.legislation.nsw.gov.au) under the authority of the NSW Government. The website contains a permanent archive of past Gazettes.

To submit a notice for gazettal – see Gazette Information.

ISSN 2201-7534

By Authority
Government Printer

COUNCIL NOTICES

SUTHERLAND SHIRE COUNCIL

Coastal Protection Act 1979, Section 55H

Gazettal and Commencement of a Coastal Zone Management Plan

SUTHERLAND SHIRE COUNCIL, with the certification of the Minister for the Environment, have prepared and adopted the North West Arm Coastal Zone Management Plan in accordance with Section 55 of the *Coastal Protection Act 1979*.

The North West Arm Coastal Zone Management Plan will help guide the future management of the North West Arm estuary health and any risks to the estuary arising from coastal hazards. The Plan contains projects to help protect and enhance the estuary, its foreshores and catchment and promotes public access to the waterways.

The Plan will remain in force until such time as it is amended or repealed by a coastal zone management plan that replaces it.

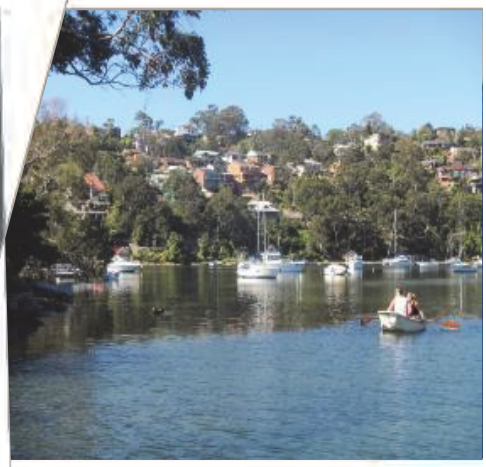
The Plan may be viewed on Council's website at www.sutherland.nsw.gov.au. For more information call 02 9710 0333.

SCOTT PHILLIPS
General Manager, Sutherland Land Council
Locked Bag 17, Sutherland NSW 1499

North West Arm

Coastal Zone Management Plan

59915032



Prepared for
Sutherland Shire Council

9 September 2015

Sutherland Shire COUNCIL

Cardno
Shaping the Future

Contact Information

Cardno (NSW/ACT) Pty Ltd
Trading as Cardno
ABN 95 001 145 035

Level 9, The Forum
203 Pacific Highway
St Leonards NSW 2065

Telephone: 02 9496 7700
Facsimile: 02 9439 5170
International: +61 2 9496 7700

Tanja.mackenzie@cardno.com.au
www.cardno.com.au

Author(s): Jennifer Cornell
Environmental Engineer

Approved By: Tanja Mackenzie
Senior Environmental Scientist

Document Information

Prepared for	Sutherland Shire Council
Project Name	Coastal Zone Management Plan
File Reference	59915032 R01 Rev0 NWArm CZMP.docx
Job Reference	59915032
Date	4 September 2015
Version Number	0
Effective Date	8 September 2015
Date Approved:	8 September 2015

Document History

Version	Effective Date	Description of Revision	Prepared by:	Reviewed by:
V1	17/03/2015	Draft for internal review.	Jennifer Cornell Chris Beadle Tanja Mackenzie	Michael Hughes
A	24/03/2015	Preliminary draft report.	Jennifer Cornell Chris Beadle	Tanja Mackenzie
B	18/05/2015	Draft for public exhibition.	Jennifer Cornell	Tanja Mackenzie
0	08/09/2015	Final	Jennifer Cornell	Tanja Mackenzie

Sutherland Shire Council has prepared this document with financial assistance from the NSW Government through its Estuary Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

Executive Summary

This Coastal Zone Management Plan (CZMP) has been prepared for Sutherland Shire Council (SSC or Council). The study addresses the requirements of the Office of Environment and Heritage (OEH) *Guidelines for Preparing Coastal Zone Management Plans* (2013a) in so far as they apply to this estuary. This study builds upon that earlier work by developing a comprehensive CZMP that addresses the key pressures affecting the estuary.

The Study Area

North West Arm is an embayment of the larger Port Hacking estuary (**Figure ES-1**). The North West Arm catchment has an area of approximately 1,035 ha and the main tributaries are Savilles and Dents Creeks. The tidal limits of the estuary are located 10.3 km from the open ocean (MHL, 2006), as shown in **Figure ES-1**. The estuary is tidal and contains extensive mangrove forests and seagrass beds.

A substantial part of the estuary foreshores are in private ownership and access to the waterway is limited. Public access to the estuary is available on the northern foreshore at Marina Crescent Reserve and at a public open space on North West Arm Road. Dents Creek may also be accessed off Huskisson Street and Cobargo Road. In addition to the numerous private jetties, there are 55 moorings located in the estuary.

Figure ES-1: The study area

Statutory Context

The North West Arm CZMP has been prepared under the *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013a) , which specify the minimum requirements that are to be met in preparing the CZMP as required in Part 4A of the *Coastal Protection Act 1979*.

The goals of the CZMP are to effectively manage issues including:

- Risks to public safety and built assets;
- Pressures on coastal ecosystems; and
- Community uses of the coastal zone.

The process of preparing the CZMP will bring Council's coastal management planning framework in line with recent coastal planning reforms undertaken by the NSW Government.

The CZMP is complementary to existing planning instruments and environmental management projects already being undertaken by Council and other stakeholders. This includes the Local Environmental Plan, Development Control Plan prepared by Council, as well as Council's Integrated Planning and Reporting system, and other broader initiatives such as the *Port Hacking Integrated Environmental Management Plan* (SSC, 2007).

Stakeholder and Community Engagement

Consultation with the community during the preparation of a CZMP is a requirement of the *Guidelines for Preparing Coastal Zone Management Plans*. Community consultation undertaken during preparation of this CZMP has included:

- Issue of a community newsletter about the CZMP;
- Establishment of a project website;
- A community survey; and
- Public exhibition of the Draft CZMP on Council's website.

In addition, the CZMP has been prepared in consultation with Council and other stakeholders engaged in management of the estuary via:

- An issues workshop;
- A workshop on management options;
- Presentation of the draft CZMP to the Port Hacking Management Panel; and
- Presentation of the draft CZMP for public exhibition to the Port Hacking Management Panel.

In this way, the CZMP has sought to consider the views and concerns of a range of stakeholders with an interest in the ongoing management of the North West Arm.

The community survey was used to gather information relating to how the community use the estuary, recreational activities they engage in, management issues they have observed and potential management options that they would like to see considered in this CZMP.

In general, visitation rates to the estuary are generally high with a relatively large number of residents visiting the estuary daily, and the majority visiting at least every 1-2 weeks. The most common recreational pursuits that respondents participated in include boating, fishing, swimming, kayaking and walking. Respondents were given a number of opportunities throughout the survey to describe any management issues that they have observed in the study area. A summary of the issues is provided in **Figure ES-2**.

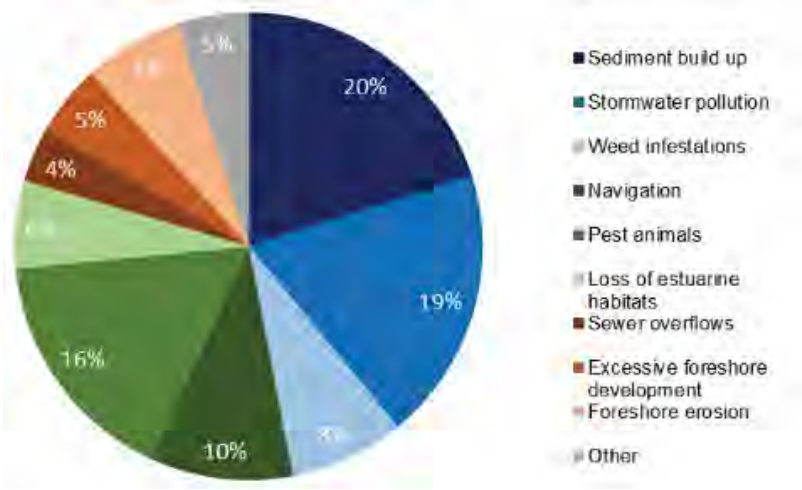


Figure ES-2: Management issues identified in community survey

Additional Investigations

A range of additional investigations have been undertaken to improve our understanding of the function of the estuary, the ecosystem health status, and exposure to coastal hazards. This included:

- Coastal hazard investigation;
- Bank and riparian condition assessments;
- A detailed assessment of dredging options proposed by the community;
- Catchment condition and water quality; and
- An assessment of risk for ecosystem health.

The full results are presented in **Sections 4 to 8** of this document and a summary is provided below.

Coastal Hazard Investigation

Wave run-up in the North West Arm is very low due to the limited fetch. The northern shoreline experiences higher significant wave heights as it is generally more exposed than other areas of the estuary. The wave overtopping assessment shows that wave overtopping discharges are generally low and structures are unlikely to be overtopped during the design storm event. The highest overtopping values occur along the northern shoreline, however the results indicate that structural damage is unlikely.

Climate change was also assessed in relation to the potential impact on coastal processes. While wave heights in the North West Arm are low in the present day, with little variance between day to day and extreme conditions, under sea level rise conditions a small increase in the frequency and intensity of large wave events may result in an increase in the incidence of wave overtopping, with potential for damage to occur to low lying foreshore structures.

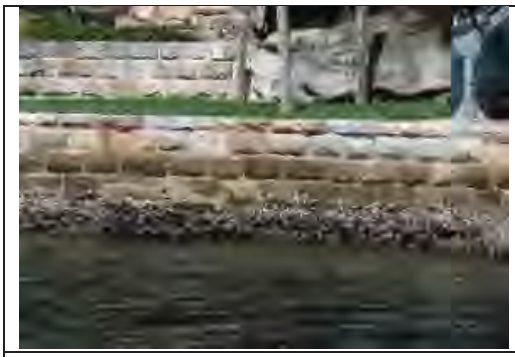
Climate change projections have identified a positive trend in the frequency and intensity of large wave events along Australia's southern coastline. Summer rainfall intensity is expected to increase. Extreme rainfall events can lead to blockages and overflows of the stormwater system resulting in catchment flooding. This may alter the hydrology of the estuary and result in more regular sediment transport in the shallower waters of the upper estuary.

Bank Condition Assessment

Approximately 4.6 km of foreshore was inspected via boat to evaluate the bank condition. Approximately 40% of the shoreline is modified and 60% is natural landform. The banks of the lower reaches of the estuary are predominantly seawalls, with only small sections of natural bank (generally rock platforms). The majority

(72%) of the seawalls are in good condition, although there are some seawalls (28%) in poor condition and at risk of failure.

Seawalls become less prevalent in the middle and upper estuary. The majority of the natural shoreline in the upper estuary consists of rock platforms, some of which are heavily vegetated with trees and shrubs. The majority (85%) of the natural bank is stable due to the prevalence of rock platforms. There are, however, some instances of erosion, particularly in the upper reaches of the estuary towards Dents Creek with approximately 15% of the natural shoreline eroding.



a) Good condition seawall in the lower estuary

b) Poor condition seawall in the upper estuary

c) Stable natural bank – rock shelf vegetated with trees and shrubs

d) Natural bank in the upper estuary with significant erosion

Figure ES-3: Bank condition assessment photographs

Dredging Options Assessment

Proposals for dredging were raised by the community during consultation undertaken for this CZMP. In order to consider whether they were feasible and to assess their relative merits, three options were subjected to a cost-benefit assessment (**Figure ES-4**):

- > 'Do nothing' (i.e. no dredging);
- > Option 1 – Navigation channel for small non-powered watercraft to provide access up to the easement from North West Arm Road on the low tide; and
- > Option 2 – Removal of top 300 mm from the fluvial delta near the deep-water section of the estuary.

The do nothing option was the highest ranked option of the three considered. Options 1 and 2 both had negative cost-benefit ratios due to the high cost of the works (estimated at around $300,000 to $400,000 for the capital works, plus maintenance dredging), limited benefits and negative environmental impacts. For example, both dredging options will result in the removal of seagrasses and mangroves, both of which are protected marine vegetation under the *Fisheries Management 1994* (FM Act).

A major constraint on dredging in the North West Arm is the restricted access. The steep topography and lack of vehicular access to the shoreline does not allow for land-based dredging methods (e.g. with a digger

located on the estuary banks). In addition, the shallow depths over the tidal delta limit access over part or all of the tidal cycle for a water-based dredge.

One of the important considerations in costing dredging works is the sustainability of the proposal with respect to the potential rate of infilling of the dredge hole (i.e. the potential maintenance dredging requirements). The key assessment finding for Option 1 is that the desired functionality of the dredging, namely to have kayak access to the easement from the North West Arm Road over the full tidal cycle, would become compromised as soon as one year after dredging due to mobilisation of sediments into the dredge footprint. For Option 2 the rate of infilling is much slower due to the fact that the dredge hole is located further downstream where the estuary waterbody widens out.

With respect to the statutory requirements for any dredging works, an environmental impact assessment under the *Environmental Planning and Assessment Act 1979* would be required, and a 'Permit to Dredge, Reclaim, Obstruct Fish Passage, Harm Marine Vegetation, Use Explosives or Electrical Devices in a Waterway in Accordance with Parts 2 & 7 of the *Fisheries Management Act 1994*' would be required. Monetary compensation and/or an environmental bond may also be required to harm marine vegetation under this permit.

Based on the outcomes of the feasibility assessment, neither of the dredging options were recommended for implementation.

Figure ES-4: Dredging options

Catchment Condition and Water Quality

Catchment processes can affect the estuary in several ways. For example, freshwater inflows from tributary creeks can lead to temporary changes in estuarine salinity, impact on water quality due to the introduction of nutrients and other pollutants, and in the case of flood events, result in increased estuarine water levels, erosional sedimentation, and potentially inundation of foreshore land. Catchment processes such as these can also impact on estuarine ecosystems and community uses.

The majority of the North West Arm catchment is urbanised, which has resulted in a significant increase in hard surfaces (impervious areas) such as roads and buildings. Green open space or forested areas (such as the Royal National Park) take up a smaller proportion of the catchment than would historically have been the case, and hence the extent of available land for natural absorption and infiltration of stormwater is relatively low. As a result of catchment development, a larger volume of stormwater reaches the North West Arm more quickly than would previously have been the case.

There is a significant amount of concern in the community regarding the impacts of stormwater pollution on the estuary. Council has a number of stormwater quality improvement devices located in the catchment that provide treatment of stormwater prior to discharge to the waterbody. Council's experience of the existing trash racks demonstrates that they can be effective in capturing gross pollutants, but that they can be expensive to maintain in a functional condition. Access is limited in parts of the catchment, such as along Dents and Savilles Creek, and for this reason it is not always practical to install a device in some locations. This is a particular issue in the North West Arm catchment.

A review of the available water quality data for Dents Creek indicates that there are periodic declines in water quality. At these times water quality may be unsuitable for both aquatic ecosystem health and recreational purposes. This suggests that there is opportunity to improve stormwater management practices in the catchment.

Less frequent but higher intensity storm events may occur in the future under climate change conditions. High intensity storms put more pressure on the stormwater network, resulting in increased severity of localised flooding, especially in times of joint occurrence with coastal inundation. Other implications of climate change for stormwater infrastructure include increased maintenance requirements due to the increased likelihood of sediment ingress from the estuary during high flow or more frequent rain events.

Estuarine Ecosystems

Estuaries typically have diverse ecosystems due to their location at the interface between terrestrial, freshwater and coastal environments. Within these broad categories, there are a number of different habitats ranging from terrestrial (or supra-tidal) habitats, to intertidal habitats, and aquatic (or sub-tidal) habitats.

Within the North West Arm there are approximately 28,000 m^2 of mangrove habitat, located primarily in the upper estuary around the confluence with Dents Creek (**Figure ES-5**). Although mangrove communities appear to have increased in recent years, the community has expressed concern over impacts from foraging deer and the establishment of tracks through the mangroves.

Two types of seagrass occur in the North West Arm; *Posidonia* and *Zostera*. *Posidonia* in Port Hacking is listed as an endangered population under the FM Act. Seagrass in the North West Arm has declined from historic levels.

The North West Arm has experienced the loss of natural habitat through urbanisation and subsequent replacement with parkland, infrastructure, housing, and other structures, such as jetties and seawalls, resulting in significantly modified estuarine foreshores in the study area.

Figure ES-5: Mangroves in the North West Arm

Highly modified foreshores can exacerbate the impact of rising sea levels associated with climate change. Seawalls and the steep topography of the North West Arm will likely limit the ability of vegetation communities to migrate landward with rising sea levels. This may result in regular and/or permanent inundation of low lying coastal areas, leading to the loss of intertidal habitat, mudflats and estuarine vegetation. Seagrass will also be impacted by rising sea levels due to a decline in light penetration to depths

currently inhabited by seagrasses and resultant shifts in the distribution of available substrate suitable to support seagrass growth.

Figure ES-6 is a conceptual model that illustrates the potential impacts of sea level rise on ecosystems in the North West Arm. The features shown on the figure include the present day and future water levels, extent of the mangroves and seagrass beds, and estuary bed and banks, and are based on their actual locations.

Ecological Health Status and Risk Assessment

An ecological health assessment was completed for the North West Arm based on the data gathered during the preparation of the CZMP. Key health indicators assessed included:

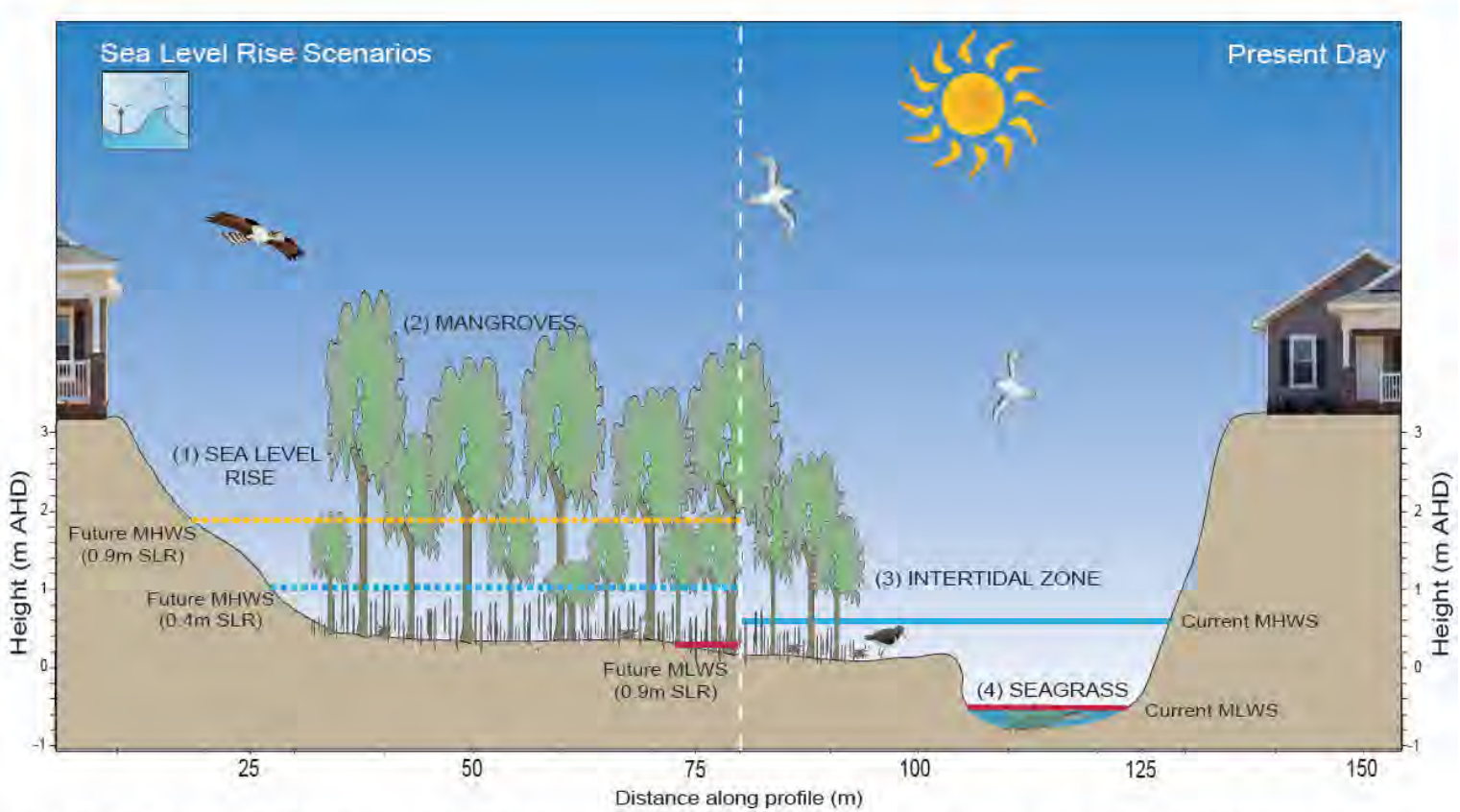
- Water quality;
- Foreshore condition;
- Estuarine flora (mangroves and seagrass);
- Riparian flora; and
- Estuarine fauna.

Although the estuarine ecosystems within the North West Arm are in a modified condition due to historic changes in catchment land use and the legacy of historic development, the overall health of the estuary is fair to good. Mangroves communities in the North West Arm have increased. Periodic declines in water quality may be experienced throughout the estuary and the clearing of riparian vegetation can lead to bank destabilisation and erosion.

A qualitative ecological risk assessment was completed to assess the likelihood and consequences of hazards, including predicted climate change impacts (where applicable), adversely influencing key attributes of the estuarine ecosystem.

The existing ecosystem health hazards include the risk of infestation of the North West Arm with *Caulerpa taxifolia* and ongoing impacts due to presence of introduced flora and fauna (e.g. deer), with resultant decline in riparian vegetation condition and/or extent.

The level of risk is expected to increase in the future, with climate change and ongoing urban development acting as stressors.



(1) SEA LEVEL RISE associated with climate change has the potential to result in more regular or permanent inundation of low lying areas, leading to loss of intertidal habitat, sandflats and estuarine vegetation. The steep banks and proximity to development limit the ability of mangroves to migrate with rising sea levels.

(2) MANGROVES provide habitat for small fish (at high tide) who feed, find shade and refuge from predators amongst the trees. In addition, mangroves support a wide range of invertebrate species. These habitats act as a buffer against pollution from surface runoff. They are also very productive habitats cycling nutrients and carbon.

(3) The INTERTIDAL sandflats provide habitat for fish and wading birds, who feed on invertebrates living in the sand. The extent of suitable habitat for wading birds will decrease as the sandflats are inundated under a SLR scenario.

(4) SEAGRASS beds are productive habitats, contributing to nutrient cycling, stabilising sediments and reducing turbidity by facilitiating sedimentation. They form essential habitat for juvenile fish and invertebrates. Under SLR conditions, their distribution may shift.

Figure ES-6: Conceptual model of sea level rise impacts on estuarine ecosystems

Management Framework & Options Assessment

A series of management objectives for the North West Arm were developed based on consideration of the estuary values identified by the community and the management issues identified in consultation with stakeholders and arising from our detailed investigations. The management objectives for the North West Arm CZMP are provided in **Table ES-1**.

Table ES-1: Management Objectives for the North West Arm CZMP

	Management Objectives
1	*Protect and improve the condition of natural bushland, riparian and estuarine vegetation.*
2	*Maintain and improve estuarine water quality for aquatic ecosystem health and recreational purposes.*
3	*Maintain and (where feasible) improve public access to and around the estuary foreshores and waterbody.*
4	*Recognise the values and significance of the estuary to the community.*
5	*Manage the impacts of human activities on natural coastal processes and estuarine ecosystems.*
6	*Maintain the visual character of the North West Arm estuary.*
7	*Seek to engage with the community and involve them in the implementation of the CZMP for the North West Arm.*

The management objectives essentially establish the desired management outcomes for the CZMP, and have been explicitly considered in the options assessment process. A list of 35 management options was developed by the study team in consultation with Council. These options were then subjected to a quadruple bottom-line cost-benefit assessment, taking into consideration the need to:

> Adopt a risk management approach to public safety, assets and pressures on coastal ecosystems, including avoiding risks where feasible and mitigating risks where they cannot be reasonably avoided, adopting interim actions to manage high risks while long term options are implemented;

> Assess options based on the best available information and reasonable practice, including adopting an adaptive management approach; and

> Support the requirement that the priority for public expenditure is public benefit, cost-effectively achieving the best practical long term outcomes.

This resulted in the development of a shortlist of 19 options for incorporation into an Implementation Plan.

The Implementation Plan

Nineteen options have been developed into an Implementation Plan that forms the basis of the North West Arm CZMP, including the top 15 highest ranking options (noting that three options are ranked equal 15th). A further two management actions, Actions CU01 and CU03, have also been included in the Implementation Plan at the request of Council. Both these actions are more costly to implement than many other options (and therefore have lower rankings), but would further the achievement of most of the management objectives.

A summary of the Actions in the Implementation Plan is provided in **Table ES-2**.

The total cost of implementation of the Plan is $1,072,680 in capital costs and $223,620 in annually recurrent costs over a 10 year period of implementation. Of the actions identified in the Plan, 16 would be the primary responsibility of Council for implementation, summing to $1,061,980 in capital costs and $214,520 in annually recurrent costs.

Table ES-2: Implementation Plan

Actions ID.	Description	Location	Responsibility	Rank
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.	Estuary-wide	Council	1
CC01	Provide ongoing support for Bushcare groups.	Catchment-wide	Council	2
CC17	Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.	Marina Crescent Reserve	Council	3
WQ04	Assess the condition of Council's stormwater outlets to the estuary and program works as required.	Estuary-wide	Council	4
CC13	Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.	Estuary-wide	DPI (Fisheries)	5
WQ01	Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program.	Catchment-wide	Council	6
CP01	Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.	Dents & Savilles Creeks	Council	7
EE01	Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.	Estuary-wide	Council	8
WQ02	Provide ongoing support for community education to improve awareness of non-point source water pollution and provide advice on how residents can contribute to best practice stormwater management.	Catchment-wide	Council	8
CC09	Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.	Estuary-wide	RMS	10
CC20	Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources.	Catchment-wide	Council	11
CC04	Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.	Molong Road	Council	12
WQ08	Install a trash rack at the point where North West Arm Road crosses Savilles Creek to capture gross pollutants.	Savilles Creek	Council	13
WQ03	Work with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows on the estuary.	Catchment-wide	Council	14
WQ06	Install a SQID to treat stormwater draining to Dents Creek via reaches DCDCPH017 and 018, to be located near the intersection of Huskisson St and Cobargo Rd.	Dents Creek	Council	15
WQ09	Install an online SQID on the unnamed watercourse located in Kyogle Reserve to capture gross pollutants from the stormwater network and upstream reach of the creek prior to entering the estuary.	Unnamed Watercourse, Grays Point	Council	15
WQ10	Install a SQID to treat stormwater from the piped drainage catchment to the south east prior to discharge to the unnamed watercourse located in Kyogle Reserve.	Unnamed Watercourse, Grays Point	Council	15

Actions ID.	Description	Location	Responsibility	Rank
CU01	Establish a kayak trail from Swallow Rock and leading into the North West Arm.	Estuary-wide	Council	25
CC03	Assess feasibility of establishing stairs or a ramp to the water for purposes of launching small watercraft (e.g. kayaks and canoes) at the bottom of the easement located opposite the bus stop on North West Arm Road down to Dents Creek.	North West Arm Road	Council	27

Concluding Remarks

The management actions within the Implementation Plan have been prioritised to assist in allocating resources; however, it is acknowledged that the resources required to progress the Plan are significant, and that a flexible approach to undertaking works should be adopted. For example, there may be grants or other funding opportunities that arise from time to time that will allow Council to select certain lower priority management actions for implementation before higher priority actions.

The North West Arm CZMP represents a comprehensive document that provides for integrated coastal management of the system by Council and other key stakeholders. Having been placed on public exhibition for a period of 28 days, the Plan may now be presented to Council for formal adoption.

Glossary and Abbreviations

Term / Abbreviation	Explanation
Aboriginal Land Claims	Through the *Aboriginal Land Rights Act 1983*, vacant Crown land not lawfully used or occupied or required for an essential purpose or for residential land, is returned to Aboriginal people. Aboriginal land rights aim to redress past injustices when Aboriginal people were dispossessed of their land by colonisation. This dispossession led to many social, economic and physical problems for Aboriginal people.
ADCP	Acoustic Doppler Current Profiler
AHIMS	Aboriginal Heritage Information Management System
Amenity	Those features of an area that foster its use for various purposes.
Animal	Any animal, whether vertebrate or invertebrate, and at whatever stage of development.
ASS	Acid Sulfate Soils
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrences of an inundation event as big as or larger than the selected event. For example, the 20-years ARI inundation event will occur, on average, once every 20 years. However, it is implicit in this definition that periods between occurrences are generally random. That is, an event of a certain magnitude may occur several times within its estimated return period. ARI is another way of expressing the likelihood of occurrence of an inundation event.
BACI	Before-After / Control-Impact. A sampling design that include the incorporation of at least one “control” (un-impacted) and one “impact” site and that these sites must be sampled both before and after the impact (i.e. the rehabilitation works).
BDL	Below detection limit
BoM	Bureau of Meteorology
CAMBA	China Australia Migratory Bird Agreement.
Catchment	The area of land that drains to a common location or watercourse. This always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
CLD	Crown Lands Division. Crown land is land vested in the Crown and managed by the Crown Lands Division (CLD) of NSW DPI under the *Crown Lands Act 1989*.
CMA	Catchment Management Authority.
Coastal Inundation	A natural process whereby elevated ocean water levels combined with wave run-up result in seawater overtopping coastal and estuarine foreshores during storm events. This process is generally rare and episodic, occurring principally around the peak of a high tide, creating a hazard particularly in areas below about 5 mAHD.
CSE	Chief Scientist and Engineer of NSW
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CZMP	Coastal Zone Management Plan
DCP	Development Control Plan
DECCW	Former NSW Department of Environment, Climate Change and Water (now OEH)
Delft3D	Numerical modelling system
DPI	NSW Department of Primary Industries
EEC	Endangered Ecological Community as identified under the TSC Act or the EPBC Act.
ENSO	El Niño – Southern Oscillation

Term / Abbreviation	Explanation
Environmental Protection Licence (EPL)	EPLs are issued by the EPA for scheduled activities (as prescribed under the Act) to regulate emissions from a premises to air, water or land.
EPA	Environmental Protection Agency
EP&A Act	NSW *Environmental Planning and Assessment Act 1979*
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
ESD	Ecologically Sustainable Development.
FC	Faecal coliforms, a pathogenic faecal bacterium.
Fluvial	Relating to, or inhabiting a river or stream
FM Act	NSW *Fisheries Management Act 1994*
Foreshore	The area of land at the land-water interface that is likely to be affected by coastal and catchment processes.
Geographical Information System (GIS)	A system of hardware, software, data, and procedures designed to support the management, manipulation, analysis and display of spatially referenced data by trained personnel.
GHG	Greenhouse Gas Emissions
GPT	Gross Pollutant Trap (a type of SQID).
Habitat	The places in which an organism or community lives.
Hazard	A situation that poses a level of threat to life, health, property, or the environment.
Highest Astronomical Tide (HAT)	The highest level of water which can be predicted to occur under average meteorological conditions any combination of astronomical conditions over 18 years (however water levels can often exceed HAT values because of the influence of wind and waves).
Hs	Significant Wave Height. The average height of the one-third highest waves of a given wave group.
IBE	Inverse Barometer Effect
ISQG	Interim Sediment Quality Guideline
Indigenous Land Use Agreement (ILUA)	An indigenous land use agreement is an agreement between a native title group and others about the use and management of land and waters. ILUAs were introduced as a result of amendments to the Native Title Act in 1998.
Inundation	Flooding, by the rise and spread of water, of a land surface that is not normally submerged.
IPCC	Intergovernmental Panel on Climate Change
IPR	NSW Government Integrated Planning and Reporting Framework
JAMBA	Japan Australia Migratory Bird Agreement
KPIs	Key Performance Indicators
LEP	Local Environment Plan
LGA	Local Government Area
LLS	Local land services
Local sea	Local sea waves are caused by the local action of wind on the water surface (e.g. within the Harbour).
Lowest Astronomical Tide (LAT)	The lowest level of water which can be predicted to occur under average meteorological conditions over 18 years. Modern hydrographic chart datums are set at the approximate level of LAT and Tide Tables list the predicted height of tide above Chart Datum. It should be noted that water level may fall below the level of LAT if abnormal meteorological conditions are experienced or if influenced by wind and waves.
mAHD	Elevation in metres with respect to the Australian Height Datum.

Term / Abbreviation	Explanation
Mean High Water Neap (MHWN)	The height of the MHWN is the average of pairs of successive high waters during those periods (approx. once every 14 days) when the tidal range is least. The height of MLWN is the height of the high waters of neap tides.
Mean High Water Springs (MHWS)	The MHWS is the average of pairs of successive high waters in a 24-hour period in each semi-lunation (approximately every 14 days) at New and Full Moon when the tidal range is greatest. It is the average height of the high waters of spring tides.
Mean Low Water Neap (MLWN)	The height of the MLWN is the average of pairs of successive low waters during those periods (approx. once every 14 days) when the tidal range is least. The height of MLWN is the height of the low waters of neap tides.
Mean Low Water Springs (MLWS)	The MHWS is the average of pairs of successive low waters in a 24-hour period in each semi-lunation (approximately every 14 days) at New and Full Moon when the tidal range is greatest. It is the average height of the low waters of spring tides.
Mean Sea Level (MSL)	MSL is a measure of the average height of the ocean's surface such as the halfway point between the mean high tide and the mean low tide. At present, mean sea level is approximately equivalent to 0 mAHD.
MER	Monitoring, Evaluation and Reporting
MHL	Manly Hydraulics Laboratory
mLAT	Elevation in metres with respect to the Lowest Astronomical Tide
MSDS	Material Safety Data Sheets
NATA	NATA is the authority that provides independent assurance of technical competence. NATA provides assessment, accreditation and training services to laboratories and technical facilities throughout Australia and internationally.
Native Title	Under the Commonwealth Native Title Act 1993, Native Title is the recognition by Australian law that some Indigenous people have rights and interests to their land that come from their traditional laws and customs. These rights are different to and separate from the statutory right of Aboriginal Land Councils to make claims for land under the NSW Aboriginal Land Rights Act 1983.
NP&W Act	NSW *National Parks and Wildlife Act 1974*
NPWS	National Park and Wildlife Services
NRM	Natural Resources Management
NSW	New South Wales
OEH	NSW Office of Environment and Heritage (formerly known as DECCW)
PAH	Polycyclic aromatic hydrocarbons; produced during combustion.
P&E	Planning and Environment
PCB	Polychlorinated Biphenyls
PHMP	Port Hacking Management Panel
PoM	Plan of Management
QA/QC	Quality Assurance / Quality Control.
RCP	Representative concentration pathway. RCPs are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. RCPs provide a quantitative description of concentrations of the climate change pollutants in the atmosphere over time, as well as their radiative forcing in 2100 (for example, RCP 6 achieves an overall impact of 6 watts per square metre by 2100).
Riparian Vegetation	Vegetation growing along banks of rivers or a body of water.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood.
RMS	Roads and Maritime Services NSW
ROKAMBA	Republic of Korea Australia Migratory Bird Agreement

Term / Abbreviation	Explanation
$R_{U2\%}$	The wave run-up level above which only 2% of waves will exceed during a design storm.
Runoff	That proportion of rainfall that drains off the lands surface.
Seawall	Wall built parallel to the shoreline to assist in protecting the shoreline from erosion or to allow for reclamation of foreshore land.
Sedimentation	The act or process of depositing sediment, including by mechanical means, of matter suspended in a liquid.
SES	NSW State Emergency Service
Shoaling	The influence of the seabed on wave behaviour. Such effects only become significant in water depths of 60m or less. Manifested as a reduction in wave speed, a shortening in wavelength and an increase in wave height.
Shoreline recession	A net long term landward movement of the shoreline caused by a net loss in the sediment budget.
SLR	Sea level rise
SMCMA	Former Sydney Metropolitan Coastal Management Authority (now amalgamated with HNCMA).
SQID	Stormwater Quality Improvement Device
SSC	Sutherland Shire Council
Still Water Level (SWL)	Average water-surface elevation at any instant including the effects of tides and storm surge, but excluding local variation due to wind and waves.
Storm Surge	The increase in coastal water level caused by the effects of storms. Storm surge consists of three components: the increase in water level caused by the reduction in barometric pressure (barometric set-up or IBE), the increase in water level caused by the action of wind blowing over the sea surface (wind set-up), and the increase in water level caused by the piling up of waves against the coast (wave set-up).
Storm Tide	Storm tide is different from storm surge in that it includes all the elements of storm surge (IBE, wave set-up and wind set-up) as well as the astronomical tidal level.
SWAN	Wave model
Swell	Swell waves are regular wave motions caused by large meteorological disturbances such as storms that create waves in the open sea at a distant location. Swell waves can persist for a long time after the disturbance event and can travel long distances.
SWaMP	Strategic Water Quality Monitoring Program. Council water quality monitoring program which included four sites in the North West Arm and one each at Dents and Savilles Creek.
TN	Total Nitrogen
T_p	Peak wave period
TP	Total Phosphorous
TSC Act	NSW *Threatened Species Conservation Act 1995*
TSS	Total Suspended Solids
$\|v\|$	Critical velocity for marine sediments
Wave Overtopping	The process by which a wave propagates over the shoreline (or seawall) and inundates the land behind the shoreline.
Wave Run-up	The vertical distance above mean water level reached by the uprush of water from waves across a beach or up a structure.
Wave Set-up	The increase in water level within the surf zone above mean still water level caused by the breaking action of waves.
Wind Set-up	The increase in water levels caused by the action of wind blowing over the sea surface.
WSUD	Water Sensitive Urban Design

Table of Contents

Appendices

Tables

Figures

1 Introduction

This Coastal Zone Management Plan (CZMP) has been prepared for Sutherland Shire Council (SSC or Council). The study addresses the requirements of the Office of Environment and Heritage (OEH) *Guidelines for Preparing Coastal Zone Management Plans* (2013a) in so far as they apply to this estuary. To date a Scoping Study has been undertaken by BMT WBM (2012). This study builds upon that earlier work by developing a comprehensive CZMP that addresses the key pressures affecting the estuary.

Under the guidelines the CZMP is required to identify and discuss the planning framework relevant to management of the estuary, and prioritise management options based on a combination of factors. Management options are developed and prioritised by considering the social, economic and environmental factors, to identify realistic and affordable management actions.

1.1 Study Area

North West Arm is an embayment of the larger Port Hacking estuary (**Figure 1-1**). The North West Arm catchment has an area of approximately 1,035 ha and the main tributaries to the North West Arm are Savilles and Dents Creeks. The tidal limits of the estuary are located 10.3 km from the open ocean (MHL, 2006), as shown in **Figure 1-1**. The estuary is tidal and contains extensive mangrove forests.

A substantial part of the estuary foreshores are in private ownership and access to the waterway is limited. Public access to the estuary is available on the northern foreshore at Marina Crescent Reserve on Marina Crescent and at a public open space on North West Arm Road. Dents Creek may also be accessed off Huskisson Street and Cobargo Road.

The National Land and Water Resources Audit (2001) assessed Port Hacking, which includes the North West Arm, as being in a modified condition due to changes in catchment land use. The major pressures affecting the North West Arm estuary include (BMT WBM, 2012):

- Flooding;
- Degraded water quality;
- Erosion and siltation;
- Littering and dumping of rubbish;
- Feral deer; and
- Weed infestations.


Sutherland Shire COUNCIL
Study Area
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Study Area
Tidal Limit
Cadastre
Waterways
Local Parks
National Parks and Reserves
FIGURE 1-1
1:12,000 Scale at A4
Metres
0 50 100 200 300 400
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-05
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1001_Fig1-1StudyArea_v2.mxd 01
Sydney
Copyright: ©2013 Esri, DeLorme, NAVTEQ
North West Arm
GYMEA BAY
GRAYS POINT
ROYAL NATIONAL PARK
BUNARBA ROAD
DARRYL PLACE
VALLEY WAY
GYMEA BAY ROAD
NARANGANAH AVENUE
CARTER CRESCENT
COONONG ROAD
MOLONG ROAD
NULGARRA AVENUE
MARINA CRESCENT
ARCADIA AVENUE
GREENHAVEN ROAD
ANGLE ROAD
KINGFISHER CRESCENT
PENINSULAR ROAD
MANSION POINT ROAD
GRAYS POINT ROAD
SHALLOW ROCK DRIVE
BUDYAN ROAD
MOYRAN PARADE

1.2 Project Objectives

Council's brief for the project identifies a number of objectives to be achieved through development of the CZMP:

- Develop a comprehensive CZMP for the North West Arm estuary;
- Link Council's coastal zone management planning with other planning processes in the coastal zone to facilitate integrated coastal zone management;
- Involve the community in preparation of the CZMP, including making information relating to the Plan publicly available;
- Recognise and accommodate natural coastal processes and hazards. The CZMP will include strategies to deal with threats to existing development and to ensure that new development is not exposed to such threats;
- Develop a CZMP that will provide for growth and development without putting at risk the natural, cultural and heritage features of the coast;
- Establish estuary values and uses, and develop balanced long term management framework for the ecological use of the estuary and its catchment;
- Maintain the condition of high value coastal ecosystems, rehabilitate priority degraded coastal ecosystems;
- Address the current and potential risks to estuary health;
- Protect and preserve foreshore amenity, maintain and improve public access arrangements, support recreational uses and protect the cultural and heritage environment;
- Develop management actions to be implemented by Council, other authorities, community groups, or the private sector;
- The effects of climate change, including sea level rise, on coastal hazards, ecosystem health and community uses of the coastal zone will be an integral part of determining management actions;
- Base decisions for managing risks to public safety and built assets, pressures on coastal ecosystems and community uses of the coastal zone in the North West Arm estuary on the best available information and reasonable practice, including adopting an adaptive management approach;
- Adopt a risk management approach to public safety, assets and pressures on coastal ecosystems, including avoiding risks where feasible and mitigation where risks cannot be reasonably avoided, adopting interim actions to manage high risks while long term options are implemented; and
- Management actions in the CZMP will be prioritised based on public benefit, including cost-effectively achieving the best practical long term outcomes.

These project objectives have been adopted throughout the development of the North West Arm CZMP.

1.3 Document Structure

This document has been structured as follows:

- **Section 2** provides some context on the requirement for the CZMP under the relevant NSW Coastal Management Program;
- The methodology adopted for the CZMP is detailed in **Section 3**;
- A summary of the community survey is provided in **Section 4**;
- Coastal processes, including hazards, are discussed in **Section 5**;
- Catchment characteristics and water quality are discussed in **Section 6**;
- Estuarine ecosystems and ecological health are discussed in **Section 7**;
- Community uses of the North West Arm are discussed in **Section 8**;
- The management framework for the North West Arm CZMP is detailed in **Section 9**;
- The proposed implementation plan is in **Section 10**;
- The assessment of management options is provided in **Section 11**;

> **Section 12** presents a monitoring and evaluation strategy for the CZMP; and

> **Section 13** contains the concluding remarks and recommendations.

A bibliography is provided in **Section 14**. A series of appendices containing some of the more detailed analyses and results are also provided.

2 Coastal Management Framework

2.1 Statutory Framework

2.1.1 NSW Coastal Policy 1997

The *NSW Coastal Policy 1997* was developed by the state government to provide context for the ongoing management and use of the coastal zone. The Policy sets a vision for the ongoing use and development of the coastal zone within the context of the need to preserve and enhance the natural, cultural and heritage values of the coast in accordance with the principles of Ecologically Sustainable Development (ESD). The Coastal Policy contains nine management goals:

- Protecting, rehabilitating and improving the natural environment and of the coastal zone;
- Recognising and accommodating the natural processes of the coastal zone;
- Protecting and enhancing the aesthetic qualities of the coastal zone;
- Protecting and conserving the cultural heritage of the coastal zone;
- Providing for ecologically sustainable development and use of resources;
- Providing for ecologically sustainable human settlement of the coastal zone;
- Providing for appropriate public access and use;
- Providing information to enable effective management of the coastal zone; and
- Providing for integrated planning and management of the coastal.

Implementation of the Policy is provided via the *Environmental Planning and Assessment Act 1979* (EP&A Act) and the *Coastal Protection Act 1979*, amongst other statutory and non-statutory mechanisms. Under the EP&A Act, local Councils are required to consider the Policy in strategic land use planning and development controls.

2.1.2 Coastal Protection Act 1979

The objectives of the *Coastal Protection Act 1979* are:

- To protect, enhance, maintain and restore the environment of the coastal region, its associated ecosystems, ecological processes and biological diversity, and its water quality;
- To encourage, promote and secure the orderly and balanced utilisation and conservation of the coastal region and its natural and man-made resources, having regard to the principles of ecologically sustainable development;
- To recognise and foster the significant social and economic benefits to the State that result from a sustainable coastal environment, including:
  - benefits to the environment,
  - benefits to urban communities, fisheries, industry and recreation,
  - benefits to culture and heritage,
  - benefits to the Aboriginal people in relation to their spiritual, social, customary and economic use of land and water,
- To promote public pedestrian access to the coastal region and recognise the public's right to access;
- To provide for the acquisition of land in the coastal region to promote the protection, enhancement, maintenance and restoration of the environment of the coastal region;
- To recognise the role of the community, as a partner with government, in resolving issues relating to the protection of the coastal environment;
- To ensure co-ordination of the policies and activities of the Government and public authorities relating to the coastal region and to facilitate the proper integration of their management activities;
- To encourage and promote plans and strategies for adaptation in response to coastal climate change impacts, including projected sea level rise; and
- To promote beach amenity.

The North West Arm CZMP has been prepared under the current Guidelines for Preparing Coastal Zone Management Plans (OEH, 2013a) , which specify the minimum requirements that are to be met in preparing the CZMP as required in Part 4A of the *Coastal Protection Act 1979*.

The goals of the CZMP are to effectively manage issues including:

- Risks to public safety and built assets;
- Pressures on coastal ecosystems; and
- Community uses of the coastal zone.

The process of preparing the CZMP will bring Council's coastal management planning framework in line with recent coastal planning reforms undertaken by the NSW Government.

2.1.3 Coastal Reforms

The legislative and policy framework for coastal management in NSW has been undergoing a process of reform since 2012. In November 2014 the NSW Government announced the completion of Stage 1 reforms, which included:

- Amendment of the *Coastal Protection Act 1979* (completed January 2013);
- Preparation of a Code of Practice for temporary coastal protection works (OEH, 2013b; completed August 2013);
- Rescinding the NSW Sea Level Policy Statement (DECCW, 2009);
- Release of a report prepared by the Chief Scientist and Engineer of NSW on the science behind sea level rise (CSE, 2012);
- Preparation of a Coastal Erosion Stormsafe guide by the State Emergency Service (SES); and
- Release of a planning circular (PS 14-003) on coastal hazard notations on Section 149 planning certificates.

The Stage 2 reforms are now underway, and will involve the following activities:

- Drafting of a new bill, the Coastal Management Act, to repeal the *Coastal Protection Act 1979*;
- Providing improved support to Councils in decision making, to include a decision support framework, a new coastal management manual to replace the current guidelines, and improved technical advice;
- Transitioning of CZMPs into the local government Integrated Planning and Reporting (IPR) framework; and
- Review of funding arrangements and financing of coastal management legislation.

2.2 Coastal Management Principles

The *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013a) include Coastal Zone Management Principles to help inform the approach in managing coastal issues. These principles and the relevant report section where they have been addressed are presented in **Table 2-1**.

Table 2-1: Coastal Management Principles

Coastal Management Principal	Addressed by North West Arm CZMP	Report Section
Principle 1 Consider the objectives of the *Coastal Protection Act 1979* and the goals, objectives and principles of the NSW *Coastal Policy 1997* and the *NSW Sea Level Rise Policy Statement* (DECCW, 2009).	This principle was applied when identifying management options and actions for the North West Arm.	All sections of this report.
Principle 2 Optimise links between plans relating to the management of the coastal zone.	The Plan has considered related Plans of Management and Policies currently in place.	**Sections 2.3 and 2.4**
Principle 3 Involve the community in decision-making and make coastal information publicly available.	Stakeholder consultation has been conducted to assist with the identification of management issues and potential options. Consultation included a stakeholder workshop, community user survey and public exhibition of the Draft CZMP.	**Sections 3.2.2 and 4**

Coastal Management Principal	Addressed by North West Arm CZMP	Report Section
Principle 4 Base decisions on the best available information and reasonable practice; acknowledge the inter-relationship between catchment, estuarine and coastal processes; adopt a continuous improvement management approach.	This study has collated the best available information, and contributed additional information based on investigations undertaken by Cardno.	All sections of this report.
Principle 5 The priority for public expenditure is public benefit; public expenditure should cost effectively achieve the best practical long-term outcomes.	The options assessment framework provides for a triple bottom line approach to identifying those options with the highest cost-benefit ratio for inclusion in the Implementation Plan.	**Section 10**
Principle 6 Adopt a risk management approach to managing risks to public safety and assets; adopt a risk management hierarchy involving avoiding risk where feasible and mitigation where risks cannot be reasonably avoided; adopt interim actions to manage high risks while long-term options are implemented.	This report provides a review of coastal hazards affecting the North West Arm and enables property/asset owners to assess their level of risk. A risk assessment was also undertaken for ecosystem health.	**Sections 5 and 7.6**
Principle 7 Adopt an adaptive risk management approach if risks are expected to increase over time, or to accommodate uncertainty in risk predictions.	The potential for risks to change overtime has been considered in relation to climate change and land use planning; noting that the CZMP will be subject to review in approximately 5-10 years and may be updated as required at this time. The monitoring program incorporates parameters that will assist this process.	**Sections 5 and 12**
Principle 8 Maintain the condition of high value coastal ecosystems; rehabilitate priority degraded coastal ecosystems.	The current ecological health threats and pressures have been assessed with a view to considering management options to maintain or improve the ecological condition of the estuary.	**Section 7**
Principle 9 Maintain and improve safe public access to beaches and headlands consistent with the goals of the Coastal Policy.	Public access and public safety is considered in this report.	**Section 8.5**
Principle 10 Support recreational activities consistent with the goals of the NSW Coastal Policy.	Recreational uses of the study area are identified and considered in this report.	**Section 8.5**

2.3 Port Hacking Integrated Environmental Management Plan

The Port Hacking Integrated Environmental Management Plan (SSC, 2007) (hereafter referred to as the PHIEMP) was prepared by the Port Hacking Management Panel to guide the ongoing sustainable management of Port Hacking and its catchment. Specifically, the role of the panel, as detailed in its charter, is to advise Council on all matters related to the preservation, maintenance, sustainable development and use of Port Hacking.

Membership of the Port Hacking Management Panel includes:

- Sutherland Shire Council Councillors*;
- Commercial operators representative*;
- Waterfront Owners Association representative*;
- Waterways User Group representative*;
- Two environmental representatives*;
- Up to seven community representatives*;
- Representative of NSW Department of Primary Industries (DPI);
- Representative of Roads and Maritime Services (RMS);

- Two representatives from OEH, including one each for the National Parks and Wildlife Service (NPWS), and the Coastal and Estuary Management Program.
- One representative from the Environmental Protection Agency (EPA); and
- Two Council staff.

Those members marked with an asterisk (*) having voting rights.

A Working Group sits under the Port Hacking Management Panel (PHMP) to progress implementation of the PHIEMP.

As identified in the 2007-2012 update of the PHIEMP (SSC, 2007), the Panel and its members have achieved several milestones since adoption of the PHIEMP in 1992:

- An active program for improvement of water quality through a stormwater levy;
- The implementation of sewerage to Bundeena;
- The continuation of the Sydney Metropolitan Catchment Management Authority (now the Greater Sydney Local Land Services (LLS)); and
- Environmental data collection and the development of Estuary Management Plans (now known as CZMPs) for Gunnamatta, Gymea and Yowie bays.

It is noted, however, that the PHIEMP (SSC, 2007), also identified several ongoing management issues, some of which have worsened since the preparation of the original 1992 Plan:

- Increased conflict between users;
- Continued foreshore development that detracts from the natural quality of the Port as evident in the results of foreshore visual study (2002);
- Continued destruction of Aboriginal heritage sites; and
- An ongoing net loss of seagrass.

It is important that any management recommendations made in this CZMP are consistent with the PHIEMP, which is effectively the overarching plan of management for the waterbody as a whole, whereas this CZMP addresses more site-specific issues relating to the North West Arm only.

2.4 Sutherland Shire Council's Integrated Planning and Reporting Framework

The state government requires that local Councils prepare Community Strategic Plans as part of their IPR framework. These Plans sit above all other policies and plans prepared by Councils, and are supported by a number of other documents, including:

- Resourcing Strategy;
- Delivery Program;
- Operational Plan; and
- Annual Reporting of progress against the Strategic Plan.

Sutherland Shire Council has fulfilled this requirement via preparation of Our Shire, Our Future (2011), which articulates the vision, strategies and desired outcomes for the Council's operations.

As indicated in **Section 2.1**, there is a need to demonstrate that the CZMP is consistent with and can be integrated with the Council's IPR framework. **Table 2-2** identifies how the North West Arm CZMP contributes to achievement of the strategies and goals of Council's Delivery Program 2013/14 - 2016/17 and Environment and Sustainability Strategy.

Table 2-2: Achievement of Community Strategic Plan

Strategy and Goal	Addressed by North West Arm CZMP	Cross Reference
Strategy 1 – Provide Effective and Critical Infrastructure		
1.11 Sustainable Stormwater Management & Drainage and Estuary Management	Preparation of the North West Arm CZMP.	This report.
Strategy 4 – Protect Our Environment		

Strategy and Goal	Addressed by North West Arm CZMP	Cross Reference
4.5 Local community groups, business, industry and residents in initiatives which protect and/or enhance nature	Manage ongoing Bushcare Program - information to support activities provided in CZMP.	**Sections 7.3.1 & 11**
Strategy 5 – Strengthening Our Community		
5.4 Community events which facilitate people connecting at the local and Shire wide level and encourage local economic activity	Conduct community-based events and promotions – Consultation undertaken as part of this CZMP.	**Sections 3.2.2 and 4**
5.9 Local emergency services to prepare for, respond and manage natural disasters	Provision of additional information on the effect of coastal hazards on built infrastructure and the environment, including under climate change conditions.	**Section 5**
Strategy 7 - Civic Life		
7.1 Strategic Delivery: Outstanding community outcomes that fulfil local needs and expectations.	Online Interactions with Community	**Sections 3.2.2 & 4**
	Lobby Federal & NSW Governments – This project was part funded by an Estuary Management Grant awarded by OEH.	This report.
7.2 Informed Decisions: Decisions and actions based on fact, community engagement and sound judgment	Undertake community engagement to assist in decision-making	**Sections 3.2.2**

3 Study Approach and Methodology

3.1 Study Approach

The overarching study approach and the key tasks required to undertake the CZMP are shown in **Figure 3-1**. Council is developing the CZMP for the North West Arm adopting a staged approach. As discussed in **Section 3.2.2**, Council has established a committee, and has also completed the Scoping Study and Literature review (BMT WBM, 2012).

Cardno has been commissioned to undertake the preparation of the CZMP incorporating an Implementation Plan to include the tasks identified in **Figure 3-1**. The orange dashed line shows the stages of the CZMP process that are being undertaken by Council in the current study.

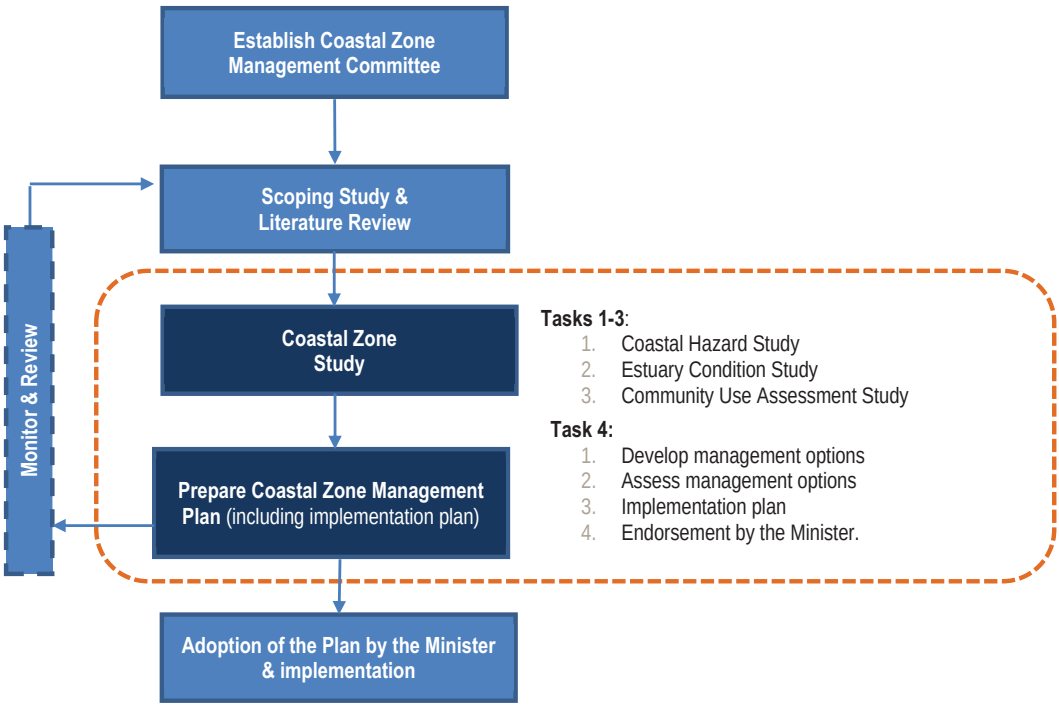


Figure 3-1: Overarching Study Approach

3.2 Methodology

A number of literature and data sources were used to inform this study, including spatial data, and relevant studies and reports associated provided by Council, OEH and other agencies. Information was also gathered via site investigations conducted on the 2 October 2014 and 11 November 2014, and community surveys conducted over October 2014 to January 2015.

3.2.1 Data Collation and Review

The first activity undertaken was data collation and review. The key document that informed this process was the Scoping Exercise, Literature and Information Review (BMT WBM, 2012), which provides a basis for the review process. That document:

> Reviews the recent previous studies and data available for the immediate and wider areas;
> Identifies local issues/threats and the priority of these; and

> Identifies data and knowledge gaps.

A number of other sources of literature and data were also used to inform this study. This included additional studies and data from Council and Cardno's extensive in-house library, and also a search of the following publicly available online databases:

> Aboriginal Heritage Information Management System (AHIMS);
> Native Title Tribunal;
> Australian Heritage Database;
> State Heritage Register;
> Maritime Heritage Database;
> Section 170 Registers maintained by OEH, Sydney Water and Roads and Maritime under the *Heritage Act 1977*;
> OEH BioNet Database / Atlas of Wildlife;
> Commonwealth *Environmental Protection and Biodiversity Conservation Act 1995* (EPBC Act) Protected Matters Search Tool;
> NSW Register of Critical Habitat;
> OEH Register of Contaminated Land and Registered Premises; and
> Online GIS databases.

Data sets were also provided by OEH, Roads and Maritime, and DPI (NSW Fisheries) in consultation with Council.

3.2.2 Stakeholder and Community Consultation

This study has included a range of consultation activities to obtain input and feedback from the community and key stakeholders.

The stakeholder consultation included the following activities:

> An issues workshop;
> A workshop on management options;
> Presentation of the investigation findings to the PHMP; and
> Presentation of the Draft CZMP to the PHMP.

Issues Workshop

The issues workshop was held on 22 September 2014 and was attended by:

> A number of Council staff, including:
  – Stormwater and Waterways Manager,
  – Manager, Parks and Reserves,
  – Manager, Natural Areas, and
  – Environmental Planning;
> OEH;
> Port Hacking Riverkeeper, Roads and Maritime;
> PHMP;
> NSW Fisheries; and
> UNSW.

The purpose of the workshop was to capture information on:

> Existing management issues;
> Current management initiatives, such as any activities currently undertaken by Council or any other agencies in relation to the North West Arm;
> Discuss potential management objectives; and
> To advise on upcoming activities.

Options Workshop

A workshop to brain-storm management options for consideration in the CZMP was held on 22 January 2015 and was attended by Council staff and OEH.

Community Consultation

The community consultation undertaken to date has included:

- Issue of a community newsletter about the CZMP;
- Establishment of a project website (accessed via http://www.sutherlandshire.nsw.gov.au/); and
- A community survey.

The community survey was issued to 1,800 residences located in the catchment on 5 December 2014.

The community survey was conducted via a series of on-site interviews with passers-by held during October and November 2014. In addition, the survey was made available online via Survey Monkey from October 2014 until 15 January 2015.

Copies of the newsletter and survey can be found in **Appendix A**.

Presentation to the Port Hacking Management Panel

The progress on the draft CZMP was presented to the PHMP on 25 February 2015. Members of the PHMP in attendance at the meeting included five Councillors, community and technical representatives, and Council officers. In addition, members of the Port Hacking Open Sailing Club were also in attendance.

At the presentation, the options assessment methodology was presented, and PHMP members were also invited to provide feedback on the level of support they had for each individual management options. This was then fed directly into the options assessment (see **Section 10**).

A second presentation to the PHMP was made on 4 June 2015. The purpose was to present the Draft CZMP prior to public exhibition. The presentation focussed on the actions contained in the Implementation Plan and dredging feasibility assessment findings, and provided the PHMP members an opportunity to ask questions.

Public Exhibition Period

In accordance with the requirements of the Guidelines for preparing Coastal Zone Management Plans (OEH, 2013a), the Draft CZMP was placed on public exhibition for a period of four weeks from 22 July until 19 August 2015.

The Draft CZMP document was made available for viewing via Council's 'Join the Conversation' webpage:

http://jointheconversation.sutherlandshire.nsw.gov.au/Join_the_Conversation

Submissions were invited via the following means:

- Online (by commenting directly on the webpage);
- By posting a written submission to Council; or
- By emailing submissions to ssc@ssc.nsw.gov.au.

One submission was received during the public exhibition period.

3.2.3 Bank and Riparian Condition Assessments

A bank condition assessment was completed as part of the field survey to identify areas suffering from foreshore erosion. Sections of the bank were assigned one of five categories depending on the bank type and condition:

- Modified – good structural condition;
- Modified – poor structural condition;
- Natural – stable;
- Natural – isolated erosion; and
- Natural – significant erosion.

Locations of stormwater outlets were also identified. The findings of the bank condition assessment is summarised in **Section 5.5.1**. It should be noted that the bank condition assessment is a general descriptive

assessment only and the results should not be used for purposes other than intended by this document. The assessment was undertaken from a boat by environmental scientists and not a qualified geotechnical engineer.

3.2.4 Visual Assessment of the Shoreline

A visual assessment of the North West Arm shoreline was conducted in 2001 as part of a larger visual assessment of Sutherland Shire's foreshore areas by PPK Environment and Infrastructure and Clouston (PPK and Clouston, 2001). In general, the North West Arm was considered to have a balance of built form and natural features.

The visual assessment of the estuary was undertaken in October 2014 and November 2014 by boat and canoe. A simple allocation of land-use categories was used to assess the current visual amenity of the foreshore as seen from the water. Sections of the foreshore were allocated to three categories: urban, semi-urban and natural; consistent with the categories in PPK Clouston (2001).

3.2.5 Coastal Hazard Investigations

The coastal hazard investigation was composed of three components:

- The deployment of an ADCP current profiler and two to record water level gauges
- An assessment of erosion hazard and siltation; and
- The assessment of design wave criteria and the resulting foreshore wave run-up and overtopping.

3.2.5.1 ADCP Deployment

An Acoustic Doppler Current Profiler (ADCP) and two tide gauges were deployed in October 2014 to take a month worth of measurements in the NW Arm (**Figure 3-2**). This was to gather valuable information about water levels and tidal currents over two spring-neap tide cycles. This information was used to calibrate the Delft3D numerical model used for the inundation hazard assessment and to determine the sediment transport regime.

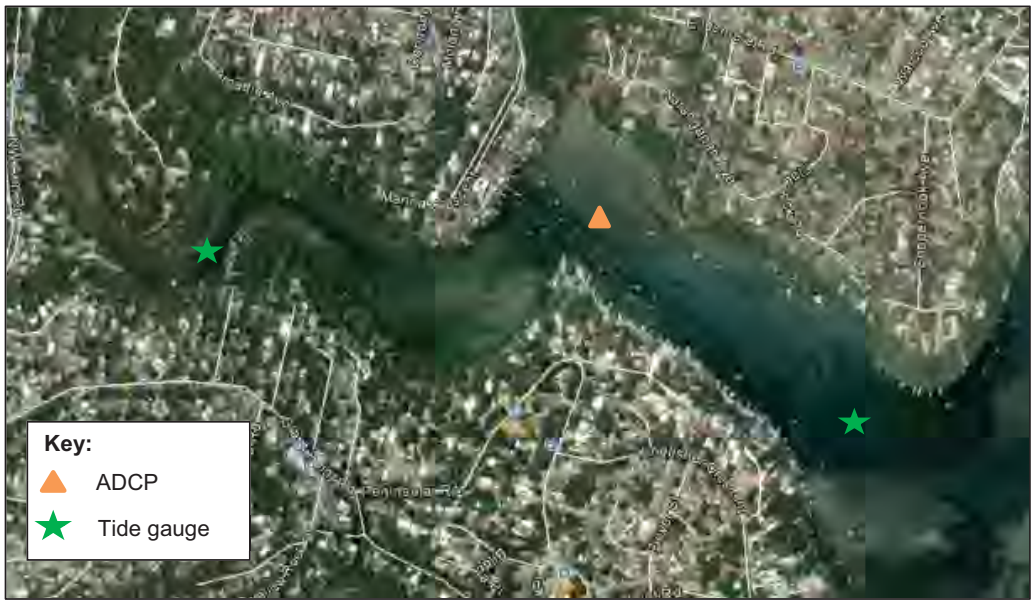


Figure 3-2: Instrument Deployment Locations

3.2.5.2 Erosion Hazard and Siltation

Estuarine foreshore erosion and channel siltation within the study area were assessed via numerical modelling using the Delft3D modelling system, described in **Appendix B**. Using this modelling system, the

erosion and siltation hazard was assessed in terms of the accumulated hours during a typical year that tidal current speeds exceed values required for sediment transport (see **Section 5.5.2**).

The assessment consisted of:

> Setting up a Delft3D hydrodynamic model of the Port Hacking estuary;
> Validating the model with the recorded tide gauge data (**Appendix B, Section B2.2**); and
> Conducting hydrodynamic simulations for a year (prototype time), and then calculating the total time during the year that tidal current speeds throughout the study area exceeded a given threshold value required for bedload transport.

Details of the model setup, validation and erosion hazard simulations are given in **Appendix B**.

3.2.5.3 Design Wave Climate, Wave Run-up and Wave Overtopping

North West Arm is situated some 6 km upstream form the Port Hacking estuary entrance. The distance from the entrance, along with the various meanders and shoals between the entrance and the North West Arm, means that there is little to no penetration of ocean swell to the study area. Consequently, the wave climate in the North West Arm is composed of short period local sea waves generated by local winds blowing across the estuary. Therefore, the assessment of design wave climate, wave run-up and overtopping consisted of:

> Setting up a SWAN wave model of the study area;
> Conducting wave hindcast modelling to determine design wave criteria and a number of locations along the study area foreshore;
> Calculating design wave run-up and overtopping values using standard engineering formulae outlined in the EurOtop Manual (2007).

3.2.6 Risk Assessments

One of the requirements for CZMPs under the guidelines (OEH, 2013a) is the adoption of a risk management approach in developing a CZMP. The process for assessing coastal hazards and allocating risk categories is prescribed in the *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013a); however, there are no specific requirements within the guidelines as to how risk to estuarine ecosystems or community uses not directly related to coastal hazards should be assessed. As such, a project specific risk assessment framework has been developed with consideration of the following relevant guidelines:

> AS/NZS ISO 31000:2009 Risk Management – Principles and Guidelines;
> HB 89-2012 Risk management – Guidelines on risk assessment techniques;
> AS 5334-2013 Climate change adaptation for settlements and infrastructure – A risk based approach;
> OEH (2011c) Guide to Climate Change Risk Assessment for NSW Local Government; and
> Beer and Ziolkowski (1995) Environmental Risk Assessment: An Australian Perspective.

The risk assessment framework adopted in this study was developed and populated by the Cardno study team of engineers and scientists. It is a qualitative risk assessment that considers:

> The principles for coastal management outlined in the guidelines (OEH, 2013a);
> Council's service standards and policies;
> Council's potential exposure to liability; and
> The community's expectations for management of the North West Arm.

4 Community Values and Uses of the Estuary

4.1 Community Survey Results

A community survey was undertaken from October 2014 to January 2015 adopting the methodology outlined in **Section 3.2.2**. The purpose of the survey was to gather information on:

- How the community use the estuary waterway and foreshore;
- The current condition and adequacy of public access and facilities;
- Management issues they have observed;
- Recreational activities they engage in; and
- Potential management options that they would like to see considered in the CZMP.

A total of 92 responses were collected.

It is noted that a number of respondents provided more general information about Port Hacking in addition to their comments on the North West Arm, including comments in relation to the Swallow Rock boat ramp. The discussion herein has been limited to feedback relating to the study area. Any comment on nearby locations such as Swallow Rock and Gymea Bay Baths have been provided to Council for their consideration.

4.1.1 Resident Status

The vast majority of survey responses were from residents of the North West Arm area, with a roughly equal divide between those with foreshore frontage, and those without foreshore frontage (**Figure 4-1**). Three responses were obtained from non-residents or visitors to the area, and two respondents skipped this question.

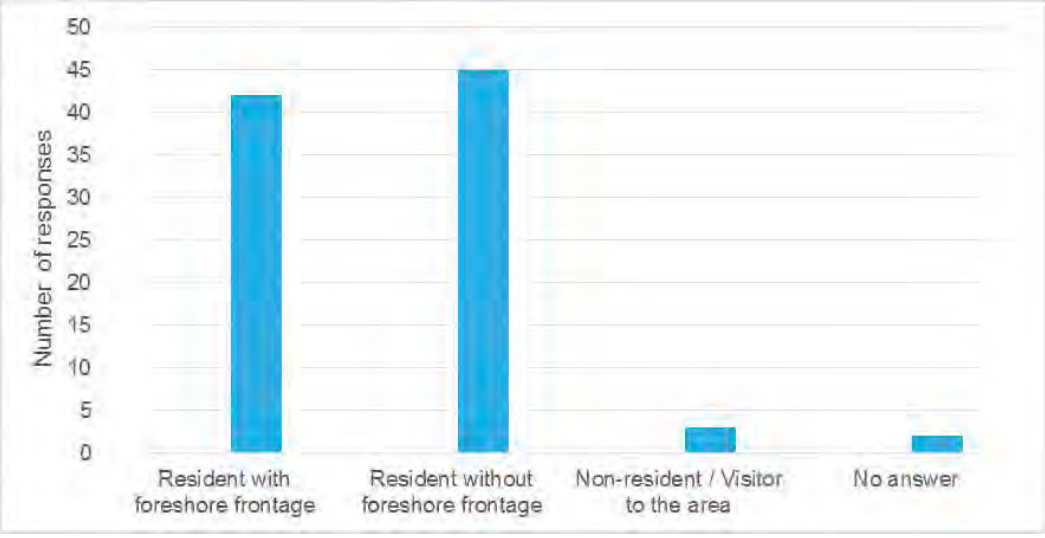


Figure 4-1: Resident Status

4.1.2 Recreational Amenity and Public Access

Question 2 asked residents whether they own a powered or non-powered watercraft. Seventy percent of respondents responded in the affirmative, with one quarter owning at least two watercraft. Of interest was the range of watercraft owned by respondents, including both powered and non-powered watercraft:

- 40% owned a canoe or kayak;
- 43% owned a dinghy;
- 34% owned a motor boat or yacht.

The majority of respondents use their vessels on a weekly to monthly basis. Generally, people used their boats more regularly in summer and during school holidays than at other times of the year.

Watercraft storage by respondents was:

- At home (e.g. in a garage or boatshed) – 45%;
- At a foreshore location or at a jetty – 11%;
- Moored on the North West Arm – 12%;
- Moored at another location – 6%.

Visitation to the estuary was primarily land-based with visits to the foreshore more frequent than trips on the waterway (**Figure 4-2**). Rates of visitation were generally high, with a relatively large number of residents visiting estuary daily, and the majority visiting at least every 1-2 weeks (**Figure 4-2**). A number of those respondents that visit daily lived in foreshore properties.

Residents with foreshore frontage visit the foreshore more regularly than those without foreshore frontage. This is not surprising given that almost the entire estuary foreshore is privately owned. It was also found that people are more likely to visit the estuary on the weekend than during the week, and most visits are during the morning, day or afternoon with only a very small number of people using the estuary at night (mainly for fishing).

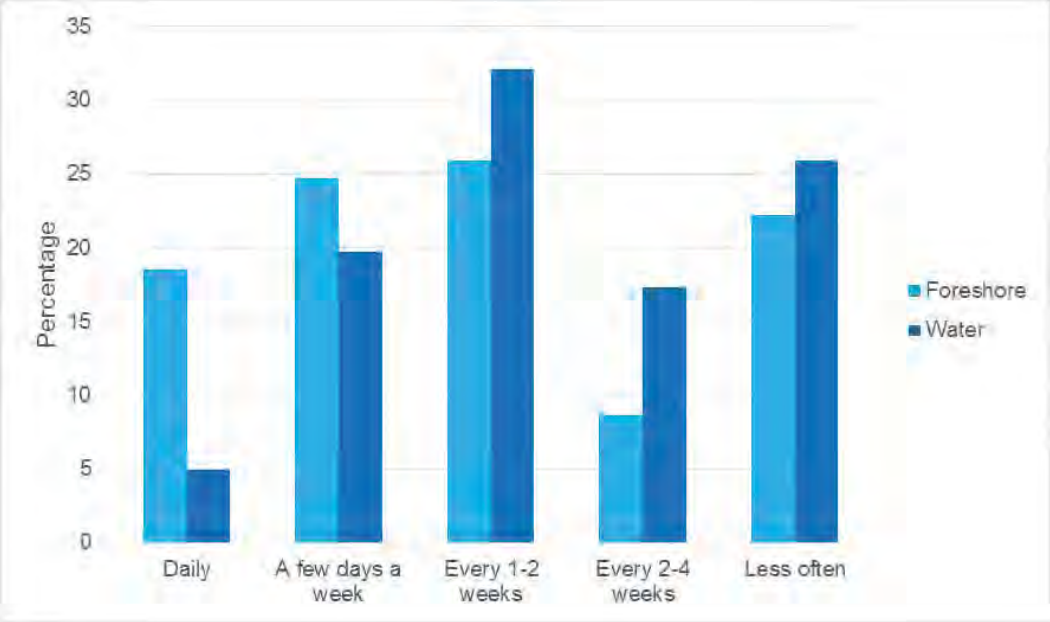


Figure 4-2: Rates of Visitation

The most common recreational pursuits that respondents participated in and around the North West Arm estuary included (see **Figure 4-3**):

- Boating (50%);
- Fishing (47%);
- Swimming (46%);
- Kayaking (43%);
- Walking (34%); and
- Picnicking (29%).

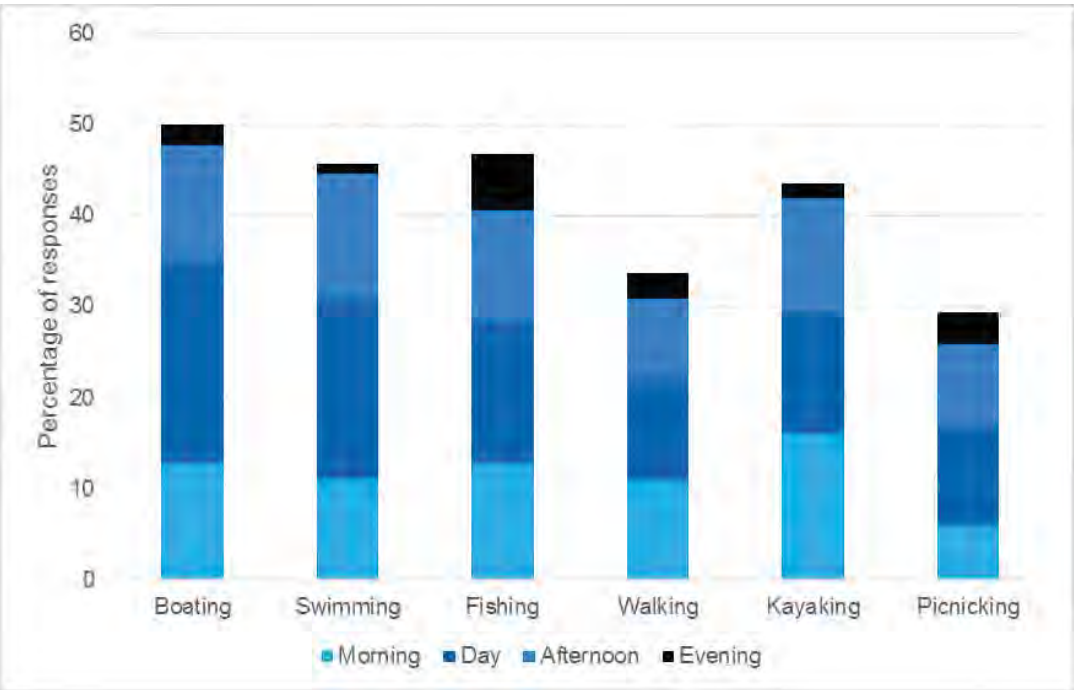


Figure 4-3: Preferred Recreational Activities

Other recreational pursuits mentioned in the survey included jogging, paddle boarding, relaxing, cycling, snorkelling and deer spotting.

Boating, fishing and kayaking are undertaken throughout the estuary and more broadly within the Port Hacking system. Swimming most commonly occurs from private properties along the foreshores. Walking is pursued in bushland areas, the National Park, Swallow Rock, Gymea and around the streets in general, highlighting the importance of providing linkages with surrounding areas. Although picnicking was identified as a popular activity, it was generally conducted either on privately owned foreshores or nearby at Swallow Rock.

The majority of respondents (57%) believe that the estuary and surrounds can get crowded at times, particularly on weekends at the boat ramps located near the study area. Large numbers of moored boats were also considered a concern for kayakers. Although most respondents believe it does get crowded, the majority (62%) suggested that they would not use the area more often if there were more facilities, and 32% of respondents said a dredging program of the North West Arm was needed.

Other suggested improvements included:

- Improved recreational spaces (e.g. BBQs, walking tracks, shade, landscaping) (15%);
- Stormwater management (e.g. GPTs (Gross Pollutant Device) and street sweeping) (9%);
- Boat ramp improvements (e.g. parking, for outside the study area) (9%);
- Public access (e.g. signage and general improvements) (8%);
- Feral deer controls (8%);
- Enforcement of boating speed limits (6%);
- Improved water quality (6%);
- Fewer moorings (4%) and more moorings (4%);
- Improved provision for small watercraft access (e.g. kayak launching points) (4%);
- Riparian vegetation and mangrove rehabilitation, and bush regeneration (4%);
- Acquisition of foreshore land for purposes of improved public access (2%);
- Off-leash dog park (2%);

- Compliance audits of foreshore structures (2%); and
- Artificial reefs to encourage fish habitat and reproduction (2%).

4.1.3 Public Access

Respondents were given a number of opportunities throughout the survey to describe any management issues that they had observed.

The availability of public access points to the North West Arm foreshore and waterway was raised as an issue by a number of respondents (44%) and there were a similar number of respondents that use public access compared to those that use private access. The majority of respondents accessing the estuary via public access points utilise Swallow Rock Boat Ramp (71%) which enters directly to Hacking River. Only 17% of respondents used the access at Marina Crescent Reserve, the North West Arm Road access way and/or the public reserve at Huskisson Street. Just fewer than half the responses believe that access to the estuary is inadequate.

Key concerns raised by the community in relation to public access to the estuary related to the lack of walking tracks and launch sites for kayaks. The only nearby boat ramp, Swallow Rock, is often crowded, with insufficient parking. Navigation in the upper reaches of the estuary was also identified as an issue, being limited to high tide due to delta sedimentation where Dents Creek meets the main waterbody. Suggestions for improvement were recommended and some of these included dredging the waterway, refurbishing current public access points and putting in signage, providing more parking for boat ramp users, and providing more recreational space in general.

One quarter of respondents believe that public access is negatively affecting the environment. Litter, bank erosion from boat wake, overfishing and over-development were listed as concerns.

When asked if there were adequate facilities provided for the public, 60% of respondents answered in the affirmative; noting that many respondents observed that there were no facilities at North West Arm. Additional facilities suggested by respondents included more access points, more parking at current access points and playgrounds. Over two thirds of respondents believe that there are no issues with the current facilities; while others expressed concern over overgrown public walking tracks and poorly maintained toilets.

4.1.4 Management Issues

Question 12 was designed to gather more information about specific pressures or issues relating to the estuary. **Figure 4-4** provides a summary of the number of responses received for each issue.

The community's perception of the most significant management issues in the North West Arm included:

- Sediment build up (20%);
- Stormwater pollution (19%);
- Pest animals (16%);
- Concerns related to navigation (10%);
- Weed infestations (8%);
- Foreshore erosion (7%);
- Loss of estuarine habitats (6%);
- Excessive foreshore development (5%);
- Sewer overflows (4%); and
- Other (5%).

Other issues included:

- The build up of debris in creeks and the estuary (3 responses);
- Water quality (2 responses);
- Overcrowding (2 responses);
- Concerns relating to the use of jet skis in the area (1 response);
- Reduction in the quality of sand (dirtier and muddy) (1 response);
- Too many moored boats creating conflicts with kayaks (1 response);
- Illegal land reclamation (1 response);

> Illegal camp fires (1 response); and
> Domestic animals (1 response).

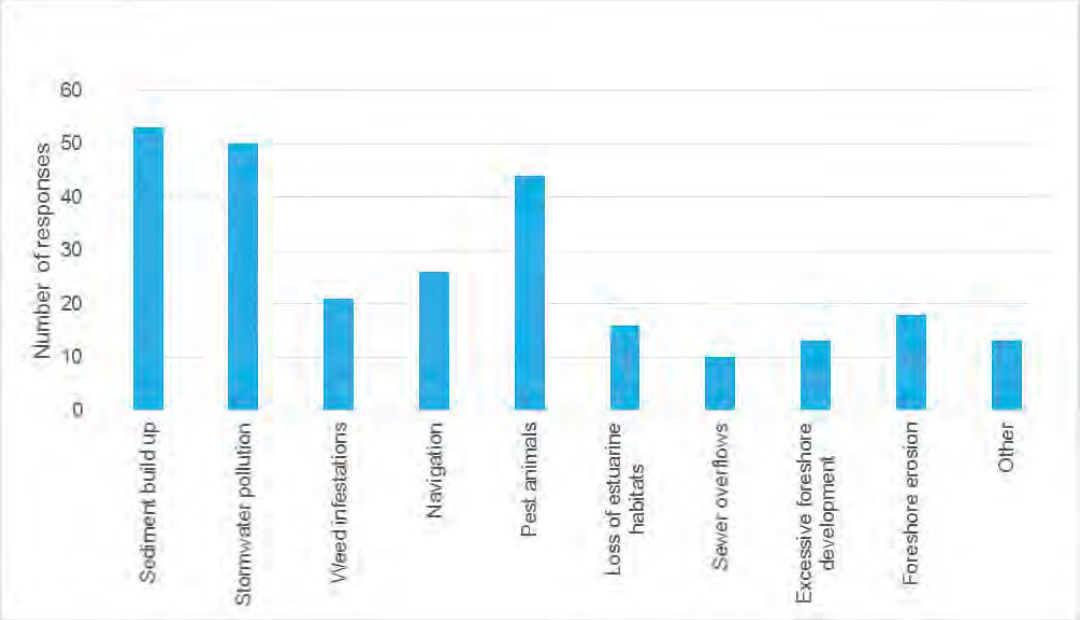


Figure 4-4: Management Issues

The upper reaches of the North West Arm were commonly mentioned as being areas of concern, with significant sedimentation and accretion of debris occurring after rainfall events. This was considered to have lead to negative impacts on navigability, reduced tidal flushing, and a reduction in flushing of stormwater out from stormwater pipes. The subdivision of land and historical development were cited as reasons for increases in sediment in the estuary. Sedimentation was also listed as a potential cause of the decline in seagrass in the estuary (refer **Section 7.2.1.3**).

Stormwater pollution following rainfall events was considered a major pressure on the estuary. In addition to the accretion of sediments and debris, some respondents noted that turbidity increases after rainfall and the water turns a deep brown. Regular street sweeping and trash racks in drains were listed as potential management options.

Deer were a major concern to residents due to their habit of trampling riparian vegetation, browsing in the mangroves and exacerbating bank erosion. Herds of deer have been seen in Dents Creek, Savilles Creek and the sandy flats of North West Arm. One respondent noted that Council's Greenweb program, which aims to protect foreshore vegetation and promote revegetation on both public and private land, is hampered by deer trampling and eating new plantings. Deer culling was suggested as a potential management option.

Weed infestations were mentioned as a general issue around the estuary. Comments made in the survey suggested that there have been fewer fish, yabbies and soldier crabs in the estuary in recent years, and concerns were raised about the clearing of large trees, a reduction in water quality and illegal reclamation of land.

4.1.5 Dredging

Dredging of the North West Arm has been raised as a management option by the community for a number of years. Although the majority of respondents suggested that dredging was necessary, many different views have been raised as to the extent of dredging required and the reason for the works. There are two main concerns that have been consistently raised with regards to dredging. The first is related to the reduction in the visual and recreational amenity of the estuary due to sedimentation, and the second is related to navigational limits of the estuary at low tide.

A number of residents said that there used to be a swimming hole in the North West Arm. The Department of Public Works Port Hacking Sediment Study (1980) notes that a deep (1.7 m) swimming hole existed in the North West Arm in the 1960's potentially as a result of scour by flood flows. By 1980, however, the hole was only 0.3 m deep due to infilling (NSW Public Works, 1980). Respondents to the survey suggested that catchment development between the 1970s and 1990s contributed significantly to the current sedimentation issues.

Although many of the comments called for dredging of the estuary in a general sense, a variety of different dredging options were suggested. These include:

> Dredging of the fluvial delta back to various historical levels (e.g. 1950s, 1980s, 1990s);
> Dredging to ensure stormwater pipes remain above base level of the waterway to ensure adequate flushing of stormwater by tidal action;
> Dredging the length of Dents Creek;
> Dredging for access and navigation purposes up to the stepping stones (North West Arm Road reserve); and
> Dredging to provide deep waterfront for properties along Peninsula Road and Arcadia Avenue.

As part of this study, Council have stipulated two dredging options to be assessed for feasibility and cost effectiveness. These are discussed further in **Appendix C**.

4.1.6 Discussion

The results of the community survey suggest that the North West Arm is greatly valued by the community for its recreational amenity and the peaceful, natural character of the waterway and its foreshores. There were suggestions that to provide more parks and facilities would only exacerbate the problem of overcrowding as there is not enough parking in the area to cater for current needs. Although residents place great value on the estuary, there was the general sentiment that the area is not being utilised to its full potential. Improvements to current access arrangements, sedimentation, water quality and native vegetation were highlighted as areas of concern.

4.2 Summary of Key Management Issues & Recommendations

A total of 28 management issues were compiled from the community survey (**Table 4-1**) and 20 management recommendations were identified by the community (**Table 4-2**). These issues and management recommendations range from general issues for the whole estuary, to specific issues and recommendations related to public access and facilities.

Table 4-1: Management Issues - Community Uses and Values

Issue Description	Priority
Illegal dumping of waste resulting in impacts on visual amenity, recreational usage of the estuary, human and environmental health.	Low
Exceedance of signposted speed limits by motor boats. This disturbs other waterway users and the resultant boat wake contributes to bank erosion.	Low
General litter throughout estuary.	Low
Overfishing and the taking of undersized fish.	Low
Increasing development intensity in the catchment, with potential for additional losses of catchment vegetation and increase in proportion of impervious surfaces.	Medium
Increased demand for waterfront structures (jetties and boatsheds).	Medium
Development controls for foreshore structures disregarded and/or not enforced.	Low
Increased development intensities around the estuary leading to decline in visual amenity.	Low
Loss of estuarine habitat (such as seagrass) as a result of human activities such as jetty construction, boating impacts, stormwater runoff etc.	Medium
Weed invasion.	High
Grazing and trampling of mangroves and riparian vegetation by deer.	Medium

Issue Description	Priority
Degradation of native vegetation due to informal access by residents walking through the bush.	Medium
Much of the estuary foreshore is in private ownership, which has compromised the natural character of the estuary and has contributed to the significant modification of the foreshores.	High
Much of the estuary foreshore is in private ownership, which limits the available access points for recreational users, such as for fishing or the launching of small and large watercraft.	High
Limited provision for public parking throughout the catchment.	Low
It is understood that there are some locations where private landowners are thought to be encroaching on public land, such as by placing materials (e.g. rocks) or watercraft on the public land.	Medium
Crowding during peak periods, such as on weekends, especially during summer.	High
Issues relating to moorings, including high demand, improper transfer of use of a mooring, and use of 'mooring minders'.	Medium
Public access to the foreshore is limited by lack of signposting, steep topography, poor condition access ways, and lack of formal access ways in some locations.	High
There is insufficient space and infrastructure to support passive recreational activities such as walking, and there are not enough playgrounds for children.	Medium
Navigation is limited at low tide.	Medium
Sedimentation is negatively impacting on visual amenity.	Low
Foreshore / bank erosion.	Medium
Sedimentation of creek lines or around stormwater outlets.	Medium
Periodic declines in water quality.	High
Poor water quality associated with stormwater runoff.	High
Poor water quality associated with sewer overflows.	High
Poor water quality due to discharges from boats (oils, sewage, etc).	Medium

Table 4-2: Management Recommendations - Community Uses and Values

Option ID	Management Recommendation
CC01	Provide ongoing support for Bushcare groups.
CC02	Compliance audit of foreshore structures (e.g. jetties, wharves and boat ramps) on private property.
CC03	Assess feasibility of establishing stairs or a ramp to the water for purposes of launching small watercraft (e.g. kayaks and canoes) at the bottom of the easement located opposite the bus stop on North West Arm Road down to Dents Creek.
CC04	Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.
CC06	Minimise illegal dumping by improving community awareness and via enforcement.
CC07	Improve the awareness of boating regulations and navigational requirements, including in relation to boat pump-outs.
CC08	Continue to enforce boating regulations.
CC09	Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.
CC10	Consider revising the Mooring Minders Policy in light of the recommended reforms in the Moorings Review Issues Paper (TfNSW, 2014).
CC11	Consider feasibility of banning 2-stroke engines (includes community consultation to seek feedback on proposal).

Option ID	Management Recommendation
CC12	Assess feasibility of banning jet skis or restricting their usage (includes community consultation to seek feedback on proposal).
CC13	Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.
CC14	Provide for ongoing enforcement of fishing regulations, including bag and size limits.
CC15	Dredging option 1 – Navigation channel for small non-powered watercraft to North West Arm Road access point at low tide.
CC16	Dredging option 2 – Removal of top 300 mm of sediments from delta.
CC17	Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.
CC18	Review current maintenance regimes for clearing blockages of debris from Savilles Creek, especially under the bridge at North West Arm Road.
CC19	Consider opportunities to acquire foreshore land to improve public access to the foreshore and waterway.
CC20	Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources. This may involve a review of street sweeping and the location of GPTs.

5 Coastal Processes

5.1 Overview of Coastal Processes

An estuary is a river or creek that connects to the ocean, and where tidal water level variations occur. The water movements (hydrodynamics) within an estuary are subject to a range of processes, including fluvial inflows from the catchment, atmospheric exchange at the water surface, and oceanic influence, all of which affect the exchange of water between the estuary and ocean. The physical processes that are important to the overall physiography and assessment of an estuarine ecosystem include:

- Catchment runoff variability, including recurrence intervals of freshwater flow events and long term drought/wet cycles;
- Atmospheric exchange of gases and water vapour resulting in evaporation and changes in salinity, nutrients and dissolved oxygen concentrations, and light and temperature, resulting in water density (salinity and temperature) changes and density driven currents;
- Ocean water level variability driven by tides, wind, barometric pressure and wider ocean effects such as El Niño-Southern Oscillation (ENSO) and other long term oscillations; and
- Surface waves driven by local winds and swell waves propagating across the ocean combining with local topographic effects to affect sediment transport and entrance conditions.

The relative influence of catchment versus oceanic processes depends on the characteristics of each individual estuary. In the case of the North West Arm, it is one of a number of embayments that form part of the larger Port Hacking estuary, which is permanently open to the ocean at Bundeena. Whilst the Port Hacking estuary is generally predominantly influenced by oceanic processes, on a smaller scale catchment processes can be more important, at least some of the time, as is the case for the North West Arm. Catchment processes will tend to dominate during and immediately after rainfall events due to stormwater and creek inflows. The distance from the ocean means that some ocean processes (e.g. swell waves) may be significantly attenuated once they reach the North West Arm.

The transport and re-distribution of sediments to and within the estuary, and fluvial sediment loads from the catchment, are affected by the hydrodynamics, which in turn determines the morphological evolution of the estuary over long periods of time (years to 1,000's of years). This evolution has been well documented by Albani and Cotis (2013), amongst others. A range of shorter term impacts, such as increased turbidity due to the re-suspension of bed sediments, influence water quality and ecosystem function.

Estuarine water quality is affected by a range of biogeochemical and mixing processes. Water quality variables, such as nutrient and algal concentrations, are influenced by both catchment and ocean inputs, turbidity and light availability for photosynthesis, internal biological nutrient uptake and recycling processes, as well as mixing and exchange (flushing) characteristics. Hence the estuarine hydrodynamics and transport processes form an important contribution to the overall estuarine behaviour and ecosystem characteristics.

5.2 Evolution of the Coastal Zone

NSW estuaries have evolved over tens of millions of years (Roy and Thom, 1981; cited by Roy, 1984) and have undergone many instances of excavation and infilling (Roy, 1984; Roy *et al.*, 2001). During glacial periods or times of low sea levels, sediments along the present day coastline were created by the action of rivers eroding valleys and delivering fluvial sediments to the coastal zone (Roy *et al.*, 2001). During interglacial periods such as the present day, coastal valleys are drowned by the sea and begin to infill with sediment eroded from the land, and also by material delivered back into the estuary by the sea (**Figure 5-1**). During the last 6,000-7,000 years of stable sea levels, NSW estuaries have been filling with sediment, however rates of infilling are variable depending on the stage of evolution of any given estuary (Roy, 1984).

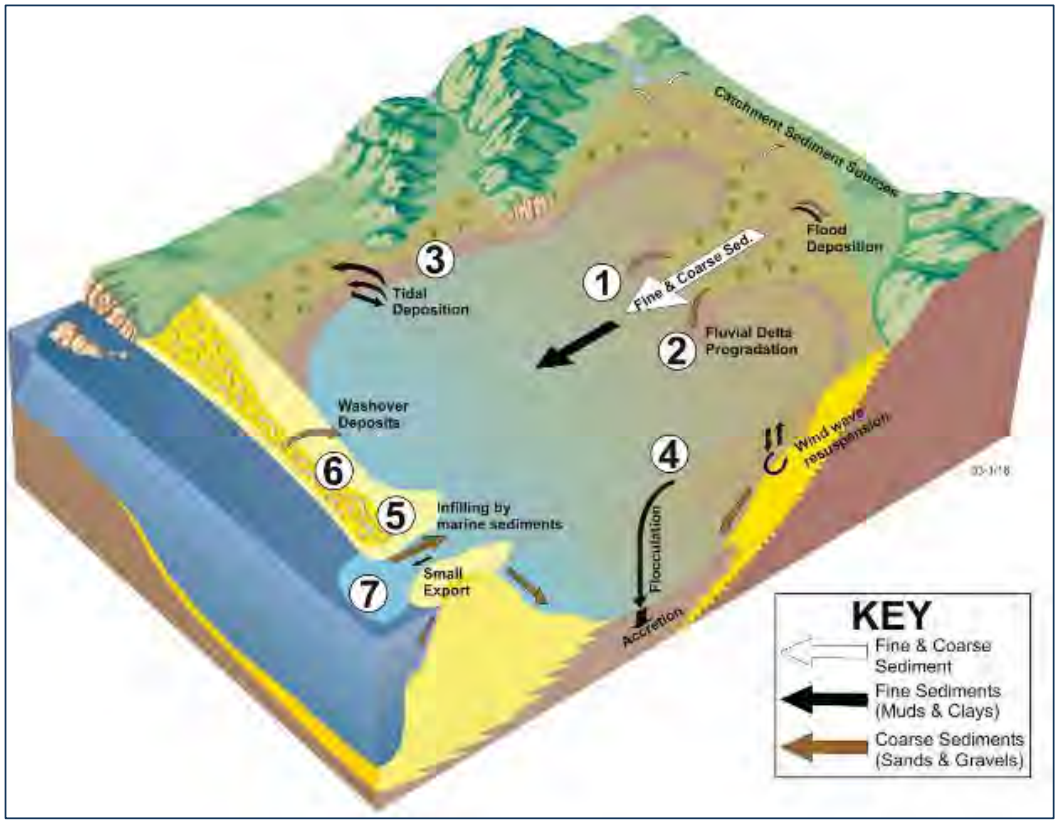


Figure 5-1: Conceptual Model of Sediment Dynamics (Source: Ryan *et al*., 2003)

Port Hacking is a drowned river valley that has been infilled by both marine and fluvial sediments in distinct sedimentary zones within the estuary (NSW Public Works, 1980). Flooding is the dominant force acting on sediment transport in the upper estuary, such as in the North West Arm, where sediments are predominantly fluvial in origin. Closer to the entrance, tidal flows and waves are the dominant processes governing sediment transport, transporting sand into the estuary mouth to form a tidal delta (NSW Public Works, 1980).

5.3 Bathymetry and Sediment Transport

5.3.1 Bathymetry

The Port Hacking estuary is a tidal estuary that is dominated by the flood tide. This is evident in the formation of large shoals within the estuary system near the entrance due to importation of sand from marine sources in the past. NSW Public Works (1980) notes this process is also likely due to the interaction of waves and tidal flows at the entrance that make conditions more ideal for importation of sand, rather than exportation. Albani and Cotis (2013) state that the supply of sand from offshore into the Port Hacking estuary is likely to be limited due to negligible net movements of material shoreward, however the waves and currents are sufficient to re-distribute the sand from the ebb tidal delta to within the estuary.

The inner estuary areas are also well infilled from sediment influx from the catchment (fluvial inputs), particularly the North West Arm where a large fluvial delta exists consisting of fine grained sediment (fine sands, silts and muds). These intertidal shoals have potential to support wading bird populations. The substrate is also ideal to support mangroves, and some of the inner fringes of the estuary are lined with mangroves.

5.3.2 Sediment Transport

A sediment study was undertaken by Albani (1999) furthered the understanding of the sediment dynamics within Port Hacking. The study found that there are four categories of sediment within the estuary:

1. Those derived from a marine source, generally located near the estuary entrance as part of the primary estuary delta - generally very well sorted medium to fine, with grain sizes around 0.25 mm;
2. Estuarine sediment in low energy areas - moderately to well sorted medium grain sand, with grain sizes around 0.2 mm;
3. Estuarine sediment in medium energy areas - moderately sorted medium grain sand, with grain sizes around 0.35 mm; and
4. Estuarine sediment in high energy areas - poorly sorted coarse grain sand, with grain sizes around 0.45 mm.

The bed sediments in Port Hacking are characteristic of this type of estuarine environment, with the coarser grains in the higher flow channels, and the finer grains in the low energy inner reaches of the estuary.

An earlier sediment study was undertaken for Port Hacking found that siltation in the North West Arm was primarily a natural phenomenon, with gradual infilling have occurred over the last 6,000 years since sea level stabilised (NSW Public Works, 1980).

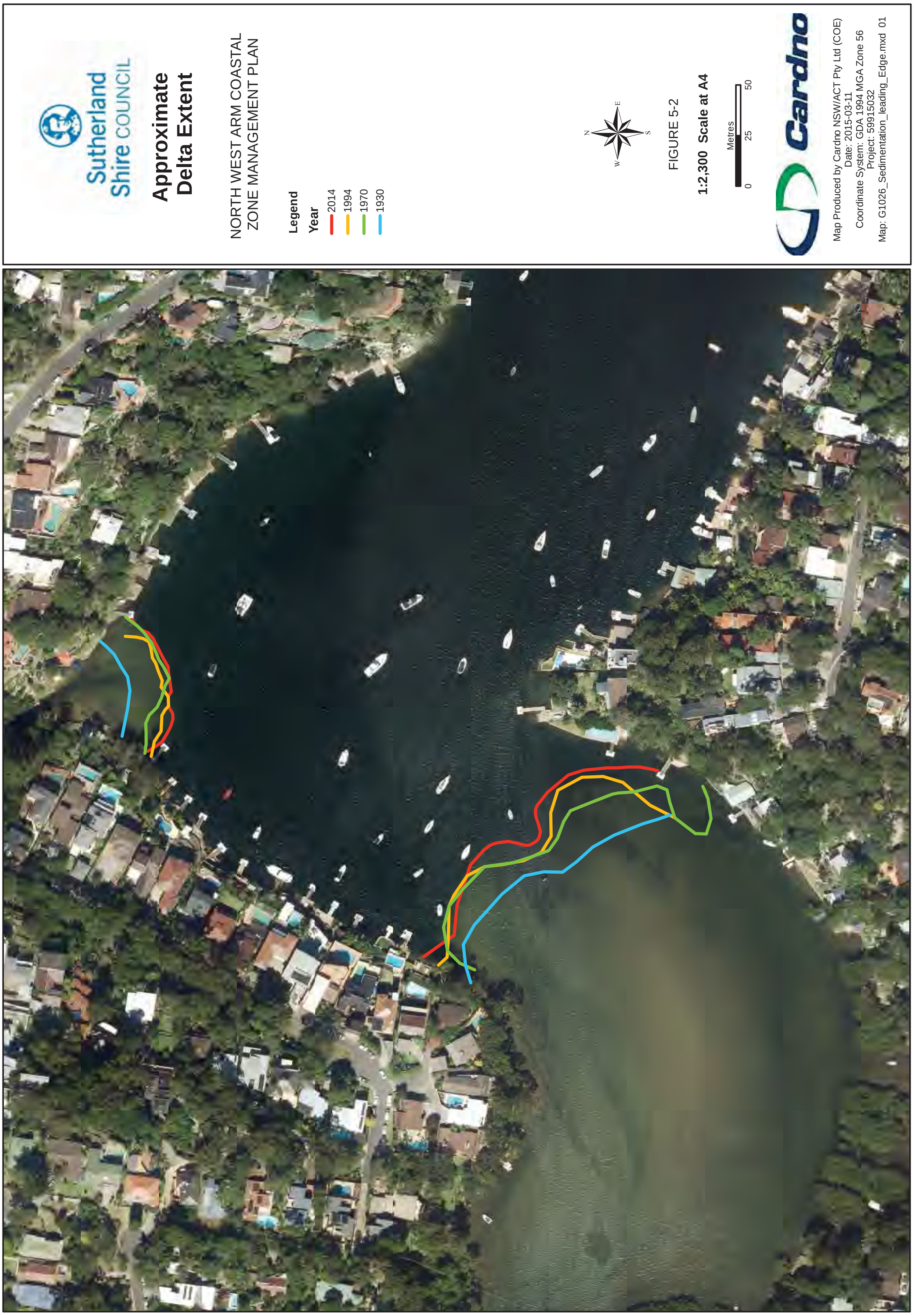
Dredging has historically been undertaken in the estuary, thought to be around 1968, although very little information is available about this activity. It is understood that the St George Sand Co. undertook extraction over a period of two to three years from the area around 50-150 m downstream of the Stepping Stones using a suction dredge with a 100 mm line (NSW Public Works, 1980). No evidence of this work remains, and it is understood that a comparison of the historical aerial photographs from 1970 to 1978 show that the dredge hole infilled over that period (pers. comm, SSC – Cardno, 22/01/2015).

As part of their analysis, NSW Public Works (1980) determined that there had been little morphological change due to catchment-derived sedimentation in the previous 50 years (apart from the local impacts near stormwater outlets). Based on consideration of historic sedimentation rates, and taking into account the dredging activities, it was estimated that around two to three thousand cubic metres of sediments are delivered to the estuary every year (NSW Public Works, 1980).

Albani and Cotis (2013) came to a similar conclusion regarding the rate of morphological change to the North West Arm, determining that there had been little change in the overall size and morphology of the delta over the last 100 years. Carbon dating of sediments cores collected by Albani and Cotis (2013) suggests that most the material within the delta area was deposited before the last 2,000 years.

Cardno have undertaken a brief analysis of the historical aerial photography for the North West Arm in order to illustrate rates of historical change in bed morphology, and the outcome is shown in **Figure 5-2**. This figure shows that the material associated with the delta and the stormwater outlet below Marina Crescent Reserve has changed little since the 1970's, noting that deposition appears to have occurred primarily between 1930 and 1970. This finding is consistent with the findings of NSW Public Works (1980). It is likely that rates of sedimentation were accelerated during development of the catchment, but have subsequently stabilised.

Whilst there may have been changes in the channel alignment and other features within the upstream section of the estuary, it is considered likely that these have arisen as a result of relatively infrequent flood events re-working material, rather than tidal currents or catchment-derived sedimentation. The historic dredging activities in the upper estuary would likely have upset the 'equilibrium' of the morphology, resulting in the infilling of the dredge hole and re-distribution of sand in this part of the estuary.


Sutherland Shire COUNCIL
Approximate Delta Extent
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Year
2014
1994
1970
1930
FIGURE 5-2
1:2,300 Scale at A4
Metres
0
25
50
Cardno
Map Produced by Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-11
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1026_Sedimentation_leading_Edge.mxd 01

It is understood that the Grays Point Progress Association had previously requested that Council dredge this section of the estuary for some time, and an investigation of the following dredging options was undertaken by NSW Public Works (1980),:

> Do nothing;
> Excavate the Stepping Stones swimming hole at the upstream extent of the tidal section of the estuary; or
> Dredge the full length of the channel that is currently exposed at low tide.

It was concluded that the two dredging options were not feasible due to the high cost of undertaking the works, limited benefits and potential environmental impacts (NSW Public Works, 1980). Do nothing was the preferred option. Specifically, NSW Public Works (1980) stated that as the estuary has been infilling with sand for thousands of years, "suggested dredging works would not be restoring a lost amenity but virtually creating a new waterway."

Once again, dredging proposals have been raised during the community consultation undertaken for this CZMP, which are largely consistent with those previously assessed by NSW Public Works (1980). Adopting a similar approach, these have been subjected to a cost-benefit assessment as part of this project, and include:

> Do nothing;
> Option 1 – Navigation channel for small non-powered watercraft to provide access up to the easement from North West Arm Road on the low tide (i.e. corresponding to the third option assessed by NSW Public Works, 1980); and
> Option 2 – Removal of top 300 mm from the delta.

A detailed consideration of the dredging options provided in **Appendix C**, which also includes a figure showing the location and extent of Options 1 and 2.

Based on the outcomes of the feasibility assessment presented in **Appendix C**, neither of the dredging options were recommended for implementation. The feasibility assessment conducted as part of this CZMP effectively arrived at the same conclusion as the NSW Public Works (1980) assessment. The do nothing option was the highest ranked option of the three considered. Options 1 and 2 both had negative cost-benefit ratios due to the high cost of the works (estimated at around $300,000 to $400,000 in capital costs, plus maintenance dredging costs), limited benefits and negative environmental impacts, including on protected marine vegetation.

5.4 Key Hydrodynamic Processes

5.4.1 Average Estuarine Water Levels

Tides in the study area are semi-diurnal; that is, there are normally two high and two low tides each day. On rare occasions there may be only one high or low tide because the lunar tidal constituents have a period of about 25 hours. There may also be a significant diurnal difference; that is, a significant difference between successive high tides and successive low tides.

There are a number of tide gauges around the Sydney area offering comprehensive tidal data records. The Fort Denison record extends back to the 19th Century. The most complete and accurate water level data sourced from this gauge covers the period from the 1960s to the present day. Port Kembla also provides a comprehensive tidal gauge record for wider-Sydney and NSW. This gauge has been in operation for 23 years, providing hourly data from 1991 to the present day. Port Hacking has a tide gauge; however, the record is sparse in terms of quality data, making it unreliable (Couriel *et al*., 2014). For these reasons, the more complete tidal data set from Fort Denison has been used for the design conditions presented in **Section B-3** of **Appendix B**, noting that they are sufficiently representative of those in the study area (see **Table 5-1**).

Table 5-1: Tidal Planes for Port Hacking (Source: AHS, 2014)

Tidal Plane	m LAT	m AHD
Highest Astronomical Tide (HAT)	2.0	1.1
Mean High Water Springs (MHWS)	1.5	0.6
Mean High Water Neaps (NHWN)	1.3	0.4
Mean Sea Level (MSL)	0.9	0.0
Mean Low Water Neaps(MLWN)	0.5	-0.4
Mean Low Water Springs (MLWS)	0.3	-0.6
Lowest Astronomical Tide (LAT)	0.0	-0.9

5.4.2 Elevated Estuarine Water Levels

Elevated estuarine water levels occur as the result of both catchment and ocean related forcings. Periods of high catchment flows (brought about by high intensity rainfall events) periodically affect water levels in the region upstream of North West Arm delta. Downstream of this region the effects of catchment floods are diminished by the large water retention capacity of Port Hacking and the large tidal exchange.

Elevated shoreline water levels can present a hazard to human users and built assets along the foreshore. The effects of elevated ocean levels may be exacerbated by climate change and result in an increased risk over time.

Design water level conditions have been determined for nearby areas previously using Fort Denison tide gauge data. Storm tide levels for selected Average Recurrence Intervals (ARIs) are provided in **Table 5-2** and are considered sufficiently representative of those in the study area. These levels exclude wave set-up. **Table 5-2** also includes design water levels for 2050 and 2100, based on adopted mean sea level rise projections of 0.4 m by 2050 and 0.9 m by 2100, relative to a 1980-1999 reference period (Watson and Lord, 2008).

Table 5-2: Design Water Level Conditions

ARI (years)	Water Level (mAHD)		
	Present Day	0.4 m Sea Level Rise	0.9 m Sea Level Rise
1	1.24	1.58	2.08
5	1.32	1.66	2.16
20	1.38	1.71	2.21
50	1.42	1.75	2.25
100	1.44	1.78	2.28

5.5 Coastal Hazard Study

5.5.1 Bank Condition Assessment

Approximately 4.6 km of foreshore was assessed via boat to evaluate the bank condition. Approximately 40% of the shoreline is modified and 60% is natural landform, as summarised in **Figure 5-3** and **Table 5-3**. The majority of the seawalls are in good condition, although there are some examples of poor condition seawalls (**Figure 5-4a and b**). The majority of the natural bank is stable, predominantly consisting of rock platforms. There are, however, some instances of erosion, particularly in the upper reaches of the estuary towards Dents Creek (**Figure 5-4c and d**).

Table 5-3: Bank Condition Assessment Results

Bank Condition	Length of shoreline (km)	% of total shoreline
Modified – good	1.3	29%
Modified – poor	0.5	11%
Total Modified	1.8	40%
Natural – significant erosion	0.2	4%

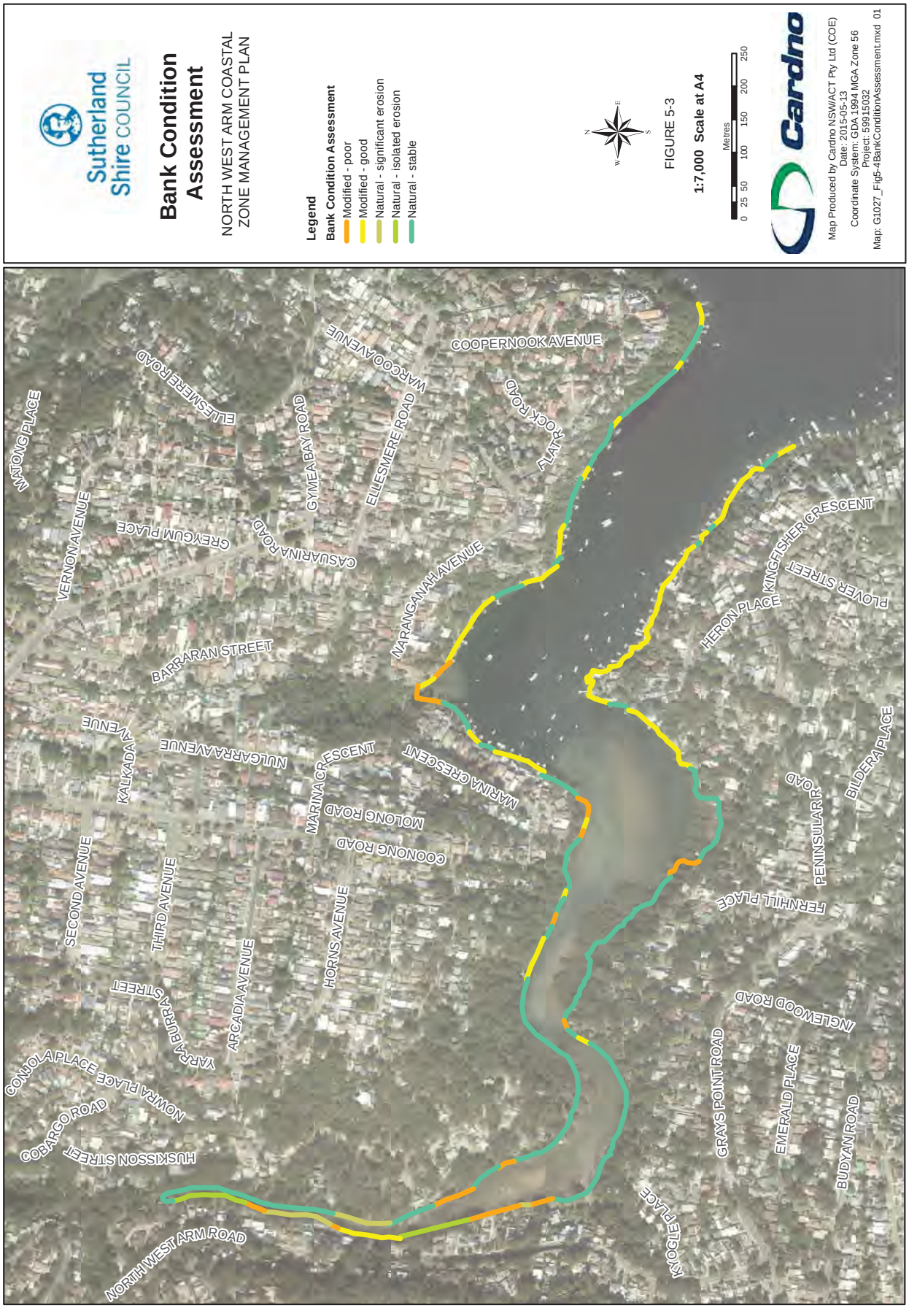
Bank Condition	Length of shoreline (km)	% of total shoreline
Natural – isolated erosion	0.2	5%
Natural – stable	2.3	51%
Total Natural	2.8	60%
TOTAL	4.6	100%

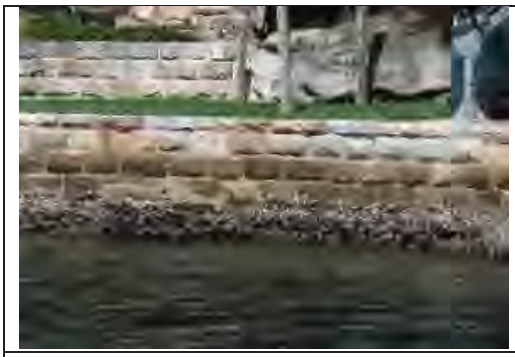
The banks of the lower reaches of the estuary are predominantly stabilised with seawalls with only small sections of natural bank (generally rock platforms) and a small beach at Marina Crescent Reserve. The seawalls are constructed from different materials (sandstone blocks, bricks, unconsolidated rocks, wood and concrete), are of varying heights, and are generally in good condition.

Seawalls become less prevalent in the middle and upper estuary. The majority of the natural shoreline in the upper estuary consists of rock platforms, some of which are heavily vegetated with trees and shrubs. Some sections of the shoreline show evidence of erosion. Deer were observed in this area during the field investigation.

Council is not responsible for asset management (seawall maintenance) or bank protection on privately owned land. Potential management options may include bank stabilisation works where erosion is a significant issue, or where publicly owned seawalls are in a poor condition. This has been considered in the *Sutherland Shire Watercourse Assessment* (Applied Ecology, 2012), which is discussed further in **Section 7.2.2.2**.

Options for deer control should be investigated and integration with ongoing existing regional pest control activities would be beneficial. For privately owned land, Council may wish to promote the education of landowners regarding permissible bank stabilisation works, weed control and foreshore plantings.


Sutherland Shire COUNCIL
Bank Condition Assessment
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Bank Condition Assessment
Modified - poor
Modified - good
Natural - significant erosion
Natural - isolated erosion
Natural - stable
FIGURE 5-3
1:7,000 Scale at A4
Metres
0 25 50 100 150 200 250
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-05-13
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1027_Fig5-4BankConditionAssessment.mxd 01
WATONG PLACE
VERNON AVENUE
GREYGUM PLACE
ELLESMERE ROAD
CASUARINA ROAD
CYMEA BAY ROAD
WARCOO AVENUE
ELLESMERE ROAD
COOPERNOOK AVENUE
ROCK ROAD
FLAT
NARANGANAH AVENUE
BARRARAN STREET
KINGFISHER CRESCENT
PLOVER STREET
HERON PLACE
KALKADA AVENUE
NULGARRA AVENUE
MARINA CRESCENT
MARINA CRESCENT
MOLONG ROAD
COONONG ROAD
SECOND AVENUE
THIRD AVENUE
HORNS AVENUE
ARCADIA AVENUE
PENINSULAR ROAD
BILDERA PLACE
FERNHILL PLACE
YARRAWARRA STREET
CONJOLA PLACE
NOWRA PLACE
COBARGO ROAD
HUSKISSON STREET
NORTH WEST ARM ROAD
KYOGLE PLACE
GRAYS POINT ROAD
INGLEWOOD ROAD
EMERALD PLACE
BUDYAN ROAD



e) Good condition seawall in the lower estuary

f) Poor condition seawall in the upper estuary

g) Stable natural bank – rock shelf vegetated with trees and shrubs

h) Natural bank in the upper estuary with significant erosion

Figure 5-4: Estuarine Bank Condition Examples

5.5.2 Sediment Transport Assessment

The potential for erosion and channel siltation within the estuary was assessed through the use of numerical modelling using the Delft3D modelling system, which is described in **Appendix B**, along with a description of the model set-up and the results of the assessment.

Using the Delft3D modelling system, the erosion and siltation hazard was assessed in terms of the accumulated hours during a typical year that tidal current speeds exceed the threshold values required for bedload sediment transport (0.3 m/s). Simulations were also conducted for climate change conditions adopting 0.4 m and 0.9 m mean sea level scenarios.

The results (see **Figure 5-5**) show that for present day mean sea level, tidal currents are rarely sufficient to initiate bedload transport. Tidal currents currently exceed the threshold around 100 hours per year (about 1.1% of the time) in the region of the second-to-last downstream bend in the creek before the main water body of the North West Arm. The total hours exceeding the threshold for sediment transport are significantly lower everywhere else in the estuary, with little to no bedload transport downstream of the fluvial delta region.

This shows that tidal currents have little impact upon the morphodynamics of the study area. Further, as mean sea level increases under climate change conditions, the influence of tidal currents on bed load transport decreases, predominantly due to increased water depths (see **Figures B-4 and B-5** in **Appendix B**).

Figure 5-5: Hours per Year Above Sediment Transport Threshold (Current MSL)

5.5.3 Design Wave Conditions

North West Arm is situated some 6 km upstream form the Port Hacking estuary entrance. Due to the Port Hacking estuary's various meanders and shoals, this means that there is little to no penetration of ocean swell to the study area. Consequently, the wave climate in the study area is composed of short period local sea waves generated by local winds blowing across the estuary.

In order to assess the local sea wave climate in the study area, numerical wave modelling was conducted using the SWAN wave model, which is incorporated as a module in the Delft3D modelling system. **Appendix B** provides a description of the model set-up and the results of the wave run-up and overtopping simulations.

The results of the modelling presented in **Appendix B** show that the 100-years ARI wave heights in the study area are low, with a fairly flat extremal distribution (that is, the 200-years ARI significant wave heights are not considerably higher than the 20-years ARI wave heights). These results can be attributed to the fetch limited nature of the study area, particularly the upstream regions. The 100-years ARI significant wave heights at each foreshore location are presented in **Figures 5-6** and **5-7** for the present day and 0.9 m mean sea level rise scenarios respectively.

The corresponding figures for the 20-years, 50-years and 200-years ARI events for present day, 0.4 m sea level rise and 0.9 m sea level rise scenarios are provided in **Appendix B**.

Figure 5-6: 100-years ARI Significant Wave Height (m) (Current MSL)

Figure 5-7: 100-years ARI Significant Wave Height (m) (0.9 m Sea Level Rise)

Within the study area, those sections of the northern shoreline located adjacent to the deep water section of the estuary (between Naranganah Ave and Coopernook Avenue) generally experience the highest waves due to their exposure to strong southerly and south-easterly winds and slightly longer, deeper fetches. The upper estuary (along North West Arm Road, Grays Point Road and Husskisson Road) and the southern

shoreline (between Goldfinch Place and Kingfisher Crescent) exhibit much smaller design waves due to the limited fetch in almost all exposed directions, and protection from strong southerly winds.

Peak wave periods across the study area are short due to the limited fetch lengths, and are in the vicinity of 2 seconds.

For most of the study area, the higher mean sea level scenario (i.e. 0.9 m sea level rise) shows only a minimal increase in design wave heights. The exception is the inner estuary around the fluvial delta, where the increase in mean sea level under climate change conditions results in greater relative increases in nearshore depth, and consequently wave heights.

5.5.4 Wave Run-up and Overtopping

While coastal inundation is predominantly an open coast hazard, the North West Arm estuary is affected by short period by local sea waves, which may lead to wave run-up and overtopping of foreshore areas.

The $R_{U2\%}$ wave run-up level (the wave run-up level above which only 2% of waves will exceed during a design storm) has been assessed, conservatively assuming a 100-years ARI still water level and 100-years ARI local sea state. Detailed results for present day, 0.4 m sea level rise and 0.9 m sea level rise scenarios are presented in **Appendix B**.

The potential average wave overtopping rates also consider the range of typical foreshore types and crest levels that may occur around the estuary, estimated based on site observations. The overtopping rates have been presented as litres of water per second per metre width of the structure.

The results of the overtopping assessment show that the $R_{U2\%}$ wave run-up levels are generally quite low, owing the small design wave heights and short wave periods (and resulting wave lengths).

For the present day mean sea level, wave overtopping discharges are generally low, particularly for structures with crest levels at 3 mAHD or higher where the overtopping discharge has been estimated as 0.2 L/s/m or less. The highest overtopping values occur on the northern shore in the deep water section of the estuary (between Naranganah Ave and Coopernook Avenue). The calculated wave overtopping levels in this area may present some hazard to pedestrians in the immediate vicinity of the seawall being overtopped, but would be unlikely to damage the structure itself.

Wave overtopping values are low in the area of the fluvial delta region and were less than 1 L/s/m crest levels of 2 mAHD and higher and virtually zero for crest levels of 2.5 mAHD or higher. Wave overtopping in this region is unlikely to cause any significant structural damages of seawalls.

For the 0.4 m and 0.9 m sea level rise scenarios, only minimal overtopping is expected for structures with crest levels above 3.5 mAHD and 4.0 mAHD respectively. For the sea level rise scenarios, some damage to foreshore structures with crest levels at 2.0 mAHD and 2.5 mAHD (respectively) or lower may be expected.

5.6 Climate Change Impacts on Coastal Processes

There is a range of literature available on historical climate change and predictions of impacts for a range of future climate scenarios. Documents subject to review for the purposes of this project include:

- *Climate Change 2013 The Physical Science Basis* (IPCC, 2013), the Fifth Assessment Report (AR5) published by the International Panel on Climate Change (IPCC);
- *East Coast Cluster Report* (Dowdy *et al.* 2015), published by CSIRO and BoM;
- *State of the Climate 2014* (CSIRO and BoM, 2014);
- *Observed Changes in NSW Climate 2010* (OEH, 2011b);
- *Metropolitan Sydney Climate Change Snapshot* (OEH, 2014a); and
- A range of peer reviewed scientific literature that considers various aspects of climate change science.

5.6.1 Historical Climate Change

Sea Level Rise

A number of analyses have been undertaken to quantify historical rates of sea level rise both internationally and in Australia. The IPCC are the peak body for assessing historical climate change and predicting future

climate change. The recently published data in AR5 indicate an average rate of global sea level rise of 1.7 mm/yr over 1901-2010, corresponding to 0.19 m of sea level rise (IPCC, 2013). It is noted, however, that the rate of sea level rise can vary over time, and for the period 1993-2010 the rate of rise was 3.2 mm/yr (IPCC, 2013), indicating an acceleration of the rate of rise over the two previous decades.

A number of analyses of local sea level data have also been undertaken (e.g. You *et al*., 2009; Watson, 2011; Wainwright and Lord, 2014; White *et al.,* 2014). **Figure 5-8** shows that mean sea levels in Australia have been rising since the 1800s. The average Australian sea level rise trend over 1966 to 2009 was 2.1 mm/yr, increasing to 2.8 mm/yr over 1993 to 2010 (White *et al.,* 2014), noting that the water level records for Fort Denison a higher rate of rise of 3.3 mm/yr sea level rise over 1996-2013.

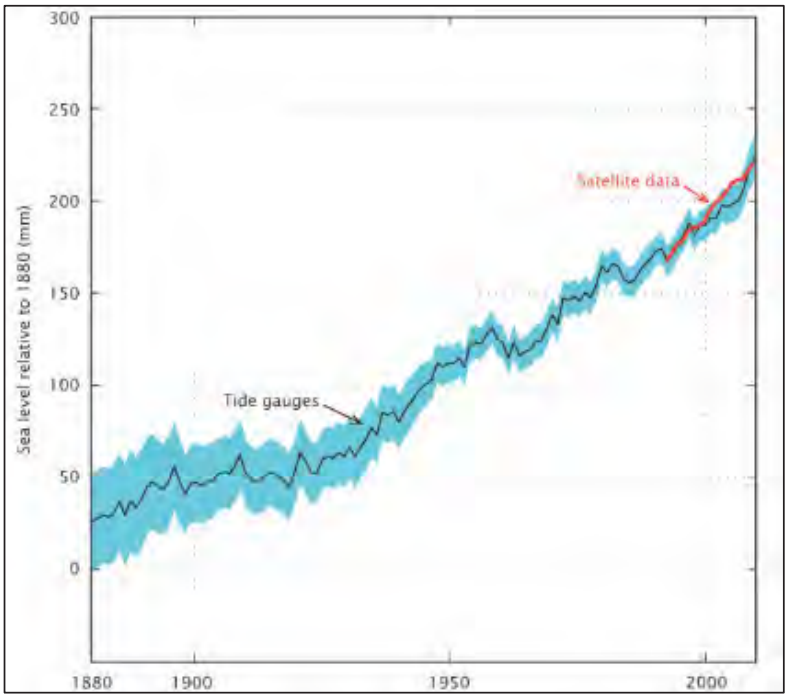


Figure 5-8: Historical Variation in Mean Sea Levels in Australia (Source: CSIRO, 2011)

5.6.2 Future Climate Change Predictions

The IPCC has produced temperature and sea level rise projections based on a range of different greenhouse gas (GHG) emissions scenarios developed to capture uncertainty of the scale of future economic activity and the global response times to reducing emissions. The four scenarios modelled in **Figure 5-9** are:

- RCP2.6 – Major GHG mitigation scenario (CO_2 concentration of 421 ppm by 2100);
- RCP4.5 – Some GHG mitigation, stabilisation scenario (CO_2 concentration of 538 ppm by 2100);
- RCP6.0 – Some GHG mitigation, stabilisation scenario (CO_2 concentration of 670 ppm by 2100); and
- RCP8.5 – Very high GHG emissions scenario, little effort to reduce emissions (CO_2 concentration of 936 ppm by 2100).

RCP8.5 is otherwise referred to as the “business as usual scenario”, whereas both the RCP4.5 and RCP6.0 scenarios both assume significant reductions in GHG emissions. RCP2.6 is quite an ambitious scenario, and while it is considered “plausible”, it is not considered realistic for strategic planning purposes.

Continued emissions of GHGs will cause further warming and changes in all components of the climate system including sea levels, rainfall, wind, waves, and extreme events. At the present time atmospheric concentrations of GHGs are approaching 400 ppm (see **Figure 5-10**). Wainwright and Lord (2014) report

that atmospheric CO_2 concentrations increased 2.18 ppm/yr over the period 2008-2013. If the rate of increase in concentrations remains constant, CO_2 concentrations would reach around 411.7 ppm by 2020 (higher than the two lowest RCPs); however, if the rate of increase is consistent with past changes in CO_2 concentrations, it would reach around 412.4 ppm, which is higher than the three lowest RCPs (Wainwright and Lord, 2014).

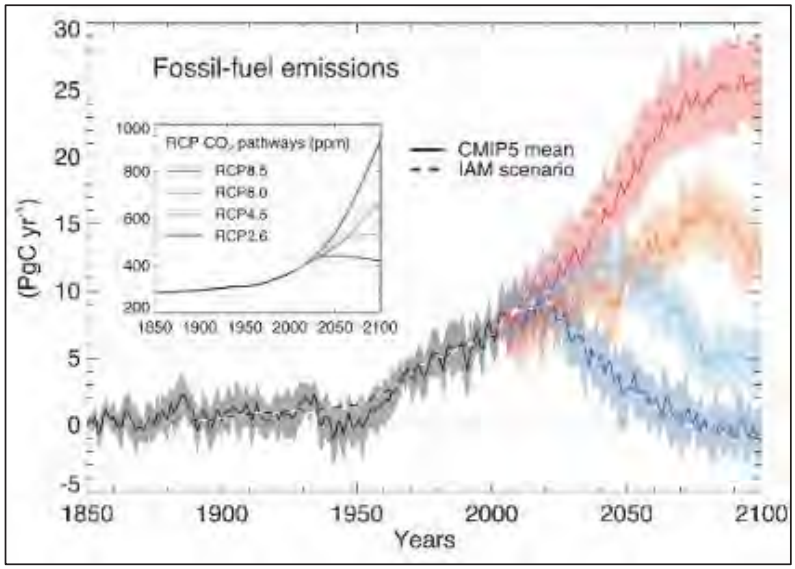


Figure 5-9: Climate Change Predictions (Source: IPCC, 2013)

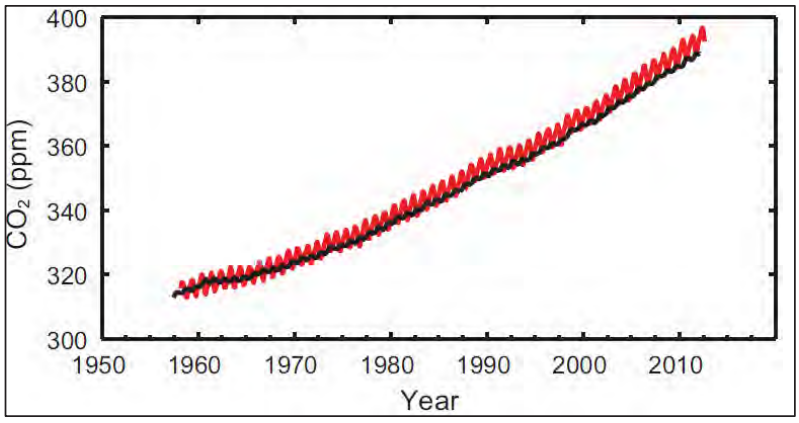


Figure 5-10: Observed Atmospheric Concentrations of CO_2 from Mauna Loa (red) and the South Pole (black) (Source: IPCC, 2013)

5.6.2.1 Sea Level Rise

Global sea level rise predictions suggest that is it likely sea level rise will continue accelerating into the future (**Figure 5-11**). Changes in sea level can result from a number of processes. Although thermal expansion of the ocean is the greatest contributor to sea level rise, processes within the ocean, atmosphere, land ice, and hydrological cycle that are climate sensitive and are expected to contribute to sea level change at regional to global scales in the coming decades to centuries (IPCC, 2013).

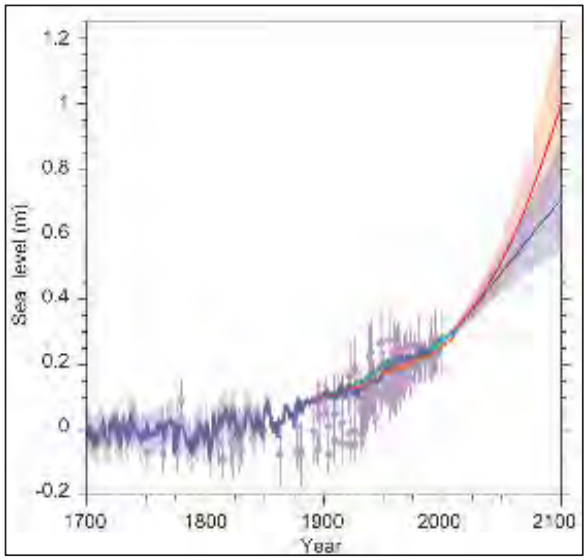


Figure 5-11: Sea Level Rise Predictions (Source: IPCC, 2013)

As discussed in **Section 2.1**, as of September 2012 the NSW Government no longer recommends the state-wide sea level rise benchmarks presented in DECCW (2009), with the intention of providing local Councils with the flexibility to consider local conditions when determining local sea level rise projections. Accordingly, Councils are required to consideration information on historical and projected sea level rise that is "widely accepted by competent scientific opinion" (CSE, 2012). The report identified that:

- The science behind the sea rise benchmarks (DECCW, 2009) was adequate;
- Sea levels have been rising since the early 1880's;
- There is considerable variability in the projections for future sea level rise; and
- The science behind future sea level rise projections is continually evolving and improving.

Short term sea level variation is strongly associated with coastal processes such as wind, waves, tides and storm surges. Coastal responses to sea level rise will be influenced by local geomorphology and are more variable in comparison to variations in global sea levels (Church *et al.,* 2006).

The IPCC (2013) sea level rise projections have been locally adjusted for the Sydney/South Coast by Wainwright and Lord (2014), and are shown in **Table 5-4**. Key points to note include:

- There is little variation in the projections for each RCP up until 2050; and
- From 2050 onwards there is a greater spread in the projections. Hence the projection adopted for a project or planning process is more important for planning processes relevant to later planning horizons.

The potential impacts of sea level rise on estuarine ecology are discussed in **Section 7.4**.

Table 5-4: Locally Adjusted Sea Level Rise Projections (Source: Wainwright and Lord, 2014)

Year	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
2030	0.05	0.07	0.10	0.05	0.07	0.10	0.05	0.06	0.10	0.06	0.07	0.10
2050	0.13	0.17	0.23	0.14	0.18	0.24	0.13	0.17	0.23	0.16	0.20	0.26
2070	0.18	0.27	0.37	0.22	0.31	0.41	0.21	0.29	0.39	0.29	0.39	0.50
2100	0.25	0.41	0.58	0.34	0.50	0.69	0.36	0.53	0.72	0.53	0.74	0.98

Sutherland Shire Council commissioned a Sea Level Rise Risk Assessment (GHD, 2011) to determine the potential impacts of a changing climate on coastal and catchment flooding. The study aimed to understand the possible extent to which sea level rise and changes in storm event patterns may impact Sutherland Shire. The study provided a preliminary regional summary of climate change impacts for the area. GHD (2011) reported that there was likely to be an increase in the depth of flood inundation due to sea level rise and storm surge. In addition, it is likely that the aerial extent of flood inundation will increase due to increases in storm (rainfall) intensities and the coincidence of catchment and coastal flooding, which would increase risk to property and infrastructure over time as sea levels rise.

5.6.2.2 Wind, Waves and Rainfall

Climate change projections have identified a positive trend in the frequency and intensity of large wave events along Australia's southern coastline (Hadwen *et al.*, 2011). While wave heights in the North West Arm are low in the present day with little variance from normal to extreme conditions, under sea level rise conditions a small increase in the frequency and intensity of large wave events may result in an increase in wave overtopping in the North West Arm (refer **Section 5.5.4**).

Changes to seasonal surface winds are predicted to be small overall, with a reduction in winter winds speeds and a general decrease in in extreme wind speeds (Dowdy *et al.*, 2015).

Rainfall projections are strongly dependent on the emissions scenario modelled. It is expected that there will be a decrease in winter rainfall with fewer winter storms, and an increase in summer rainfall intensity (Dowdy *et al.*, 2015). Extreme rainfall events can lead to blockages and overflows of the stormwater system resulting in catchment flooding. This may alter the hydrology of the estuary and result in more regular sediment transport in the shallower, upper estuary.

5.7 Summary of Key Management Issues

Table 5-5 summarises the key management issues identified for coastal processes in the North West Arm.

Table 5-5: Management Issues – Coastal Processes

Issue Description	Priority
Climate change impacts on built infrastructure, cultural heritage, and estuarine ecology.	Medium
Exceedance of signposted speed limits by motor boats. This disturbs other waterway users and the resultant boat wake contributes to bank erosion.	Low
Catchment flooding.	Medium
Navigation is limited at low tide.	Medium
Foreshore / bank erosion.	Medium
Sedimentation of creek lines or around stormwater outlets.	Medium

5.8 Recommendations for Management

Table 5-6 provides a summary of recommendations for future management of coastal processes in North West Arm.

Table 5-6: Management Recommendations - Coastal Processes

Option ID	Management Recommendation
CP01	Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.
CP02	Gain a greater appreciation of the potential impacts of climate change on the estuarine ecosystems of North West Arm. Consider the need to develop a strategic plan to manage climate change impacts on biodiversity in the LGA.
CC15	Dredging option 1 – Navigation channel for small non-powered watercraft to North West Arm Road access point at low tide.
CC16	Dredging option 2 – Removal of top 300 mm of sediments from delta.

6 Catchment Condition and Water Quality

6.1 Overview of Catchment Processes

Catchment processes can affect the estuary in several ways. For example, freshwater inflows from tributary creeks can lead to temporary changes in estuarine salinity, impact on water quality due to the introduction of nutrients and other pollutants, and in the case of flood events, result in increased estuarine water levels, erosional sedimentation, and potentially inundation of foreshore land. Catchment processes such as these can also impact on estuarine ecosystems and community uses.

The extent of the North West Arm catchment (and sub-catchments) is shown in **Figure 6-1**. The North West Arm catchment includes parts of the residential suburbs of Gymea, Gymea Bay and Grays Point, as well as a small section of the Royal National Park. The main tributaries are Dents Creek and Savilles Creek, which are 2.6 km and 3.4 km long respectively (Applied Ecology, 2012).

The total catchment size is 1,035 ha and there are four sub-catchments:

- Port Hacking (catchment no. 14), encompassing the northern shoreline and parts of Gymea Bay, which is 77.5 ha in area;
- Port Hacking (catchment no. 25), encompassing the southern shoreline and part of Grays Point, which is 107.24 ha;
- Dents Creek sub-catchment, which is 231.3 ha; and
- Savilles Creek sub-catchment, which is the largest at 619 ha.

In 2010 the NSW Government published the State of the Catchments report, prepared under the NSW Monitoring, Evaluation and Reporting (MER) framework. It provides information to the community and natural resource managers on the condition and trends across a range of areas. Port Hacking falls within the Sydney Metropolitan Region, for which the condition of estuaries is described as “fair” and under “moderate” pressure (SOC, 2010). The main pressures identified for the Sydney Metropolitan Region include:

- Development in coastal urban and peri-urban areas;
- Mining impacts;
- Ongoing land-use and land management;
- Deforestation/removal of riparian vegetation;
- Invasive species;
- Water extraction;
- Climate change; and
- Social and economic pressures.

6.2 Land Use

6.2.1 Historic Land Use

An analysis of aerial photography conducted by Albani *et al.* (2013) found that at the time of the earliest available aerial photograph from 1930, there had been some initial urbanisation of the catchment, but that it was not until the 1960’s and 1970’s that the majority of the urban development occurred. This development was largely complete by the early 1980’s (Albani *et al*., 2013).

Dents Creek was originally named for Fred Dent, who came to the area under the employ of Thomas Holt in 1861 to explore for coal, although he was unsuccessful (Applied Ecology, 2012). As reported in the community survey (see **Section 3.2.2**), a market garden was present next to Dents Creek on the Derrey’s property until the 1980’s (Barton and Turner, 2011; cited by Applied Ecology, 2012). Cattle grazing occurred in the catchment in the 1920’s, including along Dents Creek (Lawrence, 1997; cited by Applied Ecology, 2012).

In the 1920's there were a few small fibro holiday houses located in the catchment, although it is understood that these were permanent residences during the depression, with many families operating small land holdings to grow fruit and vegetables, fish and raise livestock (Applied Ecology, 2012).

At the confluence of Saville and Dents Creeks there was a deep pool, which along with a series of other swimming holes along the creek, was popular for swimming from 1922 following the opening of Savilles Creek Bridge (Barton and Turner, 2011; cited by Applied Ecology, 2012), at which time a Baptist holiday camp was established to the west of Savilles Creek.

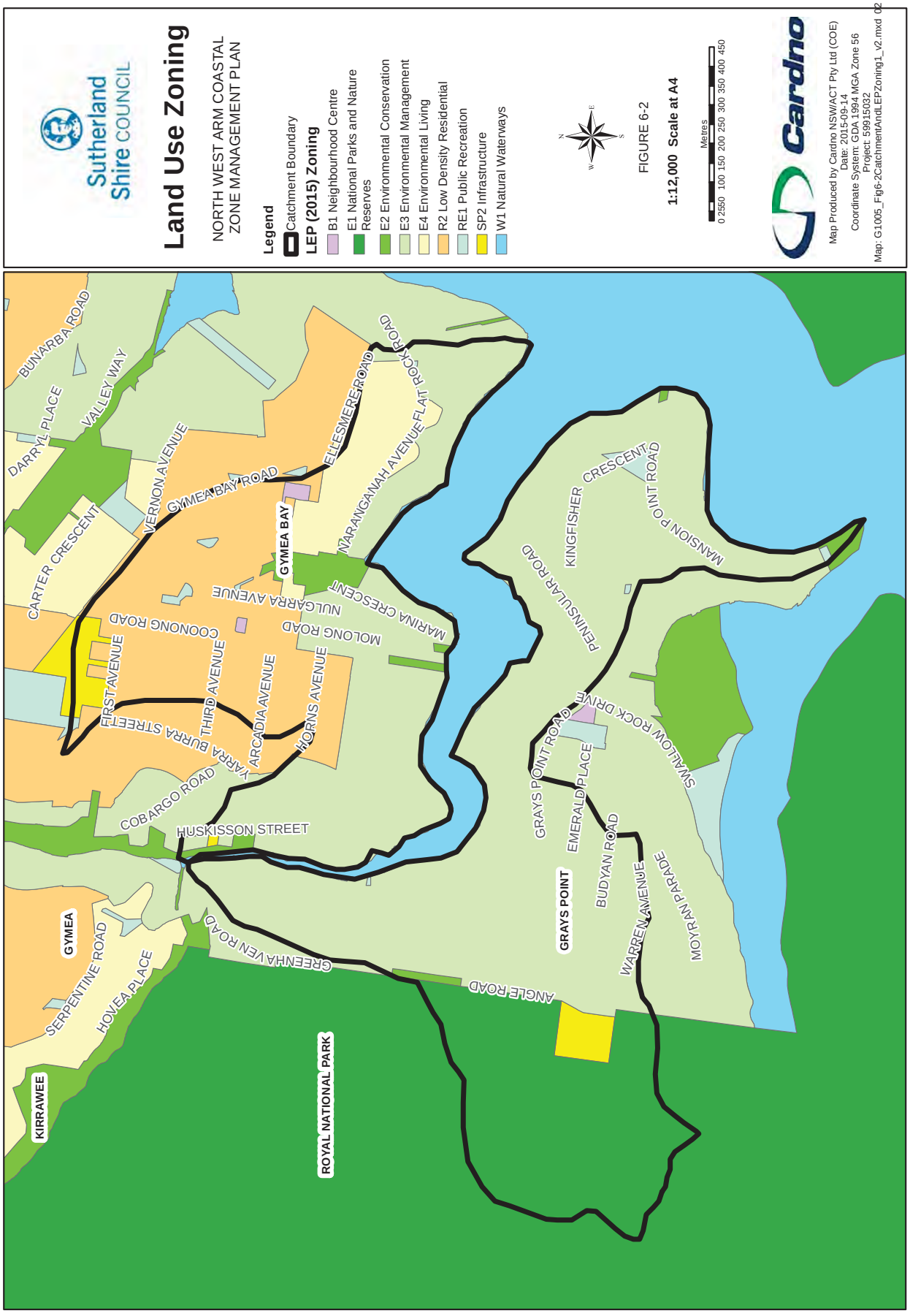
6.2.2 Current Land Use

Present day land use within the North West Arm is dominated by residential development. Land use zoning is prescribed under the Sutherland Local Environmental Plan (LEP) 2015, which identifies activities or land uses that are permissible, permissible with consent, exempt or prohibited within different land use zones. Under the LEP, land use zoning within the catchment comprises:

- B1 Neighbourhood Centre
- E1 National Parks and Nature Reserves
- E2 Environmental Conservation
- E3 Environmental Management
- E4 Environmental Living
- R2 Low Density Residential
- RE1 Public Recreation
- SP2 Infrastructure - Water Supply
- SP2 Infrastructure - Educational Establishment
- W1 Natural Waterways

The land use zoning is mapped in **Figure 6-2**.


Sutherland Shire COUNCIL
Catchment Area
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
WatercourseAssessment
Catchment Boundary
Cadastre
Waterways
Local Parks
National Parks and Reserves
FIGURE 6-1
1:12,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350 400 450
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-06
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1003_Fig6-1Catchment1_v2.mxd 01
BUNARBA ROAD
DARRYL PLACE
VALLEY WAY
VERNON AVENUE
GYMEA BAY ROAD
ELLESMERE ROAD
FLAT ROCK ROAD
NARANGANAH AVENUE
CARTER CRESCENT
MARINA CRESCENT
NULGARRA AVENUE
MOLONG ROAD
COONONG ROAD
FIRST AVENUE
THIRD AVENUE
ARCADIA AVENUE
HORNS AVENUE
YARRA BURRA STREET
COBARGO ROAD
HUSKISSON STREET
DENTS CREEK
GREENHAVEN ROAD
SERPENTINE ROAD
SAVILLES CREEK
ANGLE ROAD
KINGFISHER CRESCENT
PENINSULAR ROAD
MANSION POINT ROAD
GRAYS POINT ROAD
SHALLOW ROCK DRIVE
EMERALD PLACE
BUDYAN ROAD
WARREN AVENUE
MOYRA PARADE


Sutherland Shire COUNCIL
Land Use Zoning
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Catchment Boundary
LEP (2015) Zoning
B1 Neighbourhood Centre
E1 National Parks and Nature Reserves
E2 Environmental Conservation
E3 Environmental Management
E4 Environmental Living
R2 Low Density Residential
RE1 Public Recreation
SP2 Infrastructure
W1 Natural Waterways
FIGURE 6-2
1:12,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350 400 450
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-09-14
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1005_Fig6-2CatchmentAndLEPZoning1_v2.mxd 02
BUNARBA ROAD
DARRYL PLACE
VALLEY WAY
CARTER CRESCENT
VERNON AVENUE
GYMEA BAY ROAD
ELLESMERE ROAD
FLAT ROCK ROAD
WARANGANAH AVENUE
GYMEA BAY
NULGARRA AVENUE
MARINA CRESCENT
COONONG ROAD
MOLONG ROAD
FIRST AVENUE
THIRD AVENUE
ARCADIA AVENUE
HORNS AVENUE
YARRA BURRA STREET
COBARGO ROAD
HUSKISSON STREET
GYMEA
SERPENTINE ROAD
HOVEA PLACE
KIRRAWEE
ROYAL NATIONAL PARK
GREENHAVEN ROAD
ANGLE ROAD
GRAYS POINT
GRAYS POINT ROAD
EMERALD PLACE
BUDYAN ROAD
WARREN AVENUE
MOYRAN PARADE
SWALLOW ROCK DRIVE
PENINSULAR ROAD
KINGFISHER CRESCENT
MANSION POINT ROAD

6.3 Soils and Groundwater

6.3.1 Acid Sulfate Soils

Acid sulfate soils (ASS) are naturally occurring sediments and soils containing iron sulfides (mostly pyrite). When these sediments are exposed to the air by excavation or drainage of overlying water, the iron sulfides oxidise and form sulfuric acid. ASS are widespread in low lying coastal areas, in estuarine floodplains and in coastal lowlands.

As shown in **Figure 6-3**, the estuary bed is generally Class 1 ASS, with some areas of Class 2 ASS in the upper estuary and in some foreshore areas. The rest of the catchment falls within land zoned Class 5. The Class 1 ASS have higher acid generating potential, and Class 5 lands less acid generating potential.

Under the Sutherland Shire LEP 2015, development consent is required for the following types of development in ASS lands:

- Class 1 – any works;
- Class 2 – works below the natural ground surface, or works by which the water table is likely to be lowered;
- Class 3 – works more than 1 m below the natural ground surface, or works by which the water table is likely to be lowered more than 1 m below the natural ground surface;
- Class 4 - works more than 2 m below the natural ground surface, or works by which the water table is likely to be lowered more than 2 m below the natural ground surface; and
- Class 5 - Works within 500 m of adjacent Class 1, 2, 3 or 4 land that is below 5 mAHD and by which the water table is likely to be lowered below 1 mAHD on adjacent Class 1, 2, 3 or 4 land.

Any such works have the potential to expose ASS. If disturbed, ASS have the potential to significantly impact on water and sediment quality, damage infrastructure and impact on estuarine ecology (e.g. leading to vegetation die-back or fish kills), and specific management measures are required before undertaking any excavation works. Any actions identified as part of this CZMP that require excavation will need to consider the presence of ASS.

6.3.2 Contaminated Land

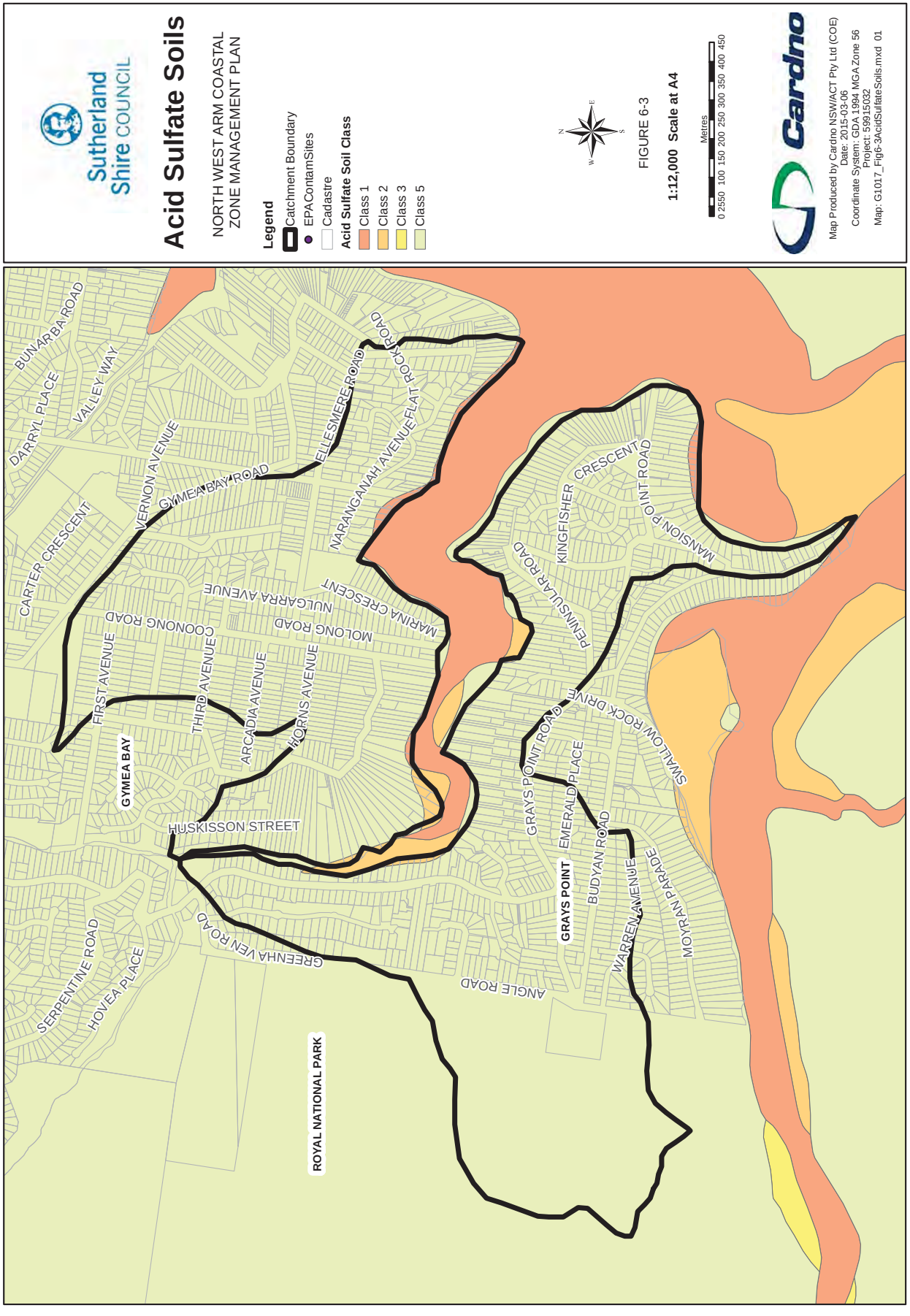
An assessment of potential point sources of pollution within the North West Arm catchment was conducted via a review of the following publicly available registers maintained by the Environmental Protection Authority (EPA), conducted on 19 January 2015:

- Register of Environment Protection Licences (EPLs) issued under the *Protection of the Environment Operations Act 1997*; and
- Register of contaminated lands under the *Contaminated Land Management Act 1997*.

EPLs are issued by the EPA for scheduled activities (as prescribed under the Act) to regulate emissions from a premises to air, water or land. For example, an EPL may be required for the operation of a wastewater treatment plant or automotive workshop. There were no records of any licenced premises within the catchment arising from the search.

Contaminated lands are a particular challenge in that they have potential to act as a threat to human and environmental health. Such lands may occur due to historic land uses such as landfills, or where industrial activities have been undertaken. A search of the EPA's register of notices issued under the *Contaminated Land Management Act 1997* did not reveal any records for the study area.

It is noted, however, that the register is not an exhaustive list of contaminated sites, and there may be previously unidentified sites within the catchment. For example, the presence of market gardens in previous years (see **Section 6.2.1**) indicates that there is potential for contamination to be present. Many market gardens use fertilisers, pesticides and herbicides that can negatively impact on the environment. It is not known if any of these chemicals were used in the market gardens, or in fact the exact location and extent of the gardens, and so the potential for contamination to be present is speculative at this time.


Sutherland Shire COUNCIL
Acid Sulfate Soils
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Catchment Boundary
EPAContamSites
Cadastre
Acid Sulfate Soil Class
Class 1
Class 2
Class 3
Class 5
FIGURE 6-3
1:12,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350 400 450
Cardno
Map Produced by Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-06
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1017_Fig6-3AcidSulfateSoils.mxd 01
BUNARBA ROAD
DARRYL PLACE
VALLEY WAY
VERNON AVENUE
GYMEA BAY ROAD
ELLESMERE ROAD
ROCKY ROAD
NARANGANAH AVENUE
FLAT ROCK
CARTER CRESCENT
MARINA CRESCENT
NULGARRA AVENUE
MOLONG ROAD
COONONG ROAD
FIRST AVENUE
THIRD AVENUE
ARCADIA AVENUE
HORNS AVENUE
GYMEA BAY
HUSKISSON STREET
KINGFISHER CRESCENT
MANSION POINT ROAD
PENINSULAR ROAD
SWALLOW ROCK DRIVE
GRAYS POINT ROAD
EMERALD PLACE
BUDYAN ROAD
WARREN AVENUE
MOYRAN PARADE
GRAYS POINT
GREENHAVEN ROAD
ANGLE ROAD
SERPENTINE ROAD
HOVEA PLACE
ROYAL NATIONAL PARK

6.4 Stormwater Management

The majority of the North West Arm catchment is urbanised, which has resulted in a significant increase in hard stand surfaces (impervious areas) such as roads and buildings. Green open space or forested areas (such as the Royal National Park) take up a lower proportion of the catchment, and hence the extent of available land for natural absorption and infiltration of stormwater is relatively low. As a result, a larger volume of stormwater reaches the North West Arm more quickly than would previously have been the case prior to development of the catchment. When rain falls on the catchment, a range of pollutants may become entrained in the flow of stormwater runoff and make their way into the estuary via tributary creeks and the stormwater network.

Council is responsible for the majority of the stormwater management planning, construction, operation and maintenance. Council has prepared a *Stormwater Management Plan for Port Hacking* (AWT, 2000) that incorporates:

- Discussion on stormwater issues;
- A review of existing water quality data;
- Objectives for stormwater management for existing and new developments (during and post-construction); and
- Actions to improve stormwater management.

As shown in **Figure 6-4**, there is an extensive stormwater network within the North West Arm catchment and there are 23 stormwater outlets draining to the estuary. Examples of stormwater outlets are shown in **Figure 6-5**. There are also a number of small outlets draining individual properties. Requirements for lot-based Water Sensitive Urban Design (WSUD) for private developments are detailed in the Sutherland Shire Development Control Plan (DCP).

Typical pollutants found in urban stormwater runoff include gross pollutants (e.g. rubbish or leaf litter), sediments, heavy metals, nutrients and faecal pathogens from animal waste and sewage overflows. The concentrations of these different pollutants will vary depending on the specific characteristics of individual sub-catchments. Depending on the attributes of the receiving waterbody, this may result in impacts on estuarine processes such as siltation and sedimentation, or algal blooms due to high nutrient concentrations.

There is a significant amount of concern in the community regarding the impacts of stormwater pollution on the estuary, and stormwater certainly appears to be a visible source of pollution, as shown in **Figure 6-5c**. The condition of the stormwater outlets is also a concern, with a number of the Council stormwater outlets / headwalls in poor condition or failing (e.g. **Figure 6-5b**). It is recommended that Council consider as part of its asset management plan a condition assessment of the stormwater outlets and prioritisation of repairs as required.

One of the issues raised by both Council and the community was sedimentation associated with creek lines and stormwater outlets, as is visible at the downstream extent of the Marina Crescent Reserve (**Figure 6-5a**). The other location of concern to the community is the sedimentation at the mouth of Dents Creek that has resulted in formation of a sand delta. This is discussed further in **Section 5.3**.


Sutherland Shire COUNCIL
Stormwater Network
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
WaterQualityDevices
Sewermain
Sewer Pumping Station
Drainage Pipes
Drainage Pits
WatercourseAssessment
Catchment Boundary
Cadastre
Waterways
Local Parks
National Parks and Reserves
FIGURE 6-4
1:12,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350 400 450
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-05
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1015_Fig6-4_Stormwater_Network.mxd 01
BUNARBA ROAD
DARRYL PLACE
VALLEY WAY
CARTER CRESCENT
VERNON AVENUE
GYMEA BAY ROAD
ELLESMERE ROAD
NARANGANAH AVENUE
FLAT ROCK ROAD
MARINA CRESCENT
MOLONG ROAD
COONONG ROAD
NULGARRA AVENUE
FIRST AVENUE
SECOND AVENUE
THIRD AVENUE
ARCADIA AVENUE
HORNS AVENUE
BURRA STREET
COBARRO ROAD
HUSKISSON STREET
DENTS CREEK
GREENHAVEN ROAD
SERPENTINE ROAD
SANDY CREEK
ANGLE ROAD
KINGFISHER CRESCENT
PENINSULA ROAD
MANSION POINT ROAD
GRAYS POINT ROAD
SWALLOW ROCK DRIVE
EMERALD PLACE
BUDYAN ROAD
WARREN AVENUE
MOYRA PARADE

a) Outlet at Marina Cres. Reserve

b) Outlet on northern shoreline.

c) Outlet in Dents Creek upstream towards the pipeline.

d) Outlet on western shoreline.

Figure 6-5: Council Stormwater Outlets

Council advises that there are a number of stormwater quality improvement devices (SQIDs) located in the catchment that provide treatment of stormwater prior to discharge to the waterbody (see **Table 6-1**).

Table 6-1: Gross Pollutant Traps in the Catchment

ID No.	Type of Device	Location	Site Description	Suburb	Catchment Size (ha)
17	Humeceptor	President Avenue	Kirrawee carpark at rear	Kirrawee	0.84
142	Litter basket	Oak Road	Kirrawee carpark entrance	Kirrawee	0.13
180	Trash rack	Rawson Avenue	SSHED Business Incubator	Loftus	6.80
177	Trash rack	Gore Avenue	Savilles Creek	Kirrawee	19.50
179	Trash rack	North West Arm Road	Dents Creek	Gymea	156.00
RD03935A	Trash rack	Forest Road	Savilles Creek	Sutherland	31.00

Trash racks are simple grills or mesh racks that capture floating trash, primarily vegetative debris, rubbish and sediments. **Table 6-2** presents some summary statistics on the material cleaned from these GPTs, also

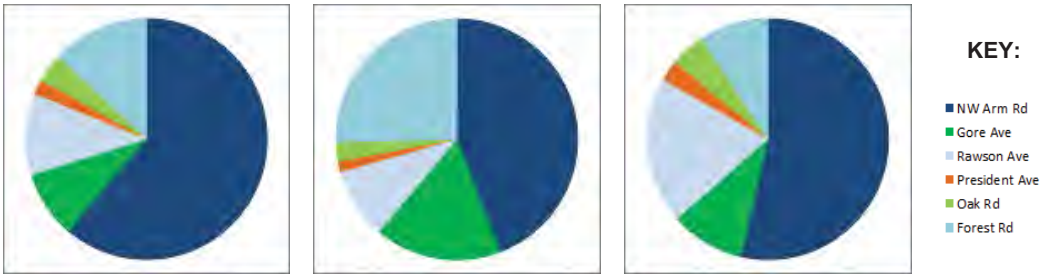
shown graphically in **Figure 6-6**. It is evident that the GPTs are generally effective in capturing gross pollutants. The Dents Creek trash rack (ID No. 179) captures a significantly higher proportion of sediments, organic matter and litter compared to the other three GPTs (**Figure 6-6**), although this may be an artefact of the method used by different contractors to sort the captured material. It is noted that the Kirrawee carpark GPTs (ID Nos. 17 and 142) have a very high proportion of "other" material, which may in fact comprise sediments, litter or organics.

A number of these devices have been installed in the catchment, although it is understood that there are difficulties in maintaining functional trash racks and other types of GPTs and they can be very resource intensive to maintain. It is recommended that Council consider optimising the current stormwater quality management program to make best use of resources. This may involve a review of street sweeping and the location of GPTs.

Historically, there has also been a street sweeping program to collect leaf litter prior to it being washed into the stormwater network. AWT (2000) report that three trucks used to sweep the streets, collecting around 3,000 tonnes of material each year.

Table 6-2: Gross Pollutant Collection Data

	GPT No. 179 (NW Arm Rd)	GPT No. 177 (Gore Ave)	GPT No. 180 (Rawson Ave)	GPT No. 17 (President Ave)	GPT No. 142 (Oak Rd)	GPT No. RD03935A (Forest Rd)
No. Times Cleaned per Year	7	8	1	3	3	N/A (installed late 2014)
Average Volumes of Material Removed per Clean						
Sediments (tonnes)	5.60	0.82	1.00	0.18	0.35	1.2
Organic Matter (m^3)	6.94	2.67	1.50	0.22	0.40	4
Litter (m^3)	1.72	0.32	0.63	0.09	0.15	0.3
Other (m^3)	1.54	0.95	N/A	4.54	5.78	N/A



a) Sediments b) Organics c) Litter

Figure 6-6: Proportion of Gross Pollutants Captured From GPTs

Another source of pollutants is sewer overflows. During rainfall events the sewage system can overflow, leading to the discharge of sewage into the environment. Illegal private sewer connections may also be present, and these can also contribute to poor stormwater quality, particularly with respect to nutrients and bacterial pathogens. Wet weather sewer overflows were estimated as contributing approximately 215 ML per annum (averaged at 1-2 events each year) from overflow points in the North West Arm, Yowie Bay, Burraneer Bay and Gunnamutta Bay (AWT, 1997; cited by AWT, 2000), although it is noted that these reports are now somewhat dated and conditions may have improved.

Sydney Water is responsible for managing sewer overflows, and has undertaken a program to repair and maintain those sewer mains on the northern side of Port Hacking that have a high likelihood of surcharging to waterways if they become blocked (OEH, 2014b). In addition, tree roots can also cause sewer leaks.

Another source of water pollution in Port Hacking is the improper disposal of sewage from vessels, as identified during the community consultation undertaken for this project. Whilst pump-outs are available, some boat users do not use them consistently, and discharge wastewater directly to Port Hacking. Pump-out facilities are provided in three locations on Port Hacking: at Burraneer Bay Marina, Cronulla Marina and Yowie Bay Marina. The facilities are available to public users for a small fee and are operated by marina staff. The sewage pump-out facility at the Burraneer Bay Marina is located 800 m north of Wallys Wharf.

Bushfires may also impact significantly on the estuary, as identified by Albani and Cotis (2013), and anecdotally by residents during the community survey. The loss of vegetation associated with a bushfire can result in the mobilisation of large amounts of sediments from the catchment, and Albani and Cotis (2013) have recorded layers of charcoal indicative of past bushfires in the estuarine sediments. Bushfires can also result in increased nutrient loads from the catchment to the waterway. There have not been any large bushfires in the catchment for several years, but there is potential for these types of event to occur in the future.

6.4.1 Optimal Placement of GPTs

As discussed in **Section 6.4**, Council has installed trash racks on both Savilles Creek and Dents Creek to manage gross pollutants in these waterways. Both trash racks are operating successfully; however, both are located a relatively large distance upstream which limits their effectiveness as they are unable to intercept flow from a large portion of the catchment. For the optimal performance of GPTs, the following basic criteria will apply:

- GPTs should be located upstream of any other water quality devices (such as wetlands, bioretention basins, sediment traps, etc.) in order to reduce the amount of gross pollutants (e.g. rubbish) entering the water quality device, thereby improving the operation and effectiveness of the downstream device;
- Where no other water quality devices are present, placing a GPT as far downstream as possible will allow for the interception of the greatest amount of pollutants, thereby providing the greatest reduction in potential for pollutants to enter the estuary;
- Following the principle outlined in the second point above, it may also be more cost-effective to have a single GPT at the downstream end of the catchment. While it would require more regular cleaning, the overall maintenance requirements are still likely to be less costly when compared to the requirement to maintain two or more functional GPTs;
- If there are known hotspots for gross pollutants and/or sediments, a localised GPT to service just the hotspot area may be warranted for purposes of relieving the pressure on downstream devices that are servicing a much greater area than just the hotspot; and
- The location of a GPT should carefully consider the maintenance requirements, and ensure there is suitable access to the device for regular cleaning. Similarly, placement of the device should not impede access by vehicles, pedestrians or vessels.

Council's experience of the existing trash racks demonstrates that they can be effective in capturing gross pollutants, but that they can be expensive to maintain in a functional condition. In addition, access is limited in parts of the catchment, such as along Dents and Savilles Creek, and hence it may not be practical to install a device in some locations. This is a particular issue in the North West Arm catchment.

6.4.2 Potential impacts of Climate Change on Stormwater Management

The inundation of low-lying areas around the estuary under sea level rise conditions can be a result of both direct inundation and the ingress of estuarine water into the stormwater system, resulting in stormwater surcharge. This may occur in areas connected to the stormwater system that are protected by a higher foreshore crest, but are lower than the estuarine water level. Other implications of climate change for stormwater infrastructure include increased maintenance requirements due to the increased likelihood of sediment ingress from the estuary during high flow or more frequent rain events. Less frequent but higher intensity storm events may also put more pressure on the stormwater network, resulting in increased severity of localised flooding, especially in times of joint occurrence of coastal inundation and catchment flooding.

6.5 Water and Sediment Quality

Council has a Strategic Water Quality Monitoring Program (SWaMP) which included two sites in the North West Arm, and one each at Dents and Savilles Creek. It is understood that this program is still underway, but now includes fewer sites. Other ongoing monitoring programs include Beachwatch run by the OEH, which monitors water quality for recreational purposes at beaches and in estuaries along the NSW coastline.

6.5.1 Tributary Creeks

Council provided water quality data collected from a site located in the freshwater section of Dents Creek over the period 2013-2014, comprising 11 samples collected on a roughly monthly basis. The results have been summarised in **Table 6-3**.

Table 6-3: Dents Creek Water Quality Data

Water Quality Parameter	Range+	Average	ANZECC (2000) Guidelines	
			Aquatic Ecosystems*	Primary Contact Recreation
Nutrients:				
Ammonia (mg/L)	BDL - 0.10	0.03	0.02	0.01
Nitrate + Nitrite as N (mg/L)	0.08 – 0.89	0.44	0.04	N/A
Total Kjeldahl Nitrogen (mg/L)	0.2 – 0.8	0.4	N/A	N/A
Total Nitrogen as N (mg/L)	0.3 – 1.5	0.77	0.5	N/A
Total Phosphorous as P (mg/L)	BDL – 0.12	0.05	0.05	N/A
Heavy metals:			95% protection limit	
Arsenic (mg/L)	BDL – 0.001	0.001	0.024	0.050
Cadmium (mg/L)	BDL – 0.0001	0.0001	0.0002	0.005
Chromium (mg/L)	BDL – 0.001	0.001	N/A	0.050
Copper (mg/L)	0.002 - 0.017	0.007	0.0014	1.000
Lead (mg/L)	BDL – 0.005	0.003	0.0034	0.050
Nickel (mg/L)	BDL – 0.002	0.002	0.011	0.10
Zinc (mg/L)	0.015 – 0.144	0.062	0.08	5.00
Biological:				
Biochemical Oxygen Demand (mg/L)	BDL – 5.00	3.75	N/A	N/A
Chlorophyll a (mg/m^3)	BDL - 84	46	5	N/A
Dissolved Oxygen (mg/L)	8.4 - 11.0	9.6	(85-110% sat.)	6.5 (80% sat.)
Enterococci (cfu/100mL)	52 - 6,200	1,204	N/A	<35# (max. 60-100 in any sample)
Physical:				
Conductivity (µS/cm)	107 - 712	502	125 – 2,200	N/A
pH	7.4 – 8.5	7.88	6.5 - 8.0	5.0 - 9.0
Suspended Solids (mg/L)	BDL – 72	14	N/A	N/A
Temperature (°C)	15.2 - 27.6	20.0	N/A	15.0 – 35.0

*South-east Australian lowland rivers.
+BDL = Below detection limit.
#Median value must be less than 35 organisms/100 mL

A review of the available water quality data for Dents Creek (**Table 6-3**) indicates that there are periodic declines in water quality, when there can be elevated concentrations of nutrients, faecal pathogens and

suspended solids. At these times water quality may be unsuitable for both aquatic ecosystem health and recreational purposes. This suggests that there is opportunity to improve stormwater management practices in the catchment.

In their review of available water quality data for Dents Creek, Applied Ecology (2012) found that nutrients (TN and TP) were somewhat elevated, as were concentrations of heavy metals (Cu, Pb and Zn) that are commonly associated with urban areas. For Savilles Creek, nutrients, Enterococci and heavy metals were also elevated (Applied Ecology, 2012).

The results indicate that the water quality of Dents Creek is somewhat modified due to activities in the catchment. It would be necessary to conduct a more extensive water quality monitoring program to improve our understanding of water quality processes in the creek and identify appropriate management options, although this is not considered warranted at this time, particularly in the context of the resources available to Council for any such investigation.

6.5.2 Estuarine Water Quality

The National Land and Water Resources Audit (2001) states that Port Hacking has extremely good water quality, due to the limited amount of industrial activity in the catchment and because there are no agricultural inputs.

The OEH's Beachwatch program provides some water quality analyses for purposes of assessing risk to human health for primary contact recreation. The Beachwatch sites located closest to the North West Arm are at Gymea Bay Baths and Lilli Pilli Baths, and the water quality results for these sites have been discussed as a proxy for the North West Arm.

As identified by local residents during the community survey, water quality in Gymea Bay can deteriorate significantly after rainfall events. OEH (2014b) grades water quality in Gymea Bay Baths as "Poor", and suitable for swimming during dry weather only due to elevated Enterococci levels following light rainfall.

In contrast, the beach suitability grade for Lilli Pilli Point is "Good", with water quality suitable for swimming most of the time, noting that stormwater pollution may result in faecal contamination after rainfall events of 55 mm or more (OEH, 2014b). The better water quality at this site, as compared to the Gymea Bay Baths site, may be due to its location away from a creek line and at a more open site that is likely subject to more efficient tidal flushing.

Stormwater was identified as the major contributing factor to faecal contamination at both the Gymea Bay Baths and Lilli Pilli Baths sites. It is recommended that swimming be avoided at sites in Port Hacking for up to three days following rainfall (OEH, 2014b). Based on these findings, it is reasonable to assume that stormwater pollution can also result in significant localised impacts on water quality in the North West Arm estuary. In addition to the implementation of SQIDs, the provision of bags for the collection of animal waste at key recreational sites may also benefit stormwater quality.

6.5.3 Sediment Quality

Fluvial sediments and associated pollutants are delivered to the North West Arm estuary via stormwater flows from the catchment. The main sedimentary contaminants associated with urban stormwater flows are heavy metals such as lead, zinc and copper. Many contaminants tend to become attached to sedimentary particles, which can flocculate out of the water column, particularly when they meet estuarine waters with higher pH and salinity. Hence sediments can act as a 'sink' for pollutants.

These contaminants may become re-mobilised into the water column when sediments are disturbed, or by biogeochemical processes. In the event there is a proposal to dredge the estuary, the material proposed for dredging must be assessed for its contamination status and the adopted method of disposal selected accordingly, whether to land or offshore. The process of removing the material can also impact on water quality as the contaminants are mobilised into the water column.

Sedimentary contamination can negatively impact on both human and ecological health, although the process is not fully understood.

In his literature review of sedimentary contamination in NSW estuaries, Birch (2000) provided a comparison of several estuaries in the Sydney metropolitan region. Enrichment with heavy metals due to anthropogenic

activities is reported by Birch (2000) as the number of times the concentration is over the background concentration. Whilst subject to significant pollution resulting in sedimentary contamination since European settlement of the catchment, Port Hacking generally has lower levels of enrichment with heavy metals when compared to other urban estuaries in NSW (**Figure 6-7**). This is likely due to the fact that much of the catchment is retained as National Park, and levels of industrial activities and shipping are generally lower than for other locations such as Port Jackson and the Georges River.

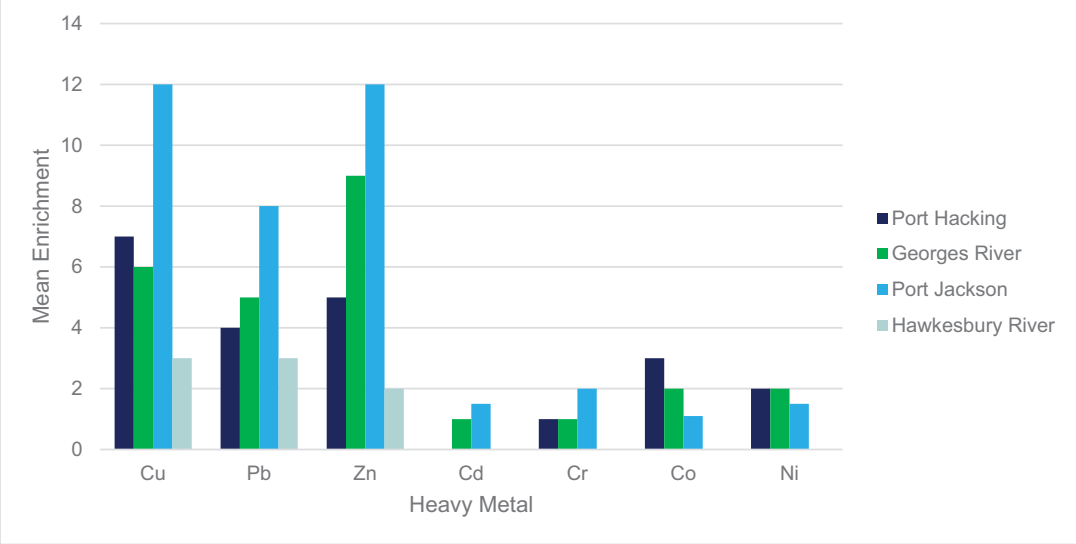


Figure 6-7: Sedimentary Heavy Metal Enrichment in Central NSW Estuaries (After: Birch, 2000)

Birch (2000) reports studies have found that the highest heavy metal concentrations are typically associated with embayments and estuarine tributaries, and stormwater is thought to be a significant contributor to the sedimentary contamination. In Port Hacking, the main contaminants are copper, lead and zinc (**Figure 6-7**), which may be derived from atmospheric fallout (e.g. motor vehicle emissions), roads and other urban or industrial development.

In addition to heavy metals, other sedimentary contaminants may include:

> Polycyclic aromatic hydrocarbons (PAH) that are generated via combustion;
> Polychlorinated biphenyls (PCB) that used to be used in a range of industrial products such as sealing and caulking compounds, paint additives, lubricants and electrical equipment; and
> Organochlorine and organophosphate pesticides.

Stark (1998) conducted an investigation of the effects of sedimentary heavy metal contamination on macrobenthic assemblages at seven sites, including four located in Port Hacking:

> North West Arm;
> South West Arm;
> Mangrove Creek; and
> Grays Point.

The North West Arm was found to have significantly higher concentrations of copper, lead and zinc when compared to the other three sites, which was attributed to the higher degree of urbanisation of the catchment (Stark, 1998). A comparative analysis of the seven sites, comprising “polluted” bays and “less polluted” bays, showed that macrobenthic assemblages were significantly different in polluted bays such as the North West Arm, which demonstrates that sedimentary contamination negatively impacts estuarine ecology (Stark, 1998).

A recent study by Lewtas *et al.* (2014) also examined the potential impacts of sedimentary contamination with heavy metals on estuarine ecology, specifically on the Greentail Prawn (*Metapeneaus bennettae*). The study analysed heavy metal concentrations in sediments and prawns taken from several sites in Port

Jackson (the “polluted” estuary) and Port Hacking (the reference or less polluted estuary), including in the South West Arm and opposite Grays Point.

Levels of sedimentary contamination averaged across all samples (size normalised) for Port Hacking reported by Lewtas *et al.* (2014) were as follows:

- Arsenic: 15 µg/g;
- Cadmium: 0.90 µg/g;
- Cobalt: 3.47 µg/g;
- Chromium: 32.07 µg/g;
- Copper: 57.88 µg/g;
- Iron: 41,271 µg/g;
- Manganese: 32 µg/g;
- Nickel: 11 µg/g;
- Lead: 70 µg/g;
- Zinc: 70 µg/g.

The concentration of lead is in excess of the Interim Sediment Quality Guideline (ISQG) – Low guideline value of 50 µg/g (ANZECC, 2000), which is the point at which there may be adverse biological effects.

Lewtas *et al.* (2014) found that the concentrations of metals in prawns were generally highest for those sites that were subject to the highest levels of contamination, which suggests uptake of sedimentary contaminants by this species. Uptake may be direct (water via the gills) or indirect (sediment or diet via the gut). It is noted that the prawns were found to be safe for human consumption.

6.6 Flooding

It is understood that a flood study was undertaken for Dents Creek in 2001; however, a formal report was not prepared. Information obtained from Council indicates that properties affected by flooding from Dents Creek have been identified and Section 149 notifications made to communicate the flood risk to property owners, but unfortunately flood extents were not available. Climate change was not considered in the flood study, and hence any changes in future flood risk have not yet been quantified, beyond the preliminary assessment conducted by GHD (2011; see **Section 5.6.2.1**).

Bewsher Consulting (2004) undertook a preliminary assessment of flooding in the Sutherland Shire aimed at prioritising catchments for more detailed flood studies. The assessment was commissioned following a flash flood in excess of a 5 year ARI event on 13 May 2003, and utilises some data collated following that event. The event was estimated at being greater than a 5 year ARI for many locations within the LGA, and greater than a 20 years ARI event as measured at the Audley rainfall gauge in the National Park. A total of 342 calls for assistance were made to the NSW State Emergency Service (SES) (Bewsher Consulting, 2004). Several complaints received were from properties located in proximity to Dents Creek, including some properties that were subject to inundation. Dents Creek was given the sixth highest risk rating from flooding from the catchments assessed (Bewsher Consulting, 2004).

In addition to mainstream flooding, other types of flooding that may occur include overland flooding and foreshore inundation. The risk of foreshore inundation due to coastal processes is discussed in **Section 5.5**. Elevated estuarine water levels can directly contribute to flooding by inundating foreshore land, but they may also prevent the outflow of stormwater from stormwater outlets during a flood event, thereby exacerbating catchment flooding. For this reason, it is important to understand the interactions between coastal and catchment processes. It is not known if this was assessed as part of the Dents Creek flood study.

Overland flooding is also a form of catchment flooding, although rather than being related to mainstream flooding (as would have been assessed in the Dents Creek flood study), overland flows describe stormwater that travels along the land surface prior to entering the stormwater network. In some locations, the stormwater network may be unable to cope with large rainfall events, exacerbating overland flooding. Given the urbanised nature of much of the North West Arm catchment, it is possible that overland flows are a contributing factor to catchment flooding. This seems to have been a factor in some of the flood-related complaints made during the 13 May 2003 flood event (Bewsher Consulting, 2004).

6.7 Summary of Key Management Issues

Table 6-4 summarises the key management issues identified for the North West Arm catchment condition and water quality.

Table 6-4: Management Issues – Catchment Condition and Water Quality

Issue Description	Priority
Climate change impacts on built infrastructure, cultural heritage, and estuarine ecology.	Medium
Sedimentation of creek lines or around stormwater outlets.	Medium
Periodic declines in water quality.	High
Poor water quality associated with stormwater runoff.	High
Poor water quality associated with sewer overflows.	High
Potential for ASS to be disturbed as a result of works in the estuary or foreshore.	Low
Difficulties in maintaining functional SQIDs.	High
Poor condition of stormwater outlets.	Medium
There are insufficient resources for water quality monitoring, which would improve understanding of water quality processes.	Medium

6.8 Recommendations for Management

Table 6-5 provides a summary of recommendations for future management of catchment condition and water quality in North West Arm.

Table 6-5: Management Recommendations – Catchment Condition and Water Quality

Option ID	Management Recommendation
WQ01	Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program. This option assumes that Council would contribute by undertaking the required monitoring at five sites in the catchment, incorporating both dry and wet weather sampling.
WQ02	Provide ongoing support for community education to improve awareness of non-point source water pollution and provide advice on how residents can contribute to best practice stormwater management.
WQ03	Work with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows on the estuary.
WQ04	Assess the condition of Council's stormwater outlets to the estuary and program works as required.
WQ05	Assess compliance of lot-based stormwater management controls for foreshore properties against the requirements of the DCP.
WQ06	Install a SQID to treat stormwater draining to Dents Creek via reaches DCDCPH017 and 018, to be located near the intersection of Huskisson St and Cobargo Rd.
WQ07	Retrofit SQIDs on individual stormwater pits to capture sediments and gross pollutants as stormwater inflows enter the drainage system. Assumed to be undertaken on up to five stormwater pits during the period of implementation of the CZMP.
WQ08	Install a trash rack at the point where North West Arm Road crosses Savilles Creek to capture gross pollutants.
WQ09	Install an online SQID on the unnamed watercourse located in Kyogle Reserve to capture gross pollutants from the stormwater network and upstream reach of the creek prior to entering the estuary.
CC20	Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources. This may involve a review of street sweeping and the location of GPTs.

7 Estuarine Ecosystems

7.1 Overview of Estuarine Ecology

Being located at the interface between terrestrial, freshwater and coastal environments, estuaries typically have diverse ecosystems. Within these broad categories, there are a number of different habitats ranging from terrestrial (or supra-tidal) habitats, to intertidal habitats and aquatic (or sub-tidal) habitats.

The condition of the North West Arm estuary is influenced by complex interactions between physical, chemical and biological processes which operate over a variety of timescales, from regular tidal flushing to irregular catchment flood events. In general, ecosystem health at any given time reflects the relative influences of a range of pressures on the system such as nutrient and contaminant loads, existing sediment and water quality, invasive species, and human uses.

This section of the CZMP provides an overview of estuarine habitats within the North West Arm, flora and fauna, and management issues relating to ecosystem health and biodiversity conservation.

7.2 Estuarine and Riparian Habitats

As discussed in **Section 6.2** and **Section 8**, the majority of the estuary catchment has been developed, resulting in significant declines in the extent and condition of habitat. This section provides a review of the historical and current extent of various habitats in the North West Arm, and the presence of different flora and fauna species, including those of conservation significance. It highlights the current ecological value of the estuary, identifies existing issues and makes recommendations for ongoing management.

7.2.1 Intertidal and Sub-tidal Habitats

7.2.1.1 Rocky Shores and Sand flats

Intertidal rocky shores and mudflats provide essential habitat for a diverse range of species found in Port Hacking and the North West Arm (see **Section 7.3.1**). Intertidal habitats are generally quite challenging environments to live in due to the variation in water levels across the tidal cycle or during storm events, exposure to wave energy, exposure to the air during low tide followed by submersion on high tides, and fluctuations in water temperature, such as where it ponds in pools.

The complex structure of rocky shore habitats, including cobbles, boulders, platforms and rock pools translates into a diverse range of sub-habitats for different plants and animals, such as:

- Crustaceans (e.g. crabs);
- A range of shellfish including gastropods (e.g. snails and periwinkles), bivalves (e.g. oysters, cockles and mussels), and cephalopods (e.g. octopus);
- Small fish; and
- A wide range of green, red and brown macroalgae.

The most obvious impact in North West Arm is the loss of natural habitat through urbanisation and subsequent replacement with parkland, infrastructure, housing, and other structures, such as jetties and seawalls. This process has significantly modified estuarine foreshores in the study area. Seawalls have become a dominant foreshore feature of urban estuaries and this is particularly evident within North West Arm, where a majority of the natural shoreline has been replaced by seawalls in order to protect low lying areas from coastal hazards and to enhance access to the estuary for water based activities (see **Section 5.5.1**).

During field investigations it was observed that at many locations in the lower estuary, seawalls abut natural rock platforms (**Figure 7-1a**) indicating that much of the foreshore was originally composed of rock outcrops similar to those seen in the mid and upper estuary (**Figure 7-1b**). As noted in **Section 5.5.1**, approximately 40% of the shoreline is now artificially stabilised and this process can significantly reduce the extent of available intertidal habitat and negatively impact ecosystem function. As seen in **Figure 7-1a** and **b**, oysters are the dominant species on the vertical tidal portions of the seawalls.

Competition for available intertidal habitat may be further exacerbated in future by the effects of sea level rise, with flora and fauna having little opportunity to migrate landward due to the presence of built infrastructure. The intertidal zone will also likely decrease significantly in horizontal extent in areas where landward migration of the intertidal zone is limited by the steep topography of the catchment.

Where seawalls are considered to be an appropriate management option, environmentally friendly seawall options should be considered to increase habitat availability and species richness. Guidelines on environmentally friendly seawalls have been prepared for use by Councils and property owners (DECC & SMCMA, 2009), and it is recommended that these be consulted to identify opportunities for the incorporation of habitat features in future foreshore construction projects.

Possible features include:

> Provision of habitat through variation in texture and form on seawall surfaces through embedded objects, cuts or holes in existing structures (DECC & SMCMA, 2009);
> Provision of artificial reef habitats directly in front of seawalls through the placement of large woody debris, boulders or reef balls;
> Considerations of the type of substrate used (i.e. sandstone versus concrete) (Connell and Glasby, 1999; Moreira, 2006; Glasby *et al*., 2007);
> Provision of native riparian vegetation buffers landward of the seawall; and
> Incorporation of estuarine vegetation such as mangroves.

Sand flats such as those found in the upper estuary provide habitat for benthic communities which include numerous different species of invertebrates that live on the estuary bed or in the mud itself, including crustaceans, molluscs (shellfish) and polychaete worms. The large expanses of mudflats also provide habitat for migratory and marine bird species (see **Section 7.3.1**), which forage on invertebrates found on the intertidal sand / mud flats and tidal drainage channels in the estuary, and also among exposed rocks. These birds rely mainly on bivalve molluscs and polychaete worms as their source of food. Mudflats not only provide foraging grounds, but may also be utilised for roosting purposes, highlighting the importance of these habitats to the maintenance of biodiversity in the North West Arm.

Dredging of tidal sand flats has the potential to destroy habitat and may result in loss of ecological diversity. Dredging may also result in the loss of seagrass in the North West Arm (refer **Section 7.2.1.3**). Historical channel dredging has destroyed seagrass in the greater Port Hacking system with a significant reduction in seagrass observed between the 1950's and 1970's (Williams and Meehan, 2004).

a) Seawall in lower estuary abutting natural rock platform

b) Natural rock platform in mid estuary

Figure 7-1: Rocky shores and seawalls in the North West Arm

7.2.1.2 Mangroves

Mangroves are a group of trees and shrubs that are capable of growing in marine, estuarine and (to a limited degree) fresh water environments. Mangrove ecosystems are valued globally for their ecological and economic value and are a common feature along the shores of many NSW estuaries. They occupy the fringe of intertidal shallows between the land and the sea, and serve three key functions (NSW DPI, 2008):

> They provide habitat – Mangroves provide a complex structure to shelter many species of juvenile and adult fish, as well as other forms of wildlife including birds. Many species of fish use mangroves as nursery grounds before moving into other habitats such as reefs or seagrass beds (Kathiresan and Bingham, 2001, Nagelkerkan *et al.*, 2008). The muddy or sandy sediments associated with this habitat are home to a variety of epibenthic and infaunal, invertebrates such as crustaceans, gastropods and worms.

> They provide food – Mangrove trees produce large amounts of organic matter, and are typically the most productive primary producers in an estuary. The fallen leaves, seeds and seedlings enter the waterway and are directly grazed by small animals, such as crabs, snails and worms. The litter is further broken down by bacteria and fungi, making it available to other animals. Decaying pieces of debris are eaten by other aquatic animals called detritivores (e.g. crabs). These animals in turn provide food for larger fish and other animals. In this way, mangroves play an important role in nutrient cycling and transfer up the food chain (see **Figure 7-2**).

> They act as a buffer, reducing erosion, trapping sediments and maintaining water quality – Mangroves protect coastal land by absorbing the energy of tidal currents and storm-driven wind and wave action, creating a natural breakwater that helps stop erosion (Alongi, 2008). The slow movement of stormwater runoff from the catchment through mangrove ecosystems enables sediment trapping and absorption of pollutants such as nutrients (Nath *et al.,* 2014).

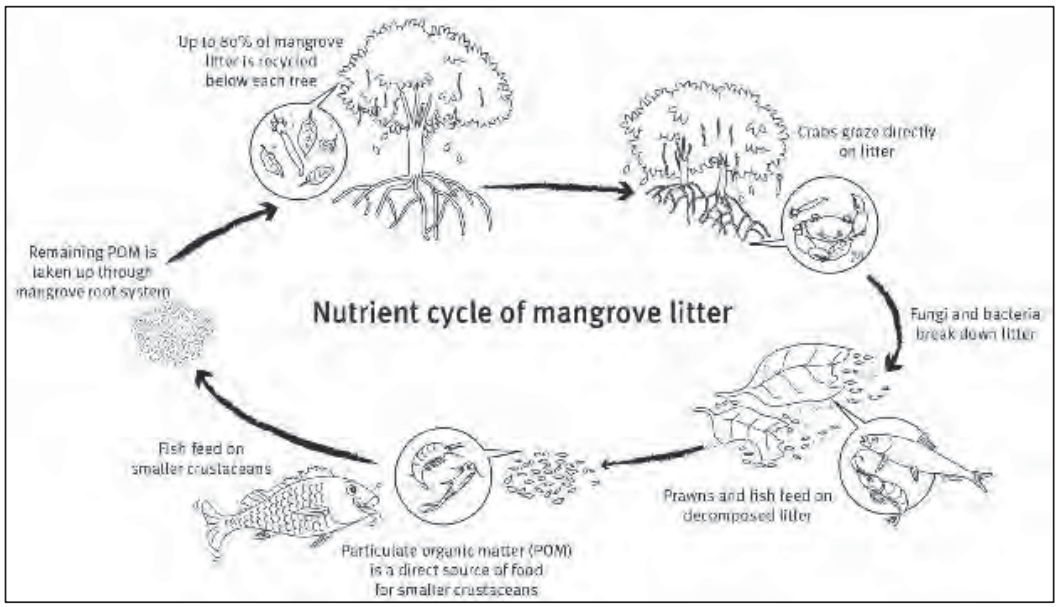


Figure 7-2: Nutrient Cycling in Mangroves (Source: BMRG, 2014)

Of the five species of mangrove that occur in NSW, *Avicennia marina* (Grey Mangrove) and *Aegiceras corniculatum* (River Mangrove) are the two most common (Nath *et al*., 2014). Within the North West Arm there are approximately 28,000 m^2 of mangrove habitat, primarily located in the upper estuary around the confluence with Dents Creek where Grey Mangroves occur. Current mangrove distribution in the North West Arm has been mapped by NSW Fisheries (see **Figure 7-3**).

In some areas there has been a large decline of mangroves due to clearing or reclamation and changes in hydrology associated with waterfront development. Mangrove communities have increased in the North West Arm since around 1930 (Williams and Meehan, 2004). Albani and Cotis (2013) estimate an increase in mangrove extent of 8,500 m^2 over the period 1930 to 2012, although it was not known if this was due to colonisation or simply recovery from extensive mangrove harvesting undertaken in the early 20th Century.

Although mangroves have expanded in recent years, the community has expressed concern over impacts from deer foraging and the establishment of tracks through the mangroves leading from private properties to the waterway.

7.2.1.3 Seagrasses

Seagrasses differ from algae in that they are flowering plants adapted to life in the shallow marine environment. Research has emphasised the importance of seagrass to the ecology of shallow estuarine environments (Larkum *et al.,* 1989). Seagrass beds often support a rich variety of flora and fauna and act as a source of food and shelter for various marine organisms (Keough and Jenkins, 1995, cited by Creese, *et al.*, 2009) including juvenile fish and mobile invertebrates, many of which are of commercial and recreational importance (Bell and Pollard, 1989).

Seagrasses also help to maintain water quality by buffering water currents, slowing down flows and trapping sediments (Smith and Pollard, 1999), stabilising sediments and assisting in the removal of nutrients from the water column (Smith *et al.,* 1997).

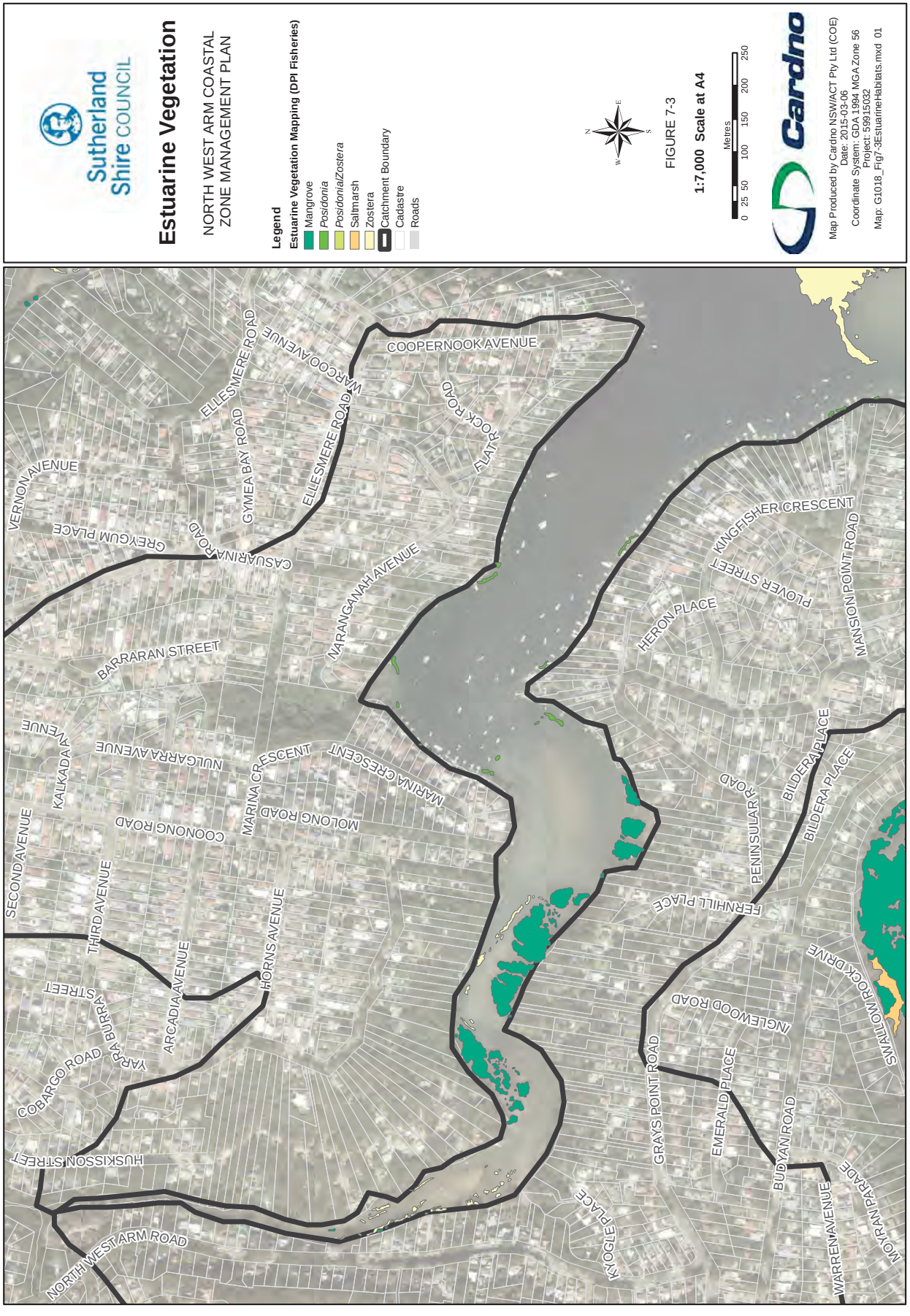
Loss of seagrass can result in the destabilisation of sediments, removal of potential nursery habitats for fish, and a decrease in primary productivity of estuaries. Depending on the species of seagrass, recovery times for seagrass beds following disturbance can be slow (McKenzie, 1994).

For these reasons, seagrass beds are seen as critically important habitats and their distribution patterns and changes in extent and condition over time have been documented as a means of monitoring the ecological health of estuaries (Williams *et al*., 2007; Roper *et al*., 2011). Excessive nutrients entering the estuary from stormwater run-off can stimulate phytoplankton and epiphytic growth (Silberstein *et al.* 1986), which reduces light penetration and limits photosynthetic activity, leading to mortality or impairment of the seagrass condition.

Aquatic vegetation maps prepared by Creese *et al.* (2009) show that two species of seagrass occur in the North West Arm: *Posidonia* and *Zostera* (**Figure 7-3**). Seagrass in the North West Arm has declined from historic levels. Williams and Meehan (2004) conclude that development of the catchment may have had a detrimental impact on seagrass due to modification of catchment runoff regimes and declines in stormwater quality.

Seagrasses were observed during the field investigations at the fluvial delta and in the upper estuary. At the time their study was published, Albani and Cotis (2013) stated that there appeared to have been a localised increase in seagrass cover on the delta front, although the net trend in seagrass extent in the estuary as a whole was not discussed.

Potential impacts to seagrass identified during the stakeholder and community consultation included: shading by pontoons and boats, and increased sedimentation smothering seagrass beds (see **Figure 7-4**).


Sutherland Shire COUNCIL
Estuarine Vegetation
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Estuarine Vegetation Mapping (DPI Fisheries)
Mangrove
Posidonia
PosidonialZostera
Saltmarsh
Zostera
Catchment Boundary
Cadastre
Roads
FIGURE 7-3
1:7,000 Scale at A4
Metres
0 25 50 100 150 200 250
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-06
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1018_Fig7-3EstuarineHabitats.mxd 01
COOPERNOOK AVENUE
ELLESMERE ROAD
WARCOO AVENUE
GYMEA BAY ROAD
ROCK FLAT RD
VERNON AVENUE
GREYGUM PLACE
CASUARINA ROAD
NARANGANAH AVENUE
BARRARAN STREET
KINGFISHER CRESCENT
PLOVER STREET
HERON PLACE
MANSION POINT ROAD
KALKADA AVENUE
NULGARRA AVENUE
MARINA CRESCENT
MARINA CRESCENT
COONONG ROAD
MOLONG ROAD
BILDERA PLACE
BILDERA PLACE
PENINSULAR ROAD
FERNHILL PLACE
SECOND AVENUE
THIRD AVENUE
HORNS AVENUE
ARCADIA AVENUE
YARRA BURRA STREET
INGLEWOOD ROAD
ROCK DRIVE
SWALLOW
COBARGO ROAD
HUSKISSON STREET
GRAYS POINT ROAD
EMERALD PLACE
BUBYAN ROAD
KYOGLE PLACE
NORTH WEST ARM ROAD
WARREN AVENUE
MOYRAN PARADE

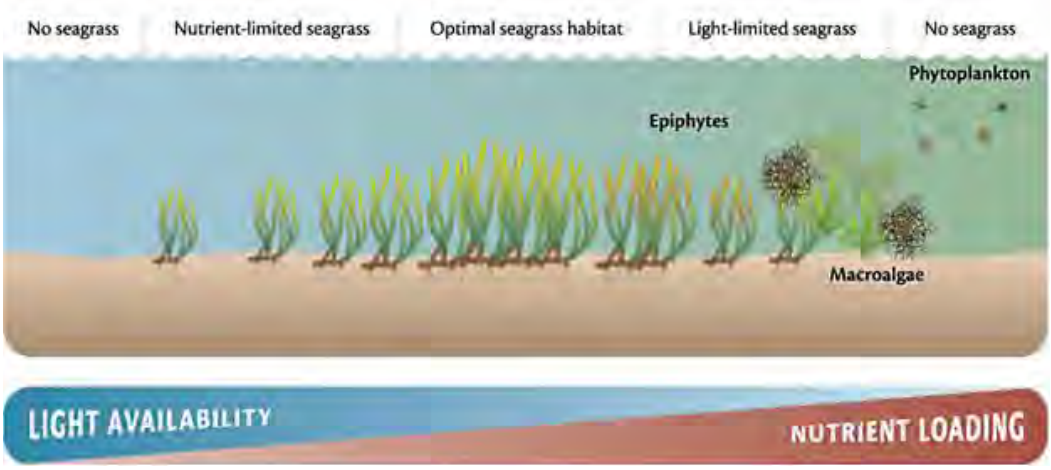


Figure 7-4: Conceptual Model Showing Impacts of Nutrient Loading & Suspended Sediments on Seagrasses (Source: Dennison *et al.*, 2009)

7.2.1.4 Macroalgae

Macroalgae are multi-celled plants that derive all their nutrients directly from the surrounding water column through their tissue. They are almost always strictly benthic algae, which are permanently attached to the seabed or a solid substratum such as rocky reef, boulders, seawalls, jetty pilings, mooring lines, etc. The most commonly observed species of macroalgae in Port Hacking include kelp (*Ecklonia radiata*), bubbleweed (*Sargassum spp.*), Neptune's necklace (*Hormosira banksii*), brown algae (*Dictyota dichotoma*, *Padina crassa* and *Colpomenia sinuosa*), sea lettuce (*Ulva spp.*) and red coralline (*Corallina officinalis*).

Only a few macroalgae, such as the introduced species *Caulerpa taxifolia*, can grow in soft sediments and anchor themselves with long root-like rhizoids.

Most macroalgae fall into three basic groups:

> Green algae such as sea lettuce;
> Brown algae that includes the large kelps; and
> Red algae, which is the most diverse group.

Macroalgae are an important as food and/or for shelter for a large range of fish, shellfish and other invertebrate species, and they often act as nurseries for juvenile fish.

Human activities contributing to widespread loss of macroalgae include direct losses due to mechanical damage, eutrophication, aquaculture, siltation, coastal structures (Millar, 2009). Macroalgae can be damaged directly by boating-related activities, dredging and reclamation, and indirectly by shading from foreshore structures such as pontoons and jetties.

Some of the large brown algae along the NSW coastline are experiencing a range retraction south as sea surface temperatures have increased over the last 60-70 years (Millar, 2007).

7.2.2 Riparian Habitats

Vegetated riparian buffer zones adjacent to streams, rivers or other water bodies greatly influence water quality and provide valuable habitat for aquatic and terrestrial species. Riparian buffer zones with dense vegetation also reduce the sediment loads carried into streams and water bodies, and protect shorelines and stream banks from erosion. Catchment vegetation mapping is provided in **Figure 7-5**.

The impacts of the removal of riparian and native vegetation include:

> Habitat destruction leading to loss of local populations of individual species;
> Fragmentation of habitats leading to smaller, isolated communities with lower resilience to further impacts compared to dense, non-fragmented communities;
> Increased availability of space for the establishment of non-native species;

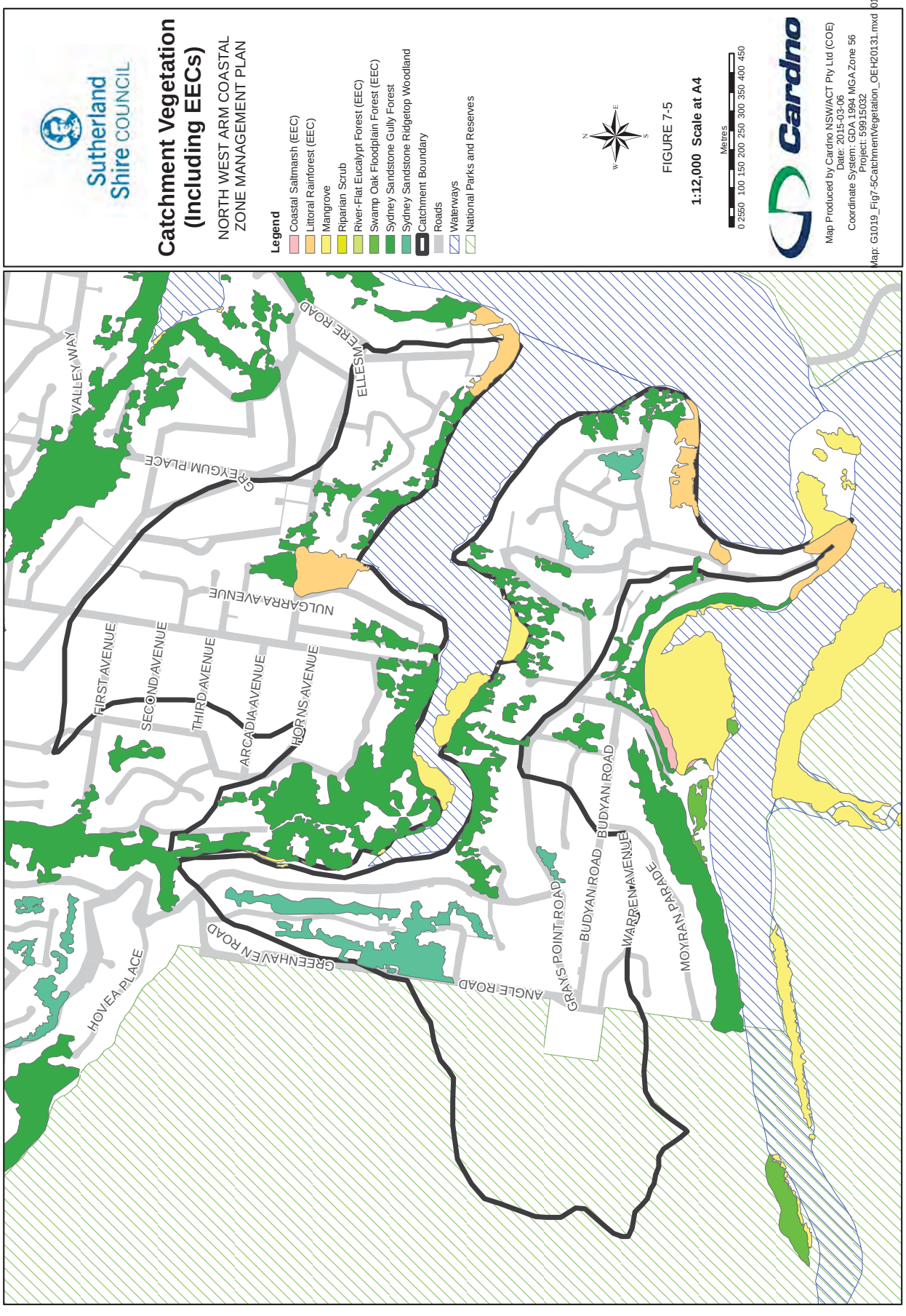
> Loss and disruption of ecological processes and function; and
> Changes in soil biota and structure leading to bank instability or erosion.

7.2.2.1 Riparian Condition Assessment

An assessment of the riparian condition in the North West Arm was conducted to evaluate the presence or absence and general condition of fringing vegetation types. The foreshore were categorised into areas of bushland, mangroves, weed hotspots, and non-native plantings and lawns. A summary of the results is presented in **Figure 7-6**.

Generally, the riparian vegetation of the North West Arm is natural bushland, with mangroves established in the upper estuary around the fluvial delta. Non-native plantings and lawns are particularly evident along the southern foreshore of the lower estuary and in sections of the upstream extent of the estuary. Weeds were more evident in the bushland of the upper estuary, and the mangroves show evidence of significant foraging by deer.

Noxious weeds of concern found around the estuary include *Lantana*, *Ligustrum lucidum* (Broad leaved privet), *Ligustrum sinense* (Small leaved privet), *Asparagus asparagoides* (Applied Ecology, 2012). Invasion, establishment and spread of *Lantana camara* is listed as a key threatening process under the *Threatened Species Conservation Act 1995* (TSC Act). Areas of weeds and exotics mapped by OEH are shown in **Figure 7-5.** Particular areas of concern include Marina Crescent reserve and Huskisson Street reserve.


Sutherland Shire COUNCIL
Catchment Vegetation (Including EECs)
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Coastal Saltmarsh (EEC)
Littoral Rainforest (EEC)
Mangrove
Riparian Scrub
River-Flat Eucalypt Forest (EEC)
Swamp Oak Floodplain Forest (EEC)
Sydney Sandstone Gully Forest
Sydney Sandstone Ridgetop Woodland
Catchment Boundary
Roads
Waterways
National Parks and Reserves
FIGURE 7-5
1:12,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350 400 450
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-06
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1019_Fig7-5CatchmentVegetation_OEH20131.mxd 01
VALLEY WAY
GREYGUM PLACE
ELLESMERE ROAD
NULGARRA AVENUE
FIRST AVENUE
SECOND AVENUE
THIRD AVENUE
ARCADIA AVENUE
NORNS AVENUE
HOVEA PLACE
GREENHAVEN ROAD
ANGLE ROAD
GRAYS POINT ROAD
BUDYAN ROAD
WARREN AVENUE
MOYRAN PARADE

Sutherland Shire COUNCIL

Riparian Condition Assessment

NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN

Legend

Type

- Non-native plantings and lawns
- Bushland
- Bushland with weeds evident
- Mangroves

N
W E
S

FIGURE 7-6

1:7,000 Scale at A4

Metres
0 25 50 100 150 200 250

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-05-13
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1016_Fig7-6_Riparian_Condition_Assessment.mxd 01

7.2.2.2 Sutherland Shire Watercourse Assessment

The Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation was completed in 2012 by Applied Ecology. The study assessed the condition of watercourses within the LGA and developed prioritised rehabilitation actions. Dents Creek catchment, Savilles Creek catchment and North West Arm catchment were assessed as part of this study. A number of works were proposed for each of these catchments summarised in **Table 7-1** below. Marina Crescent Reserve and the reserve at Kyogle Place are considered areas of high priority for rehabilitation for the North West Arm catchment.

Table 7-1: Watercourse Assessment Management Works (Applied Ecology, 2012)

Catchment	North West Arm	Dents Creek	Savilles Creek
Rock weir/rock chute	✓	✓	
Stabilise channel bed	✓		✓
Stabilise toe of bank	✓	✓	✓
Headwall/outlet protection	✓		
Re-shape/re-batter bank	✓	✓	✓
Build/rebuild retaining wall	✓	✓	
Install trash rack		✓	
Install end-of-pipe (Pratten) trap			✓
Maintain GPT/trash trap/rack	✓		
Treat noxious weeds	✓	✓	✓
Treat woody weeds	✓	✓	✓
Bush regeneration weed control	✓	✓	✓
Major weed control		✓	
Spot spray and plant		✓	
Maintenance weed control	✓	✓	✓
Supplementary planting	✓	✓	✓
Stabilisation planting	✓	✓	
Direct seed/brush mat		✓	
Install brush check dams	✓	✓	
Jute matting		✓	
Install coir logs	✓		
Other, e.g. Fencing		✓	

Priority areas for conservation and/or rehabilitation are generally provided for through the Bushcare and Greenweb programs. These programs are discussed further in **Section 7.3.1.3**. Potential management options for riparian vegetation include:

> Management of feral deer either by culling or exclusion measures such as fencing;
> Targeted weed management activities such as those outlined in the Watercourse Assessment;
> Rehabilitation of bushland areas;
> Education of landowners: native plantings, weed control activities, care of native vegetation; and
> Engagement with local Bushcare groups.

7.3 Estuarine Biodiversity

This section provides a review of the elements of the biodiversity in the North West Arm that are of conservation significance, and how they are protected under the State and Federal legislation.

The term ‘threatened species’ refers to any species, population or ecological community, and its associated habitat, defined and listed under Schedules 4 or 5 of the *Fisheries Management Act 1994* (FM Act),

Schedules 1 or 2 of the TSC Act, or Subdivisions C or D of the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act). This assessment also includes any species listed as protected under the FM Act, TSC Act and *National Parks and Wildlife Act 1974* (NP&W Act).

7.3.1 Estuarine Habitat Conservation

7.3.1.1 Protected Communities

The FM Act provides for the protection of ecologically important communities, habitats and species. Due to their ecological significance, both seagrasses and mangroves are protected in NSW under Division 4 of the FM Act (Part 7) and are specifically dealt with as "protected marine vegetation". A permit is required from NSW DPI to undertake works or activities that may harm them.

In addition, populations of *Posidonia* in Port Hacking, Botany Bay, Pittwater, Brisbane Water, Lake Macquarie and Sydney Harbour have suffered such a large reduction in abundance and geographic distribution that they are also listed as an endangered population under the FM Act.

7.3.1.2 Endangered Ecological Communities

Vegetation mapping indicates that Coastal Escarpment Littoral Rainforest is present within Marina Crescent Reserve, along the foreshore at the entrance to the estuary at Coopernook Avenue and near Mansion Bay (**Figure 7-5**). This community is listed as critically endangered under the EPBC Act (listed as Littoral Rainforest and Coastal Vine Thickets of Eastern Australia) and listed as an Endangered Ecological Community (EEC) under the TSC Act.

7.3.1.3 Sutherland Shire Development Control Plan

Chapter 4 of the DCP relates to Natural Resource Management and outlines the objectives and controls for Council's Greenweb program. The Greenweb program identifies key areas of bushland habitat in the Shire and establishes corridors to connect to help maintain healthy populations and diversity (SSC, 2015a). It targets private property owners within the Greenweb network, complementing the Bushcare program which focusses on bush regeneration on public lands.

Council offers Greenweb grants to property owners to support ecological restoration work on bushland such as (SSC, 2015b):

- The removal of invasive bushland weeds;
- Regeneration and re-vegetation of natural bushland with local native flora;
- Bank and slope stabilisation; and
- Habitat creation and/or protection.

7.3.2 Threatened and Protected Species and Populations

In order to collate a list of threatened and protected fauna species within the North West Arm relevant State and Commonwealth threatened species databases were searched, including the BioNet database and the EPBC Protected Matters Search Tool. Searches were carried out in January 2015 for species of fish, mammals, reptiles and birds, endangered populations and communities within the Sutherland Shire LGA.

Searches returned records for a range of threatened species, including 33 plants, two fish, six amphibians, 71 birds, 14 mammals (terrestrial and marine), seven reptiles and four shark species listed under the TSC, FM and/or EPBC Acts that either have previously, or have potential to occur within the LGA (**Table 7-2**); for the complete list of species refer to **Appendix D**). In addition, numerous migratory species (both terrestrial and marine) protected under the EPBC Act were also identified as having been previously recorded in, or having the potential to utilise the study area for the purposes of feeding, resting, reproducing or as part of a migratory route.

It is important to note the limitations of these database searches. Whilst the BioNet database returns records of actual observations within the search area, the record may represent a species that was passing through the area or is not otherwise resident in the area. In addition, the record may be from an individual sighting some years ago. In contrast, the EPBC Protected Matters Search Tool returns results based on the potential occurrence of species based on their potential distribution, rather than actual records.

During the community consultation several residents reported annual visit to the area by a fur seal (likely an Australian Fur Seal), although this record was not identified in the database. Residents have also observed turtles in the area.

Table 7-2: Summary of Threatened and Protected Species Records for the LGA

Common Name	Scientific Name	EPBC Act	TSC Act	FM Act
Fish				
Australian Grayling	*Prototroctes maraena*	V	-	-
Black Rockcod, Black Cod	*Epinephelus daemelii*	V	-	
Frogs				
Giant Burrowing Frog	*Heleioporus australiacus*	V	V, P	-
Green and Golden Bell Frog	*Litoria aurea*	V	-	-
Littlejohns Tree Frog, Heath Frog	*Litoria littlejohni*	V	-	-
Stuttering Frog	*Mixophyses balbus*	V	-	-
Growling Grass frog	*Litoria raniformis*	V	-	-
Birds				
White-fronted Chat	*Epthianura albifrons*	-	T, V. P	-
Regent Honeyeater	*Anthochaera phrygia*	E	E, P	-
Australasian Bittern	*Botaurus poiciloptilus*	E	-	-
Black Bittern	*Ixobrychus flavicollis*	-	V, P	-
Eastern Bristlebird	*Dasyornis brachypterus*	E	-	-
Swift Parrot	*Lathamus discolor*	E	-	-
Migratory Wetland Species				
Common Sandpiper**	*Actitis hypoleucos*	T, C, J, K	P	-
Ruddy Turnstone**	*Arenaria interpres*	T, C, J, K	P	-
Sanderling**	*Calidris alba*	T	-	-
Great Knot**	*Calidris tenuirostris*	T, C, J, K	-	-
Terrestrial and Marine Mammals				
New Holland Mouse, Pookila	*Pseudomys novaehollandiae*	V	P	-
Grey-headed Flying Fox	*Pteropus poliocephalus*	V	V, P	-
Spotted-tailed Quoll	*Dasyurus maculatus*	E	V, P	-
Greater Broad-nosed Bat	*Scoteanax rueppellii*	-	V, P	-
Large-eared Pied Bat, Large Pied Bat	*Chalinolobus dwyeri*	V	-	-
Southern Brown Bandicoot	*Isoodon obesulus*	E	-	-
Brush-tailed Rock wallaby	*Petrogale penicillata*	V	-	-
Plants				
Strapweed	*Posidonia australis*	E	E	E
Bynoe's Wattle, Tiny Wattle	*Acacia bynoeana*	V	E, P	-
Yellow Gnat-orchid	*Genoplesium baueri*	E	E, P	-
Woronora Beard-heath	*Leucopogon exolasius*	V	V	-
Deane's Melaleuca	*Melaleuca deanei*	V	V, P	-
Thick-lipped Spider-orchid, Daddy Long-legs	*Caladenia tessellata*	V	E, P	-
Thick-leaf Star-hair	*Astrotricha crassifolia*	V	-	-
Reptiles				
Green Turtles***	*Chelonia mydas*	V	-	-
Loggerhead Turtle****	*Caretta caretta*	E	-	-

P = Protected; V = Vulnerable; CE = Critically Endangered, E = Endangered; M = Migratory, T = Threatened, C = China Australia Migratory Bird Agreement (CAMBA), J = Japan Australia Migratory Bird Agreement (JAMBA), K = Republic of Korea Australia Migratory Bird Agreement (ROKAMBA)

* = Species or species habitat may occur within area; ** = Roosting known to occur within area; *** = Foraging, feeding or related behaviour known to occur within area; **** = Breeding likely to occur within area

7.3.3 Introduced Species

'Introduced' marine and terrestrial species have the potential to displace endemic Australian species and consequently alter ecosystems. Marine species may be spread via ballast water or attached to hulls of vessels (in particular sailing boats), or via accidental release, and once established in an area they may reproduce. There are three schedules of introduced marine species in Australia (Hewitt & Martin, 1996, 2001):

- Schedule 1 – Australian Ballast Water Management Advisory Committee;
- Schedule 2 – Marine pest species that pose a threat to Australia; and
- Schedule 3 – Known or likely exotic marine species in Australian waters.

Some introduced species have been declared noxious under the FM Act. The invasive green alga, *Caulerpa taxifolia*, has been declared a Schedule 1 noxious marine pest and NSW DPI have developed a control plan in response to outbreaks, highlighting the need to minimise any disturbance to *C. taxifolia*, because fragmentation of the plant is the main method by which this alga spreads and establishes itself into new areas. Due to its hardiness, ability to colonise from fragments and rapid growth rate, it can out-compete and smother seagrasses and other native aquatic flora. Mapping of *C. taxifolia* has been conducted within Port Hacking, however, the North West Arm fell outside the boundaries of mapped areas so it is not known if it occurs in the estuary. Given the fast-spreading nature of *C. taxifolia*, it is vital to incorporate mitigation measures for *C. taxifolia* in future coastal zone planning and management within North West Arm.

In addition to marine species, there are at least nine species of introduced mammals reported within the Royal National Park adjacent to North West Arm. These include cats, dogs, pigs, house mice, brown and black rats, rabbits, foxes, fallow deer and Javan rusa deer. There are also a number of species of introduced birds. Of the bird species, the mallard duck, muscovy duck and various hybrids interbreed with native species and need to be eradicated to prevent further loss of genetic integrity of these native species, notably the black duck. The fallow and Javan rusa deer are the remnant survivors of several species introduced to the Royal National Park early last century. These animals have a considerable impact (via trampling and digging, especially on saltmarsh and mangrove communities within Port Hacking) on vegetation structure, regeneration of native species and soil stability. Herbivory and environmental degradation by feral deer is listed as a key threatening process under the TSC Act. Furthermore, European honeybees present in the general study area compete with and displace native animals, particularly native bees, nectar feeding birds and small mammals and can inhibit the ecological processes of native plants. Competition from feral honey bees is also listed as a key threatening process (TSC Act).

7.4 Climate Change Impacts on Estuarine Ecosystems

Climate change projections, if realised, have the potential for detrimental impacts on estuarine ecosystems, including in the North West Arm. A review of the climate change science is provided in **Section 5.6**, noting that estuarine ecology will be more significantly impacted by shifts in more regularly occurring and day-to-day climatic factors, rather than changes to extreme events.

Sea level rise associated with climate change has the most potential to result in regular and/or permanent inundation of low lying coastal areas, leading to the loss of intertidal habitat, mudflats and estuarine vegetation. Exacerbating this impact and limiting the ability of vegetation communities and habitat types to migrate with rising sea levels, is the modified coastline and other areas of naturally steep foreshore in the North West Arm. Foreshore constructions such as seawalls prevent the landward migration of terrestrial and marine species within the inundated intertidal habitats and estuarine vegetation potentially leading to the loss of these species (Rossington, 2008).

The future intertidal zone in the North West Arm has been mapped by contouring the future MHWS level (see **Figure 7-7**). Potential obstacles to the landward migration of intertidal habitats in the estuary include seawalls, boatsheds and houses.

The more regular inundation of vegetated foreshore land will favour some species more than others. *Casuarina,* for example, is found in the upper estuary. *Casuarina* is generally tolerant to waterlogging and salinity (Barrett-Lennard, 2003), although permanent inundation may result in lethal or sub-lethal impacts due to inundation with saline water. Recruitment or germination of *Casuarina* seeds are likely to be negatively impacted by waterlogging which has been found to generally inhibit seedling growth (Clarke and

Hannon, 1970). In contrast, *A. marina* seedlings have high salt tolerances and a tolerance for wet soils (Clarke and Hannon, 1970). This suggests that mangrove encroachment into other vegetation communities may occur under climate change conditions.

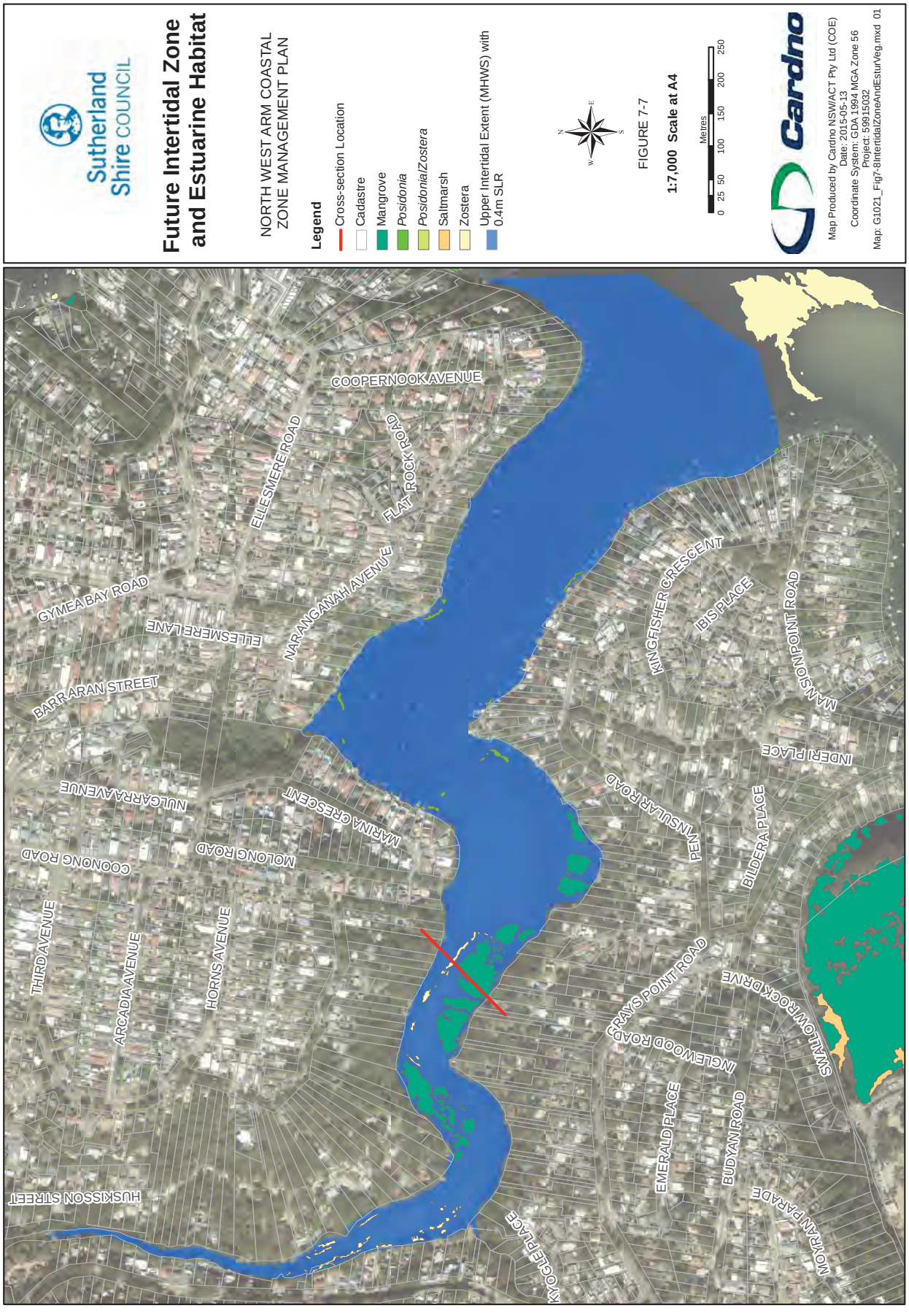
Seagrass will also be impacted by rising sea levels due to a decline in the light penetration and resultant shift in the distribution of available substrate suitable to support seagrass growth.

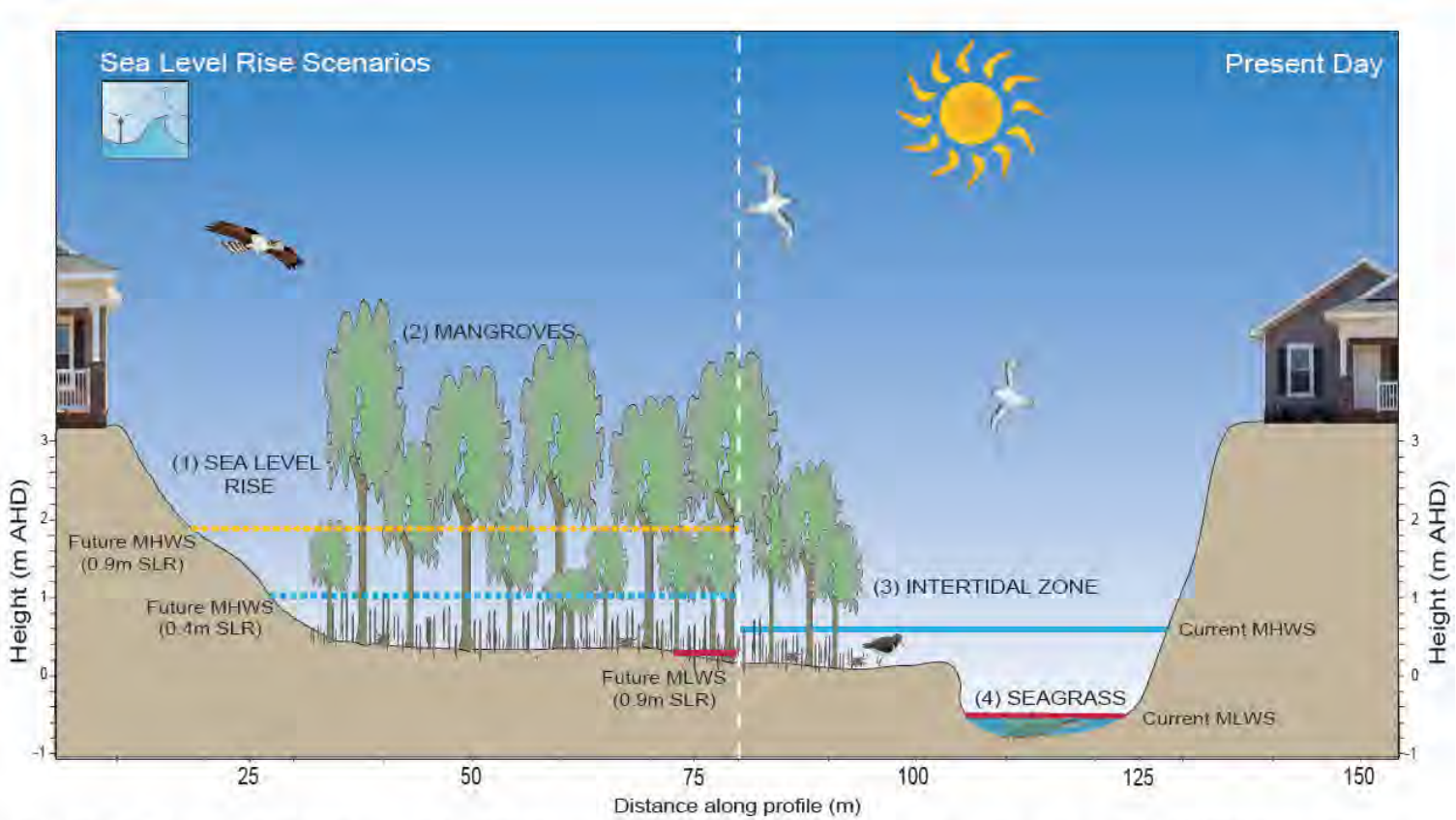
In creek systems such as Saville and Dents Creek, sea level rise as a result of climate change may lead to salt water intrusion of groundwater, thereby permanently altering freshwater ecosystems and impacting the associated aquatic flora and fauna reliant on freshwater conditions.

Changes to tidal inundation patterns may negatively impact on a range of species. Where intertidal sand flats are permanently inundated, this may result in a loss of habitat for wading birds, including threatened and migratory species such as Common Sandpipers, Ruddy Turnstones, Sanderlings and Great Knots.

Predicted higher air temperatures may result in increased evaporation and lowered sediment moisture. This decrease in sediment moisture contributes to its mobilisation potential (i.e. ability to be transported to other areas of the estuary), and combined with increased intensity of storm or wind events, may result in increased sedimentation loads within the estuary leading to declines in water quality. On a broader scale, higher sea surface temperatures (see **Section 5.6**) can impact nutrient cycling and primary productivity processes, with these impacts potentially magnified in enclosed estuary systems (Berelson *et al.* 1998, OzCoasts 2008, and Sharples *et al.*, 2008).

Figure 7-8 is a conceptual model that illustrates the potential impacts of sea level rise on ecosystems in the North West Arm. It shows a cross section extracted from the Digital Elevation Model of the estuary, based on a line drawn roughly from the terminus of Marina Crescent across the estuary and intertidal sandflats to the southern shoreline in a south-westerly direction (as shown in **Figure 7-7**). The features shown on the figure, including the present day and future water levels, extent of the mangroves and seagrass beds, and estuary bed and banks are based on their actual locations.


Sutherland Shire COUNCIL
Future Intertidal Zone and Estuarine Habitat
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Cross-section Location
Cadastre
Mangrove
Posidonia
Posidonia/Zostera
Saltmarsh
Zostera
Upper Intertidal Extent (MHWS) with 0.4m SLR
N
W
E
S
FIGURE 7-7
1:7,000 Scale at A4
Metres
0 25 50 100 150 200 250
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-05-13
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1021_Fig7-8IntertidalZoneAndEsturVeg.mxd 01
COOPERNOOK AVENUE
ELLESMERE ROAD
FLAT ROCK ROAD
NARANGANAH AVENUE
GYMEA BAY ROAD
ELLESMERE LANE
BARRARAN STREET
NULGARRA AVENUE
MARINA CRESCENT
COONONG ROAD
MOLONG ROAD
THIRD AVENUE
ARCADIA AVENUE
HORNS AVENUE
HUSKISSON STREET
KINGFISHER CRESCENT
IBIS PLACE
MANION POINT ROAD
INDERI PLACE
INSULAR ROAD
PEN
BILDERA PLACE
RAY'S POINT ROAD
INGLEWOOD ROAD
SWELLOW ROCK DRIVE
EMERALD PLACE
BUDYAN ROAD
MOYRAN PARADE
KYOOGLE PLACE



(1) SEA LEVEL RISE associated with climate change has the potential to result in more regular or permanent inundation of low lying areas, leading to loss of intertidal habitat, sandflats and estuarine vegetation. The steep banks and proximity to development limit the ability of mangroves to migrate with rising sea levels.

(2) MANGROVES provide habitat for small fish (at high tide) who feed, find shade and refuge from predators amongst the trees. In addition, mangroves support a wide range of invertebrate species. These habitats act as a buffer against pollution from surface runoff. They are also very productive habitats cycling nutrients and carbon.

(3) The INTERTIDAL sandflats provide habitat for fish and wading birds, who feed on invertebrates living in the sand. The extent of suitable habitat for wading birds will decrease as the sandflats are inundated under a SLR scenario.

(4) SEAGRASS beds are productive habitats, contributing to nutrient cycling, stabilising sediments and reducing turbidity by facilitiating sedimentation. They form essential habitat for juvenile fish and invertebrates. Under SLR conditions, their distribution may shift.

Figure 7-8: Conceptual Model of Sea Level Rise Impacts on Estuarine Ecosystems

7.5 Estuarine Health Status

The estuarine ecosystems within the North West Arm are in a modified condition due to historic changes in catchment land use (NLWRA, 2001). Based on the findings in this study, the general ecosystem health of the estuary may deteriorate periodically (e.g. following catchment flow events), particularly in the upper estuary areas subject to lower flushing rates. Human activities in the catchment have the potential to impact indirectly on the health of the ecosystem, while other activities conducted in the waterway and along the foreshores have a more direct impact on the estuary health.

A number of key issues have been identified that have negatively impacted on estuarine condition historically, or continue to do so:

- Clearing of riparian vegetation leading to bank destabilisation, loss of habitat and introduction of sediments and nutrients to the waterway;
- Clearing of terrestrial vegetation resulting in significantly altered catchment processes:
  - Increasing the volume of runoff,
  - Changing the timing of delivery of runoff to the estuary, and
  - Increasing nutrient and sediment loads;
- Water pollution from urban stormwater runoff:
  - Litter and organic (from gardens, street trees and green open spaces),
  - Sediment and suspended solids from construction sites and other un-vegetated areas,
  - Nutrients from fertilisers and detergents,
  - Nutrients and faecal contamination from animal faeces,
  - Heavy metals (lead, copper, zinc) and oils from roadways and antifouling paint, and
  - Sewage and other pollutants from shipping and waterway activities.

The Estuarine Health evaluation process applied to the study area is based on the NSW Monitoring, Evaluation and Reporting (MER) program, conducted state-wide for estuaries and coastal lake ecosystems (Roper *et al.*, 2011), incorporating a modified version of the report card system defined in the *State of the Marine Environment Report* (Zann, 1995).

The detailed ecological health assessment for the North West Arm is provided in **Appendix E**. Water quality, foreshore condition, estuarine and riparian flora, and estuarine fauna indicators were assessed. In summary, the overall health of the estuary is fair to good. Nitrate and nitrite, copper and enterococci were identified as indicators of concern; however, this may not be representative of day to day water quality due to the paucity of water quality data available for analysis. Observed water quality may differ significantly towards the mouth of the estuary due to increased tidal flushing and a decline in the influence of catchment inflows.

7.6 Ecological Risk Assessment

The *Guide to Climate Change Risk Assessment for NSW Local Government* (OEH, 2011c) provides discussion on quantitative versus qualitative risk assessments, and notes that it is generally impractical to do a quantitative assessment of all risks due to the uncertainty associated with future climate change impacts. This is a particular issue for any assessment of potential future risk. The lack of data, particularly for some aspects of the estuary ecosystem, is also a challenge.

A qualitative ecological risk assessment has been undertaken to assess the likelihood and consequences of hazards, including predicted climate change impacts (where applicable), adversely influencing key attributes of the estuarine ecosystem. The general approach to the risk assessment was to:

- Assess the current vulnerabilities and areas of risk within the estuarine ecosystem (i.e. aspects that have low adaptive capacity);
- Identify the most significant pressures (or combination of pressures) impacting on these areas of risk and hence overall estuarine ecosystem health; and
- Identify level of risk for vulnerable estuarine habitats.

The detailed ecological risk assessment is provided in **Appendix E**. The following health indicators were assessed for both the current level of risk, and the future level of risk (with 0.4 m sea level rise):

- Water quality;
- Sediment quality and transport;
- Seagrass;
- Mangroves;
- Riparian vegetation; and
- Estuarine fauna.

The hazards in the present day generally present a medium risk to the health of the estuary, though there are several low risk hazards. The high risk hazards in the present day are the risk of infestation of the North West Arm with *C. taxifolia* and ongoing impacts due to presence of introduced flora and fauna (e.g. deer), with resultant decline in riparian vegetation condition and/or extent.

The level of risk increases in the future, with climate change and urban development acting as stressors. A range of hazards become high risk, particularly those hazards stemming from an increased likelihood of intense storm events.

7.7 Summary of Key Management Issues

The key management issues identified in **Sections 7.1-7.6** have been summarised in **Table 7-3**.

Table 7-3: Management Issues – Estuarine Ecosystems

Issue Description	Priority
Climate change impacts on built infrastructure, cultural heritage, and estuarine ecology.	Medium
Increasing development intensity in the catchment, with potential for additional losses of catchment vegetation and increase in proportion of impervious surfaces.	Medium
Loss of estuarine habitat (such as seagrass) as a result of human activities such as jetty construction, boating impacts, stormwater runoff etc.	Medium
Weed invasion.	High
Grazing and trampling of mangroves and riparian vegetation by deer.	Medium
Foreshore/bank erosion caused by deer.	Medium
Pest species occur in the catchment, with potential to displace, prey on and/or outcompete native species.	Medium
Degradation of mangroves due to improper storage of dinghies.	Medium
Potential spread of *C. taxifolia* into the North West Arm with resultant negative impacts on estuarine vegetation, seagrasses in particular. There is high potential for transfer of these infestations to currently unaffected areas due to high levels of boating in the study area.	Medium
The proliferation of seawall construction has resulted in a loss of riparian and intertidal habitat, resulting in loss of habitat connectivity.	Medium

7.8 Recommendations for Management

Table 7-4 provides a summary of recommendations for future management of estuarine ecosystems in North West Arm.

Table 7-4: Management Recommendations – Estuarine Ecosystems

Option ID	Management Recommendation
EE01	Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.
EE02	Support regional pest and weed control activities, including those conducted by Council, NPWS, LLS and DPI (Fisheries).

Option ID	Management Recommendation
CC01	Provide ongoing support for Bushcare groups.
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.
CC09	Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.
CC13	Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.
CP01	Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.
CP02	Gain a greater appreciation of the potential impacts of climate change on the estuarine ecosystems of North West Arm. Consider the need to develop a strategic plan to manage climate change impacts on biodiversity in the LGA.
WQ01	Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program. This option assumes that Council would contribute by undertaking the required monitoring at five sites in the catchment, incorporating both dry and wet weather sampling.

8 Community Uses

8.1 Introduction

The North West Arm is a highly valued asset for the local community, particularly for its amenity value and because of the contribution of natural bushland and riparian areas to its visual character. The estuary is an important recreational asset for residents, although public access to the foreshore is limited because the foreshore is predominantly in private ownership. Due to the importance of the North West Arm as a community asset there is a need for effective and targeted management of the estuary.

8.2 Land Tenure

Land tenure describes the ownership of a particular parcel of land or an asset (e.g. a stormwater channel). Land tenure is important from the perspective of implementation of the CZMP as consent must be obtained from the landowner prior to undertaking any works on their land, or that affects their asset(s). Permits or environmental approvals required to undertake works may also vary depending on the tenure status of the land in question.

The ownership and control of estuarine and coastal foreshore and submerged land is spread across a number of private landholders and Council, as shown in the example in **Figure 8-1**. Types of land tenure may include:

- Crown land, National Parks and Nature Reserves;
- Community land;
- Freehold land; and
- Land held under Native Title.

In addition, some legislation regulates activities in the tidal zone and may cross multiple tenures. An example would be the FM Act, which regulates activities impacting on aquatic species and protected marine vegetation, and hence applies across the subtidal and intertidal zones (see **Figure 8-1**). Matters affecting navigation are regulated by Roads and Maritime whereas all land below MHWS is Crown land.

It is apparent that there are complex issues around land tenure and legislative jurisdiction around estuaries, particularly in the intertidal zone. The various types of land tenure are discussed briefly below with reference to the North West Arm.

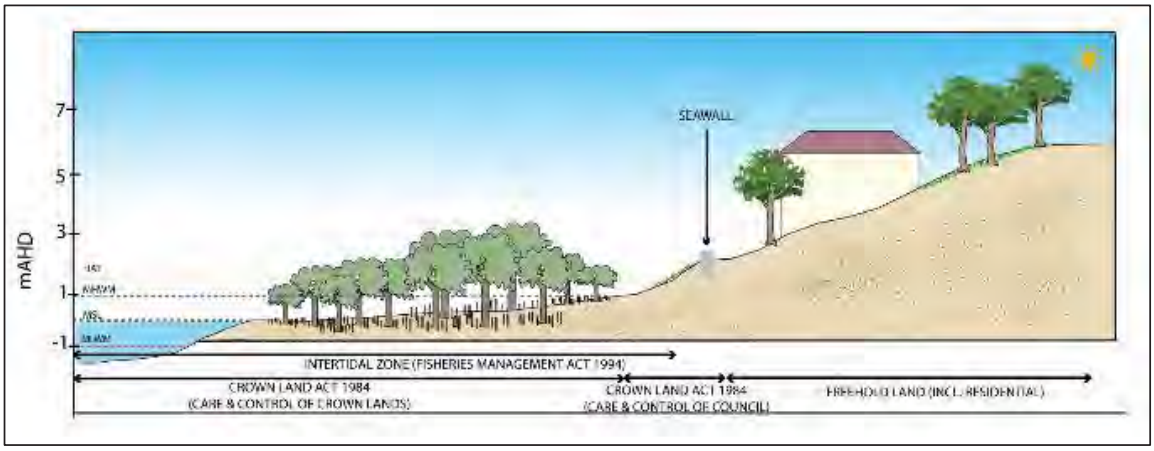


Figure 8-1: Typical Cross Section of Intertidal Land Showing Tenure Status

8.2.1 Crown Land

Crown land is land vested in the Crown and managed by the Crown Lands Division (CLD) of NSW DPI under the *Crown Lands Act 1989.* Crown lands are managed for public recreation and enjoyment, environmental conservation and heritage conservation purposes. In many parts of the State, coastal lands commonly include Crown lands. In addition, lands below the MHWS mark are also classified as Crown land. The management of Crown land may be undertaken by the CLD or by a trustee on behalf of CLD.

Where an individual or organisation proposes to undertake an activity, build a structure or use Crown land, they are required to apply for a lease or licence from the CLD. This includes the issue of domestic waterfront licences for the use of submerged and tidal Crown land where there is direct access to Crown land. This type of licence would cover facilities such as jetties, boatsheds or boat ramps. In the case of domestic waterfront licences, the CLD aims to ensure that waterways are not overcrowded and that the public's right to foreshore access is maintained.

8.2.2 Community Land

Community lands are public lands vested in, or otherwise under the control of, Council as identified under the *Local Government Act 1993*. This excludes land identified under the *Crown Lands Act 1989.* Community land is open to the public and may include parks, reserves and sports grounds. Land owned by Council is mapped in **Figure 8-2**.

Plans of Management (PoMs) have been prepared by Council for open spaces and parks under their care and control in accordance with the *Local Government Act 1993,* including:

- *Port Hacking Integrated Environmental Management Plan* (SSC, 2007);
- *Natural Areas: North West Arm Catchment PoM* (SSC, 2009a);
- *Asset Management Plan, Open Space 2013/14* (SSC, 2013); and
- *General Community Use PoM* (SSC, 2009b).

These PoMs provide an overview of the tenure status, physical infrastructure, ecology, geology, and cultural heritage values of the community land in the North West Arm and the Sutherland Shire in general. They also outline a management framework including desired outcomes/objectives, permissible activities and management strategies for implementation.

8.2.3 Native Title

Native title is the recognition by Australian law that Indigenous people have rights and interests in their land under their traditional laws and customs. Generally, native title cannot supersede the rights held by others, for example, native title may not be conferred over freehold land. However, native title does provide recognition of the rights and interests held under traditional law and custom.

Native Title may be conferred under the Commonwealth *Native Title Act 1993* or the NSW *Land Rights Act 1983*. Indigenous Land Use Agreements (ILUAs) may also be established. ILUAs are voluntary agreements between native title holders and others about the ongoing use of land and water; they effectively explain how native title can co-exist with other interests within the determination area.

The NSW *Native Title Act 1994* was introduced to work in conjunction with the Commonwealth *Native Title Act 1993*. Native Title claims, registers and ILUAs are administered under the Act.

A review of the mapping provided by the Native Title Tribunal indicates that there are no active native title claims in the study area, and as such there are no operational ILUAs present.

8.2.4 Climate Change Impacts on Land Tenure

Land boundaries may be described by either "right line" (or fixed) boundaries, or "ambulatory" boundaries. Ambulatory boundaries include those that are defined by reference to the MHWS or some other water level (e.g. HAT). Crown land, for example, is land that is seaward of the MHWS line. Climate change may impact land tenure as the MHWS line moves landward from its present day position due to sea level rise.

Various legal rulings have established that where land is gradually eroded by the sea, or covered by rising sea levels, a "right-line" boundary originally defined by survey does not survive and any part that comes to lie below MHWS line ceases to be part of the land title and reverts to the Crown (Corkill, 2013).

Some of the potential impacts of climate change include sea level rise and shoreline recession. These processes will gradually move the MHWS landward. An increasing number of land titles along the coast will lose land, as discussed by Corkill (2013). Planned retreat, the discontinuation of new development on vulnerable lands and the relocation of existing development, may be the only long-term solution to climate change impacts on coastal lands (Corkill, 2013).

8.2.5 Community Concerns

The majority of the land in the catchment and along the estuary foreshores is freehold land (**Figure 8-2**). As such, there is a general lack of public access to the foreshore and, consequently, to the waterway (refer **Section 8.5.1**). This can have implications for management, particularly when responsibility for a contiguous reach of land is divided across a number of landowners.

The community survey identified concerns relating to the encroachment of development or related activities from freehold land onto public land, with potential for negative impacts on the ability of the public to utilise the available access. These concerns include:

- Private landowners encroaching on adjacent public access areas “making these areas their own”;
- Storage of private watercraft in public access ways, limiting access to the foreshore;
- The establishment of tracks through mangroves and mud flats from private properties to the waterway (refer **Section 7.2.1.2**); and
- The construction of unauthorised structures such as retaining walls, jetties, paths or other structures into the estuary.

Such activities are commonly conducted in order to provide improved access to the waterway from a private property. This is an important issue as it commonly comes at the expense of the public right of way to and along the foreshore. As noted in **Section 8.2.1**, foreshore structures over water such as jetties and boat ramps are licenced by Crown Lands. Unauthorised foreshore structures may not have been subject to appropriate consideration of the potential impacts on the environment, which may include negative impacts on foreshore stability, foreshore vegetation and public safety. This type of issue is difficult to manage as enforcement and regulation are challenging, particularly when there is insufficient historical documentation to confirm that the activity was illegal.

8.3 Visual Amenity

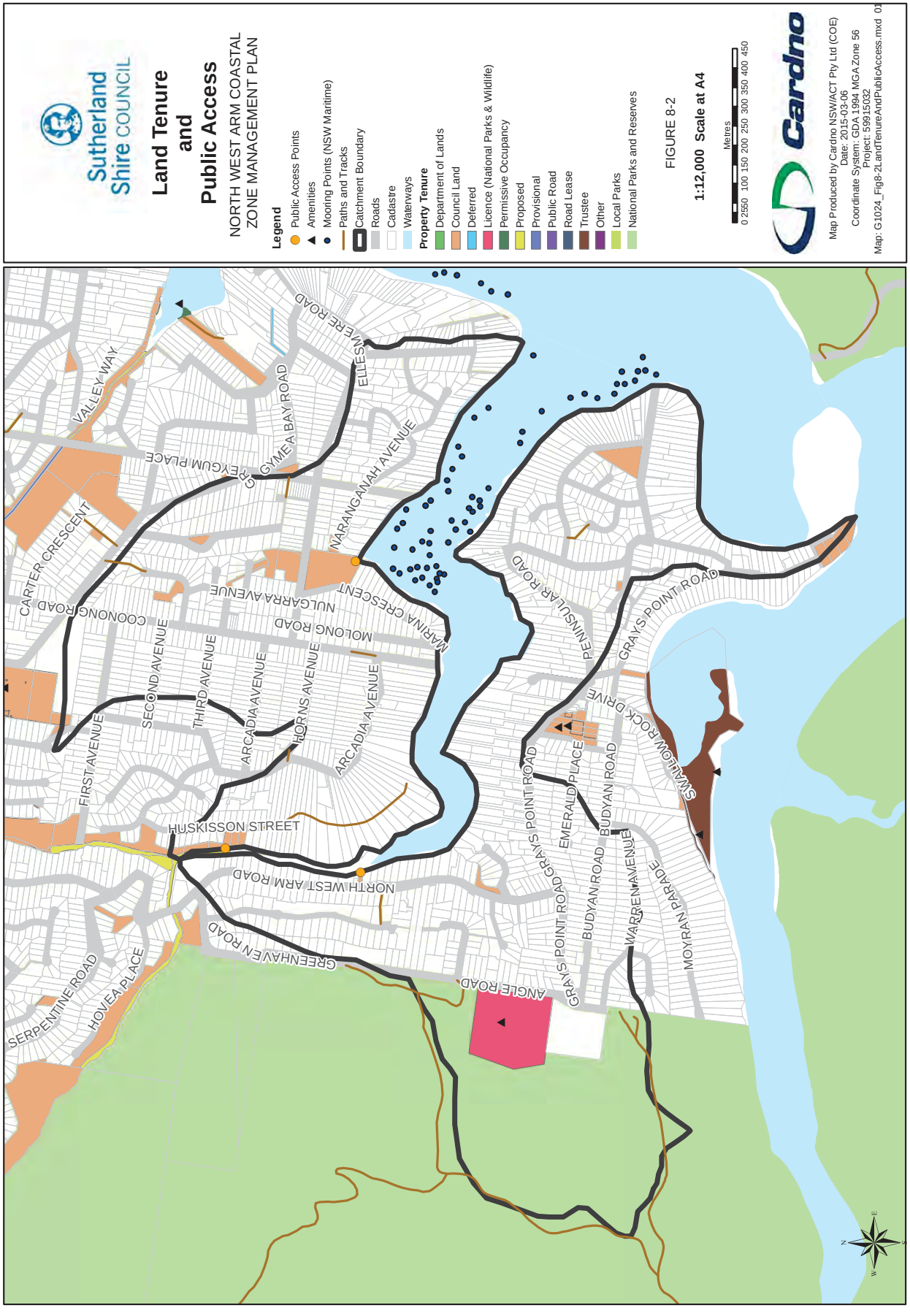
Visual amenity describes the visual character of the estuary foreshore, as perceived by the viewer. The visual character is a significant asset and the natural beauty of the estuary is highly valued by residents. Management of the landscape, built form and natural areas around the estuary is essential to ensure the conservation and/or improvement of the visual character of the North West Arm.

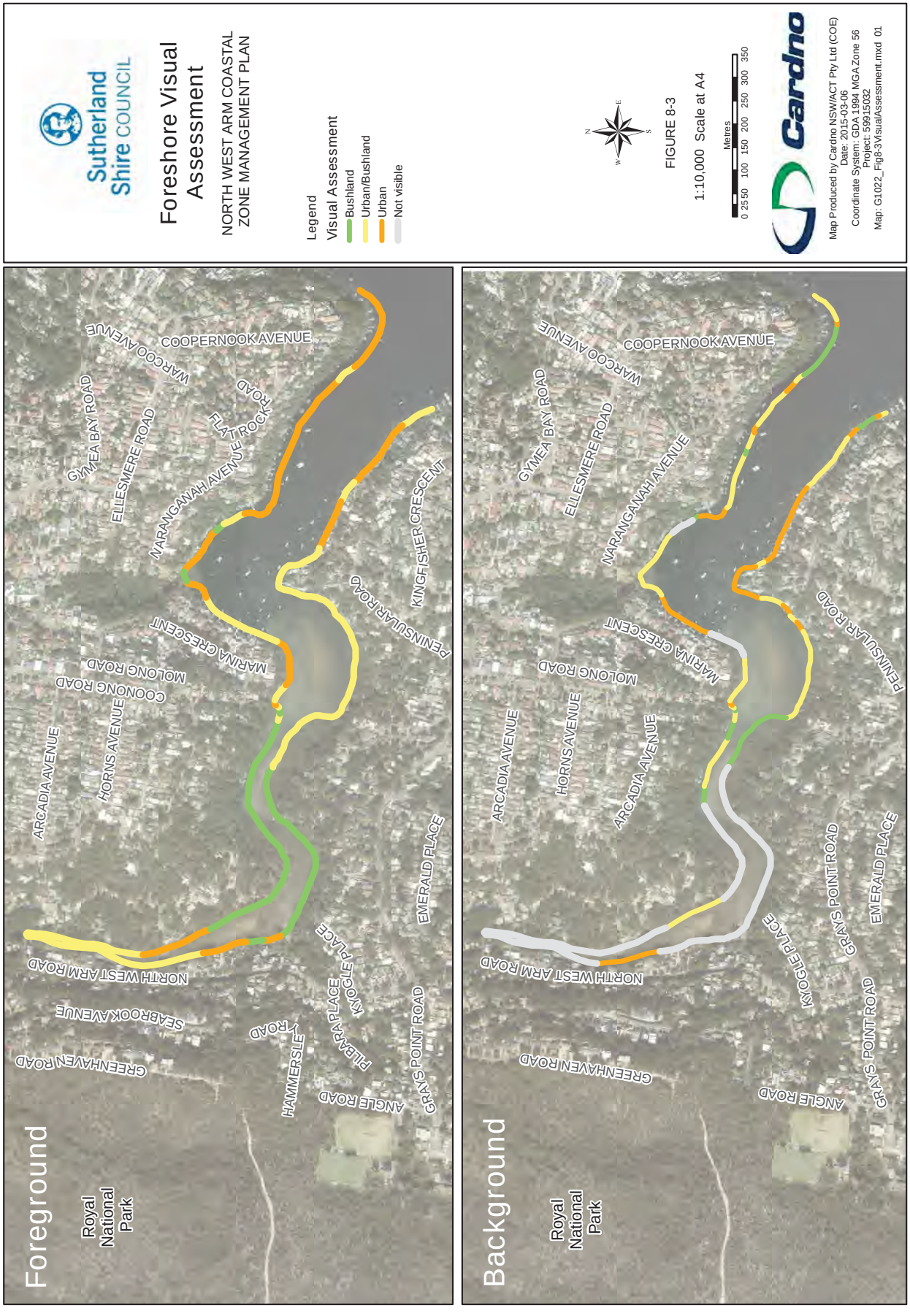
The previous visual assessment of the North West Arm (PPK and Clouston, 2001) described the scenic quality of the estuary as having a conflicting mix of built and natural form. The description of the built environment identifies the developments along Goldfinch Place, Peninsula Road and Marina Crescent as not being sympathetic with the landscape context, and the large range of ancillary activity (such as stairs and swimming pools) as detracting from the scenic quality of the estuary (PPK and Clouston, 2001). The natural environment is described as predominantly native and intact especially around the headland, inner bay areas and the ridgeline, although the shoreline had been significantly altered due the construction of seawalls, jetties and boat ramps.

As part of this study Cardno re-assessed the current visual amenity of the shoreline in accordance with the methodology described in **Section 3.2.4** and compared the results to the previous study by PPK and Clouston (2001) to identify any changes in the visual character of the North West Arm. The shoreline and ridgeline of the estuary were allocated to one of three categories, as mapped in **Figure 8-3**:

- Urban;
- Urban / bushland (or semi-urban); and
- Bushland (or natural).

It was determined that the visual amenity of the North West Arm has not changed significantly since the previous assessment of scenic quality. A balance of natural and urban (built form) features is still in evidence along the length of the estuary (**Figure 8-4**).


Sutherland Shire COUNCIL
Land Tenure and Public Access
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Public Access Points
Amenities
Mooring Points (NSW Maritime)
Paths and Tracks
Catchment Boundary
Roads
Cadastre
Waterways
Property Tenure
Department of Lands
Council Land
Deferred
Licence (National Parks & Wildlife)
Permissive Occupancy
Proposed
Provisional
Public Road
Road Lease
Trustee
Other
Local Parks
National Parks and Reserves
FIGURE 8-2
1:12,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350 400 450
Cardno
Map Produced by Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-06
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1024_Fig8-2LandTenureAndPublicAccess.mxd 01
GYMEA BAY ROAD
ELLESMERE ROAD
VALLEY WAY
GREYGUM PLACE
CARTER CRESCENT
NARANGANAH AVENUE
COONONG ROAD
NULGARRA AVENUE
MARINA CRESCENT
MOLONG ROAD
SECOND AVENUE
THIRD AVENUE
ARCADIA AVENUE
FIRST AVENUE
HUSKISSON STREET
NORTH WEST ARM ROAD
GREENHAVEN ROAD
SERPENTINE ROAD
HOVEA PLACE
ANGLE ROAD
GRAYS POINT ROAD
EMERALD PLACE
BUDYAN ROAD
WARREN AVENUE
MOYRAN PARADE
PENINSULAR ROAD
SWALLOW ROCK DRIVE


Sutherland Shire COUNCIL
Foreshore Visual Assessment
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Visual Assessment
Bushland
Urban/Bushland
Urban
Not visible
FIGURE 8-3
1:10,000 Scale at A4
Metres
0 25 50 100 150 200 250 300 350
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-03-06
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1022_Fig8-3VisualAssessment.mxd 01
Foreground
Background
Royal National Park
COOPERNOOK AVENUE
WARCOO AVENUE
GYMEA BAY ROAD
ELLESMERE ROAD
NARANGANAH AVENUE
FLAT ROCK ROAD
KINGFISHER CRESCENT
PENINSULAR ROAD
MARINA CRESCENT
MOLONG ROAD
COONONG ROAD
HORNS AVENUE
ARCADIA AVENUE
NORTH WEST ARM ROAD
SEABROOK AVENUE
GREENHAVEN ROAD
HAMMERSLEY ROAD
PILARRA PLACE
KYOGLE PLACE
ANGLE ROAD
GRAYS POINT ROAD
EMERALD PLACE

a) View towards Goldfinch Pl. and Kingfisher Cres.

b) View towards Marina Cres.

c) View towards Fernhill Pl. from the deep water

d) View towards the upper estuary from the deep water

Figure 8-4: Foreshore Visual Assessment Field Investigation Photos

Along the lower estuary foreshores, large modern houses, boatsheds and boat ramps contribute to the visual character, particularly along Goldfinch Place (**Figure 8-4a**) and Marina Crescent (**Figure 8-4b**). Natural bushland is visible on the ridgeline. The shoreline along Naranganah Avenue, Flat Rock Road and Coopernook Avenue were characterised as semi-urban maintaining a balance of urban and natural features as mature trees and shrubs have been retained along the foreshore and ridgeline.

Further into the estuary, upstream of the eight knot speed sign, the visual character of the estuary tends towards a more natural foreshore. The north-eastern shoreline along Arcadia Avenue is semi-urban, with natural bushland punctuated by boatsheds and stairways with some larger buildings visible (**Figure 8-4c**). The shoreline of the middle section of the estuary is largely hidden behind mangroves with natural bushland behind, particularly on the south-western shoreline (**Figure 8-4d**).

In the upper reaches of the estuary, the eastern shoreline is generally natural bushland with some boat ramps and buildings visible. The western shoreline tends towards a more urban character with buildings, swimming pools and balconies extending right up to the shoreline. The eastern shoreline is semi-urban with natural bushland, lawns and buildings visible.

Under the Sutherland Shire DCP, there are a number of development controls around landscaping and visual amenity, in addition to which any proposed development must consider the potential visual impacts on the surrounding environment as part of the impact assessment required under the EP&A Act.

Chapter 4 of the DCP, Natural Resource Management, outlines the objectives and controls relating to the following areas:

- Greenweb;
- Wetlands and Waterways;
- Threatened Species; and
- Tree and Bushland Vegetation.

The DCP also provides specific objectives relating to scenic and visual quality. These include:

> Prevent the degradation of visual amenity and scenic quality by requiring the retention and enhancement of vegetation in areas of high scenic quality;
> Ensure the preservation and enhancement of the natural character of foreshore areas;
> Preserve existing streetscape character;
> Preserve trees in areas where trees of a similar type or scale make a strong contribution to neighbourhood character;
> Retain individual trees which are local landmarks or which singularly make a positive contribution to the quality of the streetscape or locality;
> Ensure trees are retained along ridge tops where they provide a backdrop to development;
> Ensure remnant trees are retained throughout the urban area; and
> Provide an appropriate balance between residents' desire for views from their properties and the achievement of the objectives of this section.

As an important value of the estuary, the visual amenity and natural character should be protected and improved where possible. The following management options are recommended:

> Provide ongoing support for Bushcare groups, including the Marina Crescent Reserve group;
> Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas; and
> Develop a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.

8.4 Cultural Heritage

A desktop assessment was undertaken to identify the cultural heritage values and sites located in the study area, considering both Aboriginal and non-Aboriginal (European) heritage. Discussion is provided as to the potential opportunities and constraints (both in terms of cultural heritage and coastal processes) that are associated with the identified cultural heritage sites and values.

8.4.1 Aboriginal Cultural Heritage

Sutherland Shire is an area of significant Aboriginal cultural heritage. The Shire was originally inhabited by the Gweagal people, a Dharawal speaking clan (PPK and Clouston, 2001). Archaeological studies show occupation of the Port Hacking area for over 8,000 years (Albani and Cotis, 2013). Port Hacking contains many archaeological sites including middens, rock engravings, rock shelters, tool making grooves and other features.

SSC has mapped areas of Aboriginal Archaeological Sensitivity based on analysis of landforms and knowledge of Aboriginal occupation. Areas are mapped as having high, medium or low sensitivity. Sites of high sensitivity are typically associated with Hawkesbury sandstone terrain, where there is the greatest potential for overhanging rocks, cave formations or sandstone rock ledges and associated camp sites (SSC, 2014). The foreshore of the North West Arm is considered to have a high archaeological sensitivity.

A search of the AHIMS database returned records for 91 Aboriginal sites in or near the North West Arm catchment (see **Table 8-1**). A number of Aboriginal heritage sites and places of significance are located along the foreshore, which highlights the importance of the study area for Aboriginal people.

Table 8-1: AHIMS Records for the North West Arm (OEH, 2012; OEH, 2014c)

Site Feature	Description	No. of Records
Aboriginal Resource and Gathering	Related to everyday activities such as food gathering, hunting, or collection and manufacture of materials and goods for use or trade.	4
Art	Art is found in shelters, overhangs and across rock formations. Techniques include painting, drawing, scratching, carving engraving, pitting, conjoining, abrading and the use of a range of binding agents and the use of natural pigments obtained from clays, charcoal and plants.	12

Site Feature	Description	No. of Records
Artefact	Objects such as stone tools, and associated flaked material, spears, manuports, grindstones, discarded stone flakes, modified glass or shell demonstrating evidence of use of the area by Aboriginal people.	54
Burial	A traditional or contemporary (post-contact) burial of an Aboriginal person, which may occur outside designated cemeteries and may not be marked, e.g. in caves, marked by stone cairns, in sand areas, along creek banks etc.	1
Grinding Groove	A groove in a rock surface resulting from manufacture of stone tools such as ground edge hatchets and spears, may also include rounded depressions resulting from grinding of seeds and grains.	14
Habitation Structure	Structures constructed by Aboriginal people for short or long term shelter. More temporary structures are commonly preserved away from the NSW coastline, may include historic camps of contemporary significance. Smaller structures may make use of natural materials such as branches, logs and bark sheets or manufactured materials such as corrugated iron to form shelters. Archaeological remains of a former structure such as chimney/fireplace, raised earth building platform, excavated pits, rubble mounds etc.	2
Modified Tree	Trees which show the marks of modification as a result of cutting of bark from the trunk for use in the production of shields, canoes, boomerangs, burials shrouds, for medicinal purposes, foot holds etc, or alternately intentional carving of the heartwood of the tree to form a permanent marker to indicate ceremonial use/significance of a nearby area, again these carvings may also act as territorial or burial markers.	1
Potential Archaeological Deposit	An area where Aboriginal objects may occur below the ground surface.	4
Shell	An accumulation or deposit of shellfish from beach, estuarine, lacustrine or riverine species resulting from Aboriginal gathering and consumption. Usually found in deposits previously referred to as shell middens. Must be found in association with other objects like stone tools, fish bones, charcoal, fireplaces/hearths, and burials. Will vary greatly in size and components.	54
Stone quarry	Usually a source of good quality stone which is quarried and used for the production of stone tools.	1

It should be noted that the AHIMS search only includes information on Aboriginal objects and places provided to OEH. There may exist numerous Aboriginal objects or sites of cultural heritage value that have not been recorded on AHIMS.

Aboriginal cultural heritage is currently protected under the NP&W Act, and any activities that may impact on a site or feature listed in the AHIMS database must be assessed in accordance with the Due Diligence Guidelines (OEH, 2015). It is recognised that there is potential for previously unrecorded Aboriginal heritage items to occur in the study area, and this should be considered in any proposals in the study area.

It is noted that Aboriginal cultural heritage legislation is currently in a process of reform. It is expected that once complete a new standalone instrument will remove provisions in the current NP&W Act and create a new Act to manage Aboriginal cultural heritage.

8.4.2 Non-Aboriginal Cultural Heritage

European heritage is recognised and protected under a range of legislation:

- Locally significant heritage sites are protected under the EP&A Act which enables the local government with the power to protect items and places of heritage significance in the local area through LEPs and DCPs;
- State significant heritage are listed on the State Heritage Register and are protected under the *Heritage Act 1977*; and
- Commonwealth heritage places listed on the Commonwealth Heritage List and places of national heritage listed on the National Heritage List are protected under the EPBC Act.

A search of the Australian Heritage Database was conducted and returned no items of heritage significance within the suburbs of Gymea Bay and Grays Point. However, the Royal National Park, a portion of which lies

within the North West Arm catchment, is listed on the National Heritage List as a Listed Place (see **Figure 8-5**). A search of the NSW State Heritage Register returned no items listed under the *Heritage Act 1977*.

A number of places within the study area are listed in the LEP, three of which are within close proximity to the foreshore of the North West Arm Estuary:

> 152 North West Arm Road, House;
> 129 Peninsular Road, Grays Point – House, boatshed and seawall; and
> 38 Coopernook Avenue – Boatshed.

8.4.3 Climate Change

The potential impacts of climate change on estuarine processes are discussed in **Section 5.6**. Heritage items within the study area have the potential to be influenced by climatic changes, particularly those within or in close proximity to the foreshore and waterway. Negative climate change impacts on heritage items may include:

> Increased rate of structural decay through temperature / salinity changes (increased maintenance costs);
> Submergence of heritage items;
> Erosion of substrate (leading to partial or total loss of items); and
> Restriction on public access to heritage items.

Heritage management plans for heritage items should consider these potential impacts and include measures to mitigate any effects.


Sutherland Shire COUNCIL
Non-Indigenous Heritage
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Heritage Items (LEP 2015)
Catchment Boundary
Cadastre
Roads
Waterways
FIGURE 8-5
1:12,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350 400 450
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-09-14
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1023_Fig8-5NonAboriginalHeritage.mxd 02
Waterfront cottage
House
Gymea Baths
Boatshed
House, boatshed and sea wall
Mansion Bay, sandstone foreshore
Remains of landscape and jetty
Site of landscaping and jetty remains
Mangrove stands
Grays Point rocky foreshore to public reserve
Mangrove stands, between Swallow Rock and foreshore
"Swallow Rock" rock formations, east of boat ramp
Sandy beach next to boat ramp
Trees
Single tree
Royal National Park
Florence Parade
COOPERNOOK AVENUE
VERNON AVENUE
ELLESMERE ROAD
NARANGANAH AVENUE
BARRARAN STREET
GYMEA BAY ROAD
CARTER CRESCENT
MARINA CRESCENT
MOLONG ROAD
KALKADA AVENUE
FIRST AVENUE
JUNE PLACE
HORNS AVENUE
ARCADIA AVENUE
COBARGO ROAD
HUSKISSON STREET
NORTH WEST ARM ROAD
SEABROOK AVENUE
GREENHAVEN ROAD
ANGLE ROAD
KINGFISHER CRESCENT
IBIS PLACE
SULLIVAN ROAD
FERNHILL PLACE
PENINSULA ROAD
EMERALD PLACE
BUDYAN ROAD
WARREN AVENUE
MOYRAN PARADE
KYOGLE PLACE
GRAYS POINT ROAD
MARGA ROAD
BUNARBA ROAD
VALLEY WAY
DARRYL PLACE
MATONG PLACE
GREY GUM PLACE
TULONG PLACE
SERPENTINE ROAD
HOVEA PLACE

8.5 Recreational Usage

8.5.1 Public Access

As previously discussed, the majority of the foreshore of the North West Arm is privately owned; public access to the waterway is very limited. Public access points have been mapped in **Figure 8-2**. Where access does exist, the steep topography can limit access, especially for less mobile people.

The foreshore access at Marina Crescent Reserve (**Figure 8-6a**) is relatively steep and is adjacent to a large stormwater outlet. It was noted in the community survey that the access to the reserve is overgrown with bush and weeds. The public access on North West Arm Road is more accessible with a relatively shallow gradient (**Figure 8-6b**). At low tide large rocks are visible and pools of still water are evident. At high tide the rocks are completely covered and it is possible to launch small personal watercraft from this location; however parking along North West Arm Road is limited. The access along Huskisson Street leads to Dents Creek and the tidal limit of the North West Arm. It is possible for a small personal watercraft to access to waterway up to this point at high tide. The bank of Dents Creek is fairly steep and overgrown at this location (**Figure 8-6c**).

It was suggested in the community survey that paper roads could be turned into public parks. Two paper roads in the vicinity of the North West Arm are located at Molong Road and Coonong Road. These paper roads continue from the southern extent of the existing roads down to the foreshore of the North West Arm, however, the access to the water is relatively steep (**Figure 8-6d**).

a) Marina Crescent Reserve foreshore access

b) North West Arm Road foreshore access (Source: Google Street view)

c) Huskisson Road, bank of Dents Creek

d) Foreshore in vicinity of Coonong Road paper road

Figure 8-6: Public Access Points to the Estuary Foreshore

Access for larger watercraft to the North West Arm is restricted to private boat ramps or the Swallow Rock public boat ramp, located on the Hacking River approximately 2.5 km from the mouth of the North West Arm. A two lane boat ramp and a boat wash down area is available there. Small personal watercraft may also be launched from the beach at this location.

The community survey revealed that Swallow Rock Reserve can become extremely crowded on weekends and public holidays with many cars parking in “no parking” zones in the streets around the boat ramp due to a lack of car spaces. Swallow Rock is outside the study area, and all community feedback on this reserve has been provided to Council for their consideration.

There are currently high levels of pressure on public amenities in and around the study area due to high levels of demand. This pressure may increase over time due to an assumed increase in visitation and population in the wider area. It is evident that careful ongoing management of the public open spaces is required to manage these issues.

8.5.2 Recreational Amenity

The community survey was used to understand how the community use and value the North West Arm. As mentioned in **Section 4**, boating, fishing, swimming, walking and kayaking are the major recreational activities pursued by users of the North West Arm. During the site investigations there were a number of personal watercraft on the estuary including rowboats and kayaks, and residents were seen to be sitting on their lawns or verandas enjoying the scenic quality of the estuary.

As the majority of the North West Arm foreshore is privately owned, the major access point to the water for other residents is via the Swallow Rock boat ramp. As there are only four boat ramps servicing the Port Hacking river system, Swallow Rock can become very crowded, particularly on weekends and public holidays as it is the only public foreshore reserve in the Grays Point area.

Key issues associated with recreational usage identified from observations during the site investigations and the community survey are outlined in **Section 8.6**.

8.5.3 Impacts of Recreational Infrastructure on the Environment

The impacts of foreshore structures on estuarine ecology have been discussed in **Section 7**. There are a range of other environmental impacts arising from the presence of infrastructure such as jetties, seawalls, wharves and boat ramps, including the disruption of the natural sediment transport mechanisms and pathways. Similarly, the concentrated flows out of stormwater outlets and dredging to remove bed material, can also alter patterns of sediment transport, erosion and accretion. Unless carefully designed and/or offset with compensatory measures, the disruption of sediment transport processes can result in negative impacts adjacent to the structure, and potentially on other landholders.

For example, seawalls tend to reflect waves, resulting in increased erosion at the toe of the structure. The disruption of currents around piers supporting a jetty, and the scraping of a mooring chain along the estuary bed, can lead to localised scouring. In the event of a dredging activity, the estuary bed will tend to re-establish an ‘equilibrium’ profile, resulting in infilling of the dredge hole and potentially also morphological changes up or downstream of the area.

This is a common issue in estuaries along the Australia coastline. Despite having a relatively low energy wave environment and low tidal current velocities, there remains potential for negative impacts to arise in the North West Arm. Any proposed structures or activities should be managed in accordance with the Coastal Engineering Guidelines for Working with the Australian Coast in an Ecologically Sustainable Way (Engineers Australia, 2012a), taking into consideration the full range of potential impacts on the environment.

8.5.4 Climate Change Impacts on Recreational Infrastructure

There is also potential for climate change to impact on both existing recreational infrastructure, such as fixed and floating jetties, boat ramps, wharves, seawalls, moorings and other structures. The key coastal processes that put this infrastructure at risk are sea level rise and wave attack.

Where a structure is fixed to the land or the estuary bed, it may be subject to more regular overtopping and a more energetic wave climate, both of which can contribute to increased loading on the structure. Structures that are connected to the land via a flexible connection may be subject to movement beyond the range

provided for in the original design. These factors can contribute to increased wear and tear, higher maintenance requirements, and in some case, may render the structure inoperable or redundant.

There will therefore over time be a gradual change in maintenance regimes and some asset owners may be interested in upgrading, replacing or retrofitting structures to better cope with climate change conditions. Any new structures should take into account the design life of the structure and the potential impacts of climate change over that time period. Engineers Australia has published several guideline documents on assessing and managing the impacts of climate change on coastal structures, and on sustainability in coastal engineering more generally, including:

> *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering* (Engineers Australia, 2004);
> *Climate Change Adaptation Guidelines in Coastal Management and Planning* (Engineers Australia, 2012b); and
> *Coastal Engineering Guidelines for Working with the Australian Coast in an Ecologically Sustainable Way* (Engineers Australia, 2012a).

8.6 Summary of Key Management Issues

Table 8-2 provides a summary of key management issues identified for community uses of the estuary.

Table 8-2: Management Issues – Community Uses

Issue Description	Priority
Climate change impacts on built infrastructure, cultural heritage, and estuarine ecology.	Medium
Much of the estuary foreshore is in private ownership, which has compromised the natural character of the estuary and has contributed to the significant modification of the foreshores.	High
Much of the estuary foreshore is in private ownership, which limits the available access points for recreational users, such as for fishing or the launching of small and large watercraft.	High
Limited provision for public parking throughout the catchment.	Low
It is understood that there are some locations where private landowners are thought to be encroaching on public land, such as by placing materials (e.g. rocks) or watercraft on the public land.	Medium
Limited opportunities for the acquisition of additional land for public open space or foreshore reserves.	Medium
On occasion, poor water quality can impact on recreational use of the estuary.	Medium
User conflicts between powered and non-powered vessels.	Medium
Crowding during peak periods, such as on weekends, especially during summer.	High
Public access to the foreshore is limited by lack of signposting, steep topography, poor condition access ways, and lack of formal access ways in some locations.	High
There is insufficient space and infrastructure to support passive recreational activities such as walking, and there are not enough playgrounds for children.	Medium
Heritage items along the foreshore are vulnerable to coastal hazards.	Low

8.7 Recommendations for Management

Table 8-3 provides a summary of recommendations for future management of community uses in North West Arm.

Table 8-3: Management Recommendations – Community Uses

ID No.	Management Recommendations
CU01	Establish a kayak trail from Swallow Rock and leading into the North West Arm.
CC01	Provide ongoing support for Bushcare groups.
CC03	Assess feasibility of establishing stairs or a ramp to the water for purposes of launching small watercraft (e.g. kayaks and canoes) at the bottom of the easement located opposite the bus stop on North West Arm Road

ID No.	Management Recommendations
	down to Dents Creek.
CC04	Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.
CC10	Consider revising the Mooring Minders Policy in light of the recommended reforms in the Moorings Review Issues Paper (TfNSW, 2014).
CC14	Provide for ongoing enforcement of fishing regulations, including bag and size limits.
CC17	Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.
CC19	Consider opportunities to acquire foreshore land to improve public access to the foreshore and waterway.
EE01	Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.

9 Management Framework

9.1 Introduction

This section draws together the findings of the investigations presented in this report, along with the information provided by the community and key stakeholders, to establish the foundation for the CZMP. The estuary values and significance (**Section 9.2**) articulates the key features of the North West Arm and the human uses of the estuary that the community would seek to protect or maintain. These factors are critical considerations in understanding where we are, and where we want to go in future.

9.2 Summary of Estuary Values and Significance

A summary of the values and significance of the North West Arm is provided in **Table 9-1**.

Table 9-1: Values and Significance of the North West Arm

Scale	Values and Significance
International	The study area has habitat that may be used by a number of internationally significant migratory animals: ▪ Important migratory species occur in the study area that are listed under bilateral and multilateral agreements (e.g. JAMBA, CAMBA and ROKAMBA), such as the Common Sandpiper (*Actitis hypoleucos*) and the Great Knot (*Calidris tenuirostris*). A number of these species are not threatened at the State or National level and are therefore primarily afforded protection under these international agreements.
National	The estuary is important in providing habitat for a number of species of conservation significance at the national level: ▪ The EPBC Act identifies Littoral Rainforest and Coastal Vine Thickets of Eastern Australia as a critically endangered ecological community; ▪ There are a number of fauna species (including migratory species) that are listed under the EPBC Act as having the potential to occur in the area, such as the Grey-headed Flying Fox (*Pteropus poliocephalus*), the Southern Brown bandicoot (*Isoodon obesulus obesulus*) and the Green and Golden Bell Frog (*Litoria aurea*). ▪ A number of flora species are listed under the EPBC Act with two listed as endangered (Strapweed (*Posidonia australis*) and Yellow Gnat-orchid (*Genoplesium bauera*); and ▪ In addition, part of the Royal National Park, which is listed as a site of National heritage significance, falls within the catchment.
State	The North West Arm supports a number of important ecological communities and species that have conservation significance at the State level: ▪ The FM Act identifies mangroves and seagrass as protected for their ecological significance; ▪ The FM Act lists *Posidonia* in Port Hacking as an endangered population under the Act; and ▪ Several threatened and protected bird and mammal species are listed under the TSC Act as having the potential to occur in the area, such as the White-fronted Chat (*Epthianura albifrons*) the Black Bittern (*Ixobrychus flavicollis*) and the Greater Brown-nosed Bat (*Scoteanax rueppellii*).
Local	The estuary is very important at the local level for the following reasons: ▪ It forms part of Port Hacking, which is used intensively by both local residents and visitors from elsewhere in the region for a range of recreational activities, including boating and fishing; ▪ It is valued by local residents for the peaceful, natural character of the waterway and its foreshores. The combination of urban development and bushland is very characteristic of the area; ▪ Sites of local heritage significance located in the catchment provide an appreciation of the history of settlement and use of the area by Europeans; ▪ A number of sites and places of significance to Aboriginal cultural heritage are also located in proximity to the estuary, which highlights the historic use and occupation of the area by Aboriginal people; ▪ Mangroves and seagrasses support a diversity and abundance of fish, birds and invertebrate species, including fish species targeted by recreational anglers; and ▪ The catchment and estuary support a range of locally endemic species and the habitats that support them.

9.3 Management Objectives

For purposes of establishing the management framework for the North West Arm, a series of management objectives were developed that represent "desired outcomes" for the ongoing management of the estuary. They will guide the development and implementation of this Plan.

The objectives have been prepared by the study team in consultation with the Committee, and take into account the information presented in this report, consistent with the principles for coastal management outlined in the Guidelines (OEH, 2013a).

The management objectives are also used to inform the options assessment, as outlined in **Section 10**.

The management objectives are listed in **Table 9-2**, along with some brief notes on the rationale behind each specific objective.

Table 9-2: Management Objectives for the North West Arm CZMP

Management Objective	Notes
Protect and improve the condition of natural bushland, riparian and estuarine vegetation.	As identified in **Section 7**, the vegetation present in the estuary and it's catchment fulfils a range of important functions, including: ▪ Providing habitat for native animals, including some commercial species; ▪ Mediating water quality by preventing erosion, trapping sediments, and filtering pollutants from stormwater runoff; ▪ Contributing to the visual character of the catchment and estuary foreshores; and ▪ Providing shade for recreational users. Historic land use activities have resulted in the clearing of large areas of vegetation from the catchment and the foreshore has been cleared for residential development. There is therefore a need to conserve the remaining vegetation, improve vegetation condition, and identify opportunities to rehabilitate cleared areas. This is in accordance with Principle 8 under the Guidelines for CZMPs (OEH, 2013a). Council is currently doing a series of activities to further this objective, such as through the Bushcare and Greenweb programs, and via the implementation of planning controls in the DCP. It is noted that some of the vegetation present in the study area is protected under one or more pieces of legislation, including the FM Act, NP&W Act, TSC Act and/or the EPBC Act.
Maintain and improve estuarine water quality for aquatic ecosystem health and recreational purposes.	Water quality is critical for environmental and human health. In terms of estuarine ecosystem health, changes in water quality parameters can have a significant impact on species or communities (see **Section 7**). In addition, a certain standard of water quality must be maintained in order to ensure recreational users of the waterway are not subject to human health impacts. This is typically assessed on the basis of secondary contact recreation (such as boating, where the level of contact with the water is more limited) and primary contact recreation (such as swimming). The key document with respect to water quality criteria is the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC, 2000). Council has implemented a range of measures to improve stormwater quality, including controls on new development that require the implementation of Water Sensitive Urban Design (WSUD) and the implementation of stormwater quality improvement devices.
Maintain and (where feasible) improve public access to and around the estuary foreshores and waterbody.	The maintenance of public access to and along the estuary foreshores, to the waterway, and between the foreshore and the waterway, is of critical importance to the community. For this reason, it has been articulated as Principle 9 of CZMP Guidelines (OEH, 2013a). Historic foreshore development of the North West Arm has significantly restricted public access, as discussed in **Section 8.5.1**. As a minimum it is important to maintain existing access ways and to identify opportunities to improve these, where appropriate. The opportunity to improve access is limited due to the fact that most foreshore land is in private ownership, but should be considered where possible.

Management Objective	Notes
Recognise the values and significance of the estuary to the community.	As outlined in **Section 9.2**, the North West Arm has is of importance to the community for a range of reasons, including: ▪ Cultural heritage; ▪ As a recreational resource for members of the public; ▪ For waterborne transport; ▪ As an environmentally significant area they can enjoy and appreciate; and ▪ It's inherent natural beauty. There is therefore a significant driver to conserve, enhance and promote these values, and to ensure the ongoing human uses of the North West Arm. Support for recreational use of the coastal zone is espoused in Principle 10 of the CZMP Guidelines (OEH, 2013a). In addition, some sites of heritage significance are protected under the Sutherland LEP, *Heritage Act 1977*, NP&W Act, and/or the EPBC Act.
Manage the impacts of human activities on natural coastal processes and estuarine ecosystems.	The principles for coastal management outlined in the CZMP Guidelines (OEH, 2013a) identify the need to recognise and accommodate natural coastal processes. This management objective articulates this requirement as part of the North West Arm CZMP. Human activities, in particular foreshore or waterway developments, have potential to disrupt the natural hydrodynamic, sedimentary and water quality processes occurring in the estuary. These activities may also impact directly on ecosystems (e.g. via clearing vegetation) or indirectly by modifying these natural processes. It is therefore important to minimise these impacts, consistent with the principles of Ecologically Sustainable Development (ESD). There are a range of organisations and agencies involved in minimising the impacts of human activities on the environment, including: ▪ Council, who regulates development via the LEP and DCP, and also has a compliance role; ▪ RMS, which regulates navigation and environmental management for water-based activities; ▪ NSW Fisheries, which regulate fishing activities; and ▪ EPA, which regulates licenced premises and contaminated lands, amongst other activities. It is noted that the minimisation and management of impacts on the environment, in this case coastal processes, is a requirement under both the EP&A Act and *Coastal Protection Act 1979*.
Maintain the visual character of the North West Arm estuary.	The visual character of the North West Arm was identified as a highly valued feature by members of the community. The visual character may be defined by landscape features (e.g. headlands), particular types of vegetation, or development patterns. The way members of the public experience views is also important, be it looking towards the waterway, or looking back from the waterway and shoreline. There are development controls outlined in the DCP that seek to maintain visual character, in addition to which any visual impacts associated with development must be considered as required under the EP&A Act.
Seek to engage with the community and involve them in the implementation of the CZMP for the North West Arm.	As outlined in Principle 3 of the CZMP Guidelines (OEH, 2013a), involving the community in the CZMP is an important requirement for coastal management. It is also an important requirement under Council's IPR system. Council currently engages in a range of activities with the community, ranging from Bushcare to education activities. As outlined in **Section 3.2.2 and 4**, the community has been consulted with throughout the development of this CZMP, and will have a role in decision making regarding the management actions. It will be important to continue community involvement in the implementation phase to engender ownership of the CZMP, and also to provide opportunity for environmental education.

10 Management Options Assessment

10.1 Introduction

One of the important requirements for this project was to develop a CZMP that was reasonable and feasible, acknowledging that there are limited resources for implementation. Consistent with the requirements of the Guidelines (OEH, 2013a; see **Section 1.2**), the assessment of management options is required to:

- Adopt a risk management approach to public safety, assets and pressures on coastal ecosystems, including avoiding risks where feasible and mitigating risks where they cannot be reasonably avoided, adopting interim actions to manage high risks while long term options are implemented;
- Be developed and assessed based on the best available information and reasonable practice, including adopting an adaptive management approach; and
- Support the requirement that the priority for public expenditure is public benefit, cost-effectively achieving the best practical long term outcomes.

The management options are essentially the activities proposed to fulfil the management objectives for the North West Arm. This section of the Plan details the process by which management options were developed and assessed for their relative costs and benefits, and identifies the recommended options for inclusion in the Implementation Plan.

10.2 Options Development Process

An initial list of 28 management options was developed by the Cardno study team based on their experience in coastal management, the outcomes from the technical investigations undertaken, and the suggestions made by the community in their survey responses. This list was then discussed with Council and OEH at a meeting held on the 22 January 2015. Once all the options identified during this consultation process had been collated, the list comprised a total of 35 management options for the North West Arm estuary. Each management option was given a unique alpha-numerical identifier. These management options are listed in **Table 10-1** and those relevant to a specific location are mapped in **Figure 10-1**.

In many cases, a management option was developed to address a specific management issue observed by the study team, Council or the community. In other cases a management option may have been developed to assist in the implementation of the Plan, or conduct research or monitoring to address data gaps, and thereby further enhance the understanding of estuarine processes. In all cases, the options were considered with respect to the management objectives identified for the North West Arm estuary as outlined in **Section 9.3**.

Table 10-1: Description of Management Options

Option ID	Option Description	Location
CC01	Provide ongoing support for Bushcare groups.	Catchment-wide
CC02	Compliance audit of foreshore structures (e.g. jetties, wharves and boat ramps) on private property.	Estuary-wide
CC03	Assess feasibility of establishing stairs or a ramp to the water for purposes of launching small watercraft (e.g. kayaks and canoes) at the bottom of the easement located opposite the bus stop on North West Arm Road down to Dents Creek.	North West Arm Road
CC04	Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.	Molong Road
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.	Estuary-wide
CC06	Minimise illegal dumping by improving community awareness and via enforcement.	Catchment-wide
CC07	Improve the awareness of boating regulations and navigational requirements, including in relation to boat pump-outs.	Estuary-wide

Option ID	Option Description	Location
CC08	Continue to enforce boating regulations.	Estuary-wide
CC09	Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.	Estuary-wide
CC10	Consider revising the Mooring Minders Policy in light of the recommended reforms in the Moorings Review Issues Paper (TfNSW, 2014).	Estuary-wide
CC11	Consider feasibility of banning 2-stroke engines (includes community consultation to seek feedback on proposal).	Estuary-wide
CC12	Assess feasibility of banning jet skis or restricting their usage (includes community consultation to seek feedback on proposal).	Estuary-wide
CC13	Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.	Estuary-wide
CC14	Provide for ongoing enforcement of fishing regulations, including bag and size limits.	Estuary-wide
CC15	Dredging option 1 – Navigation channel for small non-powered watercraft to North West Arm Road access point at low tide.	Dents Creek
CC16	Dredging option 2 – Removal of top 300 mm of sediments from delta.	Upper estuary
CC17	Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.	Marina Crescent Reserve
CC18	Review current maintenance regimes for clearing blockages of debris from Savilles Creek, especially under the bridge at North West Arm Road.	Savilles Creek
CC19	Consider opportunities to acquire foreshore land to improve public access to the foreshore and waterway.	Estuary-wide
CC20	Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources. This may involve a review of street sweeping and the location of GPTs.	Catchment-wide
CP01	Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.	Dents & Savilles Creeks
CP02	Gain a greater appreciation of the potential impacts of climate change on the estuarine ecosystems of North West Arm. Consider the need to develop a strategic plan to manage climate change impacts on biodiversity in the LGA.	Estuary-wide
WQ01	Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program. This option assumes that Council would contribute by undertaking the required monitoring at five sites in the catchment, incorporating both dry and wet weather sampling.	Catchment-wide
WQ02	Provide ongoing support for community education to improve awareness of non-point source water pollution and provide advice on how residents can contribute to best practice stormwater management.	Catchment-wide
WQ03	Work with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows on the estuary.	Catchment-wide
WQ04	Assess the condition of Council's stormwater outlets to the estuary and program works as required.	Estuary-wide
WQ05	Assess compliance of lot-based stormwater management controls for foreshore properties against the requirements of the DCP.	Estuary-wide
WQ06	Install a SQID to treat stormwater draining to Dents Creek via reaches DCDCPH017 and 018, to be located near the intersection of Huskisson St and Cobargo Rd.	Dents Creek
WQ07	Retrofit SQIDs on individual stormwater pits to capture sediments and gross pollutants as stormwater inflows enter the drainage system. Assumed to be undertaken on up to five stormwater pits during the period of implementation of the CZMP.	Catchment-wide
WQ08	Install a trash rack at the point where North West Arm Road crosses Savilles Creek to capture gross pollutants.	Savilles Creek

Option ID	Option Description	Location
WQ09	Install an online SQID on the unnamed watercourse located in Kyogle Reserve to capture gross pollutants from the stormwater network and upstream reach of the creek prior to entering the estuary.	Unnamed Watercourse, Grays Point
WQ10	Install a SQID to treat stormwater from the piped drainage catchment to the south east prior to discharge to the unnamed watercourse located in Kyogle Reserve.	Unnamed Watercourse, Grays Point
EE01	Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.	Estuary-wide
EE02	Support regional pest and weed control activities, including those conducted by Council, NPWS, LLS and DPI (Fisheries).	Catchment-wide
CU01	Establish a kayak trail from Swallow Rock and leading into the North West Arm.	Estuary-wide


Sutherland Shire COUNCIL
Management Options
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Management Options
Management Options
Catchment Boundary
Roads
Cadastre
Waterways
Local Parks
National Parks and Reserves
FIGURE 10-1
1:12,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350 400 450
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-05-13
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1025_Fig10-1Management Options.mxd 01
CU01
CC10
CC09
CC01
CP01
CC17
CC04
CC16
CC15
CC03
WQ09
CP01
CC01
WQ10
WQ06
CP01
WQ08
CC18
CP01
HUSKISSON STREET
NORTH WEST ARM ROAD
GREENHAVEN ROAD
ANGLE ROAD
GRAYS POINT ROAD
BUDYAN ROAD
EMERALD PLACE
MARREN AVENUE
MOYRAN PARADE
SWALLOW ROCK DRIVE
PENINSULAR ROAD
GRAYS POINT ROAD
NARANGANAH AVENUE
ELLESMERE ROAD
GYMEA BAY ROAD
GREYGUM PLACE
VALLEY WAY
CARTER CRESCENT
COONONG ROAD
SECOND AVENUE
THIRD AVENUE
ARCADIA AVENUE
HORNS AVENUE
ARCADIA AVENUE
FIRST AVENUE
SERPENTINE ROAD
HOVEA PLACE

10.3 Options Assessment Methodology

Management options were compiled and collated via the following process:

> A preliminary options list was compiled by Cardno's environmental scientists/engineers and coastal engineers;
> The preliminary options list was discussed with Council and OEH; and
> Obtaining feedback from the PHMP (and other parties present at the meeting of 25 February 2015) on the proposed options.

The options assessment process adopted for this project has been developed to enable direct comparisons between each option, and to rank options in a transparent and unbiased manner, so as to identify those having the greatest overall benefit for estuary management. In recognition of the fact that the resources for implementation of these options are limited, the process of ranking management options will also assist in prioritising options for implementation.

The assessment of management options adopted a multi-criteria matrix-based approach. In the case of the dredging options, these were also informed by the outcomes of the feasibility study presented in **Appendix C**.

10.3.1 Multi-Criteria Matrix Assessment

In broad terms, each identified management option has been assessed based on:

> Achievement of the management objectives (i.e. if implemented, would the option achieve one or more of the objectives for management set out in **Table 9-2**); and
> A qualitative evaluation of the impact of the option, if implemented, on estuary processes (positive or negative).

More specifically, each management option has been assessed using a multi-criteria matrix based framework that acts as a decision-support tool. The multi-criteria matrix incorporates the calculation of a cost-benefit index based on a quadruple bottom line assessment (accounting for economic, social, environmental and governance factors) in accordance with the requirements of the NSW Government's Estuary Management Policy.

10.3.1.1 Scoring of Indicators

The benefit index assessment has been prepared using the following social, environmental and governance indicators:

> Environmental Factors:
  – Vegetation / Habitat Condition,
  – Water Quality,
  – Impact on Coastal / Ecological Processes;
> Social Factors:
  – Public Access,
  – Community Uses (i.e. recreation, cultural heritage etc.),
  – Visual Character,
  – Community Engagement;
> Governance:
  – Compatibility with policy and legislative framework; and
> Economic:
  – Capital cost of implementation,
  – Annually recurrent cost.

Each management option was scored to assess how well it performed against each of the assessment criteria in accordance with the methodology described in **Table 10-2**. These scores were then summed to calculate a raw benefit index with possible values between -24 and +24.

Table 10-2: Management Objectives for the North West Arm CZMP

Criteria	Likely Outcome (Qualitative Assessment)						
	-3	-2	-1	0	1	2	3
Vegetation / Habitat Condition	Direct negative impacts on vegetation/habitat condition over the long term; permanent loss of species or habitat.	Direct negative impacts on vegetation/habitat condition over the short-medium; permanent loss of species or habitat for at least one site.	Indirect negative impacts on vegetation/habitat condition; direct negative impact over the short term.	No net impacts on vegetation or habitat condition.	Indirect positive impacts on vegetation/habitat condition; direct positive impact over the short term.	Direct positive impacts over the short-medium term; provides for the conservation, management and rehabilitation of a number of sites, species or habitats.	Results in a more strategic approach to the protection of vegetation/habitat condition; provides for the long term conservation, management and rehabilitation of the estuary.
Water Quality	Decline in water quality throughout estuary over the medium-long term.	Decline in water quality over the short term at a limited number of locations.	Decline in water quality for only a limited number of parameters.	No net impact on water quality.	Improvement in water quality for a limited number of parameters.	Improvement in water quality over the short-medium term.	Improvement in water quality throughout estuary over the medium-long term.
Impact on Coastal / Ecological Processes	Results in direct negative impact on coastal/ecological processes throughout estuary.	Direct negative impact at limited number of locations or over the short-medium term.	Indirect negative impacts on coastal / ecological processes.	No net impact on coastal or ecological processes.	Indirect positive impacts on coastal / ecological processes.	Direct positive impact at limited number of locations or over the short-medium term.	Enhances understanding of coastal/ecological processes; results in direct positive impact on coastal/ecological processes.
Public Access	Complete loss of one or more access points; lack of coordinated planning.	Reduction in public access at one or more access points.	Minor reduction in public access at an existing access point; for options negatively impacting on a limited range of user groups.	No net impact on public access.	Public access is subject to minor improvements at an existing access point; option improves access for limited number of user groups.	Public access is improved in one or more locations.	Public access is improved via proper management and coordination of initiatives; creation of a new access point.
Community Uses	Reduction in the community uses (recreation, cultural or heritage) of the estuary over the long term.	Reduction in the community uses of the estuary over the medium term.	Minor reduction in community uses; option negatively impacts limited number of user groups.	No net impact on community uses.	Minor improvements to community uses; option improves uses for a limited number of user groups.	Improvement in community uses of the estuary over the medium term.	Community uses of the estuary are positively affected across the estuary for all user groups over the long term.
Visual Character	Reduction in visual character throughout the whole estuary over the long term.	Reduction in the visual character of the estuary at limited number of locations; or over the medium term.	Minor reduction in the visual character of the estuary; reduction in amenity at one area.	No net impact on visual character.	Minor improvements in the visual character of the estuary; or improvements over the short term.	Improvements in the visual character of the estuary at limited number of locations; or improvements over the medium term.	Visual character is improved throughout the whole estuary over the long term.

Criteria	Likely Outcome (Qualitative Assessment)						
	-3	-2	-1	0	1	2	3
Community Engagement	No consultation Negative press at national/state level. Reputational damage. Significant number of complaints to Council.	No consultation. Negative press at local level. Moderate number of complaints to Council.	Limited consultation/lack of involvement of the community. Negative press from community members. A limited number of complaints to Council a year.	No net impact on community engagement.	Short term information, communication or education engaging the community in a positive way (e.g. newsletter).	Medium term information, communication or education engaging the community in a positive way (e.g. educational signage).	Long term, direct or broad scale information, communication or education promoting a positive community engagement (e.g. public awareness campaign).
Compatibility with policy and legislative framework	N/A	Illegal or in direct contravention with policy/guidelines.	Inconsistent with relevant policies/ guidelines.	N/A	Consistent with relevant policies/guidelines.	Reinforces or provides support for existing policies/guidelines (LEP Zoning, State and Federal legislation); results in creation of new policy.	N/A

10.3.1.2 The Net Present Value

The Net Present Value of each option was calculated based on a function of the preliminary estimate of capital cost and the annually recurrent cost over a 10 year period of implementation, adopting a 7% discount rate.

It is noted that these cost estimates are indicative only and further detailed costings would be required in the event an option is considered for implementation.

10.3.1.3 Agency and Council Feedback

The multi-criteria matrix also incorporates a mechanism by which feedback from Council and the relevant government agencies can also be included. This mechanism is essentially a scoring process, with scores allocated on the following basis:

- Score ± 2 = Strongly in favour of / opposed to the option;
- Score ± 1 = In favour of / opposed to the option to a limited degree; or
- Score 0 = Neutral/no opinion.

A score is allocated on the basis of an average score provided by the PHMP after the meeting of 25 February 2015. These scores are then summed with the Raw Benefit Index in order to calculate Adjusted Benefit Index.

10.3.1.4 Rankings

Once each option has been assessed using the methodology described above they can be ranked on the basis of the Adjusted Benefit Index.

The full list of management options was ranked on the basis of the Adjusted Benefit Index. The results of the options assessment are provided in **Table 10-3**. The full list of management options is provided in unranked and ranked format in **Appendix F**.

Table 10-3: Ranked Management Options

Option ID	Option Description	Location	Rank
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.	Estuary-wide	1
CC01	Provide ongoing support for Bushcare groups.	Catchment-wide	2
CC17	Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.	Marina Crescent Reserve	3
WQ04	Assess the condition of Council's stormwater outlets to the estuary and program works as required.	Estuary-wide	4
CC13	Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.	Estuary-wide	5
WQ01	Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program.	Catchment-wide	6
CP01	Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.	Dents & Savilles Creeks	7
EE01	Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.	Estuary-wide	8
WQ02	Provide ongoing support for community education to improve awareness of non-point source water pollution and provide advice on how residents can contribute to best practice stormwater management.	Catchment-wide	8
CC09	Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.	Estuary-wide	10

Option ID	Option Description	Location	Rank
CC20	Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources.	Catchment-wide	11
CC04	Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.	Molong Road	12
WQ08	Install a trash rack at the point where North West Arm Road crosses Savilles Creek to capture gross pollutants.	Savilles Creek	13
WQ03	Work with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows on the estuary.	Catchment-wide	14
WQ06	Install a SQID to treat stormwater draining to Dents Creek via reaches DCDCPH017 and 018, to be located near the intersection of Huskisson St and Cobargo Rd.	Dents Creek	15
WQ09	Install an online SQID on the unnamed watercourse located in Kyogle Reserve to capture gross pollutants from the stormwater network and upstream reach of the creek prior to entering the estuary.	Unnamed Watercourse, Grays Point	15
WQ10	Install a SQID to treat stormwater from the piped drainage catchment to the south east prior to discharge to the unnamed watercourse located in Kyogle Reserve.	Unnamed Watercourse, Grays Point	15
CC07	Improve the awareness of boating regulations and navigational requirements, including in relation to boat pump-outs.	Estuary-wide	18
EE02	Support regional pest and weed control activities, including those conducted by Council, NPWS, LLS and DPI (Fisheries).	Catchment-wide	19
CC06	Minimise illegal dumping by improving community awareness and via enforcement.	Catchment-wide	20
WQ07	Retrofit SQIDs on individual stormwater pits to capture sediments and gross pollutants as stormwater inflows enter the drainage system.	Catchment-wide	21
CP02	Gain a greater appreciation of the potential impacts of climate change on the estuarine ecosystems of North West Arm. Consider the need to develop a strategic plan to manage climate change impacts on biodiversity in the LGA.	Estuary-wide	22
CC08	Continue to enforce boating regulations.	Estuary-wide	23
CC14	Provide for ongoing enforcement of fishing regulations, including bag and size limits.	Estuary-wide	24
CU01	Establish a kayak trail from Swallow Rock and leading into the North West Arm.	Estuary-wide	25
CC19	Consider opportunities to acquire foreshore land to improve public access to the foreshore and waterway.	Estuary-wide	26
CC03	Assess feasibility of establishing stairs or a ramp to the water for purposes of launching small watercraft (e.g. kayaks and canoes) at the bottom of the easement located opposite the bus stop on North West Arm Road down to Dents Creek.	North West Arm Road	27
WQ05	Assess compliance of lot-based stormwater management controls for foreshore properties against the requirements of the DCP.	Estuary-wide	28
CC10	Consider revising the Mooring Minders Policy in light of the recommended reforms in the Moorings Review Issues Paper (TfNSW, 2014).	Estuary-wide	29
CC18	Review current maintenance regimes for clearing blockages of debris from Savilles Creek, especially under the bridge at North West Arm Road.	Savilles Creek	30
CC02	Compliance audit of foreshore structures (e.g. jetties, wharves and boat ramps) on private property.	Estuary-wide	31
CC12	Assess feasibility of banning jet skis or restricting their usage (includes community consultation to seek feedback on proposal).	Estuary-wide	32

Option ID	Option Description	Location	Rank
CC11	Consider feasibility of banning 2-stroke engines (including community consultation to seek feedback on proposal).	Estuary-wide	33
CC15	Dredging option 1 – Navigation channel for small non-powered watercraft to North West Arm Road access point at low tide.	Dents Creek	34
CC16	Dredging option 2 – Removal of top 300 mm of sediments from delta.	Upper estuary	35

11 Implementation Plan

11.1 Implementation Plan

Nineteen options have been developed into an Implementation Plan that forms the basis of the North West Arm CZMP (see **Table 11-1**), including the top 15 highest ranking options ranked 1 to 15 (noting that three options are ranked equal 15th). A further two management actions, Actions CU01 and CU03, have also been included in the Implementation Plan at the request of Council. Both these actions are more costly to implement than many other options (and therefore have lower rankings), but would further the achievement of most management objectives. Hence they have been included in the Plan.

The total cost of implementation of the Plan is $1,072,680 in capital costs, and $223,620 in annually recurrent costs, over a 10 year period of implementation. Of the actions identified in the Plan, 16 would be the primary responsibility of Council for implementation, summing to $1,061,980 in capital costs and $214,520 in annually recurrent costs.

It is noted that if Action CC04 is implemented, Action CC03 would no longer be required (i.e. both provide for a kayak launching facility). Hence, the total cost of implementation shown above excludes the cost associated with Action CC03.

Other organisations or agencies have been identified as having primary responsibility for implementing the remaining actions, and the relevant parties have provided their in principle support.

Table 11-1: Implementation Plan

Action ID	Action Description	Location	Rank
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.	Estuary-wide	1
CC01	Provide ongoing support for Bushcare groups.	Catchment-wide	2
CC17	Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.	Marina Crescent Reserve	3
WQ04	Assess the condition of Council's stormwater outlets to the estuary and program works as required.	Estuary-wide	4
CC13	Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.	Estuary-wide	5
WQ01	Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program.	Catchment-wide	6
CP01	Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.	Dents & Savilles Creeks	7
EE01	Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps).	Estuary-wide	8
WQ02	Provide ongoing support for community education to improve awareness of non-point source water pollution and provide advice on how residents can contribute to best practice stormwater management.	Catchment-wide	9
CC09	Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.	Estuary-wide	10
CC20	Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources.	Catchment-wide	11
CC04*	Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.	Molong Road	12

Action ID	Action Description	Location	Rank
WQ08	Install a trash rack at the point where North West Arm Road crosses Savilles Creek to capture gross pollutants.	Savilles Creek	13
WQ03	Work with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows on the estuary.	Catchment-wide	14
WQ06	Install a SQID to treat stormwater draining to Dents Creek via reaches DCDCPH017 and 018, to be located near the intersection of Huskisson St and Cobargo Rd.	Dents Creek	15
WQ09	Install an online SQID on the unnamed watercourse located in Kyogle Reserve to capture gross pollutants from the stormwater network and upstream reach of the creek prior to entering the estuary.	Unnamed Watercourse, Grays Point	15
WQ10	Install a SQID to treat stormwater from the piped drainage catchment to the south east prior to discharge to the unnamed watercourse located in Kyogle Reserve.	Unnamed Watercourse, Grays Point	15
CU01	Establish a kayak trail from Swallow Rock and leading into the North West Arm.	Estuary-wide	25
CC03*	Assess feasibility of establishing stairs or a ramp to the water for purposes of launching small watercraft (e.g. kayaks and canoes) at the bottom of the easement located opposite the bus stop on North West Arm Road down to Dents Creek.	North West Arm Road	27

*Only one of these two actions would be implemented – both provide for a kayak launching facility and hence only one is required.

Sections 11.1.1 to 11.1.13 provide further detail on the key considerations for implementation of the actions identified in the Implementation Plan. The actions are mapped in **Figure 11-1**.


Sutherland Shire COUNCIL
Implementation Plan
Management Actions
NORTH WEST ARM COASTAL
ZONE MANAGEMENT PLAN
Legend
Management
Management
Cadastre
Waterways
Local Parks
National Parks and Reserves
FIGURE 11-1
1:10,000 Scale at A4
Metres
0 2550 100 150 200 250 300 350
Cardno
Map Produced by: Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-05-14
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1029_Fig11-1Actions.mxd 01
Bank rehabilitation works
Additional stormwater quality improvement devices
Create new public reserve at Molong Road.
Condition assessment of Marina Crescent Reserve
Upgrade to seagrass friendly moorings
Establish a kayak trail
Additional stormwater quality improvement devices
CP01
CP01
WQ06
WQ08
CC04
CC17
CC09
WQ09
WQ10
CU01
WQ01: Support for ongoing water quality monitoring for Strategic Water Monitoring Program
CC20: Review of stormwater management pactices to optimise use of resources
WQ03: Reduce impacts of sewer overflows
CC05: Provide Greenweb Grants to private landowners
WQ04: Condition assessment of stormwater outlets
CC01: Provide ongoing support for volunteer Bushcare groups
EE01, WQ02, CC13: Community education

11.1.1 Action CC05 – Provide Greenweb Grants to Private Land Owners

Action Description: Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.

Cost: $6,000 per year.

Primary Responsibility: Council.

Approvals Pathway: N/A

Other Environmental Approvals Required: N/A

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☒ Coastal / ecological processes ☐ Public access ☐ Community uses ☒ Visual character ☒ Community engagement

Notes: The Greenweb program aims to protect foreshore vegetation and promote revegetation on both public and private land. Chapter 4 of the DCP identifies land falling under the Greenweb program, as discussed in **Section 7.3.1.3**.

Council provides funding of up to $20,000 each financial year under their Greenweb Program (http://www.sutherlandshire.nsw.gov.au/Community/Grants/Greenweb-Grants). This option assumes that three grants of up to $2,000 each are awarded to property owners along the North West Arm.

11.1.2 Action CC01 – Support Bushcare Groups

Action Description: Provide ongoing support for volunteer Bushcare groups working around the estuary.

Cost: $90,000 per year.

Primary Responsibility: Council.

Approvals Pathway: As required.

Other Environmental Approvals Required: As required.

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☒ Coastal / ecological processes ☒ Public access ☐ Community uses ☒ Visual character ☒ Community engagement

This action provides for ongoing support of Council's Bushcare program. The cost estimate for this action assumes $70,000 salary for a full time Bushcare Officer and $20,000 for expenses, which may include plants, landscaping supplies, training, or other equipment. Labour is provided by the community on a volunteer basis.

11.1.3 Action CC17 – Condition Assessment for Marina Crescent Reserve

Action Description: Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.

Cost: $4,800 to conduct the assessment, and an assumed $7,500 per year to undertake regular maintenance works arising from the condition assessment.

Primary Responsibility: Council.

Approvals Pathway: If required.

Other Environmental Approvals Required: If required.

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☒ Coastal / ecological processes ☒ Public access ☒ Community uses ☒ Visual character ☒ Community engagement

The community consultation revealed that the access ways in Marina Crescent Reserve are overgrown, in poor condition and requiring maintenance. A condition assessment of the reserve would involve a Council officer visiting the site and determining the works required to improve public safety and amenity.

Recommendations may include weed removal, trimming of vegetation, or improvements to pathways or the stairway to the water. The recommendations following on from the condition assessment would then need to be scheduled into Council's program of works and funds allocated.

11.1.4 Action WQ04 – Condition Assessment of Stormwater Outlets

Action Description: Assess the condition of Council's stormwater outlets to the estuary and program works as required.

Cost: $8,000 to conduct the assessment, no provision for works arising from the assessment.

Primary Responsibility: Council.

Approvals Pathway: N/A

Other Environmental Approvals Required: N/A

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☒ Coastal / ecological processes

☐ Public access ☐ Community uses ☒ Visual character ☒ Community engagement

Council and the community have raised concerns regarding sedimentation around stormwater outlets and the potential for ponding of dirty stormwater immediately downstream of the outlet. Cracked and blocked stormwater outlets may not function properly, and may also represent a risk to public safety. This management action would require inspection of each stormwater outlet that discharges into the North West Arm to assess its condition (including structural and operational aspects) to ensure the outlet can perform as intended.

A report of the condition of each outlet and any recommendations for improvement would be developed. Any recommendations would need to be costed and scheduled into Council's asset management plan and prioritise repairs as required.

11.1.5 Actions EE01, WQ02 and CC13 – Community Education

Action EE01 Description: Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.

Action WQ02 Description: Provide ongoing support for community education to improve awareness of non-point source water pollution and provide advice on how residents can contribute to best practice stormwater management.

Action CC13 Description: Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.

Cost: Each action has a capital cost of $10,700 and annually recurrent costs of $5,500 (summing to $32,100 in capital costs and $16,500 in annually recurrent costs).

Primary Responsibility: Council.

Approvals Pathway: N/A

Other Environmental Approvals Required: N/A

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☒ Coastal / ecological processes

☐ Public access ☐ Community uses ☒ Visual character ☒ Community engagement

Public education can significantly improve the community's awareness of the environment, their understanding of how they impact on the environment, and what they can do to minimise their impacts and improve the condition of the estuary. In addition, many estuarine and catchment processes are influenced by a range of factors, or are impacted by activities that are conducted at a number of locations. For example, there are very few readily identifiable point sources of pollution in the catchment, and stormwater quality is likely dictated by the cumulative effects of all local businesses and residents living in the catchment.

These options provide for community education on three key issues:

- The management of foreshore land;
- Catchment management and stormwater quality; and
- Ecological conservation.

Residents may not be aware of their statutory responsibilities for environmental management, or may not be aware of what constitutes best environmental management practice. The education programs would provide information to residents to inform them of these aspects.

For purposes of costing these actions, it has been assumed that a Council officer's time would be required in the first year to detail the desired outcomes of the education programs, review existing materials, collate relevant material, and to undertake any website updates or graphic design of new materials. The annually recurrent cost of implementation is in updating the materials as required, or for posting out information to residents (e.g. with rates notices).

The materials used for education purposes may comprise brochures, posters, advertisements or relevant articles in the local newspaper or on Council's website.

11.1.6 Action WQ01 – Water Quality Monitoring

Action Description: Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program. This option assumes that Council would contribute by undertaking the required monitoring at five sites in the catchment, incorporating both dry and wet weather sampling.

Cost: Annually recurrent costs of $51,000

Primary Responsibility: Council.

Approvals Pathway: N/A

Other Environmental Approvals Required: N/A

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☐ Coastal / ecological processes ☐ Public access ☒ Community uses ☒ Visual character ☒ Community engagement

This action provides for the continuation of monitoring currently undertaken by Council under its Strategic Water Monitoring Program. This action is one of the more costly actions for implementation; however, it has a range of benefits, including:

- Improved understanding of water quality processes and enabling of adaptive management;
- Risk management with respect to poor water quality;
- Compliance management in the event of any illegal discharges; and
- Opportunity for community engagement.

This action is also consistent with local and State Government policies and plans for water quality improvements.

The costing has been prepared based on an assumed monitoring program incorporating monthly dry weather monitoring and quarterly wet weather sampling of in situ parameters plus nutrients, total suspended solids, biochemical oxygen demand, chlorophyll-a, and dissolved oxygen, and two rounds of biotic index sampling annually. It also includes some provision for database management, brief quarterly reports and annual reports analysing the data.

No approvals or permits would be necessary except where water quality monitoring sites require access through private land.

11.1.7 Action CP01 – Bank Rehabilitation Works

Action Description: Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.

Cost: Capital cost of $269,600 and annually recurrent costs of $2,320 (assumed to be 3% of the capital cost).

Primary Responsibility: Council.

Approvals Pathway: Review of Environmental Factors (REF) under Part 5 of the EP&A Act.

Other Environmental Approvals Required: Permits or approvals may be required under the *Crown Lands Act 1984*, *Fisheries Management Act 1994* and/or *Water Management Act 2000*.

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☒ Coastal / ecological processes

☐ Public access ☒ Community uses ☒ Visual character ☒ Community engagement

This action provides for implementation of weed control, bank stabilisation works and riparian plantings identified in the Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation (Applied Ecology, 2012) for:

> Reach DCCPH001 in Dents Creek, which was classed as being in poor condition; and
> Reach SCSCPH002 in Savilles Creek, which was classed as being in fair but unstable condition.

Further detail can be found in the Applied Ecology (2012) report. Costings have been based largely on their cost estimates and include design and construction, preparation of a REF, other permits and approvals, and project management by Council.

The concept designs for each creek have been extracted from the Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation (Applied Ecology, 2012) and provided as **Figures 11-2 and 11-3**.

The main cost component of the works would be plant (e.g. excavator) and labour hire with additional costs involved in sourcing and procuring vegetation for planting along the creek bank. A Council project manager would be required to oversee the works. Maintenance of the planted vegetation for the first two-three years and toe protection after storm events may be required.

OVERALL OBJECTIVES

1. Improve general habitat condition
2. Stabilise channel (banks/bed)
3. Reduce downstream impacts

WORKS REQUIRED

Treat woody weeds

Bush regeneration weed control

Spot spray and plant

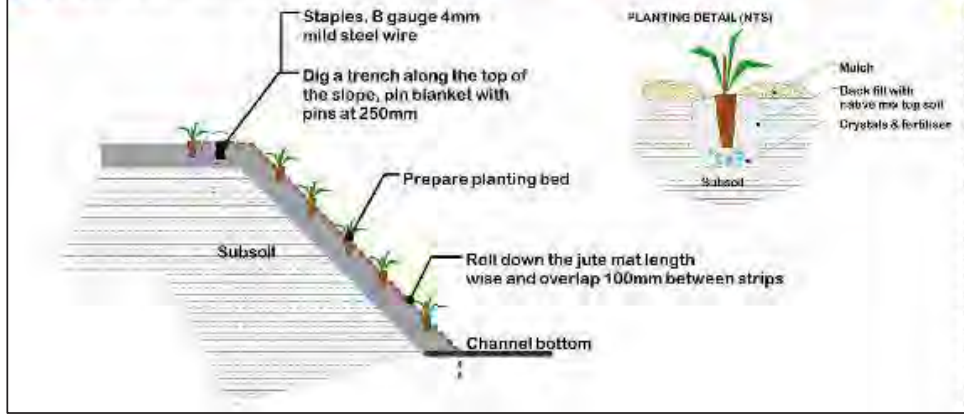
Stabilisation planting

Stabilise top of bank

Jute matting

Terraced retaining walls

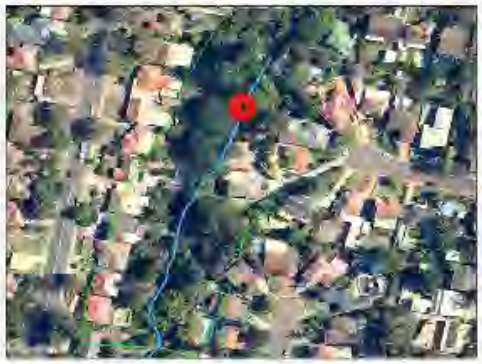
JUTE MAT BANK TREATMENT (NTS)



VEGETATION COMMUNITY:

Sydney Sandstone Gully Forest

(Coastal Enriched Sandstone Sheltered Forest)



SUPPLEMENTARY PLANTING SPECIES LIST

CORE SPECIES	ADDITIONAL SPECIES
TREES & SHRUBS	
Angophora costata	*Acacia linifolia*
Corymbia gummifera	*Acacia longifolia subsp. Longifolia*
Eucalyptus piperita	*Boronia ledifolia*
Eucalyptus pilularis	*Bossiaea heterophylla*
Eucalyptus umbra	*Bossiaea obcordata*
Allocasuarina littoralis	*Dampiera stricta*
Banksia serrata	*Dillwynia retorta*
Elaeocarpus reticulatus	*Glochidion ferdinandi*
Pittosporum undulatum	*Grevillea buxifolia subsp. buxifolia*
Ceratopetalum gummiferum	*Grevillea sericea subsp. sericea*
Acacia suaveolens	*Hakea dactyloides*
Leptospermum trinervium	*Hakea sericea*
Persoonia levis	*Kunzea ambigua*
Acacia ulicifolia	*Lamberbia formosa*
Acacia terminalis	*Lasiopetalum ferrugineum*
Lomatia silaifolia	*Leucopogon encoides*
Dodonaea triquetra	*Notelaea longifolia*
Banksia spinulosa var. spinulosa	*Ozothamnus diosmifolius*
	Persoonia linearis
	Persoonia pinifolia
	Platylobium formosum
	Platysace lanceolata
	Pultenaea daphnoides
	Racinocarpos pinifolius
	Woollsia pungens
	Zieria pilosa
VINES & GROUNDCOVERS	
Smilax glyciphylla	*Actinotus helianth*
Billardiera scandens	*Actinotus minor*
Cassytha pubescens	*Amperea xiphoclada*
Dianella caerulea	*Anisopogon avenaceus*
Entolasia stricta	*Calochlaena dubia*
Lomandra longifolia	*Caustis flexuosa*
Xanthosia pilosa	*Entolasia marginata*
Pteridium esculentum	*Hardenbergia violacea*
	Imperata cylindrica
	Lepidosperma laterale
	Lomandra cylindrical
	Lomandra filiformis
	Lomandra glauca
	Lomandra gracilis
	Lomandra multiflora
	Microlaena stipoides var. stipoides
	Pandorea pandorana
	Pomax umbellata
	Thirmeda australis
	Xanthorrhoea media
	Xanthosia tridentata

Figure 11-2: Bank Stabilisation Works for Dents Creek (Source: Applied Ecology, 2012)

OVERALL OBJECTIVES

1. Improve riparian condition
2. Improve general habitat condition
3. Stabilise channel (banks/bed)

WORKS REQUIRED

Stabilise toe of bank

Rebatter bank

Stabilise channel bed

Treat noxious weeds*

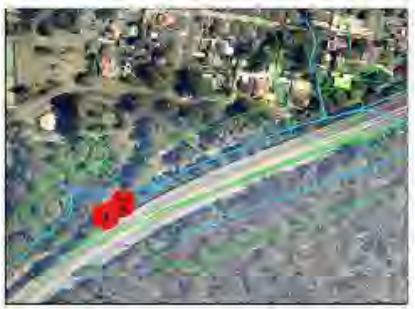
Bush regeneration weed control

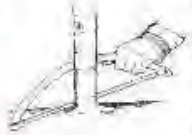
Supplementary planting

VEGETATION COMMUNITY:

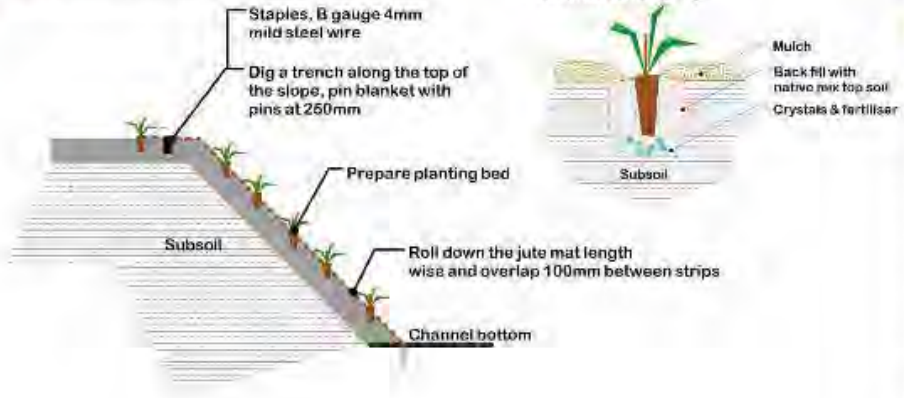
Sydney Sandstone Gully Forest

(Coastal Enriched Sandstone Sheltered Forest)





JUTE MAT BANK TREATMENT (NTS)



PLANTING DETAIL (NTS)

SUPPLEMENTARY PLANTING SPECIES LIST

CORE SPECIES	ADDITIONAL SPECIES
TREES & SHRUBS	
Angophora costata	*Acacia linifolia*
Corymbia gummifera	*Acacia longifolia subsp. Longifolia*
Eucalyptus pipenta	*Boronia ledifolia*
Eucalyptus pilularis	*Bossiaea heterophylla*
Eucalyptus umbra	*Bossiaea obcordata*
Allocasuarina littoralis	*Dampiera stricta*
Banksia serrata	*Dillwynia retorta*
Elaeocarpus reticulatus	*Glochidion ferdinandi*
Pittosporum undulatum	*Grevillea buxifolia subsp. buxifolia*
Ceratopetalum gummiferum	*Grevillea sericea subsp. sericea*
Acacia suaveolens	*Hakea dactyloides*
Leptospermum trinervium	*Hakea sericea*
Persoonia levis	*Kunzea ambigua*
Acacia uncifolia	*Lambertia formosa*
Acacia terminalis	*Lasiopetalum ferrugineum*
Lomatia silaifolia	*Leucopogon ericoides*
Dodonaea triquetra	*Notelaea longifolia*
Banksia spinulosa var. spinulosa	*Ozothamnus diosmifolius*
	Persoonia linearis
	Persoonia pinifolia
	Platylobium formosum
	Platysace lanceolata
	Pultenaea daphnoides
	Ricinocarpos pinifolius
	Woollsia pungens
	Ziera pilosa
VINES & GROUNDCOVERS	
Smilax glyciphylla	*Actinotus helianthi*
Billardiera scandens	*Actinotus minor*
Cassytha pubescens	*Amperea xiphoclada*
Lisanella caerulea	*Anisopogon avenaceus*
Entolasia stricta	*Calochlaena dubia*
Lomandra longifolia	*Caustis flexuosa*
Xanthosia pilosa	*Entolasia marginata*
Pteridium esculentum	*Hardenbergia violacea*
	Imperata cylindrica
	Lepidosperma laterale
	Lomandra cylindrical
	Lomandra filiformis
	Lomandra glauca
	Lomandra gracilis
	Lomandra multiflora
	Microlaena stipoides var. stipoides
	Pandorea pandorana
	Pomax umbellate
	Themeda australis
	Xanthorrhoea media
	Xanthosia tridenta

Figure 11-3: Bank Stabilisation Works for Savilles Creek (Source: Applied Ecology, 2012)

11.1.8 Action CC09 – Upgrade to Seagrass Friendly Moorings

Action Description: Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.

Cost: Annually recurrent costs of $3,600 (assumes one is replaced each year).

Primary Responsibility: Roads and Maritime Services.

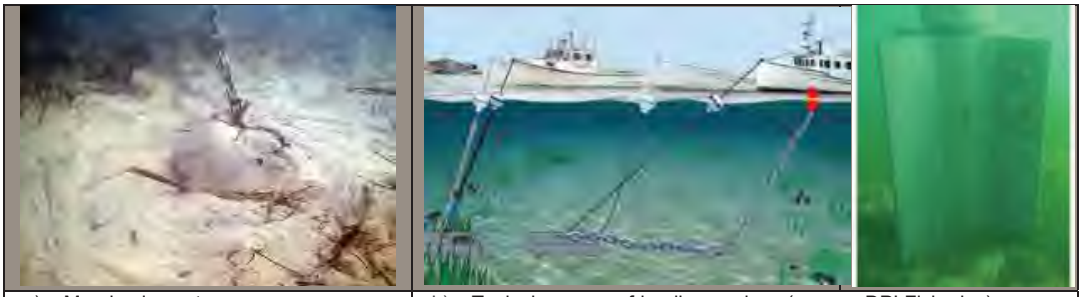
Approvals Pathway: REF under Part 5 of the EP&A Act (may be required).

Other Environmental Approvals Required: May require approvals under the *Crown Lands Act 1984* and/or *Water Management Act 2000*.

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☐ Coastal / ecological processes

☐ Public access ☐ Community uses ☐ Visual character ☒ Community engagement

The traditional moorings can have significant impacts on seagrass beds to due abrasion of the bed by the dragging chain (see **Figure 11-4a**). In recent years a range of seagrass friendly mooring types have been developed that minimise these impacts (see **Figure 11-4b**), some of which have been trialled in Sydney by DPI Fisheries. The trials involving the replacement of traditional moorings have shown that seagrass can recolonise the previously bare areas.



a) Mooring impacts on seagrass | b) Typical seagrass friendly moorings (source: DPI Fisheries)

Figure 11-4: Examples of Moorings

This action would involve the progressive replacement of each mooring in the North West Arm with a seagrass friendly mooring.

11.1.9 Action CC20 – Review of Stormwater Management Practices

Action Description: Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources. This may involve a review of street sweeping and the location of GPTs.

Cost: Capital cost of $12,000.

Primary Responsibility: Council.

Approvals Pathway: N/A.

Other Environmental Approvals Required: N/A

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☐ Coastal / ecological processes

☐ Public access ☐ Community uses ☐ Visual character ☒ Community engagement

As discussed in **Section 6.4**, Council is responsible for the majority of the stormwater management planning, construction, operation and maintenance. The community consultation indicates that there is a strong desire to improve stormwater quality and minimise impacts on the estuary, and several respondents suggested the installation of additional SQIDs or more street sweeping. Consultation with Council indicates these activities can be very costly to maintain, and there needs to be careful prioritisation of activities that takes into account the available budget.

This action provides for a review of current practices with a view to rationalising activities and/or identifying opportunities – it effectively aims to identify the optimal use of Council's limited resources. It should be based on assessment of catchment hydrology, pollutant sources and potential impacts (positive or negative) on the receiving environment. The optimal placement of gross pollutant traps in discussed in **Section 6.4.1** and these guidelines should be consulted when conducting a review.

11.1.10 Actions WQ06, WQ08, WQ09 and WQ10 – Stormwater Quality Improvement Devices

Action WQ06 Description: Install a SQID to treat stormwater draining to Dents Creek via reaches DCDCPH017 and 018, to be located near the intersection of Huskisson St and Cobargo Rd.

Action WQ08 Description: Install a trash rack at the point where North West Arm Road crosses Savilles Creek to capture gross pollutants.

Action WQ09 Description: Install an online SQID on the unnamed watercourse located in Kyogle Reserve to capture gross pollutants from the stormwater network and upstream reach of the creek prior to entering the estuary.

Action WQ10 Description: Install a SQID to treat stormwater from the piped drainage catchment to the south east prior to discharge to the unnamed watercourse located in Kyogle Reserve.

Cost: Each action has a capital cost of $109,000 and annually recurrent costs of $8,000 (summing to $436,000 in capital costs and $32,000 in annually recurrent costs).

Primary Responsibility: Council.

Approvals Pathway: REF under Part 5 of the EP&A Act.

Other Environmental Approvals Required: Permits or approvals may be required under the *Crown Lands Act 1984*, *Fisheries Management Act 1994* and/or *Water Management Act 2000*.

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☐ Coastal / ecological processes
☐ Public access ☒ Community uses ☒ Visual character ☒ Community engagement

A review was undertaken of the catchment and existing stormwater treatment assets in order to consider options for additional SQIDs that may be implemented by Council in the event of additional capital works and ongoing funding. A series of four potential options for SQIDs was developed based on consideration of:

- The location and effectiveness of existing SQIDs;
- Catchment land use;
- Catchment hydrology;
- Availability of space for installation;
- Availability of access for ongoing maintenance; and
- Technical feasibility.

Due to the limitation of funds, it is suggested that the implementation of these Actions be staged, and implemented if additional funding becomes available. It is recommended that Action CC20 is undertaken and the findings considered prior to moving forward with Actions WQ06, WQ08, WQ09 or WQ10.

11.1.11 Actions CC04 – Create New Public Reserve at Molong Road

Action Description: Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.

Cost: Capital cost of $346,400 and annually recurrent cost of $2,750 (assumed to be 2% of the capital cost).

Primary Responsibility: Council.

Approvals Pathway: REF under Part 5 of the EP&A Act.

Other Environmental Approvals Required: Permits or approvals may be required under the *Crown Lands Act 1984*, *Fisheries Management Act 1994* and/or *Water Management Act 2000*.

Key Benefits: ☐ Vegetation / habitat condition ☐ Water quality ☐ Coastal / ecological processes

☒ Public access ☒ Community uses ☐ Visual character ☒ Community engagement

A number of respondents to the community survey highlighted the lack of recreational amenity around the North West Arm, with limited access to the foreshore and very few parks or reserves available for public enjoyment of the estuary. The main objective of this Action would be to increase public access to the estuary, and to provide improved recreational amenity for a variety of users.

This land is currently road reserve under the care and control of Council. The project would require vegetation removal, the construction of a walking track and a jetty or pontoon to provide access to the waterway. The land is fairly steep as it grades down towards the waterway, and stairs may need to be constructed for the public to reach the pontoon. The main issue with the implementation of this Action is the ability of Council to provide regular and ongoing maintenance for purposes of public safety.

The works would provide facilities for passive recreation, as well as for swimmers, fishers and users of small watercraft such as kayakers. A typical concept for the jetty/pontoon is provided in **Figure 11-5**.

It is noted that both Actions CC03 and CC04 include a kayak launching facility, hence Action CC03 would not be required in the event Action CC04 is implemented. When calculating the total cost of the Actions in the Implementation Plan, the higher costing of these two actions has been included.

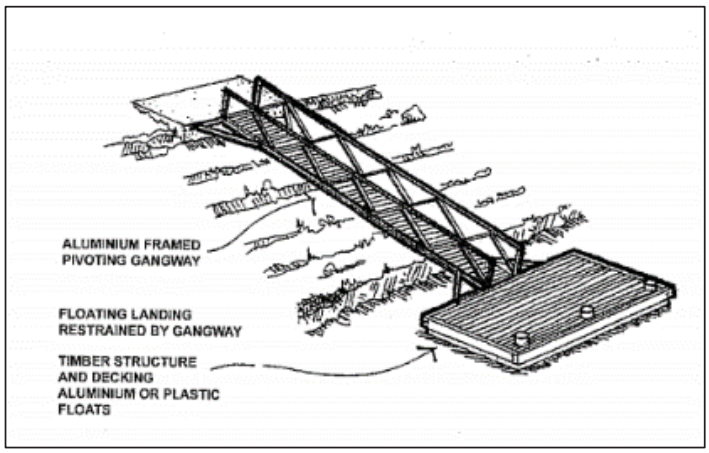


Figure 11-5: Typical pontoon structure (Source: Mid Murray Council, n.d.)

11.1.12 Action WQ03 – Reduce Impact of Sewage Overflows

Action Description: Work with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows on the estuary.

Cost: Annually recurrent cost of $11,200 (assumes three days per month of a Council officer's time).

Primary Responsibility: Council.

Approvals Pathway: N/A.

Other Environmental Approvals Required: N/A.

Key Benefits: ☒ Vegetation / habitat condition ☒ Water quality ☒ Coastal / ecological processes

☐ Public access ☒ Community uses ☒ Visual character ☐ Community engagement

This action involves Council working with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows that negatively impact on estuarine water quality and ecology from time to time. A number of respondents to the community survey raised this as an issue that they have observed after rainfall events.

The sewage network is owned and operated by Sydney Water under an Environment Protection Licence issued under the *Protection of the Environment Operations Act 1997*. Sewer overflows may occur during wet weather due to the introduction of stormwater into the sewage network and subsequent capacity issues, which may result in overflows and the release of raw sewage to the environment. Sydney Water operates a SewerFix Program, which is program of works to improve flow in pipes, reduce overflows and reduce impacts on human and environmental health.

Whilst the SewerFix Program is implemented by Sydney Water, local councils often work with Sydney Water on sewer overflows. This is due to the fact that local councils often directly receive complaints on sewer overflows and related issues from members of the public, which they then pass on to Sydney Water. In addition, Council may themselves assist Sydney Water in identifying issues.

Private sewer connections (i.e. from residential dwellings to the main network) can also contribute to sewer leaks when they are damaged or have been improperly (or illegally) connected. In this case both Council and Sydney Water may work with the landowner to address the issue.

11.1.13 Action CU01 – Establish a Kayak Trail

Action Description: Establish a kayak trail from Swallow Rock and leading into the North West Arm.

Cost: Capital cost of $37,500 and annually recurrent cost of $750 (assumed to be 3% of the capital cost).

Primary Responsibility: Council.

Approvals Pathway: REF under Part 5 of the EP&A Act.

Other Environmental Approvals Required: Permits or approvals may be required under the *Crown Lands Act 1984*, *Fisheries Management Act 1994* and/or *Water Management Act 2000*.

Key Benefits: ☐ Vegetation / habitat condition ☐ Water quality ☐ Coastal / ecological processes
☒ Public access ☒ Community uses ☐ Visual character ☒ Community engagement

Council has indicated that they do not wish to exclude those Actions with a relatively high Net Benefit Index simply because they are costly to implement, and therefore have a lower ranking. Council specifically requested the inclusion of Action CU01 in the Implementation Plan. The kayak trail would direct users of small watercraft from Swallow Rock boat ramp and around the estuary, identifying key features of the estuary, encouraging active recreation and providing an opportunity for environmental education.

Council officers would work with a graphic designer to develop up to five signs for installation. In addition, the options costing also provides for preparation and distribution of a community brochure to inform community members of the establishment of the kayak trail.

11.2 Potential Funding Options

One of the challenges of implementation of the CZMP relates to the availability of funding, which may come from Council directly or via a grant program. Whilst an effort has been made to make the Implementation Plan reasonable and feasible, taking into account the available resources, it is acknowledged that resource constraints may lead to some actions not being implemented over the next 5-10 years. It is important to note that the CZMP is subject to regular review, and there is opportunity to incorporate any actions that were not implemented in the current cycle into the updated CZMP.

This section of the CZMP provides an overview of some of the potential sources of funding available to Council.

Council funding is allocated based on the Resource Strategy, a 10 year Long Term Financial Plan, which supports the Four Year Delivery Program and the Annual Operational Plan under the IPR System (see **Section 2.4**).

Some management actions may be funded under existing Council programs such as the following:

- Stormwater Levy – The levy collects approximately $2 million per year and provides for drainage construction, water quality and stormwater maintenance works throughout the entire LGA. The majority of this budget is already allocated to ongoing programs including works and maintenance;
- Bushcare program; and

> Greenweb Grants – Council provides grants of up to $2,000 each (total of $20,000 worth of grants) for private landowners for ecological restoration works. Applications open in August each year.

While a total of 19 management actions have been identified as a priority for implementation, it is recognised that the Plan needs to retain sufficient flexibility such that Council (or other responsible agencies) may implement any of the management actions at any time, regardless of their priority. Such an instance may arise where, for example, funding becomes available through a specific grant or funding program.

Potential funding options are provided in **Table 11-2**. It should be noted that this is not an exhaustive list of all funding opportunities available.

Table 11-2: Funding Opportunities

Grant	Provider	Purpose	Application Period	Funding Available
Environmental Education Grants	Environmental Trust (OEH)	To support educational projects or programs that develop or widen the community's knowledge of skills in, and commitment to, protecting the environment and promoting sustainable behaviour.	March – April	$500,000 - Community programs (total) $500,000 - State and Local Government programs (total)
Environmental Restoration and Rehabilitation Grants	Environmental Trust (OEH)	To facilitate projects run by community organisations and government entities working to prevent or reduce environmental degradation of any kind. To improve the capacity of communities and organisations to protect, restore and enhance the environment.	August	$2 million - Community programs (total) $2 million - Government entities (total)
Environmental Research Grant	Environmental Trust (OEH)	To support applied research projects that help address environmental problems in NSW.	February – March	Up to $150,000 per grant ($1 million total)
Coastal and Estuary Management Grants	OEH	Preparation (or updating) of CZMPs and associated technical studies (including coastal hazard assessments). Action to manage the risks from coastal hazards (noting that for identified hotspot locations, these actions must be listed as a priority in a CZMP certified by the Minister). Action to implement environmental repairs, including habitat restoration and conservation projects. Pre-construction activities for projects that are eligible and are likely to proceed to construction. Development of management tools (such as education projects).	January – March	Grant offers are subject to availability of funds for each financial year and state-wide priorities. Funding of up to 50% of a project's costs will normally be offered for successful grant applications.
Sponsorship	OEH	OEH offers limited sponsorship opportunities for projects, programs and events that advance their goals but are not covered under their various grant programs.	All year	N/A
Habitat Action Grants	DPI	To provide funding for habitat rehabilitation projects such as rehabilitation of riparian lands (river banks, wetlands, mangrove forests, saltmarsh), removal of exotic vegetation from waterways, bank stabilisation works, and reinstatement of natural flow regimes	N/A	N/A
Green Army Grants	Commonwealth Department of Environment	Projects must contribute to Australia's national and international environmental priorities and obligations. Projects may also include activities to protect and conserve matters of national and environmental significance. Local priorities can include: propagation and	-	A Green Army Team of up to nine Participants and a Team Supervisor working to deliver conservation activities for between 20 and 26 weeks.

Grant	Provider	Purpose	Application Period	Funding Available
		planting of native seedlings, weed control, habitat protection and restoration, improving water quality by cleaning up waterways, creek bank regeneration, and foreshore and beach restoration.		

12 Monitoring and Evaluation Strategy

12.1 Overview

Monitoring and evaluation is a key component of the CZMP for two purposes:

> To monitor, evaluate and report on the health of the North West Arm; and
> To determine if implementation of the Plan has been successful in meeting the management objectives.

Monitoring and evaluation permits adaptive management, whereby the adopted management approach can be modified in response to any change in circumstance, or to provide improved management outcomes.

12.2 Key Performance Indicators

To assist in measuring the success of the implementation of the Plan, Key Performance Indicators (KPIs) have been developed for the North West Arm estuary. A simple approach would be to assess the number of management actions that have been initiated or have been completed. In addition, a series of KPIs have been developed to allow Council to measure whether the actions implemented under the Plan have been successful in working towards achievement of the management objectives (**Table 12-1**). The KPIs are not specific with how they should be measured or time-phased to provide flexibility to Council.

These KPIs should be assessed after a period of no more than five years, and a decision made by Council as to whether it is necessary to update the Plan. This process will assist Council in determining whether the actions list needs updating and additional options incorporated for the forthcoming implementation period.

Table 12-1: Key Performance Indicators for Management Plan Objectives

Management Objective	Key Performance Indicator
Protect and improve the condition of natural bushland, riparian and estuarine vegetation.	▪ The net extent and percentage cover of estuarine vegetation is maintained or improved as reported via aerial photographs or survey. ▪ As above for riparian vegetation. ▪ Reduction in extent of weed coverage in the catchment. ▪ No increase (or net reduction) in the extent (linear length) of artificial structures along the estuary foreshores. ▪ Reduction in the extent (linear length) of actively eroding natural shoreline. ▪ Aquatic habitats such as intertidal sand flats and rock platforms are recognised as important habitats and conserved (within relevant development control plans or other Council policies or plans).
Maintain and improve estuarine water quality for aquatic ecosystem health and recreational purposes.	▪ Reference conditions for the estuary are established for parameters listed in the NSW MER program. ▪ Estuarine water quality shows improved compliance with the ANZECC (2000) and OEH (2013c) guidelines for aquatic ecosystem health. It may be necessary to validate the guideline values against baseline conditions for the estuary. ▪ The incidence of reported sewer overflows as recorded by Sydney Water is reduced. ▪ The number of complaints regarding water quality reported to Council is reduced.
Maintain and (where feasible) improve public access to and around the estuary foreshores and waterbody.	▪ The extent of publicly accessible foreshore is maintained or improved.
Recognise the values and significance of the estuary to the community.	▪ Community education strategies recognise the significance of the estuary to the community.
Manage the impacts of human activities on natural coastal	▪ Reduction in reported incidences of illegal dumping.

Management Objective	Key Performance Indicator
processes and estuarine ecosystems.	▪ Development applications for foreshore land explicitly consider the objectives of this Plan. ▪ Foreshore residents have improved awareness of estuarine processes and how these may potential impact on their land.
Maintain the visual character of the North West Arm estuary.	▪ The potential visual impacts of any development proposals are considered during determination of the development application.
Seek to engage with the community and involve them in the implementation of the CZMP for the North West Arm.	▪ Number of events / communications each year increases.

12.3 Monitoring, Evaluation and Reporting Requirements

The *New South Wales Natural Resources Monitoring, Evaluation and Reporting Strategy 2010-2015* (DECCW, 2010a) guides the Monitoring, Evaluation and Reporting (MER) of the status of natural resources in NSW. It presents a standard approach to coordinate the efforts of natural resource and land management agencies (including State Government agencies and the Local Land Services) to better understand whether the overall health of the natural resources of NSW are changing and to assess the effectiveness of remedial action in reversing observed negative trends. The state-wide natural resource condition targets in the Strategy (DECCW, 2010a) provide the structure for the MER program. The outcomes of the MER program also feed into the State of the Environment reporting prepared by OEH.

The MER Strategy aims to guide monitoring, evaluation and reporting efforts over five years to:

> Support continuous improvement of Natural Resources Management (NRM) and investment decisions;
> Inform evaluation and reporting on progress towards the NRM targets at the State and catchment level scales;
> Improve our knowledge of the condition of natural resources and the pressures on them, as well as on trends in the condition of our natural resources;
> Improve capacity to report on achievements of investments in NRM programs;
> Improve data management and sharing arrangements among MER partners; and
> Enhance collaborative partnerships with key NRM players to strengthen the MER effort.

OEH provides guidance on implementation of the MER Strategy for estuaries in the document: Assessing estuary ecosystem health: sampling, data analysis and reporting protocols (OEH, 2013c). The North West Arm falls under the “Estuaries and Coastal Lakes” theme, under which a series of indicators are identified for monitoring. According to OEH (2013c), monitoring as part of the estuaries theme of the MER Program focuses on estuarine biology to determine condition in preference to the stressors and pressures which are the external factors that cause changes in condition.

The estuarine ecosystem health indicators listed in OEH (2013c) are summarised in **Table 12-2**. The MER water quality monitoring is scheduled to be undertaken approximately every three years, between mid-September and the end of March, in accordance with the sampling program outlined in Section 7.4 of OEH (2013b). It is understood that the estuarine macrophytes and fish sampling would follow a similar cycle of sampling roughly every three years (DECCW, 2010a). The data collected is to be incorporated into the state-wide MER.

Table 12-2: Estuarine Ecosystem Health Indicators (After: OEH, 2013c)

Indicator	Method
Water Quality Indicators	
Chlorophyll *a*	Filtration and extraction
Water clarity and turbidity	Secchi disk; NTU
Other Indicators	
Estuarine macrophytes (seagrass, mangroves and saltmarsh)	Areal extent

Indicator	Method
Fish assemblages	Estuarine Fish Community Index
Optional Additional Indicators	
Macroalgae	Areal extent
Dissolved Oxygen	24 hour in-situ monitoring

OEH (2013c) notes that these protocols do not address matters that reflect broader estuary uses, human health and community values such as the assessment of recreational water quality (see Beachwatch protocols), however, there may be opportunities to include additional indicators when reporting on estuary health or water quality more broadly.

12.4 Proposed Monitoring Program

As part of developing this CZMP, an Estuary Health Monitoring Program has been prepared for use as a baseline to track how well the estuary is being managed over time, as well as whether implementation of the completed CZMP is contributing to improved estuary health. The key objectives of the monitoring are to establish baseline conditions for the North West Arm and assess how the overall health of the estuary changes over time. This is very important in enabling identification of issues and an adaptive management response. It is also important in improving the general understanding of how the estuary functions and responds to certain events or stressors.

It is acknowledged that environmental monitoring can be a very costly exercise. Hence, the guidance on monitoring provided in **Appendix G** identifies a wide range of parameters that may be considered by Council, some of which are highlighted in green to indicate that they are a higher priority. Depending on the amount of available funding, additional parameters may be incorporated into the program.

13 Concluding Remarks

This CZMP for the North West Arm has been prepared by Cardno on behalf of Sutherland Shire Council in accordance with the requirements of the NSW *Coastal Protection Act 1979*, and with reference to the *Guidelines for Preparing Coastal Zone Management Plans* (OEH, 2013a).

This CZMP has built on the scoping study, literature and information review prepared by BMT WBM (2012). It synthesises the existing literature on the North West Arm estuary and presents the findings of additional investigations undertaken by Cardno to improve our understanding of the functioning of the estuary, including an assessment of risk from coastal hazards and description of ecological health status. In addition, the CZMP reports on the outcomes of a program of community and stakeholder engagement that investigated the values and significance of the estuary to the community, and their desired outcomes for ongoing management. The CZMP summarises the management issues identified through this process, and identifies a series of management options for consideration in the CZMP.

The CZMP includes an Implementation Plan consisting of 19 management actions proposed for execution over the next 10 years, shortlisted on the basis of a quadruple bottom-line cost-benefit assessment from a longer list of 35 management options. The Plan clearly identifies the responsible organisation for implementation of each management action, be it Council or other organisations with a role in coastal management in Port Hacking.

The indicative total cost of implementation of the Plan is $1,072,680 in capital costs, and $223,620 in annually recurrent costs, over a 10 year period of implementation. Of the actions identified in the Plan, 16 would be the primary responsibility of Council for implementation, summing to $1,061,980 in capital costs and $214,520 in annually recurrent costs.

Other organisations or agencies have been identified as having primary responsibility for implementing the remaining actions, and the relevant parties have provided their support. Copies of the relevant correspondence are held by Council.

The management actions within the Implementation Plan (**Section 11**) have been prioritised to assist in allocating resources when carrying out the Plan; however, it is acknowledged that the resources required to progress the Plan are significant, and that a flexible approach to undertaking works should be adopted. For example, there may be grants or other funding opportunities that arise from time to time that will allow Council to select certain types of lower priority management actions for implementation before higher priority actions.

In order to measure the success of implementation of the Plan, a monitoring and evaluation strategy is also included (**Section 12**) that provides for regular assessment against a range of KPIs, as well as more regular monitoring of estuarine health. The North West Arm CZMP should be viewed as a 'living document' that is reviewed and updated over time in accordance with the principles of adaptive management. The monitoring and evaluation strategy will be a key input into this process.

The North West Arm CZMP represents a comprehensive document that provides for integrated coastal management of the system by Council and other key stakeholders. In accordance with the requirements of Section 55 of the *Coastal Protection Act 1979*, the Plan was placed on public exhibition for 28 days.

The North West Arm CZMP will now be presented for formal adoption by Council.

14 References

Albani, A.D. and Cotis, G. (2013) *Port Hacking. Past and present of an estuarine environment*. Prepared for Sutherland Shire Council

Albani, A.D. (1999) *Port Hacking Tidal Delta Sediment Study*. Prepared for the Hacking River Catchment Management Committee.

Alongi, D. M. (2008). *Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change*. Estuarine, Coastal and Shelf Science 76 (1-13).

ASSMAC (1998) *Acid Sulfate Soils Assessment Guidelines*. NSW Acid Sulfate Soils Management and Advisory Committee.

Australian Hydrographic Service (2014) *Australian National Tide Tables 2014. Australia, Papua New Guinea, Solomon Islands, Antarctica and Timor-Leste. Australian Hydrographic Publication 11.*

ANZECC & ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Applied Ecology (2012) *Sutherland Shire watercourse assessment and rehabilitation prioritisation*. Applied Ecology Pty Ltd. Prepared for Sutherland Shire Council, September 2012.

AWT (1997) *Modelling of the Impact of Existing and Abated Sewage Overflows on Water Quality in Port Hacking.*

AWT (2000) *Hacking River Stormwater Management Plan.* Prepared for Wollongong City Council and Sutherland Shire Council.

Barrett-Lennard, E.G. (2003) The interaction between waterlogging and salinity in higher plants: causes, consequences and implications. *Plant and Soil*, 253, pp: 35-54

Beer, T. & Ziolkowski, F. (1995) *Environmental Risk Assessment: An Australian Perspective*. Australian Academy of Science Fenner Conference on the Environment, Canberra.

Bell, J.D. & Pollard, D.A. (1989) E*cology of Fish Assemblages and Fisheries Associated with Seagrass Ecosystems - An Australian Perspective.*

Berelson, W.M., D. Heggie, A. Longmore, T. Kilgore, G. Nicholson and G. Skyring (1998) *Benthic nutrient recycling in Port Phillip Bay, Australia*. Estuarine, Coastal and Shelf. Shelf Science 46 (917-934).

Bewsher Consulting (2004) *Initial Subjective Assessment of Major Flooding*. Prepared for Sutherland Shire Council.

Birch, G.F. (2000) Marine pollution in Australia, with special emphasis on central New South Wales estuaries and adjacent continental margin, *International Journal of Environment and Pollution*, Vol. 13, Nos. 1–6, pp. 573–607.

BMRG (2014) *Marvellous Mangroves Australia. A Wetlands Education Resource Book for Australia.* Published by the Mangrove Action Project and the Burnett Mary Regional Group for Natural Resource Management Ltd.

BMT WBM (2012) *Preparation of a Coastal Zone Management Plan for the North West Arm Estuary: scoping exercise, literature and information review*. BMT WBM Pty Ltd. Prepared for Sutherland Shire Council, August 2012.

BoM (2015) Climate Data Services Weather Station Directory http://www.bom.gov.au/climate/data/stations/ Accessed 26 January 2015.

Chessman, B. (2003) SIGNAL 2.iv A Scoring System for Macroinvertebrates ('Water Bugs') in Australian Rivers Users Manual. Monitoring River Health Initiative Technical Report, Report No. 31. Commonwealth of Australia. September 2003, pp.: 34.

Chief Scientist and Engineer (2012) *Assessment of the Science Behind the NSW Government's Sea Level Rise Planning Benchmarks*. NSW Government.

Church, J.A., Hunter J.R., McInnes, K., and White N.J. (2006) Sea-level rise around the Australian coastline and the changing frequency of extreme sea-level events. *Australian Meteorological Magazine*, vol. 55, pp. 253-260

Clarke, L.D. and Hannon, N.J. (1970) The mangrove swamp and salt marsh communities of the Sydney district. III Plant growth in relation to salinity and waterlogging. *Journal of Ecology,* 58(2), pp: 351-369

Connell, S.D. & Glasby, T.M. (1999) *Do urban structures influence local abundance and diversity of subtidal epibiota?* Marine Environmental Research, 47(4), 373-387.

Corkill J.R. (2013) Ambulatory boundaries in New South Wales: Real lines in the sand. *Property Law Review* 3(2) pp67-84.

Couriel, E., Modra, B., Jacobs. R. (2014) *NSW Sea Level Trends – The Ups and Downs*. Paper presented to 17th Australian Hydrographers Association Conference Sydney. 28-31 October 2014.

Creese, R.G., Glasby, T.M., West, G. & Gallen, C. (2009) *Mapping the Habitats of NSW Estuaries.* Prepared for the Hunter Central Rivers Catchment Management Authority.

CSIRO (2011) *Climate Change: Science and Solutions for Australia.* Commonwealth Scientific and Industrial Research Organisation

CSIRO and BoM (2014) *State of the Climate 2014*. Commonwealth Scientific and Industrial Research Organisation and the Bureau of Meteorology.

DECC & SMCMA (2009) *Environmentally Friendly Seawalls: A guide to improving the environmental value of seawalls and seawall-lined foreshores in estuaries*. NSW Department of Environment and Climate Change and the Sydney Metropolitan Catchment Management Authority.

DECCW (2009) *NSW Sea Level Rise Policy Statement*. NSW Department of Environment, Climate Change and Water.

DECCW (2010) *New South Wales Natural Resources Monitoring, Evaluation and Reporting Strategy 2010-2015.* NSW Department of Environment Climate Change and Water.

Dennison, W.C., Thomas, J.E., Cain, C.J., Carruthers, T.J. B., Hall, M.R., Jesian, R.V., Wasniak, C.E. & Wilson, D.E. (2009) *Shifting Sands: Environmental and Cultural Change in Marylands Coastal Bays.* University of Maryland Centre for Environmental Science.

Dowdy A. *et al.* (2015) *East Coast Cluster Report*, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports, eds. Ekström, M. et al., CSIRO and Bureau of Meteorology, Australia.

DPI (n.d.) Traditional boat moorings in sensitive habitats. Retrieved May 2015, from http://www.dpi.nsw.gov.au/fisheries/habitat/threats/traditional-boat-moorings-in-sensitive-habitats

Engineers Australia (2004) *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering*. National Committee on Coastal and Ocean Engineering, Engineers Australia.

Engineers Australia (2012a) *Coastal Engineering Guidelines for Working with the Australian Coast in an Ecologically Sustainable Way*. National Committee on Coastal and Ocean Engineering, Engineers Australia.

Engineers Australia (2012b) *Climate Change Adaptation Guidelines in Coastal Management and Planning*. The National Committee on Coastal and Ocean Engineering, Engineers Australia.

EurOtop (2007) *EurOtop Wave Overtopping of Sea Defences and Related Structures: Assessment Manual.*

Extreme Storms (2014). East Coast Low 14th to 15th October 2014<http://www.extremestorms.com.au/east-coast-low-14th-to-15th-october-2014/>. Accessed on 21 January 2015.

GHD (2011) *Sea Level Rise Risk Assessment: Potential impacts of a changing climate on coastal and catchment flooding*. Prepared for Sutherland Shire Council, September 2011

Glasby, T.M., Connell, S.D., Holloway, M.G. & Hewitt, C.L. (2007) Non-indigenous biota on artificial structures: could habitat creation facilitate biological invasions? *Marine Biology,* 151(887-895).

Green, R.H. (1979) *Sampling design and statistical methods for environmental biologists*. Cambridge University Press: Cambridge, England.

Hadwen, WL, Capon, SJ, Kobashi D, Poloczanska, ES, Rochester, W, Martin, TG, Bay, LK, Pratchett, MS, Green, J, Cook, BD, Berry, A, Lalonde, A, Hall, A & Fahey, S (2011), *Climate change responses and adaptation pathways in Australian coastal ecosystems: Synthesis report*, National Climate Change Adaptation Research Facility, Gold Coast, 359 pp.

Hewitt, C.L. & Martin, R.B. (1996) *Port Surveys for Introduced Marine Species – Background considerations and sampling protocols. Technical Report No.4*. Commonwealth Scientific and Industrial Research Organisation.

Hewitt, C.L. & Martin, R.B. (2001) *Revised Protocols for Baseline Port Surveys for Introduced Marine Species: survey design, sampling protocols and specimen handling. CRIMP Technical Report No. 22*. Commonwealth Scientific and Industrial Research Organisation.

IPCC (2013) *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1,535 pp.

Kathiresan K. & Bingham B. L. (2001) *Biology of mangroves Ecosystems.* Advances in Marine Biology 40 (81-251).

Keough, M.J. & Jenkins, J.P. (1995) *Seagrass Meadows and their Inhabitants: Coastal Marine Ecology of Temperate Australia*. University of New South Wales.

Larkum, A.W.D., McComb, A.J. & Shepherd, S.A. (1989) *Biology of seagrasses : a treatise on the biology of seagrasses with special reference to the Australian region*. New York, Amsterdam, Elsevier.

Lewtas, K.L.M., Birch, G.F., and Foster-Thorpe, C. (2014) Metal accumulation in the greentail prawn, Metapenaeus bennettae, in Sydney and Port Hacking estuaries, Australia, *Environmental Science and Pollution Research*, Vol. 21, pp. 704-716.

Massachusetts Dept. of Environment (n.d.) *Stone Toe Protection*. Massachusetts Nonpoint Source Pollution Manual. Massachusetts Department of Environment

McKenzie, L.J. (1994) *Seasonal changes in biomass and shoot characteristics of a Zostera capricornii Asher*. Australia Journal of Marine & Freshwater Research 45 (1337-52).

MHL (2006*) Survey of tidal limits and mangrove limits in NSW estuaries 1996 to 2005*. Prepared by Manly Hydraulics Laboratory (Report No. MHL 1286, Commerce Report No. 03081) for the Department of Natural Resources.

Mid Murray Council (n.d.) *Information Sheet 4: Lodging an application for a jetty/pontoon*. Mid Murray Council.

Millar, A.J.K. (2007) The Flindersian and Peronian Provinces. McCarthy, P. M. & Orchard, A E. (Eds.) *Algae of Australia: Introduction*. Collingwood, CSIRO Publishing.

Millar, A.J.K. (2009) *NSW DPI Primefacts X: Macroalgae*. NSW Department of Primary Industries.

Moreira, J. (2006) *Patterns of occurrence of grazing molluscs on sandstone and concrete seawalls in Sydney Harbour (Australia)*. Molluscan Research, 26 (1)51-60.

Nagelkerken I., Blaber S.J.M, Bouillon S., Green P., Haywood M., Kirton L.G., Meynecke J.-O., Pawlik J., Penrose H.M., Sasekumar A., & Somerfield P.J. (2008). *The habitat function of mangroves for terrestrial and marine fauna: A review*. Aquatic Botany 89(155-185).

Nath, B., Chandhuri, P. and Birch, G. (2014) *Assessment of biotic response to heavy metal contamination in Avicennia marina mangrove ecosystems in Sydney Estuary, Australia*. Ecotoxicology and Environmental Safety 107(284-290).

NHMRC (2008) Guidelines for Managing Risks in Recreational Waters. National Health and Medical Research Council, Australian Government, February 2008.

NLWRA (2001) National Land and Water Resources Audit data. Downloaded from 'OEH (2015) *CERAT*. OzCoasts: Australian Online Coastal Information. Office of Environment and Heritage'.

NRMMC (2007) National Protocol for Monitoring of Cyanobacteria and their Toxins in Surface Waters. Natural Resource Management Ministerial Council. Draft (Under Review). Canberra.

NSW DPI (2008) *Primefact 746 Mangroves.* NSW Department of Primary Industries.

NSW EPA (2014) *Waste Classification Guidelines.* Prepared by the NSW Environmental Protection Agency.

NSW Government (2005) *Floodplain Development Manual*.

NSW Public Works (1980) *Port Hacking Sediment Study. Interim Report*. NSW Department of Public Works. August 1980

NSW Trade and Investment (2012) *NSW Government Sustainable Dredging Strategy 2012/13 – 2014/15.* NSW Trade and Investment

OEH (2011a) *CERAT*. OzCoasts: Australian Online Coastal Information. Office of Environment and Heritage.

OEH (2011b) *Observed Changes in NSW Climate 2010.* Office of Environment and Heritage.

OEH (2011c) *Guide to Climate Change Risk Assessment for NSW Local Governmen*t. Office of Environment and Heritage.

OEH (2011d) *Estuaries and Coastal Lakes technical Report Series. Assessing the condition of estuaries and coastal lake ecosystems in NSW.* Office of Environment and Heritage.

OEH (2012) *Guide to completing the AHIMS Site Recording Form.* Office of Environment and Heritage.

OEH (2013a) *Guidelines for Preparing Coastal Zone Management Plans.* Office of Environment and Heritage.

OEH (2013b) *Code of Practice under the Coastal Protection Act 1979.* State of NSW and Office of Environment and Heritage.

OEH (2013c) *Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols.* State of NSW and Office of Environment and Heritage.

OEH (2014a) *Metropolitan Sydney Climate Change Snapshot.* Office of Environment and Heritage.

OEH (2014b) *State of the Beaches 2013-2014 Sydney Region New South Wales.* Office of Environment and Heritage.

OEH (2014c) *Aboriginal Heritage Information Management System (AHIMS) Web Services*. Retrieved December 2014, from http://www.environment.nsw.gov.au/awssapp/Login.aspx.

OEH (2015) *Aboriginal cultural heritage conservation*. Retrieved March 2015, from http://www.environment.nsw.gov.au/conservation/aboriginalculture.htm

OzCoasts (2008) Impacts on Estuaries from Global Warming Projected for Australia. Online, Geoscience Australia, http://www.ozcoasts.org.au/indicators/greenhouse_effect.jsp (Accessed on January 28 2014).

PPK and Clouston (2001) *The Shires Foreshores. Achieving Scenic Quality.* PPK Environment and Infrastructure and Clouston.

Roper, T., Creese, B., Scanes, P., Stephens, K., Williams, R., Dela-Cruz, J., Coade, G., Coates, B., and Fraser, M. (2011) *Assessing the condition of estuaries and coastal lake ecosystems in NSW. Monitoring, evaluation and reporting program.* Technical Report Series. State of NSW and Office of Environment and Heritage.

Rossington S. (2008) *Modelling Large-Scale Estuarine Morphodynamics Using Equilibrium Concepts: Responses to Anthropogenic Disturbance and Climatic Change*.

Roy P.S (1984) *New South Wales estuaries: Their origin and evolution*. Thom, B. G. (Ed.) *Coastal Geomorphology* in Australia. Australia, Academic Press.

Roy, P. S., Williams, B.J., R. J., Jones, A. R., Yassinid, I., Gibbs, P. J., Coates, B., West, R. J., Scanes, P. R., Hudson, J. P. & Nichol, S. (2001) Structure and Function of South-East Australian Estuaries. *Estuarine, Coastal and Shelf Science*, 53(351-384).

Ryan, D.A., Heap, A.D., Radke, L. & Heggie, D.T. (2003) *Conceptual Models of Australia's Estuaries and Coastal Waterways. Application for Coastal Resource Management*. Geoscience Australia.

Scanes, P., Coade, G. and Dela-Cruz, J. (2009) *Monitoring, Evaluation and Reporting Sampling Protocols*. Department of Environment, Climate Change and Water. November 2009, pp.: 24.

Sharples C., Carley J., & Attwater C. (2008) *Three Pass Assessment Approach To Coastal Risk Management 'Coast-to-Coast' Collaboration, Crossing Boundaries*. Australia's Biennial National Marine Conference, Darwin, 18-22 August 2008: Program Handbook and Abstracts, August 2008, Darwin, Northern Territory, pp. 89-89. ISBN 978-0-646-49805-8

Silberstein, K., Chiffings, A.W. & McComb, A.J. (1986) The loss of seagrass in Cockburn Sound, Western Australia. III The effect of epiphytes on productivity of Posidonia australis Hook. *Aquatic Botany*, 24, pp.355-371.

Smith, A.K., Holliday, J.E. & Pollard, D.A. (1997) *Management of seagrass habitats in NSW estuaries*. Wetlands Australia, 16(2), 48-55.

Smith, A.K and Pollard, D.A. (1999) *Policy and Guidelines Aquatic Habitat Management and Fish Conservation: 1999 Update*. NSW Fisheries: Port Stephens Research Centre.

SOC (2010) *State of the Catchments 2010 Overview Sydney Metropolitan Region*. NSW Government.

Standards Australia (2013) AS 5334-2013 Climate change adaptation for settlements and infrastructure – A risk based approach. Standards Australia, New South Wales.

Standards Australia (1998a) AS/NZS 5667.1:1998 Water Quality - Sampling - Guidance on the Design of Sampling Programs, Sampling Techniques and the Preservation and Handling of Samples. Standards Australia, New South Wales.

Standards Australia (1998b) AS/NZS 5667.6:1998 Water Quality - Sampling - Guidance on Sampling of Rivers and Streams. Standards Australia, New South Wales.

Standards Australia (1999) AS/NZS 5667.12:1999 Water Quality - Sampling - Guidance on Sampling of Bottom Sediments. Standards Australia, New South Wales.

Standards Australia (2009) AS/NZS ISO 31000:2009 Risk Management – Principles and Guidelines. Standards Australia, New South Wales.

Standards Australia (2012) HB 89-2012 Risk management – Guidelines on risk assessment techniques. Standards Australia, New South Wales.

Stark, J.S. (1998) Heavy metal pollution and macrobenthic assemblages in soft sediments in two Sydney estuaries, Australia, *Marine and Freshwater Research*, Vol. 49, pp. 533-540.

Sutherland Shire Council (2007) *Port Hacking Integrated Environmental Management Plan Update 2007-2012.* Prepared by the Strategic Planning Unit of Sutherland Shire Council for the Port Hacking Catchment Management Panel.

Sutherland Shire Council (2011) *Our Shire Our Future. Our Guide to Shaping the Shire to 2030. Sutherland Shire's Community Strategic Plan December 2011.*

Sutherland Shire Council (2009a) *Natural Areas: North West Arm Catchment Plan of Management.*

Sutherland Shire Council (2009b) *General Community Use Plan of Management.*

Sutherland Shire Council (2013) *Asset Management Plan, Open Space 2013/14.*

Sutherland Shire Council (2014) *Aboriginal Sensitivity Mapping*.

Sutherland Shire Council (2015a) *Greenweb*. Retrieved February 2015, from http://www.sutherlandshire.nsw.gov.au/Outdoors/Environment/Plants-and-Bushland/Greenweb

Sutherland Shire Council (2015b) *Greenweb Grants*. Retrieved February 2015, from http://www.sutherlandshire.nsw.gov.au/Community/Grants/Greenweb-Grants

TfNSW (2014) *Moorings Review Issue Paper.* Transport for New South Wales.

Underwood, A.J. (1994) On Beyond-BACI: Sampling designs that might reliably detect environmental disturbances. *Ecological Applications*, 4 (1), pp. 3-15.

Underwood, A.J. (1992) Beyond BACI: The detection of environmental impacts on populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology*, 161, pp. 145-178.

Underwood, A.J. (1991) Beyond BACI: Experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Research*, 42, pp. 569-587.

USACE (2002) *Coastal Engineering Manual*. Engineer Manual 1110-2-1100, U.S Army Corps of Engineers, Washington, D.C (in 6 volumes).

Van Rijn (1990) *Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas.* AQUA Publications.

Wainwright, D. and Lord, D. (2014) *South Coast Regional Sea Level Rise Planning and Policy Response Framework.* Prepared for Eurobodalla Shire Council and Shoalhaven City Council.

Watson, P.J. (2011). Is there evidence yet of acceleration in mean sea-level rise around mainland Australia? *Journal of Coastal Research*, 27: 368–377

Watson P.J and D.B Lord (2008) *Fort Denison Sea Level Rise Vulnerability Study*. Prepared by the Coastal Unit, NSW Department of Environment and Climate Change, October.

White, N.J., Haigh, I.D., Church, J.A., Koen, T., Watson, C.J., Pritchard, T.R., Watson, P.J., Burgette, R.J., McInnes, K.L., You, Z-J, Zhang, X., and P. Tregoning (2014) Australian sea levels – Trends, regional variability and influencing factors. *Earth-Science Reviews*, 136: 156-174.

Williams, R.J. and Meehan, A.J (2004) Focusing management needs at the sub-catchment level via assessments of change in the cover of estuarine vegetation, Port Hacking, NSW, Australia. *Wetlands Ecology and Management,* 12, pp. 499-518

Williams, R.J., West, G., Morrisson, D. & Creese, R.G. (2007) Estuarine Resources of NSW. The NSW Comprehensive Assessment Toolkit.

You, J-Z, Lord, DB, & Watson, PJ (2009) *Estimation of Relative Mean Sea Level Rise from Fort Denison Tide Gauge Data*. Proceedings of the 19th Australasian Coastal and Ocean Engineering Conference, Wellington, New Zealand.

Zann, L.P. (1995) *Our Sea, our future: Major findings of the state of the marine environment report for Australia*. Great Barrier Reef Marine Park Authority.

Coastal Zone Management Plan

APPENDIX A

COMMUNITY CONSULTATION MATERIALS

NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN

COMMUNITY NEWSLETTER | DECEMBER 2014

Project Overview

In August 2014, Sutherland Shire Council and the NSW Office of Environment and Heritage (OEH) engaged Cardno to prepare a Coastal Zone Management Plan (CZMP) for the North West Arm, an embayment located in Port Hacking. The project is being jointly funded by Council and the OEH under the NSW Estuary Management Program.

The overarching objective of this study is to develop a comprehensive CZMP for the North West Arm Estuary. The CZMP will provide for growth and development without putting at risk the natural, cultural and heritage features of the coast.

The project builds upon earlier work presented in the Scoping Exercise, Literature and Information Review completed in 2012.

The CZMP is being undertaken with the support of the OEH, and will be prepared in accordance with the requirements of the OEH guidelines for Preparing Coastal Zone Management Plans.

About the North West Arm

The North West Arm is a tributary of Port Hacking, draining a catchment of 10.6 km^2 including residential lands and the Royal National Park. The estuary water body is approximately 0.26 km^2 in area. The two main inflows to the North West Arm estuary are Savilles Creek and Dents Creek.

The estuary foreshores are characterised by estuarine mangrove forests, boat ramps and jetties. A substantial part of the estuary foreshores are in private ownership and access to the waterway is limited. The exception is a small parcel of land on Marina Crescent known as the Marina Crescent Reserve, and a stretch of foreshore land in the upstream reaches of Dents Creek off Huskisson Street and Cobargo Road.

Specific concerns in the North West Arm catchment include:

- Flooding
- Degraded water quality
- Erosion and siltation
- Littering and dumping of rubbish
- Feral deer and weed infestations

These issues are likely to exacerbated in the future due to population increases, redevelopment in the catchment, the modified condition of the tributary creeks, and climate change (including projected sea level rise).

In developing the Plan, all values and uses of the North West Arm will be considered with a view to developing a balanced long-term management framework for the ecologically sustainable use of the estuary and its catchment. The management actions will be implemented by Council, other authorities and potentially community groups or the private sector, and may include a variety of activities.

The NSW Coastal and Estuary Management Process

The primary purpose of a CZMP is to describe proposed actions to be implemented by Council, other public authorities and potentially by the private sector to address priority management issues in the coastal zone over a defined implementation period. These issues include:

- Managing risks to public safety and built assets,
- Pressures on coastal ecosystems, and
- Community uses of the coastal zone.

CZMPs should support the goals and objectives of the NSW Coastal Policy 1997 and assist in implementing integrated coastal zone management. The three broad steps in preparing a CZMP are as follows:

1. Identify hazards / management issues and their severity,
2. Identify and evaluate management options, and
3. Propose management actions in an implementation schedule.

Community User Survey

We are currently undertaking a community user survey to help us to better understand existing and potential future issues associated with public access, facilities and recreational uses of the study area, and we invite you to participate.

The survey can be accessed at: https://www.surveymonkey.com/s/NorthWestArmCZMP

Further Information

For further information, please visit: http://www.sutherlandshire.nsw.gov.au

This project is supported by the NSW Government's Estuary Management Program.

Cardno Shaping the Future | NSW Government Office of Environment & Heritage | Sutherland Shire Council

Date _____ Survey No. ___

General Information

1) How would you describe yourself
   - ☐ Resident with foreshore frontage
   - ☐ Resident without foreshore frontage
   - ☐ Non-resident / visitor to the area

2) Do you own a vessel or personal watercraft?

   Type of vessel:.....

   Moring Point: .....

   Frequency of use:.....

3) How often do you visit/use the North West Arm?

Foreshore:	☐ Daily	☐ A few days a week	☐ 1-2 weeks	☐ 2-4 weeks	☐ Less often
Water:	☐ Daily	☐ A few days a week	☐ 1-2 weeks	☐ 2-4 weeks	☐ Less often

4) When do you visit the North West Arm?

Weekday:	☐ Morning	☐ Day	☐ Afternoon	☐ Night
Weekend:	☐ Morning	☐ Day	☐ Afternoon	☐ Night

Public Access

5) Where do you generally access the foreshore and/or water from?

Private Access	
Public Access	

6) Do you believe there is adequate access to and along the foreshore, and to the estuary waterway?

   ☐ Yes ☐ No

7) Are there any issues with current access to the foreshore or water?

Issue	Where	When

8) How do you think public access can be improved?

.....

.....

.....

9) Do you believe that public access is impacting on the environment in a negative way? If yes, how?

Yes	Comment:
No	

Public Amenity

10) Do you believe there are adequate facilities provided? If no, please tell us what facilities you would like to see and where.

Yes	Comment:
No	

11) Are there any issues with existing facilities? If yes, what is the issue and where is it? For example, are BBQs or walking tracks in poor condition.

Yes	Comment:
No	

12) In the 2012 community survey conducted by Council, the two highest rated pressures were sedimentation and stormwater pollution, others included weeds and pest animals. We would like to understand more about these issues: where they occur, and for how long they have been a problem.

Pressures/Issues	**Where and, if applicable, when.**
Sediment build up	
Stormwater pollution	
Weed infestations	
Navigation	
Pest animals	
Loss of estuarine habitats (mangroves, seagrasses, sandy flats)	
Sewer overflows	
Excessive foreshore development	
Foreshore erosion	
Seawall stability	
Other	
Other	

Recreational Usage

13) In the 2012 survey community survey conducted by Council, the community described which activities they participate in, in and around the North West Arm. The activities are listed in order of popularity below. If you participate in these activities, where and when do you do so?

Activity	Morning	Day	Afternoon	Night	Where (e.g. private foreshore)
Boating	☐	☐	☐	☐	
Swimming	☐	☐	☐	☐	
Fishing	☐	☐	☐	☐	
Walking	☐	☐	☐	☐	
Kayaking	☐	☐	☐	☐	
Picnicking	☐	☐	☐	☐	
Other	☐	☐	☐	☐	
Other	☐	☐	☐	☐	
Other	☐	☐	☐	☐	

14) Do you think that it can get crowded at times? When / where? What are they key issues?

Yes	Comment:
No	

15) If there were more public BBQs, walking tracks, boat moorings etc. would you use the area more often?

Yes	Comment:
No	

16) What do you think would enhance your recreational usage of the estuary and/or its foreshores?

.....

.....

.....

.....

Management Options (optional)

17) As a regular visitor or resident we appreciate you may have views on what you would like to see done and what is most important to you. Can you please tell us what activities or management actions would be in your top 3?

1	
2	
3	

Additional comments:

Coastal Zone Management Plan

APPENDIX B

COASTAL HAZARD MODELLING

Cardno
Shaping the Future

B1 Coastal Hazard Modelling Systems

The Delft3D hydrodynamic modelling system and SWAN wave modelling systems were applied for this study. This hydrodynamic modelling system is a world leading hydrodynamic model which has been extensively utilised at sites around Australia and internationally. The following section provides a brief introduction to the numerical scheme and application of the Delft3D model system.

B1.1 Delft3D FLOW

Investigations of water levels, currents, transport-dispersion and turbulent processes require the application of a high level model capable of simulating a range of processes including: ocean wave and tidal forcing, with some confidence. Such simulations can be successfully undertaken using the Delft3D modelling system.

This modelling system can include wind, pressure, tide and wave forcing, three-dimensional currents, stratification, sediment transport and water quality descriptions and is capable of using irregular rectilinear or curvilinear coordinates.

Delft3D is comprised of several modules that provide the facility to undertake a range of studies. All studies generally begin with the hydrodynamic Delft3D-FLOW module. From Delft3D-FLOW, details such as velocities, water levels, density, salinity, vertical eddy viscosity and vertical eddy diffusivity can be provided as inputs to the other modules. The wave and sediment transport modules work interactively with the FLOW module through a common communications file.

B1.1.1 Hydrodynamic Numerical Scheme

The Delft3D-FLOW module is based on the robust numerical finite-difference scheme developed by Stelling (1984) at the Delft Technical University in The Netherlands. Since its inception the Stelling Scheme has undergone considerable development and review by Stelling and others.

The Delft3D Stelling Scheme arranges modelled variables on a horizontal staggered finite difference Arakawa C-grid. The water level points (pressure points) are designated in the centre of a continuity cell and the velocity components are perpendicular to the grid cell faces. Finite difference staggered grids have several advantages including: -

- Boundary conditions can be implemented in the scheme easily;
- It is possible to use a smaller number of discrete state variables in comparison with discretisations on non-staggered grids to obtain the same accuracy;
- Staggered grids minimise spatial oscillations in the water levels.

Delft3D can be operated in two-dimensional (2D) (vertically averaged) or three-dimensional (3D) mode. For this project the model was operated in 2D, this being appropriate for the simulation of shallow water waves and inundation modelling. This also ensured that the model was computationally efficient.

Delft3D allows the application of a specialised advection scheme that can be implemented for problems that include rapidly varying flows for instance in hydraulic jumps, bores and tsunami inundation (Stelling and Duinmeijer, 2003). The scheme is denoted as the 'Flooding Scheme' and was developed for 2D simulations with a rectilinear grid for the inundation of dry land with obstacles such as road embankments and levees. The integration of the advection term is explicit and the time step is restricted by the Courant number for advection.

The model is particularly robust when applied to rapidly varying depth-averaged flows, for instance, the inundation of dry land or flow transitions due to large gradients of the bathymetry (obstacles). The scheme is also accurate for obstacles, represented by only one point on coarse grids. In combination with the local invalidity of the hydrostatic pressure assumption, conservation properties become crucial. In flow expansions a numerical approximation is applied that is consistent with conservation of momentum and in flow contractions a numerical approximation is applied that is consistent with the Bernoulli equation.

Horizontal solution is undertaken using the Alternating Direction Implicit (ADI) method of Leendertse for shallow water equations. Vertical turbulence closure in Delft3D is based on the eddy viscosity concept.

B1.1.2 Wetting and Drying Algorithm

Many nearshore areas include shallow inter-tidal regions; consequently Delft3D includes a robust and efficient wetting and drying algorithm to handle this process. In combination with the flooding scheme for advection in the momentum equation, the algorithm is also effective and accurate for rapidly varying flows with large water level gradients because of the presence of hydraulic jumps or the occurrence of bores as a result of dam breaks. This capability ensures the applicability of Delft3D to tsunami inundation modelling.

B1.1.3 Conservation of Mass

Problems with conservation of mass found in some numerical models, such as a 'leaking mesh', do not occur within the Delft3D system. However, whilst the Delft3D scheme is unconditionally stable, inexperienced use of Delft3D, as with most modelling packages, can result in potential mass imbalances.

Potential causes of mass imbalance and other inaccuracies include: -

- Inappropriately large setting of the wet/dry algorithm and unrefined inter-tidal grid definition
- Inappropriate bathymetric and boundary definition causing steep gradients
- Inappropriate time step selection (i.e. lack of observation of the scheme's allowable courant number condition) for simulation.

The Delft3D model has been schematised for the tsunami inundation modelling to ensure that these potential causes of mass imbalance have been avoided.

B1.1.4 Domain Decomposition

Delft3D provides the facility to adopt a modelling approach known as 'domain decomposition'. Domain decomposition is a technique in which a model is divided into several smaller model domains that are dynamically coupled. The subdivision is based on the horizontal and vertical model resolution required for adequately simulating physical processes. Computations can be carried out separately, yet concurrently, on these domains. The communication between the domains takes place along internal boundaries. Computations are carried out concurrently, via parallel computing, thus reducing the turn-around time of multiple domain simulations. Domain decomposition allows for local grid refinement, both in the horizontal direction and in the vertical direction in 3D models. Grid refinement in the horizontal direction means that in one domain smaller mesh sizes (fine grid) are used than in other domains (coarse grid). In the case of vertical grid refinement one domain, for example, uses ten vertical layers and another domain five layers, or a single layer (depth-averaged).

Domain decomposition is widely recognised as an efficient and flexible tool for the simulation of complex physical processes. The structured multi-domain approach combines the advantages of the modelling flexibility of the single-domain unstructured approach with the efficiency and accuracy of the single-domain structured approach.

B1.2 SWAN

The wave model Cardno applied in this study is based on the third generation wind/wave modelling system, SWAN, which is incorporated as a module into the Delft3D modelling system. This model was developed at the Delft Technical University and includes wind input (local sea and developing storm cases), combined sea and swell, offshore wave parameters (swell cases), refraction, shoaling, non-linear wave-wave interaction, a full directional spectral description of wave propagation, bed friction, white capping, currents and wave breaking. SWAN also includes phase-averaged diffraction based on the model of Holthuijsen et al.

SWAN includes a nested grid capability that allows coarser grids in deeper water and finer grids in shallow water where better definition of seabed form and depth are needed and may use the same or different grids from those used in the hydrodynamic modelling. Output from the model includes significant wave height, dominant wave direction, spectral peak and mean periods and (optionally) the full directional wave spectra. It can be coupled with Delft3D to include the inter-action between waves and tidal/wind driven flows.

B2 Erosion Hazard Assessment

The potential for estuarine foreshore erosion and channel siltation within the study area was assessed through the use of numerical modelling using the Delft3D modelling system. Using this modelling system, the erosion and siltation hazard was assessed in terms of the accumulated hours during a typical year that tidal current speeds exceed values required for sediment transport.

B2.1 Model Set-up

The hydrodynamic model set-up consisted of two grids linked through Delft3D's domain decomposition functionality. The first grid was of 50 m resolution and extended from the Port Hacking entrance to the downstream end of the study area. Linked to this was a grid of 10 m resolution, covering the North West Arm study area, from the downstream extent of North West Arm to the Dent's Creek weir (as per the extent shown in **Figure B-1**). The model was driven from the downstream end (ocean boundary) by recorded water level data from Port Hacking, and included spatially variable Chezy roughness parameters as required to replicate the friction generated by the Port Hacking sediment shoals. The model set-up is depicted in **Figure B-1**.

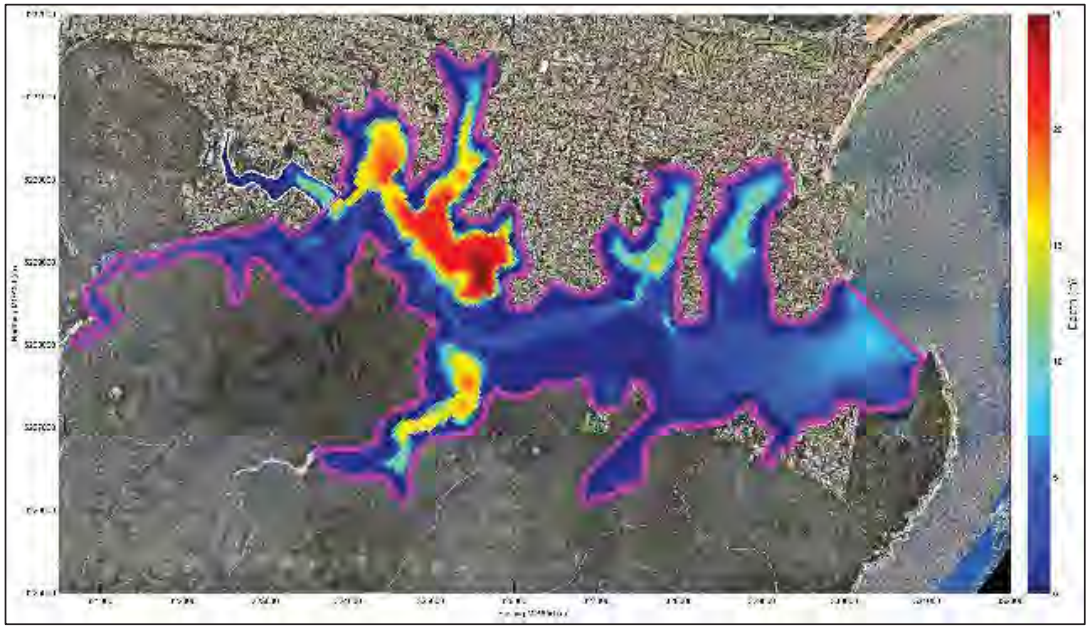


Figure B-1: Delft3D Hydrodynamic Model Set-up

B2.2 Model Calibration and Verification

In order to provide confidence that the Delft3D model was accurately reflecting the hydrodynamics of the study area (and Port Hacking as a whole), it was necessary to properly calibrate and verify the modelled water levels against water levels recorded as part of the data collection activity (see Section 3.2.1 of the CZMP).

Subsequently, the hydrodynamic model was run for a one month period covering the full range of tide gauge data collection.

The results are depicted in **Figure B-2** in the form of modelled and measured water level time series. The result show that the measured and modelled water levels at the eastern (downstream) tide gauge location are in good agreement in terms of the tidal phase and amplitude. At the western (upstream) tide gauge, the tidal signal also shows good agreement for the most part. However, from the 14 -27 October 2014 the water

levels show a slight divergence. This is due to the high levels of rainfall the study area received during the east coast low event over 14-15 October 2014, during which 123 mm of rainfall was recorded at Oyster Bay (Green Point Road) in the 24 hours to 9 am on 15 October 2014. This significant level of rainfall and associated catchment runoff resulted in recorded water levels at the upstream tide gauge being 0.1 - 0.2 m higher than modelled water levels for up to a week after the event. There was no such increase in water levels at the downstream tide gauge. This highlights the impact of rainfall events on the catchment, with large volumes of water being delivered to the estuary over a short period of time. As well as impacting on estuary water levels, this can result in significant changes in water quality, including changes to water temperature and decreasing in salinity. In addition, the passage of the water into the estuary can scour the creek bed and banks, until such time as it meets the main estuarine water body and the flow velocity decreases.

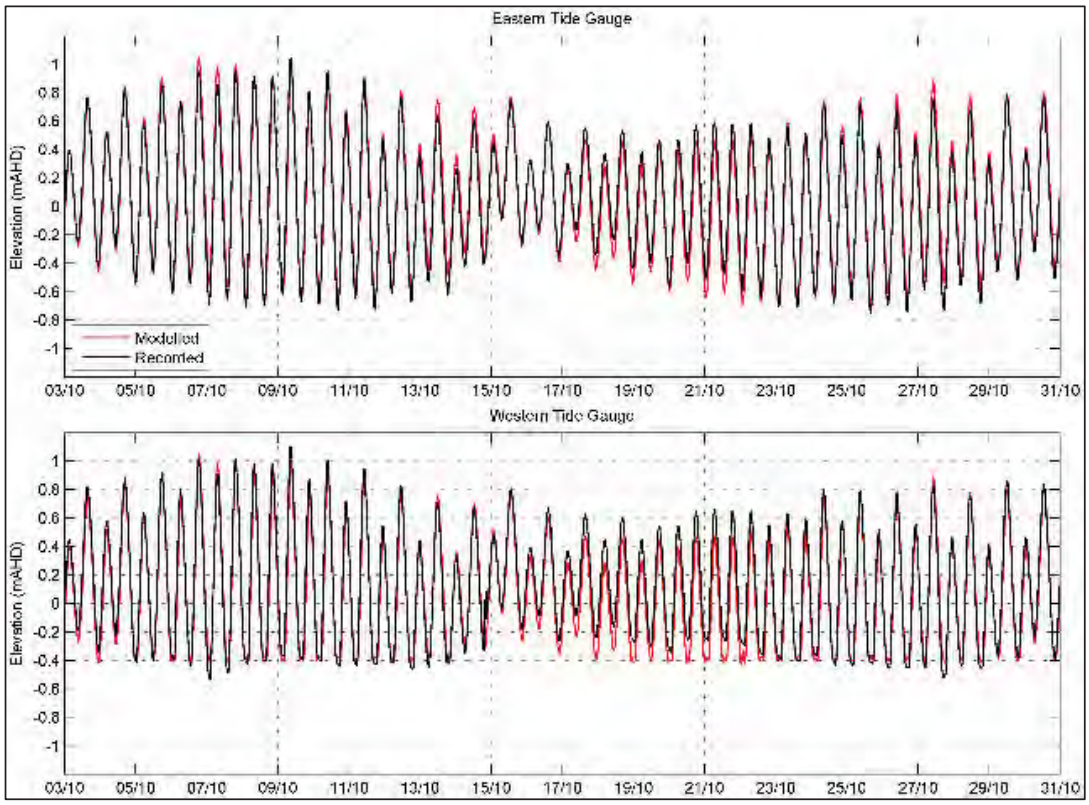


Figure B-2: Delft3D Hydrodynamic Model Verification

B2.3 Erosion/Siltation Simulations

Using the calibrated and verified hydrodynamic model set-up, the erosion and siltation hazard was assessed in terms of the accumulated hours during a typical year that tidal current speeds exceed the values required for sediment transport.

For this task, the hydrodynamic model was run for a full year, and then the total time during the simulation that tidal current speeds exceeded a threshold value required for bedload transport in each grid cell were analysed. The threshold value was taken as 0.3 m/s, as this is the critical velocity considered in the sediment flux equation is that proposed by van Rijn (1993) for marine sediments (i.e. bedload transport occurs only in regions where $|v| > 0.3$ m/s).

Additionally, simulations were conducted for the 0.4 m and 0.9 m mean sea level scenarios. It should be noted the model bathymetry was the same for the present day and future mean sea level scenario

simulations. That is, it is assumed that the fluvial delta in the study area would not increase at the same rate as mean sea level rise.

Figure B-3 shows that for present day mean sea level, tidal currents are rarely sufficient to initiate bedload transport. Tidal currents currently exceed the threshold around 100 hours per year (about 1.1% of the time) in the region of the second-to-last downstream bend in the creek before it hits the main water body of the North West Arm. The total hours exceeding the threshold are significantly lower everywhere else in the estuary, with little to no bedload transport downstream of the fluvial delta region. This shows that tidal currents have little impact upon the morphodynamics of the study area.

Figures B-4 and B-5 show that as mean sea level increases, the influence of tidal currents on bed load transport decreases, predominantly due to increased water depths.

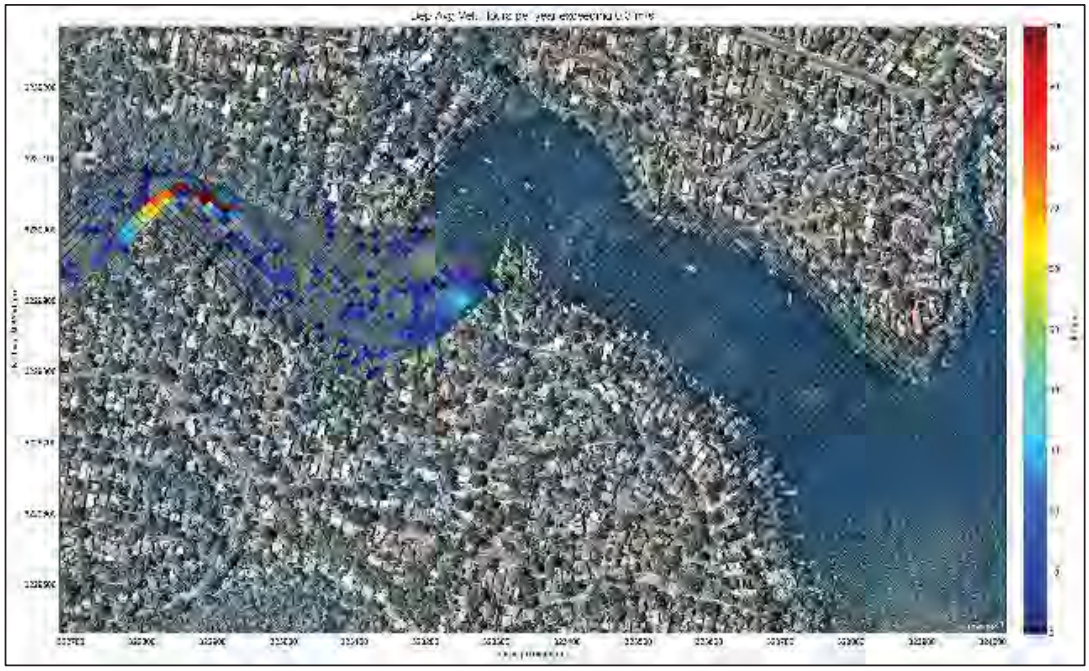


Figure B-3: Hours per Year Above Sediment Transport Threshold (Current MSL)

Figure B-4: Hours per Year Above Sediment Transport Threshold (0.4 m Sea Level Rise)

Figure B-5: Hours per Year Above Sediment Transport Threshold (0.9 m Sea Level Rise)

B3 Wave Run-up and Overtopping

North West Arm is situated some 6 km upstream form the Port Hacking estuary entrance. Combined with the estuary's various meanders and shoals, this means that there is little, to no, penetration of ocean swell to the study area. Consequently, the wave climate in the study region is composed of short period local sea waves generated by local winds blowing across the estuary.

Therefore, in order to assess the local sea wave climate in the study area, numerical wave modelling was conducted using the SWAN wave model, which is incorporated as a module in the Delft3D modelling system.

B3.1 Model Set-up

The SWAN wave model set-up consisted of two nested grids which covered the full range of estuary fetches affecting the study area. The first grid was of 10 m resolution and covered the region from Gymea Bay in the north to Mansion Bay in the south. Within this lay a nested grid on 2 m resolution covering the North West Arm study area. The Model Set-up is depicted in **Figure B-6**.

B3.2 Wave Model Simulations

Numerical modelling of the local sea waves was undertaken using wave hind-casting techniques incorporating historical wind data from Sydney Airport (from 1939 to present) obtained from the Bureau of Meteorology. The SWAN wave model was used to develop the local sea wave climate at the study site by providing a basis for transforming historical wind conditions to wave conditions.

Historical wind-wave conditions were developed by modelling a large range of wind directions from north, clockwise through to north (round-the-clock), at 11.25^{o} increments. Additionally, a range of wind speeds from 2.5 to 30 m/s were included, leading to 384 wave modelling cases. The results of this wave modelling provided a basis for the transfer of the historical wind conditions to an equivalent time-series of wave data at the selected model output locations at the study site, in terms of significant wave height, mean wave period and mean wave direction.

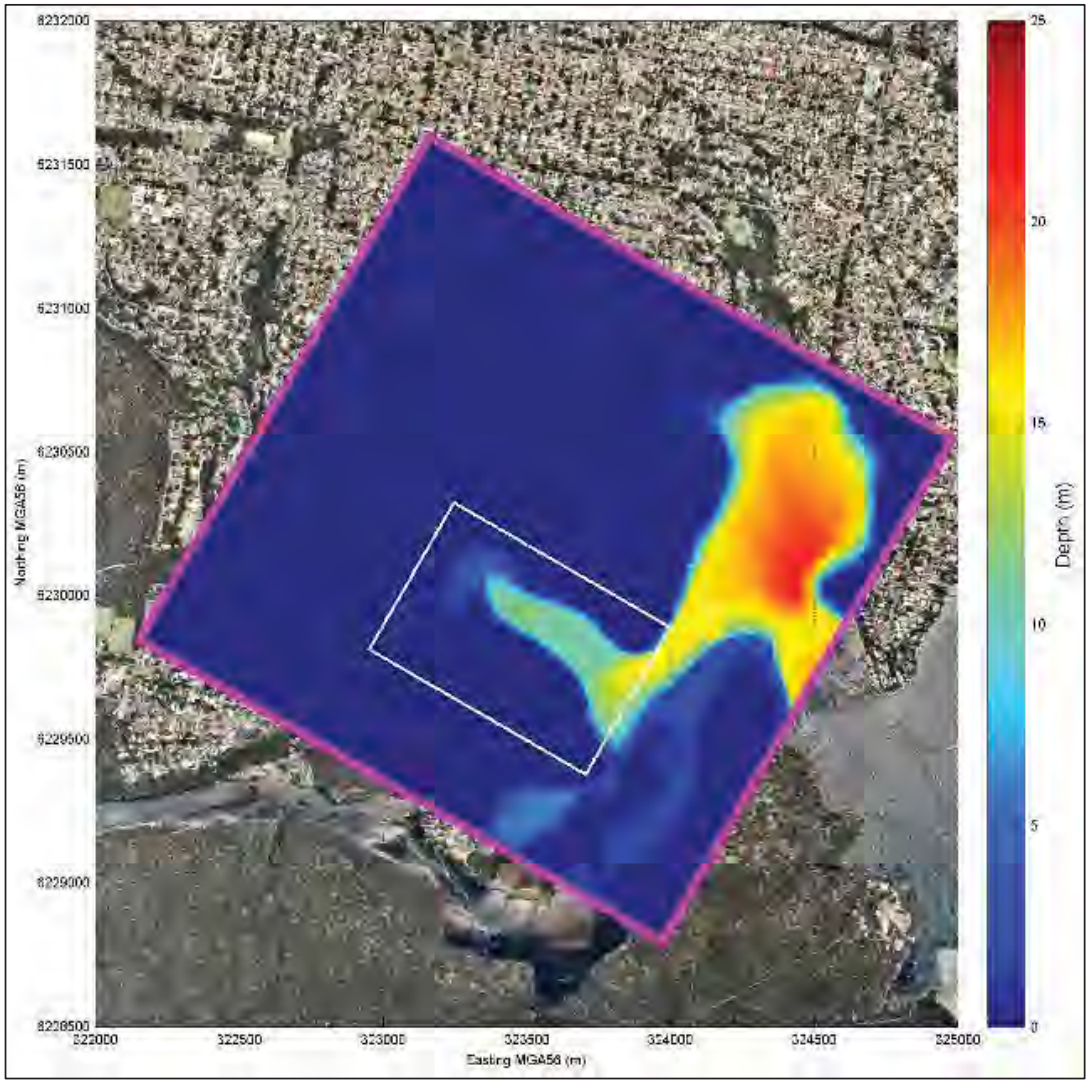


Figure B-6: SWAN Wave Model Set-up

B3.2.1.1 Design Wave Climate

In order to develop the design wave criteria, the "extreme" significant wave height events at each foreshore location were isolated and an extreme value analysis was undertaken using the maximum likelihood method, fitting to the Weibull Distribution. The 100-years ARI significant wave heights at each foreshore location are depicted in presented in **Figures B-7** to **B-9** for the present day, 0.4 m mean sea level rise, and 0.9 m mean sea level rise scenarios respectively. The equivalent plots for the 20-years, 50-years and 200-years ARI events are provided as **Figures B10** to **B18**.

100 years ARI

Figure B-7: 100-years ARI Significant Wave Height (m) (Current MSL)

Figure B-8: 100-years ARI Significant Wave Height (m) (0.4 m Sea Level Rise)

Figure B-9: 100-years ARI Significant Wave Height (m) (0.9 m Sea Level Rise)

20 years ARI

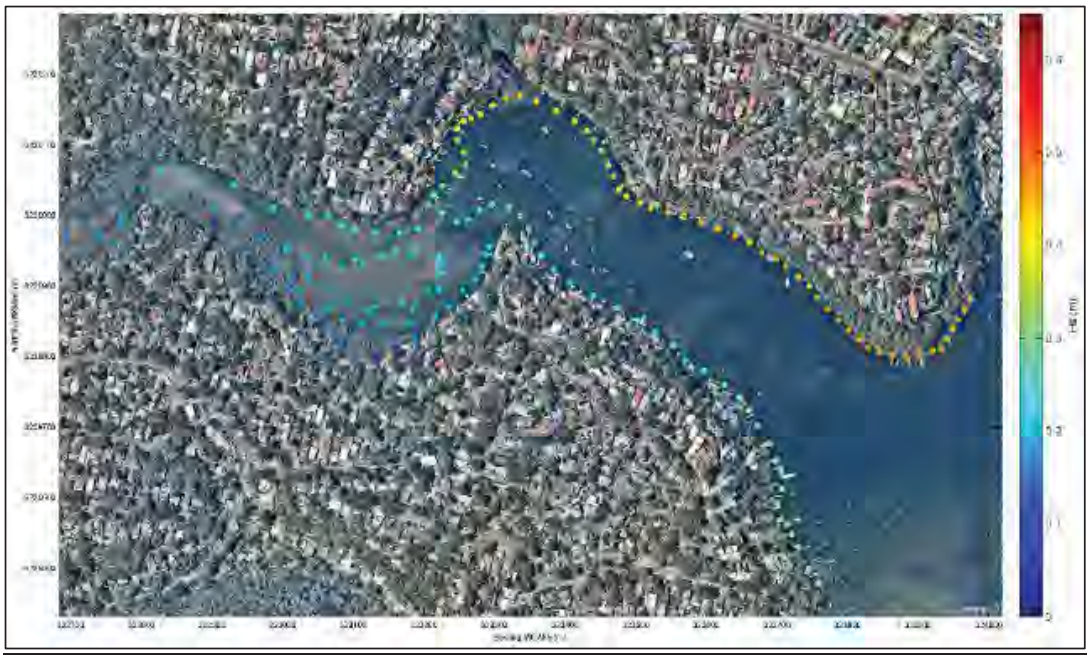


Figure B-10: 20 years ARI Significant Wave Height (m) (Current MSL)

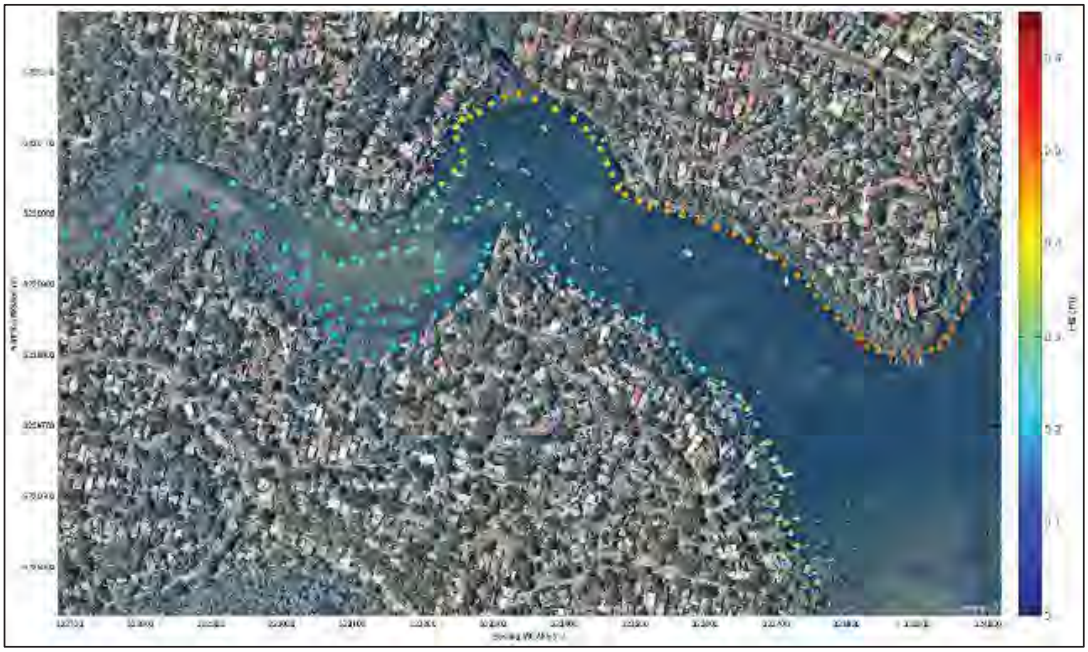


Figure B-11: **20 years ARI Significant Wave Height (m) (0.4 m Sea Level Rise)**

Figure B-12: **20 years ARI Significant Wave Height (m) (0.9 m Sea Level Rise)**

50 years ARI

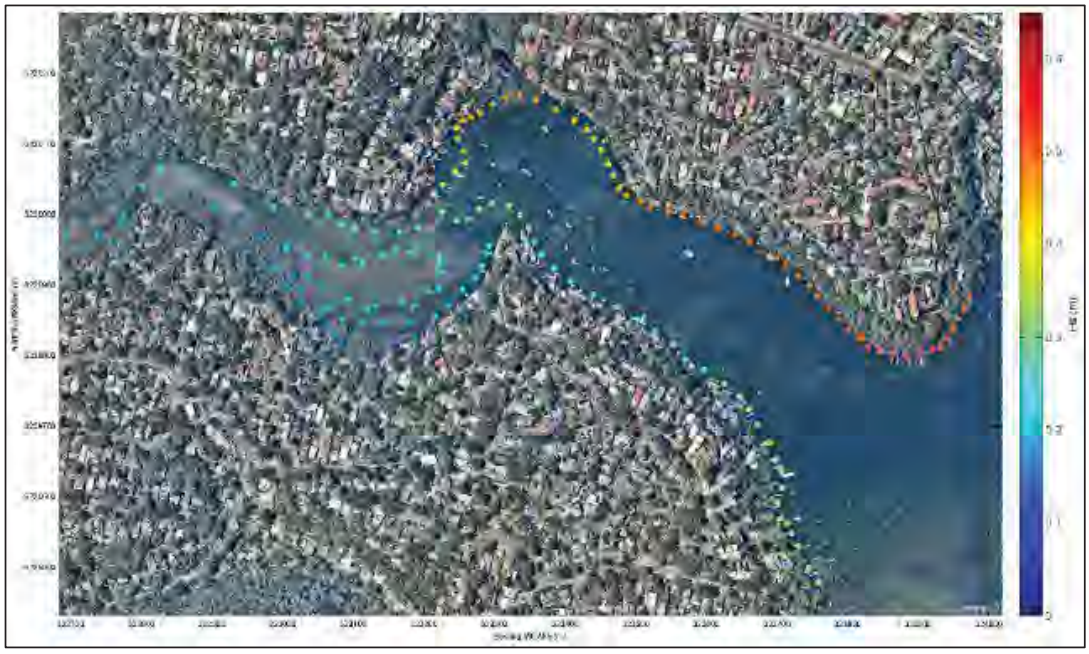


Figure B-13: 50 years ARI Significant Wave Height (m) (Current MSL)

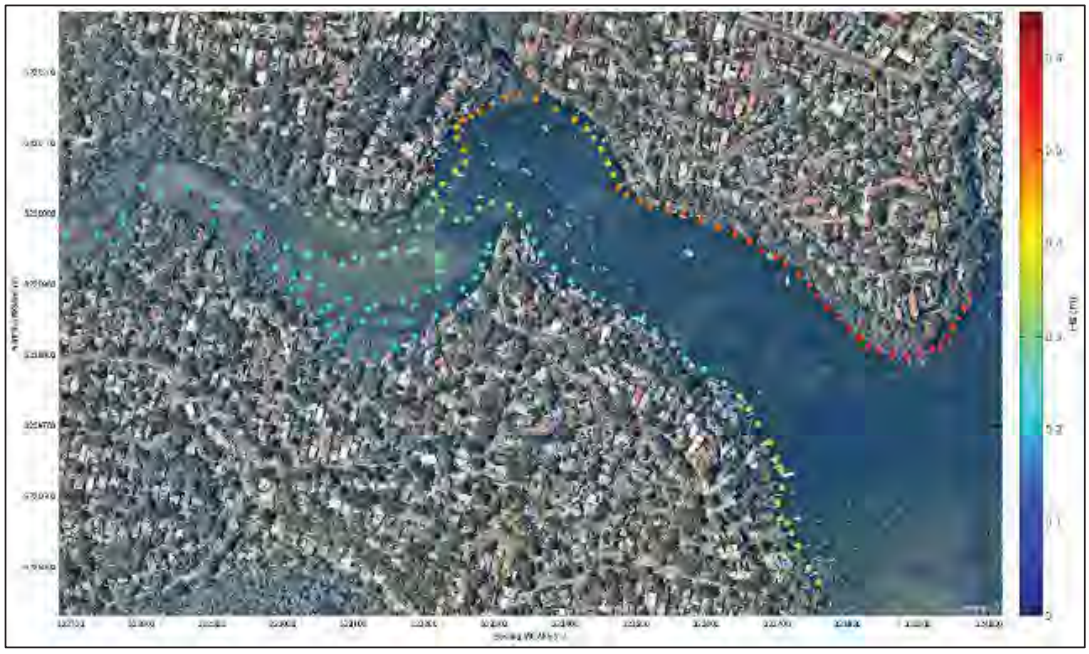


Figure B-14: 50 years ARI Significant Wave Height (m) (0.4 m Sea Level Rise)

Figure B-15: 50 years ARI Significant Wave Height (m) (0.9 m Sea Level Rise)

200 years ARI

Figure B-16: 200 years ARI Significant Wave Height (m) (Current MSL)

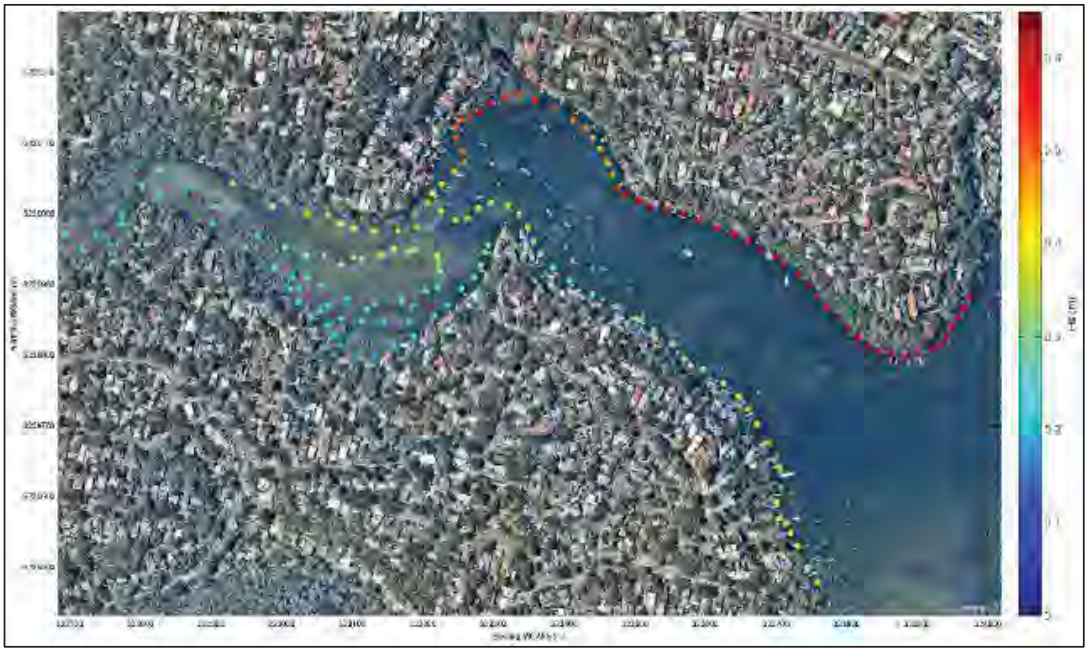


Figure B-17: 200 years ARI Significant Wave Height (m) (0.4 m Sea Level Rise)

Figure B-18: 200 years ARI Significant Wave Height (m) (0.9 m Sea Level Rise)

In order to summarise the results, the study area has been discretised in regions of similar wave conditions. These regions are depicted in **Figure B-19**, and design wave criteria in terms of significant wave height (Hs) and peak wave period (Tp) for each region are presented in **Tables B-1** to **B-3**.

Figure B-19: Regions for Design Wave Criteria

The results show that the 100-years ARI wave heights in the study area are low, with a fairly flat extremal distribution (that is, the 200-years ARI significant wave heights are not considerably higher than the 20-years ARI wave heights). Both of these results can be attributed to the fetch limited nature of the study area, particularly the upstream regions.

Within the study area, Regions A and B generally experience the highest waves due to their exposure to strong southerly and south-easterly winds and slightly longer, deeper fetches. Regions C and D exhibit much smaller design waves due to the small, shallow fetches in these regions. Design waves are also fairly low in Regions F and G, which have limited fetched in almost all exposed directions, and are protected from strong southerly winds. Peak wave periods across the study area are short due to the limited fetch lengths, and are in the vicinity of 2 seconds.

The results show that for most of the study area, higher mean sea level scenario (i.e. 0.9 m sea level rise) shows only a minimal increase in design wave heights. The exceptions are Regions D and E, where the increase in mean sea level under climate change conditions results in a greater relative increases in nearshore depth, and consequently wave heights.

Table B-1: Design Wave Criteria (Current MSL)

Region	20-yrs ARI		50-yrs ARI		100-yrs ARI		200-yrs ARI	
	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
A	0.47	2.1	0.51	2.2	0.54	2.3	0.57	2.3
B	0.41	2.0	0.44	2.1	0.47	2.1	0.50	2.2
C	0.42	2.0	0.47	2.1	0.50	2.2	0.53	2.3
D	0.27	1.5	0.30	1.6	0.32	1.6	0.34	1.7
E	0.25	1.5	0.26	1.6	0.28	1.6	0.29	1.6

F	0.28	1.7	0.31	1.8	0.33	1.8	0.35	1.9
G	0.35	2.0	0.37	2.0	0.39	2.0	0.41	2.1

Table B-2: Design Wave Criteria (0.4 m Sea Level Rise)

Region	20-yrs ARI		50-yrs ARI		100-yrs ARI		200-yrs ARI	
	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
A	0.50	2.2	0.54	2.3	0.58	2.3	0.61	2.4
B	0.43	2.1	0.47	2.2	0.50	2.2	0.53	2.3
C	0.44	2.1	0.48	2.2	0.52	2.2	0.55	2.3
D	0.31	1.6	0.34	1.7	0.36	1.7	0.38	1.8
E	0.27	1.6	0.29	1.7	0.31	1.7	0.32	1.7
F	0.29	1.7	0.32	1.8	0.34	1.9	0.36	2.0
G	0.37	2.0	0.41	2.0	0.43	2.1	0.46	2.1

Table B-3: Design Wave Criteria (0.9 m Sea Level Rise)

Region	20-yrs ARI		50-yrs ARI		100-yrs ARI		200-yrs ARI	
	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
A	0.52	2.2	0.57	2.3	0.61	2.4	0.65	2.5
B	0.44	2.1	0.49	2.2	0.52	2.3	0.55	2.4
C	0.45	2.1	0.50	2.2	0.53	2.3	0.57	2.3
D	0.33	1.7	0.36	1.7	0.38	1.8	0.40	1.9
E	0.29	1.6	0.31	1.7	0.33	1.8	0.34	1.8
F	0.31	1.8	0.33	1.8	0.35	1.9	0.37	2.0
G	0.39	2.0	0.43	2.1	0.46	2.2	0.49	2.2

B3.2.1.2 Design Wave Run-up and Overtopping

Whilst coastal inundation is predominantly an open coast hazard parameter, the North West Arm estuary is affected by short period by local sea waves, which may lead to wave run-up and overtopping of foreshore areas.

The $R_{U2\%}$ wave run-up level (the wave run-up level above which only 2% of waves will exceed during a design storm) has been assessed, conservatively assuming a 100-years ARI still water level and 100-years ARI local sea state. $R_{U2\%}$ levels were calculated using standard engineering formulae given in the EurOtop Manual (2007). This task has been undertaken for 2050 and 2100 by including the 0.4 m and 0.9 m sea level rise projections.

Additionally, potential average wave overtopping rates have been calculated for a range of estimated foreshore structure crest levels based on site observations. The overtopping rates have been presented with the units of litres of water per second per metre width of the structure. This undertaking has been repeated for the 0.4 m and 0.9 m mean sea level rise scenarios in addition to the present day.

The results presented in **Tables B-4 to B-6** show that the 100-years ARI $R_{U2\%}$ wave run-up levels and wave overtopping discharges, while **Figure B-20** shows the typical consequences associated with these wave overtopping discharges, as given in USACE (2002). The $R_{U2\%}$ wave run-up levels are generally quite low, owing the small design wave heights and short wave periods (and resulting wave lengths).

For the present day mean sea level, wave overtopping discharges are generally low, particularly for structures with crest levels at 3 mAHD or higher where the overtopping discharge has been estimated as 0.2 L/s/m or less. The highest overtopping values are seen in regions A, B, C and G, which experience the highest design wave heights and slightly longer wave periods. **Figure B-20** shows that the calculated wave overtopping levels in these regions may present some hazard to pedestrians in the immediate vicinity of the seawall being overtopped, but would be unlikely to damage the structure itself.

Wave overtopping values are low in regions D, E and F and were less than 1 L/s/m crest levels of 2 mAHD and higher and virtually zero for crest levels of 2.5 mAHD or higher. Wave overtopping in these regions is unlikely to cause any significant structural damages of seawalls.

Only minimal overtopping is expected for structures with crest levels above 3.5 mAHD and 4.0 mAHD under 0.4 m and 0.9 m sea level rise scenarios respectively. **Figure B-20** indicates that for the 0.4 m and 0.9 m mean sea level rise scenarios, some damage to foreshore structures with crest levels lower at 2.0 mAHD and 2.5 mAHD (respectively) or lower may be expected.

Table B-4: 100-years ARI Wave Run-up Level (RU2%) and Wave Overtopping Discharge (L/s/m) – Present Day

Region	$R_{u2\%}$ Wave Run-up Level (mAHD)	Wave Overtopping Discharge (m3/s/m) for Crest Level of:				
		2.0 mAHD	2.5 mAHD	3.0 mAHD	3.5 mAHD	4.0 mAHD
A	3.2	6.5	1.1	0.2	0.0	0.0
B	3.0	3.2	0.4	0.0	0.0	0.0
C	3.1	3.5	0.4	0.1	0.0	0.0
D	2.5	0.7	0.0	0.0	0.0	0.0
E	2.4	0.1	0.0	0.0	0.0	0.0
F	2.5	0.6	0.0	0.0	0.0	0.0
G	2.7	1.7	0.1	0.0	0.0	0.0

Table B-5: 100-years ARI Wave Run-up Level ($R_{U2\%}$) and Wave Overtopping Discharge (L/s/m) – 0.4 m Sea Level Rise

Region	$R_{u2\%}$ Wave Run-up Level (mAHD)	Wave Overtopping Discharge (m3/s/m) for Crest Level of:				
		2.0 mAHD	2.5 mAHD	3.0 mAHD	3.5 mAHD	4.0 mAHD
A	3.6	25.3	4.5	0.8	0.1	0.0
B	3.4	15.8	1.9	0.2	0.0	0.0
C	3.5	16.7	2.2	0.3	0.0	0.0
D	2.9	8.8	0.6	0.0	0.0	0.0
E	2.8	3.7	0.1	0.0	0.0	0.0
F	2.9	6.0	0.3	0.0	0.0	0.0
G	3.2	11.3	1.0	0.1	0.0	0.0

Table B-6: 100-years-ARI Wave Run-up Level ($R_{U2\%}$) and Wave Overtopping Discharge (L/s/m) – 0.9 m Sea Level Rise

Region	$R_{u2\%}$ Wave Run-up Level (mAHD)	Wave Overtopping Discharge (m3/s/m) for Crest Level of:				
		2.0 mAHD	2.5 mAHD	3.0 mAHD	3.5 mAHD	4.0 mAHD
A	4.3	N/A*	28.1	5.4	1.1	0.2
B	4.0	N/A*	17.1	2.2	0.3	0.0
C	4.0	N/A*	18.0	2.5	0.4	0.1
D	3.5	N/A*	10.1	0.8	0.1	0.0
E	3.4	N/A*	4.8	0.2	0.0	0.0
F	3.4	N/A*	6.4	0.3	0.0	0.0
G	3.8	N/A*	12.7	1.3	0.1	0.0

N/A* indicates that no overtopping calculation has been performed as crest of structure would be inundated by the elevated still water level.

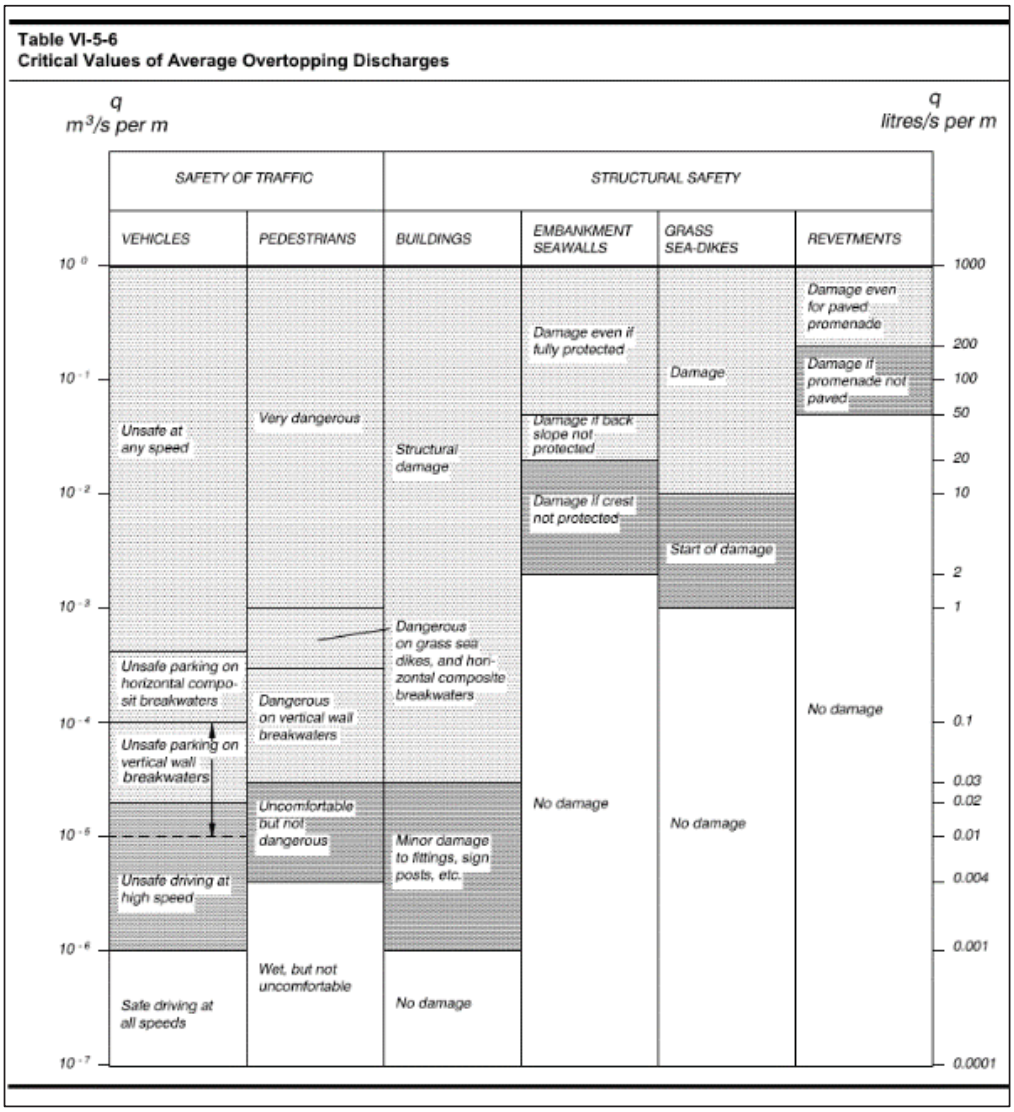


Figure B-20: Figure 3-1: Critical Values of Wave Overtopping Discharges (Source: USACE, 2002)

B4 References

EurOtop (2007) *EurOtop Wave Overtopping of Sea Defences and Related Structures: Assessment Manual.*

USACE (2002) *Coastal Engineering Manual*. Engineer Manual 1110-2-1100, U.S Army Corps of Engineers, Washington, D.C (in 6 volumes).

Van Rijn (1990) *Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas.* AQUA Publications.

Coastal Zone Management Plan

APPENDIX C

DETAILED CONSIDERATION OF DREDGING

Cardno
Shaping the Future

C1 Detailed Consideration of Dredging Options

C1.1 Introduction

Sedimentation of the North West Arm has been raised as an issue by the community for a number of years particularly in relation to visual amenity and navigational limits at low tide (refer to Section 4.1.5 of the CZMP). Council asked Cardno to assess the feasibility of two dredging options identified in consultation with the community, and this appendix presents the assessment methodology and findings.

Three options considered in this assessment are:

> **Option 1 – Navigation channel for small non-powered watercraft to North West Arm Road access point at low tide**

  This option provides a channel of sufficient width for two small watercraft (e.g. kayaks) to pass side-by-side.

> **Option 2 – Removal of top 300 mm of sediments from the delta.**

  It is understood that the community considers the delta to have accreted in recent years, and has a perception that this not a natural process and that the estuary should be "restored" to its natural condition. This option provides for the dredging of the tidal delta for aesthetic purposes.

> **Do nothing.**

  The "do nothing" option is included in the assessment as the base case for purposes of comparison.

The options are summarised in **Table C-1**, and mapped in **Figure C-1**.

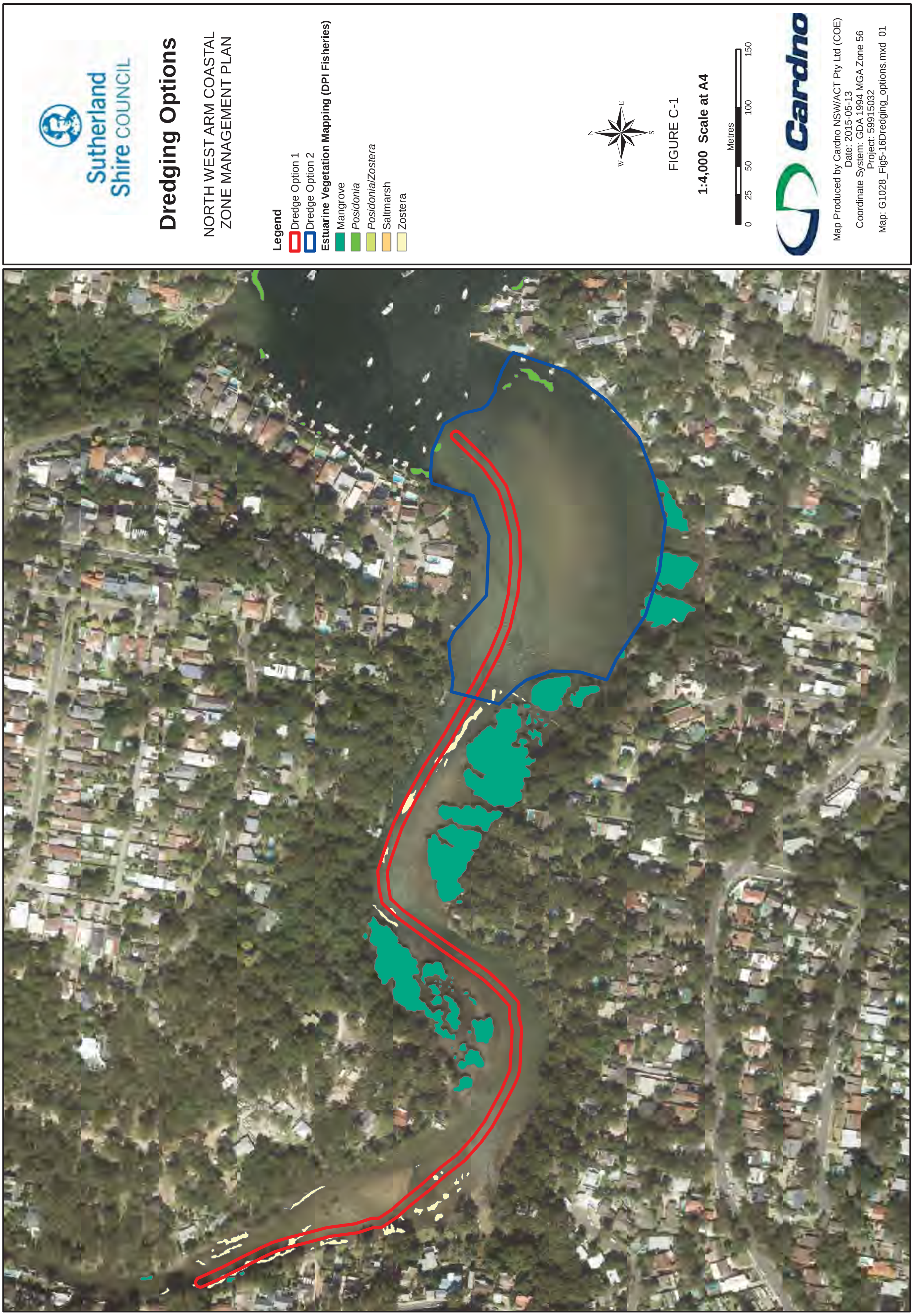
Table C-1: Approximate Dredge Footprint Features for Option 1 and Option 2

Features	Option 1	Option 2
Dredge Dimensions	Channel length: 1000 m Channel width: 3 m	Area: 40,000 m^2 Depth: 300 mm
Minimum navigable depth	0.5 m at LAT	N/A
Batter slopes (V:H)	1:3	1:3
Dredge volume	14,700 m^3	12,100 m^3

The dredging options assessment has considered:

> Construction methodology;
> Environmental considerations;
> Social considerations;
> Statutory and non-statutory requirements; and
> Cost.

The assessment methodology adopted has, where possible, been consistent with that adopted for the options assessment (see Section 10 of the CZMP).


Sutherland Shire COUNCIL
Dredging Options
NORTH WEST ARM COASTAL ZONE MANAGEMENT PLAN
Legend
Dredge Option 1
Dredge Option 2
Estuarine Vegetation Mapping (DPI Fisheries)
Mangrove
Posidonia
Posidonia/Zostera
Saltmarsh
Zostera
N
E
S
W
FIGURE C-1
1:4,000 Scale at A4
Metres
0 25 50 100 150
Cardno
Map Produced by Cardno NSW/ACT Pty Ltd (COE)
Date: 2015-05-13
Coordinate System: GDA 1994 MGA Zone 56
Project: 59915032
Map: G1028_Fig5-16Dredging_options.mxd 01

C1.2 Construction Methodology

A major constraint on dredging in the North West Arm is the restricted access. The steep topography and lack of vehicular access to the shoreline does not allow for land-based dredging methods (e.g. with a digger) in many locations. In addition, the shallow depths over the tidal delta limit access over part or all of the tidal cycle for a water-based dredge. As a result, the type of dredge used to conduct any such works requires careful consideration. There are also implications for the duration of any such works, assuming limitations on access at certain times in the tidal cycle. Both of these factors have potential to impact on the cost of dredging.

Based on Cardno's experience on other projects, a cutter suction dredge was identified as a suitable type of dredge. A cutter suction dredge is a floating barge with a cutter used to loosen material on the seabed which is then sucked into a pipe intake by on board pumps.

The dredged material must be disposed of in some manner. Disposal options were considered in the dredging feasibility assessment conducted by NSW Public Works (1980). These options included:

> By barge to sea;
> By barge to elsewhere in Port Hacking;
> By truck for sale to industry; and
> By truck to dump as fill.

The disposal options depend on the quality of the sediments, which has been discussed in **Section C1.3.2** of this Appendix.

C1.3 Assessment of Rates of Dredge Hole Infilling

The potential infilling of the proposed dredge schemes was assessed by modelling the sediment transport resulting from the tidal and catchment flows in the study area with Delft3D. Three mechanism of infilling were modelled, namely:

> Re-distribution of bed material by tidal currents, which would act to fill in portions of the dredged regions; and

> Episodic deposition of fluvial material during significant rainfall events.

C1.3.1 Re-distribution of Sediments by Tidal Currents

In order to assess the potential infilling of the proposed dredge schemes due to the redistribution of bed material by tidal currents, morphological modelling was conducted for each dredge scheme over a period of one year (model time). No sediment loads were input via the model boundaries, rather simulations were conducted only to assess how tidal currents might redistribute the in-situ bed sediments in the study region for a period of one year post-dredging.

The results are depicted in **Figures C-2** and **C-3** for Option 1 and 2 respectively, and in **Figure C-4** for the existing bed condition (i.e. do nothing option). They show that for Option 2, the redistribution of sediments would be localised to the bending sections of the estuary where tidal currents are higher, with the amount of bed change over a one year period generally less than 5 cm in these regions. The results also show little to no tidal redistribution of sediments under Option 1. These results indicate two points:

> That the tidal currents in the estuary are generally too low to mobilise sediments (which is supported by the modelling results discussed in Section 5.5.2.3 of the CZMP); and

> That neither of the proposed dredging option are likely to significantly alter the current regime to the point where the currents will rework the in-situ bed sediments.

Figure C-2: Tidal Redistribution of Sediments Over One Year – Option 1 (as indicated by the red arrow)

Figure C-3: Tidal Redistribution of Sediments Over One Year – Option 2

Figure C-4: Tidal Redistribution of Sediments Over One Year – Existing Bed Condition (i.e. do nothing)

C1.3.2 Episodic Fluvial Deposition from Catchment Flood Events

Potential deposition of fluvial sediments resulting from catchment flood events was assessed by modelling an approximate 1-Year ARI catchment flood using Delft3D. Catchment flows were derived using the Rational Method outlined in AR&R (1987), which is based on site specific data, including:

- The catchment size;
- A rainfall run-off coefficient, sourced from AR&R (1987) for the Port Hacking Region; and
- The 1-Year ARI average rainfall intensity (mm/hr) for the Port Hacking Region for a 6 hour rainfall event (sourced from Bureau of Meteorology IFD data).

The resulting peak discharge at the upstream extent of the study area (implemented as the upstream boundary condition in the model) was found to be 15 m^3/s. Suspended sediment loads for the Port Hacking region were sourced from NSW OEH (2011c), which shows that for an urbanised catchment in the Sydney region such as North West Arm, suspended sediment loads are generally between 5.3 mg/L (upper 95% confidence interval) and 129 mg/L (lower 95% confidence interval). In order to assess a range of potential suspended sediment loads, flood simulations were conducted using both the upper and lower 95% confidence intervals. The results are presented in **Figures C-5** to **C-7** for the high (129 mg/L) suspended sediment concentration simulations.

Figure C-5 shows that for Option 1, the section of Dent Creek upstream of the dredged channel has scoured around 0.2 to 0.5 m, and that some of the scoured sediments have subsequently infilled the upstream portions of the dredged channel in the order of 0.7-0.8 m. This infilling extends approximately 70 to 80 m from the upstream limit of the dredge channel. Downstream of this point, only minimal bed changes occurred (i.e. in the order of less than 0.1 m). As a result of the flood related infilling, bed levels have increased to the level of (approximately) MLWS. Hence the modelling indicates that there is a risk that the upper extent of the dredged channel would become difficult to access on low tides after a 1-year ARI flood event. Subsequent catchment inflow events would likely move this plug of sediment further downstream, further reducing access. This magnitude event is likely to occur on average once every year, which means that the dredge profile may potentially require annual maintenance, or at least every 2-3 years.

Figure C-5: 1-Year ARI Catchment Flood Erosion and Sedimentation – Option 1 – High Sediment Load

Figure C-6: 1-Year ARI Catchment Flood Erosion and Sedimentation – Option 2 – High Sediment Load

Figure C-7: 1-Year ARI Catchment Flood Erosion and Sedimentation – Existing Bed Condition (do nothing option) - High Sediment Load

Figure C-6 shows that for Option 2, sediments scoured out from the upstream regions of the estuary do not appear to show significant deposition in the region of dredging following a 1-year ARI flood event. It is expected that several flood events of a similar magnitude, or a larger event, would be required before more significant deposition occurs in the dredged area. Hence, the maintenance dredging requirements would be much lower than for Option 1.

Figure C-7 highlights that there will changes in the bed morphology in relation to catchment inflows, with scour in some locations and deposition in others. For a 1-year ARI the magnitude of change is not significant, but over successive catchment inflow events the changes would be more readily observable. The assessment of the do nothing option (existing bed condition) is also useful to highlight the importance of natural in-stream processes in mobilising sediments from one location in the estuary to another, irrespective of whether additional sediments are being delivered to the estuary.

C1.4 Environmental Considerations

This section provides an overview of the key environmental considerations and discusses their relevance to the feasibility assessment. This is important in terms of considering:

- The relative compatibility of the dredging options with the statutory and policy framework, and hence the likelihood of receiving the necessary environmental approvals; and
- Implications for the cost of undertaking the works.

C1.4.1 Flora and Fauna

A number of ecological impacts may potentially occur in relation to dredging activities in the North West Arm. Both dredging options will result in the removal of seagrasses and mangroves, both of which are protected marine vegetation under the *Fisheries Management 1994* (FM Act). More specifically, Option 2 would result in the removal of *Posidonia* seagrass, which is listed as an endangered population in Port Hacking under the FM Act. It is noted that the estuarine macrophyte mapping used to estimate areas for removal seagrasses was prepared by Creese *et al.* (2009) and is thought to exclude some seagrass beds that were observed in recent aerial photography and during the site inspection. Hence, the areas for removal presented in **Table C-2** are likely to underestimate potential impacts.

The removal of mangroves and seagrasses, along with the physical disturbance of the bed, would result in a decrease in the area of available habitat for a range of fauna species. It is noted that the recovery of seagrasses, either by natural recruitment or transplanting, is very difficult to achieve, particularly for *Posidonia*. As a result, the loss of seagrasses may translate into medium-long term impacts.

In addition, the lowering of the bed resulting from the dredging works would also decrease the area of available intertidal foraging habitat for wading birds, several species of which are protected and/or threatened. As discussed below with reference to sediment transport processes, the dredge hole would not likely infill in the short term, and hence this reduction in habitat for wading birds would be ongoing for the medium term.

Indirect impacts of any proposed dredging works would include increased turbidity and sedimentation during the works period. This may lead to smothering of mangrove pneumatophores and seagrasses in the vicinity of the works. In addition, the short term water quality impacts also have potential to negatively impact on aquatic fauna (e.g. fish), as well as impacting foraging success for some species of birds. Indirect impacts also include general disturbance of species due to the presence of the dredger and the associated noise emissions.

C1.4.2 Sediment and Water Quality

Section 6.5.3 of the CZMP provides a review of the available data on sediment quality in the North West Arm. It is noted that previous studies have identified that there is some relatively low level contamination of sediments (Albani and Cotis, 2013; Birch, 2000; Lewtas *et al*., 2014; Stark, 1998). For example, the samples collected by Lewtas *et al.* (2014) indicate sedimentary concentrations of lead above the Interim Sediment Quality Guidelines – Low guidelines, which indicates there is potential for impacts and further investigation would be required (ANZECC, 2000). This would result in additional expense for the required field sampling and laboratory analysis. Dredging has potential to disturb contaminated sediments, mobilising any contaminants present into the water column, where they may negatively impact on estuarine biota.

In addition, there is also potential for the occurrence of Acid Sulfate Soils (ASS) in the dredged material. If mobilised, this would result in negative impacts on water quality, under a worst case scenario resulting in death of fish. The estuary bed is Class 1 ASS, with some areas of Class 2 ASS in the upper estuary.

In order to fulfil the requirements of the following instruments, sediment sampling would need to be undertaken to characterise the material proposed for dredging:

- *Protection of the Environment Operations Act 1997*;
- *Protection of the Environment Operations (Waste) Regulation 2014*;
- ASSMAC (1998) *Acid Sulfate Assessment Guidelines;* and
- NSW EPA (2014) *Waste Classification Guidelines*.

Further consideration of the requirements for these various guidelines would need to be undertaken in order to identify the sampling requirements for Options 1 and 2, but the cost of collecting and analysing the samples has been estimated at $10,400 (excl. GST), noting that additional sampling and reporting may be required pending the outcomes of the original assessments. This is therefore a conservative estimate.

In the event the sediments are found to be contaminated, this will not be a barrier to undertaking the project, but may increase the cost of the works due to the need to undertake additional testing and more costly disposal.

Depending on the quality of the sediments, the disposal options would include:

- Beneficial re-use under the *Protection of the Environmental Operations (Waste) Regulation 2014* (e.g. for fill on another site). This would require transfer of the dredged material to a truck and transport to the subject site;
- Disposal in the estuary or at sea, which would require transport via barge (or other vessel) to the dumping site; or
- If poor quality, the sediments may require disposal at a suitably licenced waste management facility. This would require transfer of the dredged material to a truck and transport to the facility. This would typically be the most expensive option.

It is noted that the potential impacts on the receiving site for the dredge spoil would also need to be assessed.

Given that the cost of the various disposal options is quite variable, the cost estimates for the dredging works do not incorporate disposal costs.

C1.4.3 Sediment Transport Pathways and Infilling

The natural sediment transport pathways described in Section 5.3.2 of the CZMP would be disrupted as a result of dredging activities.

One of the important considerations in costing dredging works is the sustainability of the proposal with respect to the potential rate of infilling of the dredge hole. As discussed in Section 5.3.2 of the CZMP, the dredge hole associated with the dredging conducted in the late 1960's appears to have infilled some time before 1978, indicating that the life of the dredging works in this area was a maximum of 10 years and possibly less.

The potential infilling of the proposed dredge holes associated with each of the dredging options was assessed by modelling the sediment transport from tidal and regular catchment flows in the area with Delft3D (see **Section C1.3**).

The key finding of the assessment for Option 1 is that the desired functionality of the dredging, namely to have kayak access to the easement from the North West Arm Road over the full tidal cycle, would become compromised due to difficulties in achieving access in low tides as soon as one year after dredging. It is noted that subsequent catchment inflow events would re-work the bed material, likely resulting in a downstream translation of the infilling over time, further reducing accessibility for watercraft. Based on these findings, it has been estimated that maintenance dredging would be required every 2-3 years, albeit for a lesser volume than the capital dredging works. This is important in terms of cost the works.

For Option 2 the rate of infilling is much slower due to the fact that the dredge hole is located further downstream where the estuary waterbody widens out. This is the point at which catchment inflows slow down and any sediments transported in the flow of water are deposited on the bed. Only minor deposition would be expected after a 1-year ARI flood event, although there is higher potential for deposition over subsequent events or for bigger flood events. Hence, maintenance dredging may be required only once in the 10 year implementation period for the CZMP.

C1.5 Social Considerations

Dredging activities may potentially result in both positive and/or negative impacts on residents and users of the North West Arm.

During the dredging works, negative impacts on residents and visitors would include noise, a decline in visual amenity, disruption to navigation in the North West Arm from the dredge barge and associated pipes, and potentially traffic impacts if dredged material is required to be transported by trucks for disposal.

For Option 1, the positive impact on access and recreational use would be confined to users of small watercraft such as kayaks. The benefits would generally not accrue to the wider community as a whole. Furthermore, based on the assessment of rates of dredge hole infilling, the benefits would only be short term, unless there is a commitment to maintain the dredge profile on a regular basis.

It is understood that some residents consider that dredging would improve the attractiveness of the estuary by removing muddy sediments. As such, medium to long term benefits would be realised with respect to visual amenity of the estuary; however, the community consultation indicates that this view is not shared by all residents.

Considering the do nothing option, the existing level of impact on a small number of residents with respect to limitations on navigation in the upstream extent of the estuary would continue. No other positive or negative impacts would be anticipated.

C1.6 Statutory and Non-Statutory Considerations

Both dredging options would require assessment under Part 4 of the EP&A Act, and would likely be considered integrated development. To meet the requirements of the EP&A Act, an environmental impact assessment would be required.

It is considered that, based on the stated purpose of the dredging options and their respective impacts, the proposals would not fall under the *State Environmental Planning Policy (Infrastructure) 2007*, and hence would not fall under Part 5 of the EP&A Act.

For both the dredging options, Parts 2 and 7 of the FM Act are triggered. A 'Permit to Dredge, Reclaim, Obstruct Fish Passage, Harm Marine Vegetation, Use Explosives or Electrical Devices in a Waterway in Accordance with Parts 2 & 7 of the *Fisheries Management Act 1994*' would be required. The permit fee for both options is likely to be around $719.

In addition, applicants for permits to harm marine vegetation may also have to pay compensation and/or an environmental bond. NSW DPI calculates habitat compensation on a minimum 2:1 basis for all key fish habitat to help redress other indirect impacts of development. This is calculated at the rate of $51/m^2 for marine and freshwater vegetation, equating to $102/m^2 to meet the 2:1 habitat offset requirement. This offset requirement sums to a total of $34,884 for Option 1 and $44,064 for Option 2. A more detailed ecological assessment would be required to confirm the extent of estuarine vegetation to be impacted by the works.

C1.7 Impact Assessment Summary

Table C-2 provides a summary of the potential impacts associated with each of the two dredging options and the Do Nothing Option.

Table C-2: Impact Assessment for Dredging Options

Criteria*	Dredging Option 1 – Navigation Channel	Dredging Option 2 – Tidal Delta	Do Nothing
Vegetation / Habitat Condition	**Direct impacts:** removal of 342 m^2 of *Zostera* seagrass and resultant loss of habitat for estuarine fauna. Loss of small area of intertidal wading bird habitat. Medium to long term recovery. **Indirect impacts:** short term decline in water quality (increased turbidity), potential for smothering of estuarine vegetation and decline in seagrass condition due to shading and poor water quality.	**Direct impacts:** Removal of 232 m^2 of *Posidonia* seagrass, 50 m^2 of *Zostera* and 150 m^2 of mangroves. **Indirect impacts:** as per Option 1.	No negative impacts.
Water Quality	**Direct impacts:** disturbance of potentially contaminated material and potential ASS. **Indirect impacts:** potential short term decline in water quality during the works. Potential indirect impacts on estuarine biota.	As per Option 1.	No negative impacts.
Impact on Coastal / Ecological Processes	**Direct impacts:** modification of bed form and disruption of natural sediment transport processes. High rates of infilling. See above for ecological processes. **Indirect impacts:** unlikely to impact significantly on currents.	**Direct impacts:** as per Option 1, noting slow rates of infilling. **Indirect impacts:** as per Option 1.	No negative impacts.
Public Access	Improvement on access for small watercraft only.	No improvement in public access.	As per Option 2.
Community Uses	Improved navigation facilitates greater use of the estuary for users of small watercraft (e.g. kayakers).	No impact on recreational amenity and community use of the estuary.	As per Option 2.
Visual Character	Short term negative impacts on visual amenity. No long term impacts.	As per Option 1, noting the long term impact is considered neutral on the whole.	No impacts.
Community Engagement	Opportunity for community consultation and education.	As per Option 1.	As per Option 1 (this report).

Criteria*	Dredging Option 1 – Navigation Channel	Dredging Option 2 – Tidal Delta	Do Nothing
Compatibility with policy and legislative framework	**Not compatible:** Inconsistent with NSW Sustainable Dredging Strategy. Inconsistent with the principles for coastal management (see Section 2.2 of the CZMP). Would require several approvals due to the nature of the impacts.	As per Option 1.	Not incompatible.

*See Section 10 of the CZMP

C1.8 Preliminary Cost Estimate

Preliminary cost estimates were sought from a number of dredging companies estimated based on a preliminary methodology and a number of assumptions. The preliminary cost estimates for each option are provided in **Table C-3**.

These estimates were based on Cardno's experience with other dredging projects, as well as consultation with dredging companies. A 20% contingency factor has also been incorporated into the cost of the dredging works to account for any potential variation in the quoted price, or for factors such as poor weather during the works. As previously indicated, the cost of disposal is not included in the cost estimates.

The annually recurrent costs were calculating assuming a 10 year period of implementation (consistent with the CZMP) and based on the rates of infilling of the dredge hole. For Option 2, it was assumed that it may be necessary to repeat the dredging once every ten years. This is due to the relatively slow rates of infilling.

For Option 1, noting the rate of infilling described in **Section C.1.3.2** of this Appendix, it has been assumed that maintenance dredging would be required every three years to remove a volume of 3,000 m^3 of material, which is roughly equivalent to the amount that might infill the hole over this period of time assuming two 1 year ARI events (i.e. a 1 year ARI event does not necessarily occur every year).

Table C-3: Preliminary Cost of Dredging Options

Dredging Option	Option 1	Option 2
Sediment Quality Investigations	$10,400	$10,400
Estuarine Macrophyte Survey	$6,500	$6,500
Assessment of Disposal Options Report	$8,400	$8,400
Environmental Impact Assessment	$10,000	$10,000
Construction Environmental Management Plan	$3,000	$3,000
Fisheries Permit and Offsets	$35,600	$44,800
Dredging Costs	$330,960	$200,160
Total Capital Cost	**$404,860**	**$283,260**
Annually Recurrent Costs	**$40,320**	**$20,016**

C1.9 Cost Benefit Analysis Results

The information presented in this Appendix has been used to conduct a cost-benefit analysis of the two dredging options for comparison against the base case, or Do Nothing option (**Table C-4**). The methodology is consistent with that adopted in Section 10 of the CZMP for ease of incorporation into the wider options assessment.

Table C-4: Cost-Benefit Assessment of Dredging Options

Option	Preliminary Estimate of Capital Cost	Preliminary Estimate of Annually Recurrent Cost	Net Present Value	Vegetation / Habitat Condition	Water Quality	Impact on Coastal / Ecological Processes	Public Access	Community Uses	Visual Character	Community Engagement	Compatibility with policy and legislative framework	Raw Benefit Index	Cost-Benefit Index	Option Rank
Dredging option 1 – Navigation channel for small non-powered watercraft to North West Arm Road access point at low tide.	$404,860	$40,320	$688,051	-2	-2	-2	1	2	0	1	-1	-3	-0.51	2
Dredging option 2 – Removal of top 300 mm of sediments from delta.	$283,260	$20,016	$423,834	-3	-2	-2	0	0	1	1	-1	-5	-1.07	3
Do Nothing		No cost		0	0	0	0	0	0	1	0	1	1.11	1

As expected, the Do Nothing option has a positive cost-benefit ratio as it avoids all the impacts associated with the dredging works, and it would not require any expenditure of funds. It is therefore the highest ranking option of the three.

Option 1 has a negative cost-benefit ratio of -0.51, but ranks higher than Option 2. Although Option1 would result in some benefits due to increased accessibility for kayakers, the high cost of the works, high maintenance requirements and the negative environmental impacts (removal of habitat in particular) lead to it having a negative cost-benefit ratio.

Option 2 has a negative cost-benefit ratio of -1.07 and is the lowest ranking option. Whilst it is significantly cheaper than Option 1, the benefits are very limited and there are a range of negative environmental impacts associated with the works. In particular, Option 2 would result in almost 80% more clearing of estuarine vegetation (including the protected *Posidonia* seagrass) compared to Option 1.

C1.10 Discussion

Whilst the two dredging options have negative cost-benefit ratios, they are both technically feasible and may be implemented, provided the relevant environmental approvals are obtained and funding allocated to undertake the works.

As discussed in Section C1.6, There would also be a need to obtain a range of environmental approvals for both dredging options, including a Fisheries Permit under the *Fisheries Management Act 1994* and a licence under the *Crown Lands Act 1984*. Depending on whether the proponent is a public authority or not, a Controlled Activity Approval may also be required under the *Water Management Act 2000*. The approval authorities would require that the proponent demonstrate that the benefits of the proposed dredging activity outweigh the environmental impacts, and this may be challenging in light of the anticipated impacts, particularly on the Endangered Population of *Posidonia*.

In the event approvals are obtained, the funding of works may represent a second challenge.

Funding for dredging options may come from a number of sources including:

- Funding through the *NSW Government Sustainable Dredging Strategy*;
- A grant under OEH's Estuary Management Program;
- Council; and
- Private contributions.

The *NSW Government Sustainable Dredging Strategy 2012/13 – 2014/15* (NSW Trade and Investment, 2012) defines the State Government's approach to dredging. Prioritisation of investment is based on a range of factors, several of which have also been considered in the dredging options assessment presented in this report:

- **Access to existing government maritime infrastructure** – neither option would provide or improve access to any existing or proposed maritime infrastructure;
- **Extent and value of boating activity** – very limited, small number of personal watercraft only;
- **Longevity and practicality of dredging** – longevity limited particularly for Option 1;
- **Severity of shoaling** – the existing shoaling only limits small watercraft such as kayaks and only for part of the tide, there is no safety or navigational risk associated with the proposed dredging locations. Furthermore, watercraft users are unlikely to have a desire to go further upstream as the watercourse is effectively inaccessible to watercraft/vessels immediately upstream;
- **Environmental sensitivity and benefits** – Significant environmental impacts in relation to loss of sensitive habitats, including part of the Endangered Population of *Posidonia* seagrass in Port Hacking. No environmental benefits;
- **Contribution to regional economies** – negligible;
- **Compatibility with estuary management planning** – not compatible with principles of coastal management; and

- **Demonstrated support from local community** – support from a small number of community members.

Funding arrangements under the Strategy fall into a number of categories:

- Rescuing our Waterways: First Priority
  - Projects in specific waterways previously identified as priorities.
  - Not relevant to the dredging proposals in North West Arm.
- Rescuing our Waterways: Second Priority
  - Other dredging of estuaries to provide public benefits with preference for projects where the main purpose is to aid navigation by recreational and commercial vessels.
  - Minimum 50% contribution from local stakeholders.
  - Not relevant to the dredging proposals in North West Arm.
- Coastal Infrastructure Program
  - Dredging to maintain navigation access to government-owned maritime infrastructure and at "trained" river entrances where breakwaters have been constructed to assist in providing stable navigation conditions.
  - Not relevant to the dredging proposals in North West Arm.
- Dredging to address coastal flooding, coastal hazard management and environmental issues
  - Funded under the Coastal, Estuary and Floodplain Management Programs (administered by OEH).
  - Minimum 50% contribution by local government.
- Private sector dredging
  - Nil contribution by State Government.

Considering the *NSW Sustainable Dredging Strategy 2012/13 – 2014/15* (NSW Trade and Investment, 2012), it is unlikely that the proposal would meet the requirements for financial support from the State Government. Whilst it is possible for SSC to make an application to OEH for a grant under the NSW Estuary Management Program, either of the dredging proposals would not necessarily be supported when assessed for their relative merits against the range of applications from across NSW received by OEH. If successful, the funding would be up to a maximum of 50% of the capital works, and the maintenance works would be subject to future grant applications.

The most likely outcome of any funding application is that it would need to be financially supported by Council and/or the community. As discussed in **Section 11.2**, Council has limited funds for capital works, and any such dredging proposals would require careful consideration prior to allocation of the necessary budget.

C1.11 Concluding Remarks

On the basis of the assessment provided in this appendix, neither of the dredging proposals are recommended.

The benefits associated with both dredging options are very limited and do not adequately offset the potential negative impacts. As discussed in Section 5.3.2 of the CZMP, the nature of an estuary is to undergo gradual infilling over time, as has been documented for the North West Arm estuary. Whilst there may have been a period of time when rates of sedimentation were accelerated due to development of the catchment, the rate of sedimentation has subsequently declined. In any case, the shoaling of sediments in the upper estuary will be ongoing due to the re-distribution of sediments already within the estuary and Dents Creek following catchment flood events, and this process is a much more significant determinant of water depths in the short to medium term.

As discussed in Section C1.10, whilst both dredging options are technically feasible, they may not receive project approval, and would place a significant financial burden on Council, which is already experiencing budgetary constraints. Hence, it is also unlikely to be practical to implement the dredging options.

It is recommended that the Do Nothing approach is adopted.

C2 References

Albani, A.D. and Cotis, G. (2013) *Port Hacking. Past and present of an estuarine environment*. Prepared for Sutherland Shire Council

ANZECC & ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Birch, G.F. (2000) Marine pollution in Australia, with special emphasis on central New South Wales estuaries and adjacent continental margin, *International Journal of Environment and Pollution*, Vol. 13, Nos. 1–6, pp. 573–607.

Creese, R.G., Glasby, T.M., West, G. & Gallen, C. (2009) *Mapping the Habitats of NSW Estuaries.* Prepared for the Hunter Central Rivers Catchment Management Authority.

Lewtas, K.L.M., Birch, G.F., and Foster-Thorpe, C. (2014) Metal accumulation in the greentail prawn, Metapenaeus bennettae, in Sydney and Port Hacking estuaries, Australia, *Environmental Science and Pollution Research*, Vol. 21, pp. 704-716.

NSW DPI (n.d.) *Activities requiring a permit*. NSW Department of Primary Industries. Retrieved 29 April 2015 from http://www.dpi.nsw.gov.au/fisheries/habitat/protecting-habitats/activities-requiring-a-permit

NSW Trade and Investment (2012) *NSW Government Sustainable Dredging Strategy 2012/13 – 2014/15.* NSW Trade and Investment

OEH (2011c) *Estuaries and Coastal Lakes technical Report Series. Assessing the condition of estuaries and coastal lake ecosystems in NSW.* Office of Environment and Heritage.

Stark, J.S. (1998) Heavy metal pollution and macrobenthic assemblages in soft sediments in two Sydney estuaries, Australia, *Marine and Freshwater Research*, Vol. 49, pp. 533-540.

Coastal Zone Management Plan

APPENDIX D

SPECIES RECORDS

D Estuarine Biodiversity

This Appendix provides a complete list of species listed under the EPBC, TSC and FM Acts recorded in the Sutherland Shire LGA.

Table C-1: Species in the Sutherland shire LGA

Common Name	Scientific Name	EPBC	TSC	FM
Fish				
Australian Grayling	*Prototroctes maraena*	V	-	-
Black Rockcod, Black Cod	*Epinephelus daemelii*	V	-	
Frogs				
Giant Burrowing Frog	*Heleioporus australiacus*	V	V, P	-
Green and Golden Bell Frog	*Litoria aurea*	V	-	-
Littlejohns Tree Frog, Heath Frog	*Litoria littlejohni*	V	-	-
Stuttering Frog	*Mixophyses balbus*	V	-	-
Growling Grass frog	*Litoria raniformis*	V	-	-
Birds				
White-fronted Chat	*Epthianura albifrons*	-	T, V. P	-
Regent Honeyeater	*Anthochaera phrygia*	E	E, P	-
Australasian Bittern	*Botaurus poiciloptilus*	E	-	-
Black Bittern	*Ixobrychus flavicollis*	-	V, P	-
Eastern Bristlebird	*Dasyornis brachypterus*	E	-	-
Swift Parrot	*Lathamus discolor*	E	-	-
Orange-bellied Parrot	*Neophema chrysogaster*	CE	-	-
Australian Painted Snipe	*Rostratula australis*	E	-	-
White-bellied Storm-Petrel	*Fregetta grallaria grallaria*	V	-	-
Southern Giant-Petrel	*Macronectes giganteus*	E	-	-
Northern Giant-Petrel	*Macronectes halli*	V	-	-
Gould's Petrel	*Pterodroma leucoptera leucoptera*	E	-	-
Kermadec Petrel*	*Pterodroma neglecta neglecta*	V	-	-
Australian Fairy Tern	*Sternula nereis nereis*	V	-	-
Superb Fruit-Dove	*Ptilinopus superbus*	-	V, P	-
Fork-tailed Swift	*Apus pacificus*	-	P	-
Square-tailed Kite	*Lophoictinia isura*	-	V, P	-
Eastern Osprey	*Pandion cristatus*	-	V, P	-
Black Falcon	*Falco subniger*	-	V, P	-
Sooty Oystercatcher	*Haematopus fuliginosus*	-	V, P	
Pied Oystercatcher	*Haematopus longirostris*	-	E, P	-
Caspian Tern	*Hydroprogne caspia*	-	P	-
Little Tern	*Sternula albifrons*	-	E, P	-
Gang-gang Cockatoo	*Callocephalon fimbriatum*	-	V, P	-
Glossy Black-Cockatoo	*Calyptorhynchus lathami*	-	V, P	-
Major Mitchell's Cockatoo	*Lophochroa leadbeateri*	-	V, P	-
Purple-crowned Lorikeet	*Glossopsitta porphyrocephala*	-	V, P	-
Powerful Owl	*Ninox strenua*	-	V, P	-
Masked Owl	*Tyto novaehollandiae*	-	V, P	-
Sooty Owl	*Tyto tenebricosa*	-	V, P	-
Varied Sittella	*Daphoenositta chrysoptera*	-	V, P	-

Common Name	Scientific Name	EPBC	TSC	FM
Pink Robin	*Petroica rodinogaster*	-	V, P	-
Southern Royal Albatross*	*Diomedea epomophora epomophora*	V	-	-
Northern Royal Albatross*	*Diomedea epomophora sanfordi*	E	-	-
Antipodean Albatross*	*Diomedea exulans antipodensis*	V	-	-
Tristan Albatross*	*Diomedea exulans exulans*	E	-	-
Gibson's Albatross*	*Diomedea exulans gibsoni*	V	-	-
Wandering Albatross*	*Diomedea exulans (sensu lato)*	V	-	-
Buller's Albatross, Pacific Albatross*	*Thalassarche bulleri*	V	-	-
Shy Albatross*	*Thalassarche cauta cauta*	V	-	-
Salvin's Albatross*	*Thalassarche cauta salvini*	V	-	-
White-capped Albatross*	*Thalassarche cauta steadi*	V	-	-
Chatham Albatross*	*Thalassarche eremita*	E	-	-
Black-browed Albatross*	*Thalassarche melanophris*	V	-	-
Campbell Albatross*	*Thalassarche melanophris impavida*	V	-	-
Migratory Wetlands Species				
Common Sandpiper**	*Actitis hypoleucos*	T, C, J, K	P	-
Sharp-tailed Sandpiper**	*Calidris acuminata*	T	-	-
Curlew Sandpiper**	*Calidris ferruginea*	T, C, J, K	E, P	-
Broad-billed Sandpiper**	*Limicola falcinellus*	T, C, J, K	-	-
Terek Sandpiper**	*Xenus cinereus*	T	-	-
Ruddy Turnstone**	*Arenaria interpres*	T, C, J, K	P	-
Sanderling**	*Calidris alba*	T	-	-
Red Knot, Knot**	*Calidris canutus*	T	-	-
Great Knot**	*Calidris tenuirostris*	T, C, J, K	-	-
Red-necked Stint**	*Calidris ruficollis*	T, C, J, K	P	-
Great Egret, White Egret	*Ardea alba*	T	-	-
Cattle Egret	*Ardea ibis*	T, C, J	P	-
Double-banded Plover**	*Charadrius bicinctus*	T	-	-
Pacific Golden Plover**	*Pluvialis fulva*	T, C, J, K	P	-
Grey Plover**	*Pluvialis squatarola*	T	-	-
Greater Sand Plover, Large Sand Plover**	*Charadrius leschenaultii*	T	-	-
Lesser Sand Plover, Mongolian Plover**	*Charadrius mongolus*	T	-	-
Oriental Plover, Oriental Dotterel**	*Charadrius veredus*	T	-	-
Painted Snipe**	*Rostratula benghalensis*	E	-	-
Latham's Snipe, Japanese Snipe**	*Gallinago hardwickii*	T	-	-
Grey-tailed Tattler**	*Heteroscelus brevipes*	T	-	-
Bar-tailed Godwit**	*Limosa lapponica*	T, C, J, K	-	-
Black-tailed Godwit**	*Limosa limosa*	T	-	-
Eastern Curlew**	*Numenius madagascariensis*	T, C, J, K	-	-
Little Curlew, Little Whimbrel**	*Numenius minutus*	T	-	-
Whimbrel**	*Numenius phaeopus*	T, C, J, K	-	-
Migratory Terrestrial Species				
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	T, C	P	-
White-throated Needletail	*Hirundapus caudacutus*	T, C, J, K	P	-
Rainbow Bee-eater	*Merops ornatus*	T	-	-
Black-faced Monarch	*Monarcha melanopsis*	T	-	-
Spectacled Monarch	*Monarcha trivirgatus*	T	-	-
Satin Flycatcher	*Myiagra cyanoleuca*	T	-	-
Rufous Fantail	*Rufous Fantail*	T	-	-

Common Name	Scientific Name	EPBC	TSC	FM
Terrestrial and Marine Mammals				
New Holland Mouse, Pookila	*Pseudomys novaehollandiae*	V	P	-
Grey-headed Flying Fox	*Pteropus poliocephalus*	V	V, P	-
Spotted-tailed Quoll	*Dasyurus maculatus*	E	V, P	-
Koala	*Phascolarctos cinereus*	V	V, P	-
Eastern Pygmy-possum	*Cercartetus nanus*	-	V, P	-
Yellow-bellied Sheathtail-bat	*Saccolaimus flaviventris*	-	V, P	-
Eastern Bentwing-bat	*Miniopterus schreibersii oceanensis*	-	V, P	-
Southern Myotis	*Myotis macropus*	-	V, P	-
Greater Broad-nosed Bat	*Scoteanax rueppellii*	-	V, P	-
Large-eared Pied Bat, Large Pied Bat	*Chalinolobus dwyeri*	V	-	-
Southern Brown Bandicoot	*Isoodon obesulus obesulus*	E	-	-
Brush-tailed Rock wallaby	*Petrogale penicillata*	V	-	-
Blue Whale	*Balaenoptera musculus*	E	-	-
Humpback Whale	*Megaptera novaeangliae*	V	-	-
Plants				
Strapweed	*Posidonia australis*		E	E
Bynoe's Wattle, Tiny Wattle	*Acacia bynoeana*	V	E, P	-
Downy Wattle, Hairy Stemmed Wattle	*Acacia pubescens*	V	-	-
Allocasuarina glareicola	*Allocasuarina glareicola*	E	-	-
Asterolasia elegans	*Asterolasia elegans*	E		
White-flowered Wax Plant	*Cynanchum elegans*	E	-	-
Yellow Gnat-orchid	*Genoplesium baueri*	E	E, P	-
Small-flower Grevillea	*Grevillea parviflora subsp. parviflora*	V	-	-
Woronora Beard-heath	*Leucopogon exolasius*	V	V	-
Biconvex Paperbark	*Melaleuca biconvexa*	V	-	-
Deane's Melaleuca	*Melaleuca deanei*	V	V, P	-
Omeo Stork's-bill	*Pelargonium sp. Striatellum*	E	-	-
Hairy Persoonia	*Persoonia hirsuta*	E	E, P	-
Nodding Geebung	*Persoonia nutans*	E	-	-
Villous Mintbush	*Prostanthera densa*	V	V, P	-
Prostanthera saxicola	*Prostanthera saxicola*	-	E	-
Pimelea curviflora var. curviflora	*Pimelea curviflora var. curviflora*	V	-	-
Camfield's Stringybark	*Eucalyptus camfieldii*	V	V, P	-
Leafless Tongue-orchid	*Cryptostylis hunteriana*	V	-	-
Thick-lipped Spider-orchid, Daddy Long-legs	*Caladenia tessellata*	V	E, P	-
Thick-leaf Star-hair	*Astrotricha crassifolia*	V	-	-
Illawarra Greenhood	*Pterostylis gibbosa*	E	-	-
Sydney Plains Greenhood	*Pterostylis saxicola*	E	-	-
Botany Bay Bearded Greenhood	*Pterostylis sp. Botany Bay*	E	-	-
Pultenaea aristata	*Pultenaea aristata*	V	-	-
Siah's Backbone	*Streblus pendulinus*	E	-	-
Magenta Lilly Pilly	*Syzygium paniculatum*	V	-	-
Kangaloon Sun Orchid	*Thelymitra kangaloonica*	CE	-	-
Austral Toadflax	*Thesium australe*	V	-	-
Allocasuarina diminuta subsp. *mimica*	*Allocasuarina diminuta* subsp. *mimica*	-	E	-
Hibbertia puberula	*Hibbertia puberula*	-	E, P	-
Maundia triglochinoides	*Maundia triglochinoides*	-	V, P	-

Common Name	Scientific Name	EPBC	TSC	FM
Netted Bottle Brush	*Callistemon linearifolius*	-	V, P	-
Reptiles				
Green Turtles***	*Chelonia mydas*	V	-	-
Loggerhead Turtle****	*Caretta caretta*	E	-	-
Hawksbill Turtle***	*Eretmochelys imbricata*	E	-	-
Leatherback Turtle*	*Dermochelys coriacea*	E	-	-
Flatback Turtle	*Natator depressus*	V	-	-
Broad-headed Snake*	*Hoplocephalus bungaroides*	V	-	-
Rosenberg's Goanna	*Varanus rosenbergi*	-	-	-
Sharks				
Grey Nurse Shark	*Carcharias taurus*	CE	-	-
Great White Shark	*Carcharodon carcharias*	V	-	-
Green Sawfish	*Pristis zijsron*	V	-	-
Whale Shark	*Rhincodon typus*	V	-	-

P = Protected
V = Vulnerable
T = Threatened
E = Endangered
CE = Critically Endangered
C = CAMBA (China Australia Migratory Bird Agreement)
J = JAMBA (Japan Australia Migratory Bird Agreement)
K = ROKAMBA (Republic of Korea Australia Migratory Bird Agreement)

Coastal Zone Management Plan

APPENDIX E

ESTUARINE HEALTH STATUS AND ECOLOGICAL RISK ASSESSMENT

Cardno
Shaping the Future

E1 Estuarine Health Status

The estuarine ecosystems within the North West Arm are in a modified condition due to historic changes in catchment land use (NLWRA, 2001). Based on the findings in this study, the general ecosystem health of the estuary may deteriorate periodically (e.g. following catchment flow events), particularly in the upper estuary areas subject to lower flushing rates. Human activities in the catchment have the potential to impact indirectly on the health of the ecosystem, while other activities conducted in the waterway and along the foreshores have a more direct impact on the estuary health.

A number of key issues have been identified that have negatively impacted on estuarine condition historically, or continue to do so:

- Clearing of riparian vegetation leading to bank destabilisation, loss of habitat and introduction of sediments and nutrients to the waterway;
- Clearing of terrestrial vegetation resulting in significantly altered catchment processes:
  - Increasing the volume of runoff,
  - Changing the timing of delivery of runoff to the estuary, and
  - Increasing nutrient and sediment loads;
- Water pollution from urban stormwater runoff:
  - Litter and organic (from gardens, street trees and green open spaces),
  - Sediment and suspended solids from construction sites and other un-vegetated areas,
  - Nutrients from fertilisers and detergents,
  - Nutrients and faecal contamination from animal faeces,
  - Heavy metals (lead, copper, zinc) and oils from roadways and antifouling paint, and
  - Sewage and other pollutants from shipping and waterway activities.

The Estuarine Health evaluation process applied to the study area is based on the NSW Monitoring, Evaluation and Reporting (MER) program, conducted state-wide for estuaries and coastal lake ecosystems (Roper *et al.*, 2011), incorporating a modified version of the report card system defined in the *State of the Marine Environment Report* (Zann, 1995). A summary of the status categories for ecosystem health for North West Arm is presented in **Table E-1** and is based on the MER descriptors and for all quantitative data, grading is based on the level of exceedances as defined by Roper *et al.* (2011). Qualitative data is based on descriptive categories only, defined by Zann (2005). Furthermore, **Table E-2** includes a range of ecosystem health indicators, for each of which a health status, potential sources for indicator/parameter and overall trend is provided (where available).

Table E-1 Status for Ecological Health Report Card (after: Roper *et al.*, 2011)

Status	Descriptor
5	Very Good - Slight effects from human activities (or ≥90% of data falls within guidelines)
4	Good - General slight effects, or few sites with moderate effects (or 75 to <90% of data within guidelines)
3	Fair - General moderate effects, or some sites with serious effects (or 50 to <75% of data within guidelines)
2	Poor - General serious effects (or 10 to <50% of data within guidelines)
1	Very Poor - Very serious effects (or <10% of data within guidelines)
ND	Not Determined due to lack of data available

The historic trends in particular indicators are indicated by one of four values:

- ↔ = Stable / no apparent trend;
- ↑ = Improvement, positive trend;
- ↓ = Decline, negative trend; and
- **ND** = Not determined due to insufficient information.

It should be noted that the health status assessment is subject to a number of limitations. The North West Arm is a small tributary estuary of the Port Hacking system, and there is limited data available for the North West Arm itself. Some of the information for this assessment has been inferred from data available for Port Hacking.

All water quality data were taken within the catchment area except where noted otherwise. Water sampling was conducted on a monthly basis at a freshwater section of Dents Creek over the period of July 2013 to June 2014 as part of Sutherland Shire Water Quality Monitoring Program. The limited temporal resolution of the water quality data does not allow for an evaluation of the long term trends in water quality. In addition, observed water quality may differ significantly towards the mouth of the estuary due to increased tidal flushing and a decline in the influence of catchment inflows.

In several cases the trend is either not known or has not been clearly established. In the event that Council would like to understand the trends, additional monitoring or investigation may be required.

Table E-2 North West Arm Ecological Health Status

Indicator	Parameters (where applicable)	State: Current	State: Reference Values ANZECC (2000)*	State: Status	Pressures: Potential Sources / Causes	Pressures: Trend
Water Quality+						
Nutrients	Ammonia (mg/L)	<0.01 – 0.05	0.02	3	Sewage, stormwater runoff, faeces from domestic animals & wildlife, fertilisers, & detergents.	ND
	Total Nitrogen as N (mg/L)	0.3 – 1.5	0.5	2		ND
	Total Kjeldahl Nitrogen (mg/L)	0.2 – 0.6	No specific criteria	ND		ND
	Nitrate + Nitrite as N (mg/L)	0.08 – 0.89	0.04	1		ND
	Total Phosphorous as P (mg/L)	<0.01 – 0.12	0.05	3		ND
Heavy Metals	Zinc (mg/L)	0.06	0.08	3	Historic industry in Port Hacking, anti- fouling paints, runoff from roads, atmospheric fallout, lead-based paints, copper pipes.	ND
	Arsenic (mg/L)	<0.001 – 0.001	0.024	5		ND
	Cadmium (mg/L)	<0.0001 – 0.0001	0.0002	5		ND
	Chromium (mg/L)	<0.001 – 0.002	0.050**	5		ND
	Copper (mg/L)	0.002 – 0.017	0.0014	1		ND
	Lead (mg/L)	<0.001 – 0.005	0.0034	5		ND
	Nickel (mg/L)	<0.001 – 0.002	0.011	5		ND
Biological	Biochemical Oxygen Demand (mg/L)	<2 – 5	No specific criteria	ND	Decay of organic matter.	ND
	Chlorophyll a (mg/m3)	<1 – 84	5	4	Increased availability of nutrients.	ND
	Dissolved Oxygen (mg/L)	8.4 – 11	6.5** (80% saturation)	5	Plant photosynthesis, increased plant production (from increased nutrient loads), diffusion of oxygen from the atmosphere into the waterway, running waters, changing water temperatures.	ND

Indicator	Parameters (where applicable)	State: Current	Reference Values ANZECC (2000)*	Status	Pressures: Potential Sources / Causes	Trend
	Enterococci (cfu/100mL)	52 – 4,900	<35**	1	Stormwater runoff, sewage, faeces from domestic animals & wildlife.	ND
Physical	Conductivity (µS/cm)	107 – 712	125 – 2,200	5	Modified flow regime.	ND
	pH	7.4 – 8.5	6.5 - 8.0	4	Input of chemicals & detergents associated with urban runoff, rock & soil weathering, modified flow regimes.	ND
	Suspended Solids (mg/L)	<1 – 72	No specific criteria	ND	Erosion and sedimentation	ND
	Temperature (°C)	12 – 27.6	15.0 – 35.0**	5	Seasonal variations, modified flow regimes	ND
Foreshore						
Extent of foreshore erosion	-	0.8 km, or 9%, of the shoreline has isolated or significant erosion[1]	No specific criteria	3	Trampling, inappropriate foreshore access, foreshore development / asset protection, vegetation loss, & stormwater erosion	↓
Extent of foreshore modification	-	1.8 km, or 40%, of the shoreline has been modified[1]		2		↓
Estuarine and Riparian Flora						
Mangroves (m^2)	-	28,000m^2 of mangroves. Increase in mangrove extent of 8,500 m^2 from 1930 to 2012 (Albani and Cotis, 2012).	After Creese *et al.* (2009)	4	Development and clearing of vegetation with spatial variation in the degree of modification. Periodically poor water quality due to stormwater runoff, sea level rise.	↑
Riparian vegetation and extent	-	Historic declines in condition and extent of riparian vegetation assumed. Weed invasion in native vegetation observed.		3		↓
Seagrass habitat present (m^2)	-	*Posidonia* spp. = 1,000 m^2 *Posidonia* spp./*Zostera* spp. = 1,000 m^2 *Zostera* spp. = 26,000 m^2 Historic decline in seagrass noted by Williams and Meehan (2004) though localized increases noted by Albani and Cotis (2013).		4	Poor water quality due to stormwater runoff resulting in increased epiphyte loads, sea level rise, sedimentation, & direct and indirect impacts from boating activities.	ND
Estuarine Fauna						
Fish distribution &	-	Unknown	No specific	ND	Loss or degradation of habitat, declines in water	ND

Indicator	Parameters (where applicable)	State Current	Reference Values ANZECC (2000)*	Status	Pressures Potential Sources / Causes	Trend
abundance			criteria		quality, modified flow regimes.	
Exotic fauna distribution & abundance (known or likely to occur)	-	At least nine introduced terrestrial mammals. *C. taxifolia* potential to occur.		3	Introduced via ballast water, accidental releases.	**ND**

[+]It is noted that there was very little water quality data available, and hence the health status designations are preliminary in nature. For example, although fewer than 10% of the data meet the criteria for dissolved Copper, this is based on consideration of only 11 samples, and is unlikely to be representative of day to dissolved copper concentrations. The same is

*ANZECC (2000) guidelines values for aquatic ecosystem health.

**Where ANZECC (2000) guidelines for aquatic ecosystems are unavailable, values for primary contact recreation are used.

1: Based on Cardno site inspections.

2: Creese *et al*. (2009).

E2 Ecological Risk Assessment

The *Guide to Climate Change Risk Assessment for NSW Local Government* (OEH, 2011) provides discussion on quantitative versus qualitative risk assessments, and notes that it is generally impractical to do a quantitative assessment of all risks due to the uncertainty associated with future climate change impacts. This is an issue for any assessment of potential future risk. The lack of data, particularly for some aspects of the estuary ecosystem, is also a challenge.

A qualitative ecological risk assessment has been undertaken to assess the likelihood and consequences of hazards, including predicted climate change impacts (where applicable), adversely influencing key attributes of the estuarine ecosystem. The general approach to the risk assessment was to:

- Assess the current vulnerabilities and areas of risk within the estuarine ecosystem (i.e. aspects that have low adaptive capacity);
- Identify the most significant pressures (or combination of pressures) impacting on these areas of risk and hence overall estuarine ecosystem health; and
- Identify level of risk for vulnerable estuarine habitats.

Risk is assessed by considering both the likelihood and consequences of an event occurring. The consequences (**Table E-3**) indicate how hazards would impact aspects of the estuarine ecosystem. In this context, the key hazards include ongoing community uses and maintenance of existing development. In addition, it has been assumed that there may be a change in risk profile in future due to population growth in the Sydney region resulting in higher levels of utilisation of the study area, and also due to climate change (e.g. sea level rise). The likelihood scale (**Table E-4**) describes the probability of the risk actually occurring.

The level of risk (**Table E-5**) is a function of the consequences and likelihood of occurrence of hazards on that specific aspect of the ecosystem. The results of the risk assessment are in **Table E-6**.

Table E-3 Qualitative Measures of Consequence – Ecological Risk Assessment

Rating	Stormwater Quality / Quantity	Sediment Quality and Transport	Sub-tidal habitats (e.g. seagrasses)	Intertidal habitats (e.g. mangroves)	Riparian Vegetation
Catastrophic	Irreversible change or significant deterioration in multiple water quality parameters over a large area. Little to no potential for recovery or restoration. Considerable clean up and remediation required. Major flow modification.	Irreversible change or deterioration in sediment quality for several parameters & over a large area. Sediment toxicity resulting in impacts on estuarine ecology. Mobilisation of contaminants from sediments to the water column. Considerable clean up and remediation required. Permanent loss or modification of sediment supply.	Significant net loss of seagrasses, including Complete loss of *Posidonia* in the estuary. No potential recovery.	Significant net loss of mangroves across the estuary. No potential recovery/restoration.	Significant net loss of riparian vegetation across the estuary. Complete loss of habitat connectivity. No potential or unassisted recovery. Significant investment in restoration required.
Major	Significant degradation or deterioration of multiple water quality parameters over a large area. Limited potential for recovery and restoration. Some clean up and remediation required. Major flow modification in some locations.	Significant deterioration in sediment quality for several parameters & over a moderate sized area. Sediment toxicity resulting in impacts on estuarine ecology. Some mobilisation of contaminants to the water column. Some clean up and/or remediation required. Major modification of sediment transport pathways throughout estuary over the long term.	Significant net loss of seagrass or loss of some *Posidonia.* Significant habitat fragmentation. Decline in condition seagrass throughout estuary (e.g. increase epiphyte loads, reduced cover/density). Limited potential for recovery or restoration.	Significant net loss of mangroves over a large area. Significant habitat fragmentation. Some habitat restoration required. Some recruitment potential.	Significant net loss of riparian vegetation over a large area. Major fragmentation and loss of connectivity. Limited potential for unassisted recover. Restoration works required.
Moderate	Degradation or deterioration of a limited number of parameters throughout estuary, or for several parameters in specific location. Potential for recovery by restoration works or longer term natural processes. Minor flow modifications	Degradation of sediment quality in one location or for a limited number of parameters. Minor impacts on estuarine ecology. Good potential for recovery by restoration works or longer term natural processes. Modification of sediment transport pathways in some	Localised seagrass losses, including some *Posidonia*. Some habitat fragmentation. Decline in condition seagrass species in parts of estuary (e.g. increase epiphyte loads, reduced cover/density). Potential for recovery by restoration works or	Loss of mangroves from one location. Some habitat fragmentation. Short term degradation over large area. Potential for recovery by restoration or recruitment.	Loss of small area of riparian vegetation, or degradation of a large area. Some habitat fragmentation. Some potential for natural recovery. Restoration work required.

Rating	Stormwater Quality / Quantity	Sediment Quality and Transport	Sub-tidal habitats (e.g. seagrasses)	Intertidal habitats (e.g. mangroves)	Riparian Vegetation
	across estuary.	areas of the estuary.	recruitment/growth.		
Minor	Deterioration of 1-2 water quality parameters in a particular location. Good potential for recovery by restoration works or short term natural processes. Minor flow modification at limited locations.	Minor deterioration of sediment quality in one location for 1-2 parameters. Good potential for recovery by natural processes. Limited modification of sediment transport pathways over the short term.	No net loss of seagrass. Minor degradation in seagrass condition. Excellent potential for recovery by restoration works or short term natural processes.	Minor degradation of mangroves. Excellent potential for recovery by restoration works or natural recruitment.	Some degradation in riparian vegetation condition. Good potential for recovery. No restoration works required.
Insignificant	No or negligible change or deterioration in water quality.	No or negligible change or damage to sediment quality or transport.	No or negligible change or damage to seagrasses.	No or negligible change or damage to mangroves.	No or negligible change or damage to riparian vegetation.

Table E-4 Qualitative Measures of Likelihood

Probability Category	Description
Rare	Outcome is not expected to occur
Unlikely	Outcome will only occur in few circumstances
Possible	Outcome may occur
Likely	Outcome will occur in most circumstances
Almost certain	Outcome is expected to occur

Table E-5 Qualitative Measures of Risk

	Consequence				
Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost Certain	**Medium**	**Medium**	**High**	**Extreme**	**Extreme**
Likely	**Low**	**Medium**	**High**	**High**	**Extreme**
Possible	**Low**	**Medium**	**Medium**	**High**	**High**
Unlikely	**Low**	**Low**	**Medium**	**Medium**	**Medium**
Rare	**Low**	**Low**	**Low**	**Low**	**Medium**

Table E-6 Present Risks to Indicators of Health for Estuarine Ecosystems

Health Indicator at Risk	Potential Hazards	Current Consequence	Current Likelihood	Current Risk	Future Consequence	Future Likelihood	Future Scenario*
Water Quality	Development in the catchment leading to modification of stormwater flows and quality resulting in periodic declines in estuarine water quality.	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
	Intense storm events with potential generate larger volumes of stormwater over short periods of time, increasing the erosion potential along Dents and Savilles Creek leading to a reduction in estuarine water quality.	Moderate	Unlikely	**Medium**	Moderate	Likely	**High**
	Increased water temperature and carbon dioxide concentrations altering ecosystem processes (such as plant growth and nutrient cycling) leading to a reduction in water quality	Minor	Unlikely	**Low**	Moderate	Possible	**Medium**
Sediment Quality and Transport	Increased urban development (including foreshore structures) altering natural sediment drainage pathways modifying estuary processes	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
	Intense storm events with potential for larger volumes of stormwater runoff from urban areas leading to an increase in sediment and reduction in sediment quality	Moderate	Unlikely	**Medium**	Moderate	Likely	**High**
	Mobilisation of contaminants from the sediments to the water column as a result of human disturbance.	Moderate	Possible	**Medium**	Moderate	Possible	**Medium**
Seagrasses	Population increase leading to more intense usage of the waterway, resulting in increased rates of damage to seagrasses from boating activities (e.g. motor scars, moorings)	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
	Increased urban development (including foreshore structures) impacting seagrasses (e.g. shading)	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
	Infestation of North West Arm with *Caulerpa taxifolia*.	Major	Possible	**High**	Major	Possible	**High**
	Sea level rise altering the availability of seagrass habitat, resulting in a decline in seagrass	Moderate	Rare	**Low**	Moderate	Possible	**Medium**
	Intense storm events and large volumes of stormwater runoff increasing pollution and sedimentation of the waterway, leading to decline in seagrass (due to smothering and/or decline in water quality)	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**

Health Indicator at Risk	Potential Hazards	Current Consequence	Current Likelihood	Current Risk	Future Consequence	Future Likelihood	Future Scenario*
Mangroves	Population increase leading to an increased intensity of waterway usage, resulting in damage to mangroves from boating activities (e.g. due to improper storage of boats or access via mangroves to the waterway).	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
	Steep topography and urban development limiting ability of mangroves to migrate under sea level rise conditions, resulting in a net decline in mangrove extent.	Moderate	Rare	**Low**	Moderate	Likely	**High**
	Increased urban development leading to direct removal of mangrove habitat, resulting in decline in estuarine biodiversity.	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
	Intense storm events and large volumes of stormwater runoff increasing pollution and sedimentation in the waterway leading to decline in mangrove (due to smothering of pneumatophores and/or decline in water quality).	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
Riparian Vegetation	Additional development in the catchment resulting in removal of riparian vegetation.	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
	The presence of urban development limits the ability of riparian vegetation to migrate under climate change conditions, resulting in a net loss of riparian habitat.	Major	Rare	**Low**	Major	Possible	**High**
	Ongoing impacts due to presence of introduced flora and fauna, with resultant decline in riparian vegetation condition and/or extent.	Moderate	Likely	**High**	Moderate	Likely	**High**
Estuarine Fauna	Increased urban development (including foreshore structures) displacing habitat for native fauna species.	Moderate	Unlikely	**Medium**	Moderate	Possible	**Medium**
	Population increase in the catchment resulting in increasing intensity of disturbance and displacement of native fauna.	Minor	Unlikely	**Low**	Minor	Possible	**Medium**
	Sea level rise resulting in contraction of existing habitat.	Major	Unlikely	**Medium**	Major	Possible	**High**

* Future scenario assumes increased urban development (due to population increase) and includes 0.4m sea level rise.

E3 References

ANZECC & ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Creese, R.G., Glasby, T.M., West, G. & Gallen, C. (2009) *Mapping the Habitats of NSW Estuaries.* Prepared for the Hunter Central Rivers Catchment Management Authority.

OEH (2011) *Guide to Climate Change Risk Assessment for NSW Local Governmen*t. Office of Environment and Heritage.

NLWRA (2001) National Land and Water Resources Audit data. Downloaded from 'OEH (2015) *CERAT*. OzCoasts: Australian Online Coastal Information. Office of Environment and Heritage'.

Roper, T., Creese, B., Scanes, P., Stephens, K., Williams, R., Dela-Cruz, J., Coade, G., Coates, B., and Fraser, M. (2011) *Assessing the condition of estuaries and coastal lake ecosystems in NSW. Monitoring, evaluation and reporting program.* Technical Report Series. State of NSW and Office of Environment and Heritage.

Zann, L.P. (1995) *Our Sea, our future: Major findings of the state of the marine environment report for Australia*. Great Barrier Reef Marine Park Authority.

Coastal Zone Management Plan

APPENDIX F

MANAGEMENT OPTIONS

F1 Unranked Management Options

Option ID	Strategy Outline	Location	Primary Responsibility	Preliminary Estimate of Capital Cost	Preliminary Estimate of Annually Recurrent Cost	Net Present Value	Vegetation / Habitat Condition	Water Quality	Impact on Coastal / Ecological Processes	Public Access	Community Uses	Visual Character	Community Engagement	Compatibility with policy and legislative framework	Raw Benefit Index	Council / PHMP Response	Adjusted Benefit Index	Cost Benefit Index	Option Rank
CC01	Provide ongoing support for Bushcare groups.	Catchment-wide	Council	$ -	$ 90,000	$ 632,122	3	1	2	1	0	2	2	2	13	1.7	14.7	2.53	2
CC02	Compliance audit of foreshore structures (e.g. jetties, wharves and boat ramps) on private property.	Estuary-wide	Council	$ 1,600	$ 9,600	$ 69,026	0	0	1	0	0	1	0	1	3	1.3	4.3	0.90	31
CC03	Assess feasibility of establishing stairs or a ramp to the water for purposes of launching small watercraft (e.g. kayaks and canoes) at the bottom of the easement located opposite the bus stop on North West Arm Road down to Dents Creek.	North West Arm Road	Council	$ 178,400	$ 1,350	$ 187,882	0	0	0	2	2	0	0	1	5	0.7	5.7	1.07	27
CC04	Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.	Molong Road	Council	$ 346,400	$ 2,750	$ 365,715	0	0	-1	3	3	0	2	2	9	1.3	10.3	1.86	12
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.	Estuary-wide	Council	$ -	$ 6,000	$ 42,141	2	1	2	0	0	2	2	2	11	1.3	12.3	2.67	1
CC06	Minimise illegal dumping by improving community awareness and via enforcement.	Catchment-wide	Council	$ 2,000	$ 5,000	$ 37,118	1	1	1	0	0	1	1	1	6	1.3	7.3	1.60	20
CC07	Improve the awareness of boating regulations and navigational requirements, including in relation to boat pump-outs.	Estuary-wide	RMS	$ -	$ 8,000	$ 56,189	1	1	1	0	1	0	1	2	7	1.0	8.0	1.68	18
CC08	Continue to enforce boating regulations.	Estuary-wide	RMS	$ -	$ 8,000	$ 56,189	1	0	1	0	1	0	1	2	6	1.0	7.0	1.47	23
CC09	Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.	Estuary-wide	RMS	$ -	$ 3,600	$ 25,285	2	0	0	0	0	0	2	3	7	1.3	8.3	1.89	10
CC10	Consider revising the Mooring Minders Policy in light of the recommended reforms in the Moorings Review Issues Paper (TfNSW, 2014).	Estuary-wide	RMS	$ 3,000	$ -	$ 3,000	0	0	0	0	0	1	0	1	2	1.3	3.3	0.96	29
CC11	Consider feasibility of banning 2-stroke engines (includes community consultation to seek feedback on proposal).	Estuary-wide	RMS	$ 12,000	$ -	$ 12,000	0	1	0	0	-1	0	-1	0	-1	-0.3	-1.3	-0.33	33

Option ID	Strategy Outline	Location	Primary Responsibility	Preliminary Estimate of Capital Cost	Preliminary Estimate of Annually Recurrent Cost	Net Present Value	Vegetation / Habitat Condition	Water Quality	Impact on Coastal / Ecological Processes	Public Access	Community Uses	Visual Character	Community Engagement	Compatibility with policy and legislative framework	Raw Benefit Index	Council / PHMP Response	Adjusted Benefit Index	Cost Benefit Index	Option Rank
CC12	Assess feasibility of banning jet skis or restricting their usage (includes community consultation to seek feedback on proposal).	Estuary-wide	RMS	$ 12,000	$ -	$ 12,000	0	0	0	0	0	0	0	0	0	0.0	0.0	0.00	32
CC13	Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.	Estuary-wide	DPI (Fisheries)	$ 10,700	$ 5,500	$ 49,330	2	0	1	0	0	1	3	2	9	1.3	10.3	2.20	5
CC14	Provide for ongoing enforcement of fishing regulations, including bag and size limits.	Estuary-wide	DPI (Fisheries)	$ -	$ 8,000	$ 56,189	0	0	1	0	0	0	2	2	5	1.7	6.7	1.40	24
CC15	Dredging option 1 – Navigation channel for small non-powered watercraft to North West Arm Road access point at low tide.	Dents Creek	Council	$ 404,860	$ 40,320	$ 688,051	-2	-1	-1	1	2	0	0	-1	-2	-0.7	-2.7	-0.46	34
CC16	Dredging option 2 – Removal of top 300 mm of sediments from delta.	Upper estuary	Council	$ 283,260	$ 20,016	$ 423,844	-3	-1	-1	0	0	1	0	-1	-5	-1.3	-6.3	-1.13	35
CC17	Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.	Marina Crescent Reserve	Council	$ 4,080	$ 7,500	$ 56,757	1	1	1	2	2	2	1	1	11	1.0	12.0	2.52	3
CC18	Review current maintenance regimes for clearing blockages of debris from Savilles Creek, especially under the bridge at North West Arm Road.	Savilles Creek	Council	$ 3,200	$ 5,000	$ 38,318	0	1	1	0	0	1	0	0	3	1.3	4.3	0.95	30
CC19	Consider opportunities to acquire foreshore land to improve public access to the foreshore and waterway.	Estuary-wide	Council	$ -	$ 93,000	$ 653,193	1	0	0	1	1	1	1	1	6	0.7	6.7	1.15	26
CC20	Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources. This may involve a review of street sweeping and the location of GPTs.	Catchment-wide	Council	$ 12,000	$ -	$ 12,000	1	2	0	0	0	0	1	2	6	1.7	7.7	1.88	11
CP01	Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.	Dents & Savilles Creeks	Council	$ 269,600	$ 2,320	$ 285,895	2	2	2	0	0	1	1	1	9	2.0	11.0	2.02	7
CP02	Gain a greater appreciation of the potential impacts of climate change on the estuarine ecosystems of North West Arm. Consider the need to develop a strategic plan to manage climate change impacts on biodiversity in the LGA.	Estuary-wide	Council	$ 75,000	$ -	$ 75,000	1	0	0	0	0	1	2	2	6	1.3	7.3	1.50	22
CU01	Establish a kayak trail from Swallow Rock and leading into the North West Arm.	Estuary-wide	Council	$ 37,500	$ 750	$ 42,768	0	0	0	1	2	0	2	1	6	0.0	6.0	1.30	25

Option ID	Strategy Outline	Location	Primary Responsibility	Preliminary Estimate of Capital Cost	Preliminary Estimate of Annually Recurrent Cost	Net Present Value	Vegetation / Habitat Condition	Water Quality	Impact on Coastal / Ecological Processes	Public Access	Community Uses	Visual Character	Community Engagement	Compatibility with policy and legislative framework	Raw Benefit Index	Council / PHMP Response	Adjusted Benefit Index	Cost Benefit Index	Option Rank
EE01	Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.	Estuary-wide	Council	$ 10,700	$ 5,500	$ 49,330	2	1	1	0	0	1	2	1	8	1.3	9.3	1.99	8
EE02	Support regional pest and weed control activities, including those conducted by Council, NPWS, LLS and DPI (Fisheries).	Catchment-wide	Council	$ -	$ 90,000	$ 632,122	3	0	0	0	0	2	1	2	8	1.7	9.7	1.67	19
WQ01	Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program. This option assumes that Council would contribute by undertaking the required monitoring at five sites in the catchment, incorporating both dry and wet weather sampling.	Catchment-wide	Council	$ -	$ 51,000	$ 358,203	1	2	0	0	2	0	3	2	10	1.3	11.3	2.04	6
WQ02	Provide ongoing support for community education to improve awareness of non-point source water pollution and provide advice on how residents can contribute to best practice stormwater management.	Catchment-wide	Council	$ 10,700	$ 5,500	$ 49,330	1	1	0	0	0	1	3	2	8	1.3	9.3	1.99	8
WQ03	Work with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows on the estuary.	Catchment-wide	Council	$ -	$ 11,200	$ 78,664	1	2	1	0	1	1	0	1	7	1.7	8.7	1.77	14
WQ04	Assess the condition of Council's stormwater outlets to the estuary and program works as required.	Estuary-wide	Council	$ 8,000	$ -	$ 8,000	2	1	1	0	0	1	1	2	8	1.3	9.3	2.39	4
WQ05	Assess compliance of lot-based stormwater management controls for foreshore properties against the requirements of the DCP.	Estuary-wide	Council	$ 1,600	$ 9,600	$ 69,026	0	1	1	0	0	0	1	1	4	1.0	5.0	1.03	28
WQ06	Install a SQID to treat stormwater draining to Dents Creek via reaches DCDCPH017 and 018, to be located near the intersection of Huskisson St and Cobargo Rd.	Dents Creek	Council	$ 109,000	$ 8,000	$ 165,189	1	1	0	0	1	1	1	2	7	2.0	9.0	1.72	15
WQ07	Retrofit SQIDs on individual stormwater pits to capture sediments and gross pollutants as stormwater inflows enter the drainage system. Assumed to be undertaken on up to five stormwater pits during the period of implementation of the CZMP.	Catchment-wide	Council	$ 24,012	$ 12,500	$ 111,807	1	1	0	0	1	1	0	2	6	2.0	8.0	1.58	21
WQ08	Install a trash rack at the point where North West Arm Road crosses Savilles Creek to capture gross pollutants.	Savilles Creek	Council	$ 36,000	$ 8,000	$ 92,189	1	1	0	0	1	1	1	2	7	2.0	9.0	1.81	13
WQ09	Install an online SQID on the unnamed watercourse located in Kyogle Reserve to capture gross pollutants from the stormwater network and upstream reach of the creek prior to entering the estuary.	Unnamed Watercourse, Grays Point	Council	$ 109,000	$ 8,000	$ 165,189	1	1	0	0	1	1	1	2	7	2.0	9.0	1.72	15
WQ10	Install a SQID to treat stormwater from the piped drainage catchment to the south east prior to discharge to the unnamed watercourse located in Kyogle Reserve.	Unnamed Watercourse, Grays Point		$ 109,000	$ 8,000	$ 165,189	1	1	0	0	1	1	1	2	7	2.0	9.0	1.72	15

F2 Ranked Management Options

Option ID	Strategy Outline	Location	Primary Responsibility	Preliminary Estimate of Capital Cost	Preliminary Estimate of Annually Recurrent Cost	Net Present Value	Vegetation / Habitat Condition	Water Quality	Impact on Coastal / Ecological Processes	Public Access	Community Uses	Visual Character	Community Engagement	Compatibility with policy and legislative framework	Raw Benefit Index	Council / PHMP Response	Adjusted Benefit Index	Cost Benefit Index	Option Rank
CC05	Seek opportunities through Council's Greenweb program to work with private landholders to rehabilitate foreshore and riparian areas.	Estuary-wide	Council	$ -	$ 6,000	$ 42,141	2	1	2	0	0	2	2	2	11	1.3	12.3	2.67	1
CC01	Provide ongoing support for Bushcare groups.	Catchment-wide	Council	$ -	$ 90,000	$ 632,122	3	1	2	1	0	2	2	2	13	1.7	14.7	2.53	2
CC17	Conduct a condition assessment of the facilities and access ways in Marina Crescent Reserve and consider works as required to improve public safety and amenity.	Marina Crescent Reserve	Council	$ 4,080	$ 7,500	$ 56,757	1	1	1	2	2	2	1	1	11	1.0	12.0	2.52	3
WQ04	Assess the condition of Council's stormwater outlets to the estuary and program works as required.	Estuary-wide	Council	$ 8,000	$ -	$ 8,000	2	1	1	0	0	1	1	2	8	1.3	9.3	2.39	4
CC13	Improve community awareness and stewardship of estuarine habitats, including mangroves, saltmarshes, intertidal mudflats and rock platforms.	Estuary-wide	DPI (Fisheries)	$ 10,700	$ 5,500	$ 49,330	2	0	1	0	0	1	3	2	9	1.3	10.3	2.20	5
WQ01	Provide support to ongoing water quality monitoring including Beachwatch and the Strategic Water Monitoring Program. This option assumes that Council would contribute by undertaking the required monitoring at five sites in the catchment, incorporating both dry and wet weather sampling.	Catchment-wide	Council	$ -	$ 51,000	$ 358,203	1	2	0	0	2	0	3	2	10	1.3	11.3	2.04	6
CP01	Implement actions outlined in Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation for North West Arm, Dents Creek and Savilles Creek with a view to managing erosion and reducing sedimentation.	Dents & Savilles Creeks	Council	$ 269,600	$ 2,320	$ 285,895	2	2	2	0	0	1	1	1	9	2.0	11.0	2.02	7
EE01	Develop and implement a community education strategy to ensure foreshore residents are aware of their responsibilities in relation to management of foreshore land and structures (e.g. jetties, wharves and boat ramps) under the DCP and relevant legislation, and to encourage best practice environmental management.	Estuary-wide	Council	$ 10,700	$ 5,500	$ 49,330	2	1	1	0	0	1	2	1	8	1.3	9.3	1.99	8
WQ02	Provide ongoing support for community education to improve awareness of non-point source water pollution and provide advice on how residents can contribute to best practice stormwater management.	Catchment-wide	Council	$ 10,700	$ 5,500	$ 49,330	1	1	0	0	0	1	3	2	8	1.3	9.3	1.99	8
CC09	Consider opportunities to upgrade existing moorings with seagrass friendly moorings through the regular maintenance program.	Estuary-wide	RMS	$ -	$ 3,600	$ 25,285	2	0	0	0	0	0	2	3	7	1.3	8.3	1.89	10
CC20	Conduct a review with the aim of optimising the current stormwater quality management program to make best use of resources. This may involve a review of street sweeping and the location of GPTs.	Catchment-wide	Council	$ 12,000	$ -	$ 12,000	1	2	0	0	0	0	1	2	6	1.7	7.7	1.88	11

Option ID	Strategy Outline	Location	Primary Responsibility	Preliminary Estimate of Capital Cost	Preliminary Estimate of Annually Recurrent Cost	Net Present Value	Vegetation / Habitat Condition	Water Quality	Impact on Coastal / Ecological Processes	Public Access	Community Uses	Visual Character	Community Engagement	Compatibility with policy and legislative framework	Raw Benefit Index	Council / PHMP Response	Adjusted Benefit Index	Cost Benefit Index	Option Rank
CC04	Consider feasibility of formalising the existing Molong Road reserve between Marina Crescent and the foreshore into a public reserve. Consider incorporating a jetty or boardwalk from the reserve for fishing and/or launch point for small watercraft (e.g. kayaks and canoes), seating and educational signage.	Molong Road	Council	$ 346,400	$ 2,750	$ 365,715	0	0	-1	3	3	0	2	2	9	1.3	10.3	1.86	12
WQ08	Install a trash rack at the point where North West Arm Road crosses Savilles Creek to capture gross pollutants.	Savilles Creek	Council	$ 36,000	$ 8,000	$ 92,189	1	1	0	0	1	1	1	2	7	2.0	9.0	1.81	13
WQ03	Work with Sydney Water to manage the impacts of illegal sewer connections and sewage overflows on the estuary.	Catchment-wide	Council	$ -	$ 11,200	$ 78,664	1	2	1	0	1	1	0	1	7	1.7	8.7	1.77	14
WQ06	Install a SQID to treat stormwater draining to Dents Creek via reaches DCDCPH017 and 018, to be located near the intersection of Huskisson St and Cobargo Rd.	Dents Creek	Council	$ 109,000	$ 8,000	$ 165,189	1	1	0	0	1	1	1	2	7	2.0	9.0	1.72	15
WQ09	Install an online SQID on the unnamed watercourse located in Kyogle Reserve to capture gross pollutants from the stormwater network and upstream reach of the creek prior to entering the estuary.	Unnamed Watercourse, Grays Point	Council	$ 109,000	$ 8,000	$ 165,189	1	1	0	0	1	1	1	2	7	2.0	9.0	1.72	15
WQ10	Install a SQID to treat stormwater from the piped drainage catchment to the south east prior to discharge to the unnamed watercourse located in Kyogle Reserve.	Unnamed Watercourse, Grays Point		$ 109,000	$ 8,000	$ 165,189	1	1	0	0	1	1	1	2	7	2.0	9.0	1.72	15
CC07	Improve the awareness of boating regulations and navigational requirements, including in relation to boat pump-outs.	Estuary-wide	RMS	$ -	$ 8,000	$ 56,189	1	1	1	0	1	0	1	2	7	1.0	8.0	1.68	18
EE02	Support regional pest and weed control activities, including those conducted by Council, NPWS, LLS and DPI (Fisheries).	Catchment-wide	Council	$ -	$ 90,000	$ 632,122	3	0	0	0	0	2	1	2	8	1.7	9.7	1.67	19
CC06	Minimise illegal dumping by improving community awareness and via enforcement.	Catchment-wide	Council	$ 2,000	$ 5,000	$ 37,118	1	1	1	0	0	1	1	1	6	1.3	7.3	1.60	20
WQ07	Retrofit SQIDs on individual stormwater pits to capture sediments and gross pollutants as stormwater inflows enter the drainage system. Assumed to be undertaken on up to five stormwater pits during the period of implementation of the CZMP.	Catchment-wide	Council	$ 24,012	$ 12,500	$ 111,807	1	1	0	0	1	1	0	2	6	2.0	8.0	1.58	21
CP02	Gain a greater appreciation of the potential impacts of climate change on the estuarine ecosystems of North West Arm. Consider the need to develop a strategic plan to manage climate change impacts on biodiversity in the LGA.	Estuary-wide	Council	$ 75,000	$ -	$ 75,000	1	0	0	0	0	1	2	2	6	1.3	7.3	1.50	22
CC08	Continue to enforce boating regulations.	Estuary-wide	RMS	$ -	$ 8,000	$ 56,189	1	0	1	0	1	0	1	2	6	1.0	7.0	1.47	23

Option ID	Strategy Outline	Location	Primary Responsibility	Preliminary Estimate of Capital Cost	Preliminary Estimate of Annually Recurrent Cost	Net Present Value	Vegetation / Habitat Condition	Water Quality	Impact on Coastal / Ecological Processes	Public Access	Community Uses	Visual Character	Community Engagement	Compatibility with policy and legislative framework	Raw Benefit Index	Council / PHMP Response	Adjusted Benefit Index	Cost Benefit Index	Option Rank
CC14	Provide for ongoing enforcement of fishing regulations, including bag and size limits.	Estuary-wide	DPI (Fisheries)	$ -	$ 8,000	$ 56,189	0	0	1	0	0	0	2	2	5	1.7	6.7	1.40	24
CU01	Establish a kayak trail from Swallow Rock and leading into the North West Arm.	Estuary-wide	Council	$ 37,500	$ 750	$ 42,768	0	0	0	1	2	0	2	1	6	0.0	6.0	1.30	25
CC19	Consider opportunities to acquire foreshore land to improve public access to the foreshore and waterway.	Estuary-wide	Council	$ -	$ 93,000	$ 653,193	1	0	0	1	1	1	1	1	6	0.7	6.7	1.15	26
CC03	Assess feasibility of establishing stairs or a ramp to the water for purposes of launching small watercraft (e.g. kayaks and canoes) at the bottom of the easement located opposite the bus stop on North West Arm Road down to Dents Creek.	North West Arm Road	Council	$ 178,400	$ 1,350	$ 187,882	0	0	0	2	2	0	0	1	5	0.7	5.7	1.07	27
WQ05	Assess compliance of lot-based stormwater management controls for foreshore properties against the requirements of the DCP.	Estuary-wide	Council	$ 1,600	$ 9,600	$ 69,026	0	1	1	0	0	0	1	1	4	1.0	5.0	1.03	28
CC10	Consider revising the Mooring Minders Policy in light of the recommended reforms in the Moorings Review Issues Paper (TfNSW, 2014).	Estuary-wide	RMS	$ 3,000	$ -	$ 3,000	0	0	0	0	0	1	0	1	2	1.3	3.3	0.96	29
CC18	Review current maintenance regimes for clearing blockages of debris from Savilles Creek, especially under the bridge at North West Arm Road.	Savilles Creek	Council	$ 3,200	$ 5,000	$ 38,318	0	1	1	0	0	1	0	0	3	1.3	4.3	0.95	30
CC02	Compliance audit of foreshore structures (e.g. jetties, wharves and boat ramps) on private property.	Estuary-wide	Council	$ 1,600	$ 9,600	$ 69,026	0	0	1	0	0	1	0	1	3	1.3	4.3	0.90	31
CC12	Assess feasibility of banning jet skis or restricting their usage (includes community consultation to seek feedback on proposal).	Estuary-wide	RMS	$ 12,000	$ -	$ 12,000	0	0	0	0	0	0	0	0	0	0.0	0.0	0.00	32
CC11	Consider feasibility of banning 2-stroke engines (includes community consultation to seek feedback on proposal).	Estuary-wide	RMS	$ 12,000	$ -	$ 12,000	0	1	0	0	-1	0	-1	0	-1	-0.3	-1.3	-0.33	33
CC15	Dredging option 1 – Navigation channel for small non-powered watercraft to North West Arm Road access point at low tide.	Dents Creek	Council	$ 404,860	$ 40,320	$ 688,051	-2	-1	-1	1	2	0	0	-1	-2	-0.7	-2.7	-0.46	34
CC16	Dredging option 2 – Removal of top 300 mm of sediments from delta.	Upper estuary	Council	$ 283,260	$ 20,016	$ 423,844	-3	-1	-1	0	0	1	0	-1	-5	-1.3	-6.3	-1.13	35

Coastal Zone Management Plan

APPENDIX G

ESTUARINE HEALTH MONITORING PROGRAM GUIDANCE

Cardno
Shaping the Future

G1 Estuarine Health Monitoring Program Guidance

This Appendix provides guidance on the implementation of the proposed estuarine health monitoring program for the North West Arm estuary. It also identifies a range of additional parameters that could potentially be incorporated into the monitoring program in the future in the event that additional funding becomes available.

It should be noted that while this section describes the proposed monitoring program developed during the preparation of this CZMP, there may be changes over time to aspects such as indicators sampled, sites, sampling periods and analysis of data. This will allow for improvements to be made once more information becomes available, as well as to adopt changes to State-wide programs such as MER that may be rolled out and need to be complied with.

G1.1 Monitoring Program

G1.1.1 Parameters

The estuary health monitoring program is based around using key indicators that are monitored at the State level under the MER Program. This includes monitoring:

- Chlorophyll a;
- Turbidity;
- Other supporting physico-chemical indicators such as salinity, dissolved oxygen, pH, and temperature;
- Estuarine macrophytes (seagrasses, saltmarsh, mangroves) distribution change; and
- Riparian vegetation distribution and condition.

Table G-1 outlines the trigger values and suggested monitoring frequencies for each indicator. **Table G-2** identifies a range of additional parameters and their associated details that could potentially be incorporated into the monitoring program in the future in the event that additional funding becomes available.

The assessment of chlorophyll *a* and turbidity data should be in accordance with the methodology used under the MER Program (OEH, 2013c). The methodology for assessing change in macrophyte distribution over time will also follow the MER methodology.

Table G-1: Trigger Values and Monitoring Frequency*

Indicator	Trigger Value	Monitoring Frequency
Chlorophyll *a*	3.4 µg/L (upper <10 ppt salinity) 2.9 µg/L (mid 10-25 ppt salinity) 2.3 µg/L (lower >25 ppt salinity)	Monthly Fortnightly sampling over the warmer months to be considered – roughly mid-September to end of March. Fortnightly sampling over the warmer months is recommended as algal productivity is greatest over these months and as per MER methodology, will ensure that the chlorophyll a maxima is more likely to be accurately captured
Turbidity	6.6 NTU (upper <10 ppt salinity) 3.5 NTU (mid 10-25 ppt salinity) 2.8 NTU (lower >25 ppt salinity)	Monthly
Estuarine Macrophytes	N/A	5-10 years to compare with existing data to identify change in extent and condition over time
Riparian Vegetation Distribution	N/A	5-10 years to compare with existing data to identify change in extent and condition over time

* Note: These trigger values were derived from data from reference estuaries sampled as part of the NSW MER.

G1.1.2 Sampling Sites

To gain a representative picture of the overall health of the North West Arm estuary, it is recommended that at least two sites are sampled. One of these sites should be in the lower estuary in the deep water section, and one in the upper estuary towards Dents Creek.

G1.1.3 Sampling Methodology

Sampling for the monitoring program should be conducted in a way that is broadly consistent with the methods outlined in "Assessing estuary ecosystem health: sampling, data analysis and reporting protocols" (OEH 2013c).

G1.1.4 Reporting

Evaluation and interpretation of the data is important for determining whether any priorities of the CZMP need to be amended or specific actions need to be taken. This should be an ongoing process.

Reporting of the data is important for highlighting to key stakeholders and the community in general how the health of the North West Arm is changing over time, and how it compares to other estuaries. Reporting should be in the form of yearly report cards on estuary health/water quality.

G1.2 Additional Guidance

In order to develop a comprehensive data set that can be analysed in a statistically rigorous fashion it is necessary to carefully consider the design of the sampling program.

G1.2.1 Sources of Variation

Variables are characteristics that can differ from location to location, or from day to day. Consideration must be given to potential sources of variation beyond the sources of specific variables that are the subject of the monitoring program. These potential sources of variation must be identified and minimised where possible, so that clear conclusions can be drawn from the monitoring data.

The main sources of variation relevant to the water quality monitoring program may include spatial and temporal variation, weather, tides, natural variation and sampling or analytical error.

It is impossible to remove or minimise all sources of variation through the sampling design process. However, they should be minimised as much as possible. It is necessary to make an attempt to control or separate out these sources of variation in order to isolate variation attributable solely to the variable of interest.

G1.2.2 Sampling for Impact Assessment – Making Comparisons with Baseline Data

The estuarine health monitoring program is effectively an impact assessment of the hypothesis that the management activities outlined in the implementation strategy will have a positive impact on estuarine health, and that therefore the general condition of the estuary will improve from its current condition. Sampling methodologies and statistical design for impact assessment have been refined by a number of researchers beginning with the introduction of the "before-after / control-impact" (or BACI) design (Green, 1979) and further developed by others (including Underwood, 1991, 1992, 1994).

The basic premise of a BACI design is that in order to detect impacts in a statistically rigorous fashion, the sampling design must include the incorporation of at least one "control" (un-impacted) and one "impact" site and that these sites must be sampled both before and after the impact (i.e. the rehabilitation works). This design accounts for both spatial and temporal variation. As discussed in a literature review by Underwood (1994), this analysis will be confounded by the lack of replication for control and impact sites. Ideally, control and impact sites should be spatially and / or temporally replicated, preferably in an orthogonal fashion (Underwood, 1991). An orthogonal design has equal numbers of replicates at all levels or treatments (e.g. the same number of samples for the "Before" treatment as for the "After" treatment). This is known as a "Beyond-BACI" sampling design. Times of sampling are random and therefore this type of design nests sources of variation in the data (Underwood, 1991).

A Beyond-BACI style sampling design is not strictly possible for the North West Arm estuarine health monitoring program due to the lack of what may strictly be termed "control" sites (i.e. unaffected sites).

However, the basic sampling design should still consider the requirements of statistical tests by developing an orthogonal design. It is recommended that observed trends in estuarine health for the North West Arm estuary be compared to those in Gymea Bay, which will provide some indication of whether changes in variables are the result of natural background variation or due to actual improvements against baseline conditions.

G1.2.3 Field Sampling

G1.2.3.1 Sampling Protocols

There are a number of current documents that detail appropriate sampling protocols for different parameters. Where specific sample techniques exist to monitor a particular parameter, the relevant document has been noted in the table, to ensure the sampling and handling methodology is consistent across all sites. The key documents that detail sampling protocols are:

- The MER Sampling Protocols (OEH, 2013c; Scanes *et al.,* 2009), which provides protocols for sampling for key estuarine MER indicators;
- Australian Standards including:
  - AS/NZS 5667.12:1999 Water Quality - Sampling - Guidance on Sampling of Bottom Sediments,
  - AS/NZS 5667.1:1998 Water Quality - Sampling - Guidance on the Design of Sampling Programs, Sampling Techniques and the Preservation and Handling of Samples, and
  - AS/NZS 5667.6:1998 Water Quality - Sampling - Guidance on Sampling of Rivers and Streams;
- Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC, 2000), which provides protocols for sampling of surface waters, sediments and aquatic organisms;
- Guidelines for Managing Risks in Recreational Waters (NHMRC, 2008), which provides protocols for sampling bacteria; and
- National Protocol for Monitoring of Cyanobacteria and their Toxins in Surface Waters (NRMMC, 2007), which provides protocols for sampling cyanobacteria.

For purposes of field QA/QC, it can be useful to take field duplicates and field blanks. Field blanks and field duplicates are collected and analysed in order to quantify any variations resulting from the field sampling process itself. For example, water samples may be contaminated during the sampling process. It is also one way of identifying any sources of error or variation relating to laboratory analytical processes. These blanks and duplicates should be allocated in a random fashion at the outset of the sampling campaign.

G1.2.3.2 Sampling Locations

A number of work health and safety issues need to be considered when selecting sampling sites. Some issues to consider include safe vehicular/pedestrian access to the site, unobstructed and stable ground conditions at the site (particularly along natural creek banks), the sampling requirements (e.g. timing with a rainfall event or particular tidal conditions), travel times between sites, and whether any special sampling equipment will be required (e.g. a boat, or esky).

Some of the variables suggested for monitoring require the use of chemical preservatives during storage. The relevant Material Safety Data Sheets (MSDS) should be made available to sampling staff and care should be taken in handling any preservatives.

A First Aid kit is an important component of any field kit. Where possible, a person trained in First Aid should be included in the sampling team.

G1.2.3.3 Field Data Sheet

The field data sheet is used to record information relevant to the data analysis, such as weather conditions, the date and time a sample is taken. Space should be provided to make notes or observations. For example, it is prudent to keep track of the photographs that have been taken so that they can be accurately identified later on. Field observations and photographs can be a valuable source of information during the data analysis where unusual or unexpected results are observed. A list of staff who undertook the sampling should also be recorded for QC purposes and so that the individual undertaking the data analysis knows to whom to direct any questions.

For the purposes of the water quality monitoring program, the field data sheet should include:

- Date of sampling;
- Name of samplers;
- Weather conditions;
- Space under each site for:
  - Time sample collected,
  - Observations,
  - Photo number,
  - Water level.

Field data should be entered into a database after the sampling run. In addition to the electronic version, the original data sheets should be kept on file.

G1.2.4 Laboratory Techniques and Controls

An internationally accredited and appropriately certified laboratory (e.g. NATA) should be used. The laboratory should have in place QA/QC procedures to maintain the quality system, monitor results and perform internal audits.

To ensure QA/QC of water quality samples sent to a laboratory for analysis, the following activities should be undertaken:

- Ensure chain of custody documentation is provided as this is essential to ensure that errors can be traced,
- Ensure the laboratory receives the samples within the required holding times for each parameter and that samples are stored correctly i.e. on ice if samples require chilling,
- Laboratories generally provide quality control reports and include laboratory control samples and surrogates. Additional samples should also be collected and sent to the laboratory for blanks, laboratory duplicates and matrix spike testing, and
- Review laboratory reports as soon as they are received to check for anomalies in the data, which could be an error on the part of the laboratory. Most samples are retained by the laboratory for an additional short period of time in the event additional sample or checking of anomalous results in required.

G1.2.5 Analysis of Data

Concurrent with the process of confirming the parameters for inclusion in the estuarine health monitoring program, the Committee should also consider what statistical or other analyses may be required. This is a key consideration as the selection of sites and parameters will be driven in the first instance by the need for accuracy and resolution, as well as quality control issues.

The statistical techniques used to analyse and interpret the data should be informed by the guidelines or other criteria against which the data is being compared. However, more general, useful statistical analyses include:

- Mean (+/- standard deviation),
- Median,
- 90th percentile, and
- 10th percentile.

For the seasonal Estuary Health Report Cards for the North West Arm estuary it is recommended the data should be simplified and aggregated using a simple scoring system to indicate ecosystem health on a scale of A to F. However, a more comprehensive internal annual report should also be prepared to enable the Committee to obtain a more advanced appreciation of trends in estuarine health and factors driving them. Over the first few years of the monitoring program, it will be necessary to gain an understanding of rates of variation in environmental variables for the North West Arm estuary to permit development of a 'baseline' condition, and possibly also to develop estuary-specific criteria for ecological health (where appropriate).

G1.2.6 Work Health and Safety

All sampling should be undertaken in accordance with relevant legislation such as the *Work Health and Safety Act 2011*, *Work Health and Safety Regulation 2011*, and relevant work health and safety policies of the organisations undertaking the monitoring.

Work health and safety considerations for sampling include working near water when collecting water quality samples and when surveying aquatic species (using personnel floatation devices), and ensuring safe site access at each sampling location. In particular, protective gloves should also be worn when undertaking water and sediment quality sampling in case contaminated water or sediments are encountered.

Table G-2: Additional Sampling Parameters for Consideration in the Monitoring Program

ID	Category	Parameter^	Units/ Attributes	Relevant Sampling Protocol(s)	Relevant Guideline or Trigger Values		Suggested Sampling Sites	Suggested Sampling Frequency (DWS = Dry weather sampling; WWS = Wet weather sampling)^^	Notes
					Ecosystem Health	Recreational Contact (Primary)			
WQ.1	Water Quality - Physical	Turbidity	NTU	Scanes *et al.* (2009)	0.5 - 10 NTU	N/A	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. the deepwater near the Marina Crescent Reserve stormwater outlet).	Measured in situ with a water quality probe. Suggest taking vertical profiles at each mainstream site.
WQ.2	Water Quality - Physical	Water clarity	Secchi depth (m)	Scanes *et al.* (2009)	N/A	<1.6m	Estuary - min. 2 x locations.	Montly DWS from September to March	Measured in situ using a secchi disc. Indicator for light penetration.
WQ.3	Water Quality - Physical	Total Suspended Solids (TSS)	mg/L		N/A	N/A	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. the deepwater near the Marina Crescent Reserve stormwater outlet).	Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.
WQ.4	Water Quality - Physical	Total Dissolved Solids (TDS)	mg/L		N/A	1,000 mg/L	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. the deepwater near the Marina Crescent Reserve stormwater outlet).	Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.
WQ.5	Water Quality - Physical	Temperature	degrees celcius		N/A	N/A	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Measured in situ with a water quality probe. Suggest taking vertical profiles at each mainstream site.
WQ.6	Water Quality - Physical	pH	-		7.0 - 8.5	6.5 - 8.5	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Measured in situ with a water quality probe. Suggest taking vertical profiles at each mainstream site. Alt: water sample collection for laboratory analysis - refrigerate, max. holding time is 6hrs.
WQ.7	Water Quality - Physical	Dissolved Oxygen (DO)	% saturation mg/L	Scanes *et al.* (2009)	80 - 110% saturation	>80% saturation	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Measured in situ with a water quality probe. Suggest taking vertical profiles at each mainstream site. Alt: Water sample collection for laboratory analysis - fix oxygen in the field, store in the dark, max. holding time is 24hrs.

ID	Category	Parameter^	Units/ Attributes	Relevant Sampling Protocol(s)	Relevant Guideline or Trigger Values		Suggested Sampling Sites	Suggested Sampling Frequency (DWS = Dry weather sampling; WWS = Wet weather sampling)^^	Notes
					Ecosystem Health	Recreational Contact (Primary)			
WQ.8	Water Quality - Physical	Biochemical Oxygen Demand (BOD)	mg/L		N/A	N/A	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS	Water sample collection for laboratory analysis - refrigerate and store in the dark and max. holding time is 24hrs.
WQ.9	Water Quality - Physical	Salinity	ppt µS/cm	Scanes *et al.* (2009)	200 - 300 µS/cm	N/A	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Measured in situ with a water quality probe. Suggest taking vertical profiles at each mainstream site. Alt: Water sample collection for laboratory analysis - max. holding time is 24hrs.
WQ.10	Water Quality - Physical	Reduction-Oxidation Potential	mV		N/A	N/A	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Measured in situ with a water quality probe. Suggest taking vertical profiles at each mainstream site.
WQ.11	Water Quality - Physical	Captured Gross Pollutants	kg type	Weigh captured material during its removal and undertake periodic waste classification surveys / audits to determine types of pollutants captured.	N/A	N/A	N/A	N/A	Pollutants should be recorded as per Council's operation and maintenance protocols.
WQ.27	Water Quality - Physical	Heavy Metals	mg/L		various	various	Estuary - min. 2 x locations.	Quarterly DWS	As per laboratory requirements.
WQ.28	Water Quality - Physical	Total Petroleum Hydrocarbons	µg/L		various	various	Estuary - min. 2 x locations.	Quarterly DWS	As per laboratory requirements.
WQ.29	Water Quality - Physical	Organochlorine and Organophosphate Pesticides	mg/L		various	various	Estuary - min. 2 x locations.	Quarterly DWS	As per laboratory requirements.
WQ.30	Water Quality - Physical	Oil and Grease	mg/L		N/A	N/A	Estuary - min. 2 x locations.	Quarterly DWS	As per laboratory requirements.
WQ.19	Water Quality - Nutrients	Total Nitrogen (TN)	µg/L		300 µg/L	N/A	Estuary - min. 2 x locations.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.

ID	Category	Parameter^	Units/ Attributes	Relevant Sampling Protocol(s)	Relevant Guideline or Trigger Values		Suggested Sampling Sites	Suggested Sampling Frequency (DWS = Dry weather sampling; WWS = Wet weather sampling)^^	Notes
					Ecosystem Health	Recreational Contact (Primary)			
							Tributaries - major.		
WQ.20	Water Quality - Nutrients	Nitrates and Nitrites (NOx)	µg/L		15 µg/L	Nitrate: 10,000 µg/L Nitrite: 1,000 µg/L	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Biologically available form of Nitrogen. Can be useful as a complement to TN data to identify potential sources. Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.
WQ.21	Water Quality - Nutrients	Ammonia (NH4+)	µg/L		15 µg/L	10 µg/L*	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Biologically available form of Nitrogen. Can be useful as a complement to TN data to identify potential sources. Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs. *Ammonia as N
WQ.22	Water Quality - Nutrients	Ammonium (NH3)	µg/L		N/A	N/A	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Can be useful as a complement to TN data to identify potential sources. Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.
WQ.23	Water Quality - Nutrients	Total Kjeldahl Nitrogen (TKN)	µg/L		N/A	N/A	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Biologically available form of Nitrogen. Can be useful as a complement to TN data to identify potential sources. Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.
WQ.24	Water Quality - Nutrients	Total Phosphorous (TP)	µg/L		30 µg/L	N/A	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.
WQ.25	Water Quality - Nutrients	Filterable Reactive Phosphorous (FRP)	µg/L		5 µg/L	N/A	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Biologically available form of Phosphorous. Can be useful as a complement to TP data to identify potential sources. Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.

ID	Category	Parameter^	Units/ Attributes	Relevant Sampling Protocol(s)	Relevant Guideline or Trigger Values		Suggested Sampling Sites	Suggested Sampling Frequency (DWS = Dry weather sampling; WWS = Wet weather sampling)^^	Notes
					Ecosystem Health	Recreational Contact (Primary)			
WQ.26	Water Quality - Nutrients	Orthophosphate	µg/L		N/A	N/A	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek).	Can be useful as a complement to TP data to identify potential sources. Water sample collection for laboratory analysis - refrigerate and max. holding time is 24hrs.
WQ.12	Water Quality - Biological	Macroinvertebrates	Biotic Index (SIGNAL Score)	Chessman (2003)	Chessman (2003)	N/A	Tributaries - major.	Quarterly	Indicator for water quality and ecosystem health.
WQ.13	Water Quality - Biological	Faecal coliforms (FC)	cfu/100mL	ANZECC (2000) NHMRC (2008)	N/A	150 cfu/100mL* (1000 cfu/100mL**)	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek for source tracking purposes).	Water sample collection for laboratory analysis in sterile sample bottles - refrigerate, store in the dark, analyse preferably within 8 hrs. *Primary contact recreation; median value based on min. of 5 samples collected at regular intervals not exceeding one month, with no single sample exceeding 600 cfu/100mL. **Secondary contact recreation; median value based on min. of 5 samples collected at regular intervals not exceeding one month, with no single sample exceeding 4000 cfu/100mL.
WQ.14	Water Quality - Biological	Enterococci	cfu/100mL	ANZECC (2000) NHMRC (2008)	N/A	35 cfu/100mL* (230 cfu/100mL**)	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek for source tracking purposes).	Enterococci have a higher tolerance for saline water than FC. Water sample collection for laboratory analysis in sterile sample bottles - refrigerate, store in the dark, analyse preferably within 8 hrs. *Primary contact recreation; median value based on min. of 5 samples collected at regular intervals not exceeding one month, with no single sample exceeding 60-100 cfu/100mL). **Secondary contact recreation; median value based on min. of 5 samples collected at regular intervals not exceeding one month, with no single sample exceeding 450-700 cfu/100mL.

ID	Category	Parameter^	Units/ Attributes	Relevant Sampling Protocol(s)	Relevant Guideline or Trigger Values		Suggested Sampling Sites	Suggested Sampling Frequency (DWS = Dry weather sampling; WWS = Wet weather sampling)^^	Notes
					Ecosystem Health	Recreational Contact (Primary)			
WQ.15	Water Quality - Biological	Escherischia coli	cfu/100mL	ANZECC (2000) NHMRC (2008)	N/A	N/A	Estuary - min. 2 x locations. Tributaries - major.	Monthly DWS Event - 3 x WWS per year (to incl. Dents Creek for source tracking purposes).	Water sample collection for laboratory analysis in sterile sample bottles - refrigerate, store in the dark, analyse preferably within 8 hrs.
WQ.16	Water Quality - Biological	Chlorophyll a	µg/L	Scanes *et al.* (2009)	4 µg/L	N/A	Estuary - min. 2 x locations. Tributaries - major.	Fortnightly DWS from September to March Monthly DWS for remainder of year	In-situ fluorometry, sampling by boat. If more accurate measurements required collect water sample for laboratory analysis and use analyses of extracts technique - samples must be refrigerated and kept in the dark until filtered and max. holding time is 24hrs (i.e. filter same day as collection).
WQ.17	Water Quality - Biological	Phytoplankton	cells/mL	Collect a composite sample for each site comprising five 50cm depth-integrated column (hosepipe) subsamples collected along a 20–30m transect and mixed into a single container (e.g. bucket). Where wading or boat access is not available, collect surface-grab samples (e.g. dipped-bucket samples) instead from around shoreline.	various	N/A	Estuary - min. 2 x locations.	Montly DWS from September to March Weekly during algal blooms	Composite water sample for laboratory analysis in sample bottle dosed with iodine preservative.
WQ.18	Water Quality - Biological	Cyanobacteria	cells/mL	Open water composite sampling is preferred to avoid buyoant blooms near the shoreline and to account for spatial variability. Sample in the middle of the day.	various	N/A	Estuary - min. 2 x locations.	Montly DWS from September to March Weekly during algal blooms	Composite water sample for laboratory analysis in sample bottle dosed with iodine preservative.
EE.1	Estuarine Ecology	Estuarine Macrophytes (seagrass,	Extent (ha)	As per MER requirements.	N/A	N/A	Entire study area	As per MER requirements (annually if possible, at least every 5 to 10 years).	For comparison against the baseline. Review number of relevant

ID	Category	Parameter^	Units/ Attributes	Relevant Sampling Protocol(s)	Relevant Guideline or Trigger Values		Suggested Sampling Sites	Suggested Sampling Frequency (DWS = Dry weather sampling; WWS = Wet weather sampling)^^	Notes
					Ecosystem Health	Recreational Contact (Primary)			
		saltmarsh and mangroves)							community reports to Council and compare with previous years.
EE.2	Estuarine Ecology	Seagrass Depth Limits	mAHD	Water depth (for a known tidal level) at the margin of the seagrass bed at 1m intervals, location of each point to be taken using differential-GPS.	N/A	N/A	Suggest *Posidonia* seagrass beds at tidal delta	Coincident with estuarine macrophyte mapping.	Indicator for long term water quality (light penetration).
EE.3	Estuarine Ecology	Estuarine Fish Populations	Taxonomic richness Abundance Biomass	As per MER requirements. Nested sampling design using gear types that target species from different habitats and adquately covers spatial variation.	N/A	N/A		As per MER requirements (annually if possible, at least every 5 to 10 years).	Review number of relevant community reports to Council and compare with previous years.
EE.4	Estuarine Ecology	Terrestrial Vegetation	Extent (ha)		N/A	N/A	Entire study area	As per MER requirements (annually if possible, at least every 5 to 10 years).	Review number of relevant community reports to Council and compare with previous years. Reports from Bushcare groups and Greenweb members may be suitable for this prupose.
EE.5	Estuarine Ecology	Terrestrial Weeds	Extent (ha) New infestations		N/A	N/A	Entire study area	As per MER requirements (annually if possible, at least every 5 to 10 years).	Review number of relevant community reports to Council and compare with previous years. Reports from Bushcare groups and Greenweb members may be suitable for this prupose.
EE.6	Estuarine Ecology	Avifauna	Density (no. birds per ha) Guild richness (no. birds per guild)		N/A	N/A	Entire study area	Annually.	Existing data from bird watching clubs within the LGA may be suitable for this purpose.

^ Parameters marked as green indicate higher priority, should additional funding become available
^^DWS: Dry weather sampling; no rainfall in preceeding 48 hrs. WWS: Wet weather sampling; >30mm rainfall in the preceeding 24 hrs.
NB: Key reference documents for sampling and analytical methodologies include: Where other guidelines on sampling protocols are relevant, they have been referenced.

G2 References

ANZECC & ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Green, R.H. (1979) *Sampling design and statistical methods for environmental biologists*. Cambridge University Press: Cambridge, England.

NHMRC (2008) Guidelines for Managing Risks in Recreational Waters. National Health and Medical Research Council, Australian Government, February 2008.

NRMMC (2007) National Protocol for Monitoring of Cyanobacteria and their Toxins in Surface Waters. Natural Resource Management Ministerial Council. Draft (Under Review). Canberra.

OEH (2013c) *Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols.* State of NSW and Office of Environment and Heritage.

Scanes, P., Coade, G. and Dela-Cruz, J. (2009) *Monitoring, Evaluation and Reporting Sampling Protocols*. Department of Environment, Climate Change and Water. November 2009, pp.: 24.

Underwood, A.J. (1994) On Beyond-BACI: Sampling designs that might reliably detect environmental disturbances. *Ecological Applications*, 4 (1), pp. 3-15.

Underwood, A.J. (1992) Beyond BACI: The detection of environmental impacts on populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology*, 161, pp. 145-178.

Underwood, A.J. (1991) Beyond BACI: Experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Research*, 42, pp. 569-587.

[n2018-269]