BMT

Information Synthesis Report

Lake Illawarra

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Shellharbour CITY COUNCIL

Document Control Sheet

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Synopsis: This report collates and reviews the background information regarding Lake Illawarra. The report will contribute to the preparation of the Lake Illawarra Coastal Management Program.

It should be noted that this report was initially written in late 2016 and is largely based on information and studies that were available at that time. While an attempt to include key new information from studies completed after 2016 has been made in the latest version, it is not exhaustive, and has focused on those which are more likely to have management implications.

REVISION/CHECKING HISTORY

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DISTRIBUTION

Destination	Revision										
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WCC and SCC	PDF	PDF	PDF	PDF	PDF	PDF	PDF	PDF			
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Acronyms

Acronym	Meaning
ACLUMP	Australian Collaborative Land use and Management Program
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment and Conservation Council
ARI	Average Reference Interval
BOM	Bureau of Meteorology
CAP	Catchment Action Plan
CERAT	Coastal Eutrophication Risk Assessment Tool
CMP	Coastal Management Program
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CZMP	Coastal Zone Management Plan
CZMS	Coastal Zone Management Study
DA	Development Application
DCP	Development Control Plan
DECCW	Department of Environment, Climate Change and Water
DO	Dissolved Oxygen
DPIE	Department of Planning, Industry and Environment
DPIE - Coasts & Estuaries	DPIE Environment, Energy and Science: Coasts and Estuaries
DPIE – Crown Lands	Department of Planning, Industry and Environment – Crown Lands
DPI Fisheries	DPIE Regions, Industry, Agriculture and Resources – Department of Primary Industries Fisheries
EAC	East Australia Current
EEC	Endangered Environmental Communities
EIS	Environmental Impact Statement
EOI	Expressions of Interest
EPA	Environment Protection Authority
ESD	Ecologically Sustainable Development
FRMP	Floodplain Risk Management Plan
FRMS	Floodplain Risk Management Study
FTN	Filtered Total Nitrogen
FTP	Filtered Total Phosphorus
GA	Geoscience Australia

Acronyms

Acronym	Meaning
GMSL	Global Mean Seal Level
GPT	Gross Pollutant Trap
IBRA	Interim Biogeographic Regionalisation for Australia
ICOLL	Intermittently Closed and Open Lake or Lagoon
IPCC	Intergovernmental Panel on Climate Change
ISRP	Illawarra-Shoalhaven Regional Plan
KMC	Kiama Municipal Council
LALC	Local Aboriginal Lands Council
LEP	Local Environmental Plan
LGA	Local Government Area
LIA	Lake Illawarra Authority
LIEMC	Lake Illawarra Estuary Management Committee
LLS	Local Land Services
MEEKP	Marine Estate Expert Knowledge Panel
MER	Monitoring, Evaluation & Reporting
MHL	Manly Hydraulics lab
MOU	Memorandum of Understanding
MSL	Mean Sea Level
NARCliM	NSW and ACT Regional Climate Modelling
NHMRC	National Health and Medical Research Council
NPWS	Department of Planning, Industry and Environment - National Parks and Wildlife Services
NRC	Natural Resource Commission
OEH	Office of Environment and Heritage
PKC	Port Kembla Copper
PMT	Project Management Team
POM	Plan of Management
SCC	Shellharbour City Council
SCCAP	South Coast Catchment Action Plan
SCLLS	South Coast Local Land Services
SEPP	State Environmental Planning Policy
SILO	Scientific Information for Land Owners
SLR	Sea Level Rise
SQID	Stormwater Quality Improvement Device
SRCAP	Southern Rivers Catchment Action Plan
SRCMA	Southern Rivers Catchment Management Authority

Acronyms

Acronym	Meaning
STP	Sewage Treatment Plant
TfNSW	Transport for NSW
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
WCC	Wollongong City Council
WSUD	Water Sensitive Urban Design
WWTP	Waste Water Treatment Plant

Acronym	Legislation
BC Act	Biodiversity Conservation Act 2016
BS Act	Biosecurity Act 2015
CL Act	Crown Lands Act 1989
CLM Act	Contaminated Land Management Act 1997
EP&A Act	Environmental Planning and Assessment Act 1979
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
FM Act	Fisheries Management Act 1994
LG Act	Local Government Act 1993
LLS Act	Local Land Services Act 2013
MEM Act	Marine Estate Management Act 2014
NPW Act	National Parks and Wildlife Act 1974
POEO Act	NSW Protection of the Environment Operations Act 1997
SLEP	Shellharbour Local Environmental Plan 2013
TSC Act	Threatened Species Conservation Act 1995
WDLEP	Wollongong Local Environmental Plan (West Dapto) 2010
WLEP	Wollongong Local Environmental Plan 2009
WM Act	Water Management Act 2000
WMA Act	Water Management Amendment Act 2014

Glossary of Terms

Term	Definition
Anthropogenic	Changes in the environment originating from human activity.
Bathymetric	The measurement of depth of water in oceans, seas, or lakes.
Biodiversity	The variety of wildlife (both plants and animals) and habitats.
Brackish water	Water with higher salinity than fresh water and lower than seawater.
Breakwater(s)	A man-made structure built offshore to protect coastal areas such as harbours, anchorage etc. from offshore waves.
Catchment area	The area which drains naturally to a particular point on a river, thus contributing to its natural discharge.
Climate change	The long-term change (decades or longer) in patterns of weather, and related changes in oceans, land surfaces and ice sheets.
Coastal inundation	The temporary and permanent flooding of a portion of land within the coastal zone.
Coastal vulnerability area	Defined as land subject to coastal hazards.
Contaminant	Substances or groups of substances that are toxic, likely to bioaccumulate and/or give cause for concern.
Dredging	An underwater excavation activity intended to remove sediments and debris. Often used to keep navigable pathways within waterways.
Dynamic	A process or system characterised by constant change, activity, or progress.
Ebb tide delta	The bulge of sand formed at the seaward mouth of tidal inlets as a result of interaction between tidal currents and waves.
Ecosystem	A community of living organisms and the surrounding nonliving environment interacting as a system.
Endangered Ecological Communities	An assemblage of species occupying a particular area, listed as endangered under relevant State and Federal legislation.
Entrance management	Includes artificial opening of entrances, managing the configuration, height or location of the beach to enable entrance opening at a level lower than the natural range.
Entrance training	Deployment of man-made structures designed to constrain river discharges to a desired location.
Erosion	The removal of land by natural forces such as waves, tidal currents and / or littoral currents.
Estuarine macrophytes	Vegetation that can grow emergent, submerged or floating within the water of estuarine environments e.g. saltmarsh, mangroves and seagrass.
Estuarine vegetation	Vegetation found in the sub-tidal zone, inter-tidal zone, and riparian vegetation which include seagrasses, mangroves, saltmarsh, and Swamp-oak forest.
Estuary	The section of a river affected by tidal activity where fresh water from the river mixes with saltwater from the ocean.

Term	Definition
Eutrophication	Excessive richness of nutrients in a lake or other body of water, frequently due to run-off from the land, which causes a dense growth of plant life.
Fetch	The distance travelled by wind or waves across open water.
Flood tide delta	Deposit of marine sediment (usually sand) within a coastal embayment that has formed at the landward side of a tidal inlet by rising (or flood) tidal currents.
Foreshore	The section of the shore between the low and high tidal limits.
Geomorphology	A branch of physical geography encompassing the formation of the earth's surface, distribution of land, water etc.
Gross pollutant trap (GPT)	A filter that catches stormwater pollution before it has a chance to enter the waterways. GPTs catch most of the litter and silt but don't stop chemicals going into the environment.
Groundwater	Water that is located beneath the earth's surface accumulated from rain and rivers that penetrates the ground through soils and rocks where it is then stored.
Hydrodynamic	Relates to the specific scientific principles that deal with the motion of fluids and the forces acting on solid bodies immersed in fluids, and in motion relative to them.
Inundation (estuarine)	Rising waters caused by a combination of catchment flood waters (from rainfall) and oceanic waters (from tides and high sea levels that occur during storms).
Littoral current	A current flowing parallel to and near the shore, usually generated by breaking waves at the shoreline. Also known as longshore currents.
Littoral transport	Transportation of non-cohesive sediments (usually sand) along the shore by littoral or longshore currents. Also termed longshore sediment transport.
Loam	A fertile soil of clay and sand containing humus.
Marine debris	Solid man-made material which is disposed of directly or indirectly into the marine environment.
Marine pest	Introduced (or non-native) plant or animal that has a detrimental impact on the marine environment.
Morphological change	Changes in the form, structure or composition of the Lake due to the introduction of the entrance channel.
Midden	Aboriginal place of significance where debris from eating shellfish and other food has accumulated over time. Often found on headlands, beaches and dunes, around estuaries, swamps and along the banks of rivers, creeks and lakes.
Natural processes	The processes over which people have no control, such as wind and waves.
Nutrient cycling	The movement and exchange of organic and inorganic matter back into the production of matter.
Ocean waves	Waves occurring in the ocean that have been generated from wind blowing over the ocean surface over long distances (known as the fetch). Swell or incident waves on the coast typically have a wave period of 8 to 10 seconds, with large storm waves having periods of 12 seconds or greater.

Term	Definition
Podsol	An infertile acidic soil having an ash-like subsurface layer (from which minerals have been leached) and a lower dark stratum, occurring typically under temperate coniferous woodland.
Rehabilitate	The process of returning the environment in a given area to some degree of its natural state, after some process has resulted in its damage.
Resilience	The ability of a system (in this case natural systems and states, and human systems along the coast) to 'bounce back' after a hazard or threatening event, returning to some quasi stable state and maintaining functions, processes and services.
Riparian vegetation	Vegetation located along the banks of a body of water, usually rivers.
Scour	Localised loss of soil often present around a foundation element.
Semi-diurnal	A water body that experiences two high and two low tides of approximately equal size every lunar day.
Shoal	A sandbank or sand bar in the bed of a body of water, especially one that is exposed above the surface of the water at low tide.
Shoreline hardening	The installation of engineered-shore structures to stabilise sediment and prevent erosion and/or provide flood protection.
Sea level rise	A long-term increase in mean sea level, usually associated with climate change and increase in temperature in particular.
Sedimentation	The settling of particles (e.g. sand or mud) out of the water column onto the bed of a waterbody.
Sediment cores	A method of sampling soil deposits in the bottom of a water body using a long narrow metal tube.
Stakeholders	Persons or organisations with an interest or concern in a given matter.
Surface water	Natural water sources found on the earth's surface such as rivers, wetlands, oceans and lakes.
Sustainable management	Develops and implements proposals that meet the needs of present communities without compromising the ability of future generations to meet their own needs.
Sustainability	A state in which the demands placed on the environment can be met without reducing its capacity to allow all people to live well, now and in the future.
Terrestrial pest	Introduced (or non-native) plant or animal that has a detrimental impact on the terrestrial environment.
Tidal currents	Currents caused by the incoming (flood) or outgoing (ebb) tide (see Tide). Tidal currents are typically the main current within estuaries, particularly in the entrance area where tidal currents transport marine sediments (sand).
Tidal Prism	The total amount of water that flows into a harbour, estuary or lake or out again with movement of the tide, excluding any freshwater flow.
Tide	The periodic rise and fall of the water of oceans, seas, bays, etc., caused mainly by the gravitational interactions between the Earth, Moon and Sun.
Topographic	The arrangement of the natural and artificial physical features of an area.
Tributary	A stream or river that flows into a larger stream or lake.

Term	Definition
Trophic level	Each of several hierarchical levels in an ecosystem, consisting of organisms sharing the same function in the food chain and the same nutritional relationship to the primary sources of energy.
Wave dominated barrier estuary	A wave-dominated estuary represents a coastal bedrock embayment that has been partially infilled by sediment from both the catchment and marine sources, in which waves are the dominant force shaping geomorphology.
Wetland	Areas of land that are partly saturated by water, including marshes, swamps etc.
Wind waves	All waves are generated by wind, however the term “wind waves” is associated with small, short period (3-5 second) waves that are generated locally within a small fetch. Wind waves can be generated on smaller water bodies such as lakes, lagoons, or tidal inlets.

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Acknowledgement to Country

This report focusses on the present-day condition and threats relevant to Lake Illawarra and its surrounds and is written with respect and acknowledgement of the tens of thousands of years of interconnectedness of this landscape with Aboriginal people.

1 Introduction

1.1 Lake Illawarra Study Area

Lake Illawarra (the Lake) is a large wave dominated barrier estuary system located 80 km south of Sydney and 10 km south of Wollongong. The Lake catchment covers an approximate area of 240 km^2, with a lake surface area of around 35 km^2 and an average depth of 2.1 m (OEH, 2012). The Lake and its catchment span both the Wollongong and Shellharbour Local Government Areas (LGAs) (refer to Figure 1-1). The main features of the Lake, such as points, bays and tributary creeks, are illustrated in Figure 1-2.

The Lake is a highly modified barrier estuary system with a shallow flat bottomed bed. In its previously natural condition, the entrance was typically narrow, shoaled and intermittently closed, opening in response to elevated water levels following rainfall events. Between 2000 and 2007, in conjunction with channel dredging, the entrance breakwaters were constructed to keep the Lake continuously open to the ocean. The entrance breakwaters have resulted in major geomorphic, hydrodynamic and ecological changes to the Lake.

Lake Illawarra is a significant natural asset for the Illawarra region and is highly valued by the community. Predominantly the Lake is co-managed by Wollongong City Council (WCC) and Shellharbour City Council (SCC), as well as by State agencies such as the Department of Planning, Industry and Environment - Environment, Energy and Science: Coasts and Estuaries branch (herein referred to as DPIE - Coasts & Estuaries), and Department of Planning, Industry and Environment - Crown Lands (herein referred to as “DPIE– Crown Lands”). Most notably, DPIE- Crown Lands now manages the Lake Illawarra entrance management works.

1.2 Why Prepare a CMP

A Coastal Management Program (CMP) is a strategic document that outlines priority actions to be implemented over a 5-10 year period, to protect valued aspects and tackle the key threats identified for the Lake. By prioritising management actions, a CMP promotes a targeted and coordinated approach to the use of the limited budget and funding resources available to councils. A certified CMP greatly boosts Council’s eligibility for funding to implement the actions, particularly State Government programs such as the Coastal and Estuary Grants Program, and other mechanisms.

This Synthesis Report is a precursor to the development of the Lake Illawarra CMP. It details the current status of understanding of the ecology, physical characteristics, water quality, human impacts and management regime of Lake Illawarra, based on a review of all available and relevant information relating to the Lake.

Title:

Locality Map
Lake Illawarra

Figure: 1-1

Rev: C

N

0 2000 4000km

Approx. Scale

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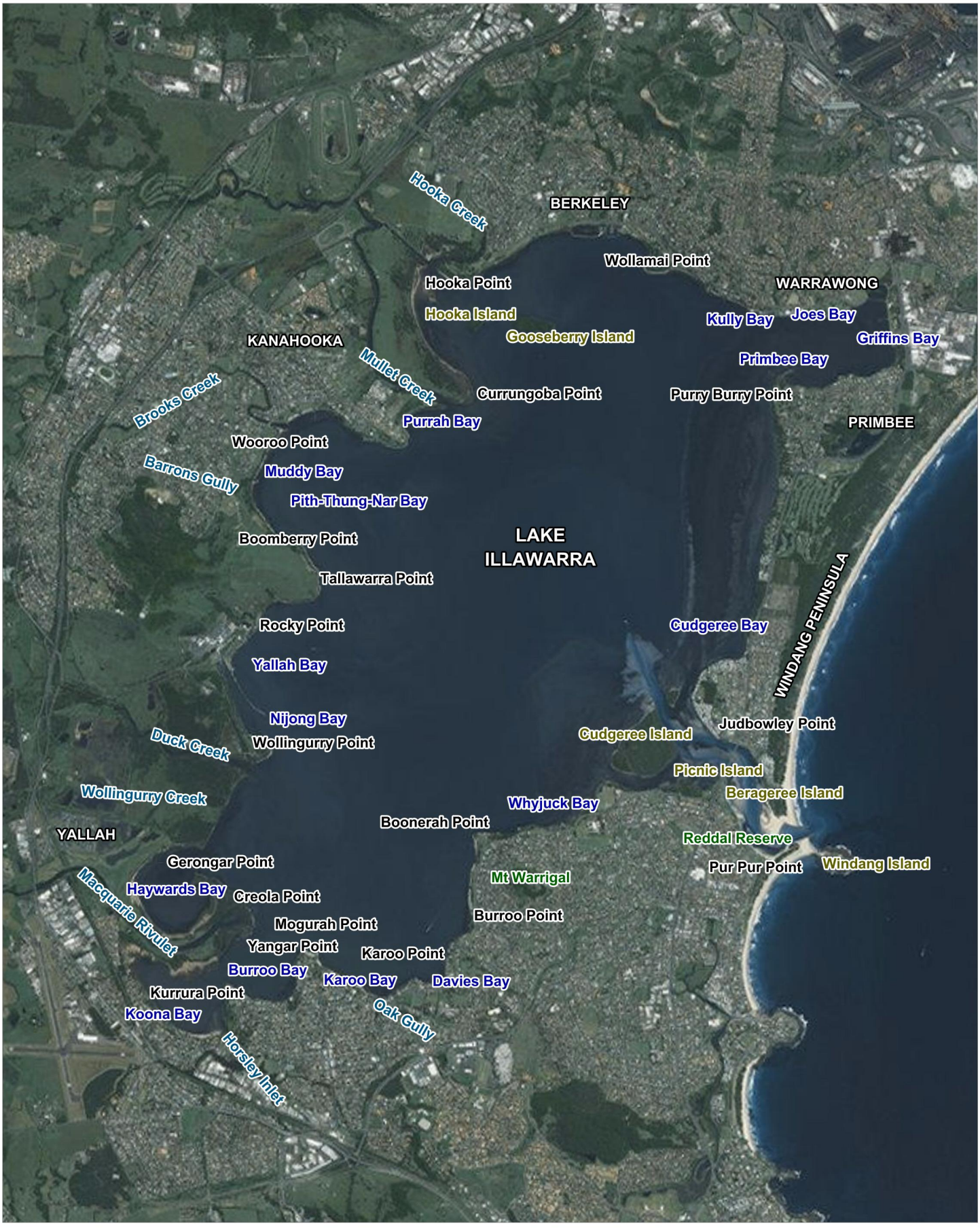
Filepath: K:\N20606_Lake Illawarra CZMP\GIS\GIS_2019\Synthesis Report\DRG001_LocalityMap_Fig1.1.wor



Title:

Features of Interest Around Lake Illawarra

Figure: **1-2**

Rev: **B**

N

0 1.25 2.5km

Approx. Scale

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1.3 Management Context

As the catchment of Lake Illawarra extends across both WCC and SCC areas, both have a role to play in ensuring the environmental health and recreational values are maintained and improved. Therefore, both councils have agreed to collaborate on preparing a CMP and managing the Lake, which will ensure the judicious management of the Lake and its surrounds into the future. Financial and technical support for the development of the CMP is also being contributed by DPIE - Coasts & Estuaries, through the NSW Estuary Management Program. Agencies deemed either 'responsible' or 'supporting' (e.g. Sydney Water, Department of Planning, Industry and Environment - National Parks and Wildlife Services (NPWS), Property NSW) against management actions within the CMP have had significant involvement in the document's production. These agencies are required to 'sign off' on the CMP; indicating a commitment to deliver and/or contribute to the delivery of management actions via their usual agency planning and budgetary processes (refer to Section 1.3.3).

The Lake and its immediate surrounding environment were managed by the Lake Illawarra Authority (LIA) from 1988 to 2014. In July 2014, the LIA was disbanded and its responsibilities transferred to WCC and SCC and a number of State Agencies (refer to Section 1.3.3 for more detail on Lake ownership and responsibilities).

During the 1980's, a combination of high catchment sediment and nutrient loads, climate variations (i.e. drought periods) and natural processes (such as the Lakes frequently closed entrance condition) resulted in poor water quality, algal blooms, seagrass dieback and significant community concern regarding the Lake's management and condition. In response to the declining health and environmental condition of the Lake, the LIA was formed by the NSW Government in 1988. Over the next 20 years, the LIA managed Lake Illawarra and undertook numerous foreshore rehabilitation projects as well as algal harvesting, bank stabilisation and the construction of several gross pollutant traps and artificial wetlands around the Lake.

Increased sediment and nutrient loads into the Lake continued to impact the Lake's condition, and in an attempt to manage this and increase tidal flushing, the Lake was substantially modified by the staged construction of a permanent trained opening, which was completed under the LIA between 2000 and 2007. The entrance breakwaters and training of the entrance channel have resulted in a significant increase in the Lake's tidal prism and associated current velocities. The increased tidal prism has caused a rapid ingress of marine sands and progradation of the marine delta fan into the Lake basin.

There has been a progression of works including bridge construction, open water reclamation, shoreline hardening, and dredging undertaken in and around Lake Illawarra over the past 100 years, by both public and private land managers. Today the catchment is about 60% cleared land, including urban, industrial and rural land uses.

The Lake is highly valued from an ecological, cultural, social and economic perspective. A number of protected species and ecological communities utilise and are contained within the Lake. Fringing endangered ecological communities include coastal saltmarsh, swamp oak forest and littoral rainforest. The gently sloping foreshores provide habitat for extensive seagrass and saltmarsh. Black necked storks and pied oystercatchers are amongst the bird species that utilise the Lake. Areas of mangrove and saltmarsh are reported to have been increasing, however, there are also signs that

some of the newly established saltmarsh areas could be outcompeted by mangroves (Baxter and Daly, 2010; Williams and Wiecek, 2017), as documented for many NSW estuaries.

The Lake is frequently utilised for recreational activities such as fishing, sailboarding, boating, swimming and picnics. Boat ramps, jetties, wharves and picnic facilities support these uses in the Lake, as well as the associated commercial industries of tourism and fishing. There is a significant general commercial fishing effort in Lake Illawarra with the overall catch dominated by sea mullet, blue swimmer crab, dusky flathead and school prawns.

The Lake contains areas of cultural significance, from both the long history of Aboriginal use of the estuary, and non-indigenous development and use of the Lake over the last 100 years.

The pressures on the natural resources of Lake Illawarra are significant, and include both natural coastal hazards as well as those brought about by human use of the foreshore and catchment. Population growth and growing residential development needs, tourism and recreational activities as well as the potential impacts of climate change all place pressure on the Lake.

The CMP will build on the work that has already been undertaken by the former Lake Illawarra Authority and others. It will also need to provide a sustainable planning and management approach to address the many competing pressures on the Lake's natural resources.

1.3.1 Legislation Relating to Management of Lake Illawarra

The legislation and policies governing the management of Lake Illawarra and its catchment is complex. It underpins the Lake's management, protection, uses, regulation, and restrictions with consideration to environmental, social, and fiscal impacts. Legislation pertaining to the management of Lake Illawarra aims to ensure present actions, procedures, and changes to the Lake's management are in line with values that will aid its longevity into the future.

A comprehensive overview of legislation relating to the management of Lake Illawarra is contained in Appendix A.

1.3.2 Community Involvement

Community and stakeholder involvement are crucial to the success of the CMP. Members of the community contribute extensively to understanding the key values and issues that impact on the Lake.

Inevitably, plans of this nature require trade-offs and it is unlikely that everyone will be happy with all aspects of the CMP. This increases the need for a transparent process with appropriate opportunities for community and stakeholder consultation, in the hope of a genuine two-way flow of information and preparation of a CMP everyone can support.

A Communications Strategy to be undertaken during the development of the plan has been prepared by the project team, which includes consultants from BMT, the Project Management Team (PMT, with representatives of both Councils and DPIE - Coasts & Estuaries) and Lake Illawarra Estuary Management Committee (LIEMC). Community involvement will continue to be crucial for implementation of the CMP. As contained within the Communications Strategy, a series of consultation activities have been conducted through the course of CMP development, including:

- Information sessions, to elicit community views regarding key values and issues affecting the Lake;
- Letters to foreshore residents;
- Letters to State Government Agencies;
- Letters to identified community groups and other stakeholders;
- Media Releases;
- Information Sessions – open to everyone;
- Pop up information kiosks to be undertaken at various locations;
- Community presentations of proposed options;
- Meetings with Aboriginal groups; and
- Surveys (online and hard copies).

This document reports on the available published scientific and governance information. The subsequent document, the Community Uses, Values, Threats and Opportunities of Lake Illawarra (BMT, 2020a), reports back on the insights, values, issues and aspirations gleaned through the consultation process.

1.3.3 Current Ownership of Land

Much of the Lake's foreshore is in private ownership. The remainder is owned and managed by Department of Planning, Industry and Environment (DPIE) - Crown Lands, Government Property NSW, SCC and WCC.

The status of land ownership around the Lake remains complex due to the transition from the LIA to the Councils. Prior to July 2014, the LIA jointly managed the Lake Illawarra foreshore public lands with WCC and SCC. Following the disbandment of the LIA, land and assets were to be transferred back to the State Government and local Councils. Transfer of lands has been finished and there are no more negotiations. Land ownership is summarised below.

WCC - all Council owned land and assets within the Wollongong LGA, including:

- Predominantly open space along Northcliffe Dr between Yacht Club and Hooka Point;
- Fred Finch Park;
- Lakeside Avenue;
- Kanahooka;
- Purry Burry Avenue;
- Primbee and Judbooley Parade (east from the block of flats);
- The foreshore and boardwalk adjacent to Windang Beach Tourist Park; and
- Stormwater outlets within the Wollongong LGA.

SCC - all Council owned land and assets within the Shellharbour LGA, including:

- Reddall Reserve and open space either side of Windang Bridge;
- Windang Island and islands in the Lake Entrance;
- Hooker Park;
- Boonerah Park and Boonerah Point Reserve;
- Foreshore lands around Karoo Bay and Koona Bay;
- Stormwater outlets within the Shellharbour LGA; and
- Public foreshore structures around the Lake in the Shellharbour LGA.

Government Property responsibility includes:

- King St Developable lands including Kully Bay wetland;
- Northcliffe Dr open space from Naval Cadets in the west to King St in the east; and
- Jetties and wharves adjacent to these lands.

DPIE – Crown Lands responsibility includes:

- Management of the Lake Illawarra Entrance Management Works;
- Berkeley Harbour and Kiosk, Yallah Bay open space, old squash court, jetties, paths, etc.;
- Shared path and boardwalk from Gilba Road to Yallah Bay;
- Judbooley Parade flats and foreshore strip to the west; and
- All jetties, wharves and boat ramps (except in Kully Bay).

1.4 Documents Reviewed in the Synthesis Report

A range of data, reports, plans and policies relating to Lake Illawarra have been documented over the past 10 years or so. Some reports are directly relevant to determining the estuary processes or past and present management approaches for Lake Illawarra, while others may have some indirect relevance.

To streamline the review of reports for this Synthesis Report, a list of all available documents, brief description of their content, and relevance as primary (direct), secondary (indirect), or not relevant sources of information was compiled, in Appendix B. In general, all primary resources have been reviewed and used to compile this Synthesis Report, with secondary resources included where possible. The information in this report has been arranged in terms of its description of the discrete estuary processes. References to reports are cited as relevant to the information and listed in the References section at the end of the report.

2 Summary of Estuary Processes

2.1 Physical Characteristics

2.1.1 Estuary Type and Characteristics

Lake Illawarra is a large, shallow coastal lake, characterised as a wave dominated barrier estuary system. It is situated between the wide, long coastal barrier system of Windang Peninsular in the east, which extends from Windang to Port Kembla (Perkins Beach); and the steep western backdrop of the Illawarra Escarpment. The physical characteristics of the Lake are summarised in Table 2-1. It should be noted that these characteristics are highly dynamic due to the constantly changing hydrodynamic environment the Lake is exposed to, particularly with respect to the breakwaters and training wall.

The main waterbody of the Lake is elongated in a general southwest - northeast direction. It has a surface area of around 35 km^2 and an average and maximum water depth of 2.1 and 3.2 m respectively (OEH, 2012; Sloss, 2005), however, recent hydrographic surveys have identified some areas of much greater depth within the entrance channel (MHL, 2016). The Lake is fringed by low lying land, particularly along its eastern margin adjacent to Windang Peninsular, and where Macquarie Rivulet and Mullet Creek flow into the estuary along its western margin.

The Lake is now permanently open to the sea due to the entrance breakwaters, with the entrance channel positioned between Windang Island and Windang Beach. The average Lake water level is around 0.2 m above sea level (OEH, 2012), with tides occurring around this.

2.1.2 Catchment Topography and Description

The Lake Illawarra catchment covers an area of 240 km^2 (OEH, 2012). There are a number of major watercourses, small creeks and drainage lines that drain into the Lake. Five major watercourses that flow into the Lake are:

- Macquarie Rivulet;
- Mullet Creek;
- Brooks Creek;
- Duck Creek; and
- Horsley Creek.

Macquarie Rivulet and Mullet Creek are the two main watercourses, with their headwaters sourced from the Illawarra Escarpment. The catchment headwaters rise to a maximum elevation of 760 m at Mouth Murray (Lawson and Treloar, 2001). The combined sub-catchments of Macquarie Rivulet and Mullet Creek comprise approximately 70% of the total Lake Illawarra catchment area (Lawson and Treloar, 2001).

Table 2-1 Lake Illawarra Fast Facts

Physical Characteristics (OEH, 2012 unless stated otherwise)	
Entrance location	34.54 °S, 150.88 °N
Catchment area	238.4 km^2
Estuary area	35.8 km^2
Estuary volume	74275.1 ML
Average depth (m)	2.1 m
Maximum depth (m)	7.9 m (hydrosurvey (MHL, 2016))
Estuary Classification (per Roy *et al*., 2001)	Group: Wave dominated estuary Type: Barrier estuary Evolutionary stage: Intermediate
Entrance Conditions	Open and Trained
Freshwater Inputs	Macquarie Rivulet (SW) Mullet Creek (NW) Other smaller streams / creeks
Tidal Characteristics (OEH, 2012)	
Average water level (Lake/Entrance Channel)	0.16 / 0.14 m AHD
Ebb tide range[1]	0.88 m
Flood tide range[1]	0.84 m
Ebb flow[2]	4.80 x 10^6 m^3
Flood flow[2]	5.46 x 10^6 m^3
Historic (Pre-Training) Entrance Conditions (WBM, 2003)	
Closed	10% of time
Very heavily shoaled	20% of time
Heavily shoaled	50% of time
Moderately shoaled	15% of time
Scoured / Fully Open	5% of time

[1] Tide range data recorded from permanent Lake Illawarra Site 2, approximately 1km from the ocean on 11/08/2016 (MHL, 2016)

[2] Ebb and Flood Tide statistics based on data collected by MHL in March 2016 from Lake Illawarra Site 1, approximately 130m upstream from the ocean (MHL, 2016). Note the hydrodynamics and associated tidal characteristics of the Lake and entrance channel are constantly changing as a result of the artificial entrance training works completed in 2007 (see Section 2.5). As such, the stated tidal prism will continue to increase in future until the entrance channel establishes a new state of equilibrium.

2.2 Climate

The Illawarra region is dominated by a temperate climate with a maritime influence, characterised by warm summers and drier winters. Weather statistics presented below have been sourced from the Bureau of Meteorology (BoM) weather station at Illawarra Regional Airport at Albion Park, located on the southwest corner of the Lake, with additional modelled weather data provided by the Scientific Information for Land Owners climate database (SILO). Weather and climate influence hydrodynamic, geomorphologic and ecological processes and therefore play an important part in driving estuary processes of the Lake.

Rainfall is typically highest during the February and March when about 25% of the total annual rainfall falls (see Table 2-2). Topographical variations in annual average rainfall also occur throughout the catchment, with significantly higher rainfall occurring across the Escarpment within the headwaters of the Lake catchment (WBM Oceanics, 2003).

Temperature varies on monthly bases, with average variations at Illawarra Regional Airport shown in Table 2-3. Here, mean maximum temperature ranges between approximately 27 and 18 degrees, with January recording the highest temperatures and July the lowest, on average.

Wind typically blows from the northeast and south during the summer months with northeast winds dominating afternoon conditions (see Figure 2-2). In winter, westerly winds dominate, with south and south-westerly winds also common (see Figure 2-2). Average wind speeds through summer and winter are similar, ranging between around 10 - 20 km/hr (see Figure 2-2). Velocities can reach up to 45 - 55 km/hr throughout the year, with greater velocities experienced during east coast low weather events (WBM, 2003).

Evaporation values interpolated from available observation data by SILO for the Lake Illawarra region are presented in Table 2-5, and plotted in relative to rainfall records in Figure 2-1. The figure indicates that an excess of evaporation over rainfall typically occurs over the summer and autumn periods, particularly between the months of September to January.

Table 2-2 Mean rainfall (mm) at Illawarra Regional Airport

Location	J	F	M	A	M	J	J	A	S	O	N	D
Mean rainfall	77.0	**135.6**	111.1	79.3	59.8	97.4	53.5	57.0	*44.5*	69.6	84.2	69.5
Highest rainfall	178.4	334.0	**422.2**	261.2	398.6	340.4	185.6	281.8	*112.0*	218.8	222.0	171.8

Table 2-3 Mean monthly temperatures (°C) at Illawarra Regional Airport

Location	J	F	M	A	M	J	J	A	S	O	N	D
Mean Max Temp	**26.7**	26.2	25.2	23.1	20.6	18.1	*17.5*	18.8	21.4	23.1	23.9	25.3
Mean Min Temp	16.8	**17.1**	15.4	12.2	8.8	7.1	*6.2*	6.4	8.5	10.7	13.4	15.1

Table 2-4 Mean monthly wind speeds (km/hr) at Illawarra Regional Airport

Location	J	F	M	A	M	J	J	A	S	O	N	D
Mean 9am Winds	11.6	9.8	*8.1*	10.7	12.4	13.6	14.4	**15.0**	15.3	14.4	12.9	12.7
Mean 3pm Winds	21.6	20.0	18.9	17.7	*17.1*	17.6	18.1	21.8	**22.6**	20.9	20.9	21.5

Table 2-5 Mean monthly evaporation (mm) interpolated for Lake Illawarra, averaged from 30 years of daily modelled data

Location	J	F	M	A	M	J	J	A	S	O	N	D
Evapo-ration	193	151	135	97	71	57	64	93	121	156	166	193
Wet evapo-transpir-ation	169	136	123	85	57	40	48	73	103	136	146	168

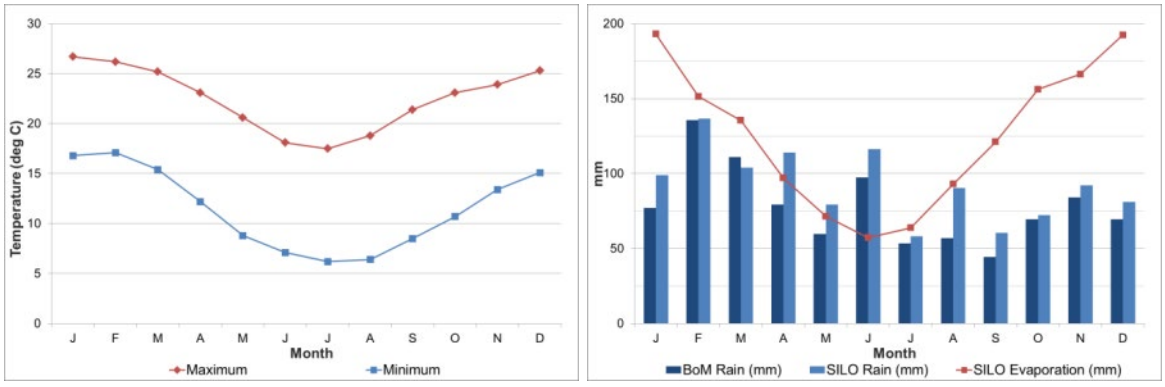

Figure 2-1 Mean temperature at Illawarra Regional Airport (recorded over 17 years; left) and; Mean rainfall and evaporation for Lake Illawarra (right), noting the BoM rainfall is measured (Illawarra Regional Airport) and the SILO data is modelled (-34.5° Lat and 150.8° Long)

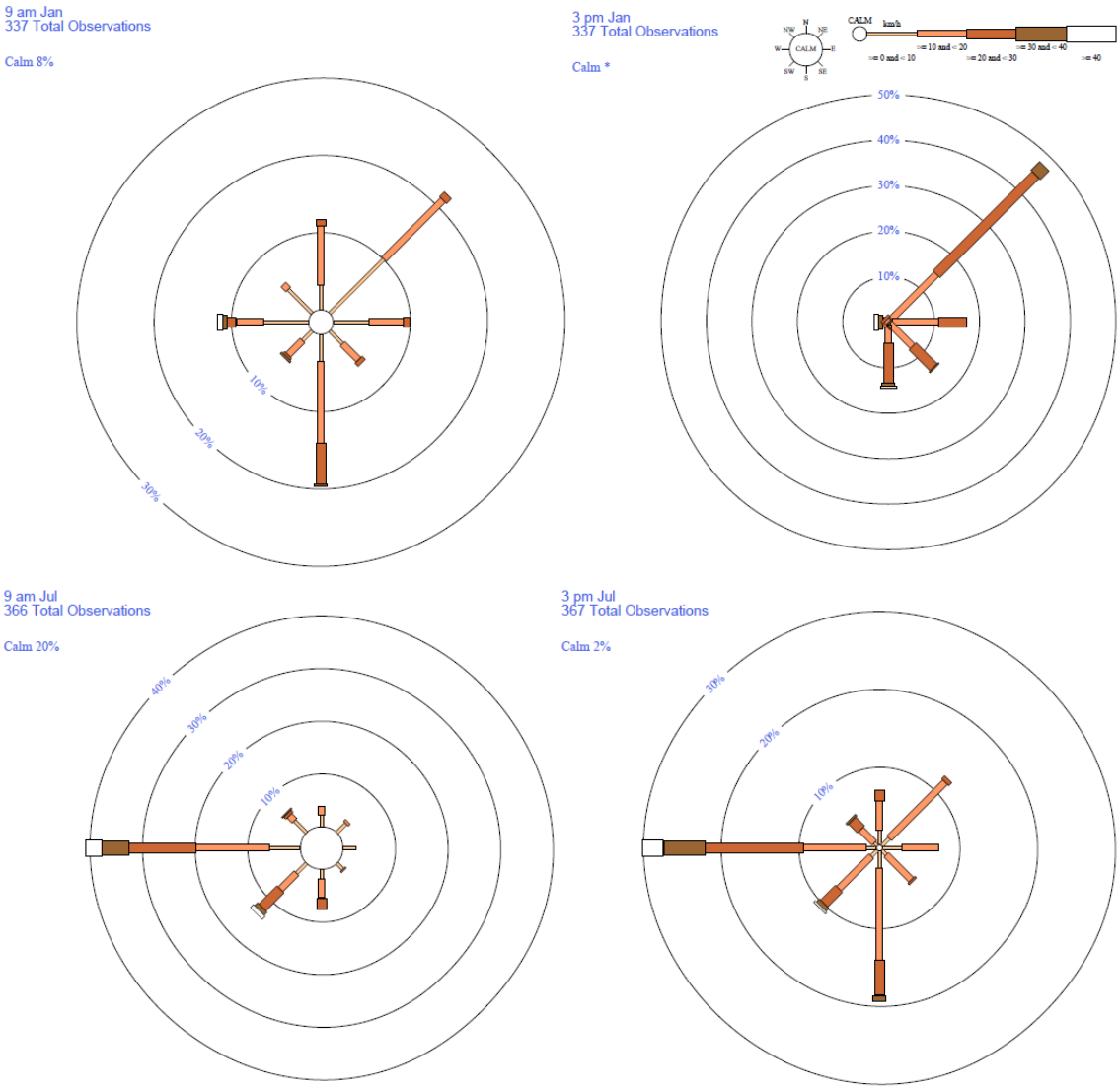

Figure 2-2 Wind Rose for Illawarra Regional Airport, showing average 9am (left) and 3pm (right) conditions for January (top) and July (bottom) (source: BoM)

2.3 Geology and Geomorphology

2.3.1 Geology and Soils

Lake Illawarra is situated in the southern sector of the Sydney Basin; a north to south trending sedimentary basin that is Permian to Triassic in age. The southern Sydney basin is formed of relatively soft bedrock substrates, including sandstones and siltstones that are both marine and fluvial in origin (GA, 2016). Lake Illawarra catchment is situated within Upper Shoalhaven Group of rocks that are upper Permian in age (Jones, 2002). These can be seen outcropping at Windang Island.

Typical soils of the Illawarra region are described as structured red and brown loams and clay loams with some areas of mellow texture and contrast soils. On beach and dune areas, the soils comprise

siliceous sands, with podsol profiles in older dunes. Peaty sands and organic silts occur in swamps and around the estuaries (NSW NPWS, 2003).

Soil Landscape mapping across the catchment (including Soil Landscapes of the Wollongong-Port Hacking 1:100000 Sheet and Kiama 1:100000 Sheet; Hazelton, 1990 and Hazelton, 1992) indicates that soils conditions are widely variable, with soil erodibility ranging from high to very low and soil fertility ranging from moderately high to low (Anderson, 2011).

2.3.2 Physical Features (landforms) and Sediments

Sedimentary landforms occurring within and around Lake Illawarra are diverse, and vary depending on the depositional environment in which they lie. Key landforms of the Lake and surrounding environment include:

- The tidal inlet, with tidal channels, flats and a marine tidal delta;
- Sand islands;
- Windang Peninsular back barrier intertidal and subtidal flats;
- Central mud basin;
- Macquarie Rivulet fluvial delta; and
- Mullet Creek fluvial delta.

A brief description of the geomorphic form, sedimentary environment, and associated estuarine habitat conditions of these key physical features is provided below.

The Lake's **tidal inlet** connects the estuary with the ocean. It is located in the south-east corner of the Lake and extends from Windang Island to west of Bevans Island. The estuary entrance is narrow, artificially trained and remains permanently open to the ocean. The inlet includes tidal channels, tidal flats and a marine tidal delta (flood tide and ebb tide delta). These features are primarily sandy and marine in origin, becoming muddier towards the Lake (Geological Survey of NSW, 2015). The landform provides important estuarine habitat, for example, large tracts of seagrass meadow inhabit the tidal and subtidal flats occurring across the western channel and flood tide delta areas.

A number of **sand islands** occur within the marine tidal delta zone, including Bevans, Cudgeree, Picnic, Werrang and Berageree Islands. These low lying islands formed of marine sand and mud provide ideal habitat conditions for estuarine vegetation, and are inhabited by a range of high value wetland communities.

Windang Peninsular back barrier tidal and sub-tidal flats and barrier dune system impound the Lake along its eastern margin. The tidal and subtidal flats, barrier dune system and adjoining beach are dominantly marine sand. Extensive seagrass meadows occupy the wide tidal and subtidal flats that fringe the Windang Peninsular foreshore.

A **central mud basin** forms the main portion of the Lake. Sediments within the Lake's central basin are muddy and estuarine in origin. The dominance of mud reflects the low energy setting of this environment. The central basin is generally shallow and has an elongate form that is orientated in a general southwest – northeast direction. While the mud basin is typically unvegetated, it does provide

habitat to estuary invertebrates. Comprised of muddy organic sediments, the Lake's basin is classified as having a high risk of potential acid sulphate soils material (OEH, 2014).

In the fluvial inlets and surrounding lowland floodplain areas, the sediments comprise a mix of fluvial sand, gravel, silt and clay in addition to organic mud and peat. As such, the fluvial inlet areas contain sediments classified as having a high risk of potential acid sulphate soils material (OEH, 2014).

Macquarie Rivulet and Mullet Creek comprise the two major fluvial inputs into the Lake. The **Macquarie Rivulet fluvial delta**, located in the southwest corner of the Lake, has an elongate 'bird's foot' form. This feature is formed primarily of fluvial sands and muds. The delta is bordered by two shallow, low energy embayments (Koona and Haywards Bay). The delta and adjoining embayments provides important estuarine habitat, with large extents of coastal saltmarsh inhabiting the low lying foreshore and seagrass meadows occurring throughout the surrounding shallow waters.

The **Mullet Creek fluvial delta** located on the western shores of the Lake has a lobate form, and is also formed primarily of fluvial sands and muds. Saltmarsh fringe the low lying foreshore and seagrasses occur across the shallow subtidal slopes. Hooka Creek inlet occurs immediately north of Mullet Creek delta, at the head of Kong Burry Bay. Seagrass meadows also occur across the wide shallow sandy-mud flats within Kong Burry Bay.

Further information regarding the Macquarie Rivulet fluvial delta and the Mullet Creek fluvial delta can be found in the following references: Maher (2011), Hopley (2011) and Skorulis (2014).

Landward of the fluvial deltas, the watercourse in-channel sediments and adjoining terraces comprise various fluvial sediments, including sands, silts, clays and gravels (Geological Survey of NSW, 2015).

2.3.3 Geomorphic Evolution of Lake Illawarra

In geological terms, Lake Illawarra formed over the past 7,000 years or more in response to the rapid rise in sea levels, then deposition of the Windang Peninsular barrier spit and associated impoundment of the back-barrier Lake.

Human practices in the Lake and its catchment over the last 200 years have impacted on the natural form and processes of this estuary system (see Section 2.3.4). More recently, works to permanently train the entrance have impacted on the tide regime and physical environment in and around the entrance (see Section 2.3.5).

Sloss (2005) identified five distinct stages in the evolution of Lake Illawarra barrier estuary system, beginning during the Last Glacial Maximum which occurred some 30,000 to 20,000 years ago when sea level was approximately 120 m below present. The five stages are described below and summarised in Figure 2-3, which are based in part on early geological studies by Roy and Peat (1975) and Thom *et al.* (1986) and conceptual coastal evolutionary models by Roy *et al.* (1984, 1994, 2001). Central to this model is the relationship of the land with the sea level.

- Stage 1: When sea levels were much lower than present, a network of fluvial channels developed across a shallow valley where the present day Lake is located. The main channel cut across the present day Windang Peninsular dune barrier at Korrungulla Swamp.

- Stage 2: Following the rapid rise in global sea levels some 8,000 – 6,500 years ago, marine sands were reworked landwards from the ocean and deposited across the present day Lake Illawarra basin. The Windang Peninsular coastal barrier spit had not yet begun to form, and open coastal conditions persisted within the present day Lake.
- Stage 3: The Windang Peninsular dune barrier began to form about 5,000 years ago, attached at its southern end, resulting in the low energy (back barrier) environment forming within the present day Lake.
- Stage 4: From 5,000 – 3,000 years ago, the Windang Peninsular dune barrier stabilised and built seawards (from marine sand reworked from the nearshore and surf zone), the northern inlet closed, and oceanic influences became further restricted within the Lake. Corresponding with these changes, the modern Lake inlet and flood tide delta formed some 3,000 years ago; and
- Stage 5: In response to changes in the catchment land use over the past 200+ years since European settlement, fluvial sedimentation increased within the Lake basin, contributing to the extension of the fluvial deltas on the Lakes western margin (see Section 2.3.4 for further details). The form and processes within and around the tidal inlet have experienced significant modification in response to entrance training works completed in 2007, see Section 2.3.5.

The conceptual coastal evolutionary models have since been revised as research conducted after 2005 shows that commentary around fluvial progradation is incorrect. Hopley, (2013) showed that progradation commenced earlier than suggested and the transgressive sand sheet is not as extensive as previously suggested.

2.3.4 Human Changes to the Natural Sedimentation Processes

Sediment transport into the Lake is a natural process that has occurred over thousands of years. The action of waves and tides move marine sands into the Lake via the entrance channel (and formed the Windang Peninsular through overwash and dune deposition processes in the past), and catchment runoff transports alluvial sediments into the Lake via its tributaries. Since the early 1800's when European occupation began within the catchment, human actions have disturbed the natural sedimentary system and resulted in increased rates of sediment transport into the Lake.

The Lake and its catchment are now a highly modified system. Land use within the catchment has been intensely modified through widespread clearing for agricultural, industrial and urban development. This has resulted in an increased rate of catchment sourced sediment supply to the estuarine basin. For example, modern estuarine sedimentation within the Lake's central mud basin has been measured up to 7 mm/year (Sloss et al., 2011) in comparison to <1 and 4 mm/year for pre-European settlement conditions (Chenhall et al., 2001; Jones and Chenhall, 2001). High post-European sedimentation rates have also been measured from the Mullet Creek, Hooka Creek and Macquarie Creek fluvial deltas, with rates ranging between 5 and >16 mm/year (Sloss et al., 2011). No negative geomorphic impacts have been found on the fluvial systems of Mullet Creek and Macquarie Rivulet due to the construction of the two weirs (Skorulis, 2014).

Major morphological changes have occurred to the Macquarie Rivulet fluvial delta as a result of the human driven increase in sediment supply, as shown in Figure 2-4. The Macquarie Rivulet now drains into the Lake via an elongate 'bird's foot' fluvial delta that is approximately 1.3 km long. The

delta is a recent landform, as the elevated rates of sedimentation post 1850's resulted in significant delta growth (Sloss et al., 2004). Hopley et al. (2007) and Hopley (2013) have since quantified the impacts of catchment modifications to both the Mullet and Macquarie rivulet deltas. Sedimentation rates have also been established based on higher resolution geochronological analysis, and it has been found that sedimentation rates fluctuate with time and variable land use Hopley et al. (2007) and Hopley (2013).

Mullet Creek has experienced impacts on sediment migration as an impact of a weir construction on the watercourse. A tank trap constructed on Mullet Creek in the 1940s has also had a significant impact on the evolution of the delta and sedimentation patterns. There is very little sediment being transported down Mullet Creek, with most sediment bypassing the creek at the tank trap. The current morphology of the creek mouth is relatively unchanged based on analysis completed by Hopley (2013).

The recent entrance training works have also had a major impact on the Lake's tides, and entrance channel morphology and sediment transport, as detailed in Section 2.3.5. Ongoing sedimentation related to present day catchment development is also discussed as a catchment influence in Section 2.8.10.

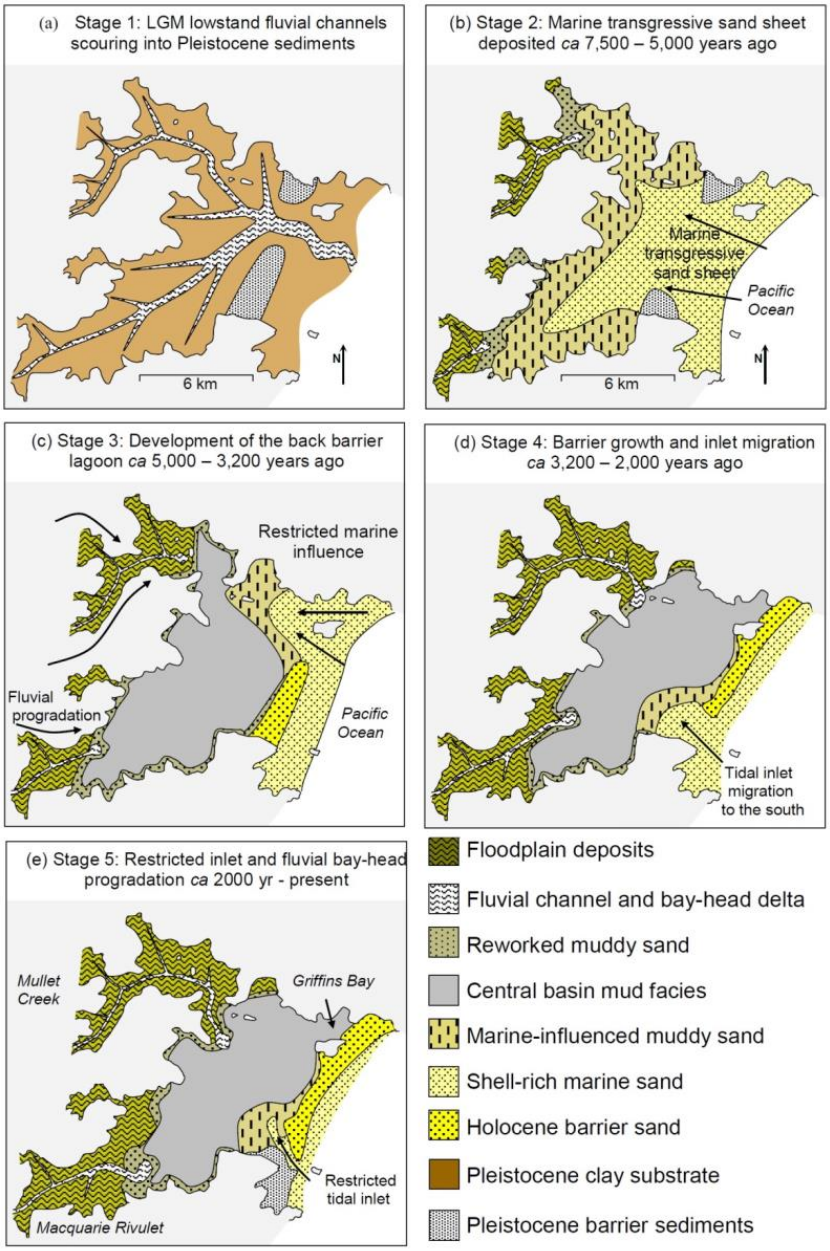

Figure 2-3 Main Stages of Geomorphology Evolution of Lake Illawarra, from Sloss, 2005

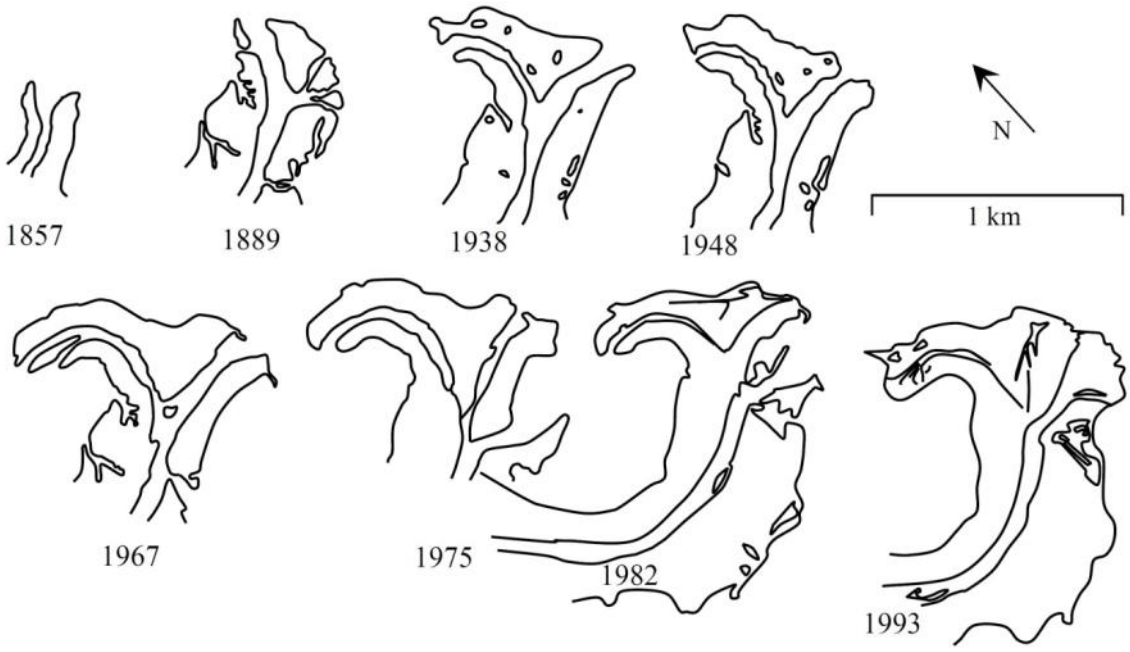

Figure 2-4 Macquarie Rivulet delta, demonstrating dramatic growth in response to increased sedimentation rates associated with post-European land use (Sloss et al, 2004)*

*More recent data for the Macquarie Rivulet (Hopley et al., 2007) and Mullet Creek delta (Hopley, 2013) has been published and utilises georeferenced methodologies.

2.3.5 Foreshore / Bank Condition

The most recent assessment of bank condition was undertaken by LIA and DPIE - Coasts & Estuaries in 2013. This report describes the perimeter of the Lake as being covered with approximately 44 hectares of rocky shoreline, particularly along the western and northern shorelines and the Lake's entrance (LIA, 2013a). Areas around the Lake considered having potential issues with foreshore/bank erosion and posing risks to the Lake at this time include: the foreshore areas of Pelican View Reserve near Picnic Island, Mt Warrigal, Lake Heights and Illawarra Yacht Club, Windang Foreshore Park, Cudgeree Bay, and the creek banks along Macquarie Rivulet (LIA, 2013a).

The study identified a number of areas where riparian vegetation rehabilitation or erosion control and bank protection measures would be favourable to limit further erosion including: the drains entering the Lake at Lake Heights foreshore/Mt Warrigal foreshore/Burroo Bay & Karoo Bay/Berkeley Boat Harbour/Windang Peninsula, Pelican View Reserve, Windang Foreshore Park, Macquarie Rivulet, and Mullet Creek (LIA, 2013a).

Since the completion of the audit described above, the Lake itself has continued to respond to the changing tidal regime and erosion continues to increase, particularly within the entrance channel on the Windang Peninsula. There was also a large east coast low event in June 2016 which resulted in significant erosion in a number of locations including, Windang, Boonerah Point, Deakin Reserve, Skiway Park and Reddall Reserve. In this case, the foreshore condition and bank erosion mapping given in the LI CMP may not have captured all recent erosion events. Other studies have also been

completed regarding bank and floodplain conditions of the main tributaries by Maher (2011), Hopley (2011) and Skorulis (2014).

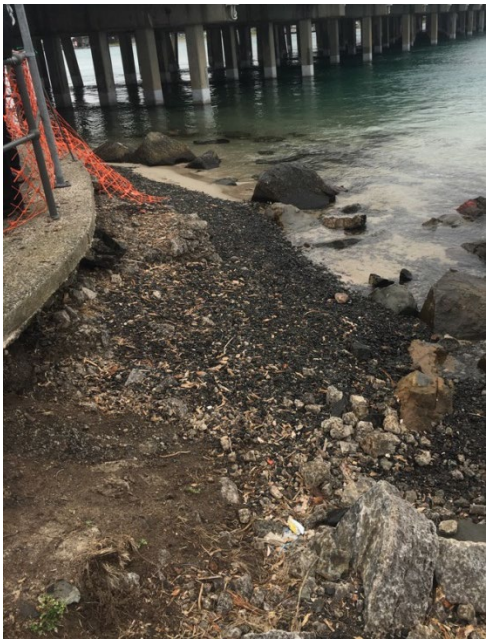

Figure 2-5 Examples of Erosion near Reddall Reserve

Much of the Lake is lined by hard structures including sections of Griffins Bay, Cudgeree Bay, the northern foreshore of Koonawarra Bay, and along the foreshore of the caravan parks on the eastern side of the Lake. The use of hard vertical structures to rectify bank erosion impacts upon the Lake's ecology, as it provides no habitat benefits, which in turn affects the fish and other species dependent upon fringing habitats. Such structures may also impound estuarine habitats by creating a barrier that limits the landward extent (e.g. saltmarsh, which is then unable to migrate and may be drowned or out-competed by mangroves). There is very little specific information regarding the ecology of the rocky areas of the Lake available, as identified in early studies (Morrison & West, 2006; LIA, 2013a).

The condition of the Lake's foreshores depends on a variety of factors such as foreshore slope, presence, density & type of vegetation, soil type, fetch of prevailing winds, wave size, and land use practices such as grazing or mowing. Foreshore areas with extensive land clearing, particularly of the riparian vegetation, are much more susceptible to erosion as the exposed banks are susceptible to erosive forces such as waves and flowing water. In attempts to rectify this, hard structures along the foreshores have been constructed, especially adjacent to private properties on the Lake's foreshore.

In addition to bank erosion around the Lake, erosion of the Lake's tributaries has been noted in response to the clearing of riparian vegetation, grazing practices and urbanisation. The greater proportion of impervious surfaces and consequential runoff has also resulted in increased peak flows in the tributaries. Increased peak flows can cause bank erosion and substantial geomorphic changes (WBM Oceanics, 2006).

2.3.6 Key Implications for Development of the Coastal Management Program

The description of geomorphologic changes to the Lake resulting from human practises over the last 200 years or so indicates:

- Changes in catchment land use to agricultural, industrial and residential uses has resulted in significant clearing of natural forested lands, and a change in land management practises (e.g. use of fertilisers, pesticides, contaminated or industrial practises on land).
- Changes in catchment land use have in turn resulted in an increase in sediment loads from the catchment flowing into the Lake. The extension of fluvial deltas into the Lake's central basin, such as the Macquarie Rivulet delta, is direct evidence of this increase in sediments.
- Increased sediments can generally cause an increase in other pollutants from the catchment, most notably nutrients from fertilisers, toxins from pesticides and industrial processes, and contaminants that are attached to the sediments flowing into the estuary. Such issues will be further explored through the water quality review in 2.6.
- There is a high risk of potential acid sulphate soils material within natural depositional environments of the Lake such as the central mud basin and fluvial deltas, which contain organic muds.
- Although areas of erosion were identified in the *Coastal Zone Management Study* (LIA, 2013a), there is a lack of recent detailed information on the location, extent and cause of bank erosion (e.g. wind waves, tidal currents etc) around the Lake's foreshores. Such information is important for developing appropriate responses to manage bank erosion. In the short term, education of public and private foreshore property owners on environmentally friendly approaches is needed, to avoid inappropriate structures that impound or reduce estuarine habitat.

The following management considerations are suggested to address the above issues:

- Management of catchment development to minimise the flow of sediments and other pollutants into the Lake; and
- Management of exposure of potential acid sulphate soils during catchment development and other activities.

2.4 Entrance Management Works

Prior to entrance training, Lake Illawarra was an ICOLL (Intermittently Closed and Open Lake or Lagoon) with the entrance heavily shoaled and/or closed around 80% of the time (WBM, 2003; see Table 2-1). The Lake's entrance pre- and post- entrance management works is illustrated in Figure 2-6.

Under naturally closed or shoaled conditions, runoff from the urbanised catchment into the Lake generated community concern about water quality. In addition, Lake water levels greatly fluctuated in response to prevailing climate conditions: during periods of flood (that didn't open or scour the Lake's entrance), infrastructure became threatened due to high Lake water levels; during periods of drought, low water levels caused a number concerns such as exposure and die off of seagrass, and a significant odour associated with the decomposing seagrass on the Lake's periphery. The shoaled

to closed entrance condition also reduced recreational amenity for some Lake users (Baxter and Daly, 2010; MHL, 2013).

In response to increasing social and political pressure, the LIA initiated works to permanently open the Lake entrance in 2000. The objectives of these works were to overcome natural closed conditions and improve tidal flushing of the Lake. By 2007, construction of the twin breakwaters and extensive channel dredging was completed, keeping the Lake continuously open to the ocean. Since the LIA was disbanded, DPIE – Crown Lands now manages the Lake Illawarra entrance management works consisting of twin breakwaters and a southern training wall.

These works have resulted in major geomorphic, hydrodynamic and ecological changes to the Lake. A brief description of the staged entrance training works is provided below and a summary of changes to the estuary biophysical condition provided in Section 2.4.2.

2000: natural entrance, with varying opening position south or north of Windang Island

2009: trained entrance, with twin breakwaters and southern training wall fixing the entrance opening position.

Figure 2-6 Lake Illawarra Entrance Pre- and Post- Entrance Management Works (Source: OEH)

2.4.1 Description of Entrance Training Works

The entrance training works were undertaken in two stages, as detailed below (Baxter and Daly, 2010; MHL, 2013, Young *et al*., 2014).

Stage 1 Entrance Training Works: completed in 2000

The **southern training wall** and associated works were constructed in 2000, fixing the position of the entrance to flow to the north of Windang Island. The works included:

- Construction of a *700m long training wall* along the southern boundary of the entrance;
- *Channel dredging* of approximately 100,000m^3;
- Construction of a short low level causeway between the training wall and Reddall Reserve foreshore; and
- *Formation of a tombolo with the dredged material,* between the southern training wall and Windang Island, to limit littoral drift of beach sediments from Warilla Beach into the entrance.

Stage 2 Entrance Training Works: completed in 2007

The **twin breakwaters** and associated works were completed by 2007, permanently opening the Lake entrance to the ocean. The works included:

- Construction of the *southern breakwater*;
- Construction of the *northern breakwater (~800m long);*
- *Channel dredging* of 215,000 m^3; and
- *Nourishment of Warilla Beach* using sand dredged from the entrance channel.

2.4.2 Impacts of the Entrance Management Works

The entrance training works have resulted in changes to the tidal hydraulics and hydrodynamics, sediment transport processes, morphology, water quality and estuarine ecology of Lake Illawarra. The changes are a response to the modified coastal processes in addition to the direct physical works undertaken.

2.4.2.1 Hydrodynamic Changes

Key changes to the Lake hydrodynamics are listed below:

- Lake water levels now continually fluctuate diurnally due to ocean tidal water levels that penetrate the Lake through a permanently open entrance (i.e. there are now two high and two low tides a day, at differing water levels). This is demonstrated in Figure 2-9 that shows Lake water levels now closely mimicking Sydney ocean tide records. Prior to entrance training, the Lake levels fluctuated in response to the prevailing entrance condition (shoaled or scoured), which in turn were driven by flood and drought cycles (MHL, 2013).
- The hydraulic efficiency of the entrance tidal inlet has increased significantly in association with the increased tidal prism within the Lake (MHL, 2013). Therefore, hydraulic tidal flows have increased.
- Manly Hydraulics Laboratory (MHL) (2013) found that since entrance training, the rate of tidal exchange is increasing at approximately 8mm/year, resulting in increased tidal scour (MHL, 2013) (see notes on morphology below).
- Increased hydraulic flow is being concentrated within the secondary tidal channel, near to Bevans Island (MHL, 2013) as can be seen in Figure 2-7 that shows the channel bathymetry (data sourced from DPIE - Coasts & Estuaries) and in Figure 2-8 that illustrates bathymetric changes between 2016 and 2018 (based on OEH data and adapted from Figure 4 in Wiecek et al., 2016).
- The permanently open entrance condition has reduced the risk of catchment flooding compared with the pre-training entrance condition that was frequently shoaled or closed (Baxter and Daly, 2010). This is because flood waters can now directly exit the Lake to the ocean, rather than be sustained within the Lake by a shoaled or closed entrance. While catchment flooding has been reduced the risk of oceanic flooding has increased.

LEGEND

Elevation (m AHD)

- 2 (higher elevations mapped as same colour)
- 1
- 0
- -1
- -2
- -4
- -8 (lower elevations mapped as same colour)

Title:

Lake Illawarra Entrance Channel Bathymetry 2016

N

0 375 750m

Approx. Scale

Figure: **2-7**

Rev: **A**

BMT

www.bmt.org

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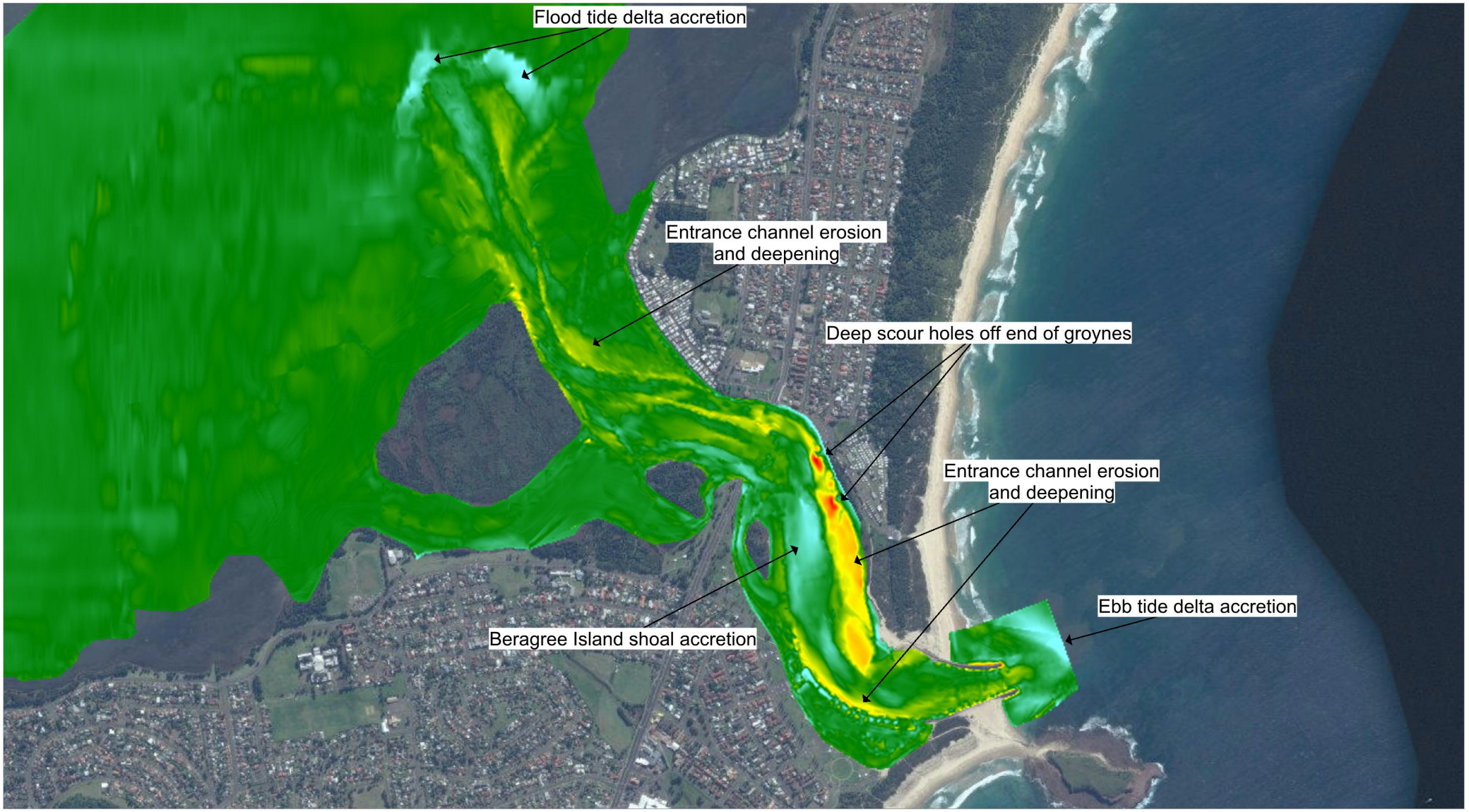

LEGEND

Bed Level change: 2016 - 2008 (metres)

- 0.25 (higher levels of accretion mapped as same colour)
- 0.00 (no change in bed levels between 2008 and 2016)
- -2.5
- -5.0
- -7.5 (greater levels of erosion mapped as same colour)

Title:

Lake Illawarra Entrance Channel Bathymetry Changes between 2016 and 2008

Figure: **2-8**

Rev: **A**

N

0 375 750m

Approx. Scale

BMT

www.bmt.org

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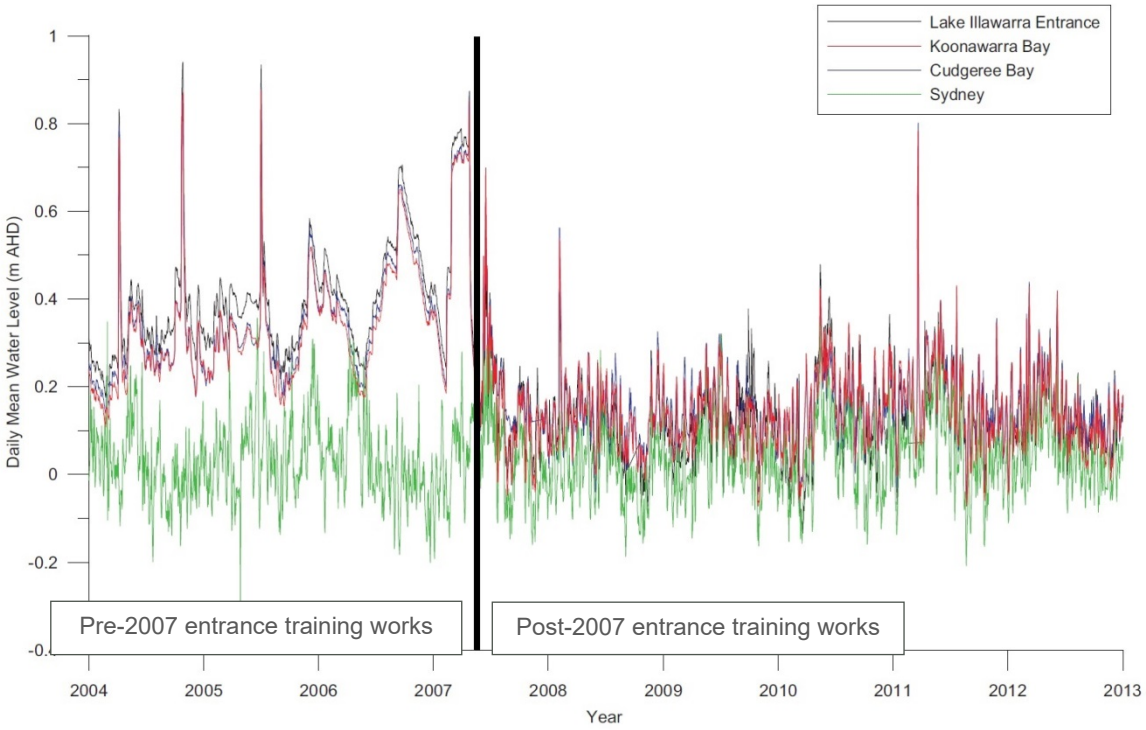

Figure 2-9 Daily water levels within the Lake, pre-and post-entrance training, relative to Sydney Ocean Tide levels (Source: MHL, 2013)

2.4.2.2 *Changes to Morphology and Sediment Transport Processes*

Key changes to the Lake morphology and sediment transport processes are listed below:

- Natural longshore sediment transport from Warilla Beach into the entrance inlet and then onto Windang-Perkins Beach has been interrupted by the entrance works. The artificial tombolo connecting Warilla Beach and Windang Island, plus the breakwaters themselves, has interrupted sand movement from Warilla Beach into the entrance and beyond. There has been considerable growth in the width and height of the dunes on the northern portion of Warilla Beach, through the capture of littoral drift sediment that would previously have continued northwards (MHL, 2013).
- The increase in hydraulic flows within the tidal channel since the training works have increased sediment transport within the channel to approximately 50,000 m^3/year (MHL, 2013) (based on works done at that time), and changed patterns of scour and deposition, as follows.
    - The entrance mouth and tidal channel are experiencing increased scour, and there has been significant reworking of sand shoals within the eastern region of the entrance channel. Empirical (Escoffier) analysis and tidal harmonic analysis conducted by MHL (2013) indicated the entrance condition is now characterised by ‘unstable scouring’. Prior to training, the entrance area was a sediment sink that become regularly shoaled.
    - West of Windang Bridge, local erosion has also occurred within the channels and on the western side of Bevans and Cudgeree Islands (MHL, 2013).
    - The marine flood tidal delta at the western end of the channel has grown significantly, extending westwards into the Lake’s central mud basin (Baxter and Daly, 2010; MHL, 2013).

This will have been supplied by a net annual westward movement of marine sand into the Lake of approximately 1000 m^3/year (MHL, 2013).

- Secondary tidal channels have developed near to the southwest of the main tidal channel, westward of Bevans Island.
- Foreshore erosion and scouring is impacting on assets along the Windang foreshore including the boardwalk (see Figure 2-10 and Figure 2-11), sections of footpath, lighting and other park infrastructure. Three groynes and a section of rock revetment have not prevented continued erosion that threatens assets both immediately upstream and downstream of these works (Wiecek *et al., 2016*).
- In the last few years, sedimentation is occurring in the popular swimming area on the western side of Berageree Island, which has caused community concern.
- More recent observations have shown how scouring is continuing to increase rapidly in front of the groynes along the Windang foreshore, along the southern breakwater, and underneath the northern portion of Windang bridge where management works are now required to ensure the bridge pylons aren't undermined. Foreshore erosion is also occurring along Berageree, Bevans and Picnic Islands, as well as significant movement of shoals either side of Windang bridge and along the Windang foreshore west of the bridge, due to ongoing channel adjustments. These changes in entrance morphology are continuing to have impacts on both built and natural assets.

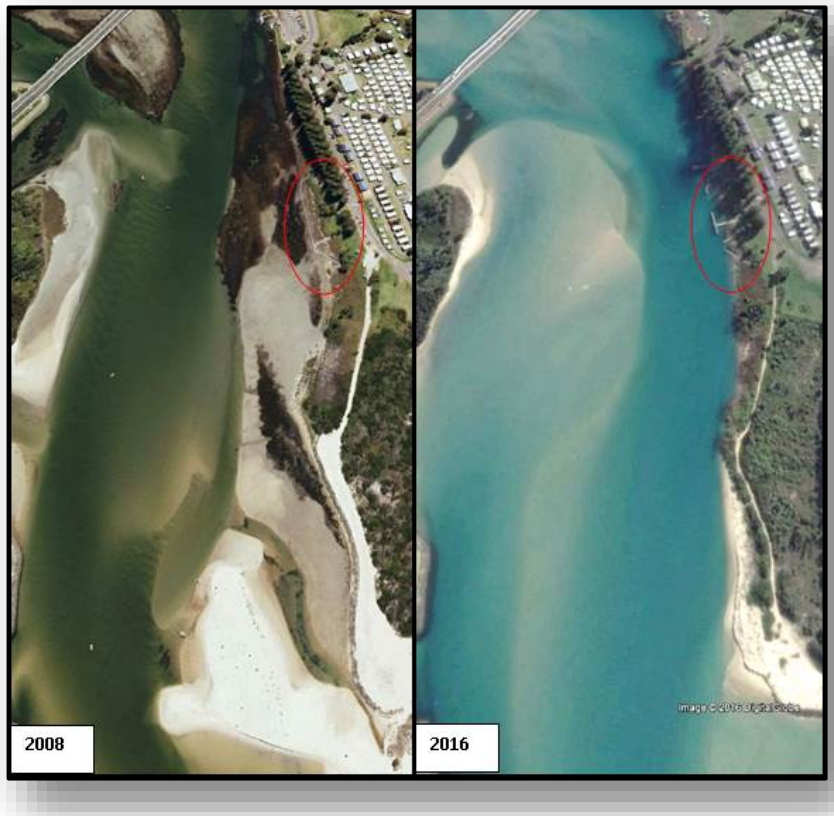

Figure 2-10 Shoreline erosion downstream of Windang Bridge (Source Wiecek et al., 2016)

Figure 2-11 Damage to sections of the boardwalk downstream of Windang Bridge, showing sections of a boardwalk that have been removed due to piles being undermined from tidal scour (2012 -2015) (Source Wiecek et al., 2016)

2.4.2.3 Changes to Water Quality and Ecology

Key changes to the Lake water quality and ecology are listed below:

- The increased tidal flushing and permanent exchange of waters with the ocean as a result of the training works have stabilised salinity and acidity levels. The increased tidal flushing has also led to reductions in the concentrations of nutrients, including total phosphorus and total nitrogen, due to quicker removal from the Lake's central basin area (Baxter and Daly, 2010). Areas of lower flushing capacity such as enclosed bays further from the entrance, continue to retain pollutants of this nature (for example Griffins Bay). Further details of present day water quality in the Lake is covered in Section 2.6.
- Lake water levels are now directly driven by the ocean tides due to the training works. This has resulted in impacts on estuarine vegetation, which are continuing to adjust to an increasing tidal range. Mangroves have begun to flourish in some areas (see Wiecek et al., 2016). An example of the increase in mangroves is shown in Figure 2-12.
- The post-training shift in water quality from one periodically dominated by freshwater flows to marine dominated has resulted in changes to the ecology of the Lake (Baxter and Daly, 2010), in some cases this may be considered an adverse impact (C. Hopley, 2019, per comms, 16 May).
- The permanently open entrance condition has increased mangrove cover and has seen a shift in species that utilise the Lake with a reduction in prawn numbers and an increase in blue swimmer crabs, and an occasional visitation by seals (Baxter and Daly, 2010). However, the permanently open conditions also increase the risk of aquatic pests being introduced to the Lake (Baxter and Daly, 2010).

- Turbidity levels in the Lake are considered as an indicator of estuary health. Turbidity in the Lake has shown no improvement since the permanent opening, and in some locations, particularly Griffins Bay and the Entrance, levels have been worse than the pre-entrance training years. Higher lake turbidity has implications for seagrasses, as the depth they can grow to may be decreasing as less light is available over time. A drop in mean water level should have meant that over time seagrasses might be able to expand into adjacent deeper water that was previously below the depth limit at which they could grow. However, colonisation of deeper parts of the Lake, including in front of tributaries, does not appear to have occurred and may be the result of increased turbidity (Wiecek et al, 2016).

Figure 2-12 Mangrove saplings establishing in Lake Illawarra viewed from Pelican View Reserve

2.4.2.4 Marine Pests

Training of the Lake's entrance created new opportunities for marine pests occurring along NSW's South Coast to more easily enter the Lake. Baxter and Daly (2010), discusses the potential for the marinisation and increased boat visitation of Lake Illawarra to result in the introduction of known marine pest species such as the European Shore Crab (*Carcinus maenas*), the New Zealand Screw Shell (*Maoricolpus roseus*) and the Japanese Goby (*Tridentiger trigonocephalus*). There have also been reported instances of the invasive upside-down Jelly Fish (Cassiopea (Cnidaria: Scyphozoa: Rhizostomeae: Cassiopeidae) (Keable et al., 2016). The presence of Cassiopea medusae in Lake Illawarra currently appears to be ephemeral, but the dormant reproductive potential of the polyp stage of jellyfish (Gershwin, 2013) means another outbreak could occur again in the future (Keable and Ahyong, 2016). These species are considered pests as they out-compete existing species for food and habitats, are invasive, breed prolifically, and are difficult to remove. They have potential to impact commercial fisheries, tourism and trophic structures.

In addition to the shorebirds example, overall fauna species compilation, distribution and abundance is also likely to have changed in response to the permanently open entrance and altered tidal regime of the Lake. Baxter and Daly (2010) reported that anecdotal evidence from commercial and recreational fisherman of the first observations of the greasyback prawn (*Metapenaeus bennettae*) in 40 years. A new species for Lake Illawarra, the Eastern King Prawn (*Penaeus plebejus*) was reported in catches over the 2008-2009 Summer.

Community consultation is reported on in the C*ommunity Uses, Values, Threats and Opportunities Report* (BMT, 2020a), however, anecdotal evidence from the community supported a change in recreational fishing catch as would be expected given the significant change in water quality and tidal dynamics. This includes a higher diversity of fish, but also (anecdotally) reduced size of fish. This may seem counter intuitive given the open access to the ocean, however, previous studies have shown that for some fish species they can become larger in ICOLLs following their isolation from the ocean and hence predators, for long periods.

2.4.3 Key Implications for Development of the Coastal Management Program

Based on the above review of the entrance training works, the following issues were identified:

- The morphology, hydrodynamics and sedimentary processes operating within the entrance channel are continuing to adjust to the training works.
- Impacts such as increased channel scour, foreshore erosion and marine tidal delta growth are likely to continue to worsen as the channel continues to evolve due to the new conditions, contributing to the threat of both sedimentation and erosion within the entrance area.
- Ongoing costs associated with managing entrance channel erosion and scour as a result of channel adjustments to accommodate an increased tidal prism and velocities will likely require long term engineering management options for the full length of this foreshore to control further erosion and future impacts to assets.
- Changed tidal regime and water levels are causing mangroves to gain an advantage and potentially place pressure on saltmarsh habitats in some areas.
- The permanently open entrance has increased the risk of invasive aquatic species and has likely led to shifts in the type and abundance of species that utilise the Lake.

2.5 Hydrodynamics

2.5.1 Tidal Range and Currents

Lake water levels and tidal range in the Lake are mostly driven by ocean tides, with some shorter term changes driven by rainfall and runoff, since the permanent opening of the entrance. Analysis of water level data recorded from within the Lake between 2007 and 2016 shows the tidal range increased at an average rate of 8 mm/year in the entrance and 6 mm/year in the Lake basin, based on mean spring tidal range, and increases of this magnitude are likely to continue into the future (Wiecek et al., 2016) due to the permanent opening of the entrance and associated changes to the Lake hydrodynamics. Associated with the changed entrance and tidal conditions, the average and

minimum water levels in the Lake has dropped since 2007 (Wiecek et al., 2016). Flow gauging data completed by DPIE - Coasts & Estuaries / MHL in March 2008, October 2012 and March 2016 is presented in Table 2-6, which shows a significant and continued increase in the hydraulic capacity of the tidal inlet post entrance training in 2007 (Wiecek et al., 2016). As indicated in Table 2-6, flood tide flows are greater than ebb tide flows within the entrance channel.

Despite the high tidal flows experienced within the tidal channel, tidal currents would be smaller within the central estuary mud basin and along the western margins of the Lake, as indicated by the absence of marine sand within these environments. A reduction in tidal flows landward of the flood tide delta is typical for wave dominated barrier systems such as Lake Illawarra (GA, 2016).

Table 2-6 Summary of velocity and discharge data (Source: Young *et al.*, 2014; MHL, 2016)

Description	2008	2012	2016
Maximum flood tide velocity (m/s)	0.72	1.08	1.22*
Maximum ebb tide velocity (m/s)	0.84	1.05	1.40*
Maximum flood tide discharge (m^3/s)	222	320	388
Maximum ebb tide discharge (m^3/s)	131	205	245
Tidal prism flood tide (10^6 m^3)	2.70	4.85	5.46
Tidal prism ebb tide (10^6 m^3)	2.14	4.09	4.80

* Note the 2016 tidal gauging was completed at a different location to the previous runs making direct comparison indicative only.

2.5.2 Wind and Wind Waves

The elongate waterbody of the Lake provides a northeast-southwest fetch of over 8 km, and northwest-southeast fetch of around 4 km. This geometry allows for the local generation of wind waves and associated currents that are strong enough to rework sediments and erode or accrete foreshore sections at times. Figure 2-13 summarises the seasonal wind climate and wind wave patterns typically experienced within the Lake.

As indicated in Figure 2-13, moderate winds from the southern sector are experienced all year round. Strong westerly winds are typically experienced during winter, while lower energy northeast winds prevail over the summer. The form and orientation of sedimentary features occurring along the Lake foreshore are consistent with the wind generated wave and current patterns expected from the prevailing winds across the fetch distances described. For example:

- The recurved spit feature at Purry Burry Point extending into Griffins Bay indicates that wind waves and associated currents from southerly winds transport sediment northwards along the northeast margin of the Lake. This inferred current and transport pathway is based on an assessment of aerial imagery undertaken for this study as is consistent with the prevailing summer north-easterlies and year-round southerlies.
- The lobate form of the Mullet and Hooka Creek mouths occurring on the western shore of the Lake is typical of wave dominated fluvial deltas (Sloss at al., 2004). For example, morphology of the recurved shoreline at Currungoba Point occurring on the northern side of Mullet Creek mouth

is consistent with the year-round winds occurring from the southern sector. Further, the asymmetrical 'zeta form' (half-heart shaped) embayment at Purrah Bay situated on the southern side of Mullet Creek mouth is also consistent with southeast and southwest wind waves and currents reworking the foreshore sediments in a northerly and westerly direction. Zeta form bays occur where a fixed point is located on the downdrift side of a shoreline exposed to dominant wave direction. In the case of Purrah Bay, Kanahooka Point is the fixed bedrock feature that controls the asymmetric form of that embayment.

- The morphology of the Macquarie Rivulet delta is highly influenced by wind wave reworking. Wind wave reworking resulted in the development of the hook shape of the delta and also reworked many of the smaller mouth bars. Furthermore, the delta is a transitional delta with an original lobate morphology attributable to wind wave reworking. Land use changes in the catchment altered sediment availability and process dominance (Hopley et al., 2007 and Hopley, 2013).

The geomorphology of the above sedimentary features indicate that wind generated waves and currents capable of eroding and transporting sediment occur along those shorelines exposed to the prevailing winds. Conversely, foreshore areas sheltered from prevailing winds undergo less reworking by waves.

Previous mapping provided by the LIA and DPIE - Coasts & Estuaries have indicated that foreshore erosion around the Lake from wind waves is not a significant issue. Isolated areas of foreshore erosion do exist and have been restabilised in the past.

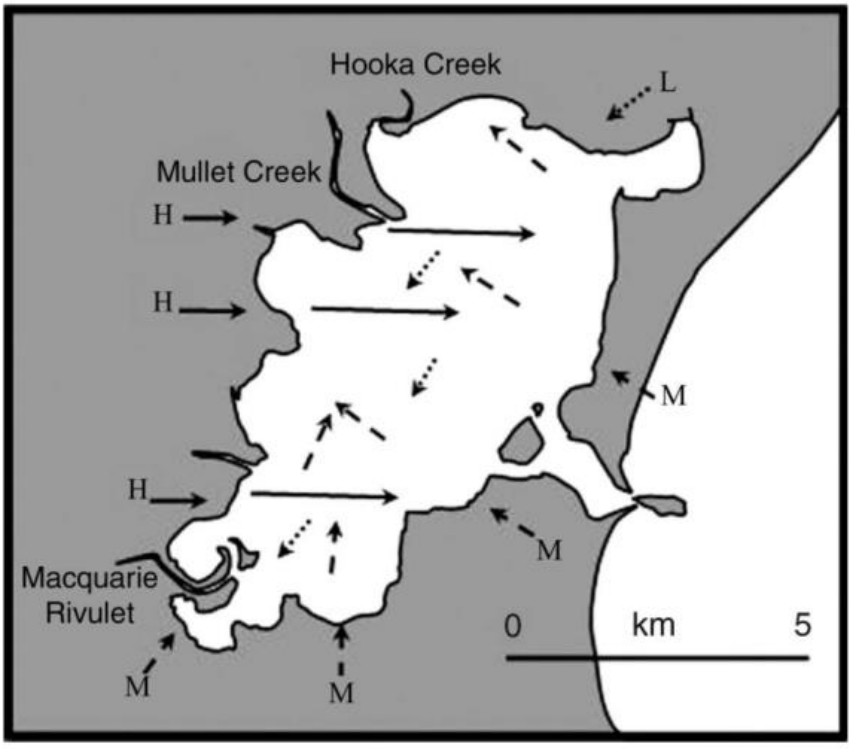

Figure 2-13 Predominant wind directions affecting Lake Illawarra during summer (dotted), winter (solid) and year-round (dashed). The resulting travel paths of the developed wind-waves are indicated in the Lake. Wind strength: H – high, M – medium, L – low (Source: Hopley et al., 2007)

2.5.3 Creek Flows

Lake Illawarra's tributaries contribute both flows and sediment to the Lake, with the volume, extent of sedimentation, and flow rates dependent on their upstream catchments, amount of rainfall, the quality of their banks, and land use activities. High rates of sedimentation in the Lake resultant from creek flows are evident by the formation of deltas at the stream mouths and the broadening of mudflats around the foreshore (LIA, 2013a). Similarly, the installation of weirs and tank traps on the Lake's two main watercourses has also impacted upon natural creek flows, sediment migration and deposition, and delta evolution (C. Hopley, 2019, per comms, 16 May).

Bank erosion has occurred and is likely to occur at locations where the riparian vegetation has been removed, where introduced weed and grass species extend to the water's edge preventing native vegetation growth, where areas have become damaged by illegal use or prohibited access, and where the surrounding land use has resulted in the degradation of creek banks, such as grazing (LIA, 2013a). Areas where revegetation has been identified to rehabilitate creek banks includes Macquarie Rivulet, Pelican View Reserve, Mullet Creek, and the creeks entering at Mt Warrigal foreshore, Burroo and Karoo Bays, Berkeley Boat Harbour, Lake Heights foreshore, Illawarra Education Centre and Windang Peninsula (LIA, 2013a).

Revegetation and re-establishment of native vegetation along the Lake's creeks will maximise the width of the existing riparian buffer zones to improve bank stability and ultimately reduce the extent of bank erosion, especially during high-flow events such as flooding following high-energy rainfall events (LIA, 2013a).

2.5.4 Flooding

Flooding of Lake Illawarra in the past has resulted in damage to property, restricted access and inconvenience to residents and tourists. The flood hazard within the Lake was initially examined by Lawson and Treloar (2001), prior to the entrance training works.

Following this, flood risks to the foreshores of Lake Illawarra within both the Wollongong and Shellharbour LGAs were investigated in the Lake Illawarra Floodplain Risk Management Study (FRMS) and Floodplain Risk Management Plan (FRMP) (Cardno, 2012b; c). The flood risk assessment determined Lake inundation levels due to catchment rainfall alone, and combined with elevated ocean water levels. The influence of changes in rainfall due to climate change and rises in sea level on Lake inundation levels at future time periods were also assessed.

The 2012 Cardno reports did assess the Stage 1 and Stage 2 of the entrance training works as a flood modification option. Cardno (2012b; c) determined the 1% AEP flood levels post completion of the entrance training works to be similar to the pre-2001 conditions modelled by Lawson and Treloar (2001). Therefore, the pre-2001 entrance conditions and associated flood levels were adopted as the 'base case' scenario for the Lake Illawarra FRMS and FRMP.

Cardno (2012b) summarise flooding in Lake Illawarra as follows:

> *"Floodwaters within the Lake and its surrounding floodplain are characterised by slow velocities and a near horizontal water surface. Closer to the Lake entrance inlet, the floodwaters accelerate into the entrance channel to pass under the Windang Road Bridge*

and out to the Tasman Sea. The high velocities in the entrance channel scour sediment from the entrance channel, widening and deepening the channel as the flood progresses, with the channel width limited by the training walls. The rate and depth of flooding of the Lake and its foreshores are controlled not only by the rate of catchment runoff but also to a large extent by the size and degree of shoaling of the Lake entrance channel at Windang and the coincident ocean level".

The Lake Illawarra Flood Study (Lawson and Treloar, 2001) identified that foreshore flooding resulting from the design flood events occurs around most of the Lake, and particularly at Primbee, Albion Park Rail, Yallah, Oak Flats and Kanahooka. Flood levels for the present day 1 in 100 year ARI (equivalent to the 1% AEP) event with a closed entrance and a 20 year ARI ocean water level boundary, and under four different climate change scenarios are given in Table 2-7 and presented in Figure 2-14.

For the tributaries flowing into the Lake, a number of individual flood studies have or are in the process of completion at present (e.g. Duck Creek, Macquarie Rivulet, Gibsons Creek and Mullet Creek). It is worth noting that the Macquarie Rivulet and Mullet Creek catchments contribute some 70% of the total catchment area (Cardno 2012b). Such studies provide important information to landowners and WCC / SCC regarding flooding relating to catchment rainfall in the tributaries combined with backwater flooding from Lake Illawarra. While not a strictly estuary management issues, it is important that such studies have and continue to be completed and updated. Such studies provide SCC and WCC with appropriate information to assess flood risk in the catchments and the Lake's foreshore as new developments and urbanisation continues in the sub-catchments.

Table 2-7 Lake Illawarra Flood Levels (adapted from Cardno, 2012b)

Boundary Condition	Lawson & Treloar (2001) MIKE11 model	Delft 3D Model (calibrated to 2008 conditions)	CC scenario 1	Scenario 2 (2050)	Scenario 3 (2100)	Scenario 4 (2050 + 20% ↑ rainfall)
Sea Level Rise (m)	Existing	Existing	0.18 m	0.55m	0.91 m	0.55 m
Catchment Rainfall	Existing 1 in 100 year 36 hour ARI event	Existing 1 in 100 year 36 hour ARI event	Existing 1 in 100 year 36 hour ARI event	Existing 1 in 100 year 36 hour ARI event	Existing 1 in 100 year 36 hour ARI event	20% increase on 1 in 100 year 36 hour ARI event
Lake Level (m AHD)	Existing	Existing: 0.13	0.29	0.66	1.00	0.66
Ocean water level (m AHD)	Unknown	Existing 20 year ARI water level: 1.41	Existing 20 year ARI + SLR: 1.59	Existing 20 year ARI + SLR: 1.96	Existing 20 year ARI + SLR: 2.32	Existing 20 year ARI + SLR: 1.96
Entrance condition (m AHD)	Unknown	Closed: 1.5 berm	Closed + SLR: 1.68 berm	Closed + SLR: 2.05 berm	Closed +SLR: 2.41 berm	Closed +SLR: 2.05 berm
Location Results (m AHD)						
Griffins Bay	2.30	2.24	2.41	2.63	3.04	2.88
Power Station	2.30	2.24	2.41	2.63	3.04	2.88
Horsley Inlet	2.30	2.24	2.41	2.63	3.04	2.88
Cudgeree Island	2.26	2.24	2.41	2.63	3.04	2.88
Windang Bridge	2.07	2.15	2.35	2.55	3.01	2.77
Entrance Channel	1.99	1.71	1.89	2.25	2.32	2.25

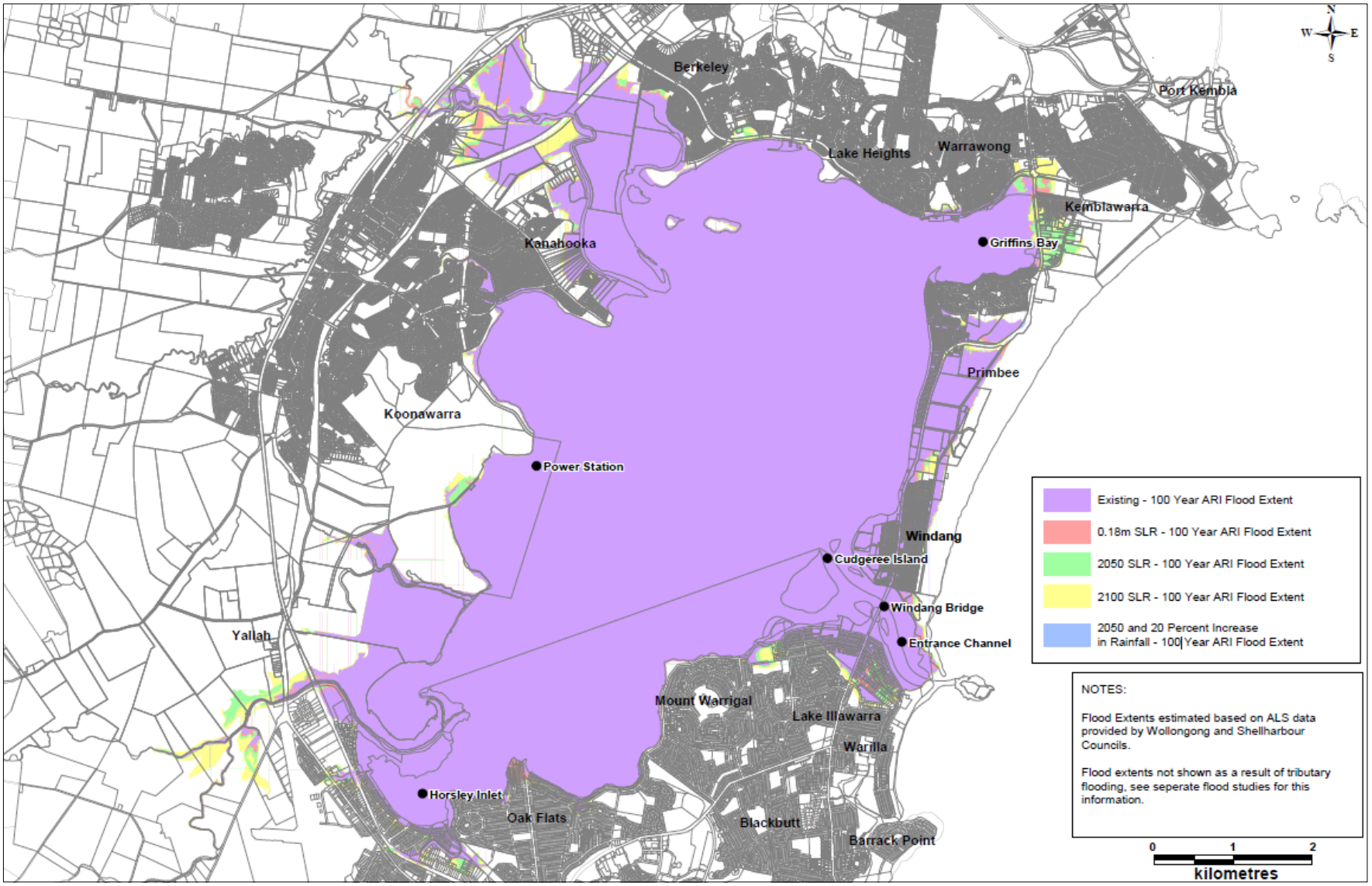

Figure 2-14 Climate Change Scenarios and Existing 100 Year ARI Flood Extent

2.5.5 Key Implications for Development of the Coastal Management Program

Based on the above information, the following issues and gaps were identified:

- The tidal regime of the Lake is still adjusting to the entrance training works and will continue to do so for a long time, possibly over 100 years.
- Bank erosion is an issue in tributary creeks.
- There is insufficient data or modelling of the potential size and impact of wind waves in the Lake, which can cause bank erosion. However, bank erosion in the Lake basin has been identified as a minor issue only.
- Risks to the Lake foreshores due to periodic catchment flooding (and elevated ocean water levels) are well documented in the Lake Illawarra Floodplain Risk Management Plan (Cardno, 2012c). Similarly, flood risks within the tributaries to Lake Illawarra have also been (or are currently being) assessed. No further management of flood risk is required in the CMP.

2.6 Water Quality

Water quality is a broad term that describes a water body's suitability for ecological, recreational or other uses. This underpinning of all uses and values makes understanding the water quality of Lake Illawarra a very important component of developing a CMP.

The water quality of Lake Illawarra is influenced by:

- Discharge from several creeks that drain sub-catchments with varying land uses (refer to Section 2.8.1);
- Sediment deposition from tributaries (refer to Section 2.3.4);
- Internal nutrient cycling and biological assimilation/transformation processes (refer to Section 2.6.1.5);
- Stormwater outlets that drain the urbanised catchment (refer to Section 2.8.6);
- Groundwater inflows that are in some cases contaminated (refer to Section 2.8.8);
- Tidal inflows through a trained entrance that allows for continuous exchange with the ocean (refer to Section 2.5.1);
- Wind, with strong winds leading to sediment resuspension and high turbidity, particularly in shallower areas (refer to Section 2.5.2);
- The mixing and flushing processes between salt and freshwater inputs of the Lake (refer to Section 2.5); and
- Deposition and contaminant transfer to and from sediments (WBM Oceanics, 2006; WCC, 2015).

Water quality is measured and reported in terms of biological, chemical and physical parameters. Assessing and describing the water quality of Australian rivers and estuaries is challenging due to the significant natural variability within and between seasons and years, and within these water

bodies themselves. This complexity is further complicated for Lake Illawarra by the change to tidal regime associated with the entrance management works (refer to Section 2.4) and ongoing catchment development. A key aim of the entrance training works was to improve water quality. Other catchment based initiatives include the implementation of water sensitive urban design for new developments and, constructed wetlands to manage stormwater inputs (WCC, 2015). The change in condition between past and recent times is also difficult to measure due to sporadic monitoring programs, with varying locations, times, and indicators measured (WCC, 2015).

The history of land clearing, and agricultural, urban and industrial development and processes is known to have accelerated the sediment supply to the Lake over the last 200 years or so (see Section 2.3.4). Contaminants such as nutrients and metals are known to bind to sediments, and so have been delivered to the Lake via this increased sediment supply (refer to Section 2.8.9).

In the past, the condition of Lake Illawarra was considered poor, with mass algal blooms frequently occurring (WCC, 2015). Data from monitoring programs conducted between 1987 and 2000, prior to the construction of the trained entrance, showed parameters such as nitrogen, phosphorus, and chlorophyll-*a* consistently exceeded ANZECC trigger values (ANZECC, 2000; WBM Oceanics, 2006; WCC, 2015). The north-eastern and south-western sections of the Lake that are more enclosed have consistently experienced significant nutrient enrichment when compared to the middle reaches, entrance, and main body of the Lake (WBM Oceanics, 2006 and WCC 2016). This is due to the high loads of nutrients entering into these areas combined with lower rates of tidal flushing, allowing accumulated nutrients to remain in the protected area of the Lake.

In 2005, two years prior to the construction of the trained entrance, the LIA commenced monitoring of the Lake, with a focus on water quality at the Lake's perimeter, rather than the main body. This data has limitations in the assessment of water quality changes arising from the trained entrance due to the lack of monitoring sites in the main Lake body (WCC, 2015). However, it does allow a comparison of water quality at these sites over time, which shows that there has not been a consistent improvement of water quality across all parameters sampled, with the Griffins Bay site in particular still showing similar water quality issues now compared to conditions pre 2007 entrance opening (Wiecek et al., 2016).

In 2013, WCC in partnership with SCC and DPIE - Coasts & Estuaries commenced a water quality and estuary health monitoring program for Lake Illawarra that build on the existing program. The revised monitoring program covers fifteen monthly monitored locations spread across the Lake (see Figure 2-16), including the main body. Sampling is undertaken monthly to assess various water quality indicators including temperature, dissolved oxygen, pH, salinity, turbidity, nitrogen, phosphorus, and chlorophyll-*a*. The value of these parameters as water quality indicators is described in Table 2-8.

Additionally, MHL were contracted to continue to undertake continuous monitoring of physicochemical indicators in both Koonawarra Bay and Cudgeree Bay (WCC, 2015). These indicators include temperature, pH, salinity, and dissolved oxygen.

The *Lake Illawarra Water Quality and Estuary Health Monitoring Program* reports (WCC 2016; 2018a; 2018b) indicate continual spatial variation in water quality parameters, particularly with regards to nutrient and chlorophyll-*a* concentrations. These parameters continue to be present in the

enclosed north-eastern and south-western portions of the Lake and reflect poorer water quality when compared to the main body of the Lake. There is apparent seasonal variability of water quality indicators such as chlorophyll-*a*, ortho-phosphorus and dissolved oxygen, with variability in water quality and estuary health indicators across the Lake (WCC, 2016; 2018a; 2018b). Furthermore, the data shows consistency in the water quality of the Lake across the monitoring program's duration despite seasonal extremes and anomalies (WCC, 2016; 2018a; WCC, 2018b).

Further description of monitoring results for key parameters are given in Sections 2.6.1.1 to 2.6.1.7. For comparison, the trigger values used in the WCC water quality monitoring program (WCC, 2016, WCC, 2018a) are provided in Table 2-9. The WCC trigger values are derived from ANZECC (2000) guideline trigger values for south-east Australian estuaries (noting DO is misquoted as 10 instead of 11 mg/L as given by ANZECC (2000)), except for Chlorophyll-*a* and Turbidity, which are based on State of NSW & OEH (2016).

Table 2-8 Major Water Quality Parameters (LIA, 2010; WCC, 2015)

Parameter	Source	Impact
Nitrogen	Fertiliser, sewerage, decaying organic matter and sediments.	Algal blooms, change in species and community composition
Phosphorus	Weathering of basaltic rocks, fertiliser, decaying organic matter and sediments.	Algal blooms, change in species and community composition
Salinity	Saline waters from opening of Lake entrance.	Most species in the Lake are euryhaline; however, few can survive in hyper-saline conditions.
Temperature	Influenced by seasonal cycles, water depth, nutrient levels, riparian vegetation removal, and industrial discharges.	Altered dissolved oxygen levels.
pH	Due to organic matter, agricultural run-off, changes in salinity, and eutrophication.	Change in species and community composition of Lake ecology.
Turbidity/TSS	Sediments are sourced from agricultural runoff, erosion from cleared land, industrial discharge, and construction processes. Also influenced by wind waves stirring up bottom sediments.	Increased particulates in the Lake reducing light availability, altering the chemistry of the Lake, and distribution of flora and fauna. Settled sediments result in increase in deltas, shallowing of bays and decreased water circulation, smothering of Lake's flora, and aquatic ecology decline.
Chlorophyll-*a*	Levels are impacted on by nutrient and light availability, and temperature.	Algal blooms, changes in species and community composition
Dissolved Oxygen (DO)	Aeration of Lake, diffusion of atmospheric oxygen, and photosynthesis of Lake flora, such as seagrass and algae.	Decreased DO can result in species death and reduced species diversity, metal toxicity, and eutrophication.

Table 2-9 Guideline Trigger Values used by WCC (2016, 2018a)

Analyte	Trigger Value (µg/L)
Ammonia (NH_4^+)	15
Filtered Total Phosphorous (FTP)	30
Filtered Reactive Phosphorous	5
Nitrites, nitrates (NOx)	15
Filtered Total Nitrogen (FTN)	300
Total Phosphorous (TP)	30
Total Nitrogen (TN)	300
Chlorophyll-*a*	3.6
Turbidity (NTU)	5.7
pH	7 to 8.5
Dissolved Oxygen (DO)	8 to 10 mg/L

2.6.1 Water Quality Considerations for Estuary Health

Lake Illawarra is a “highly disturbed ecosystem’ as defined under condition 3 of the ANZECC 2000 guidelines (LIA, 2010). Water quality in the Lake has varied in response to changes in catchment land uses, the local climate, and the condition of the entrance. So too, the monitoring of water quality in the Lake has been intermittent, with periods of data available but lacking a comprehensive and consistent dataset across time. Water quality parameters in Lake Illawarra are both highly seasonal in response to local rainfall, and highly responsive to catchment runoff.

In the *State of the Catchments: Estuaries and Coastal Lakes* (Roper et al., 2011) report, the condition rating for the Lake was scored 4.4 and classified as ‘very good’. The indicators used for this were chlorophyll-*a* (good), turbidity (good), seagrass (very good), saltmarsh (very good), and fish (good). However, this report was prepared as a broad state-based assessment used for state-wide comparisons of estuaries and coastal lakes. As such, there are limitations in using this assessment for determining the health of an individual estuary due to the unique complexities, variations, and dynamic nature of each estuary.

The joint monitoring program undertaken by WCC, SCC and DPIE - Coasts & Estuaries provides a more thorough assessment based on a greater sampling frequency and number of sites in relation to water quality indicators. Using a consistent scoring system to that outlined in Roper et al., 2011, monitoring data collected by WCC demonstrates that the Lake’s health is consistent when compared with previous years’ monitoring data. Based on the latest report (WCC, 2018), the Lake’s overall health is reported to be “good” to “very good”. Sites with consistently ‘poor’ to ‘very poor’ scores include Griffins Bay (Site 6), Berkeley (Site 5a) and Burroo Bay (Site 4). The Lake’s edges had higher concentrations of nutrients, turbidity and chlorophyll-*a*, with exceedances of the trigger values. Areas such as Griffins Bay, Macquarie Rivulet and Koonawarra remain susceptible to poor run off from catchment development and contaminated groundwater. Estuary health condition determined from chlorophyll a and turbidity measurements from the WCC (2018a; b) report are shown in Figure 2-15.

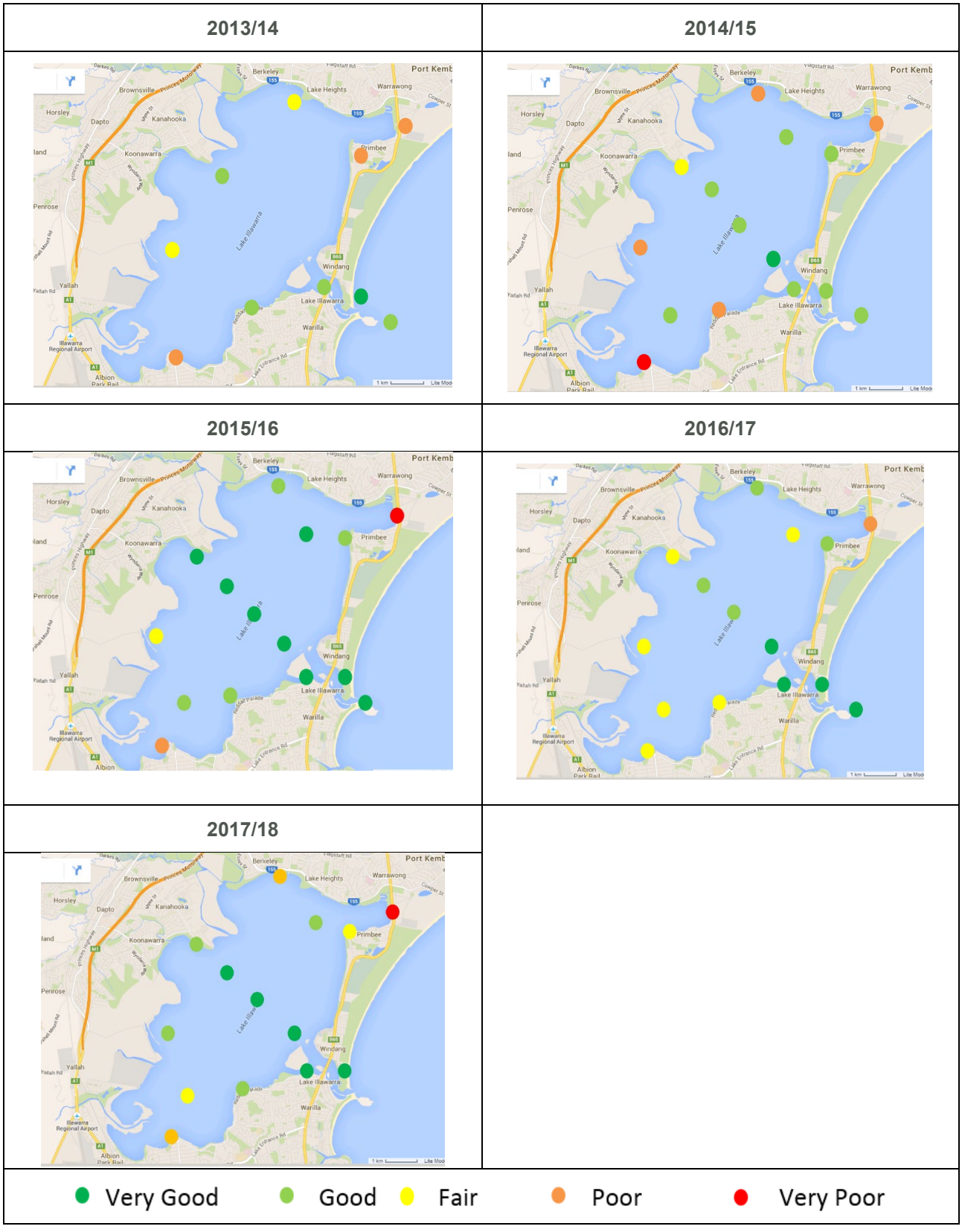

Figure 2-15 Estuary health condition for the Lake based on chlorophyll *a* and turbidity measurements (Source WCC 2018)

Title:
Lake Illawarra
Monitoring Locations

Figure: **2-16**

Rev: **A**

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

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2.6.1.1 pH

Across available data pH has varied, most likely in response to: freshwater and marine inflows in the Lake that were dependent on the condition of the Lake's entrance; the quality of water from the contributing tributaries which may include organic matter, or acidic runoff from agricultural processes; and eutrophication. pH values at Cudgeree Bay and Koonawarra Bay have become more consistent since the opening of the Lake (LIA, 2013a).

In recent water quality reporting for Lake Illawarra, pH measurements taken at the sites shown in Figure 2-16 were found to range between 7.5 and 9 with the average sitting slightly above 8 (close to the pH of seawater of 8.2) (WCC, 2018). This range of pH values is satisfactory for estuarine environments.

2.6.1.2 Salinity

Prior to entrance training, salinity fluctuated in response to the condition of the Lake's entrance. During periods when the Lake's entrance was heavily shoaled or closed, salinity levels were lower due to reduced tidal exchange with the ocean; and salinity levels increased during open entrance conditions.

Water monitoring data has shown consistency in salinity values from previous monitoring data of approximately 35 ppt (WCC, 2018). This value fluctuates with periods of high levels of rainfall (lower salinity values) or low levels of rainfall (higher salinity values).

The permanent opening of the Lake has increased tidal flushing and in turn, maintained salinity levels closer to oceanic conditions on a continual basis than previously experienced. Periods of increased rainfall and flooding resulting in increased freshwater inflows to the Lake can reduce salinity levels, particularly near tributary and stormwater outlets. The permanent opening of the Lake has also resulted in salinity levels returning to oceanic salinity levels much quicker.

2.6.1.3 Turbidity

Turbidity is caused by particles suspended or dissolved in water that scatter light making the water appear cloudy or murky. Turbidity is used as a key indicator of water quality and estuary health. Turbidity across three broad zones in the Lake has been monitored by DPIE - Coasts & Estuaries on a yearly basis since 2007. In 2014-15 turbidity was recorded at its highest, while it was at its lowest in 2007-08, indicating that turbidity has not improved with the entrance training (Wiecek et al, 2016).

Some analysis was carried out in 2010 after the Lake was permanently opened and it was noted that aesthetically the Lake waters looked better, especially within the entrance. There were signs of improving water quality indicated by a reduction in putrid conditions, algal blooms and fish kills (Baxter and Daly 2010). However, turbidity was far more variable after the opening and high rainfall events were still found to result in temporary declines in water quality.

No improvement for turbidity since the permanent opening indicates that water quality in the Lake is heavily influenced by catchment runoff, internal cycling processes, and other weather phenomenon. Results from both DPIE - Coasts & Estuaries and the LIA/Council sampling that show that the Lake may be getting more turbid due to the influence of wind induced bed stirring from a shallower Lake

since 2007, resulting in a greater ability to resuspend bed sediments. In the entrance channel increased velocities lead to enhanced scour and transport of sediments in suspension (Wiecek et al, 2016).

2.6.1.4 Dissolved Oxygen

Dissolved oxygen (DO) is important for estuary health, as organisms need it for respiration. Its concentration in water is a balance of supply (aeration, diffusion, photosynthesis) and demand (respiration, decomposition) processes. DO is also dependent on the temperature, pressure and salinity of the water. In clean surface waters with no salinity gradient, dissolved oxygen concentrations will decrease with an increase in temperature. Therefore, daily and seasonal variations in water temperature of a waterbody can be expected to affect its dissolved oxygen concentrations.

Wollongong City Council has been monitoring water quality in Lake Illawarra since October 2013, in partnership with Shellharbour City Council, and the Office of Environment and Heritage, with funding support from the NSW Government under the NSW Estuary Grants Program. Results show that daily and seasonal variations in DO are evident within the Lake, with generally higher concentrations occurring over the winter than the summer months. Results ranged from 5 to 10 mg/L, which are not unsatisfactory for maintaining estuary health (WCC, 2017).

2.6.1.5 Nutrients

Elevated nutrient levels can result in algal blooms and eutrophication of the Lake, in turn impacting on the estuarine ecology. Sources of nutrients include the use of fertilisers, erosion, livestock faeces, sewer overflows, and urban stormwater.

Monitoring data indicates that concentrations of nitrate, nitrite, and ammonia were below or close to the detection limits (0.01 mg/L) over the last 12-month period (WCC, 2018), demonstrating the bioavailability of these parameters for use in the Lake's ecosystem. This is consistent with previous monitoring data (LIA, 2013a).

FTN across the 12 months of monitoring showed better compliance with respect to the guideline trigger value (WCC, 2018). This indicates that nitrogen is being consumed by microscopic algae or is in particulate form in the water column explaining the lower FTN values when compared to TN.

The concentrations of TP measured at the Lake's monitoring sites in the recent 12 months of data exceeded the trigger values, consistent with the previous monitoring data (WCC, 2018). Sites around the Lake's edge had the highest TP concentrations when compared to the Lake's body, however most of the sites continued to exceed the trigger values. Previous monitoring programs also reported high concentrations of TP that exceeded the trigger levels for the protection of aquatic ecosystems (WBM Oceanics, 2006). Similar to FTN, FTP also demonstrated lower concentrations that generally comply with the trigger values compared to TP, except for Burroo Bay (Site 4), in the south (NS3), west (EW2) and north (NS1) of the main body of the Lake where concentrations continued to exceed the trigger value (WCC, 2018).

Chlorophyll-*a* concentrations over the last 12 month period in Lake Illawarra showed generally similar patterns when compared to previous monitoring data (WCC, 2018), with levels peaking in summer

and reducing during the winter months (to around the guideline trigger value). Along the edges of the Lake, chlorophyll *a* was most abundant at Griffins Bay (Site 6) and this is followed closely by Burroo Bay (Site 4). Within the main body of the Lake, the south (NS3) has the highest concentration, and was well above the guideline trigger value over the summer months (WCC, 2018). The higher concentrations around the edges corresponds to higher nutrient concentrations in the same locations.

Lake Illawarra is an N-limited coastal lagoon which has previously experienced high nutrient loading which resulted in exceedance of ANZECC guidelines after rainfall events for water quality parameters.

2.6.1.6 Aesthetics

The Lake's aesthetics, such as clarity, are highly dependent on concentrations of pollutants and external factors such as seasonality, temperature, and mixing (WBM Oceanics, 2006). Microphytobenthos (MPB) are algae located on the surface of sediments that aid in the cycling of nutrients by denitrification. MPB consumes nutrients and can alter the concentration of dissolved oxygen in the system and remove nitrogen to the atmosphere.

The productivity, growth, and distribution of MPB depend on the clarity of water in Lake Illawarra. Improved water clarity, through decreases in turbidity, increases the activity of MPB at greater depths of the water column due to the penetration of light, this demonstrates the synergistic relationship of the Lake's water quality with complex biological processes (WBM Oceanics, 2006).

Monitoring data for turbidity from the 2018 monitoring period again showed exceedances around edge sites compared to within the main body of the Lake. The deviation at the edge sites is associated with response to wind strength and direction, recreational use of the Lake, and turbulent swells. During this monitoring period, another factor was found which influences the turbidity of the Lake. A background seasonal pattern was shown to be emerging that suggested a summer maximum and a winter minimum. WCC (2018) suggests this is due to the microscopic algal content of the water increasing over summer, which can influence the turbidity of water.

Additionally, since the permanent opening of the Lake, anecdotal evidence suggests daily oceanic exchange has led to improved water aesthetics in the entrance area due to increased tidal flushing.

2.6.1.7 Recreational Water Quality

Recreational water quality is generally indicated by bacterial counts such as Enterococci. The Beachwatch program uses Enterococci as an indicator for the presence of sewerage contamination of recreational waterways that is specific to humans. Faecal coliforms are often also measured, but are an indicator of contamination from a range of animals.

Percent compliance with the NHMRC Guidelines for Enterococci levels at the Entrance Beach in Lake Illawarra for the period 2010-2018 is presented in Figure 2-17. The data shows most samples met the guidelines and the Beachwatch beach suitability grade is 'good'. The level of non-compliance is surprising given the proximity of this site to the permanently open entrance, however, has improved over the past 4 years. The source of this is not immediately identifiable, but possibilities include sewer

overflows, septic systems or stormwater. This issue for recreational health should be considered further in the CMP.

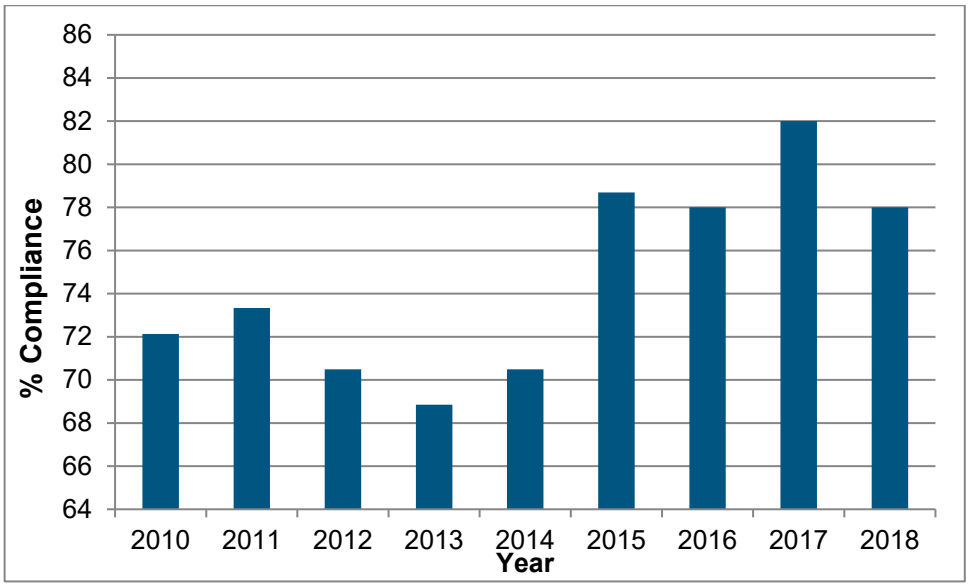


Figure 2-17 Enterococci data for the Entrance Beach indicating the rate of compliance with recreational swimming guidelines (source: Beachwatch, 2019)

2.6.2 Key Implications for Development of the Coastal Management Program

Based on the above review of available water quality data, the following issues were identified

- The permanent opening of the entrance has permanently changed the water quality of Lake Illawarra to more marine conditions.
- Water quality in the Lake improves around the middle reaches, main body, and the entrance area that are well flushed by tides, and decreases in the enclosed north-east and south-west reaches. These areas remain vulnerable to increased pollutant loads due to the low capacity for pollutant removal. This includes areas included in Councils monitoring program such as Griffins Bay, Macquarie Rivulet and Burroo Bay. Any changes to pollutant loads for the catchments draining into these areas need to consider the reduced flushing potential of these receiving environments.
- The issue of Enterococci levels at the Entrance Beach represents a risk to recreational users and should be further explored.

2.7 Estuarine Ecology

Lake Illawarra contains a diverse range of habitats including open water, seagrass systems, rocky intertidal reefs, fringing reefs, mangroves, terrestrial vegetation, saltmarsh communities and sand shoals.

Lake Illawarra is in a state of transition towards more marine-like estuarine ecology in response to the permanently open entrance conditions and changed tidal regime. The ecological response to changes in the tidal prism and range will continue to take some time, after the entrance dynamics

stabilise. The discussion below should therefore be interpreted as a snapshot of an ecosystem in a state of change.

2.7.1 Estuarine Vegetation and Assemblages

Baxter et al (2010) evaluated the available data and observations at that time, and noted that significant changes were apparent just three years after the entrance training works were finished. Given that more than 10 years have passed since the works were completed, it is expected that more extensive changes should be discernible, and this is the case in Lake Illawarra.

Increased tidal exchange has resulted in significant ecological changes throughout the Lake including redistribution of seagrass and saltmarsh. Areas of mangrove and saltmarsh are reported to have been increasing, however, there are also signs that some of the newly established saltmarsh areas could be outcompeted by mangroves (Baxter and Daly 2010), as documented for other NSW estuaries. Fringing estuarine vegetation mapping was undertaken in 2010 by Bangalay (2011) on behalf of the LIA and is shown in Figure 2-19. Mangrove mapping completed through a University of Wollongong honours project (Regena, 2016) with support from the former OEH showed significant increases in mangroves at a number of locations. This includes: 1) the entrance back channel around the islands, 2) Duck Creek and 3) the south-western corner of Koonawarra Bay.

Estuarine vegetation communities are integral to the life cycle of many species of fish which may spend some part or all of their life cycle within an estuary. Estuarine vegetation provides shelter and food for fish, especially juveniles and smaller fish species, which then move between seagrass, mangroves and saltmarsh when the Lake is inundated during spring high tides (Saintilan et al. 2007).

Recent research has shown that the amount of carbon that is sequestered by marine vegetation communities (mangrove, saltmarsh and seagrass) far outweighs that locked up by an equivalent area of any terrestrial ecosystems, including woodlands and rainforests (Lawrence et al. 2012).

2.7.1.1 Saltmarsh

Saltmarsh refers to a number of species of herbaceous plants and low shrubs that can tolerate high soil salinity and at least occasional flooding by seawater (Morrissey 1995). Lake Illawarra has extensive areas of saltmarsh and this is considered a significant natural value of the Lake.

In Lake Illawarra, saltmarsh areas provide habitat and food for a range of fishes, birds, mammals, insects and invertebrates, and contribute to the base of estuarine food chains through decomposition of vegetation. Saltmarsh has other important ecosystem functions, including acting as a buffer and filter of nutrients, reducing erosion, maintaining water quality and acting as a ‘carbon sink’ by storing large quantities of carbon within plants and sediment.

Coastal saltmarsh is listed as an Endangered Ecological Community under the *BC Act*. The saltmarsh community found around Lake Illawarra is dominated by Austral Seablite (*Suaeda australis*) and Samphire (*Sarcocornia quinqueflora*) (LIA, 2012). Other species include *Leptinella longipes*, *Samolus repens* and Sea Rush (*Juncus kraussi*) (LIA, 2012).

Saltmarsh have very particular requirements in terms of inundation frequency, salinity and depth and are therefore very susceptible to changes in tidal regime, as has been experienced through entrance management works and is expected through climate change.

The high vulnerability of this community to water level changes indicates that planning and allowing for migration and modifying current land management practices in some locations (for example, mowing) to facilitate landward migration will be an important consideration for the management plan. Williams & Wiecek (2017) identified four areas on a foreshore prioritisation map to guide where effort on mangrove monitoring and conservation of saltmarsh distribution is best placed, see Figure 2-18 and refer to Appendix E for additional details.

2.7.1.2 Mangroves

Mangroves were previously isolated and limited in extent for Lake Illawarra due to frequently shoaled or closed entrance condition, and so they were not even discussed in the previous processes study (WBM, 2003). An absence of mangroves is often associated with frequently closed Lakes, lagoons and creeks in NSW. It has been reported that mangroves were deliberately planted in the back channel area in 1999 in an attempt to stabilise the foreshore and provide habitat (Baxter et al 2010). The majority of plants however, did not survive, and those that did, failed to reproduce. Following the entrance training works, mangroves are now flourishing along the inner mudflats of the entrance back channel and Duck Creek (Baxter et al 2010, Williams & Wiecek, 2017) with a small number of fully established trees and hundreds of smaller mangroves that were estimated at that stage to be less than three years old (Baxter et al, 2010). Due to the enhanced tidal exchange associated with the entrance training works, conditions are now favourable for mangrove colonisation of other lake foreshore areas that contain soft substrate in quiescent locations (Williams & Wiecek, 2017). It is therefore expected that expansion of mangroves around Lake Illawarra is likely to continue (Wiecek et al., 2016).

Mangroves have the potential to provide a range of ecosystem services including provision of important habitat for many fish, birds and invertebrates (Bell et al. 1984; Hutchings and Saenger, 1987; Underwood & Chapman, 1995), as a stabiliser of sediment, reducing erosion and maintaining water clarity and a provider of food through leaf and other litter consumed by micro-organisms (Williams & Wiecek 2017).

Despite these benefits, mangroves have the potential to occupy the same areas as saltmarsh within the Lake and mangrove increase may also threaten saltmarsh communities. Williams & Wiecek (2017) identified four areas on a foreshore prioritisation map to guide where effort on mangrove monitoring and conservation of saltmarsh distribution is best placed, see Figure 2-18.

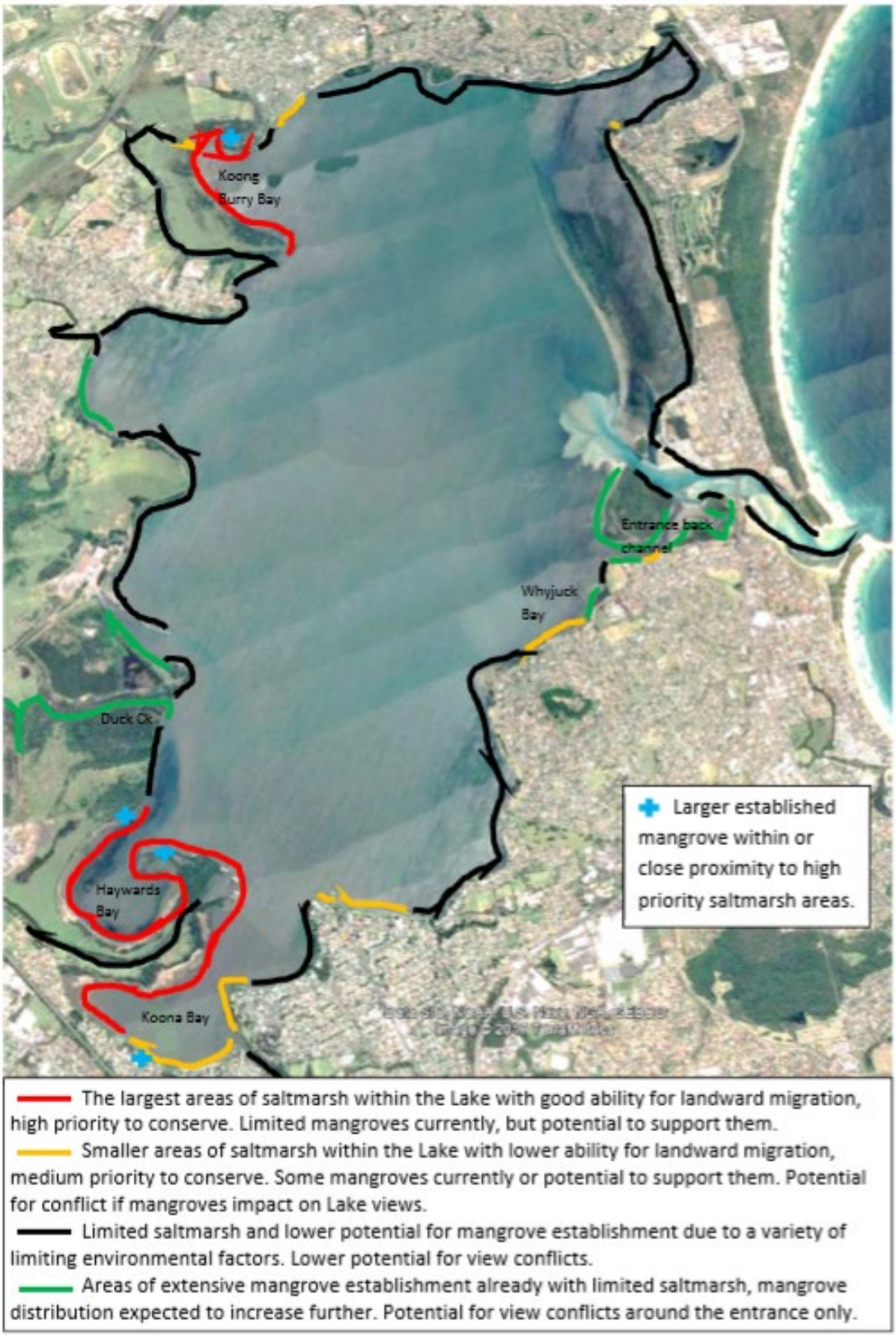
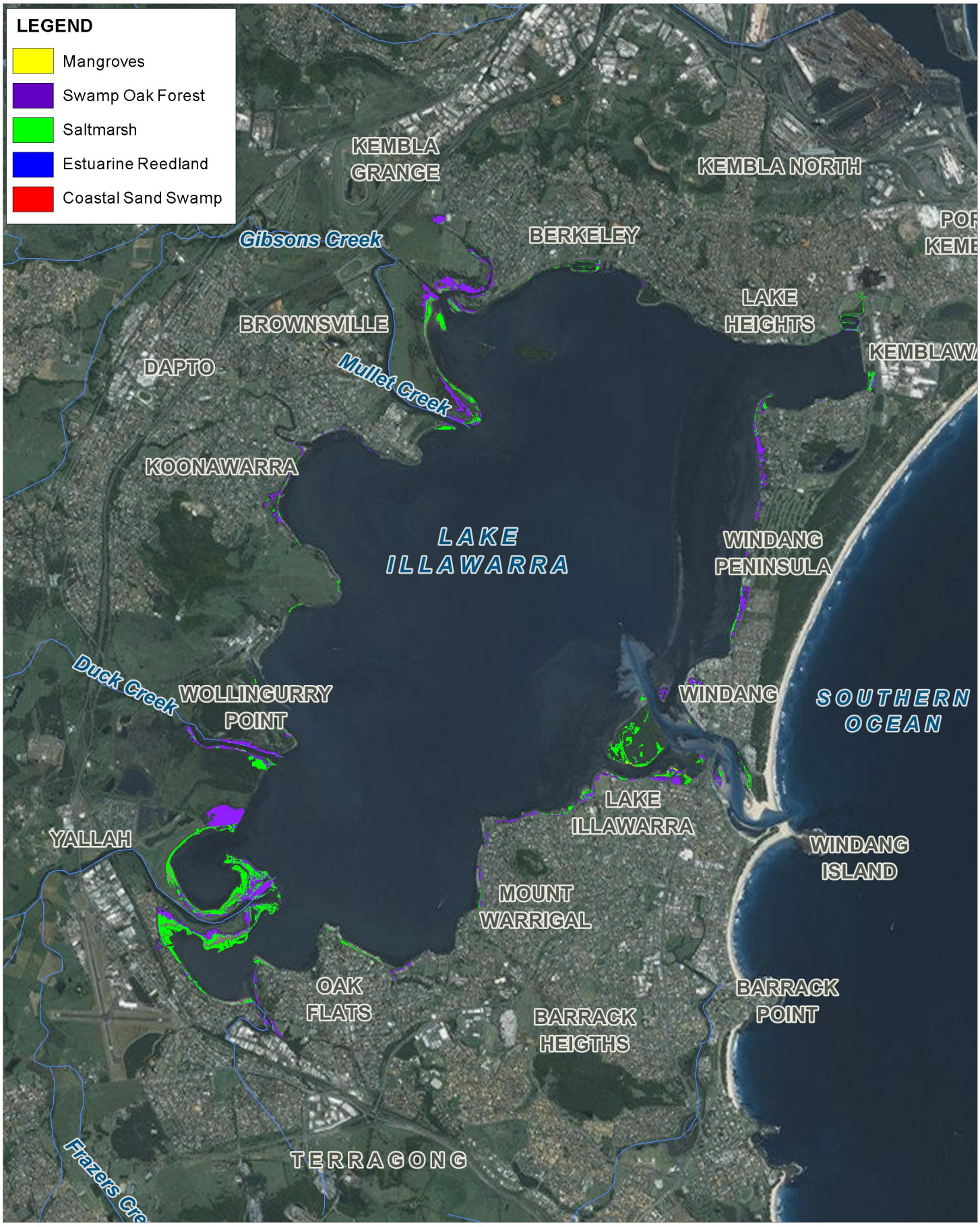


Figure 2-18 Foreshore prioritisation map to guide where effort on mangrove monitoring and conservation of saltmarsh distribution is best placed (from Williams & Wiecek, 2017)



Title:

Estuarine Vegetation

Note: Data mapped in 2010 by Bangalay (2011) on behalf of the LIA

Figure: **2-19**

Rev: **A**

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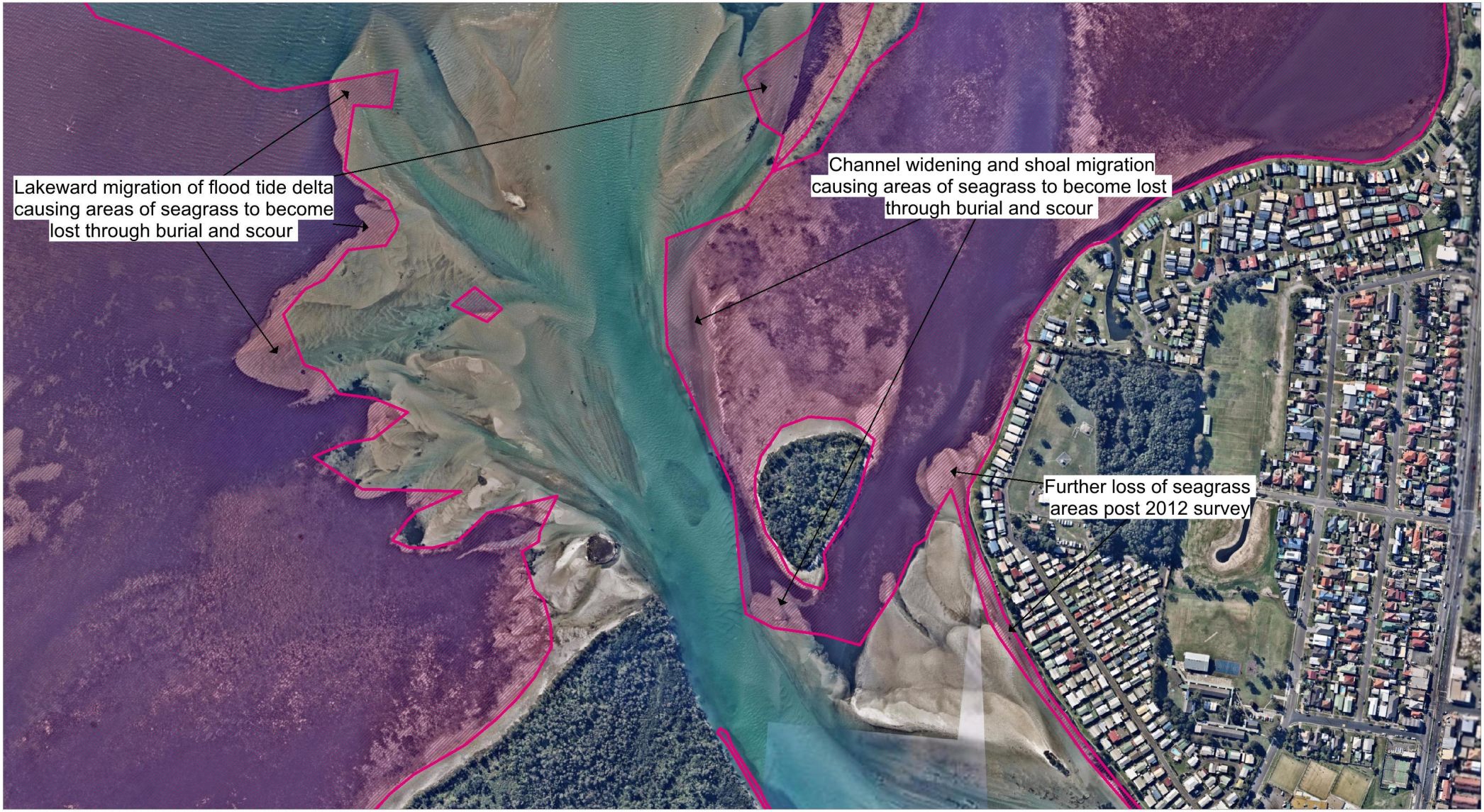

LEGEND

Seagrass extent (2012 mapping)

April 2016 aerial photography from Near Map

Title:

Recent Loss of Seagrass Areas from Bathymmetry Changes to the Entrance Channel

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Approx. Scale

Figure: **2-20**

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2.7.1.3 Seagrass & Macro Algae

Seagrasses inhabit shallow waters in protected bays and provide a range of important ecosystem functions, including primary production, sediment stabilisation and habitat provision. Seagrass vegetated soft sediments are an important habitat for juvenile stages of many commercial and recreational fish species, with different seagrass species often having distinct fish assemblages. The distribution of seagrass is depth limited due to light penetration.

Four dominant species of seagrass are known to grow within the soft sediment areas of Lake Illawarra, namely (Clearwater Ecological, 2012):

- *Zostera capricorni* (Eel Grass) – this is the most dominant species found, almost forming a fringe around the entire Lake.
- *Ruppia megacarpa* (Large Fruit Tassel) – significant areas along the Windang peninsula and west of Bevans Island.
- *Halophila ovalis & Halophilia decipiens* (Paddleweed) – relatively rare, and is mainly found on the outer margins of *Z. Capricorni* beds in the more protected corners of the Lake.

Additionally, three dominant species of macroalgae have been observed in Lake Illawarra, including) *Lamprothamnion papillosum*, *Cystoseira trinodis* and *Laurencia obtuse* (Clearwater Ecological, 2012). In a 2012 survey, these macroalgae communities were found densely growing on rock platforms dominated by *Cystoseira trinodis* around the entire Lake, particularly along the rocky areas and break walls.

A comparison of total areas of seagrass and percentage species distribution between 2000 and 2007 was undertaken by LIA (2012), and again in 2012 by Clearwater Ecological (Clearwater Ecological, 2012) as presented in Table 2-10. The results indicate an increase in total seagrass area throughout the Lake, with all species increasing in the total area covered. The percentage of *Zostera capricorni* remained the same between 2000 and 2007, but increased slightly in 2012. The percentage of *Halophila ovalis* and *Halophilia decipiens* increased slightly from 2000 to 2007, but decreased slightly between 2007 and 2012. Despite this decrease in percentage distribution of total seagrass, it is worth noting that the overall area covered by *Halophila ovalis* and *Halophilia decipiens* increased from 2007. The percentage distribution of *Ruppia megacarpa* decreased slightly between 2000 and 2007, but increased in 2012.

Overall, the distribution of seagrass was greater along the shoreline of the eastern portion of the Lake, particularly the area between Boonerah Point and Cudgeree Island, and along Windang Peninsula. A number of areas around the Lake, particularly the southern portion near Macquarie Rivulet, were devoid of seagrass.

The 2012 seagrass mapping has not been reproduced here as it now likely to be out of date. Seagrass mapping is regularly undertaken by the Tallawarra Power Station, however this data was not available for the present study. Initial community consultation undertaken for the Lake Illawarra CMP indicated the seagrass mapping from 2012 may no longer be accurate, with seagrass loss around the entrance area in particular. This is supported by the conclusions of Wiecek et al. (2016) who assessed the more recent data and concluded areas of Zostera have continued to decline since an initial increase between 2009 to 2012. Halophila was reported to have increased since 2014

(Wiecek et al., 2016). Areas of seagrass loss identified included the flood tide delta, shallow margins around the Lake, Koona Bay and near inlets to Mullet Creek, Hooka Creek and Macquarie Rivulet (Wiecek et al., 2016). Seagrass coverage is known to fluctuate in estuaries, however, Wiecek et al. (2016) outlined a number of causes that contributed to these losses, including the migration of the flood tide delta, entrance scour and burial, increased turbidity in the Lake, and a changed tidal regime including a lower mean water level and lower low tides. This example is also a good reminder of how rapidly information and spatial data sets are becoming obsolete for the rapidly changing Lake Illawarra.

Table 2-10 Comparison of seagrass area in Lake Illawarra between 2000, 2007 and 2012 (source: LIA 2013; Clearwater Ecological, 2012)

Seagrass Species	Area (ha)			% of Total Seagrass		
	2000	2007	2012	2000	2007	2012
Zostera capricorni	565	939	1506	72	72	73
Ruppia megacarpa	167	226	387	21	17	19
Halophila ovalis & Halophila decipiens	54	141	156	7	11	8
Total	786	1306	2049	100	100	100

2.7.2 Riparian Vegetation & Wetlands

Riparian vegetation and coastal wetlands have important ecological habitat values, providing a link between the terrestrial environments and estuarine vegetation such as mangroves and saltmarsh. However, riparian vegetation and wetlands also provides numerous other benefits to the Lake. These habitats filter runoff from the land into creeks and the Lake itself, reducing sediment and nutrient loads to the Lake. Riparian vegetation and wetlands also stabilise riverbanks and lake foreshores, reducing the likelihood of erosion (see Section 2.3).

Macquarie Rivulet and Marshall Mount Creek located in the west and south-west portion of the Lake Illawarra catchment have riparian vegetation communities (Riparian River Oak Forest) unique to the south-western portions of the catchment (OEH, 2002). Tall River Oak and eucalypt species line the banks of these creeks before transitioning to *Casuarina glauca* (Coastal Swamp Oak Forest) and *Melaleuca spp.* with increasing proximity to Lake Illawarra as the tidal waters influence the riparian vegetation communities. These riparian communities have weed species resultant of past clearing and grazing activities including *Lantana camara* and Privet (*Ligustrum spp.*) and exotic tree such as Camphor laurel (*Cinnamomum camphora*) and Coral tree (*Erythrina X sykesii*) (OEH, 2002).

Deltas located at the stream entrances to the Lake and around the foreshore are alluvial forests comprised of EECs. Two dominant EECs are present including Coastal Swamp Oak Forest and Coastal Saltmarsh (OEH, 2002). These EECs are surrounded by shallow waters and tidal mudflats supporting seagrasses and macroalgae communities (LIA, 2012). Lake Illawarra also supports highly degraded freshwater wetland communities located on the floodplains and deltas within the

catchment. Wetlands located on the floodplains of the Duck Creek, Mullet Creek, Macquarie Rivulet and Kembla Grange catchments are comprised of Floodplain Wetland species including: *Phragmites australis, Typha orientalis, Juncus spp.* and *Baumea spp.* These floodplain wetlands support inconsistent vegetation compositions dependent on seasonality, water levels, and disturbance to the areas (OEH, 2002).

Re-mapping of Coastal Wetlands (previously SEPP 14) to define the coastal wetlands and littoral rainforest area was produced for the Coastal Management SEPP (CM SEPP), as discussed in the Lake Illawarra CMP report (Figure 1-3, Section 1.3.2. pp. 7). The CM SEPP is further described in Appendix A.

2.7.3 Estuarine Fauna

Lake Illawarra provides habitat for a range of protected fauna including the Black-necked Stork (*Ephippiorhynchus asiaticus*), Pied Oystercatcher (*Haematopus longirostris*), Eastern Bentwing Bat (*Miniopterus schreibersii oceanensis*), Spotted-tailed Quoll (*Dasyurus maculatus*) (NPWS 2010, cited in Baxter et al 2010).

In the past LIA invested substantial resources in compensating for habitat losses for the threatened Little Terns. The Environmental Impact Statement (EIS) for the entrance works reported that Little Terns successfully nested at sand shoals near the entrance for the first time in 40 years in the summer between 2003 and 2004 (LIA, undated). The document states '*a small portion of the existing shoal immediately alongside the (then) present narrow channel which is utilised as a high-tide roosting area for aquatic bird populations, would be lost as a result of the entrance channel dredging*'. As part of the Conditions of Approval for the entrance works the LIA was required to construct a compensatory sand island. Since completion of the entrance works a range of management methods to protect bird habitat and maintain the sand island have been undertaken. The works have had mixed results (LIA, undated). In particular the highly dynamic nature of the sand shoal (both prior to, and following entrance works) and natural variability in site selection by the birds themselves make it difficult to guarantee breeding success. Impacts by humans, domestic dogs, and pest species such as foxes and seagulls also negatively impacted breeding success. Monitoring of the breeding success of Terns on this small island was undertaken during the first three years following completion of the entrance works. Visual inspections of the bird island were undertaken weekly and oblique aerials and vertical aerials were flown frequently. Predation by seagulls and foxes and high winds prevented any successful breeding events during this three year period. Attempts to maintain a sand island have now been abandoned.

A shorebird habitat and mapping exercise was undertaken by NPWS in 2009, reproduced in Figure 2-21. This information provides a baseline and should be viewed with caution given the extent of change occurring since that time. Mudflats accounted for the largest area of shorebird habitat, comprising 270.21 ha (75.0% of total assessed shorebird habitat area). Saltmarshes accounted for the second largest area of shorebird habitat, comprising of 29.90 ha (8.3% of total assessed shorebird habitat area). Sandflats, located at the Lake's entrance, comprised of 22.37 ha (6.2% of total assessed shorebird habitat area). The remaining 37.77 ha (10.5%) of shorebird habitat comprised of brackish (13.67 ha) and freshwater (10.71 ha) swamps, bushlands (2.78 ha), and naturally formed (5.37 ha) and artificial (2.82 ha) rocky shores.

Title:
Identified Shorebird Habitat

Figure: **2-21**

Rev: **A**

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

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More recent references to Lake Illawarra have been sourced from the South Coast Shorebird Recovery Newsletter for the insights they give into shorebird habitat and breeding success:

- 2015/2016 - Volunteers monitored Pied Oystercatchers at the entrance of Lake Illawarra and the birds showed early season behaviour that indicated nesting could occur on the island close to the Warilla embankment. But no nests were recorded, and the birds became less frequent at the site.
- 2014/2015 - Yet again at Windang no Little Tern nesting was recorded this season. Small numbers of Little Terns passed through the site, feeding and resting. On the south side of the Lake Illawarra entrance, the Pied Oystercatcher pair were observed on and off over the season, however no nesting was recorded.
- 2013/2014 - At Windang no Little Tern nesting was recorded this season. The 'Bird Island' nesting area is no longer maintained by the Lake Illawarra Authority and consequently there is little area left for shorebird nesting. Small numbers of Little Terns passed through the site, feeding and resting. In mid-September a pair of Pied Oystercatchers were observed on the north side of Lake Illawarra entrance. The first egg was laid on the 4th of October and the local volunteers quickly fenced the area. The pair were seen mating again and the second egg reported on the 8th of October. The nest was progressing well with the pair regularly monitored and seen sitting on the nest. However sadly the nest failed to hatch and finally when 2 weeks overdue the site coordinator removed the eggs, to encourage the pair to nest again. In early December another 2 egg nest was located but in a terrible position, about to be inundated. The eggs were moved to the old nest scrape in a higher drier position, but the pair failed to continue incubation. The eggs quickly disappeared to an unknown predator.
- 2012/2013 – At Windang, no little Tern nesting was recorded. Two Pied Oyster Catcher eggs were laid but lost to vandalism / predation.

2.7.4 Biodiversity Considerations for Estuary Health

Biodiversity provides the protection of water sources, protection and formation of soil, nutrient storage and cycling, pollution breakdown and absorption, climate change stability, ecosystem maintenance and resilience. Furthermore, biodiversity provides a range of biological and economic resources vital to the existence of humans and fauna alike, in addition to social and community benefits such as tourism, recreation, research, and education (WCC, SCC & KMC, 2011).

The wetlands associated with Lake Illawarra provide the greatest biodiversity in the Illawarra catchment (WCC, SCC & KMC, 2011). As Lake Illawarra is an estuary, its associated flora and fauna extends to a number of diverse habitats including open water, seagrass, intertidal reefs, rocky platforms, saltmarshes, intertidal flats, and sand shoals (LIA, 2013a). Macrophyte communities have a vital role in maintaining the function and diversity of fauna within the Lake, and changes in their populations can indicate a change in estuary health.

Lake Illawarra possesses a number of EECs such as Coastal Saltmarsh and Swamp Oak Floodplain Forest as well as protected species including seagrass, mangrove, and saltmarsh (see estuarine vegetation map in Figure 2-19). Mangroves are important contributors to estuarine biodiversity by providing habitat, nutrient cycling, and aiding in shoreline protection due to their affinity for silty shoreline areas (LIA, 2010). The Lake also provides an ideal habitat for saltmarsh and seagrasses

as it is relatively shallow and has gently sloping foreshores. However, during periods of high sedimentation (either sourced from the catchment, or directly from bank erosion) seagrass populations have been observed to suffer. Changes to the temporal and spatial distribution of saltmarsh communities in the Lake are also evident.

In addition to flora, changes in the diversity of aquatic fauna can be used as indicators of estuary health. As mentioned previously, there are some indications of increased biodiversity although losses of species adapted to previous conditions are also likely.

2.7.5 Key Implications for Development of the Coastal Management Program

Based upon the above information, the following aspects should be considered in the CMP.

- The ecological response to changes in entrance dynamics is measurable and ongoing. Continued collection and analysis of information is important to inform adaptive management.
- Mangroves were previously limited and isolated, but are now flourishing due to permanent lake opening. While they provide habitat value, their growth may also threaten saltmarsh habitat extents.
- The high vulnerability of saltmarsh communities to water level changes and outcompeting by mangroves indicates that planning and allowing for migration and modifying current land management practices (for example, mowing) to facilitate landward migration will be an important consideration for the management plan.
- Since permanent opening of the estuary entrance, the aquatic species utilising the Lake have changed, and may continue to change. There is currently a data gap and a need for further monitoring of the estuarine fauna now utilising the Lake.
- Shorebird nesting and habitat appears to be an important ecological value that is in decline in the entrance channel area and is under threat from the change to entrance processes, predation and habitat loss. Protecting and enhancing shorebird habitat will be an important component of the management actions assessment to ensure actions do not contribute to cumulative impacts.

2.8 Catchment Influences

2.8.1 Catchment Land Uses

The Lake Illawarra catchment is dominated by natural bushland, grazing land, urban residential areas, and industrial land uses. The Lake itself is primarily surrounded by low to high density residential development, public recreation areas, and heavy industrial land use, as defined by the WCC LEP and SCC LEP (2009). Despite the large proportion of rural and environment protection zones within the catchment, the area is undergoing land use change through re-zoning of land for residential development, especially in the areas to the west of the Lake (see Section 2.8.2).

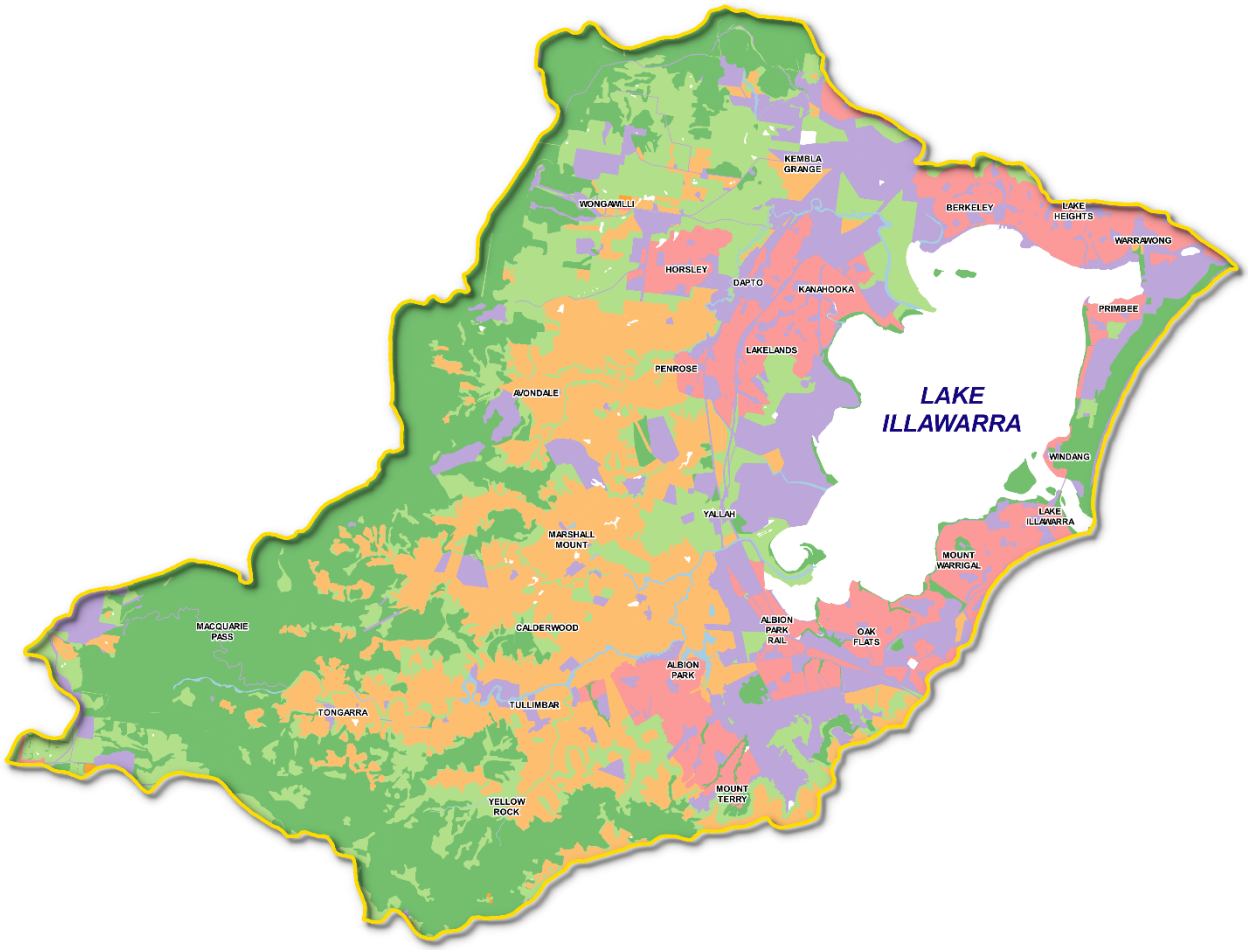
DPIE Coastal Eutrophication Risk Assessment Tool (CERAT) was used to assess the relationship between land uses in the catchment and its impacts on the Lake. CERAT indicates that the dominant catchment land use is urban residential areas and industrial land use.

CERAT describes Lake Illawarra and its associated catchment as extensively modified, with consequential increases in stormwater runoff, heavy metal contamination, increased nutrient loads, and sedimentation. This was concluded to be a 'real' threat to conservation and moderately affected ecological status. Additionally, there is a high threat to fisheries as a result of runoff from the extensively modified catchment. The SEDNET data available under the Lake Illawarra CERAT profile confirmed that fine suspended sediment yields have increased following European settlement, to more than double the estimated natural yields. Further information on the use of CERAT for Lake Illawarra is provided in Section 2.8.11.

Catchment scale land use data (updated March 2015) available from the Department of Agriculture and Water Resources was used to infer broad catchment land uses in the Lake Illawarra catchment, as displayed in Figure 2-22. The data is compiled from vector land use datasets collected as part of state and territory mapping programs through the Australian Collaborative Land use and Management Program (ACLUMP).

Land use data such as provided via ACLUMP is more useful than land zoning mapping, as it describes the current land use, not the potential land use (which is what land zoning represents). Land zoning maps are often used as a proxy for land use data, where land use data is unavailable. Landuse data, provides an accurate assessment of how land is being used, and therefore, the potential impacts from current land use and land management practises to the Lake.

Based upon the mapping in Figure 2-22, the Lake's catchment has retained some Conservation and Natural Environments, with the remainder dominated by Production from Dryland Agriculture and Plantations (largely comprised of grazing modified pastures) and Intensive Uses (largely comprising residential infrastructure, and services, with a very small percentage of purely industrial land use). This mapping broadly corresponds with that described in the CERAT Tool. Similarly, the extensive area of cleared land for grazing, and current and ongoing residential development in the catchment will be promoting an increase in sediment, nutrients (particularly from fertilisers), and other contaminants (including pesticides, as well as point sources of metals and other toxins from historical industrial practises).



Legend

- 1. Conservation and Natural Environments
- 2. Production from Relatively Natural Environments
- 3. Production from Dryland Agriculture and Plantations
- 4. Production from Irrigated Agriculture and Plantations
- 5. Intensive Uses (excl. 5.4.1)
- 6. Watercourse/Wetlands
- 5.4.1 Urban Residential
- Lake Illawarra Catchment Boundary

Data derived from NSW Landuse 2013 - obtained 12/06/2019.
Classifications as per ALUM v7

Figure **2-22**

Catchment Land Uses Lake Illawarra

N

0 2.5 5 km

Shellharbour CITY COUNCIL

2.8.2 Future Land Uses

Within the Lake Illawarra catchment, there are a number of proposed urban releases including West Dapto, Calderwood, North Huntley, Tallawarra, and miscellaneous releases within the Shellharbour LGA as shown in Figure 2-23. These account for the majority of future land uses within the catchment, with the rezoning of rural landscape, primary production, environmental management, and environmental conservation land zones to residential for development to occur. A brief overview of each development is given in Table 2-11 below.

Given the discussions regarding pollutant sources from urban land uses, proper management of stormwater runoff from the proposed urban release areas will be vital for ensuring pollutant loads and water volumes to the Lake are not increased.

Table 2-11 Future Urban Releases

Site Name	Overview
West Dapto (WCC)	Approximately 19,000 dwellings, 50,000 residents, 8 town/village centres, and 2,600 ha of natural areas including creek corridors (WCC, 2016).
North Huntley (WCC)	Residential development including approximately 156 residential lots and a golf course, rezoning the former Huntley and Avondale Colliery for private recreation, low density residential, environmental conservation, environmental management, and environmental living.
Tallawarra (WCC)	The site, previously used as a coal fired power station between 1954 and 1989, was sold and used as a combined gas turbine power station. The remaining portion of land was rezoned to residential use, environmental management, and public recreation.
Calderwood (SCC)	Approximately 4,800 residential dwellings, 50 ha of mixed use land, open space, environmental lands, internal roads, service infrastructure, and community facilities.

2.8.3 Sources of Pollutants

Lake Illawarra is a receiving waterway of a variety of pollutants originating within the catchment from point and non-point (diffuse) sources. Point sources tend to refer to industrial or commercial activities that discharge directly to the Lake, or one of its tributaries. Point sources may also include sewerage overflows, which contribute elevated levels of faecal coliforms, Enterococci and nutrients to the Lake (Cardno, 2012b). Diffuse sources are those that are transported to the Lake via various processes and are not directly discharged from their source, such as agricultural and urban runoff that is transported via stormwater drains and local tributaries into the Lake.

Sediment is a pollutant in its own right, and may also transport other contaminants such as metals and nutrients that adsorb to the sediment surface (particularly clay and silt sediments). Sedimentation rates into Lake Illawarra are widely reported to have increased since European settlement of the Lake's catchment. An increase in land clearing for agriculture and more recently for urban development has promoted the erosion of the topsoil layers, with the eroded sediments then transported to tributary creeks, the stormwater network and the Lake. Metals, nutrients and other pollutants readily attach to the clay and mud sediments on land and in water.

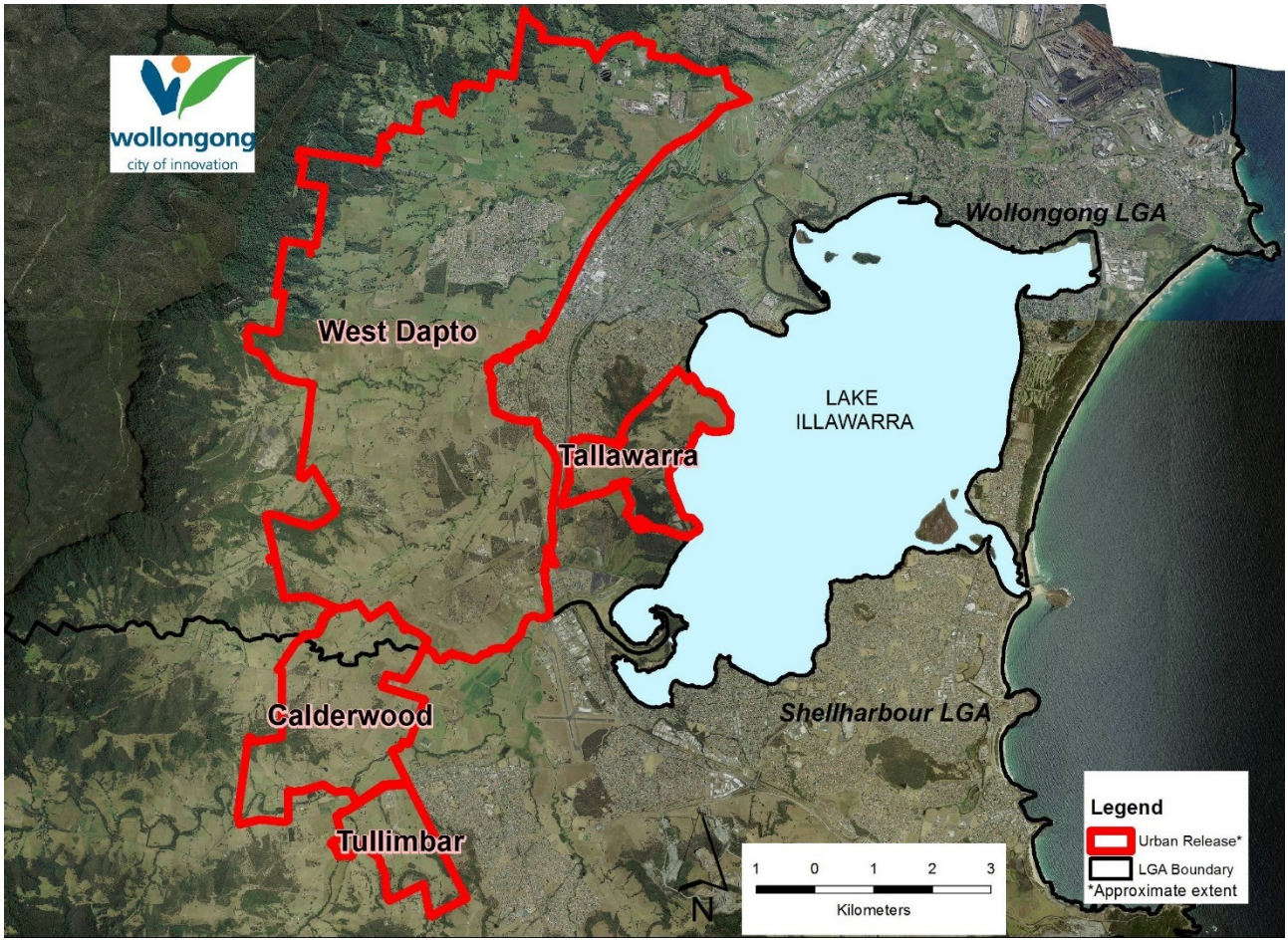


Figure 2-23 Urban Release areas (Source: WCC, 2019)

2.8.4 Licenced Premises

The Lake Illawarra catchment contains a number of premises licenced by the Environment Protection Authority (EPA) under Section 308 of the *Protection of the Environment Operations Act 1997* (POEO). A search of the POEO Public Register was conducted on 6 June 2016, with the locations of these premises shown in Figure 2-24. The licenced premises are concentrated along the northern margin of the Lake's catchment in the suburbs of Unanderra, Warrawong, Kembla Grange, and Port Kembla; with three premises along the southern margin of the Lake. The licenced activities include metal processing, shipping in bulk, waste storage, recovery and disposal, mining for coal and coal works, cement and lime handling, other extractive activities, and electricity generation from gas.

A review of the NSW EPA record of notices issued under Section 58 of the *Contaminated Land Management Act 1997* (CLM) for the Wollongong LGA and Shellharbour LGA conducted on 9 January 2019 revealed two sites within the Lake's catchment with current notices, as shown in Table 2-12 below. This list is a method of assessing, prioritising, and responding to notifications to the EPA under Section 60 of the CLM Act. Listed as a licensed premises under the POEO Act, 16 sites were found within the Lake Illawarra catchment, shown in Figure 2-24. The majority of these sites are located in Port Kembla, Cringila, and Wollongong.

Table 2-12 Sites with Current Notices within the Catchment

Site Name & Address	Notices Relating to the Site	Notice Type	Distance from Lake Illawarra
BlueScope Steel, 13 Marley Place, Unanderra	4 current	Declaration of Significantly Contaminated Land (2014), Approved Voluntary Management Proposal (2016), Amendment or Repeal of Order or Notice (2017), and Approved Voluntary Management Proposal (2018).	3.5 km north
Tallawarra Power Station site, Princess Highway, Yallah	1 current	Notice for Maintaining Remediation (2003)	On foreshore of Yallah Bay

2.8.5 Thermal Discharges

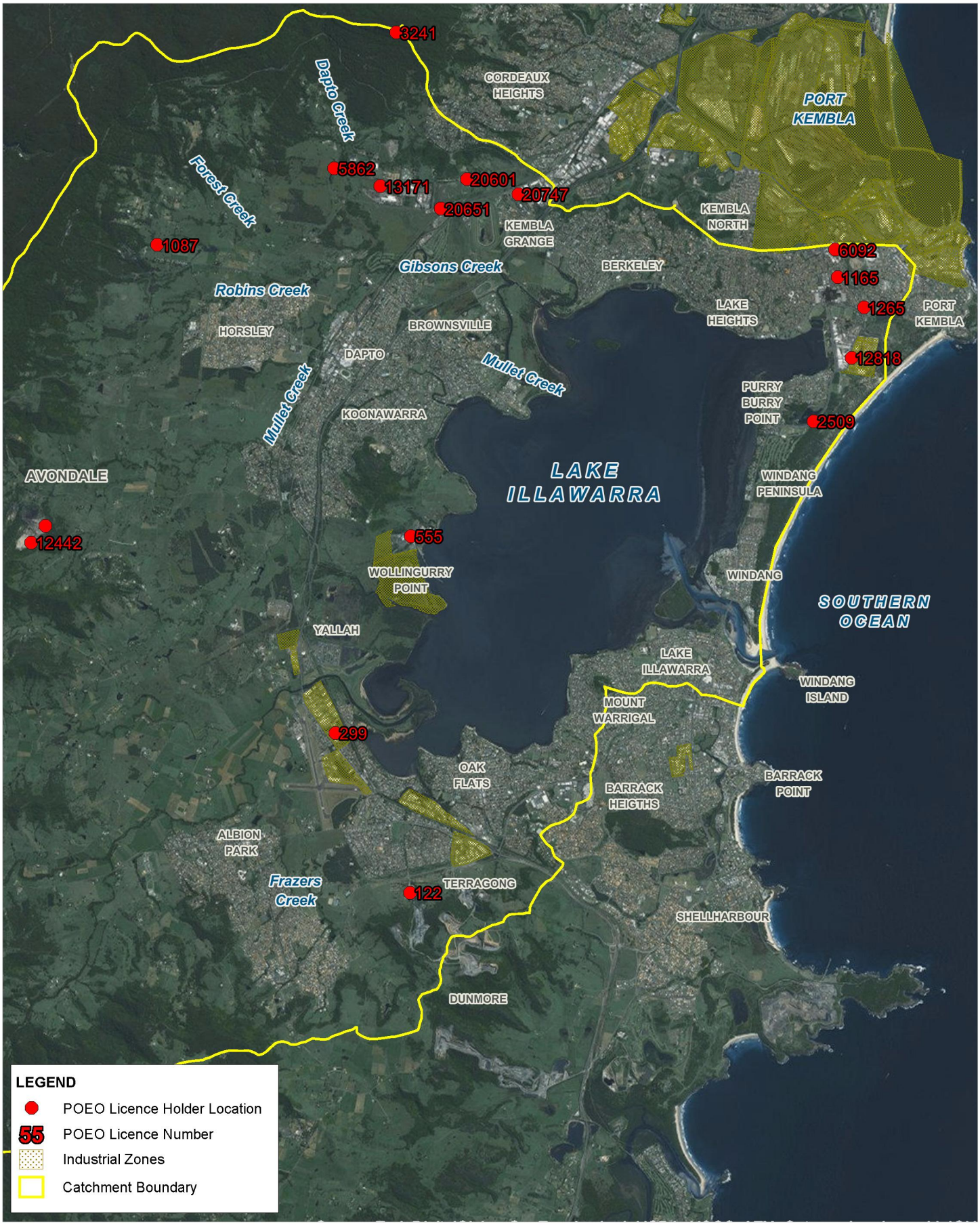
The gas fired power station at Tallawarra is a source of thermal discharge to Lake Illawarra. The following text gives examples of impacts of thermal impacts elsewhere.

Heated water plumes can affect the marine environment in diverse and sometimes unpredictable ways. Some effects include direct effects on photosynthesis (Chuang et al. 2009), particularly reducing the growth of seagrass (Robinson 1987) and other benthic cover and adversely affecting plankton and periphyton (Chuang et al. 2009). Discharged heated water can decrease fish species diversity (Teixeira et al. 2009). Thermal pollution can promote the occurrence of invasive species (Thomas et al. 1986) and has been associated with algal blooms and eutrophication, including toxic dinoflagellate blooms (Jiang et al. 2013). Increases in temperature decrease the saturation concentration of oxygen, which in some instances has led to fish kills.

If not appropriately managed, thermal discharges can impact on aquatic ecosystem health, including reducing seagrass growth. The EPA regulates the Tallawarra Power Station and requires monitoring of discharges, ambient water quality and seagrass extent to detect and manage potential impacts, and to date no major issues have been identified as a result of this discharge.

The impacts of thermal discharges on Lake Illawarra are difficult to quantify due to the cumulative impacts of other pressures such as catchment development. While the studies referenced above are not specific to Lake Illawarra, they do indicate that this is potentially another cumulative pressure acting upon the Lake ecosystem.

Changes to the way Tallawarra Power Station operates is influencing the frequency and amount of thermal discharge and consequently lessening the effects of thermal discharge in the receiving waters. Tallawarra Power Station is no longer operating full time hence no longer releasing thermal discharge at all times.



Title:

Licenced Premises in the Lake Illawarra Catchment Lake Illawarra

Figure: 2-24

Rev: A

N

0 2 4km

Approx. Scale

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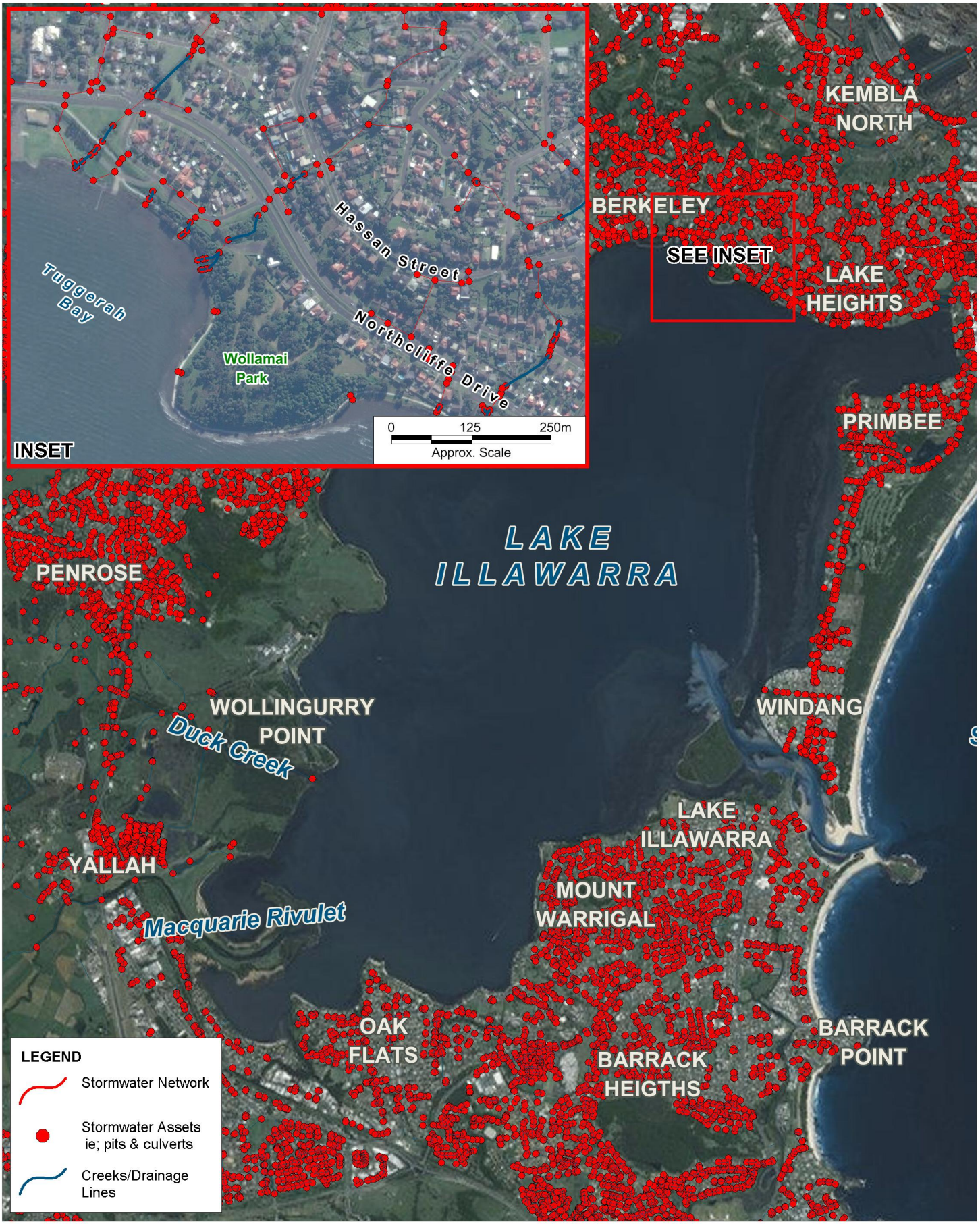
2.8.6 Stormwater Inputs

Developed areas within the Lake's catchment have a network of stormwater infrastructure (e.g. Figure 2-25). Pollutants in stormwater include gross pollutants (litter), sediments, nutrients (from fertiliser use, dog and other pet faeces), contaminants such as pesticides (from landscaping and gardening) and oil and grease (from road surfaces), and pathogens (from dog/pet faeces and sewerage overflows, see Section 2.8.7). For example, a Sydney Water investigation of the Parramatta River found that pet faeces in stormwater runoff formed a significant contribution of nutrients and pathogens to the river system (pers. comm., Steph Kermode, Sydney Water).

Lake Illawarra and its surrounds form a complex stormwater network due to the large catchment size, dense urban areas, and variety of other land uses including agriculture and industrial uses. The stormwater network is mapped in Figure 2-25. There has been an increase in urban housing developments, which add pressure to the existing stormwater drainage networks if these are not upgraded during the development. Housing developments also result in a loss of vegetation, with the associated increase in impervious surfaces adding greater volumes of runoff into the stormwater network, tributaries and the Lake, particularly during the construction phase.

Future developments such as the West Dapto Release Area (approximately 20,000 residences over 20-30 years), and the general trend of population growth around the Lake will continue to place pressure upon the Lake. Without proper stormwater management (through water sensitive urban design, appropriately sized, sited infrastructure and treatment within the catchments themselves) the increase in stormwater runoff volumes invariably increases the pollutant loads to the Lake.

Within the catchment are a number of stormwater treatment devices including gross pollutant traps, trash racks, sediment ponds, and constructed wetlands. These structures aim to reduce litter, sediment and other pollutants reaching the Lake, although they are variously more or less successful at removing pollutants. For example, gross pollutant traps tend to only remove litter, with other contaminants remaining dissolved or suspended in the water column. For these devices to remain efficient, they require regular maintenance to ensure blockages are removed, particularly for gross pollutant traps. Maintenance is generally undertaken quarterly and in response to complaints received by the councils (Cardno, 2012b). In its last annual report, the LIA noted that there was just 47% of stormwater inlets to the Lake that have some form of filtering, most were rudimentary.



Title:

Lake Illawarra
Sample Stormwater Network - Lake Heights & Berkeley

Figure: **2-25**

Rev: **A**

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Approx. Scale

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www.bmt.org

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Some of the constructed, or artificial, wetlands located within the Lake Illawarra catchment were an initiative of the LIA with the local councils during the late 1990s. Artificial wetlands were constructed at major stormwater inflow locations including Berkeley (Budjong Creek Wetland) and Warrawong (Kully Bay Wetland) with the aim to reduce sediments, nutrients and pollutants entering into the Lake. A review of the effectiveness of the wetlands revealed (Baxter, 2012):

- Kully Bay Wetland had a high retention capacity of inflows prior to discharging to the Lake which was particularly evident following rainfall events where the outflow was less than the inflow;
- There was a reduction in flow energy through Kully Bay Wetland reducing sediment-bound contaminants at the outflow location;
- Dry weather samples indicated lower efficiency of Kully Bay Wetland due to drastically reduced inflows, compared to wet weather samples which effectively reduced TN, TP, chlorophyll-*a* and TSS concentrations; and
- Despite reducing pollutant concentrations in Kully Bay Wetland, the wet weather samples were between 20-30% below the target pollutant removal efficiencies for TSS, TP and TN; Budjong Wetland was approximately 30-60% below the target pollutant removal efficiencies for TSS, TP and TN.

Despite both wetlands being significantly below the target pollutant removal efficiencies, the review noted that the target values were based on the condition of the Lake in 1994, prior to the permanent opening of the entrance. Based on this, the target pollutant efficiencies need to be reviewed in the context of the Lake's present state (Baxter, 2012).

Furthermore, Baxter (2012) also recommended a number of changes to the wetlands' designs to improve their functionality including alterations to the macrophyte zones and continual maintenance to clear debris from the structures.

2.8.7 Sewerage System Overflows

Overflows from the reticulated sewerage network are another source of contamination to the Lake. Since the 1960s, reticulated sewerage systems have been installed throughout the Lake's catchment, with systems in the major urban areas completed in the mid to late 1980s (WBM Oceanics, 2006). All new major urban developments have also been connected to the reticulated sewerage network. Planning is underway to manage increase sewage loads due to the identified increased urban development areas within the catchment. This has substantially reduced ongoing discharges to the Lake and its tributaries. However, legacy pollution from before the installation of the reticulation network continues to affect some parts of the Lake. This was confirmed by the presence of nutrient residue in bottom sediments of the Lake dating back to before the 1960s (WBM Oceanics, 2006).

The Shellharbour LGA sewerage system collects sewage from approximately 4521 ha and directs it to the Shellharbour Wastewater Treatment Plant (WWTP), servicing the southern portion of the Lake Illawarra catchment (Cardno, 2012b). For the Wollongong LGA the Lake's catchment is connected to the tertiary treatment facility at Wollongong. This facility generates recycled wastewater, which is then used at BlueScope Steel, Port Kembla Coal Terminal, Wollongong Golf Club, and by the WCC

(Sydney Water, 2009). Wollongong LGA also has two specialised storm WWTPs that store and treat excess wastewater during large rainfall events only (they do not operate during dry weather periods) located at Port Kembla and Bellambi.

The EPA regulates sewage treatment systems operated by Sydney Water for Shellharbour and Wollongong municipalities including the regulation of overflows. Presently, the effectiveness of the sewerage system within the catchment is operating within design parameters. During intense rainfall, stormwater inflows can increase flows in the sewage network. Sewage networks are designed with structures to allow overflows at these times to prevent sewage backing up to properties. Potential overflow points are illustrated in Figure 2-26. Other sources of sewage pollutants are from leaking sewer networks, dry weather overflows from chokes and failures in the pumping stations to the treatment plants. When sewage is released either by design or inadvertently, increased nutrients enter waterways and impact ecological processes. Other types of contamination that may be introduced from sewage overflows include pathogens, bacteria, PFAS and heavy metals etc.

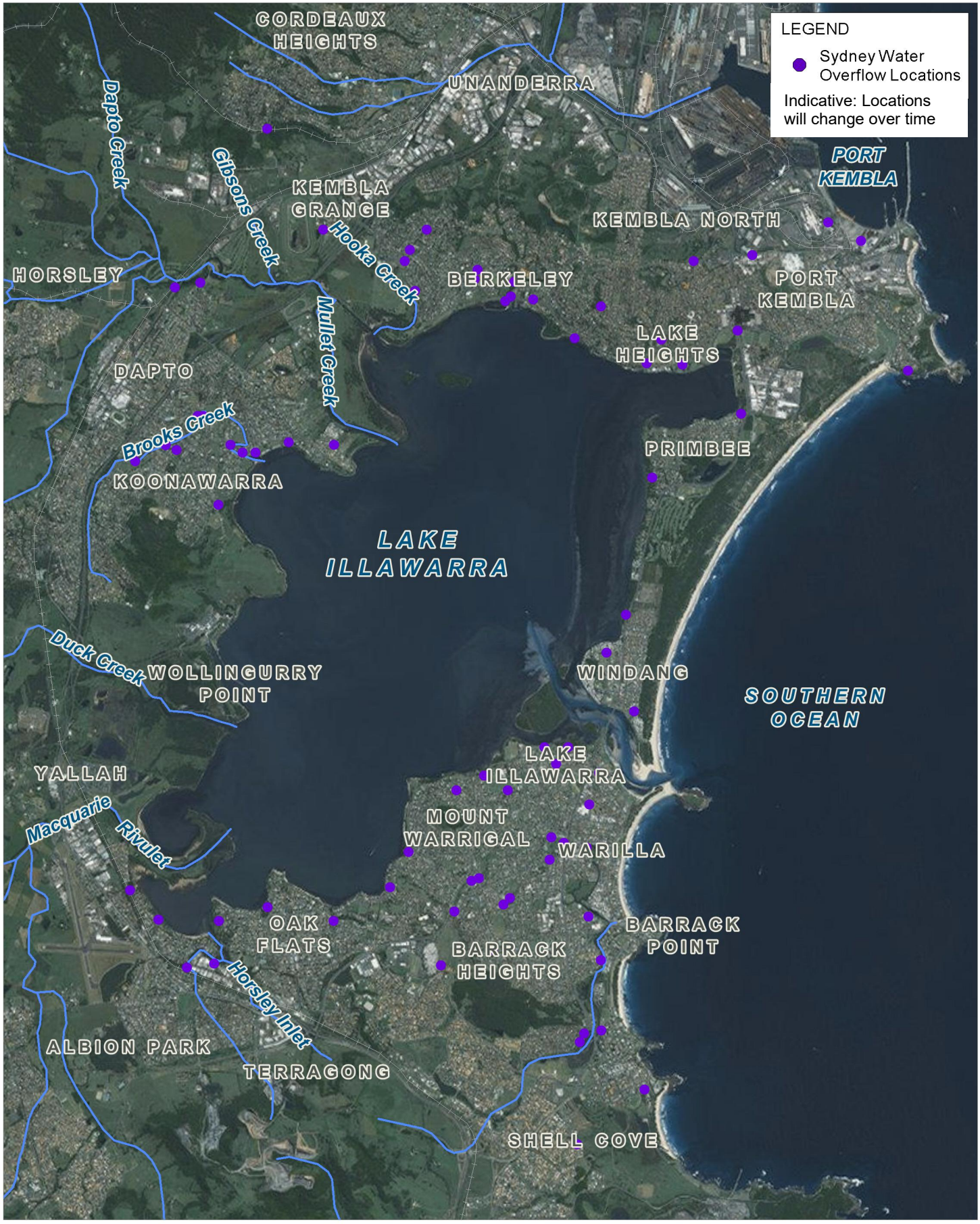
2.8.8 Groundwater Leachate

Groundwater discharges from historical and present day land uses are thought to be a source of contamination to Lake Illawarra. Potential sources of groundwater pollution include:

- Historical filling and slag disposal on the Windang Peninsula, including the Port Kembla Copper Site at Korrungulla;
- Primbee dunes as a source of nitrogen from nightsoil deposits;
- Haywards Bay slag land fill site;
- Warrawong tank trap;
- Tanneries at the woolshed and existing abattoir;
- Whytes Gully landfill depot, and
- Albion Park Fire and Rescue (FRNSW) site, as a source of per- and poly-fluoroalkyl substances (known as PFAS).

A map illustrating potential sources of groundwater contamination from known or potentially contaminated sites is provided in Figure 2-27.

The Windang Peninsula has been subjected to a number of waste disposal events since the early 1940s such as night soil deposits, copper slag emplacements, coal wash deposits, and septic effluent and screenings deposits. Recent monitoring indicates that Ammonia nitrogen within the aquifer is still well above ANZECC guidelines (e.g. Longhurst, 2015). Monitoring in the shallow edges of the Lake further indicates that ammonia entering the Lake from this source is attenuated rapidly, most likely through a combination of mixing and conversion to N_2 gas in the presence of oxygen. Further studies would be required confirm the biogeochemical cycling of high ammonia concentrations (Longhurst, 2015).



Title:

Sydney Water Designed Overflow Locations Lake Illawarra

Figure: **2-26**

Rev: **B**

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Approx. Scale

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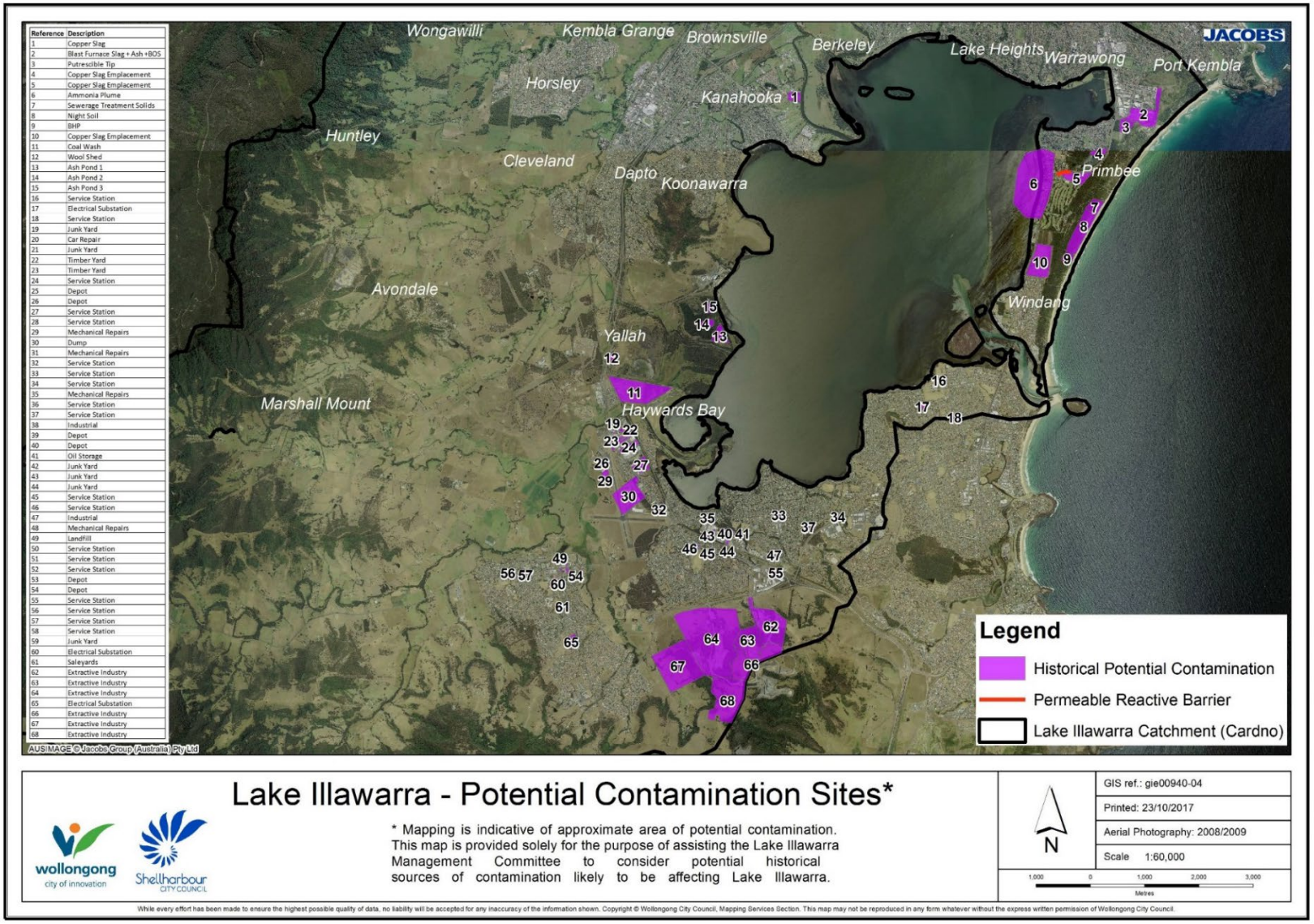


Reference	Description
1	Copper Slag
2	Blast Furnace Slag + Ash +BOS
3	Putrescible Tip
4	Copper Slag Emplacement
5	Copper Slag Emplacement
6	Ammonia Plume
7	Sewerage Treatment Solids
8	Night Soil
9	BHP
10	Copper Slag Emplacement
11	Coal Wash
12	Wool Shed
13	Ash Pond 1
14	Ash Pond 2
15	Ash Pond 3
16	Service Station
17	Electrical Substation
18	Service Station
19	Junk Yard
20	Car Repair
21	Junk Yard
22	Timber Yard
23	Timber Yard
24	Service Station
25	Depot
26	Depot
27	Service Station
28	Service Station
29	Mechanical Repairs
30	Dump
31	Mechanical Repairs
32	Service Station
33	Service Station
34	Service Station
35	Mechanical Repairs
36	Service Station
37	Service Station
38	Industrial
39	Depot
40	Depot
41	Oil Storage
42	Junk Yard
43	Junk Yard
44	Junk Yard
45	Service Station
46	Service Station
47	Industrial
48	Mechanical Repairs
49	Landfill
50	Service Station
51	Service Station
52	Service Station
53	Depot
54	Depot
55	Service Station
56	Service Station
57	Service Station
58	Service Station
59	Junk Yard
60	Electrical Substation
61	Saleyards
62	Extractive Industry
63	Extractive Industry
64	Extractive Industry
65	Electrical Substation
66	Extractive Industry
67	Extractive Industry
68	Extractive Industry

Figure 2-27 Lake Illawarra Potential Contamination Site (Jacobs, 2017)

Copper slag deposits are located towards the Korrungulla Swamp area. A recent study of the deposits and the direction of groundwater flow suggests that low metal concentrations are natural and independent of the copper slag emplacements (Longhurst, 2015). A reactive barrier made from steel furnace slag has been placed directly downgradient from the copper slag emplacements to intercept heavy metal-rich groundwater (Douglas Partners, 2012). As metals pass through the steel furnace slag, groundwater pH rises causing the precipitation of heavy metals, thus decreasing soluble metal concentrations within the aquifer (Longhurst, 2015).

A historical slag site is also located at Haywards Bay. Heavy metal and ammonia concentrations in groundwater within and downslope of the ash ponds were generally higher than background concentrations. However, these exceedances do not appear to be translating to the receiving surface water environment where concentrations are generally within background ranges. However, any future disturbance of this area has the potential to release contaminants.

PFAS is a group of manufactured chemicals that have been used since the 1950s in a range of common household products and specialty applications, including in the manufacture of non-stick cookware and fabric, food packaging, industrial processes and in some types of fire-fighting foam. There are many types of PFAS however the best known examples are perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), Perfluorohexane sulphonic acid (PFHxS). Table 2-13 describes some issues associated with PFAS.

Table 2-13 Fast Facts: Poly Fluorinated Alkyl Substances (PFAS)

What is PFAS and why is it an issue?
• PFAS are extremely stable chemical compounds that resist physical, chemical and biological degradation. • PFAS do not break down in the environment and can travel long distances in water and air currents making them a key environmental concern. • PFOS and PFOA have been shown to be toxic to some animals, and because they don't break down, they can bioaccumulate and biomagnify in some animals and humans higher up the food chain. • The toxicity, mobility, persistence and bioaccumulation potential of PFOS and PFOA pose potential concerns for the environment and for human health. PFAS has been linked to bladder and liver cancer, endocrine disruption and developmental and reproductive toxicity (including neonatal mortality).

The NSW EPA and FRNSW have investigated the presence of PFAS (per-and poly-fluoroalkyls substances) at the Albion Park FRNSW site, stemming from the historical use of fire-fighting foams (see GHD (2017a); GHD (2017b). This investigation is part of a NSW-wide investigation program being undertaken at sites where the EPA suspects PFAS was used in large quantities, including firefighting training areas, airports and industrial sites.

Five groundwater samples and five surface water samples were collected on-site and surrounding. All groundwater and surface water samples reported concentrations for PFOS/PFHxS above the 2017 Food Standards Australia New Zealand (FSANZ) screening values for the protection of drinking water. One on-site groundwater and one on-site surface water location reported concentration of PFOA above the FSANZ screening value for the protection of drinking water (GHD, 2017a).

The Phase 2 report (GHD, 2017b) investigated PFAS impact in surface water and sediments along drainage lines on and off site and Albion Creek to assess risks to down gradient Koona Bay, Lake Illawarra. Very low concentrations of PFAS were detected in sediment samples recovered from the shores of Lake Illawarra, however at the time of writing there was no screening criteria applicable for sediments. The two surface water sample sites within Lake Illawarra were not found to exceed the FNANZ drinking and recreational screening values, or the ecological screening values (GHD, 2017b).

Testing on biota within the Lake from the end of May to June 2018 has shown that no precautionary dietary advice is required for consumers of fish and seafood from Lake Illawarra and that there is no need to restrict recreational activities within Lake Illawarra. FRNSW will work with the EPA to develop a management plan for the site (D. Thompson, 2018, pers comms. 23 August).

Wollongong Waste & Recovery Park, at Whytes Gully is within the Mullet Creek catchment, and has been Wollongong's primary landfill site since the early '80s. Council is currently in the process of constructing a deep leachate drainage system in the western gully of the landfill depot to manage ammonia leachate. This is in preparation for a planned increasing of landfill capacity at the site. The approved landfill project will provide approximately six million cubic metres of additional landfill capacity at Whytes Gully. Upgrades to the site will include improved pollution control measures.

The implications of groundwater contamination to Lake Illawarra may include toxicology in the case of heavy metals and contribution to eutrophication including algal blooms for ammonia. Given the complexity of groundwater hydraulics and water quality processes, specific quantification of the impacts to Lake Illawarra are not clear. The cumulative impact of multiple pollution sources on the Lake remains one of the key challenges for the CMP.

2.8.9 Sediment Quality

Historical and present intense industrial and agricultural land uses in the catchment dating back to the late 1800s have left a legacy of contaminants within the sediments of Lake Illawarra. Sediment cores extracted from the bottom of Lake Illawarra confirm the presence of a number of metals including copper, zinc, arsenic, selenium, cadmium, and lead. Heavy metal concentrations in the sediments amongst saltmarshes in Lake Illawarra are up to 200 times greater than in other south coast areas (Chenhall et al., 1992). It is not known to what extent these contaminants may affect the saltmarsh plants.

Metal accumulation in sediments in Lake Illawarra reflects the historical events, and industrial land uses in the catchment over the past 100 years or more. Historical and present day industrial land uses include steel production at Australia's largest steelworks BHP Steel (commencing operations in 1928, with Blue Scope Steel still remaining in the catchment today), Port Kembla Copper refining and smelting plant (commenced in 1908 and closed in 2003), the Tallawarra Power Station (originally coal generated, now gas generated) (Schneider et al., 2015), and other industrial premises that remain within the catchment, as discussed in Section 2.8.4. Windang Peninsula, located along the eastern shores of the Lake, was a historical site for the deposition of copper slag whilst Tallawarra Ash Dam adjacent to Duck Creek was the site for ash deposition from the power station during the six years from 1983 to 1989 (Schneider et al., 2015).

Currently, both copper and zinc exist in Lake Illawarra sediments at concentrations that exceed the Australian and New Zealand sediment quality guideline at specific locations. Exceedances of the sediment guidelines took into account the background concentrations of the metals naturally occurring in the geology and soils of the region, such as copper in the Gerringong Volcanics. The greatest concentrations of metals in sediment occurred at those locations closest to Port Kembla, confirming industrial processes as the source of contamination. Wegit and Minnegang Creeks located close to Port Kembla are also reported to discharge metal contaminated sediments into the Lake, via Griffins Bay. Griffins Bay has had elevated metal levels compared to areas in the Lake further south. Similarly, metal contamination in the Lake that has occurred since the 1960s has coincided with the opening of Tallawarra Power Station on the western shores of the Lake in 1954, and which continued to use coal until 2009 (Schneider et al., 2015).

2.8.10 Sedimentation from Catchment Development

Sediment supply from clearing and catchment development is an important consideration for Lake Illawarra, given the amount of development currently occurring and planned for the catchment.

As described in Section 2.5.3, fluvial deltas are evident at the inlets of tributary creeks to Lake Illawarra. A historical analysis of the Macquarie Rivulet delta indicated a progradation rate increase during the mid-1970s through the 1980s in response to nine flood events (Hean & Nanson, 1985). During the 1990s the progradation rate slowed, and this coincided with a reduction in flood frequency and a decrease in the average annual number of dwellings constructed, suggesting the urban and commercial expansion in the catchment was likely to have contributed additional sediment to the system (Hopley et al., 2007).

Increased sedimentation is also evident near Hooka Point near Hooka Island and is likely derived from the West Dapto Development and creation of the tank trap. Sedimentation from catchment development is managed separately by both councils through their Development Control Plans (refer to Appendix A). The ultimate design of the stormwater management for a development, incorporation of Water Sensitive Urban Design (WSUD) principles and sediment and erosion controls during construction is assessed and approved by Council.

In the past, criteria set by the LIA for developments may not have been as stringent as criteria that would be set today, which leaves a legacy issue for Council. Particularly where the developer is also no longer involved. An example of this is at Haywards Bay. Further discussion regarding catchment pressures and land use planning is given in the following section.

2.8.11 Weeds and Pests

Since early European settlement in the 1800s, the Illawarra region, like many settled areas, has been victim to weed invasion. Presently there is over 200 known weed species, most of which are environmental weeds and pose threats to biodiversity. A number of these species are listed as noxious weeds as they threaten biodiversity by outcompeting native plants, reducing the diversity of flora and inevitably fauna by changing food sources available. These weeds include introduced species of grasses, shrubs, trees, vines, and aquatic weeds (WCC, SCC & KMC, 2011). In particular, mowed introduced grass species along the banks of Hooka Creek have been conducive to erosion into the channel (LIA, 2013a).

Another result of early European settlement was the introduction of over 220 terrestrial animal species, many of which established significant populations that pose threats to biodiversity. Pests have seen the extinction and vast reduction of native species of flora and fauna as they provide competition for food sources and degrade natural habitats. Pests in Lake Illawarra include pigs, foxes, Indian Myna birds, and rabbits (WCC, SCC & KMC, 2011). Predation of shorebird nests by foxes is noted to have been an issue for consecutive breeding seasons.

Other than their presence, pests can pose a risk to biodiversity by overgrazing, land degradation, weed dispersal, acceleration of erosion, preying on native species, providing competition for food resources and nesting sites. These factors can result in degrading water quality by increasing sedimentation rates, increasing nutrient levels, and changing ecosystems, ultimately impacting on estuary health, such as cattle grazing along the Lake's tributaries (WCC, SCC & KMC, 2011).

The *Biosecurity Act 2015* (BS Act) explains how biosecurity threats to plant, animal and human health in Australia is managed. Under the BS Act, all community members have a general biosecurity duty to prevent, minimise or eliminate any biosecurity risk. The Lake is covered by the South East Regional Strategic Pest Animal Plan 2018-2023.

2.8.12 Catchment Pressures & Land Use Planning

The Lake Illawarra catchment experiences water quality issues that generally originate in the upland escarpment areas of the catchment. Recent modelling using DPIE's CERAT as part of the Coastal Management manual-toolkit was used to create regional mapping to inform land use planning and management within the Lake Illawarra catchment. These maps highlight priority areas in need of management to reduce any impacts on the Lake's water quality and the community's uses and values (Dela-Cruz et al., 2016).

Using CERAT, three major outcomes were delivered, including: determining the existing steady-state runoff volumes, and nutrient & sediment loads for different land uses; identifying areas posing the greatest risks to water quality and ecological health; and identifying opportunities for the beneficial management of stormwater in light of future developments and the community's expectations within the catchment. A summary of the processes used to derive each outcome and the findings is given below.

Existing steady-state runoff volumes and nutrient and sediment loads for different land uses

Existing runoff and nutrient and sediment loads in the catchment were estimated from revised versions of models developed as part of the *NSW Monitoring, Evaluation and Reporting Strategy 2010-2015*. The average annual median runoff was estimated using the 2CSalt model simulated for a 40 year period (1970-2008), and calibrated against available flow data for the Lake's catchment and surrounding catchments with similar climate zones (Littleboy et al., 2009). Mean nutrient (total nitrogen (TN) and total phosphorus (TP)) loads and total suspended solids (TSS) were estimated using an export-coefficient model and checked against recent publications specific to NSW and Victoria to ensure relevance of the data (OEH, 2011; Bartley et al., 2012). The outcomes of the modelling showed:

- The current total nitrogen concentrations originating in the upland catchment areas were approximately 20% greater than the sustainable total nitrogen loads for the Lake (Dela-Cruz et al., 2016);
- The catchment escarpment and urban areas exhibited higher runoff per hectare attributed to higher rainfall and increasing impervious areas, respectively;
- Nutrient and sediment loads generally mirrored the intensity and type of land uses, whereby the greatest nutrient and sediments loads per hectare was experienced in the north-west areas of the catchment and the Lake's periphery; and
- Total runoff and nutrient & sediment loads were greatest in larger sub-catchments such as Calderwood and Marshall Mount.

Risks to estuary health

The risks to water quality and ecological health were determined using an effects-or-outcome assessment (Scanes et al., 2007; Sanderson & Coade, 2010; Dela-Cruz et al., 2016). The catchment model outputs were used as inputs in the hydraulic and ecological response models to predict the flushing of the Lake (transport of surface flows out of the Lake) and the consequent risk to the ecological condition of the Lake from TN loads (see Figure 2-28 and Figure 2-29). The hydraulic response model was based on regime theory modelling and incorporated coefficients to account for the trained entrance of the Lake. The ecological response CERAT model was used to determine the ecological condition of the Lake using the concentration of microalgae (chlorophyll) and water clarity in the Lake – two measures that predictably respond to nutrient loading in the catchment – used in the WCC health report card for the Lake (WCC, 2015) and in the State of Environment Reporting to compare the health of estuaries across NSW (EPA, 2016).

Both models were developed to examine the Lake's response to individual sub-catchment parameters and as such, determined a ranking of each sub-catchment (1-4) based on risk to impact where 1 is low and 4 is a high risk to impact. However, due to the lack of comprehensive information and data regarding the attenuation of nutrients and sediments in watercourses draining into the Lake, mapping containing the susceptibility of the Lake's tributaries to various land use activities and their proximity/connectivity to the Lake was used to cross-reference the risk to impacts. This infers that tributaries directly exporting sediments and nutrients to the Lake pose higher risks than streams with indirect connections. To supplement data gaps in community values of the Lake, aquatic assets including EECs previously listed under the *State environmental planning policy no. 14 – Coastal Wetlands* (SEPP 14) were used.

Using the data, each variable (runoff, nutrient/sediment attenuation, connection to the Lake, and aquatic assets) was categorised using a likelihood/consequence criterion (see Table 2-14 to Table 2-16) with the overall risk determined using a risk matrix to identify diffuse sources of impacts on ecological health (see Figure 2-30). From the assessment, it was found that:

- The highest risk area was the sub-catchment draining Marshall Mount, followed by two high risk areas along the periphery of the Lake;
- A number of moderate risk areas were located around the periphery of the Lake;

- The lowest risk areas were generally located in the southern reach of the catchment; and
- The escarpment area was mostly classed as a low to moderate risk.

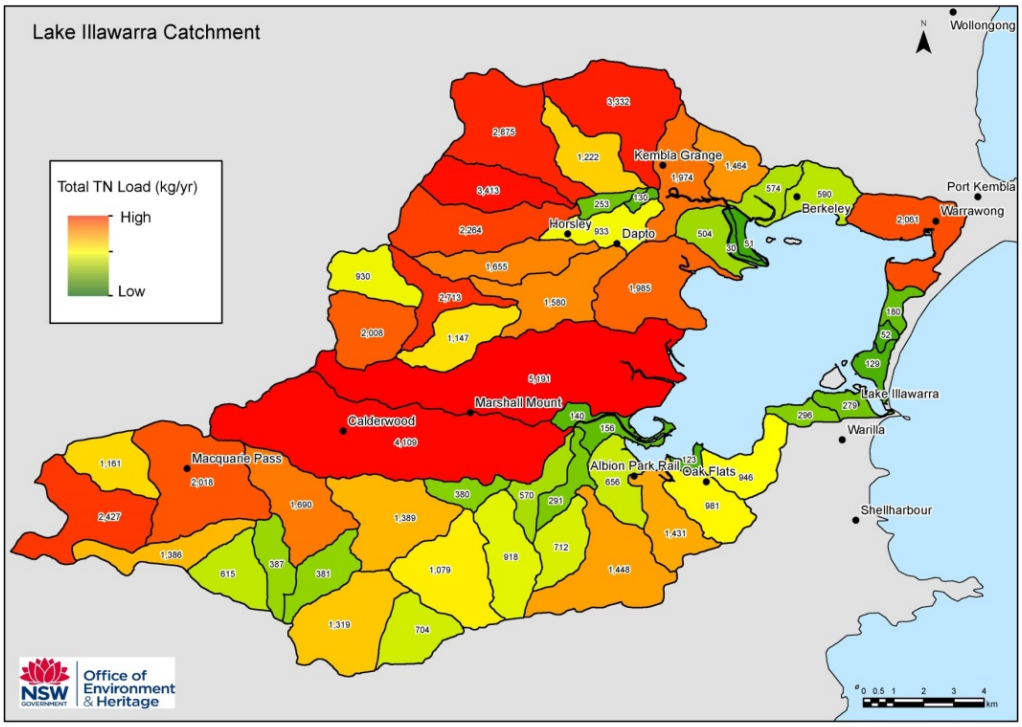


Figure 2-28 Lake Illawarra Catchment Total Nitrogen Loads (OEH, 2016)

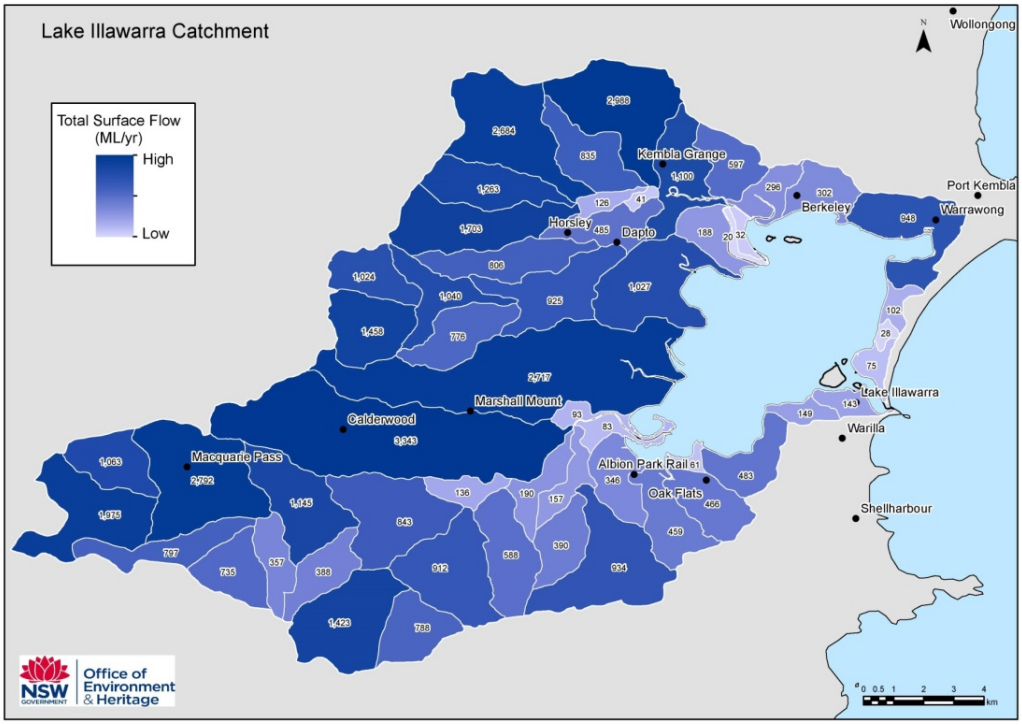


Figure 2-29 Lake Illawarra Catchment Total Surface Flows (OEH, 2016)

Table 2-14 Likelihood criteria for assessing risks to estuary health (OEH, 2016)

Likelihood	Score	Description
High	4	High chance of impacting the Lake because the surface flows from sub-catchment take > 3 days to flush from the Lake, the average TN loads exported per hectare from the sub-catchment are > 75th percentile of respective loads, the sub-catchment is directly connected to the Lake and the weighted average stream fragility index for the sub-catchment indicates that the streams have relatively high susceptibility to degradation from land use activities
Moderate	3	Moderate chance of impacting the Lake because the surface flows from sub-catchment take > 2 and ≤3 days to flush from the Lake, the average TN loads exported per hectare from the sub-catchment are > 50th but ≤ 75th percentiles of respective loads, the sub-catchment is not directly connected to the Lake and the weighted average stream fragility index for the sub-catchment indicates that the streams have relative moderate susceptibility to degradation from land use activities
Low	2	Low chance of impacting the Lake because the surface flows from sub-catchment take > 1 and ≤2 days to flush from the Lake, the average TN loads exported per hectare from the sub-catchment are > 25th but ≤ 50th percentiles of respective loads, the sub-catchment is not directly connected to the Lake and the weighted average stream fragility index for the sub-catchment indicates that the streams have relatively low susceptibility to degradation from land use activities
Very Low	1	High chance of impacting the Lake because the surface flows from sub-catchment take ≤ 1 day to flush from the Lake, the average TN load export per hectare from the sub-catchment are < 25th percentile of respective loads, the sub-catchment is not directly connected to the Lake and the weighted average stream fragility index for the sub-catchment indicates that the streams have relatively very low susceptibility to degradation from land use activities

Table 2-15 Consequence criteria for assessing risks to estuary health (OEH, 2016)

Consequence	Score	Description
High	4	Relative concentrations of chlorophyll a and water clarity as a result of surface flows and total TN loads from the sub-catchment are within the > 75th percentile of respective values estimated for the Lake; surface flows and nutrient and sediment loads from the sub-catchment drain directly to aquatic assets
Moderate	3	Relative concentrations of chlorophyll a and water clarity as a result of surface flows and total TN loads from the sub-catchment are within the > 50th and ≤75th percentile of respective values estimated for the Lake; surface flows and nutrient and sediment loads from the sub-catchment do not drain directly to aquatic assets
Low	2	Relative concentrations of chlorophyll a and water clarity as a result of surface flows and total TN loads from the sub-catchment are within the > 25th and ≤50th percentile of respective values estimated for the Lake; surface flows and nutrient and sediment loads from the sub-catchment do not drain directly to aquatic assets
Very Low	1	Relative concentrations of chlorophyll a and water clarity as a result of surface flows and total TN loads from the sub-catchment are within the ≤25th percentile of respective values estimated for the Lake; surface flows and nutrient and sediment loads from the sub-catchment do not drain directly to aquatic assets

Table 2-16 Risk matrix to rank sub-catchments according to their risk of impacts on estuary health (OEH, 2016)

		Likelihood			
		High (4)	Moderate (3)	Low (2)	Very Low (1)
Consequence	High (4)	16	12	8	4
	Moderate (3)	12	9	6	3
	Low (2)	8	6	4	2
	Very Low (1)	4	3	2	1

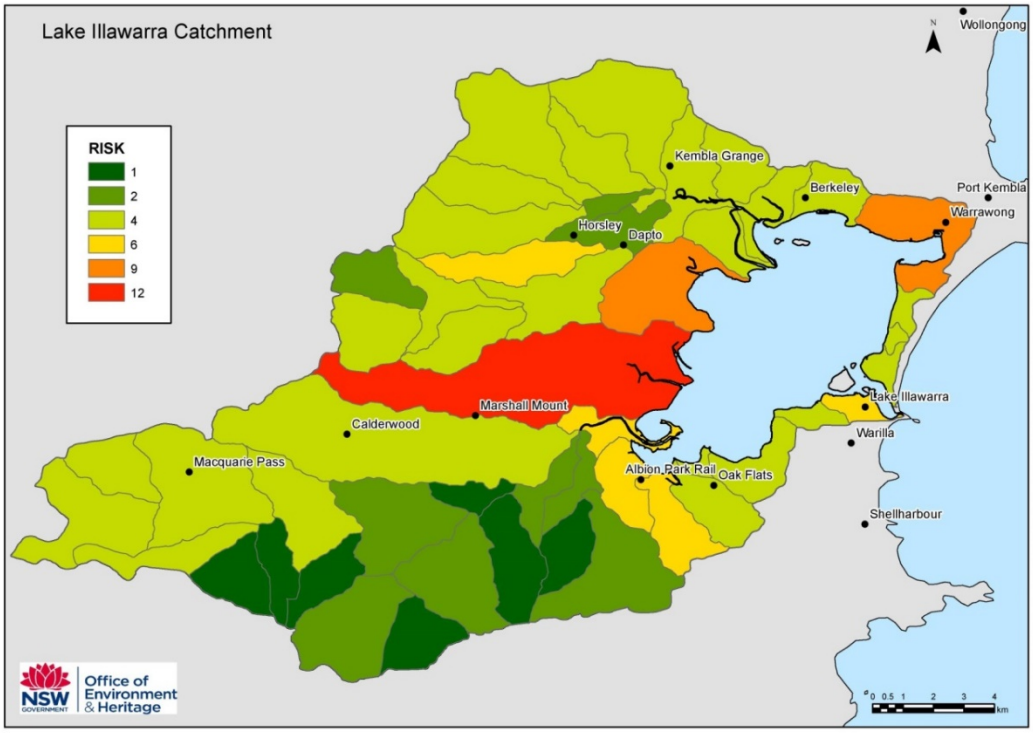


Figure 2-30 Sub-catchment Risk to Estuary Health

Cost-benefit analysis & opportunities for management

As recommended in the Illawarra-Shoalhaven Regional Plan, a risk-based framework for managing water quality and ecological health in Lake Illawarra was used as a first pass assessment based on achieving environmental outcomes, particularly in consideration of strategic planning and the development costs for stormwater management.

The benefit maps represent the outcomes of strategic impact assessments with consideration of trade-offs to achieve cost-effective management of stormwater from proposed developments in the catchment's rural areas. The strategic impact assessment showed:

- The sustainable TN load for the Lake cannot cost-effectively be achieved solely using conventional stormwater devices under greenfield (forested) development scenarios;
- There is a need for catchment planning that considers the co-benefits of restoring riparian corridors and the adoption of water sensitive approaches to water quality management (Walsh et al., 2016);
- Appropriate flow targets based on ecological condition triggers for various geomorphic types of the Lake's tributaries need to the determined; and
- Re-developments and brownfield (rural/agricultural) developments using stormwater treatment targets outlined in WCC's DCP can improve the water quality and ecological health of the Lake (Dela-Cruz et al., 2016).

In consideration of these factors, the current benefit mapping showed:

- Areas labelled 'improve' demonstrate cost-effective applications of the most stringent stormwater quality controls to achieve sustainable TN loads. These sub-catchments were mostly located on the periphery of the Lake in urbanised areas (BMT WBM & AR Volders, 2015);
- Areas labelled 'maintain' demonstrate no net increase targets for stormwater management. These sub-catchments were generally located in the southern portion of the catchment; and
- Areas labelled 'maintain or improve' provide flexibility and could be utilised as environmental offsets for areas where controls cannot be met located in the 'improve' or 'maintain' zones. These sub-catchments were mostly located in the escarpment areas of the catchment, with some located on the periphery of the Lake.
- The CERAT modelling mapping can be used to identify a sustainable TN load using a well-established ecological condition trigger explicitly linked to the community's values and uses of the Lake and its tributaries to cost-effectively manage water quality and ecological health in Lake Illawarra. Using a cost-benefit analysis of management options to achieve sustainable TN loads it was found that:
    - The reductions required to achieve a sustainable TN load for low density residential developments were between 25 to 89% and depending on the existing land use;
    - Under most development scenarios, the capital cost of achieving 25 to 89% reductions of TN loads is greater than the cost of achieving the 45% reduction targets specified in the WCC's DCP;
    - The remediation costs of potential stormwater impacts on the Lake outweigh the lifecycle costs of the stormwater infrastructure (BMT WBM & AR Volders, 2015); and
    - The overall financial benefits of maintaining or improving ecological health of the Lake were estimated to be greater than the costs acquired for managing stormwater. However, the financial benefits were limited to direct uses such as tourism and fishing and are likely to deliver a broader range of benefits provided by a health lake (Weber et al., 2015).

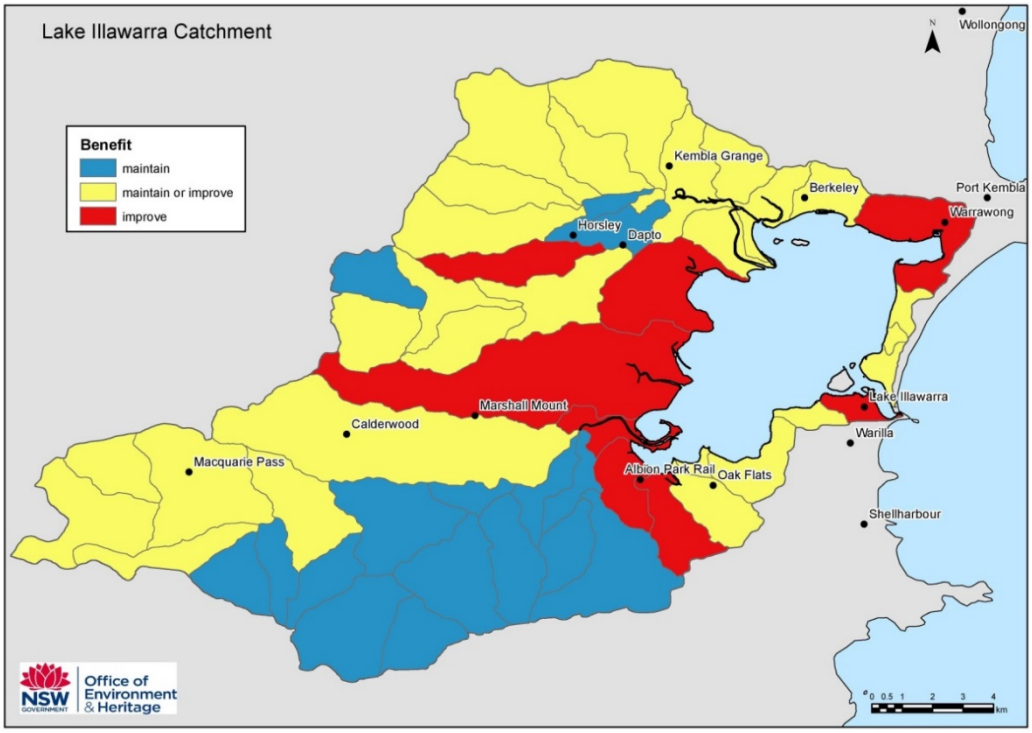


Figure 2-31 Benefit Maps Prepared through the CERAT

2.8.13 Key Implications for Development of the Coastal Management Program

Based upon the above information, the following issues and future management actions are suggested:

- Historical and present day catchment activities including agriculture, land clearing, various industrial uses, sewerage overflows, and urban development have left a legacy of contaminants within the sediments of Lake Illawarra, most notably nutrients and metals. Nutrients may cause algal blooms and eutrophication, while metals have varying and sometimes unknown detrimental impacts to aquatic fauna and flora.
- Substantial development is planned for the Lake Illawarra catchment. Proper management of stormwater runoff from the proposed urban release areas will be vital for ensuring pollutant loads and water volumes to the Lake are not increased.
- Establishing the link between catchment contaminant loads and ecological response in the receiving environment is ongoing, with the aim of retaining the level of change to Lake Illawarra at an acceptable level into the future. CERAT modelling is available for indicative catchment loads, relative changes and trends. Based on the CERAT modelling areas of benefit were identified in relation to runoff rates and nutrients and sediments. Areas identified 'improve' should be focused on for water quality improvement measures implemented.

2.9 Climate Change Considerations

As estuaries are by definition a transition zone between land, freshwater and marine habitats, the effects of climate change are likely to be prevalent within these transitional habitats. The dynamic and multifaceted nature of estuaries and coastal Lakes makes climate change predictions in these habitats complex, especially with consideration to anthropogenic stressors. These impacts are likely to extend to increased dissolved CO_2 concentrations, ocean and water temperatures, the rate and magnitude of precipitation, salinity levels, sediments, dissolved oxygen concentrations, and the circulation and exchange between freshwater with sea water due to altered sea level circulation. Furthermore, climate change is likely to result in increased water levels in the Lake as a result of more frequent extreme weather events (Gillanders et al. 2011).

2.9.1 Altered Storm and Cyclone Activity

Increased storm and extreme weather activity along the NSW coast, caused by east coast lows, is likely to result in widespread impacts, particularly concentrated along the coastline. Climate change is expected to cause an increased frequency in the occurrence of east coast lows events, leading to heavy beach erosion, periods of decreased salinity in estuarine waters, increased sediment and nutrient loads in coastal and estuarine waters, and greater amounts of plastic rubbish and marine debris in circulation. In conjunction to environmental impacts, increased east coast lows events will heighten the vulnerability of developments located at current high-tide levels to inundation. This vulnerability will only continue to increase as sea levels rise and stormwater drainage becomes less effective at draining urban areas near estuaries during catchment flooding.

The combined effect of catchment flooding and coastal inundation makes properties located in coastal estuaries particularly susceptible to inundation and widespread damage (SKM, 2009). The likely increase in catchment and coastal flooding is predicted to impact an extra 534 to 1386 properties (see Table 2-17) under various climate change scenarios due to elevated water levels in the Lake, its tributaries and the ocean (Cardno, 2012b).

Changes in rainfall trends across Australia have become more evident since the 1950s (Cardno, 2009). In eastern areas of Australia, trends have shown up to 50mm decreases in rainfall per decade with corresponding increases in winter and summer drought events and more extreme rainfall events (CSIRO, 2007; Cardno, 2009).

Table 2-17 Total Cadastral Lots Affected Under the 100 Year ARI Flood and Various Climate Change Scenarios (Cardno, 2012b)

Climate Change Scenario	Number of Cadastral Lots Affected	Increase Number of Cadastral Lots Affected Over Current
Current (No SLR)	2621	0
0.18m SLR	3155	534
2050 SLR (0.4 m)	3492	871
2050 SLR + 20%	3814	1193
2100 SLR (0.9 m)	4007	1386

Rainfall projection outputs for the NSW coast from the NSW and ACT Regional Climate Modelling (NARCliM) project show an increase in summer and autumn rainfall, with a decrease in winter and spring predicted to occur by 2030 (OEH, 2015). The modelled mean annual rainfall is projected to decrease by up to 3% for southern NSW by 2030 and rainfall erosivity projections see an increase in rainfall intensity of 20% in the Hunter, Central Coast, and Sydney regions (OEH, 2015). These increases in erosivity are likely to result in greater volumes of nutrients and sediments being discharged into estuarine and coastal waters such as Lake Illawarra, with negative implications for water quality, ecological health and estuary health.

Another weather system affected by climate change is wind, driving extreme weather events such as east coast lows. As Lake Illawarra is an exposed coastal lagoon, sustained high wind speeds are common, and could possibly become more extreme. The current dominant winds in the Lake Illawarra region originate from the south-east during winter, and north-east and east during summer (Cardno, 2009). Under climate change conditions, mean wind speeds are likely to increase across NSW during summer and decreased from the north-east. During autumn, stronger winds from the north-west are expected and stronger north-west and southerly winds are expected for winter, with a general tendency for winds during spring to increase across the state (Cardno 2009). However, on a more local scale, a modelled change in average wind speed at Kiama was between -1.3% and +1.6% by 2030, and -3.9% and +4.9% by 2070 (Holper et al., 2005). Overall, wind speeds are predicted to increase over spring and summer, and decrease during autumn and winter (Holper et al., 2005). As Lake Illawarra is a barrier estuary, wind waves and wind-induced flows are vital for water circulation. Extreme changes to the current wind regimes could cause erratic mixing of the Lake, stratification of the water column, erosion of the Lake's foreshore, and increased sedimentation resulting in shallowing of the Lake and potential segmentation via sandpits from longshore transport. Additionally, wind waves could impact on low-lying properties located on the Lake's periphery (Webb, 2006).

2.9.2 Sea Level Rise Measurements to Date

Global mean sea level rose about 1.6 mm/year on average during the 20th Century (CSIRO, 2016a). Since 1992, high quality measurements of sea level rise have been made by satellite altimeters. From 1992 to present, Global Mean Sea Level (GMSL) has risen at a rate of around 3.2 ± 0.4 mm/year (CSIRO, 2016b). The rate of sea level rise over the past 20 years is therefore about double that of the previous century. If the rate of sea level rise were to remain at its present level of 3.2 mm/year, sea level can be expected to be nearly 0.3 m higher than at present by 2100.

However, projections for sea level rise of about 0.9 m by 2100 (above 1990 sea level), as given by CSIRO (2015) and IPCC (2014), are based on the rate of sea level rise more than doubling from its present rate of 3.2 mm/year. This is not unreasonable given that the rate of sea level rise has already doubled over the last 20 years. The current rate of rise is also tracking along the rate expected under the highest carbon emission scenario modelled by CSIRO (2015) and IPCC (2014).

2.9.3 Future Projections for Sea Level Rise

The repeal in 2012 of the *NSW Sea Level Rise Policy Statement 2009* means that prescribed state-wide sea level rise benchmarks no longer apply to coastal assessments of future risk, such as for

this CMP. The NSW Government indicated that local councils "have the flexibility to determine their own sea level rise projections to suit their local conditions" (NSW Environment and Heritage, 2012), although no guidance was given to local councils on how this should be done. In lieu of prescriptive sea level rise benchmarks, DPIE - Coasts & Estuaries advised that councils should adopt sea level rise values that are "widely accepted by competent scientific opinion" (OEH, 2013).

Based upon the recent projections and the former sea level rise benchmarks, the following sea level rises listed in Table 2-18 were considered adequate when assessing future coastal inundation risks in Lake Illawarra. Coastal inundation risks associated with elevated ocean water level events are discussed in Section 2.9.4, including future risk with sea level rise. These risks include inundation of wetlands; reducing saltmarsh areas; asset and property inundation and risks to estuary health. Permanent inundation risks associated with sea level rise alone are discussed in Section 2.9.5.

Table 2-18 Sea Level Rise Projections used for this CMP

Risk Scenario	SLR Value Adopted	Rational and Reference
Immediate	**0.0 m**	This is consistent with OEH (2013) and other legislative guidance for the "immediate" timeframe, or, the present sea level.
High	**0.4 m** (above 1990 levels)	This is equivalent to either: • The lower value given by CSIRO (2015) for the highest emission scenario by 2090 (of 0.45 m); or • The current rate of sea level rise of 3.2 mm/year ± 0.4 mm, extended to the end of the century (CSIRO 2016b); or • The upper value given by CSIRO (2015) for the highest emission scenario by 2050 (of 0.36 m), which is consistent with previous scientific projections for 2050 given by IPCC (2007) plus CSIRO (2007), and the former NSW Policy Statement. Under any of the above scenarios, we may expect to reach a 0.4 m higher sea level, therefore a "high" risk is considered appropriate.
Low	**0.9 m** (above 1990 levels)	This is equivalent to the upper value given by CSIRO (2015) for the highest emission scenario by 2090 (of 0.88 m), and is also consistent with previous scientific projections for 2100 (IPCC 2007 and CSIRO 2007, as used in the former NSW Policy Statement). As the projection is an upper bound value, a "low" risk level is considered appropriate.

2.9.4 Coastal Inundation During Storms

Inundation levels inside Lake Illawarra due to present day ocean water level events, and such events at 2050 and 2100 were modelled by Cardno (2010, 2012a). The levels used by Cardno (2010, 2012a) as the ocean boundary conditions for inundation modelling within Lake Illawarra are shown in Table 2-19. Model results for flooding and sea level rise scenarios were illustrated in Figure 2-14 (Section 2.5.4).

The 100 year Average Recurrence Interval (ARI) ocean water level for the present day of 1.44 m AHD was derived from guidance by DPIE - Coasts & Estuaries (formerly DECCW) for Fort Denison in Sydney. Given the consistency in ocean tide levels along the NSW coast, the levels for Fort Denison were considered suitable for the entrance to Lake Illawarra.

For the future time periods of 2050 and 2100, Cardno (2010, 2012a) adopted a projected sea level rise of 0.4 m and 0.9 m respectively, in keeping with the former *NSW Sea Level Rise Policy Statement* state-wide benchmarks applicable at that time. While statewide benchmarks are no longer prescribed, these projections are considered to adequately represent a high and low risk scenario for future sea level rise.

Wave set up was not included in the ocean water level boundary conditions, as swell waves do not penetrate into the estuary further than Windang Bridge, and as such, do not shoal and break to generate wave set up.

The model was run to determine the water level within the Lake separately for each ocean boundary condition. Cardno (2010) found that the peak ocean still water levels are modified in the estuary due to tidal attenuation through the Lake entrance. For example, the peak 100-years ARI storm ocean water level of 1.44 m AHD translated into an estuarine water level of 0.7 m AHD upstream of Windang Bridge. A map of the coastal inundation extents derived by Cardno (2010) is provided in Figure 2-32.

Table 2-19 Ocean Water Level Boundary Conditions for Coastal Inundation Modelling

Ocean Water Level Scenario	Indicative Timeframe	Water Level (m AHD)
Immediate: 100 yr. ARI ocean water level	Present Day	1.44
High risk: 100 yr. ARI ocean water level + 0.4 m SLR	2050	1.84
Low risk: 100 yr. ARI ocean water level + 0.9 m SLR	2100	2.34

It is standard practice to analyse coastal inundation due to ocean water levels without the influence of catchment rainfall, for the purpose of a coastal risk assessment. A listing of all assets potentially affected by coastal inundation (without rainfall) for Wollongong LGA is provided in Appendix D and for Shellharbour LGA is provided in Table D-8. These tables were reproduced from the *Wollongong Coastal Zone Management Plan: Management Study* (BMT WBM, 2017c) and the *Lake Illawarra Coastal Risk Assessment* (BMT WBM, 2013) respectively. Areas affected by coastal inundation around the Lake include residential properties and public land immediately north and south of the

entrance channel, Windang peninsula, the Kemblawarra area, land and properties adjacent to Macquarie Rivulet, and low-lying areas on the Lake's periphery.

The impact of catchment rainfall alone and then combined with elevated ocean water levels is typically assessed as part of a floodplain risk management plan, as conducted by Cardno (2012b) in the Lake Illawarra Floodplain Risk Management Study. The model results showed inundation levels relating to ocean water levels alone to be consistently lower than water levels from a 100 year ARI catchment rainfall inundation event alone (i.e. excluding elevated ocean levels), for all planning horizons (Cardno, 2010; 2012b).

Wave run up and overtopping was not investigated for Lake Illawarra, as waves were said to be typically small wind waves (Cardno, 2010). Cardno (2010) assumed wave run-up and overtopping of the Lake foreshore would be attenuated within 10 m of the shoreline. This is a reasonable assumption given that Cardno (2010) found under full ocean wave conditions, wave overtopping rarely exceeded 50 m from the shoreline.

The 10 m wave run-up buffer has not been mapped or added to the inundation mapping. However, wave run up is typically greatest at the peak of the high tide, and so, not all waves during a storm will run up or overtop a coastal barrier. The modest run up levels recommended by Cardno (2010) would be expected to dissipate into the ground, stormwater system or flow back to the Lake.

2.9.5 Tidal Inundation with Permanent Opening and Sea Level Rise

While coastal inundation occurs during storm events will periodically increase water levels within the Lake, there may also be more frequent or permanent impacts upon the Lake's water levels and foreshores due to the sustained increase in the Lake's tidal range due to the permanent entrance opening; and additionally due to sea level rise. This risk is defined in the Coastal Management Act 2016 as "tidal inundation".

To support the preparation of the Lake Illawarra CMP under the NSW Coastal Management Framework, an updated assessment of the tidal inundation risks was completed, and is documented across two reports, as follows:

- The Lake Illawarra Hydrodynamic Inundation Modelling assessment completed by Kumbier et al (2019); and
- The Tidal Inundation Risk Assessment, completed by BMT (2020a) as Appendix D of the in the Community Uses, Values, Threats and Opportunities Report.

The model scenarios investigated by Kumbier are summarised in Table 2-20 and are described below.

For each timeframe, Kumbier et al (2019) modelled two tidal planes, being:

- The Mean High Water Spring (MHWS), which represents the spring tidal level occurring approximately monthly, and
- The High High Water Solstice Spring (HHWSS) which is the highest spring tide occurring around twice per year, commonly referred to as a "king tide".

Four timeframes were chosen for model output, being the present day (represented as 2016, as this is the date for measured tidal data used in the modelling), 2040 (representing 20 years from present), 2070 (representing 50 years from present) and 2100 (being the commonly applied planning horizon in NSW and generally the longest available projection date for sea level rise).

An important element of the assessment of tidal inundation in Lake Illawarra into the future is that permanent opening has exposed the Lake to regular ocean tides. The tidal range within the Lake waterbody has been measured to be increasing at a steady rate since permanent opening of the entrance in 2007, and this is expected to continue into the future (MHL, 2013; Wiecek et al., 2016). The permanent entrance has opened the entrance channel to significantly enhanced tidal current velocities that are acting to scour and change the shape of the entrance channel. The increased and increasing hydraulic efficiency of the channel is then gradually exposing the Lake waterbody to greater tidal influence, with the Lake waterbody experiencing an ongoing increase in tidal range (being the difference in water level between a low and high tide).

Based upon the analysis of tidal gauge information by Wiecek et al (2016), a tidal range increase of 8mm/year for MHWS, and of 12 mm/year for HHWSS was projected for modelling each future timeframe.

Sea level rise poses an additional element to this existing tidal inundation risk, which will increase the average lake water level and the high tide level above this. For the tidal inundation modelling scenarios, sea level rises above AHD in 2015 of 0.17 m (2040), 0.5 m (2070) and 0.98 m (2100) were adopted, based upon the High projections for RCP8.5 locally adjusted for the south coast (Whitehead and Associates, 2014). RCP8.5 or Representative Concentration Pathway 8.5 is the very high greenhouse gas emissions scenario modelled for the IPCC's fifth climate change assessment report (Climate Change 2014 Synthesis Report, or AR5). The IPCC (2014) indicates that if RCP 8.5 is realised, the Low to High projections are the *likely* range for sea level rise. The High projections equate to the high value for which 95% of IPCC model outputs were equal to or less than.

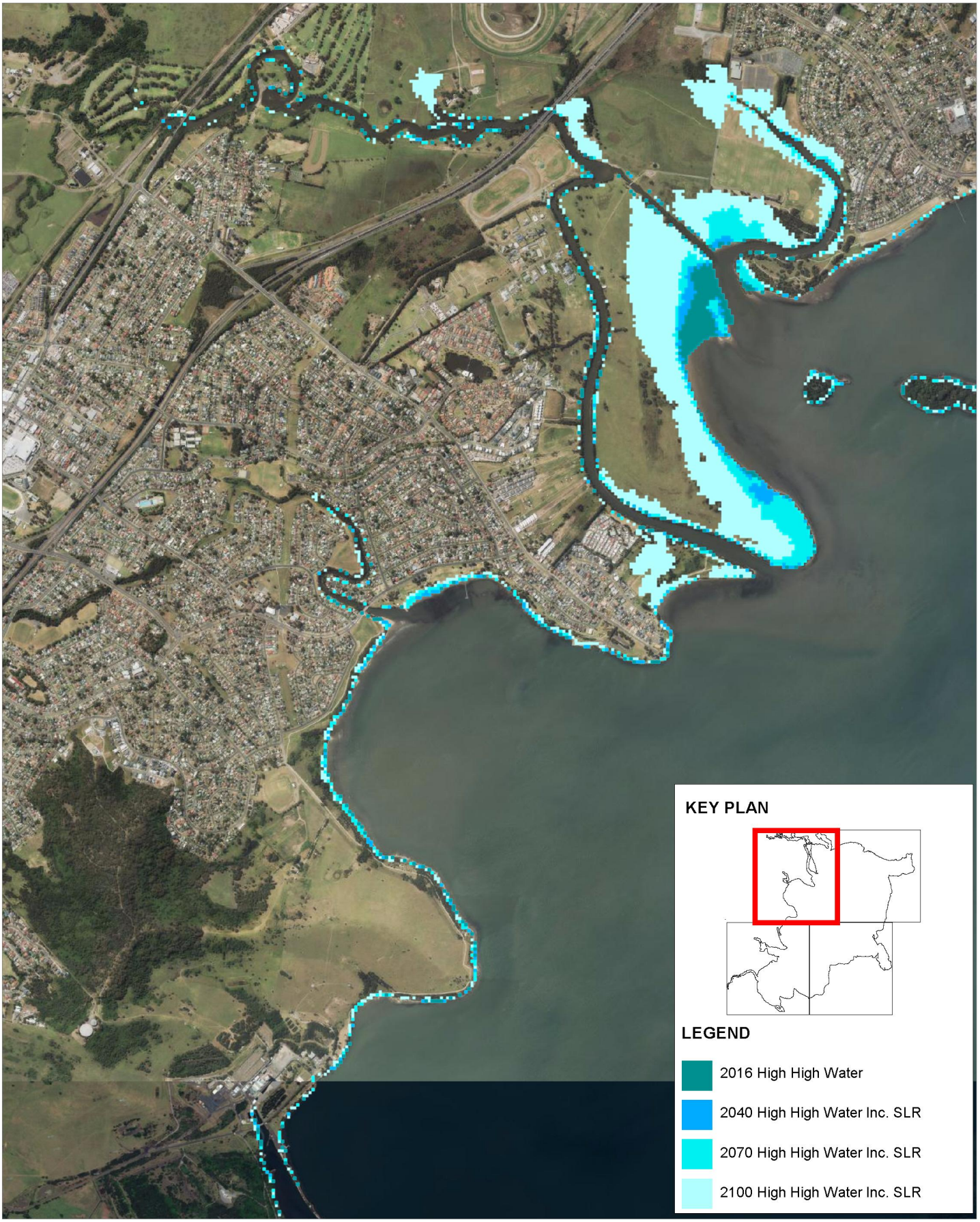
Kumbier et al (2019) produced output for each of the 12 model scenarios, as both a maximum inundation extent and a maximum inundation depth. For the purpose of assessing risk to assets over future timeframes, the inundation extents for the HHWSS scenarios were utilised, as this represents all areas affected by inundation. Mapping of the HHWSS extents at each timeframe is provided in Figure 2-32.

The tidal inundation modelling by Kumbier et al (2019) is considered suitable and fit for purpose for the tidal inundation risk assessment and the subsequent development of actions to address tidal inundation risks in Lake Illawarra that will occur through the CMP. Further discussion of the tidal inundation modelling, including calibration and model limitations, is provided in BMT (2020a).

Table 2-20 Model Scenario Parameters (after Kumbier et al., 2019)

Sim No.		Tidal plane height (m AHD) + SLR				Tidal range (m)	
	Simulation Parameters	Present (2016)	2040	2070	2100	MHWS	HHWSS
1	MHWS present	0.48				0.71	
2	HHWSS present	0.71					1.11
3	MHWS + 0.17m SLR[1] + TR[2] ↑ 8mm/yr		0.65			0.886	
4	HHWSS + 0.17m SLR[1] + TR[2] ↑ 12mm/yr		0.88				1.374
5	MHWS + 0.5m SLR[1] + TR[2] ↑ 8mm/yr			0.98		1.126	
6	HHWSS + 0.5m SLR[1] + TR[2] ↑ 12mm/yr			1.21			1.734
7	MHWS + 0.5m SLR[1] + decelerated TR[2] ↑ 4mm/yr			0.98		0.918	
8	HHWSS + 0.5m SLR[1] + decelerated TR[2] ↑ 6mm/yr			1.21			1.422
9	MHWS + 0.98m SLR[1] + TR[2] ↑ 8mm/yr				1.46	1.366	
10	HHWSS + 0.98m SLR[1] + TR[2] ↑ 12mm/yr				1.69		2.097
11	MHWS + 0.98m SLR[1] + decelerated TR[2] ↑ 4mm/yr				1.46	1.038	
12	HHWSS + 0.98m SLR[1] + decelerated TR[2] ↑ 6mm/yr				1.69		1.6035

[1] *Sea-level Rise (SLR) values are the High RCP8.5 values specified for use in coastal risk assessments for the NSW south coast by Whitehead and Associates (2014).*
[2] *Tidal range (TR) increases were determined by Wiecek et al (2016) analysis of measured tidal data from Lake Illawarra since permanent entrance opening. The decelerated TR scenarios are taken as half the expected TR increase expected for the tidal planes, i.e. Mean High Water Spring (MHWS) and High High Water Solstice Spring (HHWSS).*



Title:

Tidal Inundation Model Extents for 2016, 2040, 2070 and 2100

Figure: 2-32

Rev: A

N

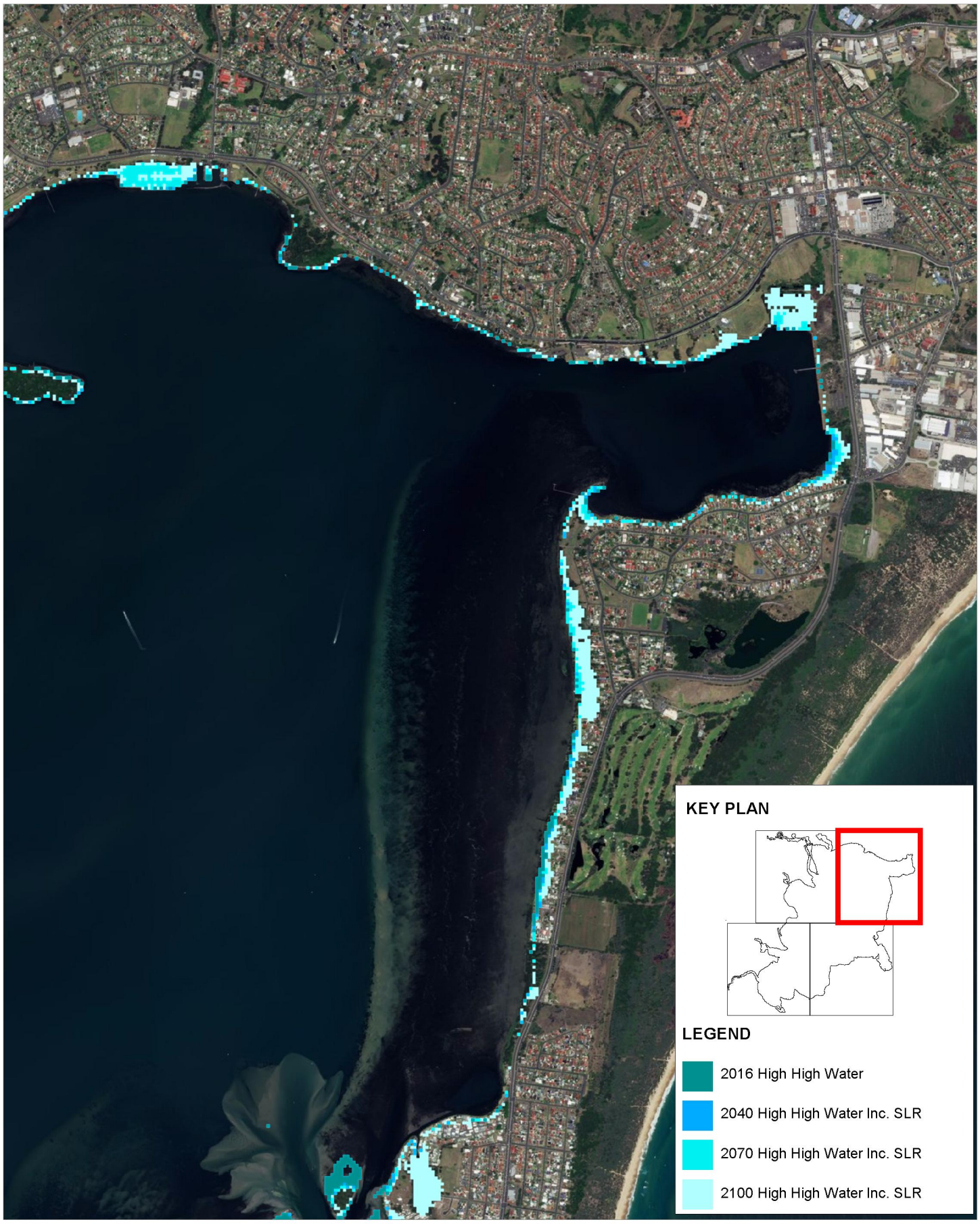
0 0.5 1km

Approx. Scale

BMT

www.bmt.org

Filepath: K:\N20606_Lake Illawarra CZMP\GIS\GIS_2019\Synthesis Report\DRG015_Tidal_Inundation_NW_Fig2.32.wor



Title:

Tidal Inundation Model Extents for 2016, 2040, 2070 and 2100

Figure: **2-33**

Rev: **A**

N

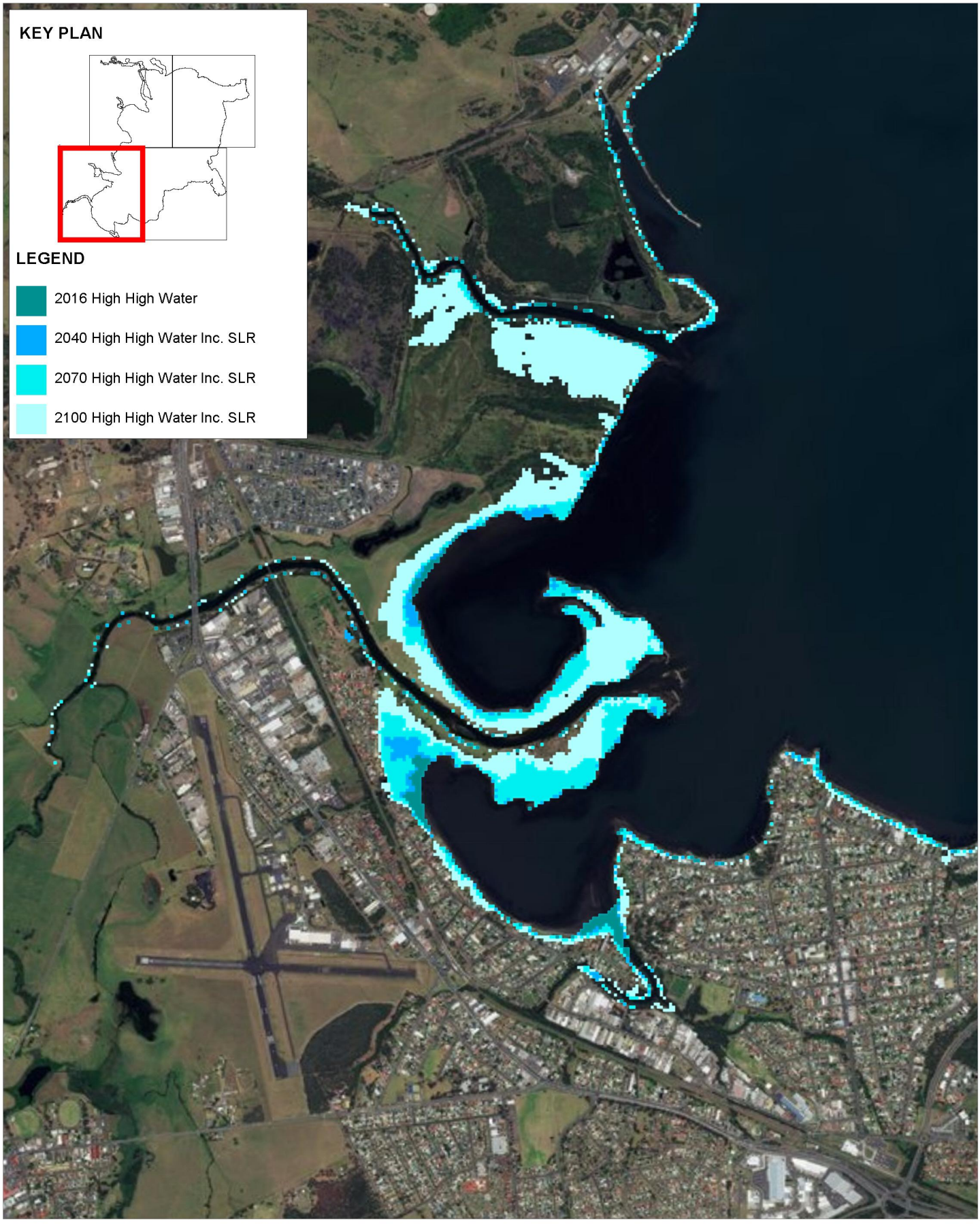
0 0.5 1km

Approx. Scale

BMT

www.bmt.org

Filepath: K:\N20606_Lake Illawarra CZMP\GIS\GIS_2019\Synthesis Report\DRG016_Tidal_Inundation_NE_Fig2.33.wor



Title:

Tidal Inundation Model Extents for 2016, 2040, 2070 and 2100

Figure: 2-34

Rev: A

N

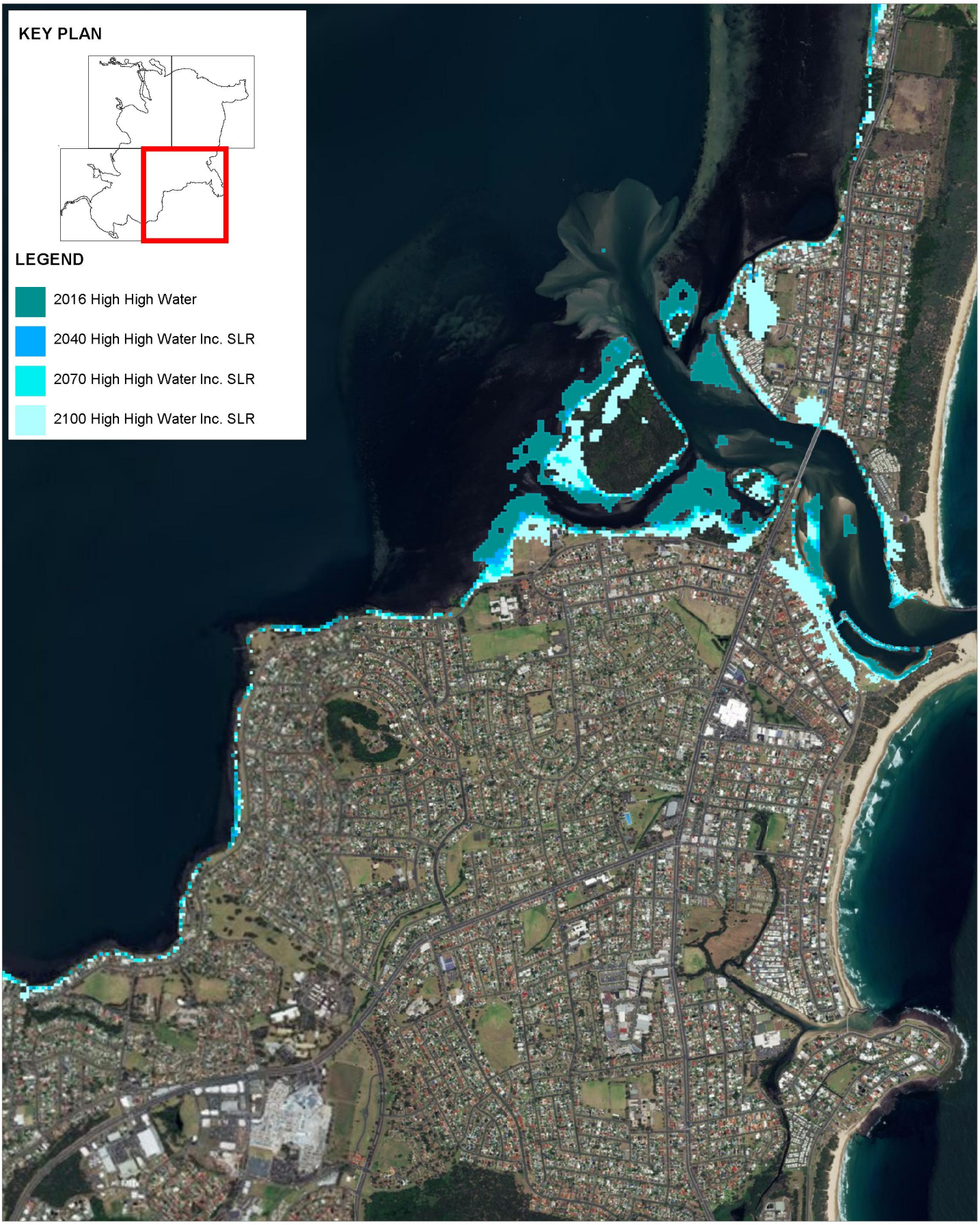
0 0.5 1km

Approx. Scale

BMT

www.bmt.org

Filepath: K:\N20606_Lake Illawarra CZMP\GIS\GIS_2019\Synthesis Report\DRG017_Tidal_Inundation_SW_Fig2.34.wor



Title:

Tidal Inundation Model Extents for 2016, 2040, 2070 and 2100

Figure: **2-35**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT

www.bmt.org

Filepath: K:\N20606_Lake Illawarra CZMP\GIS\GIS_2019\Synthesis Report\DRG018_Tidal_Inundation_SE_Fig2.35.wor

2.9.6 Climate and Sea Temperature Rise

Within Australia, climate change modelling has predicted that by 2070 ocean temperatures will rise by approximately 1-2°C. In particular, ocean warming in South East Australia is predicted to be occurring at approximately four times the global average, due to the influence of the East Australian Current (EAC) which has an increased strength and southward penetration in this region (Hobday et al. 2006; Ridgway 2007).

Climate change is likely to impact the biophysical environment of NSW. Atmospheric temperatures have risen by approximately 0.9°C between 1910 and 2004 and it is predicted that by 2050, the mean daily maximum and minimum temperatures of the Sydney region will increase by approximately 1.5-3°C across all seasons (CSIRO, 2007).Presently, the annual mean maximum temperature is 22.5°C and the annual mean minimum temperature is 11.5 (BOM, 2016).Other than temperature, climate change will impact Australia with likely increases in rainfall during summer, spring, and autumn, increased rates of evaporation during spring and summer, continual increases in sea level, and more extreme weather conditions resultant of the El Niño-Southern Oscillation.

These increases in ocean temperatures may impact on the abundance and distribution of organisms in ocean and estuarine environments, with the extent of the impacts dependent on the tolerance of individual species (Gillanders et al. 2011). In addition to altered species distribution and abundance, increased ocean temperatures will influence the expanse of macroalgae, such as seaweed and coral, eliminating habitats and vital food sources of ocean organisms, with the effect of their absence distributed through entire ecosystems.

Given the above, as an estuary with an open entrance to the ocean, the waters of Lake Illawarra should also be expected to experience increased temperatures, and this may certainly see changes in the type of species (fauna and flora) present in the Lake. The extent of changes in species type and distribution, and the timeframes for such impacts are not able to be defined for Lake Illawarra at this time, however the consequences arising from an increase in global ocean temperatures should be viewed as a threat to Lake Illawarra.

2.9.7 Altered Ocean Currents and Nutrient Inputs

In conjunction to sea level rise, the ocean is likely to receive increased and deeper penetration of light and warmth to deep ocean areas, altering the circulatory function of the ocean. Altered ocean currents can result in increased wind stress curls around the sub-tropical gyres in each ocean basin, such as those observed in South East Australia wherein the EAC has experience increased strength and southward penetration with an associated increase in latitude of the separation point (Ridgway 2007; Cetina Heredia et al. 2014).

When combined with increased sea temperatures, altered ocean currents are considered accountable for the southward range extension of many marine species currently observed in South East Australia, with greater impacts likely to emerge in the future (Verges et al. 2014).

Offshore monitoring data from Port Hacking in Sydney's south demonstrates an increase in the occurrence of the EAC at the 10 m monitoring site over the past 60 years of monitoring data. The increased occurrence of the EAC and resultant increased ocean temperatures has seen a decline in

silicate concentrations and a rise in nitrate concentrations (Thompson et al. 2009). This is likely to be attributed to the low silicate levels in the tropical waters transported south by the EAC, or due to a decrease in the export of silicate from coastal rivers into the ocean. Alterations in the ratios of nutrients in the ocean could lead to shifting phytoplankton compositions and ecological functions.

In addition to these changes, adjustments to the EAC and its upwelling processes may affect estuarine ecosystems, particularly those that tend to spend their lifetime on the open coast. It is speculated that the relationship between estuarine and marine environments may change in response to climate change (Gillanders et al. 2011).

For Lake Illawarra, a shift further southward of the EAC brings warmer waters, and a change in estuarine species that may occur. The decline in silicate concentrations has a direct impact on those organisms that use silicate (not carbonate) to build their shells, such as diatoms which are the dominant phytoplankton in this region. A decline in the dominant phytoplankton has a direct impact on the food chain because it is the major food source at the bottom of the chain. Similarly, a decline in nutrients also impacts upon food production, which also transfers up the chain to higher order species. As a significant and large estuary on the NSW coast, Lake Illawarra may also be impacted by such global or regional changes in nutrient and silicate concentrations in the ocean. The extent to which the Lake will be affected by such changes is not possible to accurately define at this stage.

2.9.8 Acidification

Acidification is the resultant state of a water body attributed to a decrease in pH levels (increasing the acidity of water) from an increased uptake of elevated atmospheric carbon dioxide (CO_2) levels. As Lake Illawarra is an estuary and contains transitional species from its tidal exchange with the Tasman Sea, it is likely to be impacted on by acidification in the longer term. CSIRO (2015) report that there is very high confidence that around Australia the ocean will become more acidic, with a net reduction in pH. There is also high confidence that the rate of ocean acidification will be proportional to the carbon dioxide emissions.

Established estuarine species present in Lake Illawarra are those more tolerant to wider and multiple environmental variables, and are more likely to survive and tolerate changing conditions within Lake Illawarra. Species in their early life stages are more likely to be impacted and not tolerate changes to ocean acidification. However, there is insufficient evidence to suggest that species will adapt to changing conditions (Nagelkerken & Connell 2015).

The acidification of Lake Illawarra could result in decreased species diversity and abundance, increased non-calcifying organisms, simplification of communities, altered metabolic functions, and a reduction in calcifying organisms such as marine mollusc vulnerable to acidification (Gillanders et al., 2011; Ross et al., 2011; Parker et al., 2013; Nagelkerken & Connell, 2015).

2.9.9 Key Implications for Development of the Coastal Management Program

Key implications arising from the above information that relate to the management responses for coastal risks are as follows.

- Management responses for the coastal inundation risk in Lake Illawarra have been documented in the *Wollongong Coastal Zone Management Plan* (CZMP) (BMT WBM, 2017b) and the *Lake*

Illawarra Coastal Risk Assessment (BMT WBM, 2013), and are reproduced in Section 3.3.2 and 3.3.3 respectively. Where relevant, the recommended actions should be included in the subsequent CMP.

- A first pass assessment of SLR impacts around the Lake's foreshores was completed using a bathtub approach (Cardno, 2012b).
- Modelling and mapping of tidal (permanent) inundation due to the combined influence of the permanent entrance opening (which is resulting on an ongoing increase in the Lake's tidal range) and sea level rise has been completed by Kumbier et al (2019), refer Section 2.9.5. A detailed Tidal Inundation Risk Assessment has also been completed through the Community Uses, Values and Opportunities Report (BMT, 2020a) to inform management actions for tidal inundation risk. This has been combined the recommendations for coastal inundation risks as noted above, to form specific actions to manage inundation risks in the CMP.

2.10 Snapshot Summary of Estuary Health

Estuaries are complex and dynamic waterbodies in a continual state of fluctuation to maintain and balance a large number of different processes and systems. Their health depends on many factors including water quality, diversity and abundance of flora and fauna, physical, biological, and chemical processes, climate and weather, and anthropogenic activities. The health of individual estuaries is highly subjective, and depends greatly on the systems involved and their adaptive qualities during periods of high stress or change.

In the assessment of estuary health, it is important to identify its state or condition (a snapshot of the health at the time of measurement of indicators), pressures (reflecting the impacts to habitats and uses), and the response of the estuary (to reveal the responsiveness of management actions). The State of NSW and OEH (2016) recommends the following core condition indicators for assessing estuary ecosystem health:

- Water quality: chlorophyll-*a* and turbidity; with monitoring of macroalgae recommended at the individual estuary level where feasible.
- Habitat quality: estuarine macrophyte mapping (seagrass, mangroves and saltmarsh), to determine the extent of these habitats, and changes in extent since previous mapping.
- Biodiversity: based on fish assemblages measured using the Estuarine Fish Community Index, which considers species diversity and composition, species abundance, nursery function, and trophic integrity.

The State of NSW and OEH (2016) also suggest the assessment of a range of pressure indicators that can support estuarine condition assessments. Based upon the condition and pressure indicators, the current state of estuary health for a location can be defined.

A snapshot of estuary health for Lake Illawarra is provided in Table 2-21, describing the pressures occurring in Lake Illawarra (using the pressure indicators recommended by Roper et al, 2011), the potential impacts and change in condition due to the pressures, and the current condition of key indicators. The table therefore provides a summary of existing condition and potential future changes relating to existing pressures on the Lake.

Table 2-21 Snapshot Summary of Pressures, Current and Potential Impacts and Current Condition of Lake Illawarra

Pressure Indicator	Current State	Current or Potential Impact	Potential Change in Condition Indicator and Cause (Δ = change, ↑ = increase, ↓ = decrease)	Current Condition
Catchment population	Increasing due to increase in urban development in the catchment.	Increased nutrients, sediments and other contaminants in stormwater runoff flowing to the Lake. Increased bank erosion where stormwater volumes / runoff is not managed. Removal of estuarine / riparian vegetation due to mowing, landscaping etc, and subsequent bank erosion. Increased threat of pest and weed invasion. Increased pressure on reticulated sewerage system (sewer overflows). Bank erosion due to trampling by walking, BMX, motorbike and 4WDs.	Primary Impacts: ↑ chlorophyll-*a*: due to nutrients. ↑ turbidity: due to sediments, erosion. ↓ mangroves, saltmarsh: due to erosion, removal. Secondary Impacts ↓ seagrass: shading due to ↑ turbidity and chlorophyll-*a*. Tertiary Impacts: ↓ fish: due to ↓ mangroves, saltmarsh and seagrass.	Chlorophyll-*a* and turbidity: spatially variable, from very good to very poor. Seagrass and saltmarsh coverage are good. Biodiversity is high, particularly associated with Lake Illawarra wetlands. Foreshore condition is poor. Erosion is evident at drains entering the Lake at Lake Heights foreshore/Mt Warrigal foreshore/Burroo Bay & Karoo Bay/Berkeley Boat Harbour/Windang Peninsula, and the banks of Pelican View Reserve, Windang Foreshore Park, Macquarie Rivulet, Mullet Creek, Illawarra Yacht Club, and Cudgeree Bay (LIA, 2013a).
Catchment land uses	Urban development Heavy Industry Contaminated sites from past industrial uses Rural and small -scale agriculture	As above for urban development. Groundwater and sediment contamination from current and past industrial land uses. Sediment and nutrient runoff to creeks from agriculture Riparian vegetation removal / degradation from uncontrolled stock access Bank erosion due to catchment runoff	As above, plus: ↓ Primary and Secondary Contact Recreation: due to chemical contaminants in groundwater ↓ riparian coverage: due to degradation, erosion Δ fish assemblages, other habitats: due to chemical contaminants in groundwater, sediments, and ↓ riparian coverage	Catchment development is spatially variable with some helpful insights and prioritisation seen in CERAT mapping. Riparian coverage / foreshore condition is poor. Erosion is evident at drains entering the Lake at Lake Heights foreshore/Mt Warrigal foreshore/Burroo Bay & Karoo Bay/Berkeley Boat Harbour/Windang Peninsula, and the banks of Pelican View Reserve, Windang Foreshore Park, Macquarie Rivulet, Mullet Creek, Illawarra Yacht Club, and Cudgeree Bay (LIA, 2013a).

Pressure Indicator	Current State	Current or Potential Impact	Potential Change in Condition Indicator and Cause (Δ = change, ↑ = increase, ↓ = decrease)	Current Condition
Licensed sewer overflows	Sydney Water permitted to allow wet weather sewer overflows to Lake	Increased sediment and nutrient loads Increased pathogens and other contaminants in water and sediments	Primary Impacts: ↑ chlorophyll-*a*: due to nutrients ↑ turbidity: due to sediments ↓ recreational water quality: due to pathogens / bacteria, contaminants Secondary Impacts ↓ seagrass: shading due to ↑ turbidity and chlorophyll-*a* Tertiary Impacts: Δ fish assemblages: due to ↓ seagrass, contaminants in sediment.	Percent compliance with the NHMRC Guidelines for Enterococci levels at the Entrance Beach has ranged from 72 to 82 % since 2010. Chlorophyll-*a* and turbidity: spatially variable, from very good to very poor. Seagrass and saltmarsh coverage are good.
Thermal discharges	Tallawarra Power Station	Impact is declining as Tallawarra Power Station no longer operates 24 hours, and has changed its thermal discharge regime.	Δ fish assemblages: due to reduced occurrence of thermal discharges.	
Foreshore structures	Reclamation, seawalls, jetties.	Removal of estuarine and riparian vegetation. Vertical seawalls impede establishment and migration of estuarine habitats (saltmarsh, mangroves), and other fish habitat.	↓ mangroves, saltmarsh: due to removal ↓ riparian coverage: due to removal ↓ fish assemblages: due to seawalls	Hard structures line much of the Lake e.g. Griffins Bay, Cudgeree Bay, northern Koonawarra Bay, eastern side of Lake along caravan parks. Most reclamation works, seawalls and jetties were built many years ago. Some evidence of “illegal” structures being built by foreshore residents. Opportunity to replace vertical /failing seawall structures with environmentally friendly structures.
Entrance works	Permanent opening with twin breakwaters completed in 2007	Changed tidal regime: increase in tidal prism and velocities resulting in erosion of the entrance channel, and sedimentation in other areas	Primary Impacts: Δ seagrass distribution: smothering by shifting shoals, growth in new areas ↑ mangroves = ↓ saltmarsh	Seagrass and saltmarsh considered good, with no evidence of loss at present. Mangrove coverage is increasing, and may start to outcompete saltmarsh.

Pressure Indicator	Current State	Current or Potential Impact	Potential Change in Condition Indicator and Cause (Δ = change, ↑ = increase, ↓ = decrease)	Current Condition
		Marine tide delta (drop-off) migrating landwards/westwards Changed saltmarsh to mangrove dynamic Increased exposure of the entrance channel to oceanic swell and elevated water levels. Changes in estuarine species due to increased salinity. Increased potential for marine pests	Δ fish assemblages: due to "marinisation" (salinity) of lake waters Δ recreational safety due to changed navigation through entrance shoals and channels	Erosion evident in the entrance channel, impacting Windang Peninsula, the boardwalk, areas of Aboriginal Cultural significance and threatens shorebird habitat. Erosion during the June 2016 storm at Reddall Reserve and Windang. Sedimentation of the popular swimming area off Reddall Reserve behind the inner southern breakwater is of community concern. Re-occurrence of species such as greasyback prawn *(Metapenaeus bennettae),* Dusky Whaler Shark, Great White Sharks, and seals; and a new species, the Eastern King Prawn (*Penaeus plebejus*) has been recorded. Pest species (upside-down jellyfish) has been recorded.
Dredging	Creeks Entrance channel	Dredging in creeks/at fluvial deltas generates fine sediment plumes that may smother nearby seagrass. Dredging of marine sand from entrance channel for navigation and recreation purposes (done in areas without seagrass). May refill quickly due to dynamic ongoing changes in response to permanent entrance opening works. However, dredged marine sand can be used to beneficial effect on areas experiencing erosion, including Warilla Beach.	For creek dredging: ↓ seagrass: shading by fine sediment plumes = ↓ fish ↓ Primary and Secondary Contact Recreation, Δ fish assemblages, other habitats: due to mobilisation of contaminants in the sediments. For dredging of marine sand in entrance: ↑ recreational values: due to improved access to swimming area, boating	Changes in condition indicators stated here were identified to occur following dredging of fluvial deltas at Warrawong and Berkeley for recreational purposes. Dredging of marine sand in entrance areas for use on Warilla Beach and elsewhere was undertaken by LIA and others in the past to good effect.

Summary of Estuary Processes

Pressure Indicator	Current State	Current or Potential Impact	Potential Change in Condition Indicator and Cause (Δ = change, ↑ = increase, ↓ = decrease)	Current Condition
Invasive / Introduced Species	Pests in lake waterbody, tributaries Weeds, terrestrial pests in contributing catchments	Terrestrial and marine pests such as Indian Myna outcompete native species for food and habitats, breed prolifically, increase weed dispersal, and are difficult to remove. Pests such as foxes also prey on native species, especially shorebirds. Weed species outcompete native flora and reduce biodiversity, further reducing nesting sites and food sources for native fauna species. Introduced species such as cows, sheep overgraze, trample and erode creek and lake banks and riparian vegetation. Dogs may prey on nesting shorebirds.	↓ mangroves, saltmarsh, riparian coverage and seagrass: due to trampling and erosion. ↓ native flora: outcompeted by weeds, grazed by pests / introduced species ↓ native fauna: directly due to preying by pests, outcompeted for habitat, and as a secondary impact of reduced native habitats for food and shelter. ↑ turbidity: due to sediments mobilised by erosion, tramping of banks. Potential ↓ commercial fisheries, tourism: due to Δ or ↓ fish assemblages, trophic structures.	Biodiversity is currently good. Recorded marine pest species include the upside-down jellyfish, European shore crab, New Zealand screw shell and Japanese Goby. Terrestrial pests include pigs, foxes, Indian Myna birds, and rabbits (WCC, SCC & KMC, 2011). Predation of shorebird nests by foxes has been an issue for consecutive breeding seasons. Over 200 known weed species (mostly environmental, some noxious weeds). Cattle grazing along the Lake's tributaries is reported (WCC, SCC & KMC, 2011).
Storm events	Periodic. Most recent large storm event = June 2016 east coast low.	Bank erosion due to combination of increased water levels and waves during the storm. Inundation due to increased water levels and waves	↓ mangroves, saltmarsh, seagrass: due to erosion, storm water currents/waves Secondary impact: ↓ fish: due to ↓ mangroves, saltmarsh and seagrass	June 2016 event caused significant erosion in many locations including Windang, Boonerah Point, Deakin Reserve, Ski way Park and Reddall Reserve (this is additional to areas of erosion identified above).
Sea level rise	Current rate of rise ~ 3.2 mm/year (= 0.27 m by 2100 above present MSL). Projected rise: ~ 0.4 m by 2050, ~ 0.9 m by 2100 (above 1990 MSL)	Permanent inundation of lake fringes (day to day). Enhanced storm inundation because sea level rise adds to storm water levels	Δ or ↓ mangroves and/or saltmarsh: where these habitats are unable to migrate with permanent day to day increase in lake water levels. Enhanced impacts noted above for storms	Impact of sea level rise to date within the Lake is unknown (and evidence may be complicated by the ongoing evolution in response to permanent entrance training works). Williams and Wiecek (2017) provide advice on migration pathways for estuarine vegetation.

Pressure Indicator	Current State	Current or Potential Impact	Potential Change in Condition Indicator and Cause (Δ = change, ↑ = increase, ↓ = decrease)	Current Condition
Air and sea temperature change	Average air temperature has risen by ~ 0.9°C (from 1910 – 2004); by 2050, mean max temperatures of the Sydney region projected to increase by ~ 1.5-3°C. Ocean temperatures projected to rise by 1-2°C by 2070. (CSIRO, 2007).	Ocean warming in SE Australia said to be occurring at ~ 4 x global average due to the EAC, which has an increased strength and southward penetration in this region (Hobday et al. 2006; Ridgway 2007). As an estuary with an open entrance to the ocean, the temperature of the waters of Lake Illawarra should also be expected to increase.	Potential Δ or ↓ in abundance and distribution of estuarine flora and fauna. E.g. likely ↑ in macroalgae such as seaweed and coral = ↓ in habitats and vital food sources for other ocean organisms, with the effect of their absence distributed through entire ecosystems.	The extent of changes in species abundance and distribution, and the timeframes for such impacts are not able to be defined for Lake Illawarra at present. The science should be reviewed at the time the CMP is reviewed and updated (5-10 years).

3 Existing Controls and Planned Management

3.1 Introduction

This section outlines the existing management initiatives implemented or being implemented that assist to manage Lake Illawarra at present. This includes an audit of the previous estuary management documents and associated plans; and a review of other plans and policies that directly manage known issues in the Lake. The intention is that existing successful management approaches should be retained in the CMP, rather than replicated or lost.

A detailed review of the legislative framework for managing the Lake and the preparation of the CMP is provided in Appendix A.

3.2 Audit of previous Estuary Management Initiatives

Staff from SCC, WCC and DPIE - Coasts & Estuaries with assistance from Cassie Baxter (formerly LIA, now Cardno,) undertook an unpublished audit of estuary and catchment management activities pertaining to Lake Illawarra (Baxter et al., 2016). Full details of the audit are included in Appendix C.

In the Lake Illawarra catchment, several management plans govern the planning, development, and use of land, and were developed by various governing bodies including SCC, WCC, and LIA. The management plans captured in the audit included:

- Lake Illawarra Estuary Management Study and Strategic Plan (WBM Oceanics, 2006);
- Draft Coastal Zone Management Study (LIA 2013a);
- Lake Illawarra Water Quality and Estuary Health Monitoring Program (WCC, 2015);
- Ecological and Bushfire Assessment and Plan of Management, Picnic Island Reserve (SCC, 2015);
- Boonerah Point Vegetation Management Plan (SCC, 2016);
- Oaklands Village and Jetties by the Lake, Windang Proposed Foreshore Stabilisation Project (LIA, 2013b);
- Purry Burry Point to Heritage Park Site Restoration Plan (LIA, 2013c); and
- Judbooley Parade Landscape Master Plan (WCC, 2010).

Some of these plans were subject to broad stakeholder input, such as the Lake Illawarra Estuary Management Study and Strategic Plan (WBM Oceanics, 2006). Others were subject to internal scrutiny only such as the Draft Coastal Zone Management Study (LIA 2013a).

Of the 8 management plans reviewed, 94 actions were identified across 11 zones of the Lake. To aid the audit, the 94 actions were categorised into remedial and environmental protection works, physical works, environmental monitoring, development and planning controls, education, further research, and policy, as displayed in Figure 3-1.

Evident in Figure 3-1, approximately 83% of actions were remedial and environmental protection works and physical works, 7% were for environmental monitoring, and development and planning controls, education, further research, and policy accounted for a combined 9.5% of actions.

The audit identified that of the 94 actions, 30 were completed, 29 were unfinished, abandoned or to be considered, and 35 were ongoing, as demonstrated in Figure 3-2. The main pressures identified contributing to the status of the actions were community pressures, especially in regard to dredging, reclaiming private land for public access, and where residential stakeholders were involved. Successful actions were centred on physical works, namely public amenity such as upgrading pathways, boating facilities, carparks, and public reserves, and the rehabilitation of foreshore areas.

The heavy focus on physical works identified through the Lake Illawarra audit is consistent with a retrospective review of some 20 Estuary Management Plans implemented over a 20 year period in NSW compiled by Fletcher et al (2014). The review found that actions involving 'physical works' such as stormwater treatment devices (gross pollutant traps) were more likely to be implemented than those involving planning and development controls or further research/studies. This was attributed to the ability to secure funding, as physical works tend to more frequently satisfy funding criterions Fletcher et al. (2014).

The audit by Fletcher et al. (2014) also demonstrated that although physical works were more likely to be implemented, ongoing costs for maintenance of the physical works were not well funded or planned, compromising the environmental and other benefits of the works. Other factors contributing to a lack of success in implementing management actions were unrealistic costs, undisclosed ongoing maintenance costs, lack of community support, and political will (Fletcher et al., 2014).

The findings of the Lake Illawarra audit are consistent with that of Fletcher et al (2014), and reinforce that actions with obvious visual results are more likely to have a positive response (i.e. a stormwater outlet, play area, jetty etc are a visible demonstration of "action"). This is also the reason attributed to the key focus of the LIA being recreational use.

3.2.1 Current state of Lakeside Facilities

Lake Illawarra Authority constructed many facilities in and around the Lake. Visual inspections indicate that many of these facilities have fallen into disrepair. The next stage of the CMP project will examine community uses and values.

Table 3-1 Example of Projects & Actions Audited

Category	Project Example
Remedial & Environmental Protection Works	• Remediation of riparian zone of Mullet Creek and Purrah Bay Foreshore • Ongoing maintenance of Budjong Creek Wetland • Changed mowing strategies • Restricted access to Mogurah and Yangar Point foreshore areas to allow native vegetation to re-establish
Physical Works	• Upgrade to Wilson Memorial Park and Deakin Reserve carpark • Construction of wharf on Macquarie Rivulet for launching small watercraft • Construction of boat-launching facility at Yallah Bay • Provision of public access linkage along Primbee Bay shoreline if reclaimed
Environmental Monitoring	• Monitoring of water quality in the Lake • Investigation of groundwater pollution (high ammonia) along Windang Peninsula • Development of ongoing monitoring program to assess encroachment of mangroves across the Lake • Monitoring of changes to Lake's ecology by regular surveys of key parameters, i.e.; seagrass
Development & Planning Controls	• Preparation of a plan of management for public lands i.e.; between Oaklands Village Caravan Park and Windang Bridge • Berkeley nature reserve plan of management to maintain and enhance the native rainforest
Education	• Community education i.e.; saltmarsh brochures, Futureworld educational package • Community engagement via encouraging volunteer groups to take part in Lake-related projects
Further Research	• Investigation of fish stock trends and commercial and recreational fishing practices by conducting surveys • Research into the driving mechanism behind algal blooms and their interactions with primary producers in the Lake
Policy	• Preparation of consolidated DCPs outlining the requirement for WSUD within certain types of developments

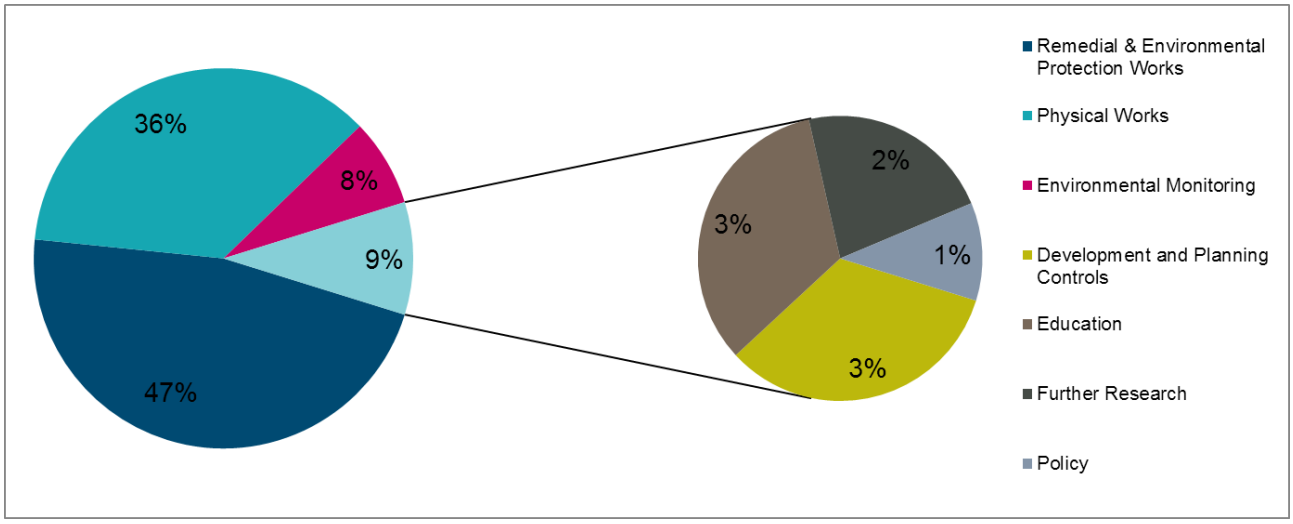


Figure 3-1 Actions based on category

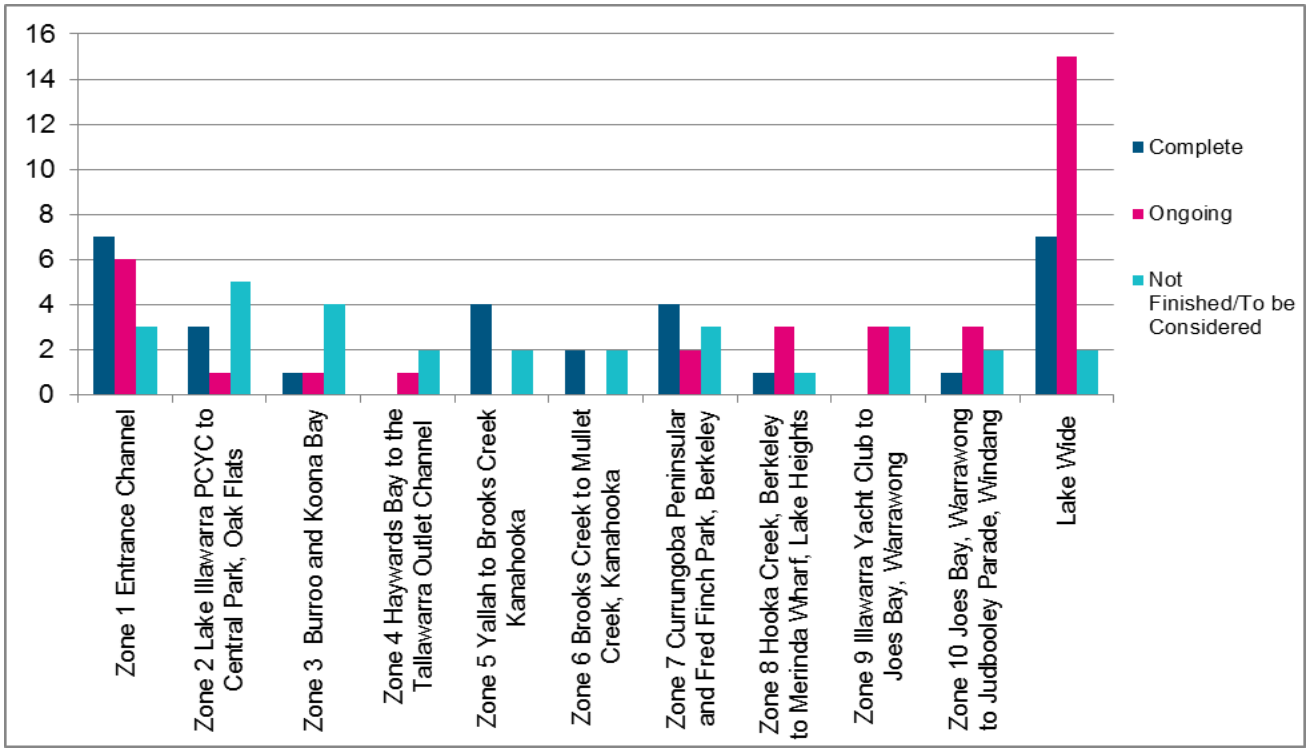


Figure 3-2 Status of actions

3.3 Other Existing Management Initiatives Relevant to the CMP

3.3.1 Floodplain Risk Management within Shellharbour and Wollongong DCPs

With regards to the Lake Illawarra CMP, Shellharbour DCP (Chapter 24 and Appendix 9) and Wollongong DCP (Chapter E13) provide suitable controls for incidentally managing risks arising from periodic coastal inundation of the Lake's foreshores, as new, infill or re-developments are undertaken around the foreshores and catchment of Lake Illawarra. Further description of both DCP chapters is provided in Appendix A.

Shellharbour and Wollongong DCP controls for floodplain risk management adequately manage future development (which includes the rebuilding of existing houses, not just new greenfield sites). However, it cannot manage existing houses that are not redeveloped. And it will not apply where assets are substantially refurbished, instead of re-developed. This is particularly relevant to community assets on Lake Illawarra's foreshores such as schools, the PCYC, scout halls and so on that may be refurbished, but not re-built and so, not trigger the application of the Shellharbour DCP Chapter 24.

Shellharbour DCP (Chapter 24 and Appendix 9) and Wollongong DCP (Chapter E13) also do not manage permanent inundation (and loss) of land (public or private) with sea level rise.

3.3.2 Wollongong Coastal Zone Management Plan

The Wollongong CZMP (BMT WBM, 2017b) was certified in December 2017. As part of the CZMP the level of risk associated with coastal inundation due to periodic ocean water level events was assessed, and actions documented to manage this risk to various public and private assets. The assessment and recommended actions cover the WCC sections of Lake Illawarra only, noting that the remainder was completed as part of the Shellharbour CZMP (BMT WBM, 2017a).

At the present time, the risk level for most assets on the Lake foreshore was assessed as low, except for Windang Road and Bridge (high risk) and land surrounding the Tallawarra (Tru Energy) Power Station (high). Areas identified at medium risk included Holborn Park Sailing Club, some areas of Swamp Oak Floodplain Forest EEC, Port Kembla Sailing Club boat ramp and harbour; various stormwater outlets/ pipes, various existing foreshore residences, three vacant land blocks at Purrah Bay, and Windang Public School.

By 2100, assets at high risk were now considered to be at extreme risk; and all assets at medium risk were now considered to be at high risk. Most areas at low risk at present had either remained at low risk or increased to medium risk by 2100. For the low risk areas then, it is feasible to accept the risk at present. Any change in this management approach can be re-assessed when the CMP is revised in 5 – 10 years' time. Furthermore, a range of "no regrets" options were recommended that will incidentally improve risk outcomes for these areas.

The recommended actions to treat the risks from coastal inundation around the WCC sections of Lake Illawarra are listed in Table 3-2.

Table 3-2 Actions to Treat Periodic Coastal Inundation (from BMT WBM, 2017b)

Ref.	Action	Assets at Lake Illawarra Managed
I.1	For all Council assets within their Asset Management Plan, add a notation indicating its proximity to the coastal hazard zones and the type of coastal hazard(s) relevant (i.e., erosion/recession, inundation, geotechnical) and estimated timeframe for impacts on the assets (immediate/2010, 2050, 2100). Prioritisation and maintenance scheduling of forward works programs should then be re-considered based on the timeframe and type of hazard exposure. This approach allows for the inundation hazard to be managed at the time the asset is replaced, not just after it is impacted.	Stormwater Outlets and Pipes
DC.2	Revise/update, adopt and implement Chapter E13 – Floodplain Management of Council's Development Control Plan (DCP) to include areas affected by Coastal Inundation as Low Risk Flood Precincts. This option involves assigning areas within the Coastal Inundation Area but outside of the existing Flood Planning Area into the Low Flood Risk Precinct of the Flood Planning Area, then managing this area according to the provisions in DCP Chapter E13 – Floodplain Management. This will include flood proofing or relocatable structures etc as required on a site by site basis as assets are redeveloped or replaced.	All built assets at risk, including assets at high risk at present: • Windang Road and Bridge • Tallawarra (Tru Energy) Power Station. And assets at medium risk at present: • Holborn Park Sailing Club, • Port Kembla Sailing Club boat ramp and harbour; • Stormwater outlets/ pipes, • Existing foreshore residences (various) • Three vacant land blocks at Purrah Bay • Windang Public School.
M.3	Monitor frequency, depth and spatial extents of coastal inundation events.	All assets/areas at risk, including the high and medium risks assets (as noted above).
V.3	Undertake an audit of all EECs and important habitat areas within the hazard zones and implement buffers and rehabilitation as appropriate. This option would involve: • Identifying important flora/fauna species that, due to their limited distribution, will need to be translocated; • Prioritising rehabilitation requirements based upon the relative threat to distributions from coastal hazard impacts, to ensure lower risk distributions are protected and enhanced; and • Identifying areas that can be designated buffers around important habitats, to enable migration in response to hazard impacts, i.e. erosion and recession, as well as migration in response to sea level rise. The outcomes of the audit should feed into existing biodiversity strategies (e.g. Illawarra Regional Biodiversity Strategy, 2010). Hazards impacts investigated should include both permanent inundation as well as recession due to sea level rise.	Swamp Oak Floodplain Forest EEC Coastal Swamp Oak Forest EEC

3.3.3 Shellharbour Coastal Zone Management Plan

Preparation of the Shellharbour Coastal Hazard Analysis (SMEC, 2010) did not include any assessment or mapping of inundation for the Shellharbour LGA portion of Lake Illawarra. As such, the Shellharbour CZMP (BMT WBM, 2017a) does not contain any actions to manage inundation risks in the Lake, and is instead focused on the open coast areas of the Shellharbour LGA.

Only one action in the Shellharbour CZMP (BMT WBM, 2017a) relates to the Lake itself, being the Beneficial Use of Dredged Sand (in Section 2.4.9 of the CZMP), which states "When dredging of the entrance to Lake Illawarra or Elliott Lake occurs, place dredged sand onto Council beaches to enhance sand reserves to buffer erosion and to improve beach amenity". Lake Illawarra CMP actions to dredge marine sand in the entrance channel will support the Shellharbour CZMP.

3.3.4 Lake Illawarra Coastal Risk Assessment

As noted in Section 3.3.2 and 3.3.3 above, the Wollongong CZMP did assess the risks from coastal inundation in Lake Illawarra because inundation extents were available for the Wollongong LGA portion of the Lake from Cardno (2010). However, similar inundation mapping was not available for the Shellharbour CMZP.

To rectify this information gap and support the former LIA in its preparation of a CMP for Lake Illawarra, the risks from coastal inundation along the foreshore of the Lake within the Shellharbour LGA were assessed through the Lake Illawarra Coastal Risk Assessment (BMT WBM, 2013). This document provides the risk assessment and actions for coastal inundation in the Lake that were not available for the Shellharbour CZMP.

The risks associated with coastal inundation and permanent inundation due to sea level rise are outlined for the entire Lake Illawarra foreshore in Section 2.9.4 and 2.9.5 respectively, based upon both Lake Illawarra Coastal Risk Assessment (BMT WBM, 2013) and Wollongong Coastal Zone Management Plan (BMT WBM, 2017b). Both documents provided a description of the level of risk from coastal inundation to all foreshore assets at present, 2050 and 2100, with detailed listing reproduced in Appendix D.

The Lake Illawarra Coastal Risk Assessment (BMT WBM, 2013) recommended management actions for the coastal inundation risk within the Shellharbour LGA portion of the Lake. The report also provides guidance for the potential risk from permanent inundation with sea level rise by 2100, in lieu of more detailed information.

Actions recommended in the Lake Illawarra Coastal Risk Assessment that are relevant to the development of the CMP are listed in Table 3-3.

Table 3-3 Actions to Treat Periodic and Permanent Coastal Inundation (from BMT WBM, 2013)

Action	Description	Risk Addressed, and other advantages	Assets treated
Water Level Monitoring	Monitoring of the frequency of inundation of assets, using Lake water level measurements.	Coastal inundation (periodic) Permanent inundation with SLR. Provides invaluable information to demonstrate the occurrence of coastal inundation, and for developing triggers for site specific management actions.	All foreshore assets.
Condition Monitoring	Monitoring of the condition of key foreshore facilities after each event or yearly, as required.	Coastal inundation (periodic) Permanent inundation with SLR	All public assets, with priority for assets that are expensive, have a long lifespan, and / or are highly important to the community, which may include natural assets.
Permanent Inundation Mapping	Conduct detailed modelling of permanent inundation of Lake Illawarra's foreshores over time with sea level rise. Model must include tidal attenuation influences specific to the Lake. Modelling may include mean sea level, plus mean and spring high tides	Permanent inundation with SLR. Provides information needed to assess the permanent impacts of sea level rise on natural and built foreshore assets.	Various assets, inc.: • Schools • PCYC • Scout halls • Parks and reserves, inc. facilities such as playgrounds, car parks, amenities blocks, BBQs, public jetties, and cycleways, • Sports fields / ovals • Habitats (EECs, environment conservation areas, etc.). • Roads • Stormwater • Private properties
Notation of inundation risk within Asset Management Plans	Notation of the risk of periodic and permanent inundation to community facilities, roads, stormwater infrastructure, sewer and water infrastructure in their respective Asset Management Plans. When asset managers progress a refurbishment or replacement of the asset, the inundation risk can then be factored into redesign / relocation of the asset.	Coastal Inundation (periodic). Permanent inundation with SLR. Action to follow on from permanent inundation mapping action. Some community facilities (e.g. schools, halls etc.) are unlikely to redeveloped in a manner that triggers the Flood DCP, but rather, be refurbished. This action aims to capture refurbishments of existing facilities, to manage the risks and prolong the life of the investment.	• Schools • PCYC • Scout halls Prior to local adaptation plan(s), also apply to: • Roads • Stormwater • Sewer • Water

Action	Description	Risk Addressed, and other advantages	Assets treated
Local Adaptation Plan(s)	A whole of area approach is needed to determine how the services to properties can be maintained with permanent inundation and where periodic inundation frequencies become intolerable. The local adaptation plan should consider local road connections (e.g. viable traffic redirections, road redesign (raising, protecting), relocation or even abandonment) stormwater networks, sewer and water etc. Implementation of the adaptation actions will need a staged, trigger based approach.	Coastal Inundation (periodic). Permanent inundation with SLR. Action to follow on from permanent inundation mapping action. The Flood DCPs will facilitate the raising of properties as they redeveloped, and evacuation planning can manage risks beyond the flood planning level. However, local adaptation planning is needed to consider the viability of an entire local suburb, such as the viability of road, stormwater, sewer etc. services to properties if these services are affected by permanent inundation or periodic inundation at intolerable frequencies.	• Local roads (i.e. managed by council) • Private residential properties • Stormwater outlets and pipes • Sewer and water services.
Council policy to manage ad hoc foreshore protection works	While built assets on private property are managed by the Flood DCPs, there is little avenue for controlling ad hoc protection structures on foreshore lands. Such ad hoc works are likely to increase as sea level rise permanently reduces foreshore property boundaries. There may also be a need to educate works crews managing the foreshore park and reserves, to reduce construction of ad hoc works on public land.	Permanent inundation with SLR. This action will be important for managing foreshore encroachments generally, not just with sea level rise.	• Private foreshore properties • Public parks and nature reserves
Adaptation planning for parks and reserves	WCC and SCC combined assessment of foreshore parks and reserves across the entire Lake Illawarra foreshore, considering permanent inundation and local and regional demand, to determine: areas that are more resilient: areas that are feasible to protect; and areas that may need to be abandoned, and rehabilitated to permit foreshore and wetland habitat migration. The adaptation plan should then be fed into masterplans / POMs for the parks, to facilitate the long term adaptation plan.	Permanent inundation with SLR Action to follow on from permanent inundation mapping action. For parks considered to be at high risk and unfeasible to maintain in the long term, the adaptation plan can facilitate a return of the “park” to “natural area”. This has the additional benefit of increasing the area available for migration of foreshore and wetland habitats with sea level rise.	All parks, reserves and sports grounds, particularly those with high usage / demand.
Habitat Adaptation Plan	Similar to the parks action above, identify: habitat areas with room to migrate that can be protected; and areas that are unable to migrate.	Permanent inundation with SLR Action to follow on from permanent inundation mapping action.	Habitat areas, EECs, environment conservation areas.

3.3.5 Generic Plan of Management for the Community Land of Wollongong City Council 2014

The Generic Plan of Management for the Community Land of Wollongong City Council 2014 (herein referred to as 'the Generic POM') covers the land parcels identified in Table 3-4. As part of the Generic POM, the management issues affecting each of the Community Land categories, and an action plan has been developed.

Table 3-4 lists the issues that are consistent with issues found at Lake Illawarra. The actions to address these issues given in the Generic POM are also listed in Table 3-1 for reference in developing the Lake Illawarra CMP, however they are generally considered to be too generic to be directly relevant to the CMP.

Discussion of the legislative elements of preparing a POM for Community Land (under the Local Government Act, 1993) and Crown Land (under the Crown Lands Act 1989) is provided in Appendix A.

Table 3-4 Relevant Management Issues and Actions for Community Land on the Lake Illawarra Foreshore from the Generic POM

Community Land Category	Park/reserve name and community land parcel number	Management Issue and why relevant to CMP	Action recommended and Performance Indicator
Park	Lakeside Drive Reserve (637) Kanahooka Park (639) Purrah Bay Reserve (640) Berkeley Foreshore Reserve (576, and 575) Purry Burry Point (642 and 643) Jerrematta Park (564) Unnamed Foreshore Park and Bushland (665)	Unlawful occupation of Parks by encroachment by adjoining landowners. *Private landholders encroaching onto public foreshore land in parks or reserves is a common problem. Some encroachments restrict public access to the Lake's foreshore.*	Identify unlawful occupation of Parks and take appropriate action to eliminate such occupation, by negotiating with encroaching landowners. KPI: Number of unlawful occupations of community land successfully eliminated.
		Impact of parks on neighbouring natural areas. *Through landscaping, mowing and clearing, park management can encroach into natural areas.*	Identify sensitive natural areas adjacent to parks. Determine management requirements and development constraints for the protection of those natural areas. Implement necessary management practices and development constraints. KPIs: Number of sites where environmental requirements determined. Percentage of environmental requirements implemented. Key environmental indicators for natural areas.
		Potential for Aboriginal heritage sites on undisturbed land. *Lake Illawarra estuary would have provided a substantial resource for food and shelter for the Aboriginal people, as such there are very likely to be undiscovered Aboriginal heritage sites on the Lake foreshores within parks and reserves*	Investigate prior to disturbance of natural ground surface. Undertake archaeological survey as required. KPI: Number of archaeological surveys carried out prior to development.
	(see specific sites below)	Potential for Aboriginal heritage sites on undisturbed land.	As above

Community Land Category	Park/reserve name and community land parcel number	Management Issue and why relevant to CMP	Action recommended and Performance Indicator
Natural Area (General Issues)		Limited participation by small sections of the community in natural area management.	Increase community participation in natural area conservation and restoration, via existing environmental education centres. Undertake effective community education campaigns and workshops. KPIs: Number of visitors to the environmental education centres. Number of people attending workshops and environmental events organised by Council.
		Invasion of exotic flora and fauna.	To contain the spread of exotics where possible, through allocation of resources and funding through the corporate planning process. KPI: Number of weed and feral animal control programs initiated at various sites.
Natural Area Wetland	641 (immediately at the confluence of Mullet Creek with the Lake)	Poor water quality from the urban areas.	Continued development and implementation of programs such as water quality monitoring, the wastewater strategy, stormwater plans and Stream watch. KPIs: Improved water quality and health of wetlands. Number of fines and notices issued under the *Protection of the Environment Operations Act 1997*.
		Sedimentation from development within the wetland catchments.	Address all breaches of conditions of development consent and of Council's Subdivision Code, and undertake appropriate action against offenders. KPI: Number of fines and notices issued under the *Protection of the Environment Operations Act 1997*.
Natural Area Bushland	Fred Finch Park (498) Purry Burry Point (643) Jerrematta Park (564) Unnamed Foreshore Park and Bushland (665)	Pressures on the bushland from the surrounding urban interface.	Ensure that areas of bushland are managed and maintained based on the Natural Area Strategic Plan and Council's allocation of resources and funding through the corporate planning process. Promote community awareness by educating people about the impacts of urban areas on bushland. KPIs: Number of enquiries and responses regarding the maintenance and management of bushland. Number of bushland sites undergoing restoration.
Natural Area Foreshore	Lakeside Drive Reserve (637) Purry Burry Point (642) Unnamed Foreshore Reserve (644)	As above	As above

3.3.6 Illawarra BIO Map Pilot Study

The Biodiversity Investment Opportunities Map (BIO Map) identifies priority areas for investment in biodiversity outcomes. These are areas where funding for biodiversity management can make the greatest difference for biodiversity.

BIO Map has been developed as a pilot in for the Illawarra. It was developed by DPIE - Coasts & Estuaries as part of the NSW Government's Green Corridors Program, and was funded by the NSW Environmental Trust. In terms of estuary management, councils can use BIO Map to obtain funding to manage bushland on its own reserves or for its work with private landowners. The BIO Map can also assist councils and the community to draw a link between local actions and wider efforts to conserve biodiversity.

It is important to note that the inclusion of land within the BIO Map does not alter a landholder's right to carry out agricultural and developmental activities. The BIO Map identifies land that may have increased opportunities to access a range of conservation funding programs. Participation in these programs is entirely voluntary.

The BIO Map identifies priority investment areas comprising of:

- Core areas - areas of native vegetation and habitat where management will be of greatest benefit to the conservation of state and regional biodiversity values within a region.
- State biodiversity corridors - key linkages of native vegetation that are identified through state-wide analysis and provide connectivity between IBRA regions and subregions.
- Regional biodiversity corridors - key linkages of native vegetation within an IBRA subregion, between IBRA subregions or between significant biodiversity features.

An extract of the mapping is shown in Figure 3-3. This indicates that there are some areas mapped as ‘core areas’ and ‘regional corridors’ in and around Lake Illawarra highlighting that the Lake supports large areas of high conversation value. These areas should be considered in the CMP in terms of management actions to enhance their protection and rehabilitation. These sites would therefore have increased opportunities to access funding.

Figure 3-3 Illawarra BIO Map priority investment areas in and around Lake Illawarra

4 Gap Analysis and Recommendations for Future Work

The list of identified data gaps shown in Table 4-1 shows the extent that is unknown with regard to Lake Illawarra's complex ecosystem. The many variables that influence the estuary such as inter and intra seasonal variability in hydrology, tidal variability, river regulation and weather patterns mean that many data sets need to be collected over the long term to allow meaningful interpretation.

Table 4-1 Summary of Information gaps identified during the synthesis report

Information Gap	Brief Description	Significance for Management Planning?	Action to address gap, and req't for preparing CMP
Ongoing adjustments to entrance management works and when these will cease	It is expected that the entrance dynamics and all flow on processes will readjust for a long time to come (100 years +)	Important as it will dictate most processes, values and issues and the success of suitable management options. Some indicative information is available through the modelling and other work done to date.	Monitoring of bathymetric – topographic changes to the entrance channel shall be an option for consideration in the CMP. As changes will be occurring over 100 years +, observations and learnings should be ongoing and inform subsequent CMP reviews.
Recreational Fishing Effort	Recreational fishing take and impacts are not documented	This is an important aspect although difficult to measure as it requires information direct from participants	Survey of recreational fishers shall be an option for consideration in the CMP. Learnings from stakeholder consultation will be suitable to inform CMP.
Aspirations of the local Aboriginal Community, tangible and intangible values	Lake Illawarra remains an important place with numerous burial sites and middens found near the Lake and its surrounding areas. Aboriginal cultural aspects are thought to include the sharing of stories and collection of wild resources.	Crucial if this value is to be protected and enhanced. Our present understanding is limited.	Learnings from stakeholder consultation will be suitable to inform CMP. Expected to be actions in CMP relating to Aboriginal heritage that will provide ongoing input to cultural understanding.
Impacts of thermal discharges	Thermal discharges from the Tallawarra Power Station are known to occur, but the impacts of these for Lake Illawarra are largely unknown.	Given that Tallawarra Power Station is now not fully operational and has reduced the frequency of thermal discharges, the priority for this action is reduced.	Work with EPA and Tallawarra Power Station to reduce thermal discharges (e.g. when licensing renewal arises) shall be an option for consideration in the CMP. Action not required prior to CMP preparation.

Information Gap	Brief Description	Significance for Management Planning?	Action to address gap, and req't for preparing CMP
Fauna utilising the estuarine habitats.	Including mammals and reptiles	Not crucial to fill in the short term. A focus on protecting key habitats should have flow on benefits for fauna	The option to undertake fauna surveys using methods recommended by OEH (2016) to better understand fish and other fauna assemblages and inform estuary health will be considered in the CMP. Action not required prior to CMP preparation.
Appropriate targets for stormwater to balance development with sustainability	This has been progressed through the development of the CERAT tool by DPIE, although it is not currently directly applicable to establishing targets for specific existing or future urban areas.	Significant, catchment development will likely be a very high threat for many of Lake Illawarra's values.	Develop and apply minimum standards and targets for stormwater quality and quantity to new developments should be an option for consideration in the CMP. Action not required prior to CMP preparation.
Present day recreational and other community uses	The information within the Synthesis report is only based on available reports	Significant. The CMP is meant to facilitate recreational and other community uses	Community recreation survey shall be an option for consideration in the CMP. Learnings from stakeholder consultation will be suitable to inform CMP.
Source of contamination to Entrance Beach	Enterococci counts are frequently above NHRMC Guidelines	This reduces recreational opportunities	Investigation to determine the source of contamination at Entrance Beach shall be an option for consideration in the CMP. Action not required prior to CMP preparation.
Conflicts between Users	It is not known to what extent that present uses are deterring or causing conflict to other uses There is some information in the mainstream media regarding conflicts between recreational and commercial fishers.	It is important that community and recreational uses are equitable	Community recreation survey shall be an option for consideration in the CMP. Learnings from stakeholder consultation will be suitable to inform CMP.

Information Gap	Brief Description	Significance for Management Planning?	Action to address gap, and req't for preparing CMP
SLR Impacts	Potential risks to foreshore habitats, public recreational land, habitats, private property and other public assets (stormwater outlets, roads, jetties, schools etc. from SLR given modified and adjusting entrance state	Not crucial for short term planning	Permanent inundation study shall form an option in the CMP. This has since been completed (refer to BMT, 2020a).
Bank erosion	There is limited detailed information on the location, extent and cause of bank erosion particularly dynamic due to the changed tidal regime and in response to June 2016 east coast low	Important for developing appropriate responses to manage bank erosion. In the short term, education of public and private foreshore property owners on environmentally friendly approaches is needed, to avoid inappropriate structures that impound or reduce estuarine habitat.	An updated bank erosion study (location, extent, cause) will form an option for the CMP. Education for land managers (public and private) regarding environmental approaches to bank erosion management will form an option for the CMP. Actions not required prior to CMP preparation.
Updated estuarine habitat mapping	LIA mapping done in 2010, DPI mapping available online is from 2005. There are very likely to have been changes since this time due to entrance	Important because the extent of change since permanent entrance opening is not known. Estuarine macrophytes are crucial habitat for fish and other species.	Updating the estuarine macrophyte mapping will form an option for the CMP. Action not required prior to CMP preparation.

5 Key Threats Identified by this Synthesis Study

Considerable effort has been expended by the former LIA, SCC, WCC and DPIE - Coasts & Estuaries and other researchers to identify, document and manage the environmental, social and economic values and issues associated with Lake Illawarra. A key priority for the CMP preparation process is to avoid duplicating effort that has already been undertaken, to continue to implement and support existing successful actions, and to focus energy on actions that have tangible benefits for the estuary, supported by the available evidence.

At this stage of the process, a first pass list of the threats (issues) in Lake Illawarra has been compiled based on the available documented information reviewed for this report. Similarly, a first past list of values has also been drafted, and will be finalised as part of a subsequent report. The lists provide a starting point for expansion and elaboration during subsequent stages of the project, particularly consultation with the Committee, key stakeholders, and the community generally.

It is noted that existing and successful management initiatives determined through the course of this synthesis report were documented in Appendix C.

5.1.1 Threats

The Lake Illawarra catchment is in a period of significant land use change, with new residential developments underway. This is in parallel to the ecosystem response to permanent changes to the entrance condition and tidal hydraulics of this already highly dynamic lake system. It is also a period of transition in governance in response to the disbanding of the LIA and transition to management by SCC, WCC, and DPIE– Crown Lands with respect to the entrance management works. There are many aspects of the management of Lake Illawarra that can be targeted through the estuary management program and there are some aspects that are beyond the reach of this process.

A first pass list of threats identified through the preparation of this Synthesis Report is outlined in Table 5-1. As noted above, this list is a starting point, to be expanded during the project, particularly consultation and engagement. It is expected to develop into a comprehensive description of threats that require management attention via the CMP.

Table 5-1 First Pass List of Threats

Threat	Key drivers	Description
Potential loss of saltmarsh areas	Entrance Management Catchment Development Climate change (SLR, increases in temperature) Mangrove encroachment	Saltmarsh remains a vulnerable community. The process often described as coastal squeeze where sea levels rise and adjacent saltmarsh is unable to migrate landward
Wetland degradation	Litter, dumping and marine debris BMX, motorbike and 4WD track creation in saltmarsh areas	Some areas of wetland that have high ecological potential are being degraded by human activities. There is community passion around assisting these areas to meet their full ecological potential and motivation to work on finding alternate locations for activities such as BMX riding.
Erosion	Entrance Management	In response to changes in the tidal prism and velocities introduced through the entrance management works, areas within the entrance channel continue to erode. This has already impacted the boardwalk, areas of Aboriginal Cultural significance and continues to threaten shorebird habitat, open public space and eventually the caravan park. Creek Erosion. east coast low event in June 2016
Migration of the entrance shoal	Entrance Management	Impacts on seagrass and swimming area
Increased wave penetration, elevated water levels, changed tidal regime	Entrance Management, Coastal Storms (into the future, sea level rise and climate change)	For example, along Reddall parade Some infrastructure is not appropriately designed for the changed hydraulics (e.g. boat ramp)
Contaminated Sediments	Legacy of historical catchment land uses and pollution sources Industrial & agricultural land uses Sewerage overflows Bank or foreshore erosion Catchment runoff	There are known levels of contaminated sediments within Lake Illawarra and particularly high concentrations have been measured in sediments amongst saltmarshes. Sediment cores high levels of metals including copper, zinc, arsenic, selenium, cadmium, and lead may be attributed to historical events and uses. Locations of particular concern are Wegit and Minnegang Creeks (toward Port Kembla),
Potential introduction of marine pests	Entrance management Recreational boating	A permanently open entrance increases the chance of the introduction of marine pests. Known locally specific possibilities include: European Shore Crabs (*Carcius maenas*) Japanese Goby (*Tridentiger trigonocephalus*)

Key Threats Identified by this Synthesis Study

Threat	Key drivers	Description
Loss of riparian habitat & shorebird communities	Illegal tree removal (poisoning, cutting down off trees) Clearing for foreshore development Bank or foreshore erosion	During the field visit and during air photo review it was apparent that illegal tree poisoning and vegetation removal had been undertaken in many locations around the Lake Changes to the extent and condition of various estuarine vegetation communities can occur in response to the estuary health and physical condition of the Lake A number of EECs exist within the Lake
Water pollution	Urban Stormwater Sewerage overflows Industrial land uses Industrial discharges Thermal discharges Bank or foreshore erosion Catchment runoff Groundwater Leachate	Water quality and estuary health in the Lake improves around the middle reaches, main body, and the entrance area, and decreases in the enclosed north-east and south-west reaches High enterococci Counts in entrance Beach
Climate Change	SLR	Loss of saltmarsh areas Inundation of public and built assets Inundation or loss of cultural heritage items/places
Catchment Development	Urban release areas	Substantial development is planned for the Lake Illawarra Catchment and this has potential to have significant impacts on the Lake through increased freshwater inputs and increases in most pollutants (particularly sediments and nutrients).
Conflicts between human uses	Overfishing Marine Debris Physical Disturbance of estuarine habitats	Including conflict between recreational and commercial fishers
Foreshore development encroaching public land	Mowing Disposal of clippings Weeds Foreshore access Signs on public land	Some private landholders are extending their foreshore blocks by mowing and small scale illegal foreshore development (e.g. BBQ areas)
Park management practices impacting adjacent natural areas	Mowing Disposal of clippings Weeds	Park managers from Council are sometimes in contradiction to best environmental practice. This sets a bad example for the community.
Inappropriate / degraded / Insufficient Infrastructure	Reduced funding, changed tidal regime, ownership negotiations	Boat ramps LIA built many jetty's but not all are utilised.
Introduced Species	Legacy introductions, marine pests through the permanently open entrance	Hard hoofed animals such as stock and horses (for riding) and feral deer impacting natural areas.

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Appendix A Legislation and Planning Context

A.1 Coastal Management Act 2016

The Coastal Management Act 2016 (CM Act) replaces the *Coastal Protection Act 1979* and establishes a new strategic framework and objectives for managing coastal issues in NSW. The objects of the CM Act are to manage the coastal environment of New South Wales in a manner consistent with the principles of ecologically sustainable development for the social, cultural and economic well-bring of the people of NSW. A key aspect of the CM Act is the division of the coastal zone into four coastal management areas:

- The coastal wetlands and littoral rainforests area;
- The coastal vulnerability area;
- The coastal environment area; and
- The coastal use area.

As well as being defined, the four areas are mapped as part of the State Environmental Planning Policy (Coastal Management) 2018 (the “CM SEPP”).

The CM Act sets the mandatory requirements for the preparation of coastal management programs (CMPs). Further requirements and guidelines additional to the CM Act for preparing CMPs are provided in the Coastal Management Manual (OEH, 2018).

A new independent NSW Coastal Council has replaced the statutory NSW Coastal Panel, as well as the Coastal Expert Panel. The NSW Coastal Council's role is to

- Provide independent advice to the Minister administering the new Act on coastal planning and management issues.
- Provide advice to the Minister when granting Ministerial certification of a CMP, and may commission technical advice on matters of strategic importance.
- Conduct, at the Minister's direction, performance audits of a local council's implementation of its CMP.

A.2 State Environmental Planning Policy (Coastal Management) 2018

State Environmental Planning Policy (Coastal Management) 2018 (the “CM SEPP”) updates and consolidates the SEPP 14 (Coastal Wetlands), SEPP 26 (Littoral Rainforests) and SEPP 71 (Coastal Protection), including clause 5.5. of the Standard Instrument – Principal Local Environmental Plan into one integrated policy. These policies are now repealed.

The Coastal Management SEPP commenced in 2018 and gives effect to the objectives of the Coastal Management Act 2016 from a land use planning perspective, by specifying how development proposals are to be assessed if they fall within the coastal zone.

An integrated and coordinated approach to land use planning is promoted by the new SEPP. It defines the four coastal management areas in the Act through detailed mapping and specifies

assessment criteria that are tailored for each coastal management area. Councils and other consent authorities must apply these criteria when assessing proposals for development that fall within one or more of the mapped areas.

A.3 Marine Estate Management Act

The NSW Government commissioned an Independent Scientific Audit of Marine Parks in NSW (the Audit) in mid-2011 and concluded that management of the marine estate required changes to governance arrangements and policy objectives, particularly in order to reduce social conflict and improve effective management of coastal and marine resources beyond existing marine parks.

Consistent with the Audit recommendations, the NSW Government implemented a new approach to sustainable management of the NSW marine estate, including all marine waters, estuaries and coastal areas and the State's six marine parks. The *Marine Estate Management Act 2014* (MEM Act) provides for strategic and integrated management of the whole marine estate.

In response to the findings of the Audit, the Government also established a new advisory Marine Estate Management Authority (the Authority), which comprises representation from the four main government agencies involved in marine estate management and an independent Chair. The four government agencies are the Office of Environment and Heritage, Department of Trade and Investment, Department of Transport, and Department of Planning and Infrastructure. It also appointed an independent Marine Estate Expert Knowledge Panel (MEEKP) to provide expert advice spanning ecological, economic and social sciences to underpin evidence based decision making.

Lake Illawarra and its associated coastline are considered a marine estate under the MEM Act which defines a marine estate as including the 'coastal waters of the State out to three nautical miles'. Included in this definition are estuaries, coastal wetlands, adjacent coastal lands influenced by oceanic processes, and coastal Lakes and lagoons.

Furthermore, Bushranger's Bay, a small rocky embayment south of Shellharbour at Bass Point is recognised as a NSW Aquatic Reserve. The bay was declared a reserve due to the presence of rock platforms, crevices, and rock pools, its unique habitat, and its role as a nursery located on the cusp of both temperate and tropical regions. It is also recognised as the southernmost distribution for a number of species of tropical fish (DPI, n.d.).

A.4 South East Local Strategic Plan 2016-2021

The former Southern Rivers Catchment Management Authority (SRCMA) was amalgamated into the South East Local Land Services (South East LLS). The area covered by South East LLS extends from Stanwell Park in the north to the Victorian border in the south, and westward from Boorowa in the north to Thredbo in the South, therefore covering Lake Illawarra.

South East LLS has prepared the South East Local Strategic Plan 2016-2021. This five-year strategic plan helps to identify strategic programs to improve the health, productivity and resilience of the landscape and its communities. The South East Local Strategic Plan 2016-2021 replaces the Southern Rivers Catchment Action Plan (SRCAP) of the former SRCMA.

The *Local Land Services Act 2013* required the development of the State Strategic Plan, which sets the vision and goals for Local Land Services for the next ten years with a focus on appropriate economic, social and environmental outcomes. The State Strategic Plan outlines the strategies through which these goals will be achieved. The South East Local Strategic Plan aligns with the state-wide vision, goals and strategies for Local Land Services and prioritises service delivery on a regional basis, reflecting regional and local priorities.

The South East Local Strategic Plan recognises climate variability (including sea level rise) as a primary driver of change influencing the South East region. Biodiversity, increasing pressure on natural resource assets, population growth and conflicting land use are also recognised as primary drivers of change.

Actions and performance measures under the goal and strategies of the Plan may align with coastal management actions outlined in the Lake Illawarra CMP, and provide a suitable avenue to see grants and funding through the South East LLS. Goals, Outcomes, Priorities and Strategies that align or are relevant to the preparation of the CMP for Lake Illawarra are listed in Table A-1.

Table A-1 Relevant Goals, Outcomes, Priorities and Strategies from the SE Local Strategic Action Plan

Goal	Outcomes	Priorities	Strategies (and actions, KPIs within the strategy)
Goal 2 – Biosecure, profitable, productive and sustainable primary industries	• early detection to prevent establishment of new weeds, invasive animals, plant pests and diseases or animal pest and disease incursions that threaten market access • improved resilience to natural disasters and seasonal variability	• Declared pests and weeds	**STRATEGY 3**: Provide products and services that support and enable customers, land managers and the community to prevent, prepare, respond and recover from biosecurity and natural disaster events. **Action 3.3:** Develop a seasonal variability strategy, including trigger points for adaptive management **Regional Performance Measures** By December 2016, implement the South East Climate Adaptation Plan. By December 2016, develop and implement the South East Local Land Services Seasonal Variability Strategy.
Goal 3 – Healthy, diverse, and connected natural environments	• clean water • healthy aquatic and terrestrial ecosystems	• Maintain good condition estuaries, coasts and marine areas • Maintain good condition native vegetation, riparian vegetation and landscape corridors • Improve soil health and manage erosion to protect priority industries and aquatic assets	

A.5 Southern Rivers Catchment Action Plan

Catchment Action Plans (CAPs) are strategic, statutory plans prepared by the former Southern Rivers Catchment Management Authority (now Local Land Services (LLS)) to provide a framework for natural resource management in a defined catchment.

The Southern Rivers CAP guides natural resource management investment in the region over the 2013 to 2023 period. The CAP outlines a number of Catchment and Management Targets to improve the catchment's natural assets. The CAP sets targets and a timetable for the CMA's action and investment and is designed to be responsive to the changing needs of the catchment and the community.

Key targets of the CAP include:

- By 2023, land and water managers are supported to increase the adoption of practices that maintain or improve the condition of priority freshwater, estuarine and marine assets; and
- From 2015, frameworks and protocols are implemented for devolved, adaptive and evidence-based decision making.

Strategies proposed to achieve these targets include:

- Maintain and improve the condition of priority fresh water, estuarine and marine assets – focus on good condition and high recovery potential natural assets.
- Implement practices that contribute to the maintenance or improvement of water quality and river health – focus on impacts from urban areas and aquatic assets that support local industry.
- Equitable sharing of water between people and the environment.
- Establish devolved and collaborative decision-making structures at the appropriate scale – industry and community participation in decision making.
- Ensure that decisions at all scales are balanced, transparent and evidence-based – land use planning consistent with land capability, development controls, water and estuary planning.
- Support the continuous improvement of national, state and regional policies, plans and priorities – Adapt to new evidence and knowledge, lessons from regions inform improvements across the state.

A.6 NSW 2021

NSW 2021 is the State Plan for the NSW Government detailing a set of priorities for NSW. Specific goals that would be particularly relevant to stormwater management in the Albion Park sub-catchments include:

- Goal 22 – Protect our natural environment;
- Goal 23 – Increase opportunities for people to look after their own neighbourhoods and environments; and
- Goal 32 – Involve the community in decision making on government policy, services, and projects.

The State Plan outlines priorities for protection of the natural environment, and indicates a goal to encourage transfer of maintenance responsibilities for looking after local environments to the community wherever possible.

A.7 Natural Resources Commission

The Natural Resources Commission (NRC) is an independent body that provides the NSW Government with advice on natural resource management in the environmental, economic, social and cultural interests of the state. The NRC's primary areas of responsibility are to independently review Catchment Action Plans (CAPs), audit their implementation and provide recommendations to the NSW Government based on the review/audit findings. The NRC also has specific roles under environmental planning legislation to review and advise the Minister on development master plans, or consider requests to waive the need for a master plan. In addition, the NRC conducts reviews of scientific and policy issues under legislation or as requested by the NSW Government.

The NRC was tasked with recommending revised state-wide standards and targets for natural resources management to the NSW Government in 2012. The state-wide targets were revised to align with the central goal of 'people working together to achieve healthy, productive, culturally vibrant and resilient landscapes. The NRC identified 5 state-wide targets for natural resource management, including:

- Community – Improve the capacity and engagement of natural resource managers.
- Land – Improve soil conditions.
- Water – Improve the condition of aquatic ecosystems.
- Vegetation – Improve the extent and connectivity of native vegetation and the condition of priority plant and animal species.
- Devolution – Improve the devolution of decision making to the most capable local level.

The state-wide targets are promoted through the CAPs and are also relevant for future development planning.

A.8 Protection of the Environment Operation Act 1997

The *Protection of the Environment Operations Act* (POEO Act) regulates water pollution, air pollution and noise pollution in New South Wales and is administered by the Environment Protection Authority, an agency within DPIE, to issue pollution license and notices, to take legal action to enforce the law and to create a range of pollution offences and penalties. The Act also enables members of the public to take legal action to enforce laws.

Under the POEO Act it is considered an offence to pollute water without an environmental protection licence. Water pollution is the placement of any matter in a position where pollution enters or is likely to enter the water. Pollution of a waterway is allowed if an environmental protection license is held, however, there are conditions of a licence.

Other activities that require a licence under the Act are dredging or extractive activities where more than 30,000 m^3 per year is being removed, for re-use or resale (refer Schedule 1).

A.9 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the main Commonwealth Law responsible for the protection of flora and fauna. The Act applies to:

- Flora and fauna within areas controlled or owned by the Commonwealth;
- Flora or fauna that may be harmed by the actions of a Commonwealth agency; and
- Actions that may have a significant effect on species on the national threatened species list.

The objectives of the EPBC Act are to protect, conserve, and enhance the environment, promote ecologically sustainable development, and to recognise and the role of and utilise Indigenous people in conservation. The EPBC Act defines matters of national environmental significance as: Ramsar wetlands, listed threatened species and communities, World Heritage properties, listed migratory species, the Commonwealth marine environment and nuclear actions (including uranium mining). The EPBC Act was amended in 2003 to include the protection of National Heritage. This amendment involved, including 'national heritage' as new matter of national environment significance, and the establishment of a national heritage list.

The EPBC Act also requires Commonwealth approval for certain actions on Commonwealth land.

A.10 Biodiversity Conservation Act 2016

The *Biodiversity Conservation Act 2016* (the BC Act) commenced on the 25 August 2017 with the intent to maintain a healthy, productive and resilient environment for the greatest well-being of the community, now and into the future, consistent with the principles of ecologically sustainable development.

The BC Act replaces the *Threatened Species Conservation Act 1995* (TSC Act) as the key piece of legislation that identifies and protects threatened species, populations and ecological communities in NSW.

The BC Act established a new legislative framework for biodiversity conservation, containing provisions relating to flora and fauna protection, threatened species and ecological communities listing and assessment, a biodiversity offsets scheme (BOS), a single biodiversity assessment method (BAM), calculation and retirement of biodiversity credits and biodiversity assessment and planning approvals.

The BC Act lists endangered species, populations, ecological communities, and species presumed to be extinct, and critically endangered species and ecological communities (Schedule 1-3). It also lists vulnerable species and vulnerable ecological communities (Schedule 5 and 6), and key threatening processes (Schedule 4).

The BC Act has established a Threatened Species Scientific Committee that is responsible for determining species, populations, ecological communities or threatening processes that should be included in Schedules 1, 2 or 3, or such can be listed upon request by the Minister (for Energy and Environment who administers this act).

Division 1 of the BC Act lists offences in relation to threatened species including, to harm, damage or pick an animal or plant that is, is part of, is critical habitat for, or is habitat for a threatened species, population or ecological community, unless a licence has been obtained under the BC Act or LLS Act.

A.11 Local Land Services Act 2013

The *Native Vegetation Act* 2003 was repealed on 25 August 2017. Legislation now governing native vegetation is the amended *Local Land Services Act 2013* (LLS Act) and the BC Act. The amended LLS Act provides a new regulatory framework for native vegetation and land management activities in NSW. The amended Act:

- Categorises regulated and exempt land to provide certainty and clarity for landholders;
- Creates Allowable Activities which simplify and expand the former routine agricultural management activities (RAMAs);
- Creates the Land Management (Native Vegetation) Code;
- Establishes a Native Vegetation Panel; and
- Enables landholders to use the Biodiversity Offsets Scheme for agricultural development.

A.12 National Parks and Wildlife Act 1974

The *National Parks and Wildlife Act 1974* (NPW Act) is the NSW legislation in place to conserve the State's natural and cultural heritage, foster public appreciation, understanding and enjoyment of NSW's natural and cultural heritage and manage any lands reserved for those purposes.

The NPW Act is the main piece of legislation for managing and protecting Aboriginal cultural heritage with Part 6 of the Act providing protection for Aboriginal objects and places. All Aboriginal sites in NSW are protected under the NPW and it is an offence to damage or destroy them (this includes collecting artefacts) without prior permission of the Director-General of Environment, Energy and Science (within DPIE).

A.13 Fisheries Management Act 1994

The *Fisheries Management Act 1994* and *Fisheries Management Amendment Act 1994* (the FM Act) are the main Acts governing the management of fish and their habitats in State waters. The aim is to conserve, develop and share the fishery resources for the state's benefit for present and future generations, whilst promoting ecologically sustainable development, including conservation of biological diversity. The FM Act applies specifically to aquatic flora and fauna, primarily fish, invertebrates and some algae, but also protects marine vegetation, including mangroves, saltmarsh and seagrass. The Act includes schedules of threatened aquatic species, populations and ecological communities, which are protected. Potential impacts to these species, populations and communities are to be assessed in accordance with the FM Act.

Dredging and reclamation activities also fall under the FM Act. Reclamation of land in the waterway shall be managed to conserve the biodiversity of fish, aquatic vegetation and fish habitat and be

consistent with the principles of ecologically sustainable development. Persons (i.e., not a public or local authority) must have a permit issued by the Minister for Fisheries before they may proceed with reclamation or dredging activities.

Under the FM Act it is an offence to harm or cause damage to (by an act or an omission) any fish, marine vegetation or habitat of a threatened species, population or ecological community, or critical habitat. This includes damage caused in the act of carrying out a development or as a failure to comply with a development consent or approval. Licences to cause harm or damage will only be granted for: scientific purposes; the welfare of fish or marine vegetation; or where there is threat to life or property.

The FM Act also includes and allows for the preparation of Habitat Protection Plans. Those plans relevant to the study area include:

Habitat Protection Plan No. 1 General

This is an advisory document summarising various protective measures in relation to dredging and reclamation activities, fish passage requirements, and the protection of mangroves, other marine vegetation and snags.

Habitat Protection Plan No. 2 Seagrasses

The Plan deals specifically with the protection of seagrasses across NSW, and discusses activities which impact on seagrasses, including the construction of jetties, wharves, and bridges, dredging and reclamation, and the collection of seagrasses.

A.14 Local Government Act 1993

The *Local Government Act 1993* (the LG Act) creates local governments and grants them the power to perform their functions, which involve management, development, protection, restoration, enhancement and conservation of the environment for the local government area. The functions of the local government are to be performed in a manner that is consistent with and promote the principles of ecologically sustainable development.

The service functions of local councils (defined in Chapter 6 of the Act) includes the classification, use and management of public land, including the objectives for management of the Community Land owned by Council (i.e. that is not Crown Land).

Plans of Management for Community Land need also to be prepared under Section 35 of the Act. Section 35 of the act provides that community land only be used in accordance with the plan of management applying to the parcel of community land; any law permitting the use of the land for a specified purpose or otherwise regulating the use of the land; and the provisions of Division 2 Chapter 6 of the Act.

Community land can be categorised into a range of categories under Section 36 of the Act, and each of these categories have their own core objectives specified under the Act. The categorisation of community lands is important as the Act requires Council to only grant a lease, licence or another estate (other than in respect of public utilities) for a purpose consistent with the core objectives of the category of that community land.

Section 733 of the LG Act offers exemption of liability to Council with respect to coastal and floodplain lands providing that Council acts in 'good faith' and manages the lands in accordance with Government guidelines and manuals. In respect to coastal lands, the relevant Government manual is the CMP Guidelines. Consequently, the development of this CMP is considered to be acting in good faith and in accordance with the appropriate guidelines, and as such, when the CMP is gazetted, Council can assume the liability exemption.

A.14.1 Generic Plan of Management for the Community Land of Wollongong City Council 2014

The Generic Plan of Management for the Community Land of Wollongong City Council 2014 (herein referred to as 'the Generic POM') covers:

- The category of all the land that is owned by Council and categorised as community land under the *Local Government Act 1993;* and
- All of the Crown Land under Council's trusteeship or care and control (where a POM is required as per the *Crown Lands Act 1989*); and
- Identifies land that is covered under an adopted site specific plan of management and therefore not covered under the Generic POM.

The Generic POM provides direction and continuity for the planning, resource management, maintenance, operation and programming of community land.

The Generic POM applies to community land that is categorised as Park, Sportsground, Natural Area (Bushland, Wetland, Watercourse, Escarpment or Foreshore) and General Community Use. Each category of community land has its own core objectives specified by the *Local Government Act 1993*, and these are reiterated in the Generic POM. The Generic POM also specifies the community values and objectives for each category of community land.

Community Land Area Maps documented in the Appendix to the Generic POM illustrate that Area 8 and 9 cover the WCC managed foreshores of Lake Illawarra. Community Land parcels, including names and community land categories on the Lake Illawarra foreshores are listed in Table A-2. Judbooley Parade Windang covers community land parcel 670 and 671 on the Lake Illawarra foreshore, and is the subject of a separate POM as discussed below.

Land categorised as an Area of Cultural Significance requires a site specific POM in accordance with Section 36(3A) of the Act. One Area of Cultural Significance covering the Port Kembla Sailing Club is identified in maps of the Lake Illawarra foreshore in the Generic POM. A POM for this site was not available at the time of this report.

Of most relevance to the development of this Lake Illawarra CMP is the management issues and action plans identified for each category of community land in the Generic POM. While these may be "generic", the issues and management actions that are relevant to the CMP are discussed in Section 3.3.5 of the main report.

It is also noted that many of these land parcels were identified in the Wollongong Coastal Zone Management Plan (BMT WBM, 2017) due to the potential for coastal inundation. BMT WBM (2012)

identified actions for these and other assets and land of Lake Illawarra affected by coastal inundation, as noted in Section 3.3.2.

Table A-2 Community Land on the Lake Illawarra Foreshore covered by the Generic POM

Community Land Category	Park/reserve name and community land parcel number
Park	Lakeside Drive Reserve (637) Kanahooka Park (639) Purrah Bay Reserve (640) Berkeley Foreshore Reserve (576, and 575) Purry Burry Point (642 and 643) Jerrematta Park (564) Unnamed Foreshore Park and Bushland (665)
Natural Area Foreshore	Lakeside Drive Reserve (637) Purry Burry Point (642) Unnamed Foreshore Reserve (644)
Natural Area Wetland	641 (immediately at the confluence of Mullet Creek with the Lake)
Natural Area Bushland	Fred Finch Park (498) Purry Burry Point (643) Jerrematta Park (564) Unnamed Foreshore Park and Bushland (665)
Area of Cultural Significance	Port Kembla Sailing Club (578)
Crown Land	Windang Beach Tourist Park (1059) Perkins Beach Crown Reserve, covering Lake Illawarra Entrance area around to Windang (687)

A.14.2 Judbooley Parade Windang Plan of Management

The area covered by the Judbooley Parade Windang Plan of Management (Judbooley POM) is located in Judbooley Parade, Windang on the western side of Windang Road and fronting Lake Illawarra, as shown in Figure A-1.

The site shares a rich Aboriginal archaeological and cultural heritage history, and a rich non-indigenous heritage. This heritage is detailed in the Judbooley POM (WCC 2008b). In relation to its cultural and community values, the basis for management of the area was identified as follows:

- Judbooley Parade is valued as a historical resource;
- Judbooley Parade is valued as a place to enjoy Lake Illawarra; and
- Judbooley Parade is valued for its recreational opportunities.

In relation to this, the Judbooley POM details the management objectives and outcomes for the area.

The Judbooley POM outlines issues and actions to manage these issues. The management actions are very site specific, and need not be reiterated through the Lake Illawarra CMP.

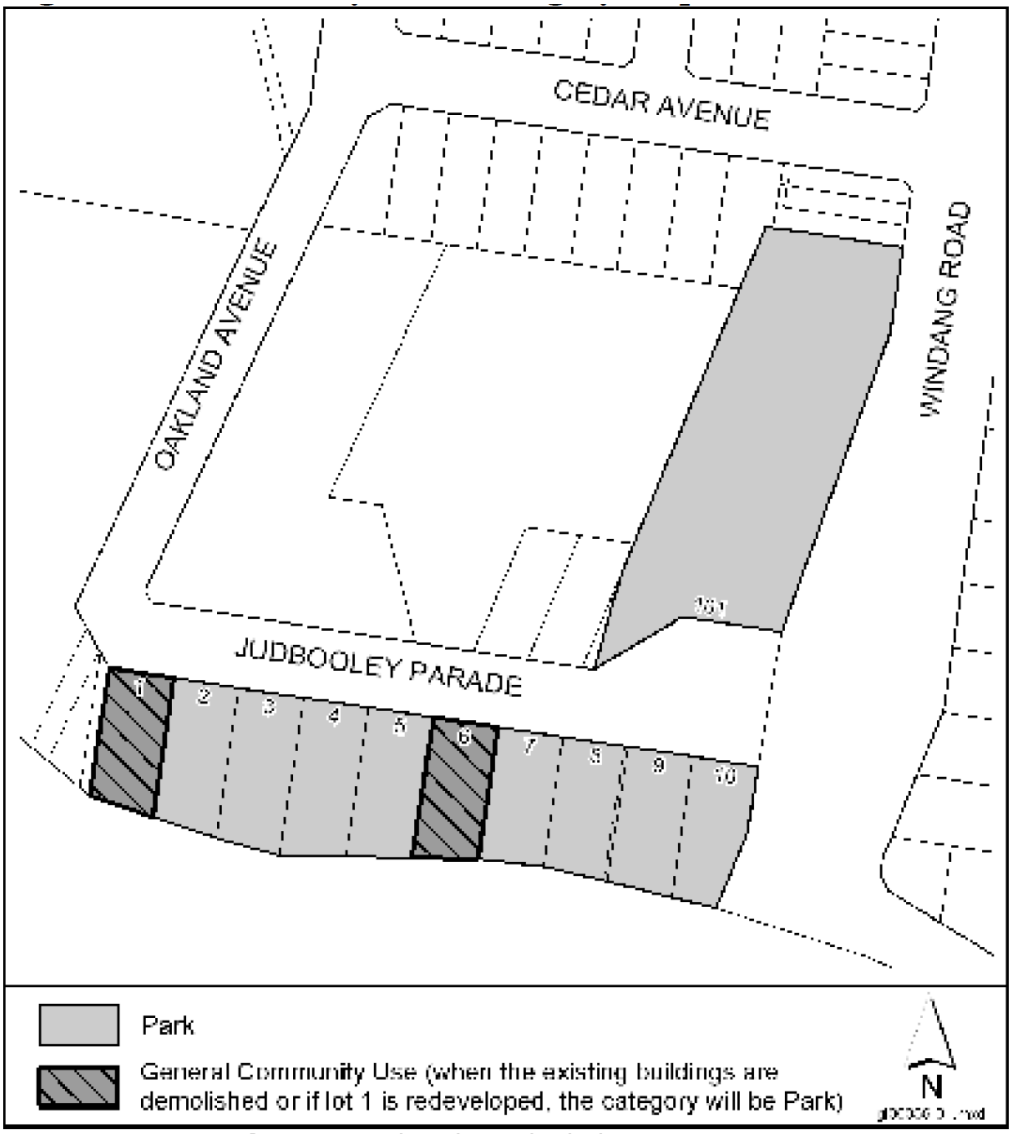


Figure A-1 Area covered by the Judbooley Parade Windang POM (source: WCC, 2008)

A.15 Crown Lands Act 1989

The *Crown Lands Act 1989* (the CL Act) provides for the administration and management of Crown land for the benefit of the people of NSW. The CL Act provides principles for the proper assessment, development, reservation or dedication and conservation of Crown Lands.

Waterbodies such as beaches and foreshores and estuaries/creeks/lagoons below the mean high water mark are designated as Crown Land and managed by DPIE – Crown Lands.

The principles of Crown Land management as defined in Section 11 of the Act are: environmental protection principles be observed in relation to the management and administration of Crown land; natural resources of Crown Land (including water, soil, flora, fauna and scenic quality) be conserved wherever possible; public use and enjoyment of Crown Lands be encouraged; where appropriate, multiple uses of Crown Land be encouraged; and where appropriate, Crown Land be used and managed in such a manner that the land and its resources are sustained in perpetuity.

In addition to these principles, the objectives of the Coastal Crown Lands Policy 1991 apply to Crown lands within the coastal zone. The policy sets specific objectives for conserving the environmental and cultural qualities of coastal Crown Land, retaining in public ownership coastal lands that are environmentally sensitive and / or required for public purpose, and providing use of coastal crown lands for recreation, tourism, residential and commercial development with due regard to the nature and consequences of coastal processes.

For all Crown land reserves, a Plan of Management (POM) is required to be prepared and adopted (in accordance with Division 6 of the *Crown Lands Act 1989*). The POM shall identify the key attributes and values of the area, general physical improvements to enhance the values and specify the permissible uses for the reserve.

The CL Act requires a land assessment to be undertaken prior to the reservation, dedication, exchange, vesting or sale of Crown land, or the granting of easements, leases or licences in respect of such land. The process for land assessment is specified by the Act and the *Crown Lands Regulation 2000*. It requires the physical characteristics of the land to be identified, the land's capabilities to be assessed and suitable uses identified. A draft land assessment is publicly exhibited for 28 days for comment. The exhibited draft may indicate a preferred use or uses.

A.16 Water Management Act 2000

The *Water Management Act 2000* (the WM Act) seeks to promote the integrated and sustainable management of the State's waters for the benefit of both present and future generations. Of key relevance to the Study area, the Act aims in particular "to protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality". The Water Management Act 2000 replaced the Rivers and Foreshores Improvement Act 1948 (RFI Act 1948) in February 2008.

The Act recognises:

- "The fundamental health of our rivers and groundwater systems and associated wetlands, floodplains and estuaries has to be protected;
- The management of water must be integrated with other natural resources such as vegetation, soils and land;
- To be properly effective, water management must be a shared responsibility between the government and the community;
- Water management decisions must involve consideration of environmental, social, economic, cultural and heritage aspects. This has been progressed by DPIE through the development of the risk based stormwater management framework, which does set specific pollutant reduction targets for new developments within the Lake catchment (refer to 2.8.12); and
- Social and economic benefits to the state will result from the sustainable and efficient use of water."

A.17 Water Management Amendment Act 2014

In 2014 the *Water Management Amendment Act 2014* (WMA Act) was passed in late 2014 and amends some of the sections of the WM Act and adds new legislation to the WM Act. The amendments to the Act include planning, licensing, and compliance in relation to water management. These amendments commenced in 2015. These changes include:

- Regulated river supplementary licences – provides security for licence holders located on regulated rivers.
- Harvestable rights – allows landholders greater flexibility in the construction and use of dams for water storage in excess of their maximum harvestable right dam capacity.
- New offences for taking water – improved offence provisions to ensure fair sharing of water when water allocations have been exceeded.
- Licensing and trading processes – simplified processes for licence holders and applicants to amend or withdraw applications, with a more streamlined and simplified approval process.
- Granting combined approvals – provide the Minister with greater flexibility to grant approval when combined approvals are required.
- Floodplain harvesting access licences – facilitates the issuing of floodplain harvesting access licences.

A.18 Councils IPR Framework

All Councils in NSW are tasked to produce a set of documents as part of the State Government's Integrated Planning and Reporting (IPR) Framework. These documents set out where Wollongong and Shellharbour want to be in ten years and how Council will respond to help achieve these aspirations through details of its budgets, activities and performance measures.

The WCC IPR documents are:

- Wollongong 2022 (Community Strategic Plan) - Long-term (ten year) aspirations of the Wollongong community. It outlines the Wollongong community's priorities and aspirations with methods for achievement. This was adopted by Council in 2012.
- Revised Delivery Program 2012-2017 - Council's five-year plan to address Wollongong 2022 adopted in 2014.
- Annual Plan 2016-2017 – Provide the community with an outline of the projects, programs and activities Council plan to carry out. Adopted 2016.
- The implementation of the Delivery Program 2012-2017 and Annual Plan 2016-2017 are monitored via Quarterly Review Statements and the Delivery Program Progress Report. The progress of the five year actions in the Delivery Program are monitored and reported in the Delivery Program Progress Report.
- Revised Resourcing Strategy 2012-2022 - Council's Long Term Financial Plan, Asset Management Strategy and Workforce Management Plan. Adopted 2014.

The SCC IPR documents are:

- Shellharbour City 2013-2023 (Community Strategic Plan) - Long-term (ten year) aspirations of the Shellharbour community. It outlines the Shellharbour community's priorities and aspirations with methods for achievement. This was adopted by Council in 2012.
- Shellharbour City Council Operational Plan 2015-2016 – an annual plan that outlines what Council will deliver from the program that year.
- Shellharbour City Council Delivery Program 2013-2017 – a four-year plan that details the Strategies and individual actions across entire Council operations.
- Shellharbour City Council Resourcing Strategy – contains information on the time, money, assets and people required by the Council to progress the Strategies in the Delivery Program.
- Biannual Delivery Program Review – a six-monthly review of the progress of Council in implementing the strategies identified in the Delivery Program.
- Quarterly Operational Plan Review – a three-monthly report on the progress achieved in implementing the actions identified in the Operational Plan.
- Annual Report – annual report to the community outlining the progress in implementing the Delivery Program and Operational Plan.
- End of Term Report – a report to the community in line with the election cycle on how successful the current Council, State, and Federal governments and community have been in achieving the objectives outlined in the Community Strategic Plan.

The CMP will be drafted to mainstream Coastal Management Actions into councils' overall service delivery and asset management planning responsibilities.

A.19 Illawarra Shoalhaven Regional Plan

The Illawarra-Shoalhaven Regional Plan (ISRP) applies to the Local Government Areas of Kiama, Shellharbour, Shoalhaven and Wollongong. The ISRP focuses on achieving a sustainable built environment where urban areas are planned, designed and managed to improve their environmental performance. A key focus is on more efficient use of urban zoned land.

One of the key targets of the ISRP is to protect the region's environmental values by focusing development in locations with the capacity to absorb this development. Another target is to embed urban design principles that support sustainability into the design of subdivisions in new urban release areas. The initial land use planning process is highlighted as the stage to identify and protect natural waterways.

Other key targets of the ISRP relevant to management of stormwater and flooding include:

- To avoid, minimise and mitigate the impact of development on significant environmental assets (identified and mapped by DPIE) during strategic and development planning. Councils are also encouraged to update the mapping as further data becomes available.

- To create a more consistent approach to protecting important riparian corridors that were assessed and mapped by the NSW Government in 2004 to ensure these riparian corridors are protected through application of appropriate development controls.
- To build resilience of the region to natural hazards and climate change. Particular concerns include rapid flooding from the escarpment, sea level rise and shoreline recession.
- To secure the health of coastal landscapes by managing land uses and water quality. Particular concerns are associated with protecting sensitive estuaries and Lakes (including Lake Illawarra) from the impacts of development.
- To implement a risk-based decision-making framework to manage water quality and waterway health outcomes for Lake Illawarra. This has been progressed by DPIE through the development of the risk based stormwater management framework, which does set specific pollutant reduction targets for new development within the Lake catchment (refer to Section 2.8.12).

A.20 Wollongong Local Environmental Plan 2009

The Wollongong Local Environment Plan 2009 ('WLEP 2009') has been prepared under the direction of the State Government to all local councils, as per the *Standard Instrument (Local Environmental Plans) Order 2006*. This Plan repeals the following environmental plans (with the exception of land identified as "Deferred matter" under clause 1.3 (1A)):

- Illawarra Planning Scheme Ordinance;
- Wollongong City Centre Local Environmental Plan 2007; and
- Wollongong Local Environmental Plan (West Dapto) 2010.

The WLEP 2009 provides local environmental planning provisions for land in Shellharbour LGA in accordance with the relevant standard environmental planning instrument under Section 33A of the EPA Act. The WLEP 2009 outlines particular aims for the use and development of land in Wollongong, which is governed by land zoning in the LEP. Those aims that are relevant to managing environmental risks in Lake Illawarra are:

"(e) to conserve and enhance remnant terrestrial, aquatic and riparian habitats, native vegetation and fauna species";

"(g) to ensure that development is consistent with the constraints of the land and can be appropriately serviced by infrastructure"; and

"(h) to ensure that significant landscapes are conserved, including the Illawarra Escarpment, Lake Illawarra, the drinking water catchment and the coastline".

The WLEP 2009 sets out the zonings that are applied to land in the LGA on the Land Application Map associated with the WLEP, and the objectives and permitted development (with or without consent) given for each land zone. The WLEP also guides the assessment and approval for Development Applications for lands within the LGA. Land use zones specified in the WLEP 2009 are given in Table A-3. For each of these zones, the LEP specifies:

- Objectives for development within the zone;

- Development that may be carried out without consent;
- Development that may be carried out only with consent; and
- Development that is prohibited.

Table A-3 Land Zones in the Wollongong LEP 2009

Rural Zones	Residential Zones	Business Zones	Industrial Zones
RU1 Primary Production	R1 General Residential	B1 Neighbourhood Centre	IN1 General Industrial
RU2 Rural Landscape	R2 Low Density Residential	B2 Local Centre	IN2 Light Industrial
RU4 Primary Production Small Lots	R3 Medium Density Residential	B3 Commercial Core	IN3 Heavy Industrial
	R4 High Density Residential	B4 Mixed Use	IN4 Working Waterfront
	R5 Large Lot Residential	B6 Enterprise Corridor	
		B7 Business Park	
Special Purpose Zones	**Recreation Zones**	**Environment Protection Zones**	**Waterway Zones**
SP1 Special Activities	RE1 Public Recreation	E1 National Parks and Nature Reserves	W1 Natural Waterways
SP2 Infrastructure	RE2 Private Recreation	E2 Environmental Conservation	W2 Recreational Waterways
SP3 Tourist		E3 Environmental Management	W3 Working Waterways
		E4 Environmental Living	

In terms of managing environmental hazards, the LEP contains a number of controls including:

- 'Part 5.5. Development within the Coastal Zone', which is a compulsory clause for all LEPs that apply to land within the coastal zone. Part 5.5 sets objectives and matters for consideration by the consent authority prior to granting consent to development on land wholly or partly within the coastal zone. The objectives include implementing the principles of the NSW Coastal Policy.
- 'Part 7.3 Flood planning' to maintain the existing flood regime and flow conveyance capacity and enable evacuations from land in flood risk areas. It also outlines controls on development to avoid significant adverse impacts on flood behaviour. It applies to land that is identified as being within a 'Flood planning area' and is at or below the flood planning level.
- 'Part 7.7 Foreshore building line' to ensure development within the foreshore areas of the Wollongong LGA will not impact on natural foreshore processes.
- 'Part 7.8 Illawarra Escarpment area conservation' that includes objectives to protect, conserve, and enhance the Illawarra Escarpment.

A.21 Shellharbour Local Environmental Plan 2013

The Shellharbour Local Environmental Plan 2013 ('SLEP 2013') has been prepared under the direction of the State Government to all local councils, as per the *Standard Instrument (Local Environmental Plans) Order 2006*. This Plan repeals the following environmental plans (with the exception of land identified as "Deferred matter" under clause 1.3 (1A)):

- Shellharbour Local Environment Plan 2000; and
- Shellharbour LEP Rural Local Environment Plan 2004.

The SLEP 2013 provides local environmental planning provisions for land in Shellharbour LGA in accordance with the relevant standard environmental planning instrument under Section 33A of the EPA Act. The SLEP 2013 outlines particular aims for the use and development of land in Shellharbour, which is governed by land zoning in the LEP. Those aims that are relevant to managing environmental risks in Lake Illawarra are:

(a) to encourage development that balances ecological sustainability, social justice principles of equality, access, rights and participation and economic viability,

(i) to protect, enhance and maintain significant landscapes with visual, scenic, historic, ecological or conservation value, including the Illawarra Escarpment, Lake Illawarra and the coastline, for the benefit of present and future generations,

(j) to protect and conserve:

(i) remnant native vegetation, and

(ii) soil stability by controlling development in accordance with land capability, and

(iii) water resources, water quality and wetland areas, natural flow patterns and their catchments and buffer areas,

(k) to conserve the scenic and environmental resources of the land, including the protection of environmental assets such as native vegetation, waterways and wetlands and habitats for threatened species, populations and endangered ecological communities, and

(m) to minimise risk to the community in areas subject to environmental hazards, particularly flooding, coastal inundation, bush fires, acid sulphate soils and unstable land.

The SLEP 2013 sets out the zonings that are applied to land in the LGA on the Land Application Map associated with the SLEP, and the objectives and permitted development (with or without consent) given for each land zone. The SLEP also guides the assessment and approval for Development Applications for lands within the LGA. Land use zones specified in the SLEP 2013 are given in Table A-4. For each of these zones, the LEP specifies:

- Objectives for development within the zone;
- Development that may be carried out without consent;
- Development that may be carried out only with consent; and
- Development that is prohibited.

Table A-4 Land Zones in the Shellharbour LEP 2013

Rural Zones	Residential Zones	Business Zones	Industrial Zones
RU1 Primary Production	R2 Low Density Residential	B1 Neighbourhood Centre	IN1 General Industrial
RU2 Rural Landscape	R3 Medium Density Residential	B2 Local Centre	IN2 Light Industrial
RU6 Transition	R5 Large Lot Residential	B3 Commercial Core	
		B4 Mixed Use	
		B5 Business Development	
		B7 Business Park	
Special Purpose Zones	**Recreation Zones**	**Environment Protection Zones**	**Waterway Zones**
SP1 Special Activities	RE1 Public Recreation	E1 National Parks and Nature Reserves	W1 Natural Waterways
SP2 Infrastructure	RE2 Private Recreation	E2 Environmental Conservation	W2 Recreational Waterways
		E3 Environmental Management	
		E4 Environmental Living	

In terms of managing environmental hazards, the LEP contains a number of controls including:

- 'Part 5.5 Development within the Coastal Zone', which is a compulsory clause for all LEPs that apply to land within the coastal zone. Part 5.5 sets objectives and matters for consideration by the consent authority prior to granting consent to development on land wholly or partly within the coastal zone. The objectives include implementing the principles of the NSW Coastal Policy which aim to protect, enhance, maintain and restore the coastal environment and associated ecology and biology, whilst maintaining public amenity.
- 'Part 5.7 Development below mean high water mark', which aims to ensure adequate environmental assessments on new developments are carried out in areas below the level of the high tide water mark.
- 'Part 6.3 Flood planning' to maintain the existing flood regime and flow conveyance capacity and enable evacuations from land in flood risk areas. It also outlines controls on development to minimise the flood risk to life and property, and to avoid significant adverse impacts on flood behaviour. It applies to land that is at or below the flood planning level.
- 'Part 6.4 Stormwater management' to minimise the impacts of urban stormwater of new developments. It outlines controls to promote urban sensitive water design, including on-site stormwater retention, and those to avoid adverse impacts of stormwater runoff to receiving waters.

A.22 Wollongong Development Control Plan 2009

The Wollongong Development Control Plan (DCP 2009) supports implementation of the WLEP 2009 and Wollongong LEP (West Dapto) 2010 (WDLEP 2010) by providing additional controls on development. This DCP was updated in 2009, and includes controls relating to residential, commercial and industrial development, as well as other general provisions.

With respect to managing development around Lake Illawarra, the DCP 2009 addresses coastal risks, flooding risks, riparian corridors, wetlands, and foreshore lands as follows:

- Residential building lines and boundary setbacks are prescribed in Chapter B1 (Section 4.14) in relation to development near the coastline. The controls aim "to minimise built intrusions into the coastal landscape", but also aim to "protect property from the threat of coastal hazards and land instability".
- Floodplain risk management controls are provided in Chapter E13, with general and specific provisions for all potentially flood prone land. The chapter outlines controls implemented to minimise the impact of development on waterways, improving the riparian corridors during development to enhance the ecological value of waterways, and reducing the risk of flooding.
- Stormwater management controls are provided in Chapter E14 and aim to reduce peak flows from sites into the Council's stormwater drainage systems and to reduce the probability of flooding downstream. This is especially relevant to new and redevelopments in areas affected by overland stormwater runoff or flooding to reduce flows downstream and to minimise runoff volumes and peak runoff flows.
- Riparian land management controls are provided in Chapter 20 under Section 20.3.6. The Riparian Management Plan outlines the objectives of the controls to protect urban creeks and riparian corridors from further degradation, improve their function, and main hydraulic properties.

A.22.1 Wollongong DCP Chapter E13: Floodplain Management

The Wollongong DCP Chapter E13: Floodplain Management ('Chapter E13') provides the criteria for determining applications for proposals potentially affected by flooding. The criteria are structured in recognition that different controls are applicable to different land uses (as defined in Chapter E13) and levels of potential flood inundation and hazard (broadly defined by the flood risk precinct applicable to the land).

With regards to the Lake Illawarra CMP, Chapter E13 provide suitable controls for incidentally managing risks arising from periodic coastal inundation of the Lake's foreshores, as new, infill or re-developments are undertaken around the foreshores and catchment of Lake Illawarra within Wollongong LGA.

Controls for development, car parking and fencing in the floodplain contain objectives, performance criteria and prescriptive controls, with the following purpose:

- ***Objectives*** represent the outcomes that the Council wishes to achieve from each control.
- ***Performance criteria*** represent a means of assessing whether the desired outcomes will be achieved.

- ***Prescriptive controls*** are preferred ways of achieving the outcome. While adherence to the prescriptive controls may be important, it is paramount that the objectives and the performance criteria are clearly satisfied.

Chapter E13 also provides guidance on filling of flood prone land.

Planning matrices provided in the Schedules in Appendix C outlining the prescriptive controls for different land use categories within the different flood risk precincts. The land use categories defined in Appendix A to Chapter E13 include essential community facilities, critical utilities and uses, subdivision, residential, commercial or industrial, tourist related development, recreation or non-urban uses, and concessional development. For each land use category within each Flood Risk Precinct (low, medium and high), the planning matrix details the planning consideration for floor level, building components, structural soundness, flood affectation, evacuation, and management and design. In some cases, the matrix states outright that a land use category is an unsuitable land use within that flood risk precinct (e.g. essential community facilities across all flood risk precincts).

There are no specific prescriptive controls for Lake Illawarra itself, in which case Schedule 10: Prescriptive Controls – Other Floodplains applies. Minnegang Creek, which is a tributary to Lake Illawarra, does has specific prescriptive controls defined in Schedule 3.

Chapter E13 also defines the information that is required to be submitted with an application to address floodplain risk management. Appendix B defines the flood compatible materials, to support the application of controls in the planning matrices.

Of relevance to the management objectives for Lake Illawarra CMP are the special considerations detailed in Chapter E13, being that "*when assessing proposals for development or other activity within the area to which this Policy applies, Council will take into consideration the following specific matters.*

(a) The proposal does not have a significant direct or cumulative detrimental impact on:

(i) Water quality;

(ii) Native bushland vegetation;

(iii) Riparian vegetation;

(iv) Estuaries, wetlands, Lakes or other water bodies;

(v) Aquatic and terrestrial ecosystems;

(vi) Indigenous flora and fauna; or

(vii) Fluvial geomorphology…

(c) The proposal must not constrain the orderly and efficient utilisation of the waterways for multiple purposes.

(d) The proposal must not adversely impact upon the recreational, ecological, aesthetic or utilitarian use of the waterway corridors, and where possible, should provide for their enhancement, in accordance with ESD principles." (Section 8, page 11 of Chapter E13).

A.23 Shellharbour Development Control Plan 2013

The Shellharbour Development Control Plan (DCP 2013) supports implementation of the SLEP 2013 by providing additional controls on development. This DCP was updated in 2013, and includes controls relating to residential, commercial and industrial development, as well as other general provisions.

With respect to managing development around Lake Illawarra, the DCP 2009 addresses coastal risks, flooding risks, riparian corridors, wetlands, and foreshore lands as follows:

- Residential building lines and boundary setbacks are prescribed in Chapter 3 (Section 3.2) in relation to development near the coastline. The controls aim "to reduce the likelihood of any risk from coastal processes, such as erosion or embankment instability".
- Floodplain risk management controls are provided in Chapter 24, with general and specific provisions for all potentially flood prone land. The chapter outlines controls implemented to minimise the impact of development on waterways, restore and rehabilitate the riparian corridors during development to enhance the ecological value of waterways, and reducing the risk of flooding.
- Bank stabilisation for rivers, Lakes, estuaries and other water bodies are outlined in Chapter 12, with provisions for developments located in close proximity to these landscapes. The objective of these controls is to promote healthy aquatic and terrestrial ecology, and to account for flooding and coastal processes.
- Stormwater management controls are provided in Chapter 25 and aim to encourage the use of Ecologically Sustainable Development during development, maintain and improve water quality within Shellharbour and its receiving waters, reduce the probability of flooding downstream, and to ensure the development minimises adverse impacts on existing drainage networks from surface and stormwater flows. This is especially relevant to new and redevelopments in areas affected by overland stormwater runoff or flooding to reduce flows downstream and to minimise runoff volumes and peak runoff flows.
- Riparian land management controls are provided in Chapter E23. The chapter outlines the objectives of the controls to protect urban creeks and riparian corridors from further degradation and improve their environmental function and viability. It uses the classification of riparian land into one of three categories depending on the function of the land and/or watercourse; Category 1 – Environmental corridor (provide habitats and restore the viability of riparian vegetation to protect water quality and bank stability), Category 2 – Terrestrial and Aquatic Habitat (aims to restore and maintain the natural stream functions to maintain vegetation and habitats whilst improving water quality and bank stability), and Category 3 – Bank Stability and Water Quality (aims to minimise sedimentation and nutrient transfer to improve bank stability, water quality, and protect native vegetation).

A.23.1 Shellharbour DCP Chapter 24 – Floodplain Risk Management

Shellharbour DCP Chapter 24 – Floodplain Risk Management and Appendix 9 applies to all potentially flood prone land in Shellharbour LGA. Chapter 24 of the Shellharbour DCP defines the

objectives for the chapter, while Appendix 9 provides the provisions for development conceptualisation and assessment for all catchments, and specific provisions for Lake Illawarra foreshores only, at this stage.

With regards to the Lake Illawarra CMP, Chapter 24 and Appendix 9 provide suitable controls for incidentally managing risks arising from periodic coastal inundation of the Lake's foreshores, as new, infill or re-developments are undertaken around the foreshores and catchment of Lake Illawarra within Shellharbour LGA.

Objectives stated in Chapter 24 that are relevant to the objectives of the Lake Illawarra CMP include:

- Objective 1: *Minimise the potential impact of development and other activity upon waterway corridors*.
- Objective 5: *Provide detailed controls for the assessment of applications lodged in accordance with the EP&A Act on land affected by potential floods*. Such controls will incidentally manage risks arising from periodic coastal inundation.
- Objective 10: *Restore / rehabilitate the riparian zone by returning as far as practicable the vegetation, geomorphic structure, hydrology and water quality of the original (pre European) condition of the stream*. This objective may drive support for riparian rehabilitation that has ecological benefits, as well as flood mitigation benefits.

Appendix 9 provides detailed development controls that apply to all land proposed to be developed within a Flood Risk Precinct (as defined in the Appendix 9). The type and stringency of controls is determined based upon both the severity and frequency of potential floods (which is broadly described by the Flood Risk Precinct applying to the land) and the land use category of the proposed development. The land use categories defined in the appendix include essential community facilities, critical utilities and uses, subdivision, residential, commercial or industrial, tourist related development, recreation or non-urban uses, and concessional development.

The format of the development controls detailed in the appendix includes:

- Objectives, which represent the outcomes that Council wished to achieve from each control;
- Performance criteria, which represent a means of assessing whether the desired outcomes will be achieved; and
- Controls, which are preferred ways of achieving the outcome.

Planning matrices provided in the Schedules to Appendix 9 provide the main guidance regarding development on flood prone land. At present, only the Lake Illawarra Floodplain has a specific DCP matrix (Schedule 2 of Appendix 9), with the remaining catchments of Shellharbour (including those flowing into Lake Illawarra such as Macquarie Rivulet) subject to the general provisions outlined in Schedule 1. For each land use category within each Flood Risk Precinct (low, medium and high), the matrix details the planning consideration for floor level, building components, structural soundness, flood affectation, evacuation and management and design. In some cases, the matrix states outright that a land use category is an unsuitable land use within that flood risk precinct (e.g. essential community facilities across all flood risk precincts).

Appendix 9 provides objectives, performance criteria and controls (which are preferred ways of achieving the outcome) for the car parking requirements, fencing requirements, and filling of flood prone land that may be associated with a development. The appendix also states the information that is required to be submitted with an application to address floodplain risk management.

Appendix B Documents Reviewed in preparation of the Synthesis Study

Table B-1 Existing Data / Reports and their Relevance to the Synthesis Report

Document	Primary or Secondary relevance	Relevance	Section Reference
Draft Lake Illawarra Coastal Zone Management Study 2013 (LIA, 2013).	Primary	Report included a Literature and Information review, Coastal Hazard Study and Estuary Condition Study.	Various Estuary Processes and Management sections
Lake Illawarra: Estuary Management Study and Strategic Plan (WBM Oceanics, 2006).	Primary	Provided the original estuary management plan for Lake Illawarra.	3.2 Audit of Estuary Management Initiatives
Condition Assessment of Lake Illawarra (LIA, 2010)	Primary	Report included a review of the condition of Lake Illawarra from water quality data derived from monitoring programs and compared it to historical data.	2.6 Water Quality; 2.7 Estuarine Ecology
Lake Illawarra Waterway Usage Management Plan (2000)	Primary	Report provides information regarding recreational usage of the Lake waterway and appropriate management responses for this.	Recreational Usage; Ch.
Lake Illawarra Saltmarsh Vegetation Classification/Mapping and Condition Mapping (2011)	Primary	Provides mapping of saltmarsh within Lake Illawarra.	2.7 Estuarine Ecology
Illawarra Biodiversity Strategy (WCC, SCC & KMC, 2011)	Primary	Documents endangered ecological communities and their threat level; and priority sites for bush regeneration in the Illawarra region, including estuarine and wetland vegetation in Lake Illawarra. The strategy outlines actions over a 5-year period that ends by 2016, and so is not considered to demonstrate existing controls of relevance to the Lake Illawarra CMP.	2.7 Estuarine Ecology
Lake Illawarra Water Quality and Estuary Health Monitoring Program (WCC, 2015)	Primary	Provides a review of the water quality and estuary health status by analysing data collected under the monitoring program undertaken by WCC and SCC, with reference to historical data.	2.6 Water Quality

Document	Primary or Secondary relevance	Relevance	Section Reference
State of the Catchment 2010: Assessing the Condition of Estuaries and Coastal Lakes in NSW. MER Technical Report Series: Estuaries and Coastal Lakes. Prepared for DPIE (Roper et al., 2011)	Primary	Reports the condition of NSW estuaries with respect to data collected under the monitoring evaluation and reporting program, and the environmental pressures facing NSW estuaries. Includes process for assessing condition, and broad results for Lake Illawarra.	2.6 Water Quality; 2.8 Catchment Influences
Catchment Scale Land Use of Australia Data (Australian Collaborative Land Use and Management Program [ACLUMP], updated March 2015)	Primary	Details the most current compilation of catchment scale land use data for Australia assembled from combining information on land tenure, land use, fine-scale satellite data, and field data through state mapping programs via ACLUMP.	2.8 Catchment Influences
Coastal Eutrophication Risk Assessment Tool (CERAT) (OEH, 2012)	Primary	Used to understand the relationship between land use and its impacts on the health of estuaries and coastal Lakes by evaluating routinely collected water quality data, spatial information, and catchment and estuary models for individual systems such as Lake Illawarra.	2.8 Catchment Influences
Lake Illawarra Entrance Inlet Stability Assessment Stage 2 (MHL, 2013)	Primary	Outlines a review of the performance of the entrance works at Lake Illawarra, including impacts relating to the works.	2.4 Entrance Management Works
Lake Illawarra – Entrance Channel Sand Movement (LIA, 2014)	Primary	Documents the channel monitoring conducted by the LIA since the entrance works at Lake Illawarra.	2.4 Entrance Management Works
Wollongong City Council Coastal Zone Study (Cardno, 2010)	Primary	Documents coastal risks (inundation) for the WCC portion of Lake Illawarra.	2.9.4 Coastal Inundation
Wollongong Coastal Zone Management Plan: Implementation Action Plan & Management Study (BMT WBM, 2017)	Primary	Documents the extent of coastal inundation risks in Lake Illawarra, based upon the Cardno 2010 study, and actions to manage such risks to assets and land in the WCC portion of Lake Illawarra.	2.9.4 Coastal Inundation, 3.3.2 Existing Management Initiatives
Cardno (2012a), *Coastal Hazard Assessment – 100-year ARI Extents*	Primary	Details the assessment of coastal inundation within Lake Illawarra relating to the combination of catchment flooding with high ocean water levels. Provides a superior assessment of flood planning levels than for rainfall or ocean water levels separately	2.9.4 Coastal Inundation
Lake Illawarra Coastal Risk Assessment (BMT WBM, 2013)	Primary	Documents the extent of periodic coastal inundation risks in Lake Illawarra, based upon modelling by Cardno (2010, 2012a), and a discussion of future permanent inundation risk. Details actions to manage such risks to assets and land in the SCC portion of Lake Illawarra.	2.9.4 Coastal Inundation 3.3.3 Existing Management Initiatives

Document	Primary or Secondary relevance	Relevance	Section Reference
Shellharbour Coastal Hazard Analysis (SMEC, 2010)	Secondary	Documents coastal risks on the open coast of Shellharbour LGA, but not within Lake Illawarra.	2.9.4 Coastal Inundation
Shellharbour Coastal Zone Management Plan (BMT WBM, 2017)	Secondary	Provides management options for the open coast of Shellharbour LGA. Actions relating to dune management near to the entrance works (northern end of Warilla Beach) may be relevant.	2.9.4 Coastal Inundation 3.3.3 Existing Management Initiatives
Shellharbour Coastal Erosion Emergency Action Sub Plan (BMT WBM, 2016)	Not relevant	Guides responses of Emergency Services and SCC before, during and after coastal erosion emergencies on the open coast of Shellharbour LGA, but not Lake Illawarra.	
Lake Illawarra Shareways 2014 (LIA, 2014)	Secondary	Booklet outlining walking and cycling routes around Lake Illawarra and the various environmental features of the Lake including birds and plants.	
Lake Illawarra Flood Study (Cardno, 2001)	Secondary	Outlines flooding risks in Lake Illawarra catchment (jointly for Wollongong and Shellharbour sections of the Lake). With respect to flooding and coastal inundation within Lake Illawarra, this report is superseded by the Cardno (2012) reports.	2.5.4 Flooding
Lake Illawarra Floodplain Risk Management Study and Plan (Cardno, 2012b; c)	Primary	Determined Lake inundation levels due to catchment rainfall alone, and combined with elevated ocean water levels (jointly for Wollongong and Shellharbour sections of the Lake). The influence of climate change induced changes in rainfall and sea level on Lake inundation levels at future time periods were also assessed. Also provided management responses to flooding risks in Lake Illawarra.	2.5.4 Flooding 2.9.4 Coastal Inundation 3.3.1 Existing Management Initiatives
Macquarie Rivulet Flood Study (WMAWater, in prep)	Secondary	The study considers flooding in the entire Macquarie Rivulet catchment in combination with backwater flooding from Lake Illawarra.	2.5.4 Flooding
A Climate Change Impact Assessment of Wollongong's Estuaries – Implications for Ongoing Estuary Management Planning (Cardno, 2009)	Not relevant	Assesses of the likely impacts of climate change on Wollongong's estuaries and the implications for current and future estuary management practices that result. The assessment does not include Lake Illawarra estuary, as this was managed by LIA at the time.	

Document	Primary or Secondary relevance	Relevance	Section Reference
Shellharbour Climate Change Adaptation Action Plan (SKM, 2009)	Secondary	Provides a risk assessment of all climate change related impacts to the Shellharbour LGA, and an adaptation action plan to manage these risks. The actions within this plan are relatively general. The process of preparing the CMP fulfils or facilitates coastal hazard actions within the Adaptation Plan (rather than the Adaptation Plan providing actions for the CMP).	
Illawarra Regional Strategy 2006 - 2031 (NSW Department of Planning, 2007)	Secondary	Strategy is intended to ensure adequate land is available for the projected housing and employment needs of the Region's population over the next 25 years. NEED to determine if this is superseded by Regional Plan below… The document also sets actions to protect the Region's natural features such as Lake Illawarra. Actions may of relevance to the CMP.	Appendix A Legislation and Planning Context
Illawarra Shoalhaven Regional Plan (NSW Department of Planning & Environment, 2015)	Primary	Will detail intentions for future development in the Lake Illawarra Catchment. Need to check if different to what is in Section 2.6.4 already….	2.8.2 Future Land Uses
Shellharbour Foreshore Management Plan (Riggall and Associates, 2004)	Not relevant	This report does not cover any area within the project area for the Lake Illawarra CMP.	
Generic Plan of Management for the Community Land of Wollongong City Council (WCC, 2011)	Primary	Outlines the values, objectives, and then issues and management actions for community land parcels (WCC owned, and Crown Land managed by WCC) throughout the Wollongong LGA, including the foreshores of Lake Illawarra. Issues and actions identified may be relevant to management actions developed for the Lake Illawarra CMP.	Existing Management Initiatives, Appendix A Legislation and Planning Context
Judbooley Parade Windang Plan of Management (WCC, 2008)	Secondary	The POM covers Judbooley Parade, Windang on the western side of Windang Road and fronting Lake Illawarra. The site has a rich Aboriginal and non-indigenous cultural heritage, which forms the basis for management, management objectives and outcomes sought through the POM. The POM is referenced as a related document to the Lake Illawarra CMP.	Appendix A Legislation and Planning Context

Document	Primary or Secondary relevance	Relevance	Section Reference
Wollongong City Foreshore Plan of Management (WCC, 2008a)	Not relevant	Details the Plan of Management for community land from Stuart Park (North Beach) to the Entertainment Centre Precinct (City Beach) of the Wollongong LGA. The POM does not cover any community land in the Lake study area.	
Southern Rivers Catchment Action Plan (SRCMA, 2006)	Not relevant	The Southern Rivers Catchment Action Plan of the former SRCMA has been replaced by the South East Local Strategic Plan 2016-2021 compiled by South East Local Land Services (South East LLS).	
Illawarra NRM Action Plan (SRCMA, 2010).	Not relevant	The NRM plan was related to the Southern Rivers Catchment Action Plan that has been superseded by the South East Local Strategic Plan 2016-2021. The NRM Plan also outlined actions for a 5-year period that has now lapsed.	
Catchment Action Plan 2013-2023. Southern Rivers Catchment Action Plan (Local Land Services [LLS], 2013)	Not relevant	As above, this has been replaced by the South East Local Strategic Plan 2016-2021.	
South East Local Strategic Plan 2016-2021 (South East LLS, 2016).	Secondary	South East Local Strategic Plan 2016-2021 replaces the Southern Rivers Catchment Action Plan (SRCAP) of the former SRCMA.	Appendix A Legislation and Planning Context
Wollongong 2022: Our Community Strategic Plan 2012-2022 (WCC, 2012) and related Delivery Program and Operational Plan	Secondary (to this report only)	This document will be vital when developing the CMP Implementation action plan, however is of secondary relevance to the synthesis report.	Appendix A Legislation and Planning Context
Shellharbour City Community Strategic Plan 2013-2023 and related Delivery Program 2013-2017 and Operational Plan 2015-2016	Secondary (to this report only)	This document will be vital when developing the CMP Implementation action plan, however is of secondary relevance to the synthesis report.	Appendix A Legislation and Planning Context
Wollongong Local Environmental Plan (2009) and Wollongong Development Control Plan (2009)	Primary	LEP and DCP will be checked for planning controls that are relevant to the current management of the Lake. These documents will also be vital when developing the CMP Implementation action plan.	Appendix A Legislation and Planning Context

Document	Primary or Secondary relevance	Relevance	Section Reference
Shellharbour Local Environmental Plan (2013) and Shellharbour Development Control Plan (2013). *Note that some land is referred to as "deferred matters" land, and for these lands, the Shellharbour LEP 2000 or the Shellharbour LEP Rural Local Environment Plan 2004 applies.*	Primary	LEP and DCP will be checked for planning controls that are relevant to the current management of the Lake. These documents will also be vital when developing the CMP Implementation action plan.	Appendix A Legislation and Planning Context
History of metal contamination in Lake Illawarra, NSW, Australia (Schneider et al., 2015).	Primary	Provides a historical analysis of metal concentrations within sediments in Lake Illawarra, with reference to relevant industrial land uses throughout time.	2.7.5 Sediment Quality
Baxter, C., and Daly, D.J 2010 Ecological changes in Lake Illawarra following the completion of entrance works in 2007	Primary	Evaluates data and observations demonstrating changes in Lake Illawarra since the permanent opening of the entrance and suggests likely long term effects of some of these changes	2.4 Entrance Management Works
Regional Boating Plan Shoalhaven – Illawarra Region (Transport for NSW [TfNSW], 2015)	Primary	Explores the main uses of waterways within the Illawarra region and the limitations to uses via community feedback.	2.8.1 Catchment land uses
Lake Illawarra South Stormwater Quality Strategy, prepared for SCC (Patterson Britton & Partners [PBP], 2007)	Primary	Outlined the current state of stormwater management in the Lake Illawarra South catchment by analysing the effectiveness of current stormwater treatment methods, and detailed recommendations for future measures.	2.6.3 Stormwater Management
Shellharbour City Council Area Aboriginal Heritage Study. Prepared for SCC (Navin Officer Heritage Consultants, 2000).	Primary	Documents the results of a study of the Aboriginal heritage of the SCC area. Identifies areas of significance and explains the methods undertaken to assess the heritage significance.	2.8.2 Cultural Heritage
LIA (undated) Lake Illawarra Entrance Works Management Methods and Maintenance Requirements of Sand "Bird Habitat" Island Project Review and Supporting Information	Secondary	Reports on the success of mitigation measures related to bird island habitat undertaken as consent conditions for the entrance management works	2.7.3 Estuarine Fauna
Short A.D., 2007. Beaches of the NSW Coast, Australian Beach Safety and Management Program.	Secondary	May provide a useful summary of the Lake's physical character.	

Document	Primary or Secondary relevance	Relevance	Section Reference
NSW Department of Land and Water Conservation 2001, Coastal Dune Management: A Manual of Coastal Dune Management and Rehabilitation Techniques, Coastal Unit, DLWC, Newcastle.	Not Relevant	May provide relevant guidance for dune management strategies, should these be outlined in the implementation action plan of the CMP	
Nielsen A.F., Lord D.B. and Poulos H.G. 1992, Dune Stability Considerations for Building Foundations, Institution of Engineers Australia, Civil Engineering Transactions, Vol. CE34, No. 2, June, pp167-173.	Not Relevant	Is relevant to determining foundation stability behind eroded frontal dunes on the open coast, and has been used where relevant in the Shellharbour and Wollongong open coastal studies.	

Appendix C Audit of Previous Action Plans

There are several documents which have previously guided, or currently guide, Lake Illawarra's management. A detailed review of actions within the relevant documents was conducted by Baxter, C., Blackburn, K., Gangaiya, P., Weicek D. and Williams, A in 2016 and is published verbatim in Table C-1. The review outlines the status of identified management actions in previous and current management plans. The management plans reviewed for this audit, and detailed in Table C-1 are:

- Lake Illawarra Estuary Management Study and Strategic Plan (WBM Oceanics, 2006);
- Draft Coastal Zone Management Study (LIA 2013a);
- Lake Illawarra Water Quality and Estuary Health Monitoring Program (WCC, 2015);
- Ecological and Bushfire Assessment and Plan of Management, Picnic Island Reserve (SCC, 2015);
- Boonerah Point Vegetation Management Plan (SCC, 2016);
- Oaklands Village and Jettys by the Lake, Windang Proposed Foreshore Stabilisation Project (LIA, 2013b);
- Purry Burry Point to Heritage Park Site Restoration Plan (LIA, 2013c); and
- Judbooley Parade Landscape Master Plan (WCC, 2010).

Table C-1 is intended to be used as a baseline regarding the outcomes of previous management planning exercises. It is not necessarily a reflection of what current and/or future management activities should be.

The audit is referenced within the main body of the report as Baxter *et al* 2016. The information provided by Baxter *et al* 2016 is reproduced here. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of this information.

Notes on columns:

(1) Generated for this table. The various geographic zones mirror those identified in the 2006 Lake Illawarra Estuary Management Study and Strategic Plan.

(2) Taken directly from the source management plan identified at 3.

(3) The previous and/or current management plan for Lake Illawarra

(4) The original issue as stated in the management plan identified at 3.

(5) The original details as stated in the management plan identified at 3.

(6) The original benefits as stated in the management plan identified at 3.

(7) The original cost as stated in the management plan identified at 3. This item in particular would need to be reassessed for any activity identified in the current planning process. If it is blank then no cost was originally identified.

(8) Completed activities or those currently underway in line with the actions identified at 2.

Any additional issues to consider in this management planning process.

Table C-1 Audit of Previous Estuary Management Initiatives

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
Zone 1 Entrance Channel								
1a	Prepare a plan of management for the public land between Oaklands Village Caravan Park and Windang Bridge. Provide a 'right of public access' around the edge of the Lake Illawarra Village (Jettys by the Lake) and Oaklands Village.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Uncontrolled access, safety, erosion.	The foreshore between Oaklands village and Jetties by the Lake (onto Windang Bridge) was identified as a missing link in the pathway around the Lake. This site is currently exposed to uncontrolled access resulting in some erosion.	Improved foreshore and public amenity	$250,000	Pathway from Oaklands to Jetties by the Lake not completed. Ministerial papers and Executive Council Minute re boundary adjustment to provide a 3m strip for continuous public access along Oaklands has been approved by the Governor. Gazettal notice placed 16/4/2010. Agreement for Lease has been finalised with Jettys by the Lake re building encroachments. Certificate of Title to foreshore land issued 8/9/2010. Lease to be executed.	For future consideration.
1b	Windang Foreshore (Jetties by the Lake and Oaklands) rehabilitation	2011 Draft Lake Illawarra Estuary Management Plan Oaklands Village and Jettys by the Lake, Windang Proposed Foreshore Stabilisation Project (2013).	Bank protection, uncontrolled fill	Shoreline is composed of various types of bank protection structures along with other structures in various states of disrepair. Survey and assessment of the foreshore was undertaken, and a draft restoration plan was proposed/ completed? Plan considered habitat friendly seawalls and removal of various uncontrolled fill and structures. Working with adjacent landholders', foreshore rehabilitation will ensure improvements in public safety and environmental value.	Improved water quality, improved public safety, habitat rehabilitation	Unknown	Preliminary concept designs completed through funding from OEH (2013).	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
1c	Judbooley Parade Foreshore Improvements	Judbooley Parade Landscape Master Plan 2010	Foreshore Improvements	Works were undertaken to improve the recreational amenity of the foreshore and ensure protection of the shoreline.	Improved foreshore amenity	$700,000	Concept being considered. Installation of recreational facilities and shore protection works complete in 2012.	N/A
1d	Judbooley Parade Foreshore Erosion control	Judbooley Parade Landscape Master Plan 2010	Shoreline erosion	Foreshore protection works required to ensure bank stability.	Erosion protection	$10,000 pa	Ongoing Some works are currently being undertaken by WCC to ensure bank stability and protection.	Works for future consideration by WCC in accordance with the Judbooley Parade Plan of Management.
1e	Bank erosion control and rehabilitation. Provide bank protection along the northern shore of the entrance channel adjoining Windang Foreshore (Pine Tree) Park to protect foreshore assets against channel migration.	2011 Draft Lake Illawarra Estuary Management Plan	Channel migration	Dynamic shifts in the geomorphology of the entrance channel occurring as a result of the entrance being trained. With more in-depth entrance monitoring and management is now required. Erosion control and bank rehabilitation works will also need to be undertaken over time as shoreline areas become exposed through increases in channel dimensions and channel movement. Groynes have recently been installed in some areas to limit erosion. Monitoring of these structures and nearby areas should continue to identify their effectiveness in limiting erosion and if further action is required.	Improved water quality, improved public safety, habitat rehabilitation, protection of foreshore reserves		Two groynes ($125,000) and a rock revetment wall ($75,000) constructed in 2012. Repair works are currently being undertaken by WCC following recent extreme weather events.	Ongoing.
1f	Provide additional car parking along Windang Foreshore Park (Pine Tree Park).	2011 Draft Lake Illawarra Estuary Management Plan	Illegal parking, erosion	Parking at Windang foreshore has been identified as inadequate to account for number of visitors to the area. This results in illegal parking on edges of the road and subsequent erosion issues.	Improved foreshore and public amenity.	$100,000	Completed. WCC installed new fence along tourist park – parallel parking permitted.	N/A

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
1g	Protection of migratory bird habitat. Develop shorebird habitat management plan for the entrance channel area including monitoring of sand movements around the bird island area	2011 Draft Lake Illawarra Estuary Management Plan	Habitat Protection	Sand shoals provide valuable habitat for migratory bird species such as Little terns and Pied Oystercatchers. This unique habitat is subject to disturbance from external factors such as dogs, foxes, humans, channel dynamics etc. Ongoing effort has been undertaken to protect this habitat particularly during key reproductive seasons for migratory birds.	Habitat protection	$10,000 (management plan)	Ongoing	Option remains relevant for entrance channel, but not necessarily the bird island which appears to be absent in 2016 aerial imagery.
1h	Implement entrance structure works (stage 2) as approved.	2011 Draft Lake Illawarra Estuary Management Plan	Declining water quality, decreased flow regime, recreational amenity,	The entrance breakwaters, which train the entrance, were completed in 2007 to ensure the Lake was permanently open to the sea. This was to result in increased tidal flushing of the Lake, reduction in flooding and improvements in water quality.	Improved public amenity, improved water quality, reduced flooding,	$4,000,000 (final cost $5.75M)	Completed. Repairs undertaken to southern wall in 2008 to 2010. Connection of northern revetment wall to northern breakwater completed (June 2011). DPIE - Crown Lands has approved repair works on the northern breakwater to take place during 16/17 ($365,000).	N/A
1i	Undertake entrance stability assessment	2011 Draft Lake Illawarra Estuary Management Plan	Decreased flow regime, recreational amenity,	Ongoing maintenance is associated with the entrance structures such as shifts in the breakwaters and mitigation of extreme changed in flow hydrodynamics.	Improved understanding of entrance channel stability and channel migration	$15,000 (Stability assessment)	Manly Hydraulics Laboratory engaged to undertook stability assessment in 2012.	DPIE are continuing monitoring of the entrance channel. WCC is considering an additional entrance stability survey to inform an implementation plan for works along entrance foreshores.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
1j	Undertake 'as required' dredging of the entrance channel.	2011 Draft Lake Illawarra Estuary Management Plan	Navigation dangers, flow management	Works were continually being undertaken to manage the entrance channel to ensure boating access and improved flows preventing algal build up.	Navigation safety, improved flows, improved water quality.	$100,000 per occurrence	Ongoing. Channel condition including drop off area being regularly monitored – quarterly aerial photos and site inspections with NSW Roads and Maritime Services Boating Officer. NSW Roads and Maritime Services maintain navigation aids as required.	For future consideration.
1k	Foreshore improvements to Reddall Reserve including lighting, car parking, replacement of toilet block, shade structures, landscaping and wharf.	2011 Draft Lake Illawarra Estuary Management Plan	Weed infestation, leaking sewage, public amenity.	Floating pontoon installed at boat ramp (2010). Replacement of toilet block to be considered. Kiosk upgraded (2011). EOI called to operate upgraded kiosk. New Operator appointed (2011)	Improved water quality, reduction in weed species	$500,000	Works in progress. Floating pontoon installed at boat ramp (2010). Replacement of toilet block undertaken in 2015. Kiosk upgraded and new Operator appointed (2011) with arrangement extended in 2015. Reddall Reserve south amenities replaced 2013/14. Shareway from Ocean St to Windang St replaced 2014/15 Design phase underway for replacement of deteriorated promenade with footpath.	SCC Aquatic Feasibility study recommended a water play area to be constructed on this site (north of the kiosk). SCC is considering updating the Masterplan for this area. Current Masterplan was developed in the early 2000's.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
1l	Revegetation and weed control of Picnic Island, Berageree Island and the adjacent Pelican View Reserve.	2011 Draft Lake Illawarra Estuary Management Plan Ecological and Bushfire Assessment and Plan of Management, Picnic Island Reserve (ELA, 2015).	Vegetation management, invasive weeds, bank stability.	These islands are subjected to weed encroachments and degradation of vegetation due to factors including uncontrolled access, erosion and natural processes.	Improved endangered ecological community habitat	$10,000	Revegetation and weed control work have been undertaken with grant assistance and as a part of the relevant Plans of Management.	Works for future consideration by SCC in accordance with the Picnic Island Reserve Plan of Management, Pelican View Plan of Management
1m	Formalise walkway around Picnic Island	2011 Draft Lake Illawarra Estuary Management Plan Ecological and Bushfire Assessment and Plan of Management, Picnic Island Reserve (ELA, 2015).	Uncontrolled access, erosion, loss of vegetation	An informal track is currently used across Picnic Island. This track is eroded and uncontrolled resulting in a loss of vegetation. The Picnic Island Reserve Plan of Management identifies the use of fencing and signage to discourage access beyond the existing walking track.	Improve habitat value and recreational amenity of the island	$70,000	A design was prepared for a raised concrete walkway, but it was not constructed due to stakeholder concerns.	Works for future consideration by SCC in accordance with the Picnic Island Reserve Plan of Management
1n	Maintain, protect and enhance Bevans Island, Cudgeree Island and Windang Island.	2011 Draft Lake Illawarra Estuary Management Plan	Antisocial behaviour, excessive weed populations, feral pest control, and uncontrolled access.	These islands contain approximately four endangered ecological communities and key habitat for many species. Due to their isolation, these islands are subject to antisocial behaviour and invasion by introduced species.	Improved foreshore and public amenity. Improved biodiversity	$5,000 pa	To be considered LIA was Trustee for these Islands.	Windang Island is managed under separate plan of management (ELA, 2015) and will not be considered as a part of the Lake Illawarra CMP.
Zone 2 Lake Illawarra PCYC to Central Park, Oak Flats								

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
2a	Continue maintenance of existing stormwater drains and controls discharging into the Back Channel and Whyjuck Bay.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Sediment deposition, litter inflows.	Sediment inflows and channel dynamics often result in blockages to the Whyjuck Bay area preventing dispersal of the poor water quality inflows.	Improved water quality.	$5,000 pa	As required 2015/16 Maintenance undertaken on wetlands by SCC in south east corner of Howard Fowles. Capital project for flow improvements currently in design phase. 2015/16 Maintenance undertaken by SCC at outlet opposite Trumper St to remove flow restrictions. 2015/16 CCTV inspection undertaken by SCC on several stormwater networks.	For future consideration as required.
2b	Replace deteriorated sections of the existing shared pathway between the Lake Illawarra PCYC and Central Park.	2011 Draft Lake Illawarra Estuary Management Plan	Public safety	The shared pathway required repairs in sections where cracks and shifts in the pavement occurred.	Improved public amenity	$50,000	Completed (2008/09)	N/A
2c	Formalise foreshore pathway along Mt Warrigal foreshore to Boonerah Point	2011 Draft Lake Illawarra Estuary Management Plan	Public safety, uncontrolled access and amenity	This area is currently used regularly for walking and bike riding resulting in erosion of the formed track.	Improved recreation value	$30,000	To be considered.	For future consideration. All works to be undertaken in accordance with the vegetation management plan for Boonerah Point.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
2d	Enhance and protect existing riparian vegetation, Boonerah Point. Plant native vegetation buffer along the shoreline. Provide bank protection to the area of shoreline that is eroding in the small bay (part of Whyjuck Bay) to the east of the Scout Hall on Boonerah Point.	2011 Draft Lake Illawarra Estuary Management Plan Boonerah Point Vegetation Management Plan (SCC, 2016)	Bank instability and erosion, weed infestation, loss of quality vegetation, declining water quality, public safety.	The Boonerah Point Park was in disrepair and required upgrades to the parkland. Revegetation works to be undertaken in accordance with the Boonerah Pont Vegetation Management Plan (SCC, 2016). An identified area of bank erosion is adjacent to the site regularly used by the Scout hall.	Improved habitat and biodiversity, reduce erosion and improve foreshore amenity.	$20,000 (revegetation and park repairs) $200,000 (Bank stability and jetty installation).	To be considered. SCC completed landscaping on Boonerah Point (2007/08). Scout Group propose installing a jetty and ramp to launch canoes (2011).	Ongoing works to be undertaken by SCC in accordance with the 2016 Management Plans for the site.
2e	Provide picnic tables and seats along foreshore.	2011 Draft Lake Illawarra Estuary Management Plan	Public amenity	Absence of usable seating in the Boonerah Point park. Many burnt or damaged.	Improved public amenity	$25,000	SCC completed works in this park (2008/09).	N/A
2f	Create a beach (adjacent to the Scout Hall) and nourish over time (as the sand washes away) to help reduce bank erosion and aid with removal of seagrass wrack.	2011 Draft Lake Illawarra Estuary Management Plan	Bank erosion, declining water quality, public safety.	Shoreline area used regularly by the scout hall for launching and retrieving boats.	Improved public access and foreshore amenity.	$50,000	To be considered No work done to date.	For future consideration.
2g	Provide bank stabilisation/erosion protection at selected locations along the foreshore.	2011 Draft Lake Illawarra Estuary Management Plan	Bank erosion, declining water quality, public safety.	General areas of steep slopes, which require stability.	Improved foreshore amenity, water quality, biodiversity.	$25,000	To be considered	For future consideration.
2h	Restrict access to Mogurah and Yangar Point foreshore areas to allow native endangered vegetation communities to re-establish	2011 Draft Lake Illawarra Estuary Management Plan	Uncontrolled access, degradation of vegetation communities.	Excessive trampling of the saltmarsh in this sheltered embayment is resulting in a loss of saltmarsh community and faunal habitat. Protection is needed from misuse and vandalism such as illegal vegetation clearing, mowing and excessive access which degrade the quality of these habitats. Bollards are proposed to reduce excessive access to this site.	Increased habitat and biodiversity	$10,000	To be considered. No work done to date.	For future consideration.
Zone 3 Burroo and Koona Bay								

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
3a	Upgrade Deakin Reserve carpark area adjacent to jetty and boat ramp.	2011 Draft Lake Illawarra Estuary Management Plan	Public amenity, safety and erosion.	The carpark currently consists of an informal gravel area, which is subjected to erosion during heavy usage and high rainfall. A sealed surface was considered a better alternative at this location.	Improved foreshore amenity.	$30,000	To be considered No work done to date.	For future consideration.
3b	Provide public access way along this section of foreshore if reclamation is carried out as part of Burroo Bay dredging.	2011 Draft Lake Illawarra Estuary Management Plan	Public amenity and safety.	The sewer alignment is currently within the Lake at this location. In addition to this, there is a need to formal access to prevent uncontrolled access and improve public safety.	Increased public access.	$100,000	To be considered as part of any future dredging works – unlikely due to resident concerns. Private jetties are an obstacle here. No work done to date.	For future consideration.
3c	Works to upgrade Wilson Memorial Park.	2011 Draft Lake Illawarra Estuary Management Plan	Public safety and amenity	Park was degraded and damaged.	Improved foreshore and public amenity.	$25,000	Complete (2007/08)	N/A

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
3d	Provide a shared pathway and boardwalk (where necessary over sections of saltmarsh) around the shoreline the Koona Bay.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Public access, protection of endangered ecological communities.	This shareway will provide a key linkage around the southern aspect of the Lake and will aim to prevent uncontrolled access and promote regrowth of damage saltmarsh.	Improved public access.	$400,000	SCC has approved preferred option 'partial foreshore filling. Approval has been granted under Part 5 of the EP&A Act. Work to be staged. Stage 1 between Wilson Memorial park and Kanahooka St completed (2010). Stage 2 between Karoo St and Wooroo St is currently under construction to be completed late 2013. Biosis engaged to prepare AHIP (2011). Stage 3 plans between Kanahooka St and Shearwater Blvd. were exhibited and approved by SCC as a preferred option in 2007. Subject to further design work and environmental approvals. Stage 4 between Shearwater Blvd. and Macquarie Rivulet and Stage 5 from Karoo Street to Koona Bay Foreshore Reserve are yet to be considered.	Include Stage 3 to 5 as option for future consideration. Design of Stage 3 deferred by SCC to 2018/19 due to competing priorities of footpath capital projects. Renewal of shareway in Mount Warrigal and Warilla programmed for 2016/17 and 2018/19.
3e	Construct wharf / low level platform on Macquarie Rivulet (southern bank) for launching / retrieval of small watercraft e.g. canoes / kayaks.	2011 Draft Lake Illawarra Estuary Management Plan	Public amenity, bank erosion	Watercraft such as canoes and kayaks are currently launched at informal parts of the bank resulting in bank erosion.	Increased waterway access and bank stability.	$50,000	To be considered No work done to date.	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
3f	Restrict Access to the Macquarie Rivulet SEPP 14 area.	2011 Draft Lake Illawarra Estuary Management Plan	Uncontrolled access, degradation of SEPP 14 wetland, antisocial behaviour	The saltmarsh habitat of Macquarie Rivulet Delta has become degraded through misuse such as illegal vehicle access and allowing cattle to graze and trample the area. Access to this site needs to be controlled to allow this large area of habitat to become restored and fully utilised as habitat for a number of species of aquatic birds. Fences in neighbouring parcels of land also need to be repaired to prevent stock escaping this area.	Saltmarsh regeneration, water quality improvements, habitat regeneration.	$10,000	Ongoing RCL have to date installed security gates, signage, and concrete blocks on the northern side of the wetland. A maintenance contractor and in more recent time local residents have been providing surveillance of the area. Recently four-wheel drive access was controlled through residents contacting the police. The stage 4 works (above at 3d) are considered part of the solution for this issue on the southern side of the rivulet.	Ongoing. For future consideration.
Zone 4 Haywards Bay to the Tallawarra Outlet Channel								
4a	Investigate options to link the shared pathway from the Macquarie Rivulet Arboretum to Haywards Bay.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Public amenity	Connecting link between Haywards Bay and Oak Flats.	Improved public amenity.	$10,000	Options include new bridge across rivulet or connection to highway bridge. Preliminary plans developed and supplied to SCC in 2013 by the LIA.	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
4b	Finalise transfer of freehold foreshore land extending to the mouth of Macquarie Rivulet and around Haywards Bay for environmental protection and public open space. Enhance riparian zone and limit illegal access of Macquarie Rivulet Riparian Habitat.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Public amenity and core Lake values.	This foreshore section (in ownership of Tru Energy) is not currently maintained and is subjected to weed invasion, degradation through uncontrolled access and dumpling of waste material. This foreshore land contains strong heritage and ecological values. The Haywards Bay Foreshore land currently maintained by Winten (now RCL) was also under negotiation with the LIA for the transfer of this land. Illegal vehicle access to the Macquarie Rivulet Delta has been destroying large areas of saltmarsh. Vehicle access needs to be limited in these areas, with the use of bollards or other structures.	Improved foreshore and public amenity. Improved water quality. Increased protection of saltmarsh and sensitive habitat areas Increased protection of Aboriginal midden.	$10,000 for transfer costs $500,000 for rehabilitation and access control works.	Under the current Deed, Winten must transfer the land to the LIA. LIA had agreed to accept the land transfer excluding the area of the water quality control pond (wetland) on the proviso that Winten maintain the wetland to meet performance criteria set down by WCC whilst development works were ongoing. WCC to provide status of hand over process?? Under the Council's conditions of consent monitoring of the wetland is to continue for 15 years after 80% of the subdivision is complete.	Land currently under control of RCL (formerly Winten) and Tru Energy. For future consideration.
4c	Enhance wetland areas and riparian corridor of Duck Ck.	2011 Draft Lake Illawarra Estuary Management Plan	Rehabilitation and weed/pest control.	High occurrence of invasive species.	Improved habitat and biodiversity Improved water quality.	$500,000	To be considered (part of Tru Energy development?)	Under control of Tru Energy. For future consideration.
Zone 5 Yallah to Brooks Creek Kanahooka								
5a	Investigate and construct boat-launching facility at Yallah Bay including provision of a jetty, fish cleaning tables, boat wash down area, car and trailer parking.	2011 Draft Lake Illawarra Estuary Management Plan	Lake accessibility	Yallah Bay was identified as a key access point, which would allow access for boats including recreational uses such as fishing.	Improved waterway access and public amenity.	$400,000	Boat ramp completed (2008/09). Jetty completed (2009/10). Car park completed (2010/11).	N/A

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
5b	Prepare a concept plan for improvements to the foreshore area from the outlet canal to Gilba Rd, Koonawarra.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Uncontrolled discharge, public safety, ecological community degradation	Section of the foreshore requirement rehabilitation works, shareway construction, bank stabilisation and stormwater outflow management.	Improved public amenity. Improved foreshore amenity.	$200,000	Yallah Bay to the northern boundary of the LIA's Amenities building at Tallawarra (approx. 600m); The end of the existing pathway to the south of Koonawarra Bay to the end of Gilba Rd fence (approx. 750m); and Just inside the Gilba Rd gate (at the end of the bitumen section) toward Elizabeth Point (approx. 150m). Shareway constructed along northern outlet canal channel (2011/12). 2km of shareway and boardwalk in the process of being constructed (complete late 2013) DPIE - Crown Lands currently undertaking maintenance of this area (~$60,000 p.a.)	N/A
5c	Construct a shared pathway (and boardwalk) along the southern shoreline between Brooks Creek and Barrons Creek.	2011 Draft Lake Illawarra Estuary Management Plan	Restrict access, public safety, revegetation	A formalised pathway and installation of bollards are required to prevent illegal dumping and to formalise pedestrian and cyclist access.	Improved public access.	$200,000	Completed	N/A
5d	Provide bank protection measures to eroded sections of shoreline.	2011 Draft Lake Illawarra Estuary Management Plan	Bank erosion, declining water quality, public safety.	General areas of slope, which require stability.	Reduce erosion and improve foreshore amenity.	$200,000	To be considered	For future consideration as required.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
5e	Prevent access and install signage on the southern end of the Brooks Creek Delta	2011 Draft Lake Illawarra Estuary Management Plan	Degradation of saltmarsh, uncontrolled access, antisocial behaviour.	Saltmarsh is currently restricted from growing at the Brooks Creek delta due to uncontrolled access including the formation of bike jumps and other activities. Isolation of this area would result in the regeneration of this area with saltmarsh and an improvement in the habitat values of this location.	Improve habitat quality, public education, water quality improvements.	$10,000	To be considered. No work done to date.	For future consideration.
5f	Provide foreshore amenities including toilets, picnic areas, shelters, playground, etc. within the Kanahooka Foreshore Reserve.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Public amenity	Provision of facilities for foreshore amenity.	Improved foreshore and public amenity.	$100,000	Bush regeneration works substantially complete – being maintained. Shelters constructed as part of Shareway project.	N/A
Zone 6 Brooks Creek to Mullet Creek, Kanahooka								
6a	Construct shared pathway linking Kanahooka Point to Purrah Bay.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Public access	There is no shareway linkage around Kanahooka Point requiring pedestrians to walk up Murra Road between foreshore parks.	Improved public access.	$50,000	To be considered. Residents adjacent to this area expressed concerns about this shareway. Shareway would require elevated boardwalk installed into the rock platform. Concept design developed. No work done to date.	For future consideration.
6b	Enhance riparian zone of Mullet Creek and Purrah Bay Foreshore.	2011 Draft Lake Illawarra Estuary Management Plan	Invasive species, degraded riparian vegetation and shoreline erosion	The Mullet Creek foreshore is subject to a large population of invasive weeds with some bank stability issues located upstream. Public access along the foreshore was also discussed as a potential future benefit to prevent uncontrolled access along the foreshore.	Improved water quality and improved habitat and biodiversity.	$500,000	To be considered. WCC has completed bank stabilisation works at William Beach Park (2009/10).	For future consideration.
6c	Provide public shelters, picnic tables and seats, Purrah Bay.	2011 Draft Lake Illawarra Estuary Management Plan	Public amenity.	There are not currently any shelters, seats or tables at the end of the Purrah Bay pathway.	Improved public amenity.	$25,000	To be considered. No work done to date.	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
6d	Establish a vegetative border around existing saltmarsh beds, Kanahooka and Purrah Bay.	2011 Draft Lake Illawarra Estuary Management Plan	Uncontrolled access	The use of a vegetative border such as Juncus or Lomandra has proven an effective deterrent for access to saltmarsh beds. These species or consistent with these communities and dur their spikey nature limit free access through the area. The use of this species can also control mowing boundaries and can allow migration of saltmarsh species.	Improved habitat and biodiversity	$10,000	Has been undertaken at some locations with success. To be considered within suite of options to improve saltmarsh habitats.	For future consideration.
Zone 7 Currungoba Peninsular and Fred Finch Park, Berkeley								
7a	Berkeley nature reserve plan of management	2011 Draft Lake Illawarra Estuary Management Plan	Restoration and rehabilitation management	The island contains remnant native rainforest along with a number of rare and protected plant species. The islands are threatened by weed invasion, vandalism and sea-level rise.	Maintenance of protected species and populations, habitat rehabilitation, reduction in invasive species populations.	Managed by National Parks and Wildlife Service	Ongoing	N/A. Works ongoing by NPWS under a separate plan of management.
7b	Investigate foreshore linkage along Koong Burry Bay foreshore (this could include the construction of a boardwalk).	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Public access and saltmarsh protection.	This area is currently accessed by cattle resulting in degradation of saltmarsh. A boardwalk though this area would protect the saltmarsh and provide recreational amenity.	Improved public access.	$20,000	To be considered (part of Currungoba land acquisition). No work done to date.	For future consideration.
7c	Investigate the possible acquisition of the land at Currungoba Peninsula (including the Tank Trap) for the purpose of constructing a regional wetland and / or providing bank protection measures to the Tank Trap.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Foreshore protection	Negotiations commenced with the owners of the land known as Currungoba Peninsula to purchase the land (or part thereof) for environmental and recreational purposes. The owner hasn't indicated if he is willing to sell. The Department of Planning has advised that should the owners decide on progressing the acquisition the Authority could make an application for funding assistance under the Coastal Lands Protection Scheme.	Improved water quality. Reduced sedimentation.	$1,000,000	Valuation of the land completed (2008).	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
7d	Construct wharf / low level platform on Hooka Creek for launching / retrieval of small watercraft e.g. canoes / kayaks.	2011 Draft Lake Illawarra Estuary Management Plan	Lake accessibility	Hooka Creek was identified as a key access point, which would allow access for boats including recreational uses such as fishing.	Increased waterway access and public amenity.	$50,000	To be considered. No work done to date.	For future consideration.
7e	Protect and enhance bird habitat area (eastern mud flats) through signage.	2011 Draft Lake Illawarra Estuary Management Plan	Habitat disturbance	This key area of bird habitat is often subject to disturbance from local children and the use of vessels such as hovercrafts and kayaks. This area is utilised for feeding and nesting grounds for many water birds.	Improved habitat and biodiversity.	$10,000	To be considered No work done to date.	For future consideration in consultation with DPIE - Coasts & Estuaries.
7f	Provide appropriate signage to illustrate the indigenous cultural heritage values of this site.	2011 Draft Lake Illawarra Estuary Management Plan	Community education - heritage	The Hooka Creek area has strong ties to the local Aboriginal community, which is communicated to the general public through signage.	Improved public awareness of aboriginal culture	$10,000	Some signage and aboriginal design work carried out on the bridge over Hooka Creek.	For future consideration.
7g	Enhance riparian zone of Hooka Ck.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Invasive weeds and degraded vegetation	Ongoing works are required along the Hooka Creek foreshore to enhance the habitat value at this location.	Improved habitat and biodiversity.	$200,000	Works completed (2008/09). Ongoing maintenance required. Residents have complained about the 'forest' of trees and potential fire hazard along the creek.	N/A. Weeding, revegetation and access management works ongoing by local community group in consultation with WCC.
7h	Complete shared pathway linkage from Hooka Point to Fred Finch Park.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Uncontrolled access	Completing a missing link to the Hooka Park shareway, which is currently used resulting in degradation.	Improved public access.	$200,000	Complete	N/A

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
7i	Install access limitations to prevent uncontrolled access to the Hooka Creek Foreshore Area	2011 Draft Lake Illawarra Estuary Management Plan	Uncontrolled access, ecological community degradation.	Measures to stop illegal vehicle access through installation of fencing, bollards, gates and working with Council to ensure existing gates are locked is required to prevent further degradation of saltmarsh and swamp oak forest and allow their rehabilitation.	Improved habitat and biodiversity, water quality	$50,000	Ongoing. Some works undertaken including the use of bollards and gates.	For future consideration.
Zone 8 Hooka Creek, Berkeley to Merinda Wharf, Lake Heights								
8a	Berkeley Boat Harbour Improvements	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Water quality, vegetation and fauna management, infrastructure management.	A number of improvements have been proposed for the harbour, which focus on water quality improvements, protection of birds such as pelicans using the area and ensuring the maintenance of harbour environment. Other issues identified include vermin, littering, arson and sedimentation.	Protection of flora and fauna, water quality improvements, improved safety.	$5,000 pa	Maintenance of western navigation channel undertaken (December 2009). Maintenance of eastern channel undertaken (May 2011). Signage installed on the seawall to deter people (and dogs) from accessing the area - “Waterbird Roosting Area – Do Not Disturb”. Designs for the upgrade to the eastern basin of harbour with formalised trailer parking and boat wash down were finalised in 2013 but not progressed due to cost. Construction of an upgraded carpark is currently in the draft WCC forward program.	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
8b	Continue maintenance of the existing Budjong Creek Wetland.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Habitat protection, sedimentation and litter.	Budjong Creek Wetland provides key bird habitat for a number of species, which utilise the Lake. This wetland also functions in improving water quality prior to discharge to the Lake. As such, sediment and litter accumulate in this wetland from time to time.	Improved water quality.	$5,000 pa	As required	For future consideration as required.
8c	Continue weed removal and bush regeneration activities on Wollamai Point.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Ongoing rehabilitation	Ongoing bush regeneration activities to improve the ecological value of the park.	Improved habitat and biodiversity.	$20,000 pa	As required - works in progress – Budjong Creek Landcare Group. Ongoing works currently being undertaken as part of an DPIE grant program.	For future consideration.
8d	Enhance the reclaimed 'spur'.	2011 Draft Lake Illawarra Estuary Management Plan	Habitat rehabilitation, antisocial behaviour	Located adjacent to 81 Northcliffe Drive, this parkland area is currently prone to antisocial behaviour and is underutilised.	Habitat improvement, improved public amenity and safety	$40,000	To be considered. No work done to date.	For future consideration.
8e	Upgrade former 'Merinda' site wharf and car park area including bank protection of eroded shoreline.	2011 Draft Lake Illawarra Estuary Management Plan	Public safety, erosion	This site is degraded and often experiences antisocial behaviours.	Improved public amenity, reduced erosion.	$100,000	Ongoing, rock rip rap placed.	For future consideration.
Zone 9 Illawarra Yacht Club to Joes Bay, Warrawong								
9a	Upgrade seawalls adjacent to the Yacht Club in accordance with best practice guidelines,	2011 Draft Lake Illawarra Estuary Management Plan	Degrading seawalls	Seawalls should be upgraded to incorporate environmentally friendly principles when it is at the end of its design life and needs to be replaced.	Improved habitat value.	Unknown	As required No work done to date.	For future consideration.
9b	Complete the amenities building and educational study centre.	2011 Draft Lake Illawarra Estuary Management Plan	Public amenity, Lake resources.	Further works were to occur at the amenities and educational centre including the construction of a nursery so that plants could be grown from seed collected around the Lake for reuse in rehabilitation programs. This would also provide educational opportunities in line with the educational centre. Other additional upgrades were also identified for the site.	Increased public amenity	$300,000 $50,000 allocated for the nursery	Minor works undertaken to surrounds – car park, shelter, etc. WCC has issued Consent to occupy the building subject to conditions (2010). Plans for the nursery were under development when the LIA was disbanded.	N/A to CMP. For future consideration by Government Property NSW / WCC.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
9c	Continue upkeep of the AFL oval.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	General Maintenance	Oval landscaping and maintenance.	Improved foreshore amenity	$2,500 pa	As required	N/A to CMP. General maintenance is covered by Government Property NSW / WCC.
9d	Continue maintenance of the old Kully Bay oval toilet block.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	General Maintenance	The toilet block is subjected to antisocial behaviour as well as general use requiring maintenance.	Improved public amenity.	$1,000 pa	As required	N/A to CMP. General maintenance is covered by Government Property NSW / WCC.
9e	Implement foreshore improvements e.g. weed removal, landscaping provision of seats and tables and possible boardwalk through Kully Bay wetland area.	2011 Draft Lake Illawarra Estuary Management Plan	Loss of quality vegetation, antisocial behaviour, uncontrolled access	Areas of the Griffins Bay foreshore including Kully Bay Wetland, require rehabilitation and in some areas formalisation of access to allow vegetation such as saltmarsh to rehabilitate.	Improved public and foreshore amenity	$200,000	To be considered Master Plan (1997) for Joes Bay area to be reconsidered	For future consideration
9f	Continue maintenance of the existing Joes Bay wetland at the southern end of King Street area and the Primbee shoreline.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Habitat protection, sedimentation and litter.	This wetland functions in improving water quality prior to discharge to the Lake. As such, sediment and litter accumulate in this wetland from time to time. This wetland is also used by water birds to feed and nest.	Improved water quality. Improved habitat.	$10,000 pa	Works were undertaken as required.	For future consideration.
Zone 10 Joes Bay, Warrawong to Judbooley Parade, Windang								
10a	Investigate problems of surface and groundwater pollution from the Kemblawarra Industrial area.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Water quality pollution	Water quality in the Griffins Bay area at times experience peaks in nutrient and metals. There are many potential sources of pollutant discharge upstream of this area including industrial land uses.	Improved water quality.	$120,000	Monitoring of water quality in the Lake indicates Griffins Bay to have very high concentrations of nutrients and chlorophyll a. Any direct links to inputs from Kemblawarra yet to be established.	Ongoing monitoring to identify changes in water quality.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
10b	Provide a SQID on the Nicolle Rd drain at the d/s end of Korrungulla Swamp.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Water quality pollution	Treatment of outflowing stormwater required to capture litter flowing through the stormwater system.	Improved water quality.	Not defined	In early 2000, Port Kembla Copper commenced infilling of the dredged pond with copper slag. Approximately 1.5 MT of copper slag has been placed in the pond since decommissioning of the Copper Smelter. Port Kembla Copper (PKC) currently monitors groundwater, surface water and sediment at the site under Licence 2509. Recent monitoring by WCC has not identified elevated levels of metals in groundwater at the end of Nicole Road. PKC is currently in negotiation with WCC on an exit strategy for the site. SQID designs were finalised by the LIA. Construction appears to have not been undertaken.	For future consideration.
10c	Investigate problems of groundwater pollution (high ammonia) along the Windang Peninsula.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Water quality pollution	Water quality in the Griffins Bay area at times experience peaks in nutrients and metals. There are many potential sources of pollutant discharge upstream of this area including historical emplacements of uncontrolled fill.	Improved water quality.	Not defined	Studies have confirmed high concentrations of ammonia in the groundwater in the area. A study currently underway to identify groundwater flow paths, including the connection with the Lake.	Ongoing monitoring to identify changes in water quality.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
10d	Limit public access to saltmarsh community, Purry Burry Point	2011 Draft Lake Illawarra Estuary Management Plan Purry Burry Point to Heritage Park Site Restoration Plan (2013)	Uncontrolled access, degradation of saltmarsh	This tidal mudflat provides unique habitat for both saltmarsh vegetation communities and wader birds. Uncontrolled access to this area has resulted in degradation of this habitat.	Increased habitat and biodiversity, improved water quality.	$10,000	Considered in Purry Burry Point to Heritage Park Site Restoration Plan (2013). No works undertaken.	For future consideration.
10e	Remove illegal and 'unsightly' foreshore structures and materials along Primbee Bay.	2011 Draft Lake Illawarra Estuary Management Plan Purry Burry Point to Heritage Park Site Restoration Plan (2013)	Illegal and uncontrolled structure	A number of residents along the Primbee foreshore have built structures on the edge of the Lake, outside their property boundary. Structures include jetties, BBQ facilities, seating, informal ramps etc.	Improved local foreshore amenity.	N/A	Review of unauthorised foreshore structures completed (2007/08). Monitoring of foreshore area undertaken on regular basis. Purry Burry Point to Heritage Park Site Restoration Plan completed in 2013.	For future consideration.
10f	Provide public access linkage along the Primbee Bay shoreline if reclamation is carried out as part of Griffins Bay dredging.	2011 Draft Lake Illawarra Estuary Management Plan 2006 Lake Illawarra Estuary Management Study and Strategic Plan	Uncontrolled access	The Primbee foreshore is regularly utilised for public access. Formalisation of this walkway was proposed to improve access and prevent erosion and loss of vegetation.	Increased public access.	$100,000	To be considered – unlikely due to resident concerns. No work done to date.	For future consideration.
Lake Wide								
Xa	Improved opportunities for estuarine vegetation migration	2011 Draft Lake Illawarra Estuary Management Plan	Estuarine vegetation migration	Foreshore landscaping and infrastructure preventing the natural migration of estuarine vegetation as a result of increased sea levels.	Maintenance of population of EEC	Unknown	No actions undertaken	For future consideration.
Xb	Creek rehabilitation	2011 Draft Lake Illawarra Estuary Management Plan	Riparian rehabilitation	Creeks discharging into the Lake often characterised by a high occurrence of litter, weeds and in some locations sediment build up or structures resulting in blockages.	Habitat rehabilitation	Unknown	Ongoing, dredging and clean ups were undertaken each year by the LIA targeting the most effected outflows	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
Xc	Mangrove migrations Develop ongoing monitoring program to assess encroachment of mangroves and changes in distribution throughout Lake Illawarra	2011 Draft Lake Illawarra Estuary Management Plan	Vegetation management	An increasing population of mangroves since ~2007 are resulting in decreases in saltmarsh areas but conversely this protected species is also being removed in areas by neighbouring residents. With mangroves flourishing, monitoring should be undertaken to identify the impacts of this increasing plant species on the existing species in the area.	Protection of listed species/communities. Monitor loss and gain of aquatic endangered ecological communities	$20,000	Draft baseline vegetation mapping was undertaken as part of 2011 EMP process. Research is currently being undertaken by UoW in partnership with DPIE - Coasts & Estuaries.	For future consideration.
Xd	Revegetation and weed control	2011 Draft Lake Illawarra Estuary Management Plan	Vegetation management	Areas dominated by invasive species or low quality vegetation.	Habitat rehabilitation, reduction in invasive species	Unknown	Ongoing	Ongoing through various programs of works.
Xe	Revise mowing strategy	2011 Draft Lake Illawarra Estuary Management Plan	Vegetation management	Mowing of foreshore areas is resulting in damage to migrating saltmarsh and changes to the species distribution.	Habitat rehabilitation	Unknown	Areas within Shellharbour municipality have been the subject of changed mowing strategies for vegetation improvement with some success.	For future consideration.
Xf	Stormwater management	2011 Draft Lake Illawarra Estuary Management Plan	Water quality	Untreated stormwater outflows resulting in decreased water quality and introduction of garbage to the Lake.	Improved water quality, reduction in litter.	A stormwater strategy has been completed for the Lake identifying known outflow points.	Numerous completed in accordance with the developed strategy with many more still to be undertaken.	For future consideration.
Xg	Formalise access routes	2011 Draft Lake Illawarra Estuary Management Plan	Erosion, habitat loss	Informal access tracks result in a loss in vegetation along these areas leading to erosion in some areas.	Habitat rehabilitation, erosion control	See shareway strategy (2012)	Ongoing, some completed.	For future consideration.
Xh	Manage illegal vegetation clearing	2011 Draft Lake Illawarra Estuary Management Plan	Erosion, habitat loss	Large areas of vegetation are cleared to allow for private recreational amity	Habitat rehabilitation, shoreline protection	Unknown	Ongoing	Ongoing as required.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
Xi	Restrict access to sensitive shoreline areas	2011 Draft Lake Illawarra Estuary Management Plan	Erosion, habitat loss	Shoreline areas open to access can be utilised for activities such as dragging boats, four-wheel-driving and horse riding resulting in degradation of saltmarsh and shoreline erosion.	Habitat rehabilitation, shoreline protection	Unknown	Ongoing. Bollards have been used to varying degrees of success around the Lake.	Ongoing as required.
Xj	Erosion control and bank stabilisation	2011 Draft Lake Illawarra Estuary Management Plan	Erosion, water quality degradation	Degraded slopes requiring bank protection of stabilisation.	Bank stabilisation, improved water quality, habitat rehabilitation	Unknown	Ongoing	Ongoing as required.
Xk	Community education	2011 Draft Lake Illawarra Estuary Management Plan	Community perception, Illegal vegetation clearing	Community engagement mediums such as signage and brochures can educate local and visiting residence on the importance of the estuarine environment and the need for its protection.	Improved environmental protection	Unknown	Ongoing Saltmarsh brochure was under development in partnership with DPI Fisheries. Future world educational package developed in partnership between LIA, WCC and Futureworld.	Ongoing activity undertaken by councils and government agencies.
Xl	Illegal structures and reclamation	2011 Draft Lake Illawarra Estuary Management Plan	Removal of habitat, water quality degradation, erosion, flow restriction.	Uncontrolled reclamation or structures have been built in numerous foreshore areas around the Lake removing estuarine habitat and having other environmental impacts.	Habitat rehabilitation, improved flows and water quality, foreshore amenity	Unknown	Ongoing A review of existing unauthorised structures and foreshore reclamations in the Lake is Complete. Existing structures at Jettys By The Lake to be assessed for licensing purposes. Shared Use Jetty proposed.	Ongoing as required.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
Xm	Provision of fish cleaning tables (3 sites had been selected)	2011 Draft Lake Illawarra Estuary Management Plan	Identified need for facilities	Providing fish cleaning tables work to improve recreational amenity and protect birds from ingesting fish remains containing objects such as hooks etc.	Public amenity, faunal protection	$15,000	Fish Cleaning table installed at Reddall Reserve (2008/09). Fish Cleaning table installed at Berkeley Boat Harbour (2011). Fish Cleaning table to be installed at Yallah Bay (2011). Fish cleaning table to be installed at Judbooley Parade (2012)	N/A
Xn	Investigate dredging (and disposal) in selected areas of the Lake including: Griffins Bay Southern Back Channel Karoo Bay Burroo Bay Koona Bay Haywards Bay Koonawarra Bay Purrah Bay Koong Burry Bay Tuggerah Bay	2011 Draft Lake Illawarra Estuary Management Plan	Boating hazards, decreased flows.	Dredging was an ongoing process of the LIA to ensure flows circulated through the Lake improving water quality and boating safety. These dredging programs were limited due to the need to store PASS classed material resulting from the activity.	Improved boating Reduced quantity of ooze Improved water quality	$2.3M - 3M $1.9M - 3M $0.75M - 1M $1.1M - 1.5M $4.5M - 6M $0.75M - 1M $0.75M - 1M $1.1M - 1.5M $5.6M - 7.5M $15,000 - 20,000	Dredging program on hold subject to identifying suitable disposal location(s) for dredged spoil (PASS) – preferred disposal site is within the Lake e.g. the hole created as part of sand extraction at Purry Burry Point. Minor work undertaken in Koonawarra Bay to improve boating access to Lakeside Drive Jetty (2010). Minor dredging of Burroo Bay undertaken (2013)	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
Xo	Adopt a policy requiring Water Sensitive Urban Design for all new urban development and provide incentives for implementation of on-site stormwater treatment and re-use for existing developments around the Lake.	2011 Draft Lake Illawarra Estuary Management Plan	Declining water quality, uncontrolled catchment flows.	The water quality of Lake Illawarra is largely control by the quality of catchment inflows. Correlation shave been drawn between the increase in urban density in the catchment and the resulting decline in the water quality of Lake Illawarra. Improving outflows through stricter development controls is one method to try and reduce this impact.	Improved water quality.	N/A	It is the Councils responsibility to ensure WSUD in developments as per planning instruments. Councils have prepared consolidated DCPs. Wollongong DCP Chapter E15 (2009) outlines WCC's requirements for WSUD for certain types of development.	N/A
Xp	Undertake further research into the driving mechanisms behind algal blooms and the dynamics of macroalgae and microalgae interactions with primary producers in the Lake.	2011 Draft Lake Illawarra Estuary Management Plan	Toxic algal blooms	Algal blooms occur within the Lake due to several potential factors. These blooms can be toxic to both humans and other fauna.	Improved public awareness. Improved habitat and biodiversity.	$20,000 pa	Potential University partnership project. Research presented at the 2009 summarised a study undertaken titled "Planktonic primary production: a decisive tool for monitoring the health of Lake Illawarra" (S. Kneeshaw et. al).	For future consideration.
Xq	Continue harvesting of macroalgae in the Lake on an as needs basis.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Water quality degradation	Since 1988 approximately 30,000T has been removed. This has resulted in the removal of substantial volumes of nutrients such as nitrogen and phosphorus from the Lake as well as improving odour.	Improved habitat and biodiversity Improved water quality	$125,000 pa	Work was undertaken by the LIA as required.	For future consideration.
Xr	Continue clean-up of foreshore areas including removal of decomposing seagrass wrack around the Lake on an as needs basis.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Water quality degradation	Since 1988 approximately 50,000T has been removed. This has resulted in the removal of substantial volumes of nutrients such as nitrogen and phosphorus from the Lake as well as improving odour.	Improved habitat and biodiversity Improved water quality	$125,000 pa	Work was undertaken by the LIA as required. In June 2016 collection of seagrass wrack was undertaken following extreme weather in a once off collection event.	For future consideration.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
Xs	Continue to provide information to the community on processes and projects within the catchment of the Lake via media announcements, pamphlets, newsletters, publications, relevant websites etc.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Community engagement	Ongoing mediums of community engagement to educate the community on the values of the Lake and works being undertaken.	Increased community knowledge and awareness.	$5,000 pa	As required – Community Updates prepared following each LIA meeting.	Ongoing activity undertaken by councils and government agencies.
Xt	Continue to encourage volunteer groups such as Landcare Groups, 'Friends of Lake Illawarra', Green Corps etc. to become involved in worthwhile projects and activities within the Lake catchment. Investigate opportunities to utilise the Education Study Centre off Northcliffe Drive, Warrawong	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Community engagement	Activities undertaken to encourage participation of Lake protection and education of Lake values.	Increased community ownership.	N/A	As required Future World was historically on a month by month holding over licence with one months' notice required from either party.	For future consideration by Government Property NSW.
Xu	Continue monitoring of water quality and water level from the 2 recording stations on the Lake	2006 Lake Illawarra Estuary Management Study and Strategic Plan 2015 Lake Illawarra Water Quality and Estuary Health Monitoring Program.	Water quality monitoring	MHL operate and maintain LIA stations on an annual basis under agreement. Monthly water quality monitoring to continue in accordance with the 2015 Lake Illawarra Water Quality and Estuary Health Monitoring Program. Sydney Water sample entrance swimming lagoon area (every 6 days) as part of the Beachwatch Program.	Improved knowledge of Lake processes.	$80,000 pa	Ongoing	Ongoing.

ID[1]	Strategy / Action[2]	Source[3]	Issue[4]	Details[5]	Benefits[6]	Identi-fied Cost[7]	Completion Status[8]	Comments for current CMP process[9]
Xv	Monitor changes to the ecology of the Lake and key performance indicators e.g. water sediment, biota and amenity.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Ecological management	Undertake regular surveys of key ecological parameters.	Improved knowledge in ecological trends to guide management decisions.	$60,000	Seagrass surveys conducted in 2007/08 and 2008/09. Symposium on Lake Illawarra held (2009). Condition / Health Assessment of the Lake prepared (2010). Research Plan prepared (2010)	For future consideration.
Xw	Investigate fish stock trends and commercial and recreational fishing practices in Lake Illawarra to determine if any seasonal restrictions or upper limits on number of commercial licences required.	2006 Lake Illawarra Estuary Management Study and Strategic Plan	Fisheries management	Carry out surveys on recreational and commercial fishing effort and catch as well as surveys on important species.	Improved knowledge in fisheries trends to guide management decisions.	$10,000	DPI Fisheries collecting ongoing data.	For future consideration.
Xx	Maintenance of existing stormwater drains and controls discharging into the Lake.	2011 Draft Lake Illawarra Estuary Management Plan	Declining water quality, introduction of litter, Stormwater blockages	Stormwater outflow drains at are subject to discharging poor water of varying quality from the surrounding catchment. In addition to this, the drains are subject to blockage by sand or sediment deposition. Works include alterations to drainage channels and the installation of Gross Pollutant Traps.	Improved water quality	Undefined	Ongoing.6 GPTs installed on drains crossing Reddall Reserve (2007/08). SCC has extended the pipeline (drain) between View St and Ocean St to overcome blockages at the outlet due to sand build up (2009/10).	For future consideration as required

Appendix D Inundation Assessment

For the purpose of preparing the Lake Illawarra CMP, the strategies for managing inundation risks to assets on Lake Illawarra's foreshore have been summarised in Section 3.3.2 for Wollongong LGA and Section 3.3.3 for Shellharbour LGA, in the main body of the Synthesis Report.

To provide details regarding the management of assets potentially affected by coastal inundation, the risk registers for Wollongong LGA and Shellharbour LGA have been reproduced below from the *Wollongong CZMP: Management Study* (BMT WBM, 2017) and the Lake *Illawarra Coastal Risk Assessment* (BMT WBM, 2013) respectively. Brief introduction to the tables is also given.

It is important to note that tidal inundation mapping and a tidal inundation risk assessment specific to Lake Illawarra have since been completed, and which supersedes the information relating to "permanent" inundation below (i.e. in Table D-2). The Lake Illawarra tidal inundation mapping and risk assessment is documented in the *Community Uses, Values, Threats and Opportunities of Lake Illawarra* report (BMT, 2020a).

Wollongong

The register of risk and recommended treatment actions for Coastal Inundation the Wollongong LGA portion of Lake Illawarra has been reproduced from BMT WBM (2012) in Table D-1. Mapping of risk for the immediate timeframes and recommended actions are reproduced from BMT WBM (2012) in Figure D-1.

Important things to note regarding Table D-1 are:

- Only the level of risk relating to periodic coastal inundation during ocean storms was assessed;
- In accordance with the risk tolerance scale devised for the Wollongong CZMP (BMT WBM, 2012), only high and extreme risks are treated in the first instance, with options specified for all timeframes; and
- The naming of options given in the table were changed and rationalised for the Implementation Action Plan of the Wollongong CZMP (BMT WBM, 2017). For the purpose of identifying recommended actions for the Lake Illawarra CMP, the new action numbering and format from the Implementation Action Plan was detailed in Section 3.3.2.

Shellharbour

The register of risk and recommended treatment action for Coastal Inundation and permanent inundation in the Shellharbour LGA portion of Lake Illawarra has been reproduced from the Lake Illawarra Coastal Risk Assessment (BMT WBM, 2013) in Table D-2 below. The table provides details regarding:

- The likelihood of impact by 2100, noting that the 'almost certain' likelihood has been assumed to be a proxy for permanent inundation also;
- The consequence of impact from both periodic coastal inundation during ocean storms, and permanent inundation due to sea level rise, with discussion;
- The level of risk at the present, 2050 and 2100 from periodic coastal inundation during ocean storms;
- The level of risk at 2100 from permanent inundation (for those assets with an 'almost certain' likelihood of inundation only, with the remaining assets noted as "n/a" until further information regarding permanent inundation extents is known); and

- A recommended strategy for management of the risk, for consideration in preparing the Lake Illawarra CMP.

Table D-1 Coastal Inundation Risk Level and Treatment Options, Wollongong LGA portion of Lake Illawarra (source: BMT WBM, 2012)

Lake Illawarra Foreshores	Inundation Risk Level			Inundation Risk Treatments					
	Inundation by 2010	Inundation by 2050	Inundation by 2100	Treated by erosion option**	Planned Retreat	Accomm-odate		No Regrets	"Do Nothing" (Accept Risk)
Parks, Beaches and open space					PR2	FDCP	A2	Investigate*	DN
Lake Illawarra Foreshore	Low	Low	Low						✓
Windang Foreshore Park	Low	Low	Low						✓
Boronia Park / Oval	Low	Low	Low						✓
Kully Bay Park	Low	Low	Low						✓
Hooka Point Park	Low	Low	Medium						✓
Fred Finch Park Natural Area	Low	Low	Low						✓
Purrah Bay Reserve	Low	Low	Low						✓
Koonawarra Bay reserve / park	Low	Low	Medium						✓
Lakeside Drive Reserve	Low	Low	Medium						✓
Holbom Park Sailing Club	Medium	Medium	High			✓		NR14	
Windang Bowls Club (private recreation)	Low	Medium	Medium			✓			✓
Illawarra Yacht Club (private recreation)	Low	Low	Medium			✓			✓
EEC Swamp Oak Floodplain Forest	Medium	Medium	High					NR11	
EEC Coastal Swamp Oak Forest	Low	Medium	Medium					NR11	✓
Community Infrastructure									
Windang Tourist Park	Low	Medium	Medium			✓			✓
Other caravan parks	Low	Medium	Medium			✓			✓
Lake Illawarra Cycleway / Shared Pathway	Low	Medium	Medium						✓
Windang Memorial Park - Toilets	Low	Low	Medium			✓			✓
Windang Memorial Park - Tennis Clubhouse (leased)	Low	Low	Low			✓			✓
Boronia Park Dressing Sheds / toilets / gardeners	Low	Low	Medium			✓			✓
Boronia Park Kiosk	Low	Low	Medium			✓			✓
Boronia Park Pigeon Clubroom	Low	Low	Medium			✓			✓
Boronia Park Scout Hall	Low	Low	Medium			✓			✓
Fred Finch Park Baseball Kiosk	Low	Low	Low			✓			✓
Fred Finch Park Pony Clubhouse	Low	Low	Low			✓			✓
Fred Finch Park - Berkeley Basketball Stadium	Low	Medium	Medium			✓			✓
Willam Beach Park Exeloo, Brownsville	Low	Low	Medium			✓			✓
Transport Infrastructure									
Major roads, bridges: Windang Rd and Bridge	High	Extreme	Extreme			✓		NR14	
Local Roads, car parks	Low	Medium	Medium						✓
Port Kembla Sailing Club Boat ramp and harbour	Medium	Medium	High			✓			
Water and sewage infrastructure									
Stormwater outlets / pipes	Medium	High	High			✓	✓	NR7, NR14	
Residential Development									
Existing Residences (numerous)	Medium	Medium	High			✓			
Vacant Land (Future Development: Tourist zone at Kully Bay)	Low	Low	Low			✓			✓
Vacant Land (3 residential zoned blocks at Purrah Bay)	Medium	Medium	Medium			✓			
Note: 674 land parcels affected									
Commercial and Industrial Development									
Oasis Resort and Caravan Park	Low	Low	Medium			✓			✓
Tru Energy Gas Powered Station	High	Extreme	Extreme			✓		NR14	
Institutional Infrastructure									
Windang Public School	Medium	High	High			✓			

Sym-bol	
N	Nourishment
S1	Seawall - long or majority of beach
S2	Seawall - short sections
DV	Revitalise Dune Care Programs
BM	Manage beach sands
PR1	Accept loss as sacrificial
PR2	Relocate out of hazard zone
PR3	Prohibit development expansion
PR4	Voluntary Acquisition
PR5	Buy back then lease back
DCP	Apply development controls (future dev't and re-dev't)
A2	Redesign / retrofit in current location
A3	Replace with relocatable structure
FDCP	Apply existing flood development controls (future dev't and re-dev't)
NR1	Update Asset Register for Hazards
NR2	Audit existing seawalls
NR3	Assess Public Buildings for "accommodate" or "relocate"
NR4	Audit Ocean Pool condition
NR5	Assess Roads for "accommodate" or "relocate"
NR6	Assess Cycleways for "accommodate" or "relocate"
NR7	Design criteria for Stormwater Assets
NR8	Design criteria for Waste water, water supply and electricity assets
NR9	Develop evacuation plans
NR10	Conduct Flood Study including ocean water levels
NR11	Audit EECs and habitats for priority conservation
NR12	Use Norfolk Island Pines in new plantings
NR13	Manage Aboriginal Heritage Items
NR14	Monitor erosion & inundation events
DN	"Do Nothing" (Accept Risk)
✓✓	Substantial risk reduction and / or highly effective in managing risk
✓	Good risk reduction and / or effective in managing risk
?	Technical feasibility of applying the option is questionable
•	"Do Nothing" option is likely to have detrimental effect OR result in increased risk over time

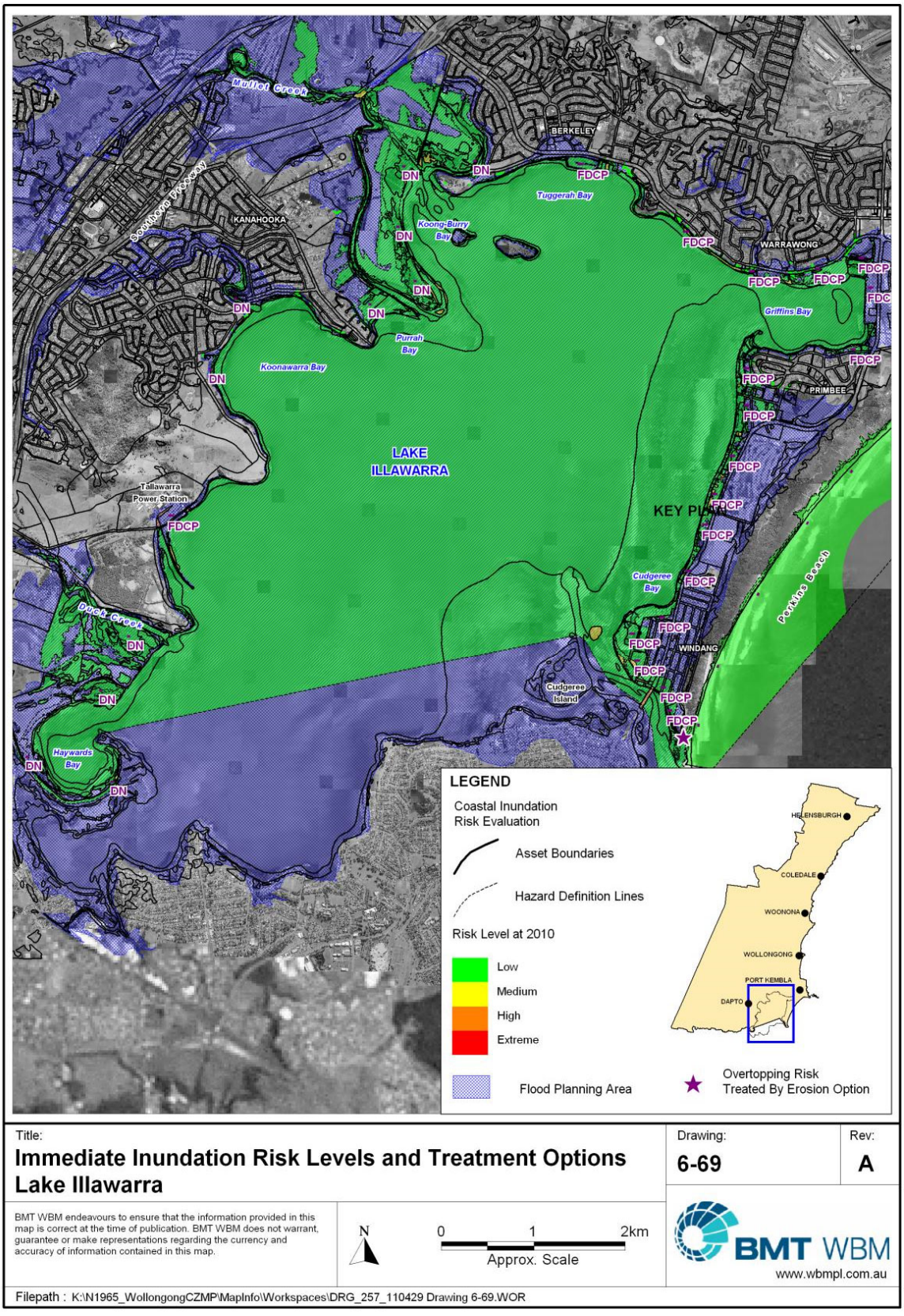


Figure D-1 Immediate Inundation Risk Levels and Treatment Options, Wollongong LGA portion of Lake Illawarra (reproduced from BMT WBM, 2017)

Table D-2 Coastal Inundation Risk Level and Treatment Options, Shellharbour LGA portion of Lake Illawarra (source: BMT WBM, 2013)

** Refers to the consequence level that was ascribed to this asset type during the Wollongong CZMP.*
*** If the consequence level from the Wollongong CZMP is considered satisfactory, no change has been made. Otherwise, a new consequence level has been assigned.*
**** Tidal (permanent inundation) mapping has since been updated and is available in BMT (2020a)*

Asset Name	*Asset Type*	*Likelihood by 2100*	*Consequence applied to LI Wollongong **	*New Consequence Level ***	*Immediate Risk Level*	*2050 Risk Level*	*2100 Risk Level*	*Permanent Inundation Consequence****	*Risk Level*	*Comments on Consequence*	*Suggested management options or existing control*	*Trigger for Implementation*
Community Land and Assets												
Lake Illawarra Public School	School	*Possible*	Moderate	Major	Low	Medium	High	Major	N/A	School communities are not considered as equipped to manage future flooding or sea level rise. Flooding impacts (permanent or periodic) may not be adequately managed through the existing Floodplain Risk Management Plan (FRMP) process, as this is focused more on future development (in-fill, re-developments).	Potential options for periodic or permanent inundation, that are based on a trigger (see adjacent) may include: - Voluntary repurchase; - community / government assistance for relocation; - engineering solutions (raising). The existing FRMP will already prescribe evacuation planning controls through SCC's DISPLAN. The FRMP will also outline planning controls for future alterations and extensions to the school.	Frequency of flood impact, e.g. when flooding occurs > 1/10 years, causing damage to buildings and property.
Lake Illawarra PCYC	Community Facilities	*Almost Certain*	Moderate		Medium	High	Extreme	Major	Extreme	As per schools above	As per schools above	As per schools above
Boonerah Park / Reserve	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme	For permanent inundation, particularly where the reserves are thin, there may be a direct loss of availability and functionality of public open space. Sporting fields in particular are under high demand, where they are located in any of the foreshore reserves. In some places, the parks do offer areas for migration of habitats (saltmarsh, mangroves), and the land becomes too 'marshy' or wet for use as parkland. In some cases, the reserves are thin, and there may be complete loss of the parkland for community, and even of habitat potential for mangroves / saltmarsh.	An assessment and adaptation plan for all of the parks, fields, reserves in Lake Illawarra (i.e., involving both Shellharbour and Wollongong Councils, with facilitation by LIA) is needed, to rationalise and determine which will need to be sacrificed, and those which shall be preserved and enhanced (including engineering to maintain functionality, and the short, medium and long term approach to provision of facilities within the park). The assessment will need to consider the likely impact and so, resilience of each park to future sea level rise, as well as community demand. This should enable a rationalisation of parks and reserves as necessary to adapt to future inundation. The assessment should also consider those reserves that should be left for migration of habitat. Once a future intent for the various parks is determined, the future intent should be communicated to the community (i.e., Community Education be undertaken). Individual assets such as amenities, bbqs, footpaths and car parks on their own are easily relocatable (replaced) or abandoned. This may be financially viable in the short to medium term, but not in the long term if the park is to be abandoned, and this approach needs to be documented for council / LIA. In some cases, the cost to maintain a park under a high risk of permanent inundation due to sea level rise may be prohibitive, and this needs to be fairly communicated to community, and alternatives enhanced or made available.	Can occur now

Asset Name	*Asset Type*	*Likelihood by 2100*	*Consequence applied to LI Wollongong **	*New Consequence Level ***	*Immediate Risk Level*	*2050 Risk Level*	*2100 Risk Level*	*Permanent Inundation Consequence****	*Risk Level*	*Comments on Consequence*	*Suggested management options or existing control*	*Trigger for Implementation*
Boonerah Reserve: Scout Hall	Community Facilities	*Almost Certain*	Moderate	Minor	Medium	Medium	High	Moderate	Extreme	This site is used less often, and seen as able to accommodate some occasional flooding. For permanent inundation, the site is considered sacrificial.	Options to relocate or abandon the structure recommended	Trigger may be a frequency of inundation e.g. 1 every 5 years.
Boonerah Jetty	Community Facilities (Waterway)	*Almost Certain*	Minor		Medium	Medium	High	Minor	High	Jetties are necessarily near to the foreshore, therefore some consequence must be accepted with the proximity to the Lake.	Jetties will necessarily continue to be located near to the foreshore. Access to the Jetty needs to be considered within the overall adaptation plan for the park. Where access can be maintained, raising the structure to maintain functionality is suitable.	Adaptation based upon monitoring of the functionality of the structure on a yearly basis.
Central Park	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme	As above for Boonerah Park	As above for Boonerah Park, Central Park should first be considered in light of overall resilience and future usability of all parks in the region. Individual assets such as amenities, bbqs, footpaths and car parks on their own are easily relocatable or abandoned. Decisions on future funding to replace or otherwise remove damaged facilities in the park should meet the short to medium term goals / expectation for the park, in context with overall LGA plan.	Triggers will be dependent on overall plan for the park. Minor facilities could be managed following monitoring of condition after events.
Central Park: Playground	Community Facilities	*Likely*	Minor		Low	Medium	Medium	Minor	N/A	Are relatively expensive assets (i.e. > $50 K) for Council to build or replace, resulting in a minor consequence from a risk impact.		
Central Park: Amenities / Blocks / Shed	Community Facilities	*Almost Certain*	Insignificant	Minor	Medium	Medium	High	Minor	High			
Central Park: Toilet Block	Community Facilities	*Possible*	Insignificant	Minor	Low	Low	Medium	Minor	N/A			
Central Park Footpath	Footpath	*Almost Certain*		Insignificant	Low	Low	Medium	Minor	High	Minimal damages expected from a flood event. Consequence increases slightly for permanent inundation. Provision of the asset is closely linked with the local park, and it should be managed in conjunction with the long term plan for the park.		
Central Park: Car Park	Car Parks	*Almost Certain*	Minor		Medium	Medium	High	Moderate	Extreme	Minor damage may occur during a periodic flood event. The consequence increases for permanent inundation impacts, especially as the provision of parking enables people from outside the locality to access parks and foreshores.		
Darcy Dunster Reserve	Parks and Public Open Space	*Likely*	Insignificant		Low	Low	Low	Moderate	N/A	As above for Boonerah Park	As above for Boonerah Park	As above for Boonerah Park
Deakin Park	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme			
Deakin Park: Sailing Club	Community Facilities	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme	Sailing clubs must necessarily remain near to the foreshore, therefore some consequence must be accepted with the proximity to the Lake.	Such facilities will necessarily continue to be located near to the foreshore. Private recreation facilities are likely to be regularly maintained or updated, at which time the Flood DCP planning controls will apply.	
Deakin Park Sailing Club Jetty	Community Facilities (Waterway)	*Almost Certain*	Minor		Medium	Medium	High	Minor	High	Jetties are necessarily near to the foreshore, therefore some consequence must be accepted with the proximity to the Lake.	Jetties will necessarily continue to be located near to the foreshore. Access to the Jetty needs to be considered within the overall adaptation plan for the park. Where access can be maintained, raising the structure to maintain functionality is suitable.	Adaptation based upon monitoring of the functionality of the structure on a yearly basis.

Asset Name	Asset Type	Likelihood by 2100	Consequence applied to LI Wollongong *	New Consequence Level **	Immediate Risk Level	2050 Risk Level	2100 Risk Level	Permanent Inundation Consequence***	Risk Level	Comments on Consequence	Suggested management options or existing control	Trigger for Implementation
Hooker Park	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme	As above for Boonerah Park	As above for Boonerah / Central Park	As above for Boonerah / Central Park
Hooker Park: Car Park	Car Parks	*Likely*	Minor		Low	Medium	Medium	Moderate	N/A	As above for Central Park Car Park		
Keith Bond Oval	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme	As above for Boonerah Park	As above for Boonerah Park	As above for Boonerah Park
Koona Bay Reserve	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme			
Oak Park	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme			
Pelican View Reserve	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme	As above for Boonerah Park	As above for Boonerah / Central Park	As above for Boonerah / Central Park
Pelican View Reserve: Toilet Block	Community Facilities	*Possible*	Insignificant	Minor	Low	Low	Medium	Minor	N/A	Are relatively expensive assets (i.e. > $50 K) for Council to build or replace		
Pelican View Reserve: BBQ Reserve	Community Facilities	*Likely*	Minor		Low	Medium	Medium		N/A			
Pelican Park Pines	Heritage	*Almost Certain*	Insignificant		Low	Low	Medium	Minor	High	The trees are likely to be able to withstand periodic inundation. Permanent inundation would result in loss of the trees. However, it should be noted that the pines do have a finite life, and may perish prior to sea level rise impacts	Replace with new trees before the trees naturally perish. Location for new trees should be considerate of overall plan for the park.	As above
Reddall Reserve	Parks and Public Open Space	*Almost Certain*	Minor		Medium	Medium	High	Major	High to Extreme	Reddall Reserve and its various assets are highly utilised with visitors from Wollongong, Sydney and beyond using its facilities, such as shore-based fishing, swimming, picnicking and so on. While the impacts of a periodic ocean event are relatively minor, the impacts of permanent inundation may be far greater, given its high usage.	Reddall reserve and its assets needs to be managed as a whole (e.g. Local Area Planning process), to understand usage of the reserve, and enable adaptation (e.g. relocation of assets) of the park as a whole, to maintain its function into the future. While a 'whole of Lake' assessment of recreational assets and future management, including both Wollongong and Lake Illawarra, is needed, it is likely that Reddall Reserve will feature as a key community asset.	Preparation of plans can commence in short to medium term
Reddall Reserve Swimming Enclosure	Community Facilities (Waterway)	*Almost Certain*	Moderate		Medium	High	Extreme					
Reddall Reserve - East: Playground	Community Facilities	*Likely*	Minor	Moderate	Low	Medium	Medium					
Reddall Reserve - North: Playground	Community Facilities	*Almost Certain*	Minor		Medium	Medium	High					
Reddall Reserve - South: Playground	Community Facilities	*Possible*	Minor		Low	Low	Medium					
Reddall Reserve: BBQ Shed (1 shed)	Community Facilities	*Likely*	Minor		Low	Medium	Medium					
Reddall Reserve: BBQ Sheds (2 sheds)	Community Facilities	*Possible*	Minor		Low	Low	Medium					
Reddall Reserve: Outside Shower	Community Facilities	*Possible*	Insignificant	Minor	Low	Low	Medium					
Reddall Reserve: Amenities / Other Shed (1 building)	Community Facilities	*Almost Certain*	Insignificant	Minor	Medium	Medium	High					
Reddall Reserve: Amenities / Other Shed (1 building)	Community Facilities	*Likely*	Insignificant	Minor	Low	Medium	Medium					
Reddall Reserve: Amenities / Other Shed (1 building)	Community Facilities	*Possible*	Insignificant	Minor	Low	Low	Medium					
Reddall Reserve: Car parks #1	Car Parks	*Possible*	Minor		Low	Low	Medium	Moderate	N/A	As above for Central Park Car Park.		
Reddall Reserve: Car parks #2, #3, #4	Car Parks	*Almost Certain*	Minor		Medium	Medium	High	Moderate	Extreme			

Asset Name	Asset Type	Likelihood by 2100	Consequence applied to LI Wollongong *	New Consequence Level **	Immediate Risk Level	2050 Risk Level	2100 Risk Level	Permanent Inundation Consequence***	Risk Level	Comments on Consequence	Suggested management options or existing control	Trigger for Implementation
Reddall Reserve: Car parks #5	Car Parks	*Likely*	Minor		Low	Medium	Medium	Moderate	N/A			
Reddall Reserve Norfolk Pines	Heritage	*Almost Certain*	Insignificant		Low	Low	Medium	Minor	High	The consequence for the pines alone is lower (see notes for Pelican Park Pines above), but management should be considered in context of the whole-of-park plan.	As above, considering the replanting of pines to replace the original pines in appropriate locations out of likely impact and in context with remainder of park.	As above
Ski-Way Park	Waterway Recreation	*Almost Certain*		Moderate	Medium	High	Extreme	Moderate	Extreme	As above for Boonerah Park, noting that this is a waterway based park, unique to the area, but also likely to be more resilient to sea level change.	As above for Boonerah Park and Central Park, noting that the facilities associated with this water based park may need to be reconfigured to continue to service the park.	Preparation of plans can commence in short to medium term
Ski-Way Park Footpath	Footpath	*Almost Certain*		Insignificant	Low	Low	Medium	Minor	High	As above for Central Park Footpath		
Ski-Way Park: Car Park	Car Parks	*Likely*	Minor		Low	Medium	Medium	Moderate	N/A	As above for Central Park Car Park		
Ski-Way Wharf, Jetty and Boat Ramp	Community Facilities (Waterway)	*Almost Certain*	Minor		Medium	Medium	High	Minor	High	Jetties, wharves and boat ramps are necessarily near to the foreshore, therefore some consequence must be accepted with the proximity to the Lake.	These structures will necessarily continue to be located near to the foreshore. Access to the wharves and boat ramp needs to be considered within the overall adaptation plan for the park. Where access can be maintained, raising the structure to maintain functionality is suitable.	Adaptation based upon monitoring of the functionality of the structure on a yearly basis.
Wilson Memorial Park	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme	As above for Boonerah Park	As above for Boonerah Park	As above for Boonerah Park
Unnamed Parks / Reserves / Open Space (numerous)	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme	As above for Boonerah Park	As above for Boonerah Park	As above for Boonerah Park
Boonerah Point Reserve Cycleway	Cycleway / Shared Path	*Possible*	Minor		Low	Medium	High	Minor	N/A	The assets may be relatively easily repaired following periodic flood events. For permanent inundation impacts, the assets are considered relocatable.	Assets can be relocated once a trigger is reached. As cycleways are a continuous asset through parks and roadways, the cycleway should be considered separately as a contiguous asset. However, relocation of specific sections within parks will need to consider the overall plan for the park.	Frequency of flood impact, e.g. when flooding occurs > 1/year
Greenhalgh Public Reserve Cycleway, Mt Warrigal	Cycleway / Shared Path	*Likely*	Minor		Low	Medium	Medium		N/A			
Hennegar Bay Reserve Cycleway, Oak Flats	Cycleway / Shared Path	*Almost Certain*	Minor		Medium	Medium	High		High			
Koona Street Cycleway	Cycleway / Shared Path	*Almost Certain*	Minor		Medium	Medium	High		High			
Macquarie Rivulet Cycleway	Cycleway / Shared Path	*Possible*	Minor		Low	Medium	High					
Oak Park Cycleway, Oak Flats	Cycleway / Shared Path	*Almost Certain*	Minor		Medium	Medium	High		High			
The Oaks Reserve Cycleway, Oak Flats	Cycleway / Shared Path	*Likely*	Minor		Low	Medium	Medium		N/A			
Reddall Parade Cycleway, Lake Illawarra and Mt Warrigal	Cycleway / Shared Path	*Almost Certain*	Minor		Medium	Medium	High		High			
Reddall Reserve Cycleway	Cycleway / Shared Path	*Almost Certain*	Minor		Medium	Medium	High		High			
Shellharbour Road Northbound Cycleway	Cycleway / Shared Path	*Almost Certain*	Minor		Medium	Medium	High		High			
Shellharbour Road Southbound Cycleway	Cycleway / Shared Path	*Almost Certain*	Minor		Medium	Medium	High		High			
Skiway Park Cycleway	Cycleway / Shared Path	*Possible*	Minor		Low	Medium	High		N/A			

Asset Name	Asset Type	Likelihood by 2100	Consequence applied to LI Wollongong *	New Consequence Level **	Immediate Risk Level	2050 Risk Level	2100 Risk Level	Permanent Inundation Consequence***	Risk Level	Comments on Consequence	Suggested management options or existing control	Trigger for Implementation
The Boulevarde Cycleway, Oak Flats	Cycleway / Shared Path	*Likely*	Minor		Low	Medium	Medium		N/A			
The Esplanade Cycleway, Oak Flats and Blackbutt	Cycleway / Shared Path	*Almost Certain*	Minor		Medium	Medium	High		High			
Recreational Waterways	Recreational Waterway	*Almost Certain*	Insignificant		Low	Low	Medium	Insignificant	Medium	Recreational waterways will become deeper, but remain equally functional with water level changes (permanent or periodic)	None required.	
Natural Assets												
Berageree Island Area (Environment Conservation Area)	Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme	This area may see a shift in habitat types and extent, as sea level rise forces migration of some habitats across the island.	A local area plan to identify habitat areas with room to migrate (which would be assisted and preserved), and those without (which would become sacrificial) is recommended.	Preparation of plans can commence in short to medium term
Berageree Island Area	Parks and Public Open Space	*Almost Certain*	Insignificant		Low	Low	Medium	Moderate	Extreme			
Bevans Island Area (Environment Conservation Area)	Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme			
Picnic Island Area (Environment Conservation Area)	Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme			
Macquarie Rivulet (Environment Conservation Area)	Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme	This area may see a shift in habitat types and extent, as sea level rise forces migration of some habitats across the island.	Haywards Bay / Macquarie Rivulet is marked for major rehabilitation and reestablishment of habitat. This area is likely to be a key area for habitat migration, as it is relatively large and currently without development or major recreational use (aside from damaging 4WD use).	Preparation of plans can commence in short to medium term
Macquarie Rivulet (Environment Management Area)	Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme			
Coastal Saltmarsh EEC	Aquatic Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme	As noted above for the parks and islands, there will be some areas where habitat will have the opportunity for migration, and others not.	A local area plan to identify habitat areas with room to migrate (which would be assisted and preserved), and those without (which would become sacrificial) is recommended.	Preparation of plans can commence in short to medium term
Mangroves	Aquatic Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme			
Estuarine Reedland	Aquatic Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme			
Sydney Freshwater Wetlands EEC	Aquatic Habitat	*Almost Certain*		Major	High	Extreme	Extreme	Major	Extreme	Freshwater wetlands are unlikely to tolerate even periodic inundation with saline seawater	As above. In some areas (e.g. without suitable area for migration) there may be loss of this habitat type.	As above
Swamp Oak Floodplain Forest EEC	Terrestrial Habitat	*Almost Certain*	Moderate		Medium	High	Extreme	Moderate	Extreme	This habitat type should be adapted to periodic flooding, but will need to migrate should higher water levels become permanent	As above for mangroves etc.	As above
Environment Conservation Area	Habitat	*Almost Certain*		Moderate	Medium	High	Extreme	Moderate	Extreme	This land zoning tends to support endangered ecological habitats that may be variously adapted to periodic flooding, and certainly need to migrate in response to permanent inundation.	As above for mangroves etc.	As above
Natural Waterways	Natural Waterway	Almost Certain		Insignificant	Low	Low	Medium	Minor	High	Natural Waterways zones were delineated based on bathymetry as areas where seagrass could grow (due to depth). If water 1m higher, would see a shift in seagrass area.	Periodic rezoning of waterway based on seagrass mapping and bathymetry, in future.	On as needed basis

Asset Name	Asset Type	Likelihood by 2100	Consequence applied to LI Wollongong *	New Consequence Level **	Immediate Risk Level	2050 Risk Level	2100 Risk Level	Permanent Inundation Consequence***	Risk Level	Comments on Consequence	Suggested management options or existing control	Trigger for Implementation
Transport Infrastructure												
Rail Infrastructure Facility	Transport Infrastructure	*Likely*		Minor	Low	Medium	Medium	Major	N/A	Railways will have been built for flooding, but probably not sea level rise	Gradual raising of infrastructure will be required, starting with lowest sections first.	A trigger for frequency of inundation (e.g. 1/10 or 20 years), to assist identification and prioritisation of railway raising.
Grande Pacific Drive	Major (Arterial) roads	*Almost Certain*	Major		High	Extreme	Extreme	Major	Extreme	While some roads may have been built to withstand flooding, not certain which ones. Road corridors usually carry services, so the impacts of inundation could be significant. Permanent inundation of roads would cause a major disruption to the community and economy, and would commence as more frequent flooding.	Arterial roads and maintenance are managed by RTA, can expect that such issues will gradually be rectified over time, with maintenance	Frequency of flooding (for example, > 1 in 10 years).
Pacific Highway	Major (Arterial) roads	*Likely*	Major		Medium	High	Extreme	Major	N/A			
Bridge - The Boulevarde	Major Bridge	*Possible*		Major	Low	Medium	High	Major	N/A			
Corona Ave	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A	The impact from periodic inundation is moderate due to evacuation access issues. Permanent inundation has a major consequence, as houses may not be able to be accessed or serviced should local roads be cut off.	Existing controls - evacuation planning within the Local Flood Plan will manage periodic inundation issues. Long term traffic planning, in conjunction with land use planning, is needed to consider and manage local roads that may be permanently cut off. This should be conducted in conjunction with planning for sea level rise affected properties (see below).	Preparation of plans can commence in short to medium term. Implementation may relate to monitoring of triggers, e.g. a frequency of inundation
Deakin Street	Minor Roads	*Likely*	Moderate		Medium	Medium	High	Major	N/A			
Kanahooka Street	Minor Roads	*Almost Certain*	Moderate		Medium	High	Extreme	Major	Extreme			
Karoo Street	Minor Roads	*Almost Certain*	Moderate		Medium	High	Extreme	Major	Extreme			
Koona Street	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
Kotari Parade	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
Mineral Road	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
Ocean Street	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
Pur Pur Avenue	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
Reddall Parade	Minor Roads	*Almost Certain*	Moderate		Medium	High	Extreme	Major	Extreme			
Shearwater Boulevard	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
Stanley Street	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
The Esplanade	Minor Roads	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
View Street	Minor Roads	*Almost Certain*	Moderate		Medium	High	Extreme	Major	Extreme			
Werrang Street	Minor Roads	*Almost Certain*	Moderate		Medium	High	Extreme	Major	Extreme			
Windang Street	Minor Roads	*Likely*	Moderate		Medium	Medium	High	Major	N/A			
Minor Bridges (1 bridge)	Minor Bridge	*Almost Certain*		Moderate	Medium	High	Extreme	Major	Extreme			
Minor Bridges (1 bridge)	Minor Bridge	*Likely*		Moderate	Medium	Medium	High	Major	N/A			
Minor Bridges (1 bridge)	Minor Bridge	*Possible*		Moderate	Low	Medium	Medium	Major	N/A			
Fisher St. Bridge Footpath, Oak Flats	Footpath	*Almost Certain*		Insignificant	Low	Low	Medium	Minor	High	Consequences of a flood event are considered insignificant, with minimal damages. The consequence increases slightly for permanent inundation, but the provision of these assets is closely linked with the minor road and local parks (see above).	These assets should be managed in conjunction with long term planning for local roads.	As above for local roads
Koona Street Footpath	Footpath	*Likely*		Insignificant	Low	Low	Low	Minor	N/A			
Princes Highway Northbound Footpath	Footpath	*Likely*		Insignificant	Low	Low	Low	Minor	N/A			
Princes Highway Southbound Footpath	Footpath	*Likely*		Insignificant	Low	Low	Low	Minor	N/A			
Pur Pur Avenue Footpath	Footpath	*Possible*		Insignificant	Low	Low	Low	Minor	N/A			
Urban Development												

Asset Name	Asset Type	Likelihood by 2100	Consequence applied to LI Wollongong *	New Consequence Level **	Immediate Risk Level	2050 Risk Level	2100 Risk Level	Permanent Inundation Consequence***	Risk Level	Comments on Consequence	Suggested management options or existing control	Trigger for Implementation
Light Industrial (1 land parcel)	Industrial Development	*Possible*	Moderate		Low	Medium	Medium	Major	N/A	The impact of permanent inundation to these land uses is likely to have a major economic and social impact, requiring considerable resources to either relocate or protect people from the impacts.	Existing FRMP controls will manage the inundation risks as properties are redeveloped; and evacuation needs. The FRMP does not cover issues relating to lake front property with sea level rise, and the accessibility (roads, services) for properties at high risk of permanent inundation. Additional controls are required for lake front properties, to manage foreshore protection works (which otherwise may be constructed illegally). And Local Area Adaptation Planning may be required, assessing both the likelihood of impact and the cost to protect, to determine actions for properties at high risk of permanent inundation. Long term strategies include: - Voluntary repurchase (then abandonment or change in land use for that land, e.g. to parkland / habitat); - protection works (such as levees, pumped drainage and seawalls) - medium term accommodation (house raising), with long term protection or relocation.	Developing controls for foreshore properties, and local adaptation planning can be conducted in the short to medium term. Implementation of actions should then be based upon monitoring for a trigger for each specific area, e.g. a frequency of inundation appropriate to the land use.
Low Density Residential (83 land parcels)	Residential Development	*Almost Certain*	Moderate		Medium	High	Extreme	Major	Extreme			
Low Density Residential (119 land parcels)	Residential Development	*Likely*	Moderate		Medium	Medium	High	Major	N/A			
Low Density Residential (168 land parcels)	Residential Development	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
Medium Density Residential (6 land parcels)	Residential Development	*Almost Certain*	Moderate		Medium	High	Extreme	Major	Extreme			
Medium Density Residential (2 land parcels)	Residential Development	*Likely*	Moderate		Medium	Medium	High	Major	N/A			
Medium Density (95 land parcels)	Residential Development	*Possible*	Moderate		Low	Medium	Medium	Major	N/A			
Rural Land - Primary Production (2 land parcels)	Rural Development	*Likely*		Moderate	Medium	Medium	High	Major	N/A			
Oaks Flats - Subdivision & Layout (the Boulevarde)	Heritage	*Possible*		Moderate	Low	Medium	Medium	Major	N/A			
California Guest House and Tree	Heritage	*Possible*		Moderate	Low	Medium	Medium	Major	N/A			
Slater's Bridge	Heritage	*Almost Certain*		Moderate	Medium	High	Extreme	Major	Extreme			
Queenslander Elevated Cottage	Heritage	*Likely*		Moderate	Medium	Medium	High	Major	N/A			
Waterway Infrastructure												
Lake Illawarra Training Walls - South (SCC)	Waterway Infrastructure	*Almost Certain*		Minor	Medium	Medium	High	Major	Extreme	The training walls have been built to withstand periodic inundation impacts. Permanent inundation impacts would be more significant (greater loads/stress on the structures, lesser performance during storm conditions).	Ongoing maintenance to ensure the structures are built to withstand wave and sea level impacts over the next 100 years +	Regular monitoring of the walls' condition, to flag minor works, and allow sufficient time for funding when major works are required.
Other Jetties / Wharves / Boat Ramps (8 sites)	Community Facilities (Waterway)	*Almost Certain*	Minor		Medium	Medium	High	Minor	High	Boat ramps, wharves and jetties are necessarily near to the foreshore, therefore some consequence must be accepted with the proximity to the Lake, for permanent and periodic inundation impacts.	Such facilities will necessarily continue to be located near to the foreshore. For Boat ramps, jetties and wharves in public ownership, adaptation to raise and maintain the structures (based on a monitored trigger) is suitable.	Trigger for adaptation may be based upon monitoring of the functionality of the structures on a yearly basis.
Stormwater Infrastructure												
Pipe - Concrete - 375mm - Addison Ave, Lake Illawarra	Stormwater Infrastructure	*Almost Certain*	Major		High	Extreme	Extreme	Major	Extreme	The consequence of either major flooding or permanent inundation of the stormwater network is necessarily major. Periodic inundation events can propagate through the stormwater network and impede flood outflow, increasing the impacts elsewhere. With sea level rise, this impact occurs more frequently and furthermore, low-lying stormwater assets may become dysfunctional. The assets are costly and difficult to replace. In	SCC intends to conduct a condition audit of all stormwater assets. The audit would benefit from inclusion of sea level rise and other flooding issues. As stormwater assets may survive for 50 – 100 years, consideration of sea level rise and flooding is highly relevant. This risk register provides a suitable starting point, as it identifies those stormwater assets for which replacement or other design requirements will be required in the medium to long term, to maintain a functioning stormwater system.	Audit can be conducted now, with replacement of key assets either at normal replacement cycles, or when monitoring of pipe condition / frequency of inundation indicates action is required.
Culvert - Corona Avenue	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 900mm - Corona Ave, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Culvert - Entrance Street	Stormwater Infrastructure	*Almost Certain*	Major		High	Extreme	Extreme	Major	Extreme			
Pipe - Concrete - 375mm - The Esplanade Oak Flats	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A			
Pipe - Concrete - 525mm - The Esplanade Oak Flats	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 450mm - Fisher St, Oak Flats	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			

Asset Name	Asset Type	Likelihood by 2100	Consequence applied to LI Wollongong *	New Consequence Level **	Immediate Risk Level	2050 Risk Level	2100 Risk Level	Permanent Inundation Consequence***	Risk Level	Comments on Consequence	Suggested management options or existing control	Trigger for Implementation
Pipe - Concrete - 600mm - Horsley Rd, Oak Flats	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A	very low-lying areas, drainage may not be possible with sea level rise, requiring pumps or other engineering solutions to maintain regular stormwater outflows for urban areas.		
Pipe - Concrete - 375mm - Koona St, Albion Park Rail	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A			
Pipe - Concrete - 1200mm - Koona St, Albion Park Rail	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A			
Pipe - Concrete - 450mm - Mineral Rd, Oak Flats	Stormwater Infrastructure	*Possible*	Major		Medium	High	Extreme	Major	N/A			
Pipe - Concrete - 525mm - Park Cres, Oak Flats	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A			
Pipe - Concrete - 375mm - Pur Pur Ave, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 450mm - Pur Pur Ave, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 525mm - Pur Pur Ave, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 600mm - Pur Pur Ave, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 675mm - Pur Pur Ave, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 750mm - Pur Pur Ave, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Culvert - Reddall Parade	Stormwater Infrastructure	*Almost Certain*	Major		High	Extreme	Extreme	Major	Extreme			
Culvert - Reddall Parade	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	High			
Pipe - Concrete - 300mm - Reddall Pde, Lake Illawarra	Stormwater Infrastructure	*Almost Certain*	Major		High	Extreme	Extreme	Major	Extreme			
Pipe - Concrete - 375mm - Reddall Pde, Lake Illawarra	Stormwater Infrastructure	*Almost Certain*	Major		High	Extreme	Extreme	Major	Extreme			
Pipe - Concrete - 450mm - Reddall Pde, Lake Illawarra	Stormwater Infrastructure	*Almost Certain*	Major		High	Extreme	Extreme	Major	Extreme			
Pipe - Concrete - 525mm - Reddall Pde, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 600mm - Reddall Pde, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 1050mm - Reddall Pde, Lake Illawarra	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A			
Pipe - Concrete - 1050mm - Reddall Pde, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 675mm - Rivulet Cres, Albion Park	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A			
Pipe - Concrete - 525mm - Shearwater Bde, Albion Park	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 375mm - View St, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 525mm - View St, Lake Illawarra	Stormwater Infrastructure	*Possible*	Major		Low	Medium	High	Major	N/A			
Pipe - Concrete - 675mm - View St, Lake Illawarra	Stormwater Infrastructure	*Almost Certain*	Major		Medium	High	Extreme	Major	Extreme			
Pipe - Concrete - 450mm - Windang St, Albion Park	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A			
Pipe - Concrete - 525mm - Windang St, Albion Park	Stormwater Infrastructure	*Likely*	Major		Medium	High	Extreme	Major	N/A			

Appendix E History and Current Status of Mangroves in Lake Illawarra (Williams and Wiecek, 2017)

History and Current Status of Mangroves in Lake Illawarra

Technical report submitted to the Lake Illawarra Estuary Management Committee, September 2017

R.J. Williams, NSW Fisheries (retired)

D. Wiecek, NSW Office of Environment and Heritage, Wollongong

Introduction

Recent construction of breakwaters at Lake Illawarra has provided permanent connection to the ocean, and as a consequence has changed the Lake's hydrology, leading to physical and other ecological changes. The Lake has entered a dynamic phase, and there are now a range of new management considerations. This report concerns itself with the history and recent proliferation of the mangrove *Avicennia marina* and what this may mean for the ongoing management of the Lake. Recommendations are provided for consideration and input into the coastal management program currently being drafted for Lake Illawarra.

Mangrove Ecology and Characteristics

Of the order of 90 species of mangrove are recognised across the globe, with at least 37 species found in tropical and temperate Australia (Stewart and Fairfull 2008). Some types of mangrove mature into large trees, whereas others occur as shrubs. Not all mangrove species are closely related taxonomically; instead, what they have in common is the capacity to exploit a habitat that other trees and shrubs have found hard to utilise – the intertidal zone. Mangrove trees exposed to consistent tidal exchange in protected waters with suitable substrata will flourish.

Six species of mangrove are present in NSW, but only one, the grey mangrove *Avicennia marina*, occurs along the whole coast, including Lake Illawarra. Growing between mean sea level and mean high tide this tree is found in dense forests, and as isolated individuals; in its mature form it can exceed 10m in height (Clarke and Myerscof 1993). *A. marina* is easily recognised by the pointed tip and grey underside of its leaves, but it is even more readily differentiated from other species by pneumatophores (peg roots) that emerge from sediment and serve to draw air into the root system. The grey mangrove is an important part of the estuarine ecosystem, providing a number of benefits including:

- a stabiliser of sediment, reducing erosion and maintaining water clarity,
- a provider of food through leaf and other litter that is consumed by micro-organisms that in turn energise food chains,
- a sustainer of habitat for juvenile and adult fish, crustaceans and molluscs.

In NSW, estuaries that are permanently open to the sea are certain to have mangroves. Estuaries that are intermittently open, particularly those that stay open for lengthy periods, are more likely to contain mangroves than estuaries that are mostly closed, where mangroves are usually absent. Where present in intermittently open estuaries *A. marina* tends to be stunted in height (<3m) and have large trunk diameter (10-15cm), implying suboptimal growing conditions. Growth of mangroves in intermittent

estuaries is thought to occur during periods when the entrance is open and tidal exchange occurs. Stunted trees could be old, reflecting long term resilience of *A. marina*.

Further evidence of the robustness of the grey mangrove is provided by the fact that in some intermittent estuaries (e.g., Deep Creek in central NSW) pneumatophores extend in length two or threefold to assist in aerial breathing when water levels remain elevated behind the berm. However, prolonged periods of closure with raised water levels inundating pneumatophores can lead to large scale die back, as occurred in the Tuross Lake in the mid 2000s where large numbers of mangroves died off as a result of permanent inundation due to closed entrance conditions not typically experienced.

A. marina, like many other plant species is dioecious, meaning an individual tree can fertilise its own flowers. While still on the tree the seeds evolve into a "propagule", i.e., they develop primary leaves and root structure, that once released from the tree can quickly grow into saplings on suitable substrate. Flower and seed production has been witnessed in trees as young as two (I. Yassini pers. comm., 2017) or three (S Paul, pers. comm. 2016) years of age and of limited stature (Figure 1). Hundreds of flowers will emerge in summer on a tree only two meters in height.

Figure 1: Propagules growing on a young mangrove less than 50cm in height from Lake Illawarra (D. Wiecek, OEH 17-5-17).

On large trees thousands of flowers can appear, in turn produce thousands of propagules, which implies a massive reproductive potential for the grey mangrove. However, the successful production of propagules can be limited by factors including a restrictive temperature envelope on flower growth. For example, in February of 2017 a heat wave and dry spell severely damaged the flower cover of trees at Sydney Olympic Park, (S. Paul, pers. comm. 2017) and in Lake Illawarra. By the end of March the dying flowers had been replaced with another cohort of flowers at both locations, once again signalling the robustness of the grey mangrove. When propagules are released from the parent tree, there are also a range of factors that limit colonisation and survival. These include the ability to be successfully dispersed via tides, currents and wind to other parts of the foreshore where suitable substrate and protection from wave energy exists.

History of Mangroves in Lake Illawarra

A. marina is currently the only species of mangrove in Lake Illawarra. Sporadic reports have been made on its presence over the past 40 years, likely due in part to its limited abundance, the latter almost certainly being a function of the lake's intermittently opening entrance. A history of periods of

closed or heavily shoaled entrance would have resulted in less than ideal mangrove establishment and growing conditions.

The first mention of mangroves existing in the Lake was in an appendix in an environmental study in 1976 written by the NSW Forestry Commission, which noted mangrove had occurred in the more saline areas but had now largely disappeared (WCC and UoW 1976). Inexplicably, in the main body of the document that included a detailed summary of vegetation in and around the Lake, there is no mention of the presence of grey mangrove. A survey of the Lake's vegetation in 1981 (Anderson *et al.* 1981) documented grey mangrove distributed sparsely around the lake periphery, and in small patches along the shoreline of the entrance channel.

In the mid 1980s *A. marina* was reported at several locations along the southern foreshore of Lake Illawarra (Yassini 1985), who attributed establishment to the creation of the low energy passive environment when the bridge piers for the southern section of Windang Bridge were replaced with a causeway in the early 1970's. Several large trees (>4m in height) were adjacent to the southwest approach to the bridge, and four smaller trees were located further to the west. One of the latter was on its own in the Back Channel not far from a now defunct jetty, and the other three adjacent the Police Citizens' Youth Club (PCYC). In 1988, as part of foreshore enhancement activity, Shellharbour Council removed the trees near the bridge and filled the wetland to create the western portion of Reddall Reserve. The smaller trees further to the west, untouched, would have been mature enough to produce propagules if environmental conditions were suitable (I. Yassini, pers. comm. 2017) and are the likely source of the many mangroves that have established along this shoreline since 2007.

The larger mangroves reported by Yassini (1985) are clearly observable in aerial photographs taken in 1977 (Figures 2 and 3), with imagery from 1974 (Figure 4) also likely showing at least one of these mangroves. To be of an observable size in the photos, the mangroves would have been in place for a period of years prior, possibly establishing in the late 1960s or early 1970s.

Figure 2: Mangroves present in Lake Illawarra along the southern foreshore west of Windang Bridge visible in aerial photography from 1977.

Figure 3: Mangrove present in Lake Illawarra along the southern foreshore adjacent to the PCYC visible in aerial photography from 1977.

Figure 4: Aerial image from 1974 of the southern foreshore immediately west of Windang Bridge that appears to show one of the mangroves visible in the 1977 aerial photography.

It is possible that a limited number of mangroves may have been present in the Lake prior to those in aerial photographs from the 1970s, but none were documented and there are no other large mangroves present in the Lake today that could have grown from this time. A composite image from aerial photos taken between 1948-51 (Figure 5) clearly shows none of the mangroves visible in later images, so we assume trees established after this time. It is possible that small mangroves were present and died off, but were not visible in photography prior to the 1970s due to factors such as the quality of the photos and/or potentially being hidden by adjacent and overhanging vegetation.

Figure 5: Composite aerial imagery from 1948-1951 of the southern foreshore immediately west of Windang Bridge that shows the larger mangroves visible in later aerial photography are not yet present.

In the mid 1980s an atlas of the location and area of estuarine macrophytes (seagrass, mangrove, saltmarsh) in NSW indicated that *A. marina* was present in Lake Illawarra but of an area so small as to not be tabulated (West *et al*. 1985). In contrast, neither Chafer (1997) nor National Environmental Consulting Services (1998; cited in WBM 2003, Section 8.21) reported mangroves in the lake. An intensive study of Duck Creek in the mid 1980s (Yassini 1988) also found no mangrove in that tributary, a situation quite different than at present (see below).

In the mid 2000s a second survey of NSW estuarine macrophytes reported the presence of *A. marina* in Lake Illawarra (Creese *et al*. 2009), and also did not quantify the small area present. Subsequently, Roper *et al*. (2011) reported this occurrence as 57m^2, but a recent inspection of GIS shapefiles (G. West, pers. comm., 2017) suggests a stand of *Casuarina* was misidentified as mangrove by Creese *et al*. (2009). Nevertheless, the lone tree seen in Figure 2 (1977) and Figure 4 (1974), near the jetty as recalled by Yassini (pers. comm., 2017), was located in a re-examination of the images used by Creese *et al*. (2009). This tree is of particular interest because it is likely to be the oldest remaining mangrove tree in the Lake, as well as the largest (height ~10m and base circumference ~1.7m).

Estimates of changes in the area of its canopy over time provide another indication of how the creation of a permanent entrance has enhanced growing conditions for *A. marina* in the lake. The canopy area of this tree has increased from approximately 16m^2 in 1977 to nearly 120m^2 in 2017, and the rate at which the canopy expanded more than doubled after breakwaters were completed (Figure 6).

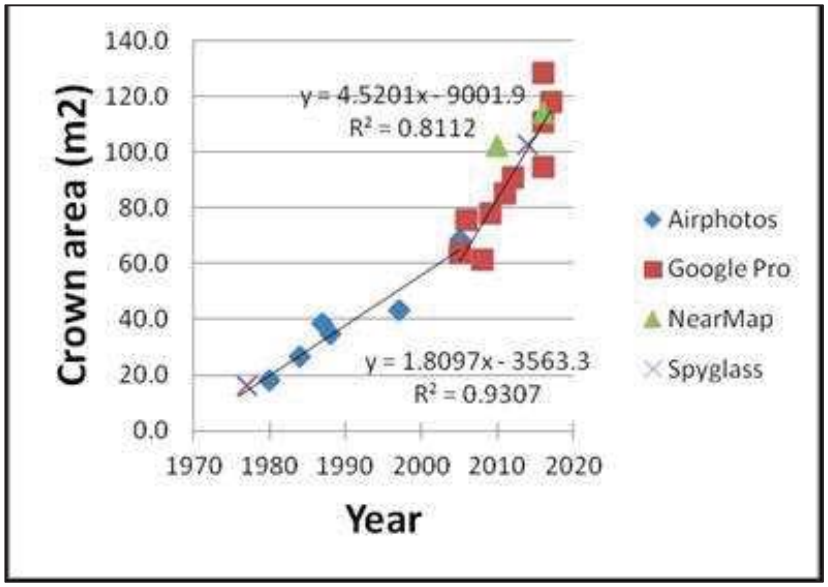


Figure 6. Change in canopy area of the largest and likely oldest mangrove tree in Lake Illawarra: 1977-2017.

The three other mangroves noted by Yassini (1985) further west of the jetty tree and adjacent to the PCYC, one of which is shown in Figure 3, are still at that location, and in April of 2017 were approximately 6 meters in height. It is conceivable that these trees were derived from propagules from those observed adjacent to Windang Bridge prior to the foreshore works.

Deliberate plantings of *A. marina* have occurred in Lake Illawarra. A resident claimed to have collected propagules from the Minnamurra River in the mid 1990s and planted them in Hooka Creek (Wiecek *et al*. 2016). In 1999 under the auspices of the Lake Illawarra Authority small trees (<500mm in height) were planted in the entrance back channel with the intent to stabilise the foreshore (Anon. 2000, Baxter and Daly 2010). It is not known precisely where the latter plantings occurred or how far west along the foreshore they extended, but to the west of PCYC and along the shore of Whyjuck Bay are cut and weathered stumps of mangroves that were around 2-3m tall in 2010 (Figure 7) and which are visible in Google Earth images from 2005. They are likely to have established in the late 1990s to early 2000s, possibly around the time the LIA did plantings of mangroves in the entrance back channel.

Figure 7: Mangroves along the foreshore of Whyjuck Bay taken on 22/6/2010 (left) that have since been cut down with the stumps still visible (right, taken 12/4/06) (D. Wiecek, OEH).

Based on our observations from aerial photographs, coupled with the references from historical surveys and accounts from Council staff involved in environmental rehabilitation projects around the Lake in the 1980s, we conclude that *A. marina* has been continually present in Lake Illawarra since at least the early 1970s, and possibly earlier, but with very restricted extent. It is likely that these mangroves established naturally during periods of time when the entrance to the Lake was open, and propagules from other estuaries had potential to be carried in.

While propagules could have only entered the lake naturally when the entrance was open, the duration over which the entrance remained opened would have been important. Periods of time associated with large floods (1919, 1943, 1959 and 1975, Soros-Longworth and McKenzie 1976), may have been particularly important for mangrove colonisation. Large floods would have scoured sand from the entrance of the lake, prolonging the time frame over which the entrance was open and tidal. Prolonged open tidal conditions would have enhanced opportunities for both carriage of propagules from outside locations into the lake, and allowed favourable establishment and growing conditions for propagules that settled.

Upstream Limits of Mangroves in Lake Illawarra

In the early and mid 2000s a field survey of the upstream limits of mangrove in NSW estuaries was commissioned to resolve jurisdictional responsibilities of state authorities for tidal and non-tidal waters. *A. marina* was encountered in several tributaries of Lake Illawarra (Table 1). The single individual, at five meters height in Hooka Creek would appear to have been in place some years before the survey. It is unlikely this single tree, or those at the other sites, would have been discovered some years later by Creese *et al*. (2009) as they are all surrounded by *Casuarina* trees such that the mangrove canopy was hidden in aerial photographs.

Table 1: Upstream locations of mangrove in Lake Illawarra (from MHL 2006) compared to recent observations from the same areas.

Location	Date Identified	Height	Comments from MHL (2006)	Recent observations (2016-17)
Hooka Creek	31/1/2002	5m	Left bank, 175m from Lake Illawarra	Large tree still present, and a single small mangrove (<1m height) on opposite bank. No upstream mangrove migration.
Duck Creek	5/8/2000	1-2m	Three mangroves at entrance to Wollingurry Creek	Extensive mangrove coverage of the whole length of Duck Creek up to the tidal limit (i.e., expansion upstream and downstream).
Wollingurry Creek	31/1/2002	seedling	Left bank 200m upstream from Duck Creek	Established trees and numerous smaller mangroves length of Wollingurry Creek up to approximate tidal limit (i.e., expansion upstream and downstream).
Koona Bay	5/8/2000	2m	Several mangroves	One large mangrove tree (>5m height) with several seedlings in close proximity and 1-2m high tree ~120m to the NW and a seedling ~400m to the SE.

Current Mangrove Distribution

Based on air photos and field survey, the most recent mapping of cover of mangrove of Lake Illawarra (Regena 2016) indicated an area of 8,781m^2, classified as large trees (~744m^2), small trees (~3,580m^2) or juveniles (~5,555m^2) based on canopy size and height. (These area estimations are non-additive due to intermingling of juveniles with the larger size classes). Two substantial concentrations of mangrove were encountered, the major one in the entrance back channel (88% of the total cover), and a smaller one at Duck Creek and adjoining foreshore (10% of the total). Single trees, or small patches of trees and seedlings, were identified at other sites around the lake (2% of cover) (Wiecek *et al*. 2016).

Comparisons of Regena's maps (2016) with recent aerial photographs clearly show expansion of cover in the entrance back channel has predominantly taken place **downslope** (areas lower in elevation) relative to prior mangrove occurrences. This would occur as the mean water level in the Lake dropped after completion of the entrance breakwaters (Wiecek *et al.* 2016; MHL 2017), and shifted the intertidal area downslope. As well, tidal range has increased, meaning that at low tide more downslope surface is exposed. While not as obvious yet, the ongoing expansion of tidal range means it is likely that there will also be more **upslope** (areas higher in elevation) migration of mangroves

into the future. The expansion of the intertidal area has increased since 2007 and is expected to keep increasing for a long time.

Expansion of cover at Duck Creek and its tributary Wollingurry Creek (Regena 2016, and recent field observations – Table 1) is most likely to have taken place via propagules from the few trees previously reported to be at that location (MHL 2006), possibly supplemented by propagules dispersed from older trees along the southern foreshore. This expansion represents an **upstream** migration, as mangroves have since colonised up close to the tidal limit in both creeks, which in Duck Creek is a distance of around 450m upstream from the trees observed in 2000 (Table 1). No such upstream migration of mangroves has yet been seen in other tributaries of Lake Illawarra including Hooka Creek, where ground survey of the Creek in 2016 found only one other small mangrove on the opposite bank close to the large mangrove observed in 2000.

Regena's study (2016) compared with earlier surveys (West *et al*. 1985, Creese *et al*. (2009) indicates a massive increase in cover of mangrove over the ensuing years. This expansion of area, particularly at the entrance back channel, has occurred most likely due to creation of favourable growth and reproductive conditions from constant tidal exchange attendant on breakwater construction. The shallowness and sheltered nature of the entrance back channel would have also enhanced the chances of propagules settling and surviving.

Management Considerations

While mangroves are an important part of estuarine ecosystems and provide a number of benefits, their expansion in a number of NSW estuaries has partly occurred in areas previously dominated by saltmarsh (Saintilan and Williams 1999). The threat to coastal saltmarsh from mangrove encroachment was one of the reasons the former was declared an Endangered Ecological Community under the NSW *Threatened Species Conservation Act 1995*. To date we know that mangroves have established amongst saltmarsh in the entrance back channel, with the massive expansion of mangroves in this area since 2007 partly occurring in areas previously dominated by saltmarsh (Wiecek *et al*. 2016). While mangrove encroachment has likely led to some loss of saltmarsh here, in the last few years in particular, saltmarsh appears to have contracted upslope along sections of the foreshore of the entrance back channel. The latter circumstance is most probably due to increased inundation associated with an increased tidal range, with sites previously covered by saltmarsh now bare sand and mud with mangroves at various stages of growth. This can be seen in photos taken in 2010 compared to 2017 (Figure 8), as well as in aerial photography (Figure 9), where an acceleration of loss of saltmarsh in the last few years is also apparent.

This has not been the case for the saltmarsh around the Lake basin yet, as tidal range increases since 2007 are not yet enough to raise high tides above previous high water stands experienced in the Lake prior to 2007 that saltmarsh would have been acclimatised too. The drop in average lake levels experienced after the entrance was permanently opened (Wiecek *et al*., 2016) has meant that it will take longer for inundation levels to reach a point where saltmarsh at current elevations is drowned out for the rest of the lake compared to the entrance, where tidal range change post 2007 has been far greater (MHL 2017).

Figure 8: Photo of the southern foreshore in the entrance back channel with thick growth of samphire dominated saltmarsh and a couple of young mangroves establishing taken 10-6-2010 (left), compared to a recent photo (8/8/2017) from the same location showing mangroves amongst mud with most saltmarsh, particularly samphire, gone (right) (D. Wiecek, OEH).

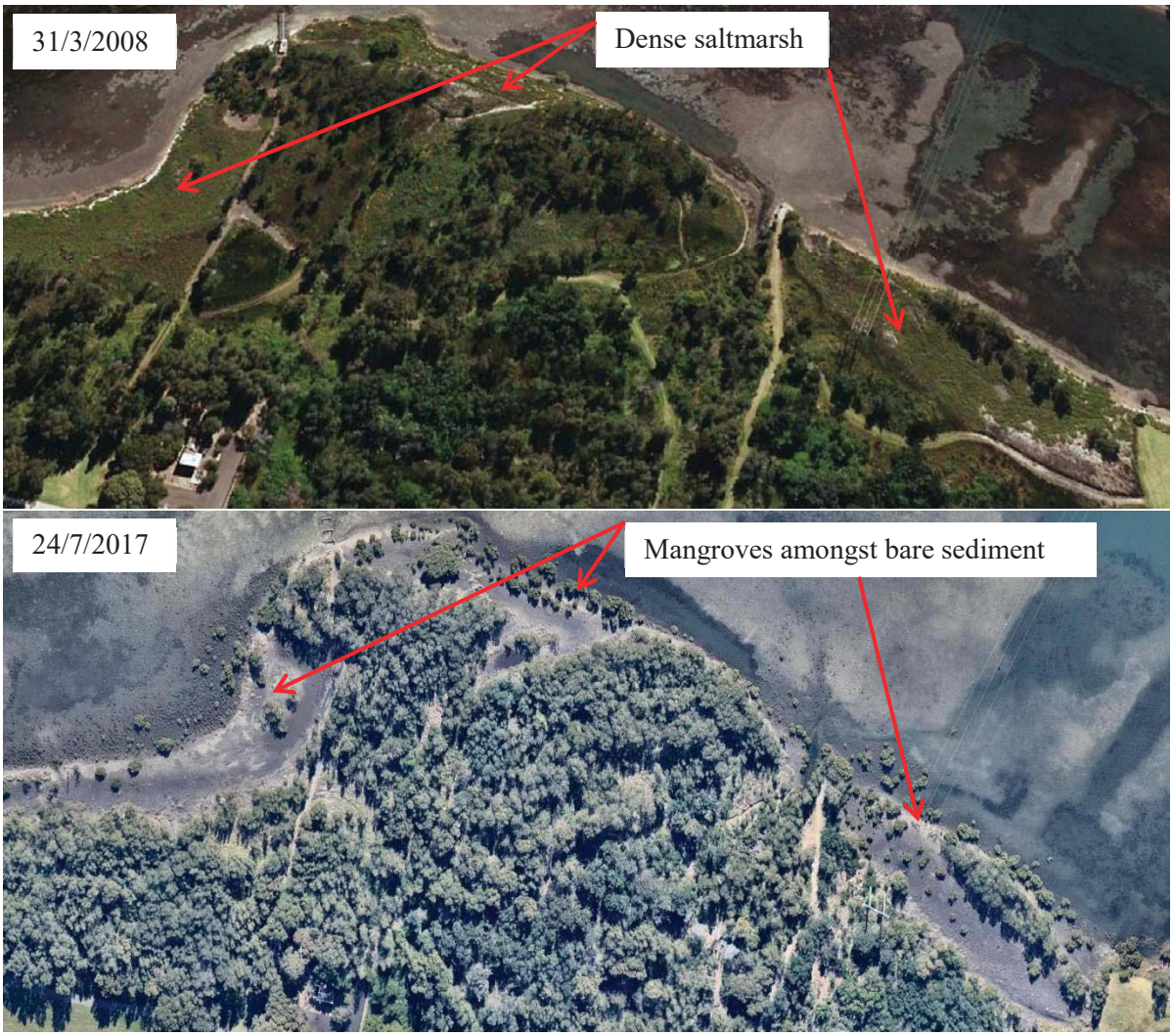


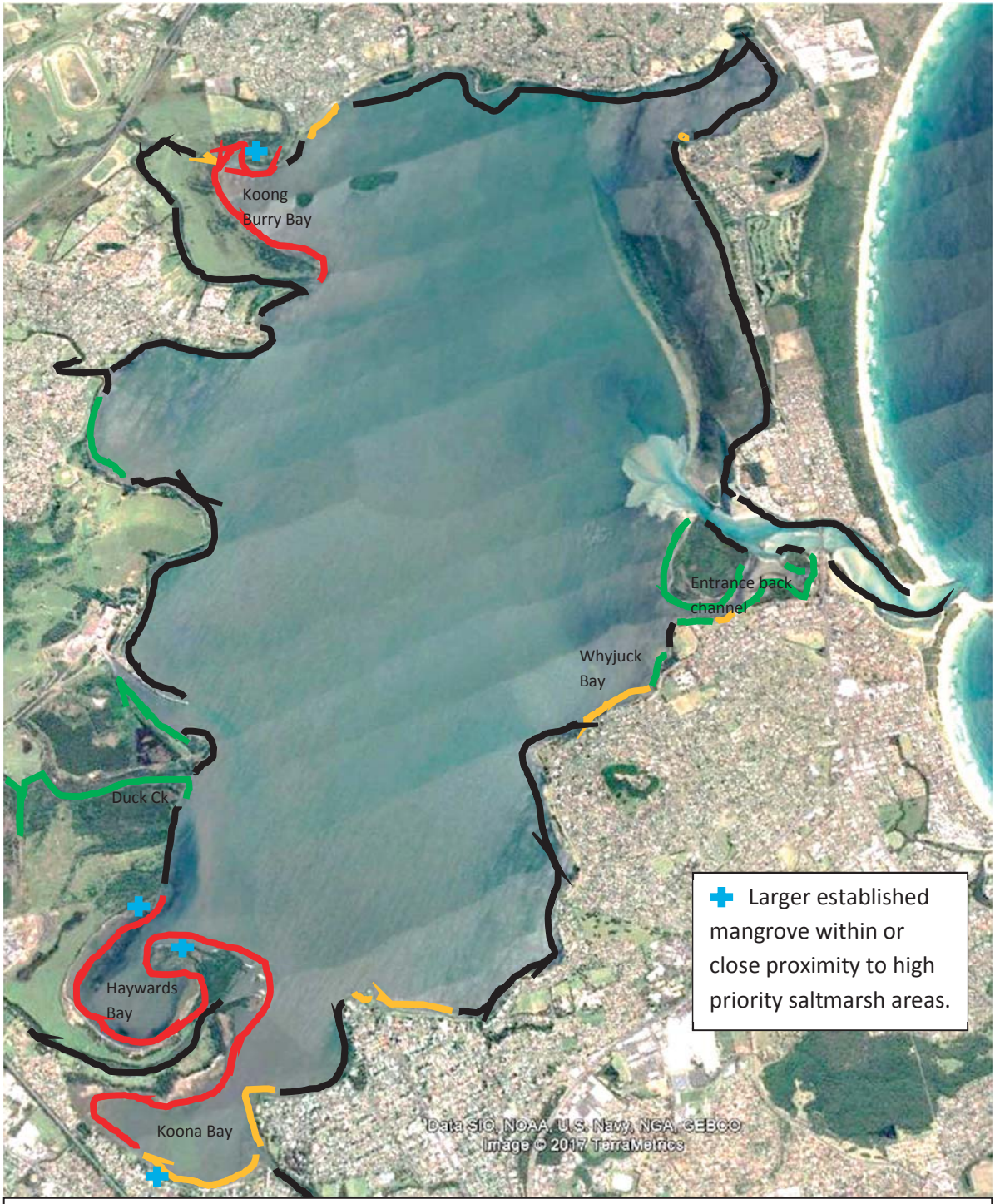
Figure 9: Aerial images of the southern foreshore in the entrance back channel showing large areas of saltmarsh have now been lost and replaced with mangroves and mud flats.

The expansion of mangroves in locations other than the entrance back channel and Duck Creek has to date been limited. A number of factors would limit mangrove establishment around large parts of the Lake, including the suitability of the substrate and exposure to wind waves (Wiecek *et al*. 2016). However, it is likely that there are other sites where the potential for mangrove colonisation and expansion is high, particularly over time as the tidal range continues to increase. These sites are likely to correspond with the largest expanses of saltmarsh within the Lake, that is, along the foreshores of Koona Bay, Haywards Bay, and Koong Burry Bay (Figure 11). These locations currently have no to very limited mangrove presence, but all have the potential for mangrove establishment.

Not only should these areas be a priority for ongoing monitoring of mangroves, but they should also be a priority for consideration of whether limiting mangrove encroachment should be a component of any strategy to conserve and manage saltmarsh distribution, particularly in the short term if monitoring confirms that mangroves are displacing saltmarsh. However, in the longer term as the tidal range within the Lake continues to increase, coupled with sea level rise, inundation of these saltmarsh areas may potentially reach a point where saltmarsh cannot survive and will contract to higher elevations. Hence, mangrove removal in these areas may only help in the short to medium term, and longer term protection of saltmarsh still needs to rely on ensuring saltmarsh has the ability for landward migration through dedicated buffers for this purpose, amongst other measures to control access and revise mowing strategies.

Mangroves, like saltmarsh, provide a number of benefits to estuaries, and any control of the former along with conservation of the latter will best be explored as part of developing the coastal management program for Lake Illawarra in consultation with DPI NSW Fisheries and other key stakeholders. It is also important to note that there may be other reasons why mangrove control in specific locations may be favoured by some members of the community, and this may also need management consideration. For example, there have been several rounds of mangrove poisoning and vandalism adjacent to the PCYC Club in the entrance back channel (Figure 10), highlighting that some individuals at least have taken exception to their proliferation. Hence, there is likely to be benefit in community education on the importance and role that mangroves provide in estuaries.

Figure 10: Examples of mangrove vandalism adjacent to the PCYC Club, showing stumps remaining from mangrove trees cut down (left) and a drill hole injected with poison in a mangrove tree (right) (D.Wiecek, OEH).



The largest areas of saltmarsh within the Lake with good ability for landward migration, high priority to conserve. Limited mangroves currently, but potential to support them.

Smaller areas of saltmarsh within the Lake with lower ability for landward migration, medium priority to conserve. Some mangroves currently or potential to support them. Potential for conflict if mangroves impact on Lake views.

Limited saltmarsh and lower potential for mangrove establishment due to a variety of limiting environmental factors. Lower potential for view conflicts.

Areas of extensive mangrove establishment already with limited saltmarsh, mangrove distribution expected to increase further. Potential for view conflicts around the entrance only.

Figure 11: Foreshore prioritisation map to guide where effort on mangrove monitoring and conservation of saltmarsh distribution is best placed.

Conclusions

- Our present understanding of the historical distribution of *A. marina* in Lake Illawarra suggests mangroves have existed in the Lake since at least the late 1960s / early 1970s. While mangroves may have been present prior to this, they were in abundance so limited as to be undetectable in the available aerial photography.
- In the late 1960s or early 1970s a few mangrove trees came to populate the southern foreshore of the lake, some of which have survived through to today.
- As a consequence of completion of breakwaters in 2007, *A. marina* has flourished in the entrance back channel and Duck Creek, where it previously existed in limited numbers, but colonisation over the rest of the Lake has been much more limited.
- Expansion of cover of mangrove has noticeably occurred downslope of where it previously existed, particularly the entrance back channel, but is also occurring upslope, which is expected to become more noticeable over time as the tidal range in the Lake continues to increase. Some upstream migration has also occurred in the Lake tributaries, but limited to Duck Creek and Wollingurry Creek.
- Conditions are now favourable, due to enhanced tidal exchange, for colonisation of other suitable lake foreshores that contain soft substrate in quiescent locations. These areas are likely to overlap with areas currently dominated by saltmarsh.
- It is to be expected that as tidal range increases, expansion of mangrove around Lake Illawarra will increase, and that this expansion will have an impact on saltmarsh.

Recommendations

1. Monitor mangrove distribution around the foreshores, focusing on the areas highlighted as high and medium priority in the foreshore prioritisation map, to inform management planning.
2. Use the foreshore prioritisation map of Lake Illawarra to inform any saltmarsh protection strategies that consider mangrove control via the process of preparing a coastal management program (CMP) for Lake Illawarra. Any strategy for mangrove control would need the support and approval of NSW DPI Fisheries, and would only be a component of a broader saltmarsh protection strategy.
3. Develop an education program for foreshore residents, lake users and the broader community on the importance of mangroves in estuaries, noting they provide a number of benefits and are a natural part of these ecosystems. This education would acknowledge that mangroves were natually present in the Lake in the 1970s, albeit with limited extent. This education could be a component of broader education program about healthy estuarine foreshores and the benefits of maintaining vegetation, or similar, developed as part of the Lake Illawarra CMP.
4. Support research initiatives on the history and ongoing spread of mangroves around the Lake and any management implications this may have including on saltmarsh. Distributional studies of current and past saltmarsh cover, and factors associated with changes in extent, would be a priority for further investigation.

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