Manly Lagoon: Review of environmental processes

WRL TR 2021/23, May 2023

By T A Tucker, D S Rayner and A J Harrison

UNSW Water Research Laboratory

UNSW SYDNEY

Manly Lagoon: Review of environmental processes

WRL TR 2021/23, May 2023

By T A Tucker, D S Rayner and A J Harrison

Project details

Report title	Manly Lagoon: Review of environmental processes
Authors(s)	T A Tucker, D S Rayner and A J Harrison
Report no.	2021/23
Report status	Final version 2
Date of issue	May 2023
WRL project no.	2020060
Project manager	T A Tucker
Client	Northern Beaches Council
Client address	55 Middleton Road Cromer NSW 2099
Client contact	Jason Ruszczyk Jason.Ruszczyk@northernbeaches.nsw.gov.au
Client reference	#

Document status

Version	Reviewed by	Approved by	Date issued
Final draft	BMM	BMM	21/10/22
Final	BMM	BMM	15/12/22
Final version 2	BMM	BMM	22/05/23

UNSW
Water Research Laboratory

www.wrl.unsw.edu.au
110 King St Manly Vale NSW 2093 Australia
Tel +61 (2) 8071 9800 ABN 57 195 873 179

Executive summary

Manly Lagoon is located on the Northern Beaches of Sydney. An approximately 1,800 hectare catchment drains into the lagoon which connects to the ocean at the north end of Queenscliff Beach (Figure ES.1). The catchment is one of the most heavily urbanised catchments in NSW and as a result the lagoon has faced a long history of poor water quality. This poor water quality continually threatens the ecological health of the lagoon. Subsequently, over time there have been numerous studies and investigations that have sought to improve the water quality of the lagoon.

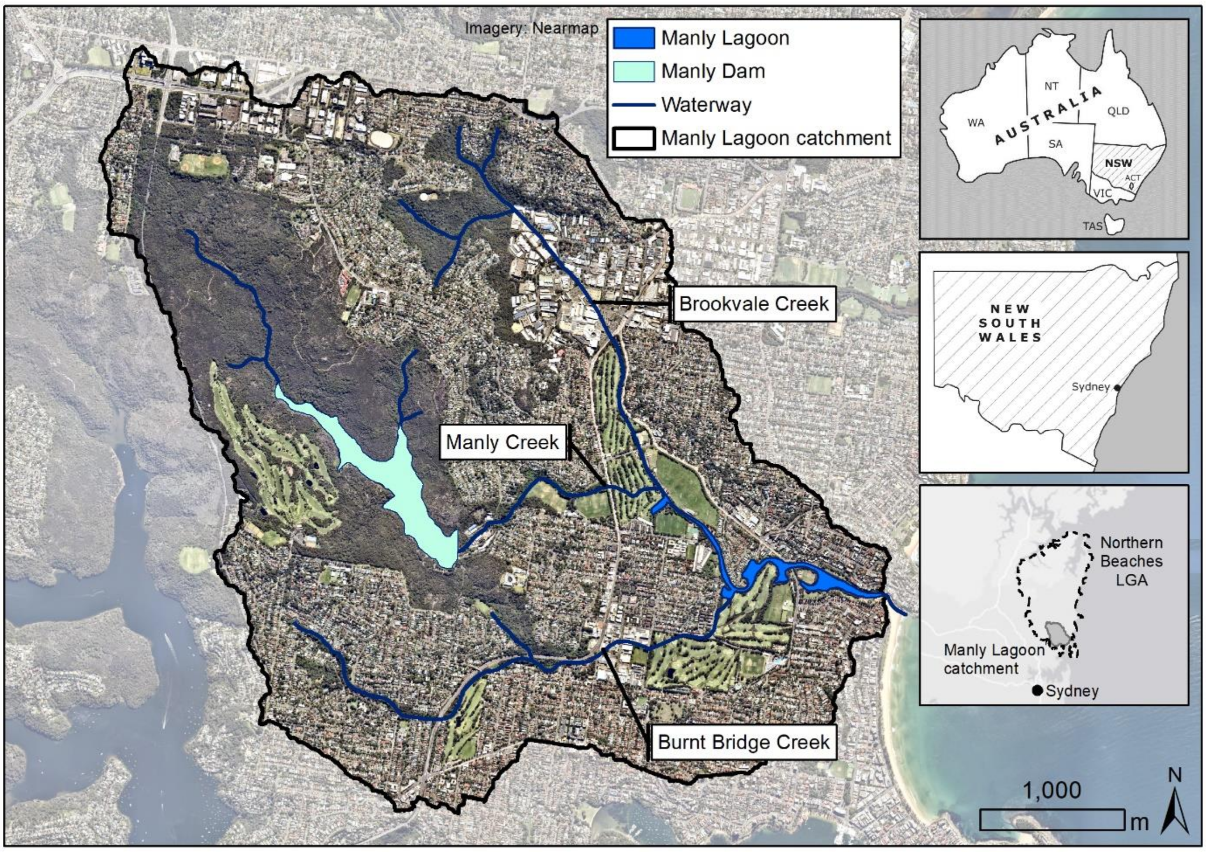


Figure ES.1: Manly Lagoon catchment and local waterways located on Sydney's Northern Beaches, NSW, Australia

Management of Manly Lagoon is now at a crucial point where the first stage in the development of a Coastal Management Program is beginning. The Coastal Management Program will provide a long-term strategy for the future management of the lagoon. It is therefore important that the current state of Manly Lagoon and the environmental process which occur throughout it are correctly understood so that the future management of Manly Lagoon is successful.

An extensive review of all available literature and data relevant to the Manly Lagoon environment has been compiled. From this a conceptual understanding of the lagoon processes was developed (Figure ES.2). Understanding these environmental processes is the first step required for determining the strategic context for the management of Manly Lagoon.

Following this review, the ecological health of Manly Lagoon has been benchmarked against relevant guideline values and other estuaries in NSW. Review of data identified the overall health of the lagoon remains poor and ongoing adaptive management is required for improvement. The ecological health of Manly Lagoon was found to be the worst of the four local lagoons on the Northern Beaches in the 2020/21 round of annual environmental sampling. Compared to all the lagoons in NSW, Manly Lagoon ranked in the bottom 25% of all estuaries for 8 of the 16 parameters used to compare their ecological health. Poor ecological health compared to other NSW estuaries was generally due to high chlorophyll-a levels, which are an indicator of high nutrients throughout the lagoon.

The future management of Manly Lagoon needs to consider the environmental values that the lagoon provides. Environmental values can be social, cultural or economic in nature and are directly related to the ecological health and biodiversity of the lagoon. The current poor ecological health of the lagoon is a result of continued pressures and threats to the lagoon environment. To identify how improvements to the lagoon's ecological health, and the values that the lagoon provides, can be achieved, a review of the values, threats and pressures has been completed. Following this, a risk assessment framework was used to determine which pressures and threats are likely to be the most detrimental to Manly Lagoon's ecological health. Climate change and poor water quality were determined to be the largest risks that the lagoon's ecological health faces.

A first-pass review of potential management opportunities was then completed as a preliminary step for guiding the future improvement of Manly Lagoon's ecological health. Management opportunities were identified and then qualitatively assessed on their ability to reduce the threats and pressures imposed on Manly Lagoon. This first-pass review is anticipated to form part of a multicriteria analysis that could be used to determine which actions result in the largest improvements in ecological health and environmental values for Manly Lagoon. Furthermore, the development of the Coastal Management Program and the strategic context of the lagoon's future long-term management will be informed by this first-pass assessment through:

- A values, pressures and threats analysis
- Benchmarking of Manly Lagoon's ecological health
- Review of Manly Lagoon's environmental processes

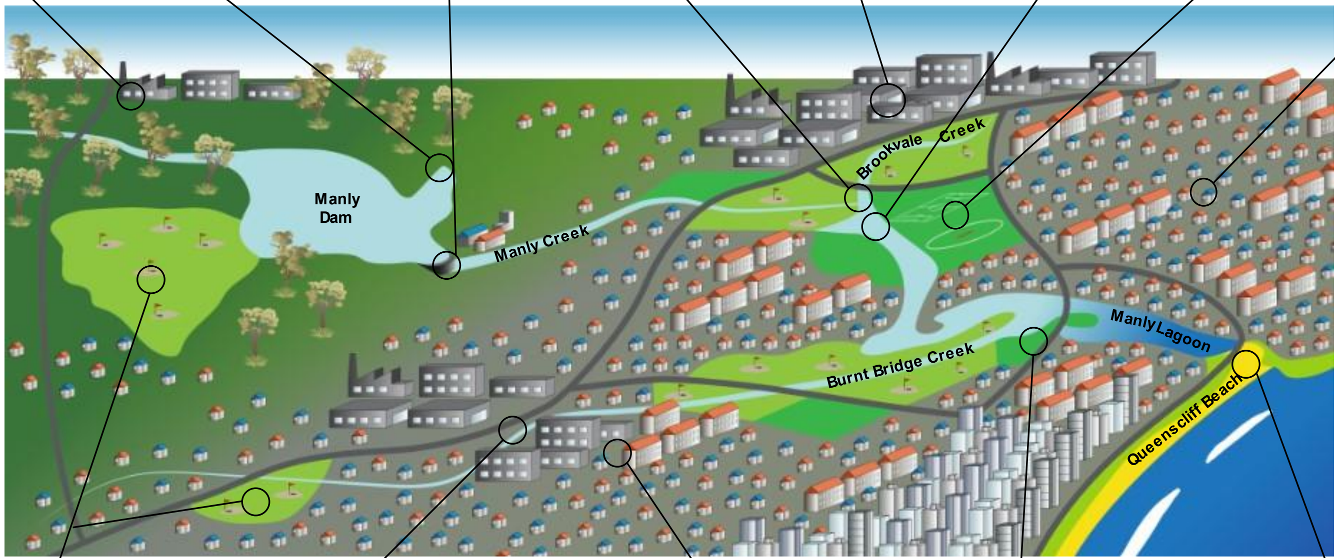


Figure ES.2: Key conceptual features influencing the Manly Lagoon catchment processes

Contents

List of tables

List of figures

1 Study overview

1.1 Study overview

Manly Lagoon is located on the Northern Beaches of Sydney (Figure 1.1). The lagoon itself has an area of approximately 10 ha, however, it's catchment area is approximately 1,800 ha. The lagoon has three main tributaries:

- Manly Creek
- Brookvale Creek
- Burnt Bridge Creek

Manly Lagoon is permanently connected to the ocean on the northern end of Queenscliff Beach via low-flow pipes. Occasionally, during large rainfall events, elevated water levels in the lagoon increase above the sand berm level at the beach and a channel is scoured through the beach dune creating another connection between the lagoon and the ocean.

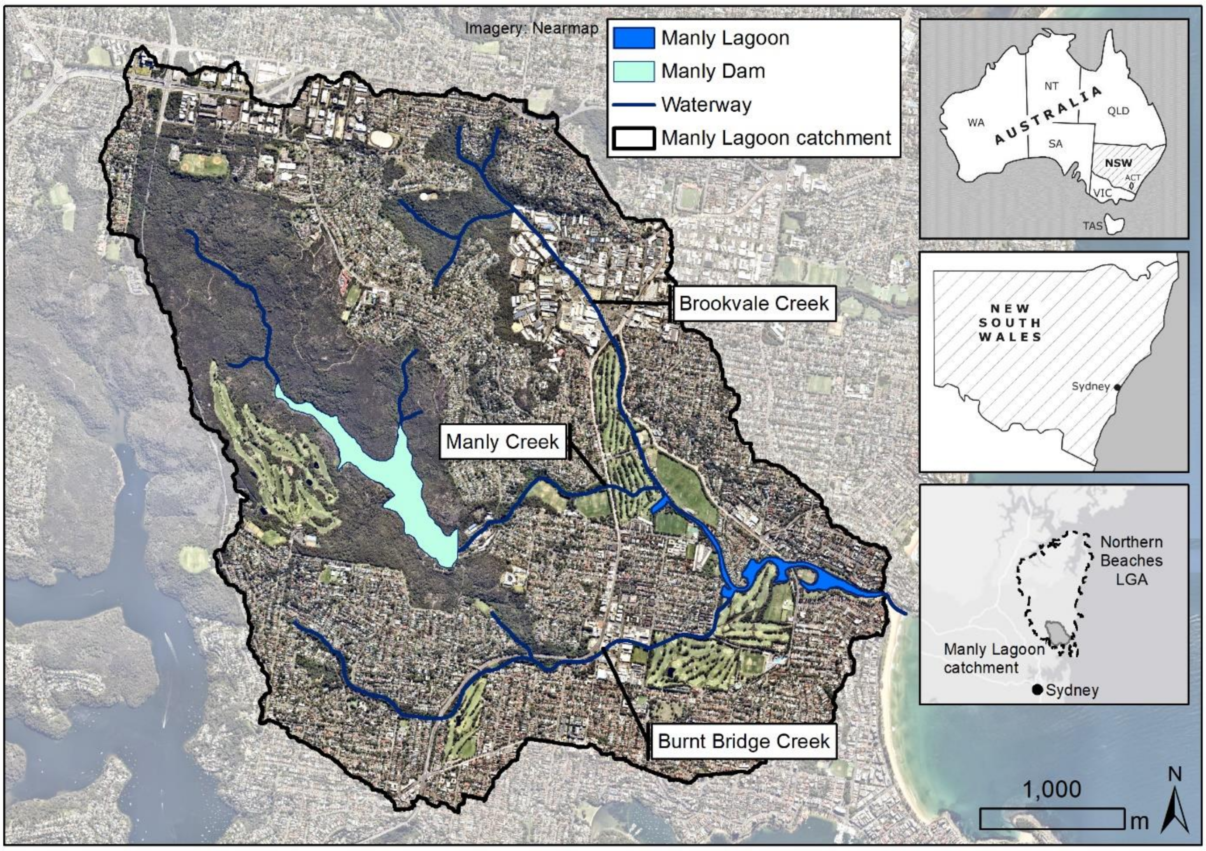


Figure 1.1: Manly Lagoon catchment and local waterways located on Sydney's Northern Beaches, NSW, Australia

Since the early 1900s Manly Lagoon and its catchment have undergone significant changes due to urbanisation. McInnes (1985) provides a description of the lagoon in the 18th Century prior to urbanisation:

“The map [Figure 1.2] indicates the size of the Manly Lagoon at the time of the first settlements, extended well inland. There were marshes or wetlands surrounding Manly Lagoon. The Lagoon was home to schooling fishes, whiting bream and turtles, which would enter the swamp and bred in the lagoon. Governor Phillip also described the swamps as dense and difficult to penetrate. One can only assume the biodiversity in the lagoon was very rich in 1788.”

Today, features of the catchment include significant residential developments, landfills, parkland, golf courses, industrial areas, a significant dam, and modifications to the entrance of the lagoon at the ocean. Due to these changes the lagoon now faces a number of environmental stressors which affect its overall water quality and ecological health (eco-health).

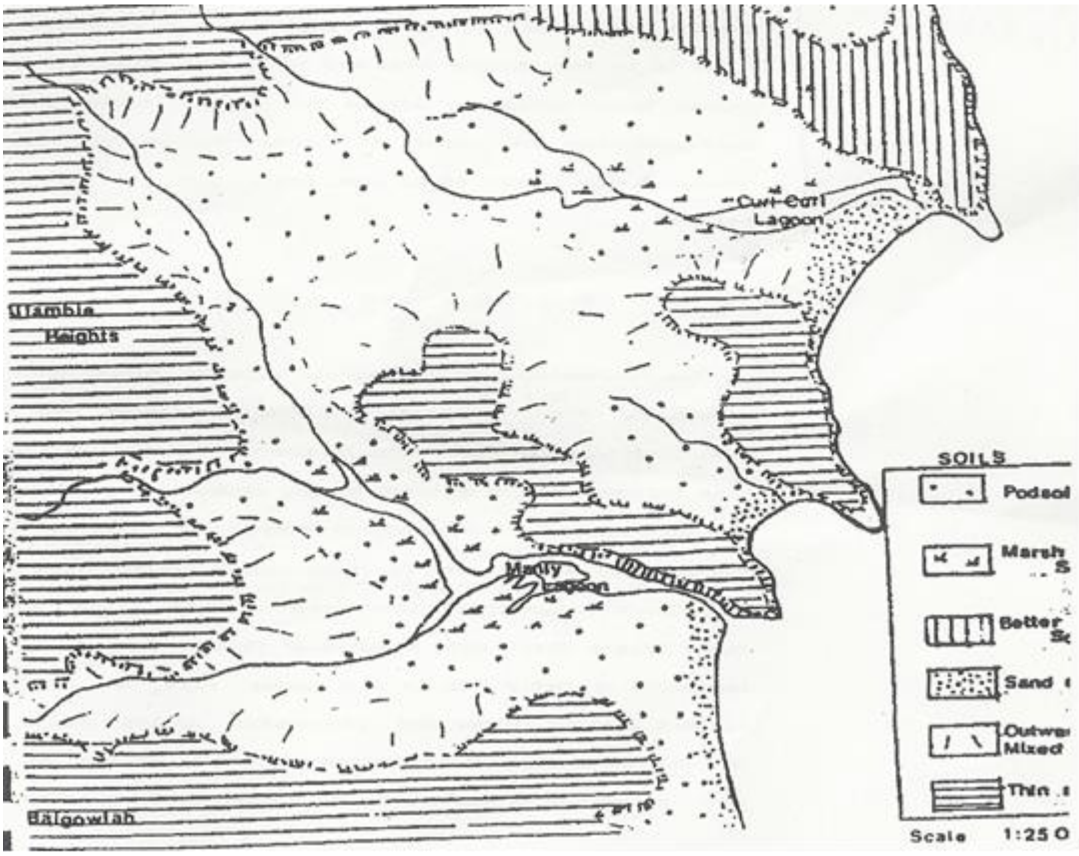


Figure 1.2: An early sketch of Manly Lagoon indicating the extent of saltmarsh (labelled as “Marsh” in the figure legend) around the lagoon around the time it was first settled by Europeans (Source: McInnes, 1985)

This study was completed to review the existing state of Manly Lagoon and provide a first-pass assessment for how the eco-health of the lagoon can be improved. Furthermore, this study has been designed to inform the development of a Coastal Management Program for the lagoon (see Section 1.2). A literature and data review of Manly Lagoon was used to develop a conceptual understanding of the lagoon’s environmental processes and to complete an evaluation of its current eco-health. A pressure and threat assessment was then completed to determine the risks to the values that the lagoon provides. Following this, a review of potential management opportunities is provided as a preliminary step to guide the future improvement of Manly Lagoon’s eco-health. It is anticipated the information found in this report will inform the strategic context for the future long-term management of Manly Lagoon.

1.2 Coastal Management Program

Realising the importance of the coastal environment, the New South Wales (NSW) Government has developed a framework to assist local authorities in NSW to manage the NSW coastline. This framework includes (OEH, 2016):

- The Coastal Management Act 2016
- The State Environmental Planning Policy (Coastal Management) 2018
- Coastal Management Programs

Coastal Management Programs provide "*the long-term strategy for the coordinated management of the coastal zone with a focus on achieving the objectives of the Coastal Management Act 2016*" (OEH, 2016). This is specifically in the context of the coastal zone which includes:

- Coastal wetlands and littoral rainforest area
- Costal vulnerability area (i.e. subject to coastal hazards)
- Coastal environment area (environmental features, e.g. estuaries)
- Coastal use area (lands adjacent to coastal waters)

Northern Beaches Council will be investing resources into the roll out of Coastal Management Programs for the estuaries it manages. This includes Manly Lagoon which is an estuary.

Development of Coastal Management Programs is a five stage process that allows for the continued adaptive management of the coastline (Figure 1.3). Manly Lagoon is in Stage 1 of this process with the scope of the Coastal Management Program soon to be developed (i.e. the Stage 1 Scoping Study). This report seeks to support the development of the Stage 1 Scoping Study of the Coastal Management Program for Manly Lagoon.

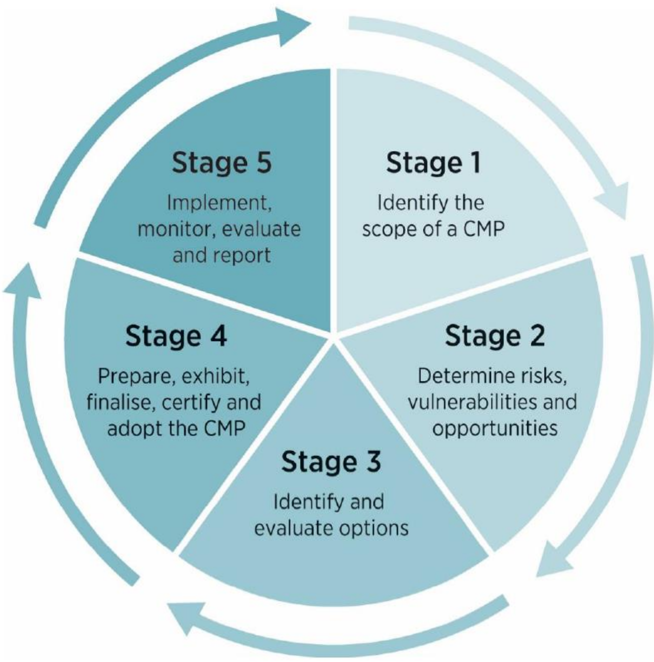


Figure 1.3: Five stage Coastal Management Program development process (OEH, 2016)

This report will assist in the develop of the Stage 1 Scoping Study and determine the adequacy of available information regarding Manly Lagoon and potential management opportunities for the protection of the coastal environment (including the identification of knowledge gaps). Note, while the Coastal Management Program focuses on coastal risks, this report also addresses environmental risks that area not coastal by nature (e.g. flooding caused by catchment events) but will impact the coastal zone. The focus of this report was to address coastal risks to the environment and does not directly consider social or economic risks. This report, along with future community and stakeholder engagement to be completed as part of the Stage 1 Scoping study, will provide strategic context for the coastal management of Manly Lagoon. Note, results of community and stakeholder engagement may impact how the findings of this report are implemented. For example the local community's attitude for risk may govern where focuses for coastal management actions take place.

This report will inform the environmental and technical context for the Stage 1 Scoping Study (and in turn inform the development of the strategic context for Manly Lagoon). Aspects of coastal management such as the monitoring, evaluation and reporting (MER) program have been considered during the development of this report. Specific pressures and threats, such as poor water quality, have been considered to inform the management of the Manly Lagoon coastal zone. Potential management opportunities have been considered with the objective of maintaining, protecting and enhancing the Manly Lagoon coastal environment.

1.3 Similar investigations

There are a number of previously completed investigations have collated and reviewed the existing information for Manly Lagoon. These studies have been reviewed in Appendix A where available. Noteworthy studies include:

- 1995 - Manly Lagoon Estuary Management Study (PBP, 1995)
- 2004 – Manly Lagoon Catchment Integrated Catchment Management Strategy (ICMS) and evaluation (UWS, 2004)
- 2017 – Manly Creek Catchment: A critical review of past investigations and a plan for future research into water quality in urban catchments (Dykman, 2017)

1.4 About this report

Following this introduction (Section 1), this report has the following sections:

- **Section 2: Conceptual understanding** – A summary of Manly Lagoon's conceptual processes
- **Section 3: Benchmarking Manly Lagoon's eco-health** – Assessment of the water quality within Manly Lagoon compared against relevant guideline values and other estuaries in NSW
- **Section 4: Values, pressures and threats** – Identification of the values provided by Manly Lagoon and the pressures and threats that they face. This section includes a risk assessment for each of the pressures/threats
- **Section 5: Potential management opportunities** – Identification of potential opportunities to improve Manly Lagoon's eco-health and a qualitative assessment of their effectiveness
- **Section 6: Conclusion** – providing a summary of this study
- **Section 7: References**
- **Appendix A: Review of literature and data** – A data and literature review of available information on the processes that occur within Manly Lagoon.

2 Conceptual understanding

2.1 Conceptual model of Manly Lagoon

This section provides a conceptual model for the hydrological and water quality processes that occur across the Manly Lagoon catchment. Details of this model have been developed from the literature and data review provided in Appendix A. Figure 2.2 identifies key conceptual features of the Manly Lagoon catchment. The following section provides further detail on specific catchment processes shown in Figure 2.2, including:

- Catchment and hydrology
- Water quality
- Sediment
- Entrance conditions
- Groundwater

2.2 Catchment and hydrology

Manly Lagoon has three key tributaries:

- Manly Creek
- Brookvale Creel
- Burnt Bridge Creek

Manly Creek flows from the upper catchment, past Manly Dam and through Warringah Golf Course into the north west of Manly Lagoon. Occasionally the section of Manly Creek upstream of Manly Dam is referred to as “Curl Curl Creek”. Manly Dam is a former water supply dam that is now used for its recreational amenity and water supply for two hydraulic research laboratories (Manly Hydraulics Laboratory and WRL). Release of water from Manly Dam to Manly Lagoon is dependent upon the operational rules in place for the dam (see Section 4.3.8). Upstream of Manly Dam, the catchment is primarily natural bushland. Runoff from Wakehurst Golf Course and some urban areas (including Northern Beaches Hospital) also flow into Manly Dam. Downstream of the dam, Manly Creek flows through residential areas before it passes through Warringah Golf Course to Manly Lagoon.

Brookvale Creek is located to the north of the Manly Lagoon catchment. Its upstream extent includes bush land at Allenby Park. The creek then flows through the Brookvale industrial area, under Waringah Mall and along Warringah Golf Course before meeting Manly Creek on the northwest of Manly Lagoon.

Burnt Bridge Creek flows from the southwest to northeast before connecting to Manly Lagoon just upstream of Pittwater Road. Its catchment includes Balgowlah Golf Course, the Manly Vale industrial area and the Manly Golf Course.

The Manly Lagoon catchment is highly urbanised with the exception of some bushland areas (e.g. upstream of Manly Dam). McManus and Knights (2011) identified that 55% of the catchment is impervious and that pervious forested and open water areas account for 26% of the catchment area (public open space and other smaller areas make up the remainder of pervious space). This affects the catchment hydrology behaviour as impervious developed surfaces (e.g. roads or rooftops) are more likely to lead to quicker runoff times compared to the natural parts of the catchment and subsequently contribute higher loads of pollution (i.e. sediment and nutrients). Figure 2.1 shows that despite making up approximately 55% of the catchment, areas characterised as having a high impervious percentage contribute the most (~93%) to sediment loading.

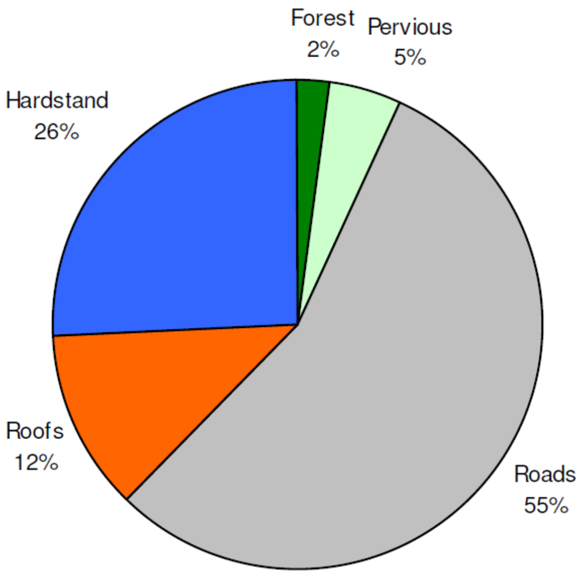


Figure 2.1: Total sediment loads for different land use types (McManus and Knights, 2011)

2.3 Water quality

Manly Lagoon faces a number of pressures that can result in poor water quality across the catchment. The highly urbanised system means stormwater runoff can easily carry pollutants into the lagoon. Sewage overflows, which can occur during intense rainfall events such as east coast lows where a high volume of rainfall falls over a short duration, also result in pollution to the catchment in the form of high nutrient levels. Between 2020 and 2021 Sydney Water (2021) identified that enterococci levels within Manly Lagoon were above safe levels for secondary contact recreation - a potential indicator of sewage overflows within the system. Other potential nutrient sources for the catchment include general stormwater runoff, fertilisers from golf courses or parks, the groundwater or lagoon sediments. The lagoon is permanently connected to the ocean allowing regular flushing of the lagoon. However, this has limited impact due to poor water quality, which is often associated with catchment derived runoff events. There is also potential for leachate from former land fill sites (such as at Condover Street Reserve and Addiscombe Road) to impact the water quality within Manly Lagoon. Water quality monitoring records have shown the following ongoing trends:

- High levels of nutrients exceeding environmental guideline levels have continuously been measured in the catchments with multiple sources speculated including: stormwater, sewage overflows (which occur during large rainfall events) and fertilisers
- Heavy metals have been measured in the catchment above guideline levels (including lead, copper, iron and zinc)
- Water quality within Manly Lagoon has consistently been rated as poor based on a range of water quality measurements

2.4 Sediment

Analysis of the sediments in Manly Lagoon have found that there are high levels of nitrogen, phosphorus and carbon (PBP, 1995). High levels of carbon in the lagoon sediments can be associated with the breakdown of organic matter. Filippini et al. (In Prep.) found that in Manly Lagoon, the breakdown of carbon in anaerobic (i.e. zero oxygen) conditions resulted in the release of nutrients. Eyre and Ferguson (2002) had similar findings and identified that the carbon breakdown process can be a major source of nutrient loading in lagoons which can lead to eutrophication. The source of carbon in Manly Lagoon sediments were found to be leaf litter from local eucalyptus and exotic vegetation such as the European flame trees seen throughout Nolan Reserve (Filippini et al., In Prep.).

2.5 Entrance conditions

Though naturally classified as an ICOLL (intermittently closed and open lakes and lagoon), community concerns in the early 1920s triggered a civil engineering solution that has permanently connected Manly Lagoon to the ocean through two low-flow pipes with an invert of -0.71 m AHD (these were since upgraded in 1999). The lagoon is also naturally connected to the ocean via a rock weir with a crest elevation at 0.2 m AHD. Sand often accumulates within this natural connection limiting connectivity between the lagoon and ocean to the low-flow pipes for all but the highest tides.

Within the natural connection, Northern Beaches Council maintains the “Scour Channel” as per their Lagoon Operational Management System (internal document) along the beach that can be broken out in the event of a flood (Lyons and Eggleton, 2013; Harrison and Rayner, 2019). The protocol for opening of the lagoon is now determined using the Manly “LagoonWatch” system (Lyons and Eggleton, 2013). This system incorporates data gathered from lagoon water levels with rainfall and flood predictions to determine the optimal time to open the lagoon. This generally occurs when the water levels in the lagoon are between 1.0 and 1.4 m AHD and there is a difference between the lagoon and ocean water levels greater than 0.6 m (Lyons and Eggleton, 2013).

The accretion of sediment at the lagoon entrance has been investigated on a number of occasions to determine how it affects tidal flushing of the lagoon, and in turn, water quality (PBP, 1995; Wiecek et al., 2006; Wiecek and Floyd, 2007; WRL, 2016; Harrison and Rayner, 2019). Wiecek et al. (2006) and Wiecek and Floyd (2007) found that the sedimentation at the lagoon entrance has limited impact on the operation of the low-flow pipes. A review completed by WRL (2016) identified that rainfall events have a significant impact within the lagoon reducing water quality. Their review also found that while the overall day-to-day water quality was still poor, data suggested the low-flow pipes have an effect to reduce the variability of water quality (WRL, 2016). Harrison and Rayner (2019) found that if the entrance to the lagoon was further modified it would change the current tidal regime within the lagoon.

2.6 Groundwater

Radon sampling measurements and water level observations across Manly Lagoon clearly showed that there is an interaction between groundwater and surface water. This interaction was found to be tidal with measurements of higher radon levels in the groundwater corresponding to lower tides suggesting that groundwater is flowing into the lagoon. Water level observations also suggested that there can be an exchange from the lagoon surface water into the groundwater in the immediate vicinity of the lagoon, particularly during drier times. Furthermore, water levels indicated that there is likely a regional groundwater flow path to the southeast of the lagoon where water passes through sand layers to the ocean bypassing the lagoon entrance. Radon measurements observed at Manly Dam have also confirmed that regional groundwater is an inflow source (Sadat-Noori et al., 2021b).

Since 2018, monitoring of groundwater data has occurred for both wet and dry periods around Manly Lagoon (WRL, 2023). The focus of this monitoring has been to identify nutrients within the groundwater and its influence on surface water. Key observations from this data include:

- Generally, the nutrient concentrations measured within the groundwater are higher than those measured in the surface water indicating that groundwater is a net source of nutrients for the lagoon
- Following wet weather events there appears to be an increase in nutrient concentrations measured in both surface and ground waters, however, the relative contribution between groundwater or surface water is unknown
- There appears to be other sources of nutrients within Manly Lagoon, particularly in the lagoon sediments (levels of total nitrogen and phosphorus in surface water bottom samples could be an order of magnitude larger than top samples)
- All nutrient samples have a high variability which means the level of influence of groundwater on the surface water quality remains uncertain

In addition to lagoon-wide groundwater monitoring of nutrients, extensive contaminant monitoring has also been completed for a landfill site located at Addiscombe Road. Results of this monitoring have indicated the following contaminants are present in the groundwater of the former landfill:

- Polycyclic aromatic hydrocarbons (PAHs)
- Zinc
- Arsenic
- Ammonia

2.7 Key catchment features

Figure 2.2 identifies key conceptual features of the Manly Lagoon catchment which influence the specific catchment processes outlined in this section, including:

- Catchment and hydrology
- Water quality
- Sediment
- Entrance conditions
- Groundwater

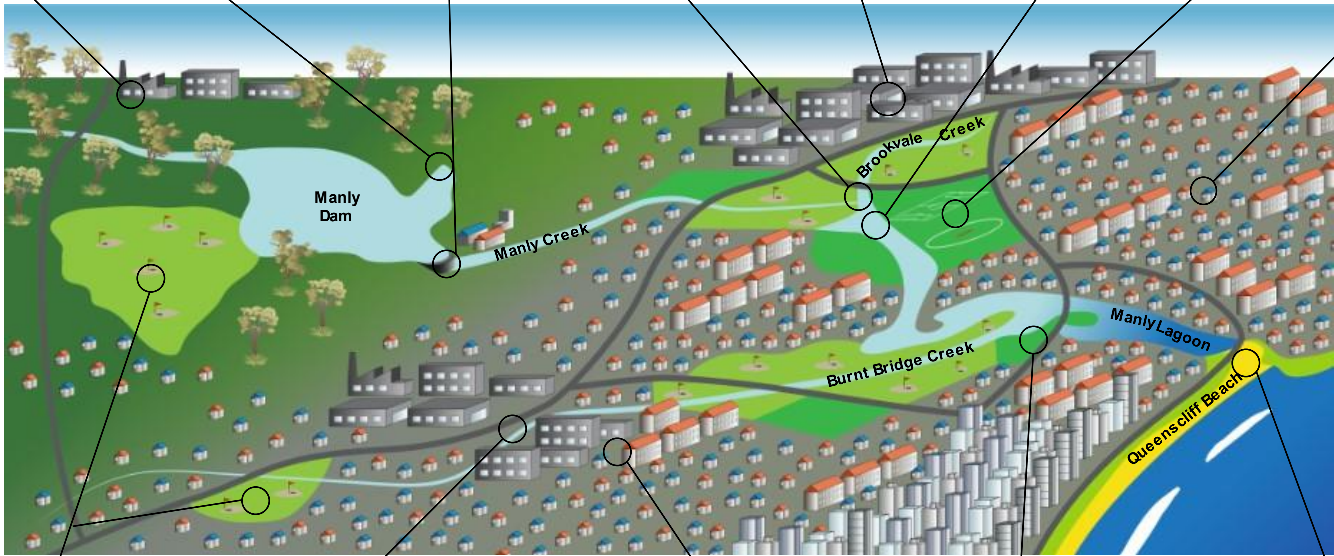


Figure 2.2: Key conceptual features of the Manly Lagoon catchment

3 Benchmarking Manly Lagoon's eco-health

3.1 Preamble

Extensive long-term water quality monitoring of Manly Lagoon has occurred for a range of water quality parameters (see Appendix A). This data can be analysed to determine the ecological health (eco-health) of Manly Lagoon. The following sections assess the eco-health of Manly Lagoon based on:

- Available guideline values
- Comparison to other local estuaries
- Comparison to estuaries within NSW

3.2 Eco-health of Manly Lagoon

To assess the eco-health of Manly Lagoon on its own, monitoring data needs to be compared to a guideline value, which is generally identified based upon what levels would be toxic for local ecology. Note, ANZG (2018) recommend developing default guideline values based upon reference site data, laboratory toxicology effects data and field toxicology effects data using a multiple lines of evidence approach. Default guideline values have been developed for Manly Lagoon within the NSW Water Quality Objectives (DEC, 2006), however, these are based upon the ANZECC and ARMCANZ (2000) guidelines and not using the method recommended by ANZG (2018). Furthermore, these were developed in 2006 with a ten year outlook so are now significantly outdated. Subsequently, without suitable default guidelines available the assessment of the eco-health of the lagoon presented here is based upon available water quality guideline values relevant for Manly Lagoon, including:

- ANZECC and ARMCANZ (2000) – Australian and New Zealand guidelines for fresh and marine water quality: default trigger values for physical and chemical stressors for slightly disturbed aquatic ecosystems south-east Australia
- ANZECC and ARMCANZ (2000) – Australian and New Zealand guidelines for fresh and marine water quality: trigger values for toxicants at alternative levels of protection

Comparison of measured water quality data to the ANZECC and ARMCANZ (2000) aquatic ecosystem guideline levels is shown in Table 3.1. This table shows that the median (50th percentile) levels of water quality data measured in Manly Lagoon for total phosphorus, total nitrogen, dissolved oxygen and chlorophyll-a are all outside of guideline values. This indicates that these parameters are more often than not outside of the guideline values and causing harm to the eco-health of Manly Lagoon. Total nitrogen is rarely within guideline values (<0.3% of the time). It is likely that high nutrient concentrations, associated with high phosphorus and nitrogen levels, are resulting in the excessive growth of vegetation within Manly Lagoon. This would explain why chlorophyll-a parameter is also regularly outside of the guideline values. Decaying vegetation, which increases chlorophyll-a, consumes oxygen causing lowering of dissolved oxygen levels. Problems that excessive vegetation growth can have on the eco-health of Manly Lagoon include (ANZECC and ARMCANZ, 2000):

- Toxicity due to cyanobacteria
- Reduced dissolved oxygen levels caused by plants dying and decomposed
- Algal blooms
- Reduced recreational value

- Blockages of the key sections within the lagoon and its tributaries
- Altered biodiversity

Problems caused by lack of dissolved oxygen include (ANZECC and ARMCANZ, 2000):

- Adverse impacts on aquatic life that require dissolved oxygen to live
- Creation of chemical conditions in sediments (i.e. reduction) that releases stored nutrients back into the water column

Table 3.1:Comparison of measured water quality data in Manly Lagoon from 2007 to 2020 against ANZECC and ARMCANZ (2000) guideline values for aquatic ecosystems

Parameter	Median values of data measured in Manly Lagoon	Acceptable guideline values	Percent of time parameter is within guideline values
Ammonia (µg/L)	10.9	Less than 15	59%
NOx (µg/L)	8.5	Less than 15	63%
Total phosphorus (µg/L)	52.7*	Less than 30	12%
Total Nitrogen (µg/L)	657.2*	Less than 300	0.3%
Dissolved oxygen (mg/L)	5.1*	Between 6 and 9	24%
pH	7.8	Between 7 and 8.5	84%
Turbidity (NTU)	3.1	Between 0.5 and 10	68%
Chlorophyll-a (µg/L)	12.3*	Less than 4	6%

*Indicates median (50th percentile) value is outside of recommended guideline values

Analysis of the yearly median values for total nitrogen, total phosphorus, chlorophyll-a and dissolved oxygen are shown in Figure 3.1. These results indicate:

- Total nitrogen levels have continued to increase over the 15 year sample period
- Total phosphorus levels peaked from 2013 to 2015 and have returned to similar levels measured from 2007 to 2011
- There has been a clear decline in the chlorophyll-a concentration since the beginning of sampling
- Dissolved oxygen levels fell below guideline values in 2017 and have yet to fully recover back to levels that are safe for aquatic life

Improvements to the eco-health of Manly Lagoon can be seen by the downward trends of total phosphorus and chlorophyll-a. Recovery of dissolved oxygen levels in recent years also indicates improving eco-health. Total nitrogen levels remain high, however, and their year-on-year median concentration is increasing. This highlights that while there have been some improvements to the eco-health of Manly Lagoon, there are still persisting water quality problems that needs to be addressed. Improvements to the lagoons eco-health have been recorded, however, the overall eco-health of Manly Lagoon is still in a poor state and ongoing adaptive management is required.

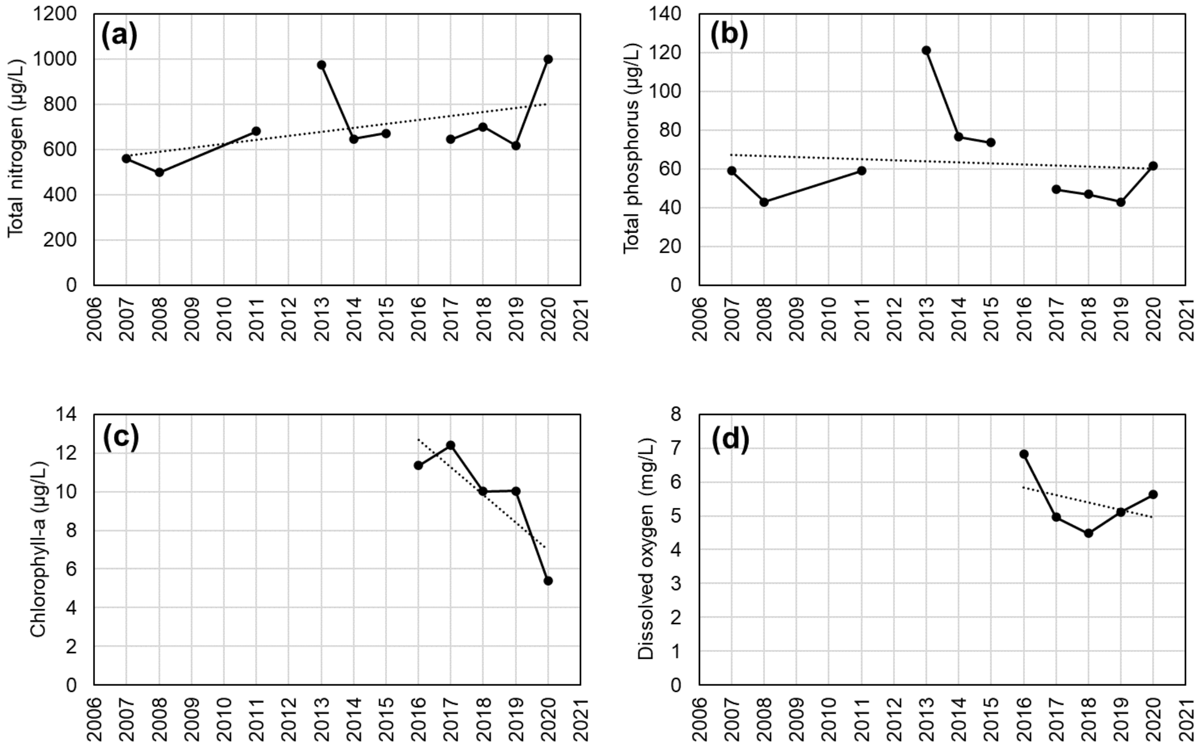


Figure 3.1: Annual median sample values for (a) total nitrogen, (b) total phosphorus, (c) chlorophyll-a and (d) dissolved oxygen (dashed line is the linear trend)

ANZG (2018) outlines level of protection classifications which are defined as the "*degree of protection afforded to a water body based on its ecosystem condition (current or desired health status of an ecosystem relative to the degree of human disturbance)"*. Based on these classifications, the current condition of Manly Lagoon could be described as a "highly disturbed system" owing to its degraded ecological value caused by the urbanisation of the surrounding floodplain. Note, the level of protection desired for Manly Lagoon is likely to be different due to factors such as community values (UWS (2004) identified that the local community desired for lower sections of Manly Lagoon to be acceptable for primary recreation). Since, the ANZECC and ARMCANZ (2000) guideline values for aquatic ecosystems south-east Australia are specified for slightly disturbed ecosystems they may misrepresent achievable water quality goals for Manly Lagoon (which is classified a "highly" disturbed ecosystem). The ANZECC and ARMCANZ (2000) guideline values may never be achievable for Manly Lagoon and subsequently, a new set of achievable guideline values for Manly Lagoon should be set taking into consideration its highly disturbed nature. Based upon a highly disturbed ecosystem level of protection, default guideline values could be determined from the data collected across Manly Lagoon using the 90th percentile values. ANZECC and ARMCANZ (2000) note default guideline values derived in this manner can be used as targets to facilitate remediation and once met, new default guideline values developed using an adaptive management strategy. Ideally default values would also be based upon toxicology effects data and a multiple line of evidence approach as per ANZG (2018). Note, the 90th percentile values for key parameters have been compared to the current ANZECC and ARMCANZ (2000) guideline values for slightly disturbed aquatic ecosystems south-east Australia in Table 3.2.

Roper et al., (2011) developed default guideline for turbidity and chlorophyll-a using the 80th percentile values for data collected for reference estuaries within NSW. Comparison of water quality measurements sampled within Manly Lagoon to these trigger values gives the lagoon an overall grade of poor to fair (Figure 2.2). Further details regarding this grading can be found in Appendix A.

Table 3.2: Comparison of indicative 90th percentile default guideline values to existing ANZECC and ARMCANZ (2000) guideline values

Parameter	ANZECC and ARMCANZ (2000) guideline value	Indicative 90th percentile default guideline value			
		Summer	Autumn	Winter	Spring
Ammonia (µg/L)	15	51.2	70.6	93.5	44.2
NOx (µg/L)	15	169.4	91.7	206.4	119.6
Total phosphorus (µg/L)	30	95.2	33.9	95.4	87.8
Total Nitrogen (µg/L)	300	668.8	379.8	961.2	527.8
Dissolved oxygen (mg/L)	6 to 9	2.8 to 6.8	2.7 to 6.9*	2.2 to 6.7	3.0 to 7.2
pH	7 to 8.5	7.5 to 9.4	7.3 o 9.6*	7.1 to 12.2	7.4 to 8.1
Turbidity (NTU)	0.5 to 10	0 to 11.4	0.3 to 2.5	0 to 11.7	0 to 7.9
Chlorophyll-a (µg/L)	4	23.2	26.1	15.8	16.4

*Insufficient data to calculate seasonal value so yearly values used

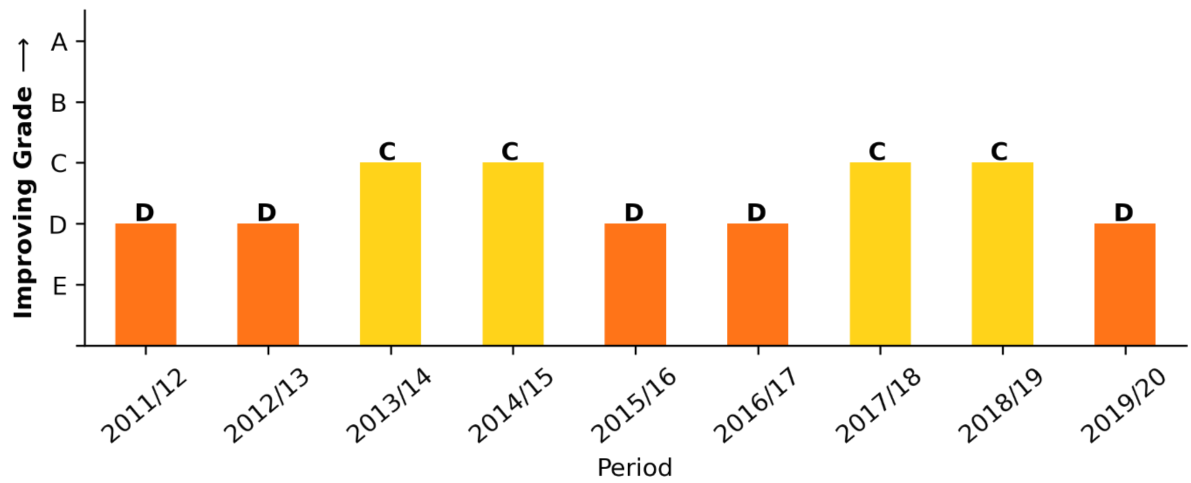


Figure 3.2: Grading of Manly Lagoon using trigger values developed by Roper et al. (2011) for NSW Estuaries (see Appendix A for further details)

3.3 Manly Lagoon's eco-health compared to other estuaries

3.3.1 MER program

The NSW government monitoring, evaluation and reporting (MER) program has measured key water quality indicators for estuaries along the NSW coastline. This enables for the comparison of estuaries to determine how they compare in terms of eco-health. Using data collected during the MER program the following section outlines how Many Lagoon compares to other local estuaries on the Northern Beaches and other NSW estuaries.

3.3.2 Comparison of Manly Lagoon to Northern Beaches estuaries

There are three other estuaries on the Northern Beaches similar to Manly Lagoon, including:

- Curl Curl Lagoon
- Dee Why Lagoon
- Narrabeen Lagoon

Each of these lagoons has been compared with Manly Lagoon in terms of eco-health using chlorophyll-a and turbidity data. The lagoons have then been ranked based upon which has the best or worst eco-health. Figure 3.3 shows that Dee Why and Narrabeen Lagoons are continually the healthiest on the Northern Beaches. Curl Curl Lagoon generally had the worst health of all the lagoons, however, Manly Lagoon has also been identified as having the worst health for a number of monitoring periods.

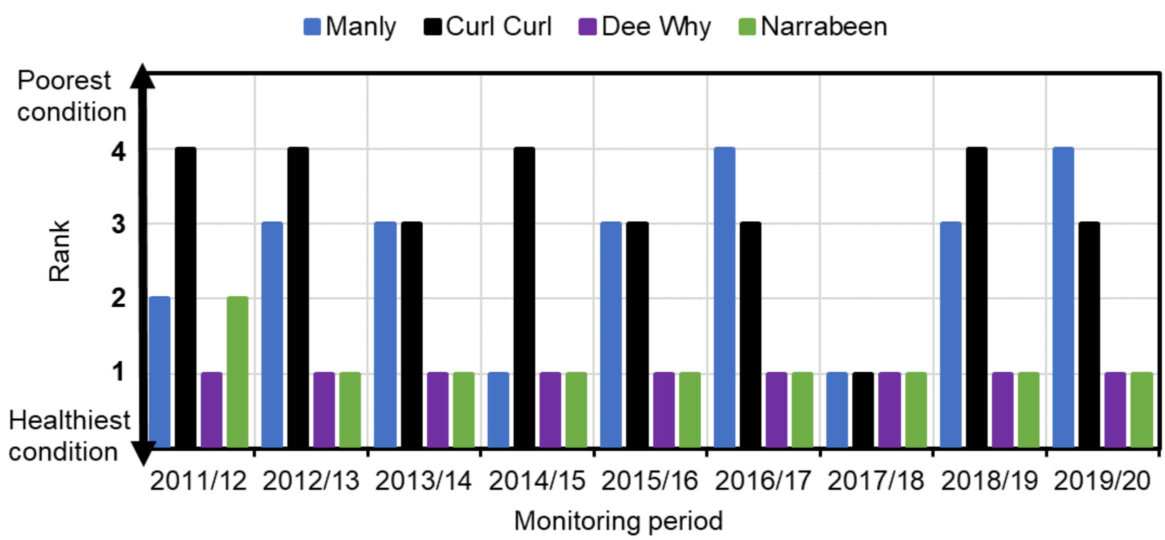


Figure 3.3: Ranking of eco-health for Northern Beaches estuaries

3.3.3 Comparison of Manly Lagoon to NSW estuaries

Data collected during the MER program was available for 170 estuaries along the NSW coastline, including Manly Lagoon. Table 3.3 shows how Manly Lagoon ranks compared to these other estuaries. Results show that Manly is within the bottom 25% of estuaries for turbidity, chlorophyll-a, blue green algae, dissolved oxygen, NOx, total dissolved phosphorus, total phosphorus and total nitrogen. Manly Lagoon was only within the top 25% of estuaries for Secchi depth recordings. Out of the 16 parameters recorded during the MER program, Manly Lagoon ranked in the bottom 50% of estuaries for 11 parameters.

Table 3.3: Comparison of Manly Lagoon to other estuaries in NSW

Parameter	Manly rank (medial values) (lower rank equals a healthier estuary#)	Manly median parameter value	Total number of estuaries with data available*	Percentage of estuaries with poorer quality median values
Secchi depth^	114	0.80 m	151	25%
Specific conductivity#	The median value for Manly Lagoon was 36,066 µS/cm. Out of 166 estuaries this is the 80th highest value (~51% of estuaries had a higher specific conductivity). Higher specific conductivity does not necessarily relate to poor water quality but indicates an increased volume of tidal flushing or connectivity with the ocean.			
pH^	The median value for Manly Lagoon was 8.11. ANZECC and ARMCANZ (2000) guidelines recommend that the pH for slightly disturbed estuary ecosystems be between 7.0 and 8.5.			
Turbidity	129	3.74 NTU	170	24%
Chlorophyll-a	132	10.80 mg/L	142	7%
fDOM	55	10.42 RFU	140	61%
Blue green algae	127	18.84 µg/L	138	8%
Dissolve oxygen^	141	5.43 mg/L	159	11%
Ammonia	99	12.11 µg/L	163	39%
Phosphate	115	4.38 µg/L	162	29%
NOx	127	10.60 µg/L	163	22%
Silica	80	469 µg/L	161	50%
Total dissolved phosphorus	129	17.01 µg/L	163	21%
Total dissolved nitrogen	98	360 µg/L	163	40%
Total phosphorus	139	47 µg/L	163	15%
Total nitrogen	123	633 µg/L	163	25%

* Not all estuaries had data available for each parameter

For specific conductivity higher levels do not necessarily relate to poor water quality and can indicate increased tidal flushing volumes

^ Assessment ranked values from high to low. Note for pH, levels outside of the range from 7.0 to 8.5 indicates poor water quality

4 Values, pressures and threats

4.1 Preamble

Management of Manly Lagoon needs to consider the values that the lagoon provides and the pressures/threats which have potential to reduce the value of the lagoon. Social, cultural and economic values arise from the improved ecological health (eco-health) of the lagoon. Pressures and threats that the lagoon face have the ability to reduce the eco-health and value of the lagoon. This section provides an overview of the values provided by Manly Lagoon and the risk that pressures/threats to the eco-health of the lagoon pose to these values. Throughout this review, where relevant, the risk based framework for considering waterway health outcomes (developed for NSW, see Dela-Cruz et al., 2017) and the threat and risk assessment for NSW estuaries (Fletcher and Fisk, 2017) have been considered.

4.2 Manly Lagoon's values

4.2.1 Identification of values

Manly Lagoon provides a number of social, cultural and economic values to the local community owing to its estuarine environment. These values can also be referred to as ecosystem services (provisioning, regulating and maintaining, and cultural) or the co-benefits of nature. Aspects of the estuarine environment at Manly Lagoon which provide value to the community have been identified following review of the available literature and data (Appendix A). These include:

- Aquatic habitat
    - Coastal Management SEPP coastal wetlands
    - Mangrove and seagrass habitat
    - Key fish habitat
- Aquiculture and aquatic foods (e.g. recreational fishing)
- Secondary contact recreational (e.g. canoeing or kayaking)
- Primary contact recreational (e.g. swimming)
- Visual amenity (e.g. walking, cycling, bird watching, picnicking)

Note, some of these values are currently not provided by Manly Lagoon and are aspirational in nature. For example the current water quality within Manly Lagoon is unsafe for primary recreation and improvements in water quality are required before the social, cultural and economic value of this activity are realised. In this aspect they can be considered potential values pending the improvement of the eco-health of Manly Lagoon. The Local Strategic Planning Statement (LSPS) for Northern Beaches Council has highlighted some of these aspirations for Manly Lagoon, including targets for 2040 (NBC, 2020) (Figure 4.1):

- Protection of aquatic ecosystems
- Secondary contact recreation

Micromex (2011) surveyed the local community and general users of Manly Lagoon and the results of this survey provide some insights into the values attributed to the lagoon. For example, the survey found that the highest occurring activities at the lagoon are exercising and beach going. In fact, the survey found that "*there is no evidence to suggest that making the Lagoon safe for swimming is a community* *priority*." Note, this survey is now over ten years old and may not reflect changing community values in a similar way to the more recent LSPS.

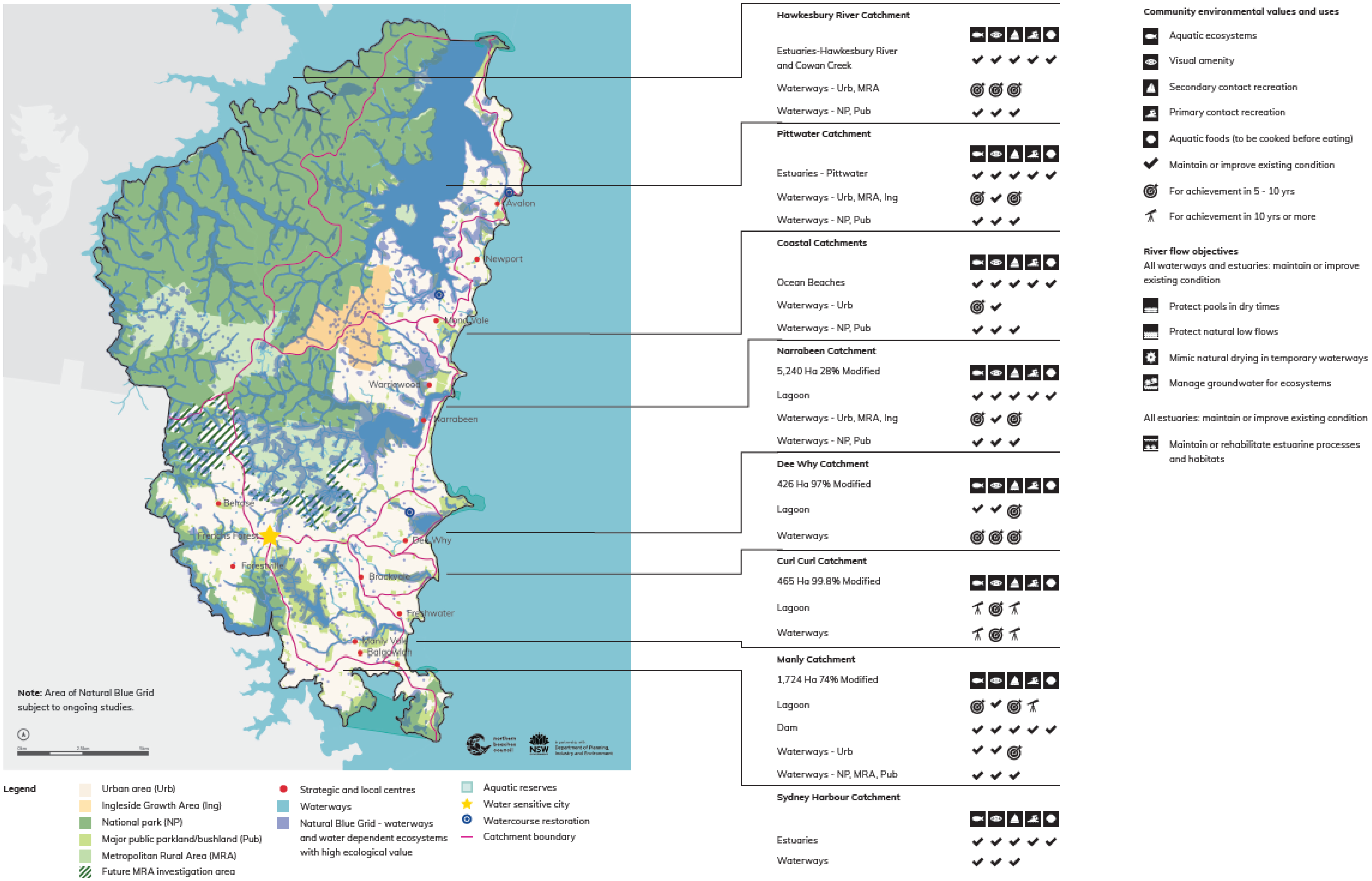


Figure 4.1: 2040 community environmental values for the Northern Beaches including Manly Lagoon (Source: NBC, 2020)

4.2.2 Aquatic habitat

Manly Lagoon provides social, cultural and economic values because of the habitat within the aquatic estuary. Mapping of aquatic habitat has been completed for:

- Coastal Management SEPP coastal wetlands (Figure 4.2)
- Mangrove and seagrass habitat (Figure 4.2)
- Key fish habitat (Figure 4.3)

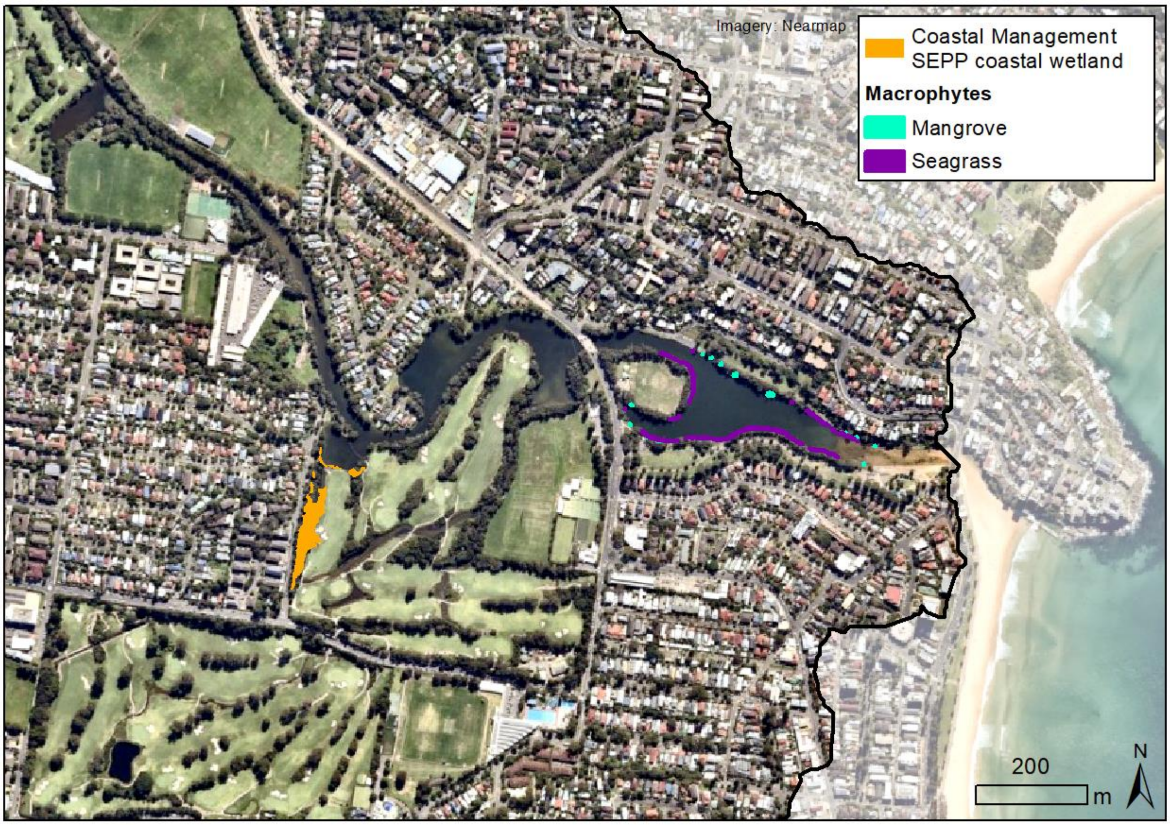


Figure 4.2: Coastal Management SEPP coastal wetlands and estuarine macrophytes (DECCW, 2016; DPIE, 2018)

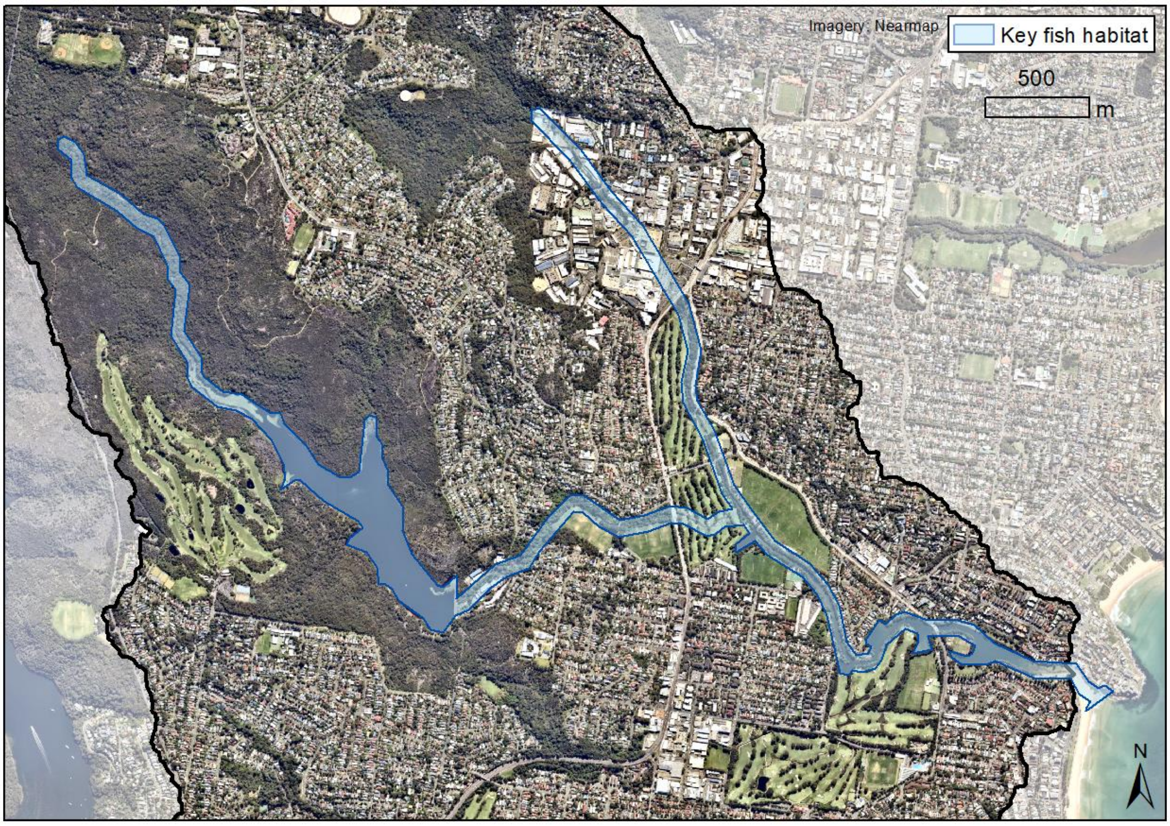


Figure 4.3: Key fish habitat (DPI, 2020)

Values associated with these include a range of ecosystem services such as carbon storage, erosion protection, flood mitigation and biodiversity. Aquatic habitat is directly affected by the eco-health of Manly Lagoon with a healthier estuary providing higher value to the community.

4.2.3 Recreational fishing

Community engagement exercises reviewed during the development of the Integrated Catchment Management Strategy (ICMS), identified that recreational fishing occurs throughout Manly Lagoon (UWS, 2004). Owing to the current poor water quality within the lagoon this is catch and release only. The value of recreational fishing to the community is directly dependent upon the eco-health of the lagoon. This is because a healthy lagoon will affect the health and stock levels of fish that can be caught for recreation. Improvements in water quality of the lagoon would also allow for cooked aquatic foods from Manly Lagoon and provide further value to the community.

While poor water quality in the lagoon currently prevents the consumption of fish caught for recreation, surveys completed by Pygas (2011b) found that the lagoon supported a diverse and abundant fish community. According to their findings, the number of fish species in Manly Lagoon is comparable to that in Narrabeen Lagoon (the lagoon with the best water quality on the Northern Beaches). This shows that there are reproductively viable fish within the lagoon and that there is ongoing active recruitment.

4.2.4 Primary and secondary recreational contact

Community engagement exercises reviewed during the development of the ICMS, identified a desire to allow primary recreational contact activities such as swimming within Manly Lagoon and secondary recreational contact activities such as canoeing or kayaking within Manly Lagoon and its tributaries

(UWS, 2004). Currently the water quality within the lagoon means that it is unsafe for primary or secondary recreational contact. Subsequently, the values associated with recreational contact are not realised. The ICMS identified that due to the highly urbanised catchment, improvements in water quality would be difficult. When large rainfall events occur, the catchment and stormwater system transport runoff with a low water quality (e.g. high in nutrients or bacteria) efficiently into Manly Lagoon. Manly Lagoon is quickly overwhelmed by the catchment flows which can peak within 1 to 2 hours after rainfall (peak flood conditions occur at a slightly longer duration of 6 to 9 hours) (Lyons and Eggleton, 2013). When the lagoon responds quickly like this it is particularly difficult to manage water quality for primary recreation safely. Despite this, a long-term strategy was developed by ICMS as both the government and local community identified a desire to enable recreational contact within Manly Lagoon.

4.2.5 Visual amenity

ANZECC and ARMCANZ (2000) note that waterways provide aesthetic value associated with the scenic qualities of flora and fauna. Similarly, de Groot et al. (2012) found that there is value in the aesthetic cultural services provided by ecosystems. These visual amenity values can also be found at Manly Lagoon which is surrounded by many facilities (e.g. bike and walking tracks, golf courses, parks) that allow the local community to take full advantage of the visual amenity of the lagoon. By ensuring the eco-health of the lagoon the visual amenity values it provides can be preserved.

4.2.6 Summary of Manly Lagoon values

A summary of the values provided by Manly Lagoon is shown in Figure 4.4.

Manly Dam provides primary recreational contact amenity.

Habitat such as vegetation on the creek bank can assist with erosion protection.

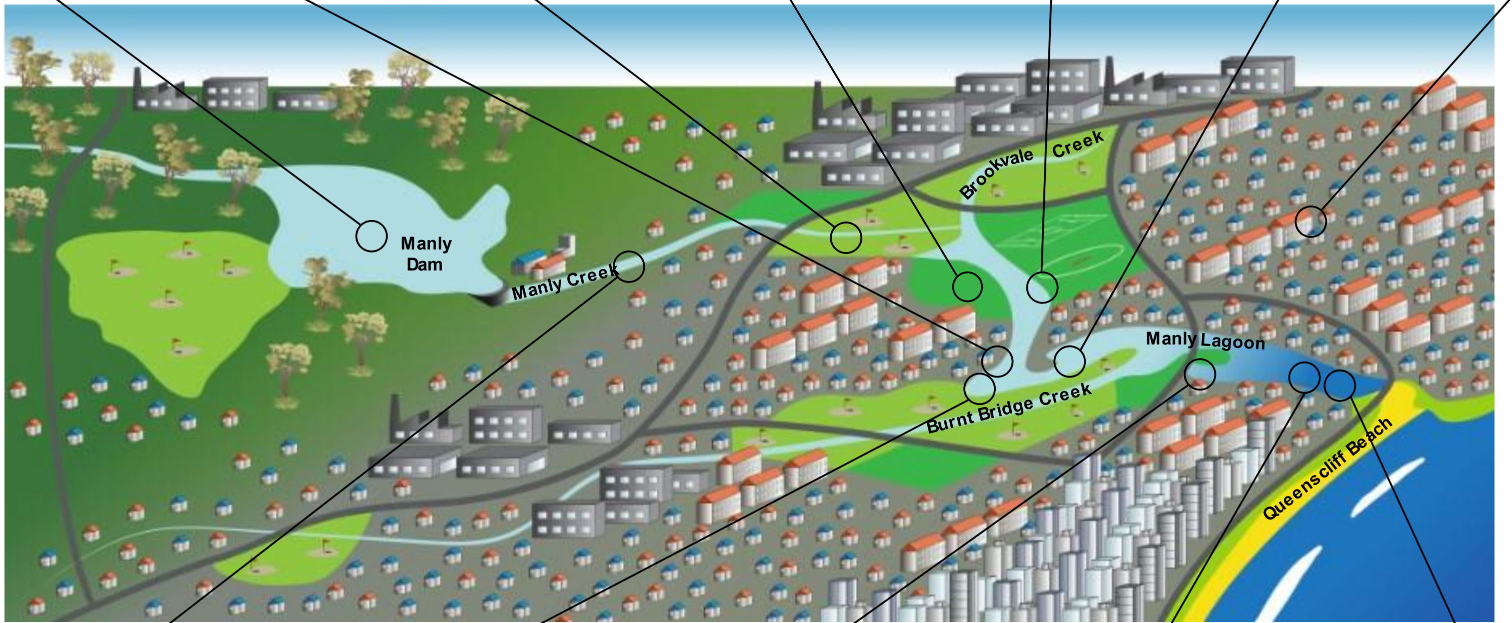
All of Manly Lagoon is ‘key fish habitat’ and ensures the survival and protection of fish

Manly Lagoon provides visual amenity for the community (e.g. bird watching, picnicking).

Currently catch an release recreational fishing occurs within the lagoon.

Improvements in the eco-health of the lagoon would allow for secondary contact recreation (e.g. canoeing).

The lagoon is able to store flood waters providing flood protection to nearby neighbourhoods.



Habitat creation allows for increased biodiversity within the lagoon.

Coastal wetlands are identified as significantly important coastal areas due to the values they provide.

Mangroves are a carbon sink and also provide protection against flooding, protection against bank erosion and valuable fish habitat

Improvements in the eco-health of the lagoon would allow for primary contact recreation (e.g. swimming).

Seagrass provides important fishery habitat and is also able to store large amounts of carbon.

Figure 4.4: Values provided by Manly Lagoon

4.3 Pressures and threats to Manly Lagoon's values

4.3.1 Identification of pressures and threats

Manly Lagoon's eco-health will face numerous pressures and threats into the future which will have potential to reduce the social, cultural and economic values provided to the community. A review of the specific pressures and threats that the eco-health of Manly Lagoon faces has been completed. This has taken into consideration the broader threat and risk assessment (TARA) completed by Fletcher and Fisk (2017) for NSW coastal estuaries and applied its findings to the specific setting of Manly Lagoon. Subsequently, the following pressures and threats to the eco-health of Manly Lagoon have been identified:

- Climate change
    - Tidal inundation
    - Reduced drainage
    - Habitat squeeze
    - Changed catchment flows
- Bank instability/erosion
- Poor water quality (i.e. water pollution)
    - Nutrients
    - Sewage overflow
    - Urban runoff
    - Lack of clear improvement objectives
- Weed/exotic vegetation
- Urban development
- Entrance management
- Catchment inflow management
- Flooding
    - Catchment
    - Tidal inundation
- Data gaps

The following section provides a review of each of these pressures and threats addressing how they specifically relate to the eco-health of Manly Lagoon.

4.3.2 Climate change

Estuaries are facing the impacts of climate change from multiple fronts at the interface between the upper catchment and ocean (Heimhuber et al., 2019). It is within estuaries like Manly Lagoon that the impacts of climate change to the ocean (such as sea level rise) and the impacts of climate change to the catchment (such as intense rainfall events) will meet. Specific ways that climate change will affect Manly Lagoon include:

- Tidal inundation (This occurs as rainfall events more frequently scour out a channel at the entrance and allow the ocean to enter the lagoon more efficiently. This is further exacerbated by storm surge and increased wave energy. During the 2021 and 2022 La Niña event this has been a frequent occurrence.)

- Reduced drainage (The floodplain is already full of tidal water from the ocean and increased low-tide levels prevent drainage through floodgates.)
- Habitat squeeze
- Changed catchment flows

While it is known that sea level rise will occur, the extent of this in the long term becomes less certain. Research is ongoing, and recently the IPCC has provided updated guidance regarding sea level rise (IPCC, 2021). A number of shared socioeconomic pathways (SSPs) have been developed which take into consideration a larger range of factors that may contribute to sea level rise. It is worth noting that predictions for sea level rise will most likely continue to improve into the future. Additionally, as the world moves to mitigate the impacts of climate change these will also be included within climate models and allow for more accurate predictions of sea level rise. IPCC (2021) have noted with high confidence that between 1901 and 2018 there has been an increase in mean sea level of 0.20 m. They also noted that for SSP-8.5, the worst case pathway, there is likely to be between 0.63 and 1.02 m of sea level rise by 2100.

Sea level rise like this will result in tidal inundation and could potentially reduce drainage surrounding Manly Lagoon. Mariani et al. (2012) provided mapping of the potential inundation areas surrounding Manly Lagoon for a 1% annual exceedance probability (AEP) wave and wind setup event for the present day, 2050 and 2100 sea level rise scenarios (Figure 4.5). OEH (2018a) identified that under a 1.5 m sea level rise scenario 2% of houses, 14% of roads and 6% of power line infrastructure surrounding Manly Lagoon will become affected by inundation.

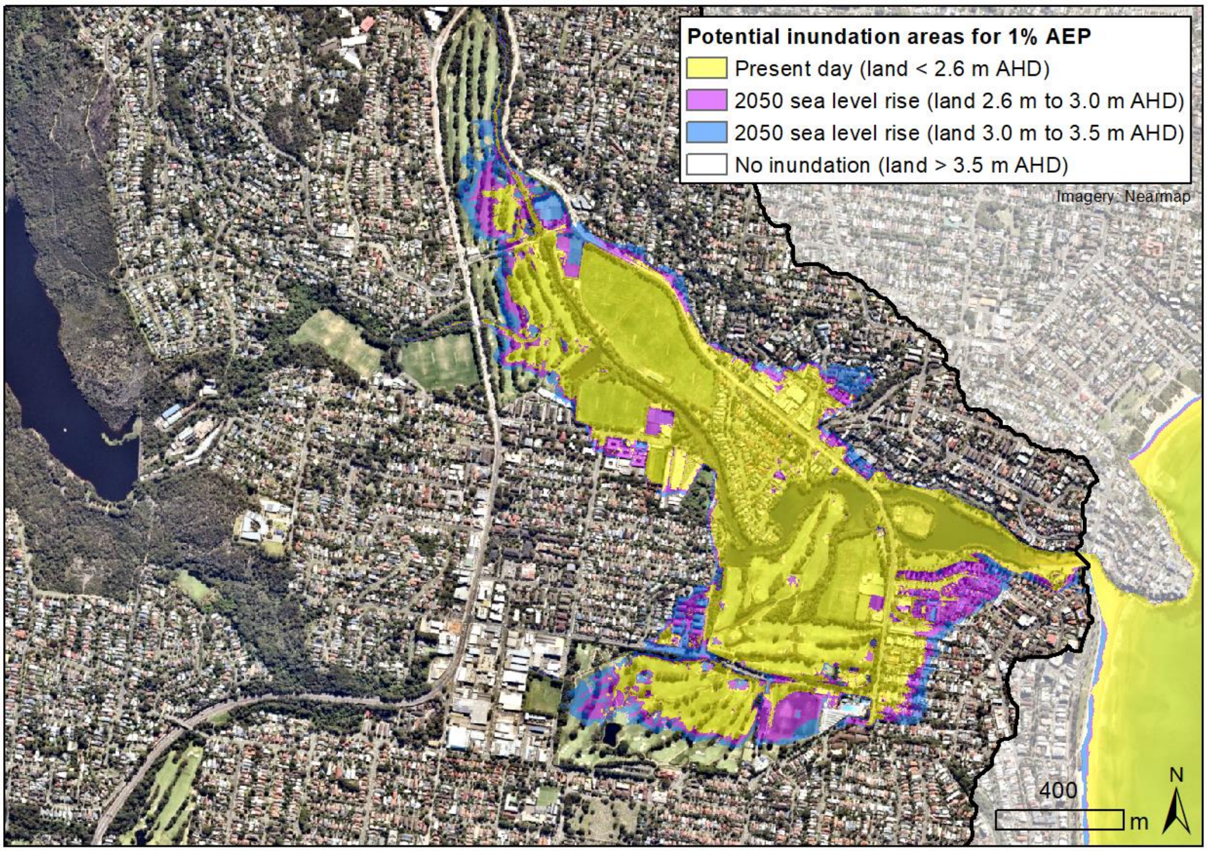


Figure 4.5: Manly Lagoon coastal inundation zones (including wave and wind setup) (Mariani e al., 2012)

In addition to impacts associated with tidal inundation, sea level rise may cause reduced drainage across the Manly Lagoon floodplain. As sea level rise occurs, the low tide elevation will also increase. An increased low-tide elevation will raise the level to which the stormwater system servicing the urban area around Manly Lagoon can drain (Figure 4.6). Increased inundation, whether from tidal inundation or reduced drainage, will require additional developments across the floodplain which may further impact the environment.

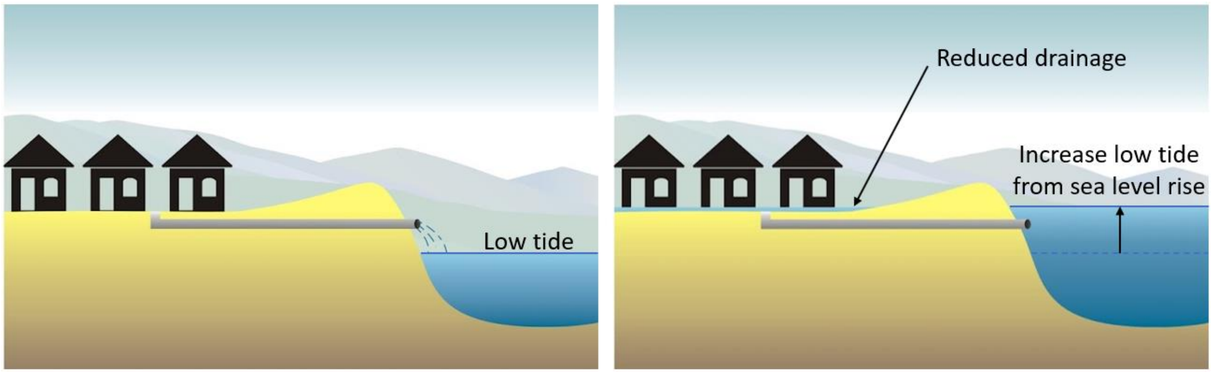


Figure 4.6: Potential mechanism for reduced drainage in urban areas caused by an increase in low-tide elevation due to sea level rise

As sea level rise occurs, within Manly Lagoon the ability for habitats to migrate will be limited due to the highly urbanised shoreline (Sadat-Noori et al., 2021a). This limited ability for landward migration of important coastal habitat will mean that the total extent of habitat decreases (Figure 4.7).

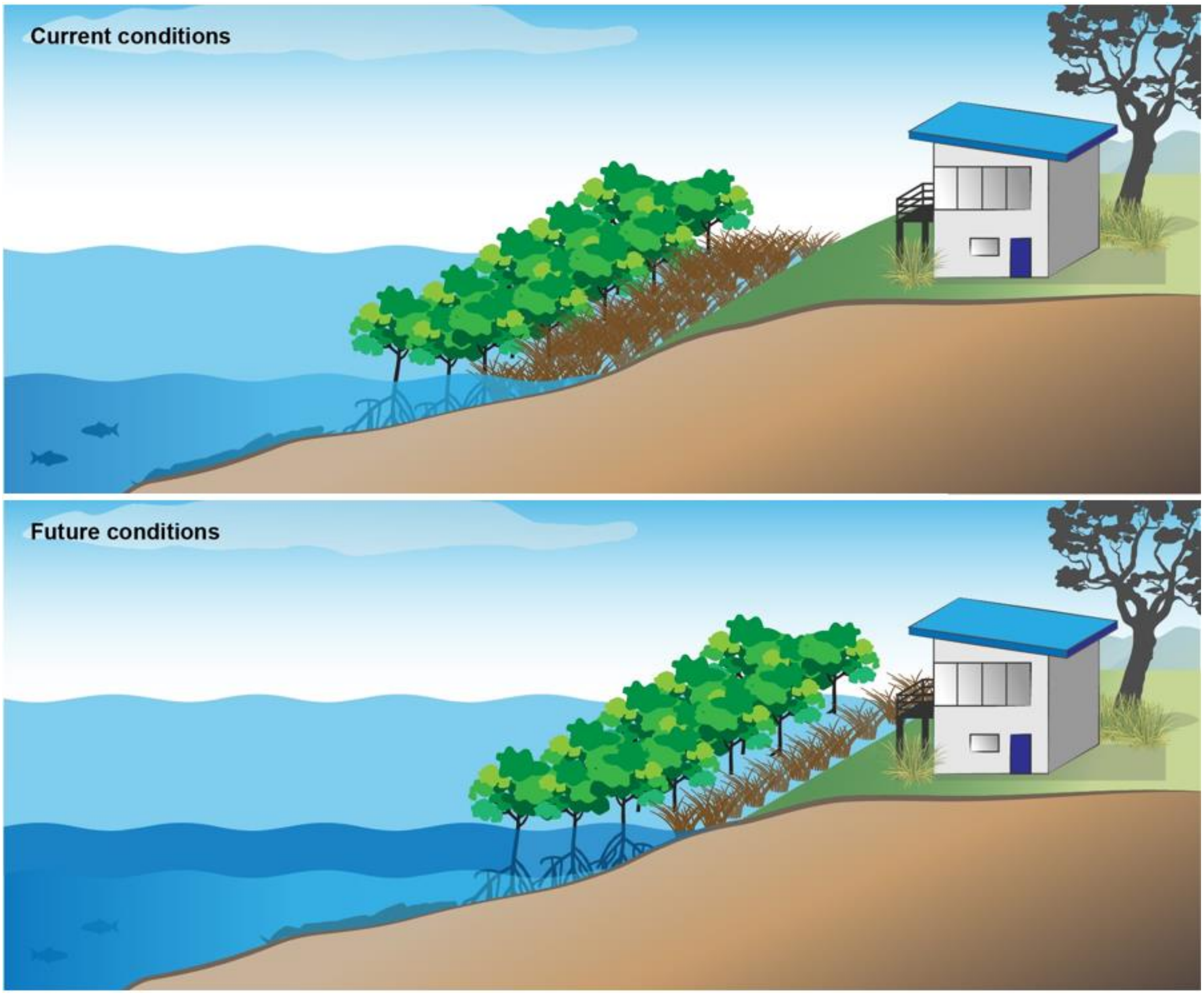


Figure 4.7: An urbanised shoreline is preventing the landward migration of important coastal habitat following sea level rise

Finally, climate change has also resulted in changes to rainfall patterns which will impact the hydrology across the Manly Lagoon catchment. Heimhuber et al. (2019) noted that climate change will result in:

- Minimal changes to long-term rainfall averages
- An increase in the intensity of extreme rainfall events (i.e. more rainfall over a shorter duration)
- An increase in the number of dry days

Changes to the hydrology like this will impact flooding as well as the day-to-day baseflow through the catchment that the environment relies on.

4.3.3 Bank stability

Review of cross-section data (Appendix A) identified that bank erosion is an issue throughout Manly Lagoon. This is also confirmed by UWS (2004), and restoration of banks within Manly Lagoon is ongoing. Bank erosion reduces water quality through introducing contaminants such as nutrients that were previously stored in the soil. Bank erosion also reduces the area available for habitat and developments on the edge of the lagoon affecting public amenity.

4.3.4 Poor water quality

Poor water quality within Manly Lagoon continues to threaten the existing values provided by the lagoon. Sources of poor water quality include:

- Nutrients
- Industrial discharges (These can be accidental or illicit. Pollutants can often be washed off impervious hardstands of industrial estates during rainfall events and be transported by the stormwater network to Manly Lagoon.)
- Sewage overflow
- Urban runoff/stormwater

Poor water quality has resulted in impacts to the environment (such as low dissolved oxygen and eutrophication) and impacts to the amenity of the lagoon (i.e. the lagoon is unsafe for recreation). Poor water quality is discussed further in Section 3. A lack of clear and achievable improvement objectives (such as specific default guideline values for Manly Lagoon) has also limited the progress to improve water quality within the lagoon.

Note, historically, operation of the Northern Beaches sewage network (which includes Manly Lagoon) has targeted a sewage overflow rate of no more than 20 overflows per 10 years. Recently, however, the operational strategy for reducing overflows in the area has changed so that sewage overflow abatement works now target higher risk overflow sites (EPA, 2022).

4.3.5 Weeds and exotic vegetation

The prevalence of weeds and exotic vegetation within Manly Lagoon has a number of impacts on the environment, including:

- Blocking flow through the waterways
- Contributing to the excessive nutrients (exotic leaf litter was found as a source of sediment nutrients by Filippini et al., (In Prep))
- Contributing to an increased carbon load
- Reducing space available for natural habitat
- Reducing visual amenity

4.3.6 Urban development

The Manly Lagoon catchment is highly developed (Figure 4.8). Natural bushland, parks or waterbodies make up 38% of the total catchment area. The remaining area (62%) includes roads, residential area and services that all contain largely impervious surfaces that result in the transport of contaminants to Manly Lagoon via the stormwater system. As the population within the local catchment increases it is likely it will increasingly impact the eco-health of Manly Lagoon. A number of urban development projects have recently been completed or are scheduled to begin within the Manly Lagoon catchment (Dykman, 2017):

- Northern Beaches Hospital
- Northern Beaches Hospital road upgrade
- Beaches Link tunnel

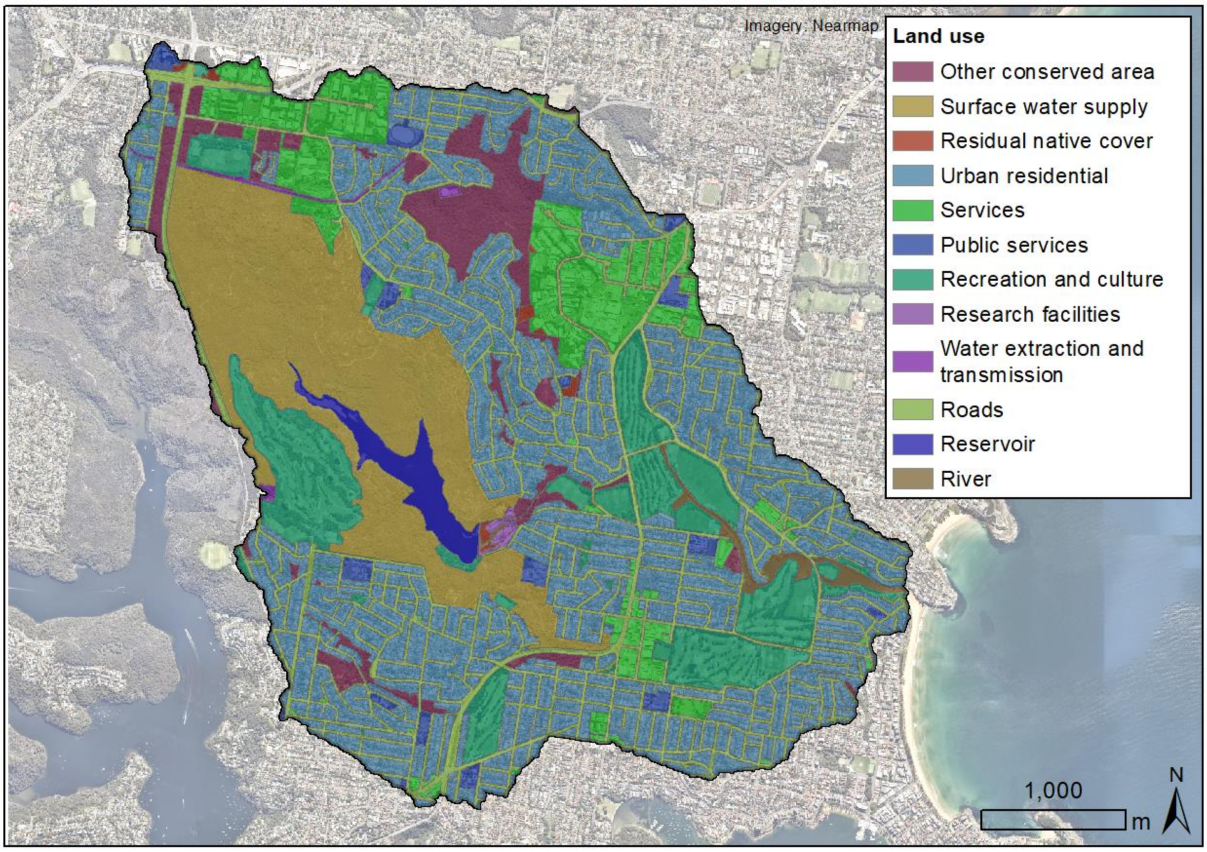


Figure 4.8:Manly Lagoon land uses

4.3.7 Entrance conditions

Management of the entrance to Manly Lagoon at the ocean is able to significantly alter the lagoons eco-health. Changes to the entrance that have been considered and would impact the Manly Lagoon environment include:

- Increased dredging of the lagoon entrance
- Improvements of water quality from flushing in relation to catchment inflows
- Lowering the rock weir at the entrance

Wiecek et al. (2006) and Wiecek and Floyd (2007) found that opening the entrance across the sand berm to the ocean via dredging can result in additional flushing. The environmental impact of this should be considered, however, as WRL (2016) found that the current low-flow pipes at the entrance have an effect to moderate the water quality within the lagoon on their own and that the lagoons water quality is largely driven by rainfall events. Harrison and Rayner (2019) found that if the rock sill at the entrance of the lagoon was altered, the tidal range would increase. While this would result in additional flushing, other environmental impacts would need to be considered, such as:

- Mobilisation and scour of bottom sediment
- Exposure of mud flats during low tides
- Changes to salinity within the lagoon
- Potential nuisance flooding during spring high tides

4.3.8 Catchment inflow management

The Manly Dam currently controls a large proportion of catchment inflows (approximately 500 ha) into Manly Lagoon (via Manly Creek) (Lyons and Eggleton, 2013). The operating rules of Manly Dam have potential to impact the environment depending upon their volume and frequency. Currently, the dam is operated by Sydney Water to release water for safety control and by Northern Beaches Council for flood mitigation (Lyons and Eggleton, 2013). WRL and Manly Hydraulics Laboratory (MHL) also divert water from the dam for use in hydraulic model testing before returning it into Manly Creek. Flow from WRL and MHL is the only mechanism by which environmental flows from the dam are maintained through Manly Creek during day-to-day conditions.

In 2016 ENSure (2016) reviewed the options for enhancing environmental flows from the dam and into Manly Creek. They identified that there may be some ecological benefits of increasing the current flow regime through Manly Creek from low to moderate. While this was the case, they also identified that this may take a significant investment and it was preferred to maintain the current low flow conditions through Manly Creek as the existing ecosystem has adapted to. Alternatively, coordination between WRL and MHL to increase the flow regime to moderate could occur for a marginal benefit.

4.3.9 Flooding

Manly Lagoon is subject to flooding through tidal inundation and through catchment runoff events. Catchment driven flood events were found to have the largest impact in regards to maximum flood levels (Lyons and Eggleton, 2013). Flood events have the ability to impact the eco-health of Manly Lagoon as they wash pollutants into the lagoon through urban runoff and cause sewage overflows.

4.3.10 Data gaps

Collection of empirical data allows for the conceptual understanding of Manly Lagoon to be developed. This helps to identify what is causing poor eco-health throughout the lagoon and allows for management actions that improve the lagoons eco-health to be implemented. Without sufficient data (of sufficient quality) the key environmental processes that occur across the Manly Lagoon cannot be correctly understood. Throughout the literature and data review (Appendix A) the following data gaps were identified:

- Long-term water quality monitoring upstream of Manly Lagoon
- Groundwater influence on nutrients in the estuary including understanding the budget, sources, and drivers (e.g. understanding if the lagoon is phosphorus or nitrogen limited)
- Nitrogen isotope/effluent source testing
- Long-term toxicity data
- Long-term salinity data
- Identification of mechanisms controlling oxygen demand within Manly Lagoon (e.g. is oxygen demand controlled by vegetation or sediment and how much potential oxygen demand is there)

4.3.11 Summary of Manly Lagoon pressures and threats

A summary of the pressures and threats Manly Lagoon faces is shown in Figure 4.9.

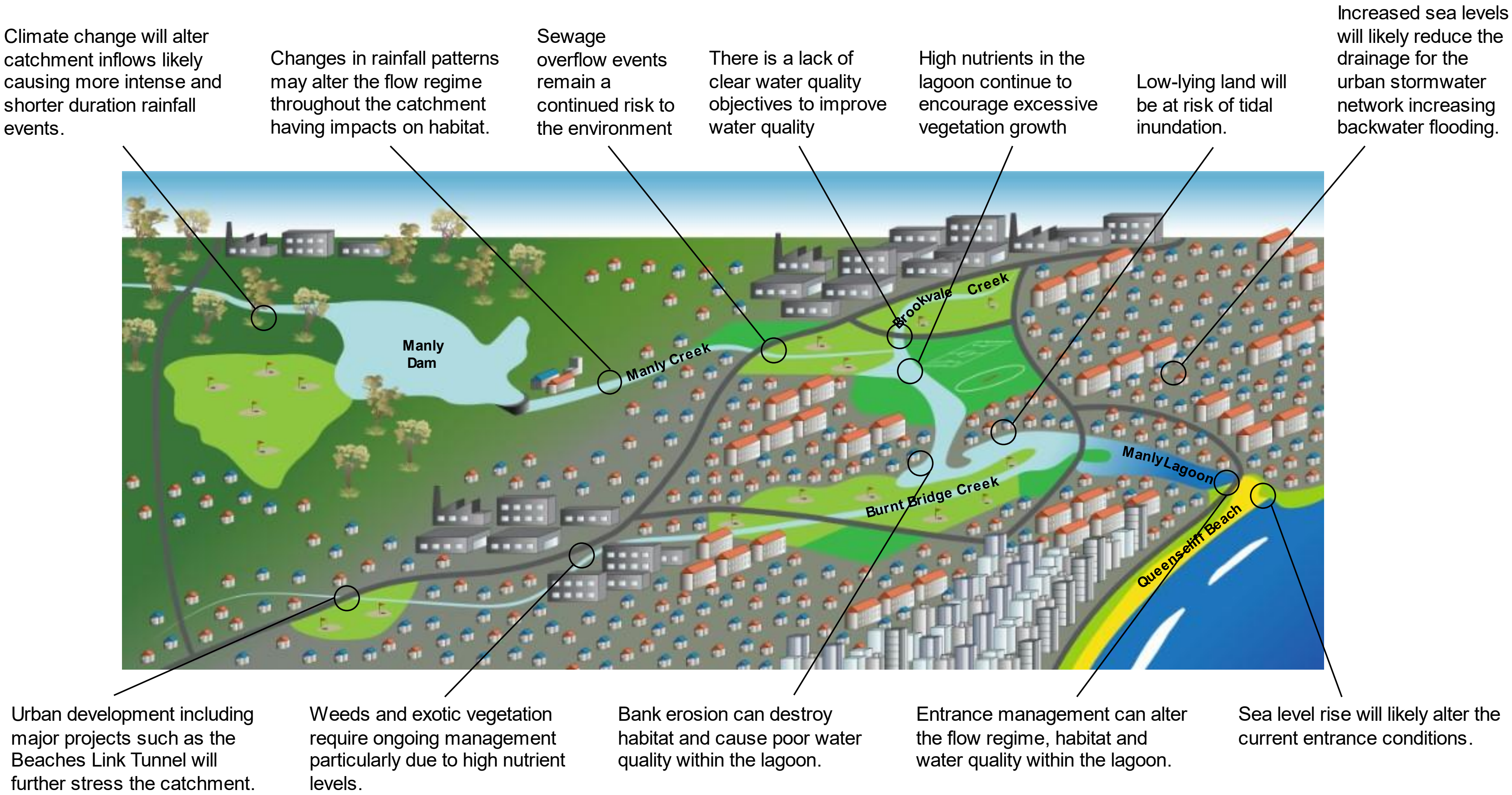


Figure 4.9: Risks and vulnerabilities faced by Manly Lagoon

4.4 Risk assessment of pressures and threats

4.4.1 Overview

A risk assessment of the pressures or threats posed to the eco-health of Manly Lagoon, and subsequently its values, has been completed. The consequence and likelihood scales have been used as per AGO (2006) as shown in Table 4.1 and Table 4.2, as recommended by OEH (2018b). The final risk matrix used is shown in Table 4.3.

Table 4.1: Consequence scale (as per AGO, 2006)

Rating	Success criteria (environment and sustainability)
Catastrophic	Major widespread loss of environmental amenity and progressive irrecoverable environmental damage
Major	Severe loss of environmental amenity and a danger of continuing environmental damage
Moderate	Isolated but significant instances of environmental damage that might be reversed with intensive efforts
Minor	Minor instances of environmental damage that could be reversed
Insignificant	No environmental damage

Table 4.2:Likelihood scale (as per AGO, 2006)

Rating	Recurrent risks	Single events
Almost certain	Could occur several times per year	More likely than not. Probability greater than 50%.
Likely	May arise about once per year	As likely as not. 50/50 chance
Possible	May arise once in ten years	Less likely than not but still appreciable. Probability less than 50% but still quite high.
Unlikely	May arise once in ten years to 25 years	Unlikely but not negligible. Probability low but noticeably greater than zero.
Rare	Unlikely during the next 25 years	Negligible. Probability very small, close to zero.

Table 4.3: Risk matrix (as per OEH, 2018b)

Consequence Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost certain	Medium	High	High	Extreme	Extreme
Likely	Medium	Medium	High	High	Extreme
Possible	Low	Medium	High	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Medium	Medium	High

4.4.2 Risk assessment results

The risk assessment for pressures and threats identified for Manly Lagoon is shown in Table 4.4. A brief note has been provided to justify each risk assessment. Climate change and poor water quality have been identified as the most significant risks for the eco-health and values of Manly Lagoon.

Table 4.4: Risks of pressures or threats impacting the eco-health of Manly Lagoon

Threat/pressure	Consequence	Likelihood	Risk	Notes
Climate change	Major	Almost certain	Extreme	IPCC (2021) have noted that the effects of climate change have already impacted sea level rise and extreme events.
Bank stability	Minor	Likely	Medium	Ongoing bank management is reversing this threat and it can continue to be managed into the future.
Poor water quality	Major	Almost certain	Extreme	Poor water quality has potential for severe implications on environmental health and is likely to be ongoing in the highly developed catchment.
Weeds and exotic vegetation	Minor	Likely	Medium	High levels of nutrients will mean weeds and the impacts of exotic species persist, however, the impacts are reversable with regular management.
Urban development	Moderate	Likely	High	Irregular urban developments have potential to cause significant environmental impacts. The consequence of this could increase into the future if not managed correctly.
Entrance management	Moderate	Possible	High	Irregular entrance management works have some potential to impact water quality, however, the primary driver of water quality is catchment events.
Catchment inflow management	Minor	Unlikely	Low	Unless catchment inflow management practices are altered there is unlikely to be a large impact on the environment.
Flooding	Moderate	Possible	High	Irregular events can cause significant impacts to the water quality within Manly Lagoon.
Data gaps	Moderate	Possible	High	Data to identify impacts to the eco-health of Manly Lagoon is important in identifying issues and assessing the success of management works.

5 Potential management opportunities

5.1 Overview

Based upon the conceptual model, review of existing data/literature and context of Manly Lagoon within broader NSW estuaries, a number of potential management opportunities that could be implemented to address risks to the ecological health (eco-health) and subsequent values of Manly Lagoon have been identified. These potential management opportunities include:

- Coastal vulnerability adaptation
    - Habitat offset/creation
    - Flood protection infrastructure
- Adaptive water quality monitoring program
- Entrance management
    - Permanent channel
    - Lowering of the rock weir with a permanent channel
    - Decommission the low-flow pipes
- Catchment management
    - Improving groundwater quality
    - Improving urban runoff
    - Reducing sewage overflows
- Dredging lagoon sediments
- Bank remediation
- Re-oxygenation
- Increase connectivity within the lagoon
- Creation of wetlands
- Removal of weeds

Northern Beaches Council currently has an ongoing program that is implementing a number of projects that seek to achieve the objectives defined by the Integrated Catchment Management Strategy (ICMS) (UWA, 2004). These projects fit into the above management opportunities. The purpose of the review of the opportunities specified here is to inform the future management of Manly Lagoon, which may include continuing actions that are already being carried out.

The following chapter provides a qualitative review of each of these management opportunities, identifying how they affect the processes that govern Manly Lagoon's eco-health. These processes directly relate to the pressures and threats outlined in Section 4.3. For the purpose of this review, the guideline in Table 5.1 was developed for each qualitative review category. Note, for a detailed assessment of these opportunities a multicriteria analysis should build upon the information presented here and include factors such as community values, urgency and costs (Section 5.12.1).

Table 5.1: Qualitative assessment criteria for the impacts of management opportunities to the processes that determine the eco-health of Manly Lagoon

Category	Description
Large improvement	Implementation of the management opportunity would result in large scale improvement in the eco-health of Manly Lagoon
Improvement	Implementation of the management opportunity would result in any improvement in the eco-health of Manly Lagoon
No change	Implementation of the management opportunity would be unlikely to affect the eco-health of Manly Lagoon
Degradation	Implementation of the management opportunity would result in some degradation of the eco-health of Manly Lagoon
Large degradation	Implementation of the management opportunity would result in large scale degradation of the eco-health of Manly Lagoon
Insufficient data	There is insufficient data to determine how the management opportunity would affect the eco-health of Manly Lagoon

5.2 Coastal vulnerability adaptation

Climate change was identified as one of the largest threats to the values provided by Manly Lagoon (Section 4.4.2). Examples of adaptation opportunities that could be implemented to mitigate the risk of climate change include:

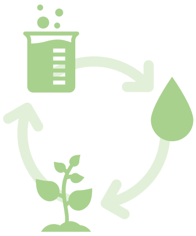
- Habitat offset
- Flood protection infrastructure

Each of these opportunities has been qualitatively assessed to inform how they may impact the processes that occur within Manly Lagoon.

5.2.1 Habitat offset/creation

Habitat offset involves identifying areas where habitat that will be impacted by sea level rise (e.g. mangroves or coastal wetlands) and can be encouraged to grow in the future. Opportunity exists to not only offset existing habitat that will be lost due to sea level rise, but to create new habitat. A qualitative assessment of the impact that this management opportunity would have on the Manly Lagoon eco-health processes is outlined in Table 5.2.

Table 5.2: Qualitative assessment of habitat offset

	Processes 	Qualitative improvement					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Habitat offset	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

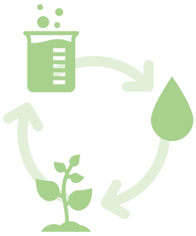
5.2.2 Flood mitigation infrastructure

To mitigate the risk that climate change poses to Manly Lagoon, construction of flood mitigation infrastructure could be considered to prevent or reduce inundation. Examples of infrastructure may include:

- Levees
- Bank protection
- Pumping systems

A qualitative assessment has been completed to inform how these types of works may impact the processes that govern Manly Lagoon's eco-health (Table 5.3).

Table 5.3: Qualitative assessment of flood protection infrastructure



	Processes	Qualitative improvement					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Flood protection infrastructure	Climate change (tidal inundation)						■
	Climate change (reduced drainage)					■	
	Climate change (habitat squeeze)			■			
	Climate change (catchment inflows)				■		
	Bank stability					■	
	Water quality (nutrients)	■					
	Water quality (industrial discharge)				■		
	Water quality (sewage overflows)				■		
	Water quality (urban runoff)	■					
	Weeds/exotic vegetation				■		
	Environmental flows				■		
	Flooding (tidal)						■
	Flooding (catchment)						■

5.3 Adaptive water quality monitoring program

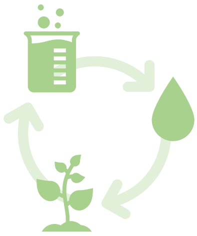
Development of an adaptive water quality monitoring program for the Manly Lagoon catchment (i.e. the lagoon and its feeder waterways) would allow for targeted and strategic improvement of the water quality within Manly Lagoon. Components of a water quality monitoring program may include:

- Default guideline values
- Water quality monitoring plan
    - Monitoring locations
    - Monitoring parameters

- Monitoring frequency
- Quality standards
- Regular review of water quality
- Regular review of projects to improve water quality

A qualitative assessment has been completed to inform how an adaptive water quality monitoring program may impact the processes that govern Manly Lagoon's eco-health (Table 5.4).

Table 5.4: Qualitative assessment of an adaptive water quality monitoring program



	Processes	Qualitative improvement					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Water quality monitoring program	Climate change (tidal inundation)				■		
	Climate change (reduced drainage)				■		
	Climate change (habitat squeeze)				■		
	Climate change (catchment inflows)				■		
	Bank stability					■	
	Water quality (nutrients)						■
	Water quality (industrial discharge)						■
	Water quality (sewage overflows)						■
	Water quality (urban runoff)						■
	Weeds/exotic vegetation					■	
	Environmental flows				■		
	Flooding (tidal)				■		
	Flooding (catchment)				■		

5.4 Entrance management

The management of the entrance conditions for Manly Lagoon has been investigated on a number of occasions as a mechanism to mitigate the poor water quality within the lagoon. Opportunities for management of the entrance of Manly Lagoon to the ocean include:

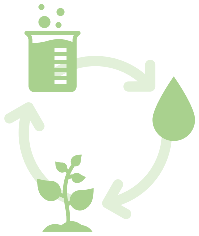
- Permanent channel: through the beach to connect Manly Lagoon to the ocean
- Lowering the rock weir with a permanent channel: through the beach to connect Manly Lagoon to the ocean
- Decommissioning of the low-flow pipes (i.e. restore the entrance)

Each of these opportunities has been qualitatively assessed to inform how they may impact the processes that occur within Manly Lagoon.

5.4.1 Permanent channel

This management opportunity would involve permanently connecting Manly Lagoon and the ocean by excavating and maintaining permanent channel through the sand at Queenscliff Beach. The purpose of this would be to increase connectivity between the lagoon and the ocean. A qualitative assessment has been completed to inform how this opportunity may impact the processes that govern Manly Lagoon's eco-health (Table 5.5).

Table 5.5: Qualitative assessment of the permanent channel opening

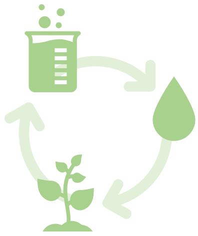


	Processes	Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Permanent channel opening	Climate change (tidal inundation)			■			
	Climate change (reduced drainage)				■		
	Climate change (habitat squeeze)	■					
	Climate change (catchment inflows)				■		
	Bank stability			■			
	Water quality (nutrients)					■	
	Water quality (industrial discharge)					■	
	Water quality (sewage overflows)					■	
	Water quality (urban runoff)					■	
	Weeds/exotic vegetation					■	
	Environmental flows				■		
	Flooding (tidal)			■			
	Flooding (catchment)				■		

5.4.2 Lowering the rock weir with a permanent channel

The rock weir that controls the water level at the entrance of Manly Lagoon could be lowered in addition to creating a permanent channel through the sand across Queenscliff Beach. This would allow for even larger tidal range and increased flushing within the lagoon (compared to just opening the channel) (Harrison and Rayner, 2019). A qualitative assessment has been completed to inform how this may impact the processes that affect Manly Lagoon's eco-health (Table 5.6).

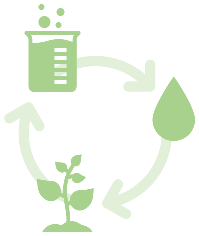
Table 5.6: Qualitative assessment of the permanent channel opening with a lowered weir

	Processes	Qualitative improvement					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Permanent channel opening with a lowered weir	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

5.4.3 Decommission low-flow pipes

By decommissioning the low-flow pipes, the Manly Lagoon entrance would be forced to revert back to its natural state. This would mean that the connection of the lagoon to the ocean would be governed by upstream catchment conditions. The objective of this would be to restore the natural hydrology within the lagoon. A qualitative assessment has been completed to inform how this may impact the processes that affect Manly Lagoon's eco-health (Table 5.7).

Table 5.7: Qualitative assessment of decommissioning the low-flow pipes



	Processes	Qualitative improvement					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Decommissioning the low-flow pipes	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

5.5 Catchment inflow management

Catchment management opportunities involve the targeted actions to improve the quality of catchment runoff before it enters Manly Lagoon. Catchment management can be divided into the following categories:

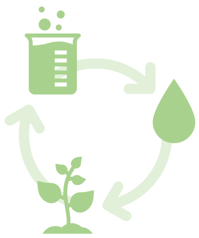
- Groundwater inflows
- Urban runoff
- Sewage overflows

Water quality can be improved by addressing pollution from these catchment sources before it enters Manly Lagoon. A qualitative assessment has been completed for the management of these catchment inflows to inform how this may impact the processes that occur within Manly Lagoon.

5.5.1 Groundwater inflow management

Large scale improvement of the groundwater can be difficult to achieve due to the slow flow rates of groundwater compared to surface water. Subsequently, improvement of groundwater inflows generally involves identifying where the source of contaminants enter the groundwater. Examples of this may be leachate from buried landfills or other inflows from the catchment. Where localised groundwater contamination occurs there can be solutions to improve its quality such as permeable reactive barriers or pumping to modify groundwater gradients and allow treatment of the contaminated groundwater. These solutions can be expensive, however, and are not as well suited to treating groundwater on a large scale. Often a better solution is to prevent contaminants entering the groundwater in the first place. A qualitative assessment has been completed to inform how reducing pollution in the groundwater may impact the processes that affect Manly Lagoon's eco-health (Table 5.8).

Table 5.8: Qualitative assessment of groundwater inflow management

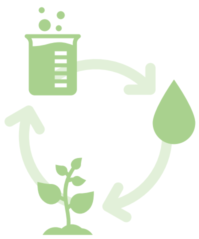


	Processes	**Qualitative improvement**					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Groundwater inflow management	Climate change (tidal inundation)				■		
	Climate change (reduced drainage)				■		
	Climate change (habitat squeeze)				■		
	Climate change (catchment inflows)				■		
	Bank stability				■		
	Water quality (nutrients)					■	
	Water quality (industrial discharge)					■	
	Water quality (sewage overflows)					■	
	Water quality (urban runoff)					■	
	Weeds/exotic vegetation					■	
	Environmental flows				■		
	Flooding (tidal)				■		
	Flooding (catchment)				■		

5.5.2 Urban runoff inflow management

Since the Manly Lagoon catchment is highly urbanised, runoff from the urban environment into the lagoon can cause significant pollution. Sources of pollution (such as gross pollutants, nutrients, sediment and metals) can include roads, residential properties, or industrial properties (McManus and Knights, 2011). These are generally washed into the lagoon via the local stormwater system. By intercepting these pollutants before they reach Manly Lagoon the water quality can be significantly improved. Note, some gross pollutant traps (GPTs) exist throughout the catchment which can assist in managing pollution when maintained effectively. A qualitative assessment has been completed to inform how reducing pollution from urban runoff may impact the processes that affect Manly Lagoon's eco-health (Table 5.9).

Table 5.9: Qualitative assessment of urban runoff inflow management



	Processes	**Qualitative improvement**					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Urban runoff inflow management	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

5.5.3 Sewage overflow management

Sewage overflows occur when the sewage network is overwhelmed. This is generally during large rainfall events as often the sewage network and stormwater network can be interconnected. It can also occur when there is a blockage of the sewer. At chosen locations, sewage is allowed to spill into natural waterways so that it does not back up in the network and impact private residences. When these spills occur there is potential that waterways can become contaminated by pathogens. To reduce the likelihood of these occurrences the sewage system capacity can be increased and/or the sewage network repaired where necessary. A qualitative assessment has been completed to inform how reducing pollution from urban runoff may impact the processes that affect Manly Lagoon's eco-health (Table 5.10).

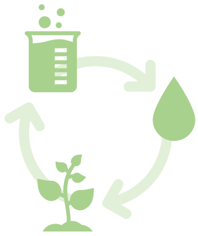
Table 5.10: Qualitative assessment of sewage overflow management

	Processes	**Qualitative improvement**					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Sewage overflow management	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

5.6 Dredging lagoon sediments

The sediment within Manly Lagoon contains organic matter which decomposes and contributes nutrients into the lagoon due to the anoxic conditions (i.e. deprived of oxygen) at the bottom (PBP, 1995). Increased sediments encourage further vegetation growth which in turn is linked to vegetation die off and the creation of the anoxic conditions that releases nutrients from the sediment. Dredging the sediment within the lagoon would reduce the nutrient levels in the lagoon. It may be possible that enough nutrients can be removed so that the tipping point whereby excessive nutrients promote vegetation growth and subsequently anoxic conditions can be reversed. Harrison et al. (2018) identified dredging as a flood mitigation option, however, they noted it would be unlikely to improve flooding significantly and only result in potential benefits to water quality. Potential ecological impacts of dredging lagoon sediments would need to be considered, particularly considering there is a healthy fish population within the lagoon, and further understanding of the linkages between aquatic biota and the carbon/nutrient cycling through the lagoon sediments may be required. A qualitative assessment has been completed to inform how this action may impact the processes that affect Manly Lagoon's eco-health (Table 5.11).

Table 5.11: Qualitative assessment of dredging

	Processes	Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
							
Dredging	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

5.7 Bank remediation

Erosion of the banks of Manly Lagoon has potential to release nutrients into the lagoon. By completing a bank assessment and targeting remediation of areas where bank erosion is occurring the water quality within Manly Lagoon can be improved. A qualitative assessment has been completed to inform how bank remediation may impact the processes that affect Manly Lagoon's eco-health (Table 5.12).

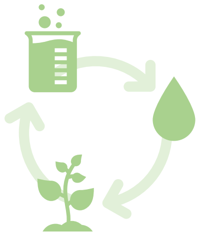
Table 5.12: Qualitative assessment of bank remediation

	Processes	Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Bank remediation	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

5.8 Re-oxygenation

Anoxic (i.e. low oxygen) conditions within the lagoon sediments result in the release of nutrients into the lagoon (Filippini et al., In Prep.). By re-oxygenating the water column, processes where nutrients become stored in the sediments as opposed to released can be encouraged. Ways oxygen can be introduced to the water is through aeration, mixing and encouraging continuous flow (e.g. ripple pools or tidal flushing). A qualitative assessment has been completed to inform how this action may impact the processes that affect Manly Lagoon's eco-health (Table 5.13). Note, the current mechanisms driving oxygen demand within Manly Lagoon have been identified as a data gap and should be assessed prior to implementation of this management opportunity (see Section 4.3.10).

Table 5.13: Qualitative assessment of re-oxygenation

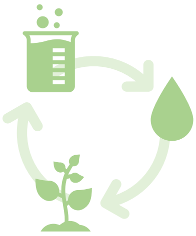


	Processes	Qualitative improvement: Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Re-oxygenation	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

5.9 Increase connectivity within the lagoon

Connectivity throughout Manly Lagoon could be increased by restoring natural flow paths. An example of this would be to reinstate flows to the south of Hinkler Park underneath Pittwater Road to Keirle Park as proposed by PBP (1995). This would allow tidal flushing that occurs at the entrance to efficiently flow to the upper lagoon. Note, previous investigations commissioned by Northern Beaches Council have determined that this specific option is not feasible (pers. coms. Jason Ruszczyk, 2022). Flood modelling found that economically this option would not be viable and it would only provide minimal (if any) flood relief (LWC, 1997; Harrison et al., 2018). A qualitative assessment has been completed to inform how increasing the connectivity within the lagoon may impact the processes that affect Manly Lagoon's eco-health (Table 5.14).

Table 5.14: Qualitative assessment of increasing the connectivity within the lagoon



	Processes	Qualitative improvement					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Increasing the connectivity within the lagoon	Climate change (tidal inundation)				■		
	Climate change (reduced drainage)				■		
	Climate change (habitat squeeze)				■		
	Climate change (catchment inflows)				■		
	Bank stability	■					
	Water quality (nutrients)	■					
	Water quality (industrial discharge)	■					
	Water quality (sewage overflows)	■					
	Water quality (urban runoff)	■					
	Weeds/exotic vegetation	■					
	Environmental flows				■		
	Flooding (tidal)				■		
	Flooding (catchment)				■		

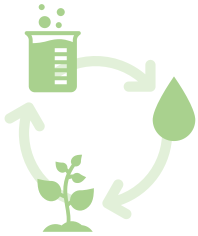
5.10 Creation of wetlands

Creation of wetland habitat at Manly Lagoon is a potential opportunity that can provide improvements to its eco-health. Wetlands provide a number of valuable ecosystem services, such as:

- Flood storage
- Improved water quality through filtering of nutrients
- Habitat

Wetland habitat can be created using a number of approaches. Modification of the lagoon hydrology can create ideal conditions for wetlands. Other options exist such as the creation of floating wetlands. A qualitative assessment has been completed to inform how creating wetland habitat may impact the processes that affect Manly Lagoon's eco-health (Table 5.15).

Table 5.15: Qualitative assessment of creating wetlands

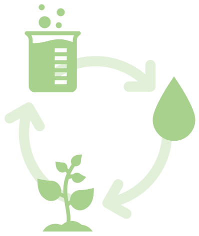


	Processes	Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Creating wetlands	Climate change (tidal inundation)						
	Climate change (reduced drainage)						
	Climate change (habitat squeeze)						
	Climate change (catchment inflows)						
	Bank stability						
	Water quality (nutrients)						
	Water quality (industrial discharge)						
	Water quality (sewage overflows)						
	Water quality (urban runoff)						
	Weeds/exotic vegetation						
	Environmental flows						
	Flooding (tidal)						
	Flooding (catchment)						

5.11 Removal of weeds

Weeds invade the habitat of native vegetation which is detrimental to the natural environment. By removing weeds the extent of natural habitat can be increased, flow paths can be restored, and visual amenity of the lagoon improved. A qualitative assessment has been completed to inform how removal of weeds may impact the processes that affect Manly Lagoon's eco-health (Table 5.16).

Table 5.16: Qualitative assessment of removing weeds

	Processes 	Qualitative improvement					
		Insufficient data	Large degradation	Degradation	No change	Improvement	Large improvement
Removing weeds	Climate change (tidal inundation)				■		
	Climate change (reduced drainage)				■		
	Climate change (habitat squeeze)				■		
	Climate change (catchment inflows)				■		
	Bank stability					■	
	Water quality (nutrients)				■		
	Water quality (industrial discharge)				■		
	Water quality (sewage overflows)				■		
	Water quality (urban runoff)				■		
	Weeds/exotic vegetation						■
	Environmental flows				■		
	Flooding (tidal)				■		
	Flooding (catchment)				■		

5.12 Next steps

5.12.1 Multicriteria analysis

This analysis has provided a first-pass assessment for how potential management opportunities can result in improved (or degraded) processes throughout Manly Lagoon that will improve its eco-health. Further investigations are however required before selection of management options. The data presented here should be incorporated into a multicriteria analysis to assess the best ways to improve the eco-health of Manly Lagoon. Additional considerations that will be required alongside this information include:

- Community values – detailed community consultation should be completed. Each potential management opportunity should then be assessed against community values to ensure that they are being achieved.
- Urgency – some management opportunities may be more urgent than others to implement.
- Costs – the economic feasibility of different options will differ.

5.12.2 Data gaps and additional studies

Where existing information is insufficient to inform the selection of management opportunities, additional investigations/studies may be required to infill data gaps.

6 Conclusion

Manly Lagoon is an important waterway that provides a number of values to the community. These values are intrinsically linked to the ecological health (eco-health) of the system. A review has been completed to provide a conceptual understanding of the processed that govern the eco-health of Manly Lagoon (Section 2). Following this, a review of the water quality information was completed to benchmark the eco-health of Manly Lagoon against relevant guideline values and similar estuaries in NSW (Section 3). The findings of this confirmed that the eco-health of Manly Lagoon is in a threatened state. Some improvements in certain aspects of the lagoon's water quality have been measured, however, the overall health of the lagoon remains poor and ongoing adaptive management is required for improvement.

A review of the specific values that Manly Lagoon provides to the community has been completed. Key existing or potential values identified for Manly Lagoon that relate to its eco-health include:

- Aquatic habitat
- Recreational fishing
- Primary contact recreation
- Secondary contact recreation
- Visual amenity

A number of pressures and threats exist that pose a risk to these future, existing and potential values. The review of the existing data and literature available for Manly Lagoon identified pressures and threats pose the biggest risk to the eco-health of Manly Lagoon. A risk assessment then found that climate change and poor water quality pose the most significant risk to the existing or potential values provided by Manly Lagoon.

A first-pass review of potential management opportunities was then completed as a preliminary step for guiding the future improvement of Manly Lagoon's eco-health. It is anticipated that this review will be able to form part of a multicriteria analysis that can be used to determine what actions will result in the largest improvements for Manly Lagoon's eco-health and subsequently improve its values. Information that should be incorporated into the future multicriteria analysis include:

- Community values
- Urgency information
- Cost feasibility

The information presented in this report is designed to provide a current snapshot of Manly Lagoon's eco-health. It also provides the first steps required for determining the management pathways for improving the eco-health of Manly Lagoon to ensure its values are realised. This information can be used to inform the development of the Stage 1 Scoping Study within the Coastal Management Program being developed for Manly Lagoon as the analysis presented in this report is designed to inform the strategic context of the lagoon's future long-term management.

7 References

AGO, 2006. Climate change impacts and risk management: A guide for business and government. Australian Greenhouse Office, Canberra, Australia.

ANZECC 1992, Australian Water Quality Guidelines for Fresh and Marine Waters, Australian and New Zealand Environment and Conservation Council, Canberra, Australia.

ANZECC and ARMCANZ 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australia.

ANZG 2018. Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Government, Canberra Australia, accessed 20/10/2021, https://www.waterquality.gov.au/anz-guidelines

Appleton 2004, Warringah Council Creek Management Study, Montgomery Watson Harza (MWH) Australia Pty Ltd, Milton, Australia.

Bauer, J. E., Cai, W., Raymond, P. A., Bianchi, T. S., Hopkinson, C. S. and Regnier, P. A. G. 2013, The changing carbon cycle of the ocean, Nature, 504(74478), pp. 61-70, DOI: 10.1038/nature12857

Bennett, M., Dale, M. 1995, Remedial Action Plan Proposed Public Open Space Addiscombe Road Manly Vale NSW. Groundwater Technology Australia Pty Limited, Kingsgrove, Australia.

Cambridge, V., Ross, J. 1997, Monitoring Well Installation and Sampling Addiscombe Road – Manly Vale. Flour Daniel GTI (Australia) Pty Ltd, Kingsgrove, Australia.

Cheng, D. 1992, Water quality management of Manly Dam, University of Technology, Sydney, Australia.

CMS 2015, Manly Lagoon Entrance Bedrock and Sand Level Surveys, CMS Surveyors Pty Limited, Dee Why, Australia.

Dale, M. and Etheridge, L. 1991. Environmental Assessment Proposed Residential Development Addiscombe Road, Manly Vale, NSW. Groundwater Technology Australia Pty Ltd, Kingsgrove, Australia.

De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L. and Hussain, S., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosystem services, 1(1), pp.50-61.

DEC 2006, NSW Water Quality and River Flow Objectives Gosford and Northern Beaches Lagoons, NSW Government Department of Environment and Conservation, accessed 08/06/2021, https://www.environment.nsw.gov.au/ieo/Gosford/report-02.htm#P188_16426

DECCW 2010, New South Wales Natural Resources Monitoring, Evaluation and Reporting Strategy 2010 – 2015, Department of Environment, Climate Change and Water NSW, Sydney, Australia.

DECCW, 2016. Estuaries (including macrophyte detail). NSW Department of environment, Climate Change and Water, accessed 22/10/2021. https://datasets.seed.nsw.gov.au/dataset/estuaries-including-macrophyte-detail5ebff

Dela-Cruz, J., Pik A. and Wearne, P. 2017, Risk-based framework for considering waterway health outcomes in strategic land-use planning decisions, Office of Environment and Heritage and Environment Protection Authority, Sydney, Australia.

DPI, 2020. Fisheries NSW Spatial Data Portal. Department of Primary Industries, accessed 22/10/2021, https://webmap.industry.nsw.gov.au/Html5Viewer/index.html?viewer=Fisheries_Data_Portal

DPIE 2020a, Summary Report for Northern Beaches Council Report Card Content 2019/2020, NSW Department of Planning, Industry and Environment.

DPIE 2020b, State of the beaches 2019-2020, Department of Planning, Industry and Environment, Parramatta, Australia.

DPIE 2021, Beachwatch water quality program, NSW Department of Planning, Industry and Environment. accessed 08/06/2021, https://www.environment.nsw.gov.au/topics/water/beaches/beachwatch-water-quality-program

DPIE, 2018. State Environmental Planning Policy (Coastal Management) 2018 download package (Coastal Wetlands). Department of Planning, Industry and Environment, accessed 22/10/2021, https://datasets.seed.nsw.gov.au/anzlic_dataset/state-environmental-planning-policy-coastal-management-2018

Dykman, C. 2017, Manly Creek Catchment: A Critical Review of Past Investigations and a Plan for Future Research into Water Quality in Urban Catchments, The University of New South Wales.

ENSure, 2016. Feasibility Study on Environmental Releases from Manly Dam. St. Leonards, Australia.

EPA, 2022. *Environment Protection License 378*. Environment Protection Authority – NSW. Parramatta, Australia.

Eyre, B. D. and Ferguson, A. J. P. 2002, Comparison of carbon production and decomposition, benthic nutrient fluxes and denitrification in seagrass, phytoplankton, benthic microalgae- and macroalgae-dominated warm-temperature Australian lagoons, Marine Ecology Progress Series, 229, pp. 43-59, DOI: 10.3354/meps229043

Filippini, G. Bugnot, A. B., Johnston, E. L., Ruzczyk, J., Potts, J., Scanes, P., Ferguson, A. and Dafforn, K. A. In Prep., Investigating links between organic matter sources and biogeochemical processes across four urban lagoons.

Fletcher, M. and Fisk, G., 2017. NSW Marine Estate Statewide Threat and Risk Assessment. BMT WBM Pty Ltd. Broadmeadow, Australia.

GHD 2020a, Northern Beaches Council Addiscombe Road, Manly Vale, Interim Site Management Plan, GHD.

GHD 2020b, Northern Beaches Council Lot 1-4 Addiscombe Road, Manly Vale, Works Specification for Triangulation of Groundwater Elevation, GHD.

GHD, 2015. Northern Beaches Hospital Connectivity and Network Enhancements Stage 2 Environmental Impact Statement: Surface Water Assessment. GHD.

Ginns, A. and Wright, G. 2014. Manly Warringah War Memorial Park Plan of Management. Gondwana Consulting Pty Ltd, Warringah Council and the Crown Lands Division, Narrabeen, Australia.

Harrison E., Joly, F. and Goonan, C. 2018. Manly Lagoon Floodplain Risk Management Study and Plan. WMA Water, Sydney, Australia.

Harrison, A. J., and Rayner, D. S. 2019. Manly Lagoon Estuary Dynamics and Entrance Modelling. UNSW Sydney Water Research Laboratory, Manly Vale, Australia.

Heimhuber, V., Glamore, W., Bishop, M., Dominguez, G., Di Luca, A., Evans, J. and Scanes, P. 2019. Module-2 Prioritizing climatic changes; Climate change in estuaries – State of the science and framework for assessment; Available online: https://estuaries.unsw.edu.au/climatechange

Higgs, K. B. and Johnson, W. D. 1982, Nutrient Levels in Manly Reservoir and its Tributaries, UNSW Sydney Water Research Laboratory, Manly Vale, Australia.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

IT Environmental 2001, Manly Vale Groundwater Flow Assessment, IT Environmental (Australia) Pty Ltd, Kingsgrove, Australia.

IT Environmental 2002, Asbestos and Metals Investigation and Groundwater Assessment Addiscombe Road, Manly Vale, IT Environmental (Australia) Pty Ltd, Kingsgrove, Australia.

IT Environmental 2005, Groundwater Monitoring Report Addiscombe Road, Manly Vale NSW, IT Environmental (Australia) Pty Ltd, Kingsgrove, Australia.

Jacobs 2020, Beaches Link and Gore Hill Freeway Connection Technical working paper: Surface water quality and hydrology December 2020, Jacobs Group (Australia) Pty Ltd.

King, I., Davies, J. and Miller, B. 2002, Environmental Modelling of Manly Lagoon, UNSW Sydney Water Research Laboratory, Manly Vale, Australia.

Lee, J. and Kim, G. 2006, A simple and rapid method for analyzing radon in coastal ground waters using a radon-in-air monitor, Journal of Environmental Radioactivity, 89(2006), pp. 219-228, DOI:10.1016/j.jenvrad.2006.05.006.

Lim, R., Cheng, D. and Jones, P. 2001, UTS Freshwater Ecology Report of 2001: Community guided research focusing on Manly Dam and associated waterways, University of Technology, Sydney, Australia.

Lyall and Associates 2020. Beaches Link and Gore Hill Freeway Connection Technical working paper; Flooding. Transport for NSW.

Lyons, D., and Eggleton, J. 2012. Manly Lagoon Flood Study – Stage 1 & 2 Interim Report: Data Review, Community Consultation and Hydrology. BMT WBM Pty. Ltd., Broadmeadow, Australia.

Lyons, D., and Eggleton, J. 2013. Manly Lagoon Flood Study – Final report. BMT WBM Pty. Ltd., Broadmeadow, Australia.

LWC, 1997. *Manly Lagoon Floodplain Management Plan*. Land and Water Conservation.

Mariani, A., Carley, J. T., Lord, D B. and Shant, T. D., 2012. Identification of coastal hazard risk areas to projected sea level rise for the Manly Local Government Area. UNSW Water Research Laboratory, Manly Vale, Australia.

McInnes, H. C. 1985. Problems and principles in estuarine management: case study: Manly Lagoon.

McManus, R. and Knights, D. 2011, Manly Lagoon Catchment – Annual Sediment and Pollutant Loading, Equatica, Strawberry Hills, Australia.

MHL 1992a. Manly Lagoon Flood Study. NSW Department of Public Works and Services, Manly Hydraulics Laboratory.

MHL 1992b, Manly Lagoon Entrance Preliminary Assessment of Outlet Extension, NSW Department of Public Works and Services, Manly Hydraulics Laboratory.

MHL, 2021. Manly Hydraulics Laboratory Queenscliff (213414) monitoring data. Available online: https://mhl.nsw.gov.au/Station-213414, [Accessed 2021]

Micromex, 2011. Manly Lagoon Community and User research. Micromex, Tuggerah, Australia.

NBC, 2020. Towards 2040: Local Strategic Planning Statement. Northern Beaches Council.

OEH 2016, Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols, NSW Natural Resources Monitoring, Evaluation and Reporting Program, The Office of Environment and Heritage, Sydney, Australia.

OEH, 2018a. *NSW Estuary Tidal Inundation Exposure Assessment*. NSW Office of Environment and Heritage, Sydney, Australia.

OEH, 2018b. Our future on the coast NSW Costal Management Manual Part B: Stage 1 – Identify the scope of a coastal management program. NSW Office of Environment and Heritage, Sydney Australia.

Parsons Brinckerhoff 2008a, Environmental and Groundwater Management Plan Lots 1 to 4 (DP 818957) Addiscombe Road, Manly Vale, NSW, Parsons Brinkerhoff Australia Pty Limited, Sydney, Australia.

Parsons Brinckerhoff 2008b, Remedial Action Plan Lots 1 to 4 (DP 818957) Addiscombe Road, Manly Vale, NSW, Parsons Brinkerhoff Australia Pty Limited, Sydney, Australia.

PBP 1995. Manly Lagoon Estuary Management Study. Patterson Britton and Partners, North Sydney, Australia.

Pygas, D. P., 2011a, Manly Lagoon Dredging Project – Water Quality Monitoring Programme: Final Report, Cardno (NSW/ACT) Pty Ltd, Brookvale, Australia.

Pygas D. P., 2011b. Manly Lagoon Fish Survey: Assessment of Abundance and Diversity. Cardno (NSW/ACT) Pty Ltd, Brookvale, Australia.

Roony, W. S., 1997, Impact of Heavy Metal Escape from the Addiscombe road incinerator site, Manly Vale into Manly Lagoon. W. S. Roony and Associates Pty Ltd, Newport, Australia

Roper, T., Creese, B., Scanes, P., Stephens, K., Williams, R., Dela-Cruz, J., Croade, G., Coates, B. and Fraser, M. 2011, Assessing the condition of estuaries and coastal lake ecosystems in NSW, Monitoring evaluation and reporting program, Technical report series, Office of Environment and Heritage, Sydney, Australia.

Sadat-Noori, M., Rankin, C., Rayner, D., Heimhuber, V., Gaston, T., Drummond, C., Chalmers, A., Khojasteh, D. and Glamore, W., 2021a. Coastal wetlands can be saved from sea level rise by recreating past tidal regimes. Scientific reports, 11(1), pp.1-10.

Sadat-Noori, M., Rutlidge, H., Andersen, M. S. and Glamore, W., 2021b. Quantifying groundwater carbon dioxide and methane fluxes to an urban freshwater lake using radon measurements. Science of The Total Environment, 797, p.149184.

Schubert, M., Paschke, A., Lieberman, E. and Burnett, W. C. 2012, Air-Water Partitioning of 222Rn and its Dependence on Water Temperature and Salinity, Environmental Science and Technology, 46(7), pp. 3905-3911, DOI:10.1021/es204680n.

Smith, V. H., Tilman, G. D. and Nekola, J. C. 1999, Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems, Environmental Pollution, 100(1999), pp. 179-196, DOI: 10.1016/S0269-7491(99)00091-3.

Stone, D. 2014. Stage 2 Northern Beaches Hospital State Significant Infrastructure Application SSI_6792 (Stage 2) Environmental Impact Statement Appendix O: Stormwater Management Strategy and Plan. Hyder, North Sydney, Australia.

Sydney Water, 2021. *Sewage Treatment System Impact Monitoring Program Volume 1 Data report 2020-21*. Sydney Water, Parramatta, Australia.

Tate, P. M., Dorairaj, S., Davies, J., Anderson, D. and Miller B. M. 2003, Analysis and reporting on water quality in Warringah Council, UNSW Sydney Water Research Laboratory, Manly Vale, Australia.

Tucker, T. A., Rayner, D. S. and Simpson, J. H. 2018, John Fisher Park Groundwater Monitoring June 2018, UNSW Sydney Water Research Laboratory, Manly Vale, Australia.

UWS 2004, Manly Lagoon and Catchment Integrated Catchment Management Strategy and Evaluation, University of Western Sydney.

Wiecek, D. and Floyd, J. 2007, Does Dredging in ICOL Entrances Improve Tidal Flushing?

Wiecek, D., Floyd, J. and Smith, P. 2006, Monitoring: The last Step in the Estuary Management Planning Process?

WRL 2016, Manly Lagoon Estuary Dynamics and Water Quality, UNSW Sydney Water Research Laboratory, Manly Vale, Australia.

WRL 2019, Manly Lagoon Water Sampling (Wet Conditions) Data. UNSW Sydney Water Research Laboratory, Manly Vale, Australia.

WRL 2023, Manly Lagoon groundwater sampling 2021. UNSW Sydney Water Research Laboratory, Manly Vale, Australia.

Appendix A Review of literature and data

A1 Preamble

To develop the conceptual model a review of recent data collected across the Manly Lagoon catchment was completed. This review included published and grey literature as well as available data. Note, some literature and data sources were not available and could not be included within the review. The following section provides a review of literature and data including:

- Groundwater
- The monitoring, evaluation, and reporting (MER) program
- Flooding
- Bathymetry
- Influences on the entrance
- Nutrient and carbon cycling within estuary sediments
- Catchment runoff and surface water quality
- Community engagement
- Coastal management

A2 Groundwater

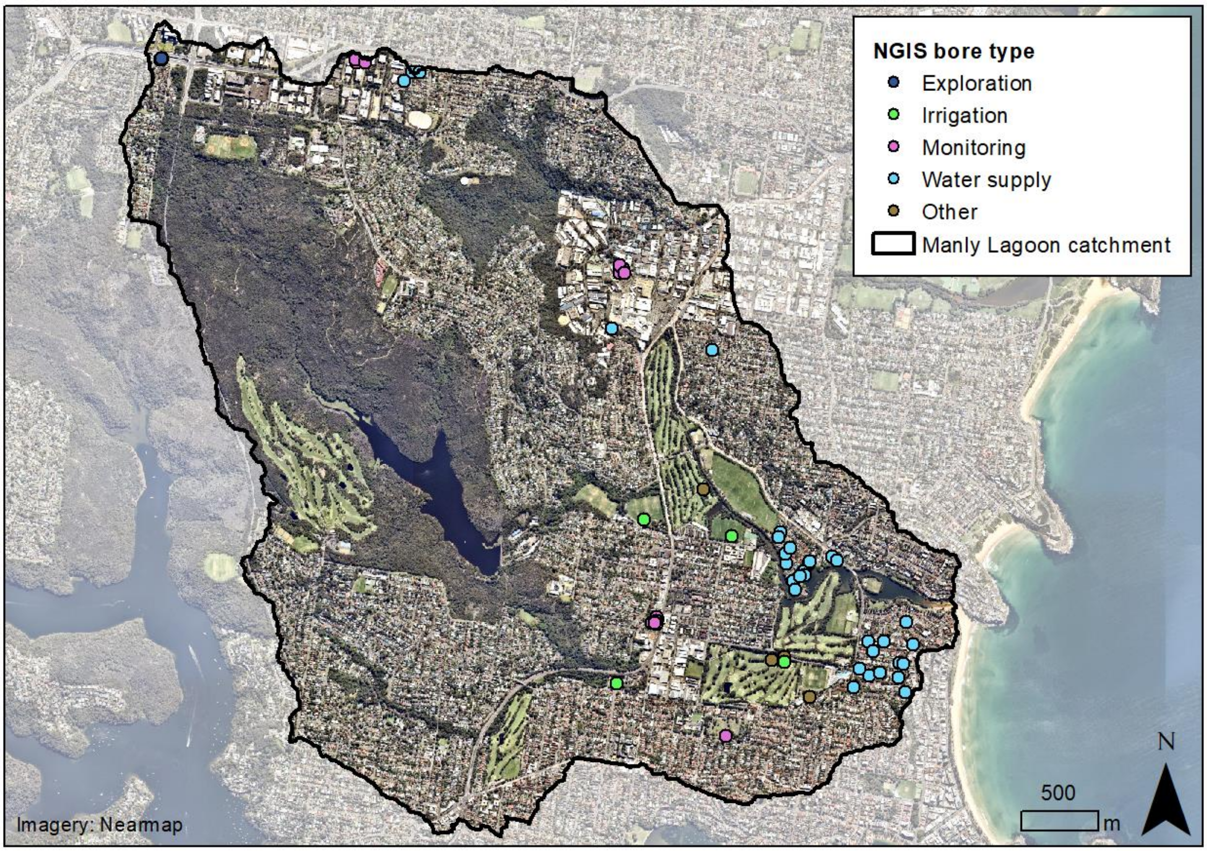
A2.1 Review of historic groundwater monitoring

Review of groundwater information identified a number of groundwater bores that have been established across the Manly Lagoon catchment for various purposes including research, water quality monitoring, water supply, exploration and irrigation. Details on groundwater bores were identified using the following information sources:

- The National Groundwater Information System (NGIS)
- Addiscombe Road remediation documentation
- Northern Beaches Council lagoon monitoring

A total of 64 bores were identified on the National Groundwater Information System (NGIS). These were constructed between 1957 and 2015 for various reasons as presented in Figure A.1. Of these bores, 32 have been identified as either functional or functioning, while the remaining 32 are of unknown status. The following data is available for some but not all of these bores:

- Construction and/or lithology logs (for 52 bores)
- Salinity data (for 10 bores)
- Hydrochemistry for bore GW037353 – the irrigation bore on Manly Golf Course (3 samples between 1975 and 1985)



A.1: Groundwater bores identified on the National Groundwater Information System (NGIS)

A number of groundwater bores have been installed at a former landfill site located on the south bank of Manly Lagoon between Addiscombe Road and Campbell Parade (Figure A.2). Seven monitoring bores were constructed in 1991 as part of an environmental assessment for a proposed development at the site (Dale and Etheridge, 1991). In 1995 further two monitoring bores were constructed during the development of a remedial action plan for the site (Bennett and Dale, 1995). Monitoring of these bores found groundwater was contaminated with heavy metals (specifically zinc, copper, chromium and lead) (Bennett and Dale, 1995; Cambridge and Ross, 1997; W. S. Roony, 1997). Of these heavy metals, zinc and copper were found to be above ANZECC (1992) guideline levels (Cambridge and Ross, 1997).

In 2002 an investigation was completed at the Addiscombe Road site to assess for asbestos and heavy metal contamination and the suitability of converting the site into public space. As part of these investigations an additional nine monitoring bores were installed in 2000 (IT Environmental, 2002). Monitoring of these newly installed bores found the following analytes were above the ANZECC and ARMCANZ (2000) guideline values (IT Environmental, 2002; IT Environmental, 2005):

- Polycyclic aromatic hydrocarbons (PAHs)
- Zinc
- Arsenic
- Ammonia

In addition to measuring water quality at these monitoring bores, measurements of water levels and hydraulic conductivity have been observed (IT Environmental, 2001; IT Environmental, 2002; IT Environmental, 2005). Hydraulic conductivity across the site was found to vary from 0.31 m/day to 0.96

m/day and interaction of the groundwater and lagoon surface water was found to occur up to approximately 50 m from the edge of the lagoon (IT Environmental, 2001).

In 2008, Parsons Brinkerhoff (2008a; 2008b) reviewed the groundwater monitoring completed at the site over the previous decade for the development of a groundwater management plan and a remedial action plan. Upon reviewing the monitoring data they concluded that the primary contaminants of concern for the site are heavy metals (zinc, copper, cadmium and lead), PAHs, total petroleum hydrocarbons (TPHs), and ammonia. Of these they noted that zinc was consistently at higher concentrations than guideline values. Review of groundwater flow by Parsons Brinkerhoff (2008a; 2008b) found that there is a hydraulic gradient of approximately 0.005 m across the site with the groundwater flowing in an easterly to north-easterly direction.

A.2: Historic monitoring bores at the Addiscombe Road remediation site

Other bores in the Manly Lagoon catchment include 21 monitoring bores constructed by Northern Beaches Council in March 2017 for the purpose of measuring groundwater quality and levels (Figure A.2). The 21 monitoring bores were constructed by Northern Beaches Council off the back of radon experiments completed in July 2016 which identified that there was an interaction between the groundwater and surface water of Manly Lagoon. Since their construction in 2017, the bores have been monitored for water quality in June 2018, March 2019, and August 2021, as well as for continuous water levels from June 2018 until July 2020.

A.3: Monitoring bores including 21 constructed by Northern Beaches Council (NBC) in 2017

Recent investigations completed by GHD found that only three of the historic bores installed at the Addiscombe Road site still exist (BH1, S6 and one in the vicinity of S7 and MV8) (GHD, 2020a). Note that as of 2019, inspections completed by WRL at the Addiscombe Road site found that ML20 and ML21 (Figure A.3) were also serviceable (WRL, 2019). As part of the development of an interim site management plan, and off the back of monitoring completed in 2017, GHD also proposed the constructed five new monitoring bores at the Addiscombe Road site (GHD, 2020a; GHD, 2020b). As part of the interim site management plan it was recommended that routine monitoring of the groundwater be undertaken.

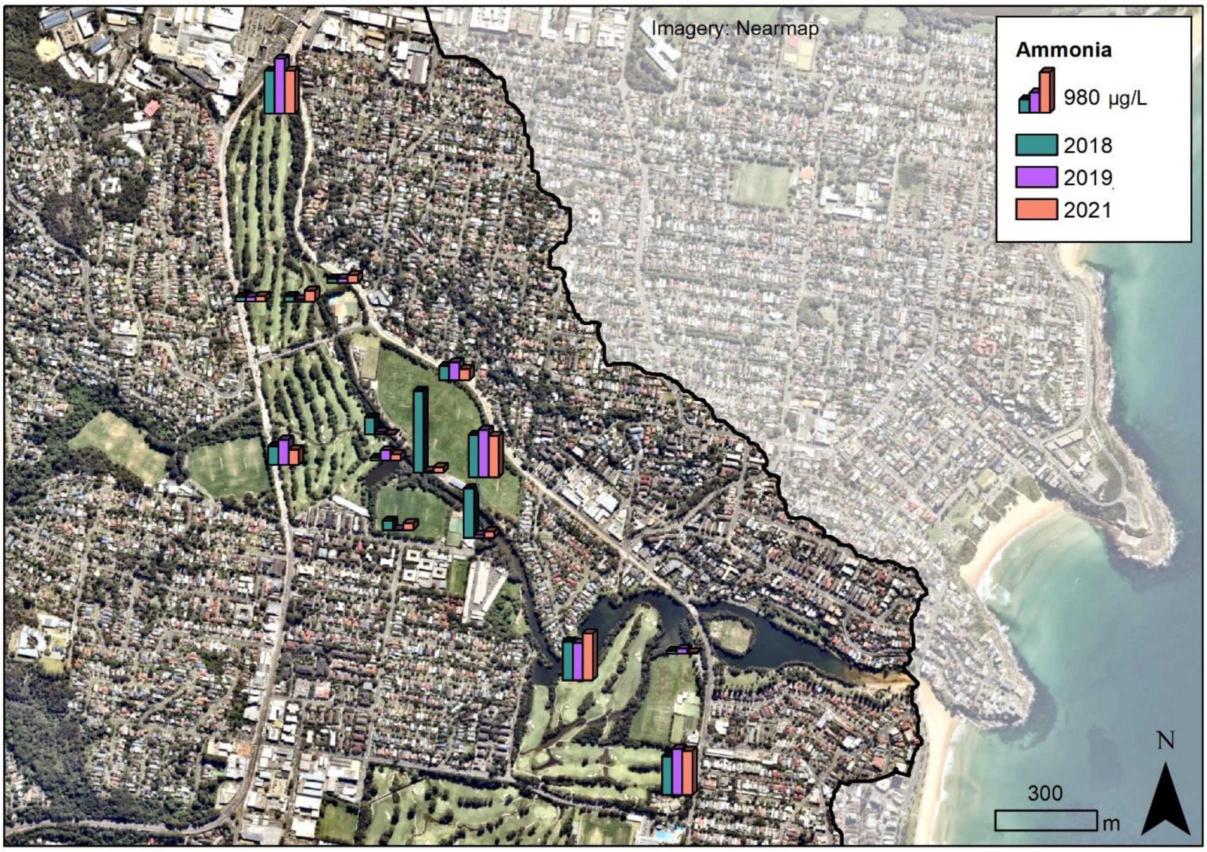
A2.2 Groundwater quality

In recent years, water quality (specifically anions, cations and nutrients) has been measured from the 21 monitoring bores constructed by Northern Beaches Council (Figure A.3) on three occasions:

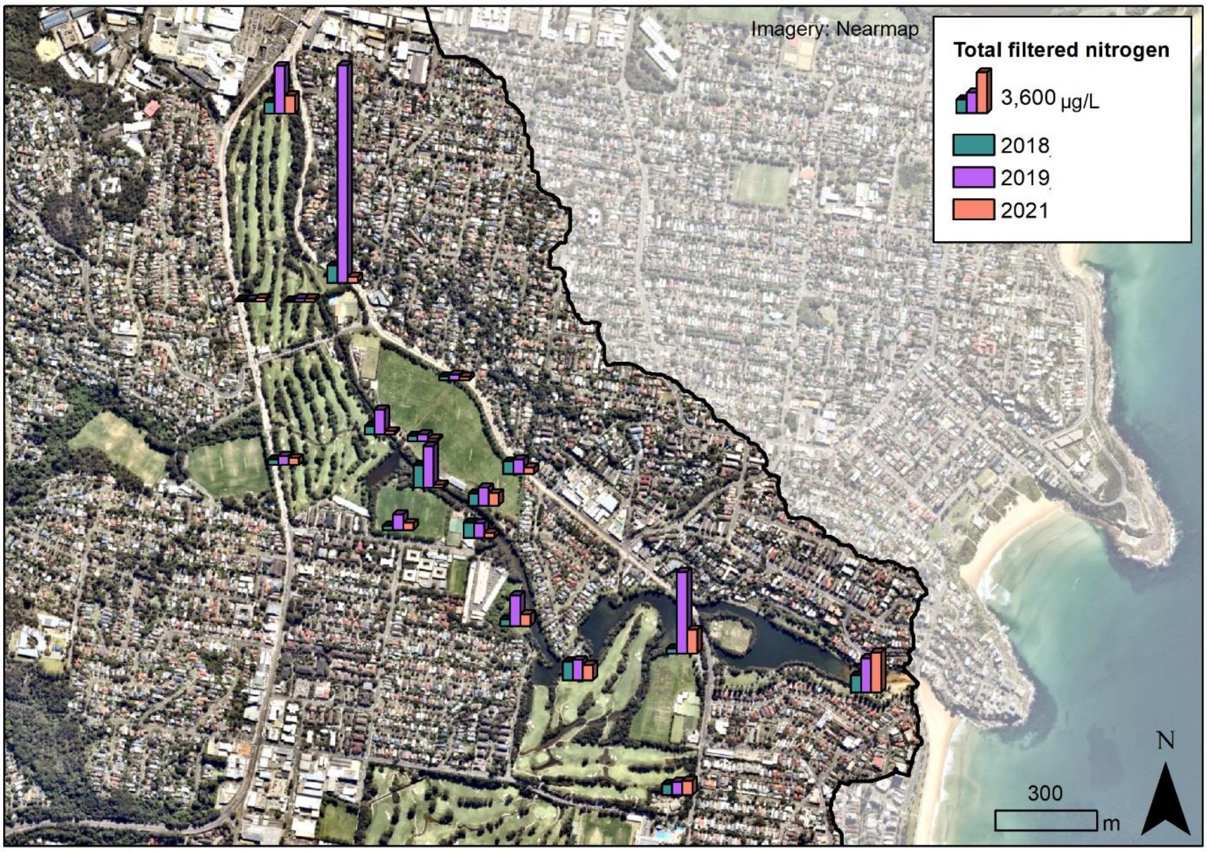
- June 2018 by OEH in dry weather conditions
- March 2019 by WRL following a wet weather event (203 mm in 8 days)
- August 2021 by WRL in dry weather conditions

These data sets have been analysed below to identify any trends between dry and wet weather conditions and any trends spatially. Note that there was considerable variability within nutrient data which has subsequently limited the analysis. Additional data collection would be required to determine the variability of nutrient concentrations throughout Manly Lagoon.

Ammonia, total filtered nitrogen and total filtered phosphorus were measured during the 2018 (dry weather), 2019 (wet weather) and 2021 (dry weather) sampling programs. A comparison between the sampling events is shown in Figure A.4, Figure A.5 and Figure A.6. Note that measurements of analytes across the site were extremely variable. Despite this, on both monitoring occasions, nutrient samples at all bores were observed above the ANZECC and ARMCANZ (2000) guideline values for aquatic ecosystems.



A.4: Comparison of ammonia sampled at Manly Lagoon



A.5: Comparison of total filtered nitrogen sampled at Manly Lagoon

A.6: Comparison of total filtered phosphorus sampled at Manly Lagoon

The following preliminary observations can be summated from review of the groundwater quality monitoring data. Note confirmation of these observations should continue following further rounds of monitoring:

- No clear trends in ammonia were found associated with wet weather events
- A significant increase in total filtered nitrogen and phosphorus appeared during the wet weather (2019) sampling compared to the dry weather sampling (2018 and 2021) at select sites (for nitrogen: ML04, ML12, ML13, ML16, ML17, ML18 and ML21; for phosphorus: ML05, ML07, ML08 ML13, ML14, ML15 and ML19)
- The highest recorded concentrations of nutrients were observed upstream of Riverview Parade for ammonia, total filtered nitrogen and total filtered phosphorus
- High concentrations of ammonia and total filtered phosphorus were found to occur at Passmore and Nolan Reserves

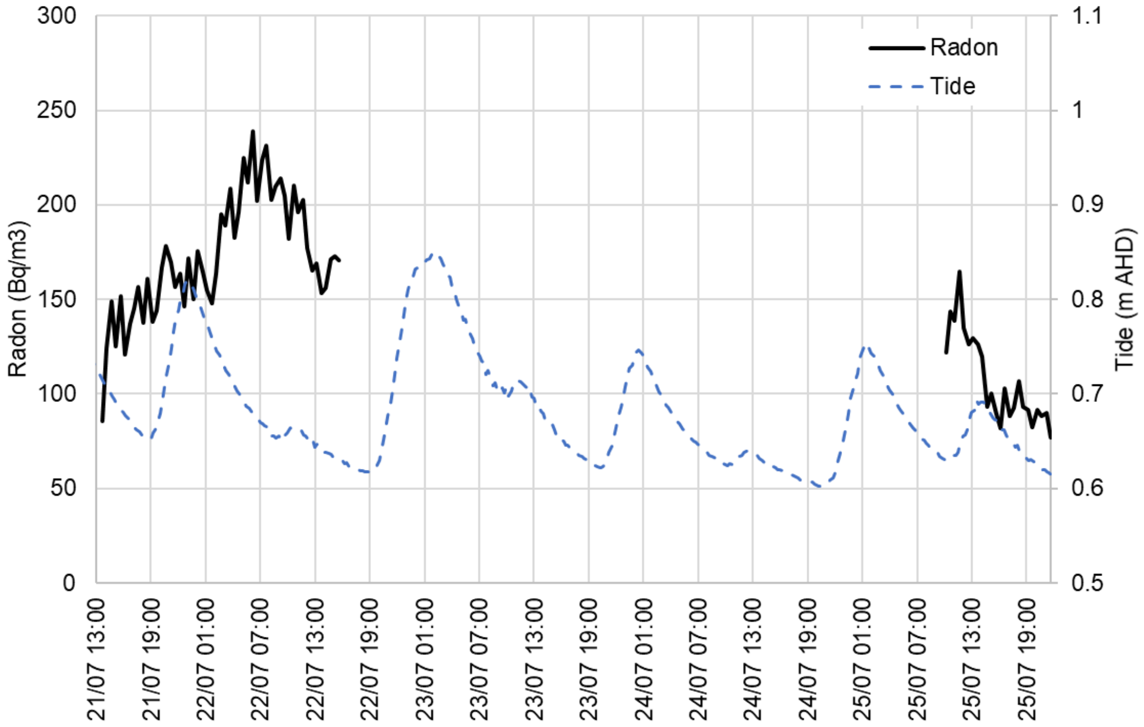
A2.3 Groundwater surface water interaction

Construction of the 21 monitoring bores around Manly Lagoon was completed for the purpose of identifying the possible interaction between groundwater and surface water. It was hypothesised that groundwater could be a potential nutrient source for the lagoon.

Radon measurements were taken in Manly Lagoon by Northern Beaches Council to determine if there was an indication of surface and groundwater interaction. Measurements have been corrected for temperature and salinity using the methods outlined by Schubert et al. (2012). Dates and times of sampling events included:

- Continuous measurements completed on 21, 22 and 25 July 2016 in the lagoon at the end of Pennant Parade
- Spot measurements at the seven water quality monitoring sites across the lagoon on 26 July 2016

A literature review completed by Lee and Kim (2006) found that the radon concentration in coastal and river waters is typically 30 to 3,000 Bq/m3 in comparison to groundwater which is generally 1000 to 53,000 Bq/m3. They also found that ocean waters generally have a radon concentration of 0.7 to 1 Bq/m3. These numbers can be compared to the results from monitoring carried out by Northern Beaches Council and presented in Figure A.7. Prior to this sampling event there was 32.5 mm of rainfall in two days with an additional 5 mm falling on 23 July 2016 meaning that it is likely that the groundwater had been recharged and had some capacity to discharge to the lagoon. Results indicate that there is a groundwater signature in the Manly Lagoon surface water with peaks occurring when the tide levels fall. This creates a gradient between groundwater and the lagoon surface water encouraging groundwater drainage to the lagoon and a subsequent spike in radon measurements as can be seen in Figure A.7.



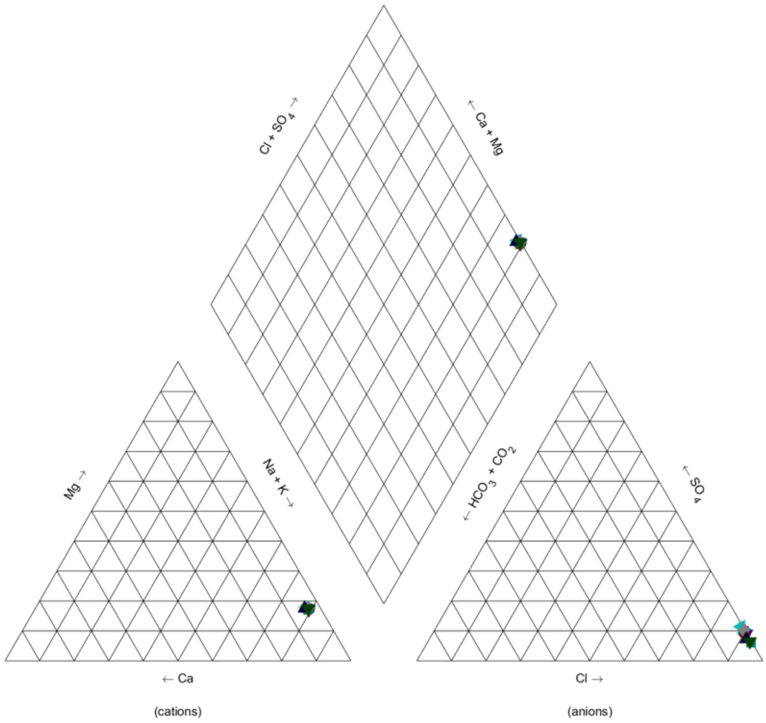
A.7: Radon measurements observed by Northern Beaches Council

Radon measurements observed at different locations across the lagoon on 26 July 2016 are presented in Figure A.8. This clearly shows that there is a greater influence of groundwater in the lagoon further from its entrance with the ocean. It is likely this is caused from flushing at the entrance with ocean water which has a low radon concentration.

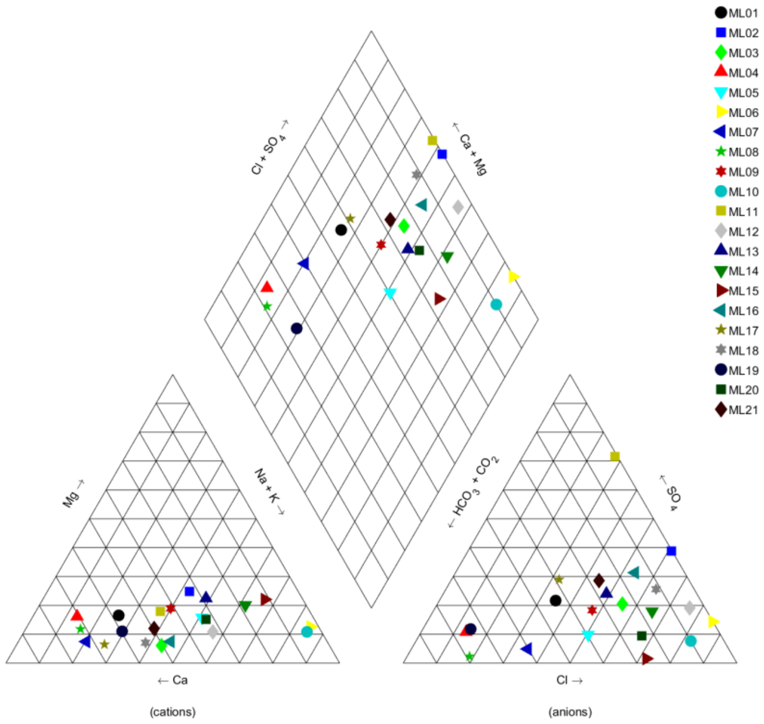
A.8: Radon measurements across Manly Lagoon on 26 July 2016

Surface water measurements taken by WRL (2019) have been analysed using a piper plot as displayed in Figure A.7. This plot shows that the surface water in Manly Lagoon has a clear signature influenced by chloride, sodium and potassium. Surface water in Manly Lagoon displays very similar hydrochemistry to that in the neighbouring Curl Curl Lagoon (Tucker et al., 2018).

A piper plot has also been created for groundwater data sampled from the monitoring bores surrounding Manly Lagoon (Figure A.8). Data was sampled following a significant wet weather event so cannot be generalised for dry conditions. Results indicate that there is a strong interaction between surface and groundwater at monitoring holes ML06 and ML10. It is possible that the surface water signature at ML06 is due to a high connectivity with the lagoon associated with its lithology consists of sand with gravel overlaying sandstone. Other sites with gravel in their lithology (ML05, ML12 and ML15) also show (although somewhat less) a tendency towards the surface water signature. The surface water signature observed at ML10 is somewhat of a mystery and further data collection is required to analyse the connection between surface and groundwater here (if it exists). One potential mechanism for the surface water signature could be that the stormwater infrastructure in the vicinity to the hole is acting to recharge the groundwater with surface water from the lagoon. Observations at the time of sampling confirm that water in the concrete stormwater channel adjacent to ML10 was overflowing at the time of sampling.

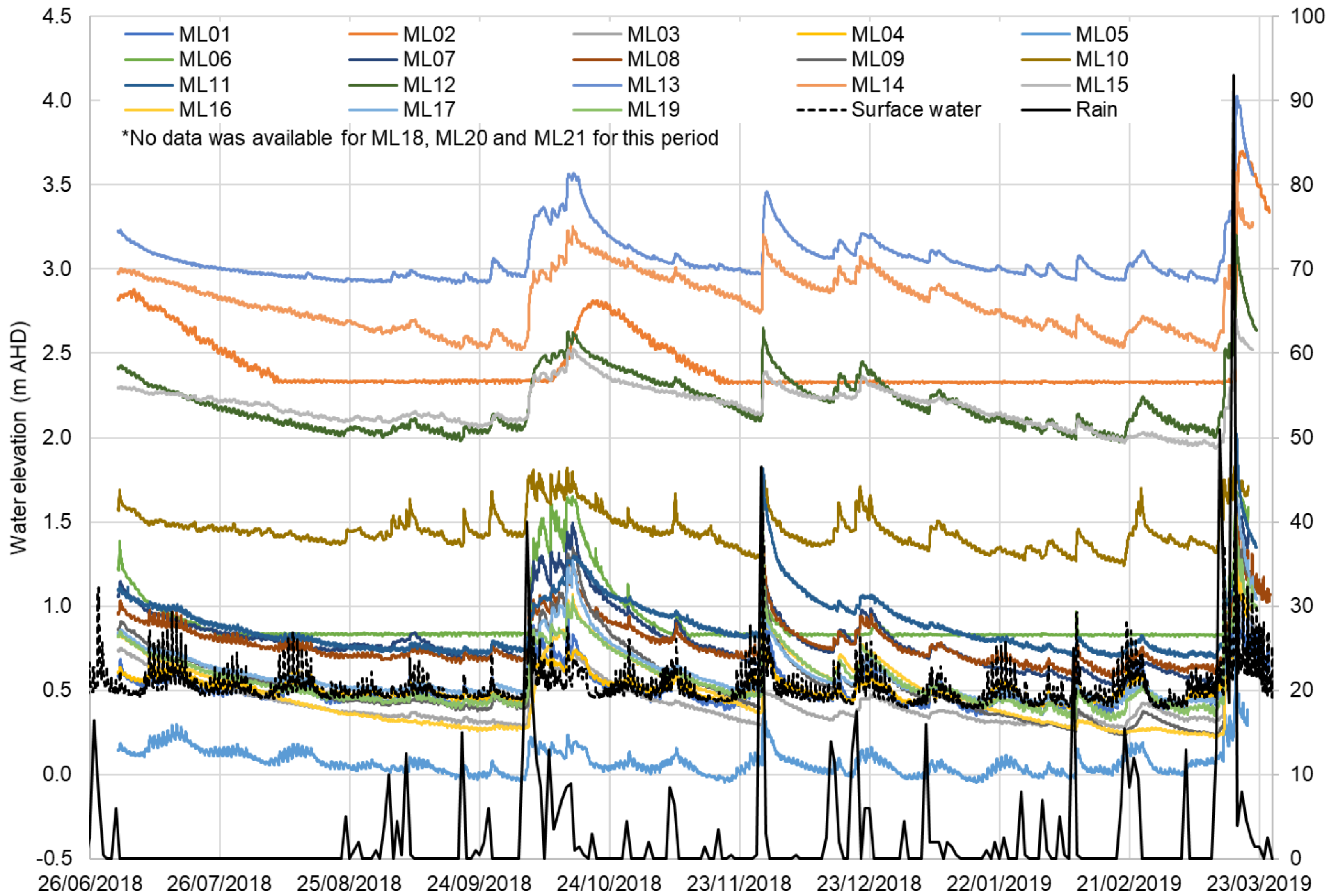


A.9: Piper diagram for surface water in Manly Lagoon

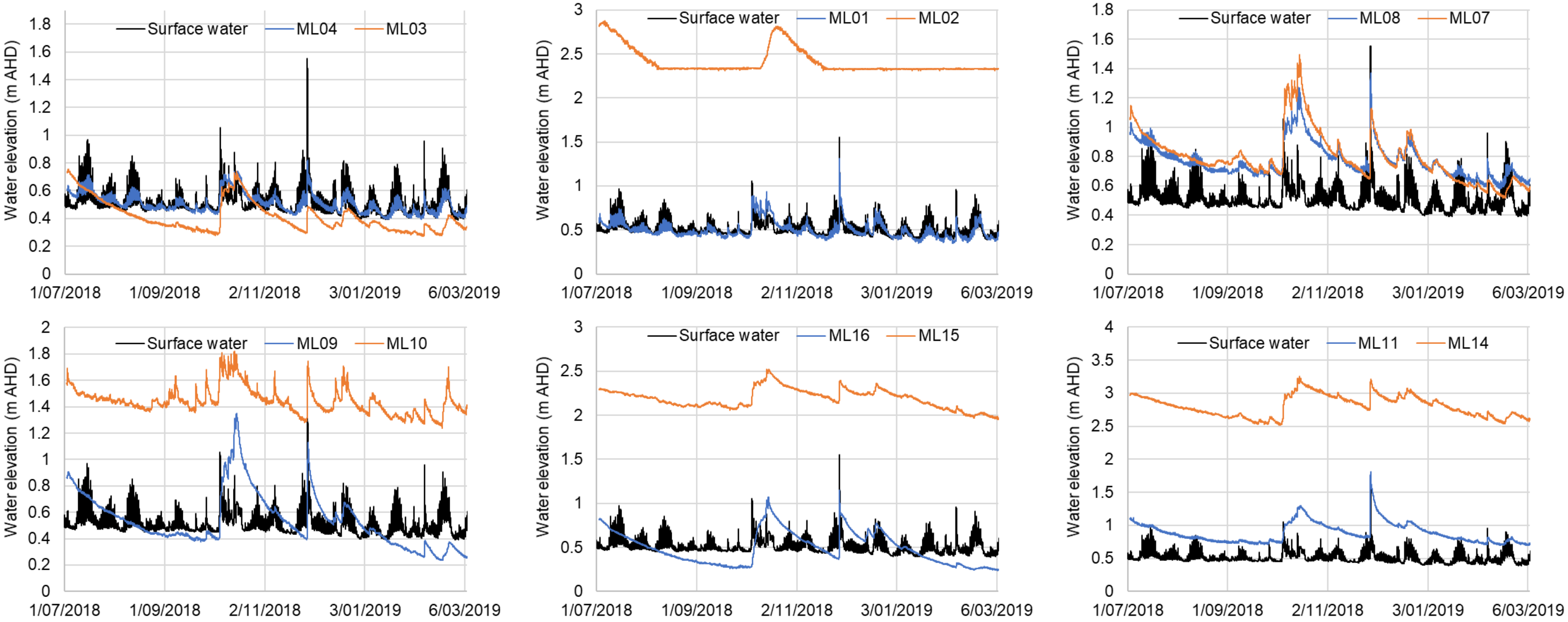


A.10: Piper plot for Manly Lagoon groundwater (dry conditions)

Long-term monitoring of groundwater levels is currently available from June 2018 to March 2019 (recent monitoring data is yet to be published). Water levels for the period available is shown in Figure A.11 along with rainfall data as measured in the Manly CBD (MHL, 2021). Figure A.12 shows the comparison between lagoon water levels and groundwater levels at varying distances from the lagoon.



A.11: Groundwater levels as recured by data loggers for each borehole (2018-2019)



A.12: Comparison of groundwater and surface water levels (2018 to 2019)

Analysis of the water level data indicates that there is a gradient from the surface water to the groundwater at a number of locations (ML03, ML05, ML09, ML16 and ML19) indicating that there is an exchange between the groundwater and surface water. Higher elevated water levels for holes that are located further from the lagoon (ML02, ML07 ML10, ML12, ML14 and ML15) indicates that the interaction between the groundwater and surface water is generally limited and only occurs close to the banks of the lagoon. In exception to this is ML03 and ML05 where the water level is lower than the lagoon surface water. These water levels indicate that water from the lagoon discharges through the groundwater on the south-east of the floodplain to the ocean.

A2.4 Groundwater/surface water nutrient interaction

A comparison between nutrient measurements for ammonia, total dissolved nitrogen and total dissolved phosphorus is shown for the 2018, 2019 and 2021 sampling events in Table A.1, Table A.2 and Table A.3, respectively. Surface water samples have been compared to bores which are located on the edge of the lagoon that have been shown to interact with the water in the lagoon. Analysis of the data shows that generally, nutrient levels in the groundwater is higher than levels measured in the surface water. The section from the entrance to Pittwater Road was an exception to this, with less ammonia in the groundwater when compared to the surface water. The highest levels of nutrients were measured in the section from Pittwater Road to Riverview Parade. Note that levels of nutrients in the lagoon and groundwater are significantly higher than the ANZECC and ARMCANZ (2000) guideline levels for aquatic ecosystems in estuaries (15µg/L for ammonia, 300µg/L for total nitrogen and 30µg/L for total phosphorus).

A.1: Comparison of nutrient levels measured in 2018 for surface and ground water

Location in lagoon	Bores	Surface samples	Ammonia (µg/L)		Total dissolved Nitrogen (µg/L)		Total dissolved phosphorus (µg/L)	
			Surface	Bore	Surface	Bore	Surface	Bore
Entrance to Pittwater Rd.	ML05 ML06	SW1 SW2	7 to 165	<1	200 to 520	1,485	7 to 20	52
Pittwater Rd. to Riverview Pde.	ML01 ML04	SW3 SW4 SW5 SW6	5 to 230	54 to 933	192 to 765	421 to 1,667	5 to 32	52 to 120
Riverview Pde. to Passmore Res.	ML19 ML20 ML21	SW7	39 to 116	<1 to 1,187	261 to 454	615 to 1,652	9 to 20	26 to 65

A.2: Comparison of nutrient levels measured in 2019 for surface and ground water

Location in lagoon	Bores	Surface samples	Ammonia (µg/L)		Total dissolved Nitrogen (µg/L)		Total dissolved phosphorus (µg/L)	
			Surface	Bore	Surface	Bore	Surface	Bore
Entrance to Pittwater Rd.	ML05 ML06	SW1 SW2	120 to 260	<10 to 30	<1000	600 to 3,000	<100	<10 to 120
Pittwater Rd. to Riverview Pde.	ML01 ML04	SW3 SW4 SW5 SW6	<100 to 400	110 to 900	<1000	1,800 to 7,200	<100	30 to 100
Riverview Pde. to Passmore Res.	ML19 ML20 ML21	SW7	370 to 620	<10 to 440	<1000	400 to 2,700	<100	20 to 360

A.3: Comparison of nutrient levels measured in 2021 for surface and ground water (WRL, 2023)

Location in lagoon	Bores	Surface samples	Ammonia (µg/L)		Total dissolved Nitrogen (µg/L)		Total dissolved phosphorus (µg/L)	
			Surface	Bore	Surface	Surface	Bore	Surface
Entrance to Pittwater Rd.	ML05	SW1 SW2	30 to 104	39	250 to 351	3,527	4 to 15	47
Pittwater Rd. to Riverview Pde.	ML01 ML04	SW3 SW4 SW5 SW6	11 to 257	26 to 1,132	228 to 739	1,357 to 2,087	≤20	24 to 63
Riverview Pde. to Passmore Res.	ML19 ML20 ML21	SW7	3 to 13	3 to 10	308 to 485	437 to 1,041	10 to 24	6 to 46

Sadat-Noori et al. (2021b) investigated the relationship between groundwater and surface water quality within Manly Dam. Using radon measurements they found that there was a clear signature for regional groundwater flow into the dam. Radon measurements also correlated to nutrient concentrations (nitrate and ammonia), that were observed within groundwater samples. This indicated that groundwater flow was a source of nutrients within Manly Dam, particularly on the western side.

A3 Monitoring, evaluation and reporting (MER) program

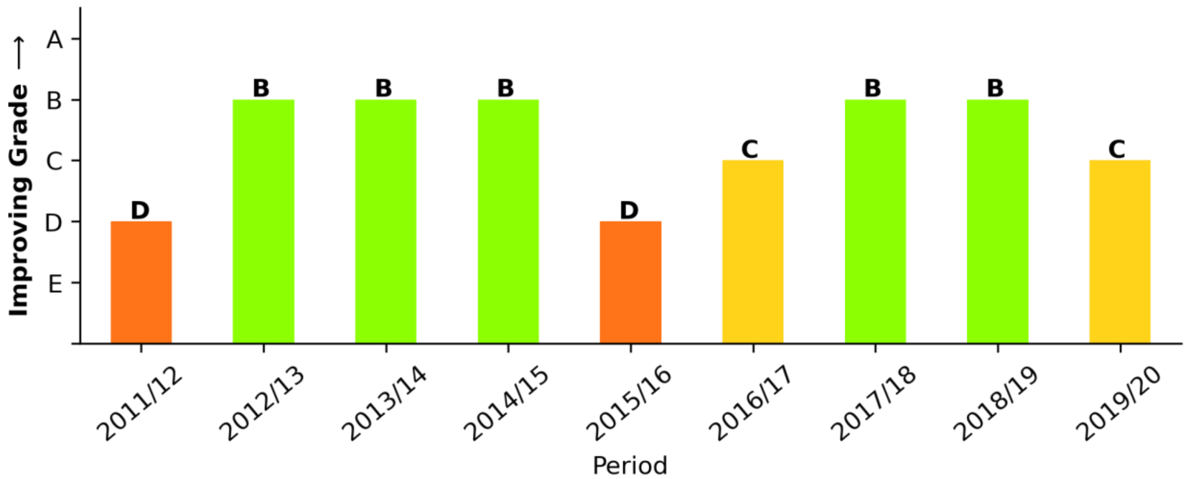
The monitoring, evaluation and reporting (MER) program was developed by the NSW Government to guide efforts in managing the natural resources of NSW (DECCW, 2010). This program has been implemented for a number of natural resource targets, including estuaries and coastal lake ecosystems.

Roper et al. (2011) completed a study to determine a baseline condition for NSW estuaries (including Manly Lagoon) and describe methods for collecting, analysing and interpreting data to compare estuaries against a baseline. Turbidity (clarity) and chlorophyll–a (algae) were used as key indicators of water quality that could be used to compare estuaries. Using these parameters Roper et al. (2011) developed a number of reference levels which could be used as a baseline from which the health of an estuary can be compared to. OEH (2016) reviewed these reference levels and have more recently updated them using additional data. This updated grading system is outlined in Table A.4.

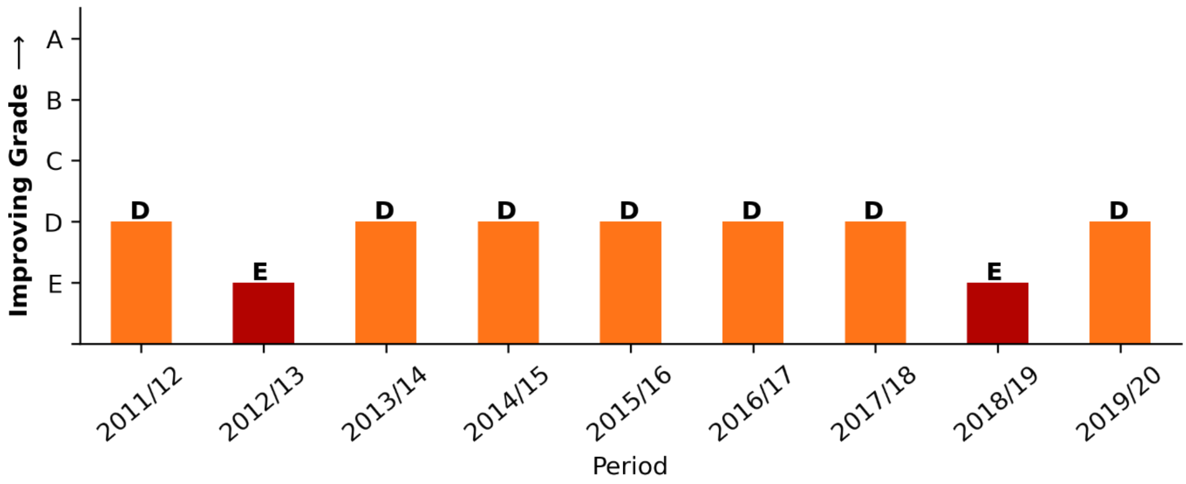
A.4: MER program estuaries report card grading (OEH, 2016)

Grade	Result	Definition (Example)	Description
A	Very good	The indicators measured meet all of the benchmark values for almost all of the time period.	Equivalent to the best 20% of scores in the state
B	Good	The indicators measured meet all of the benchmark values for most of the time period.	Equivalent to the next 30% of good scores
C	Fair	The indicators measured meet some of the benchmark values for some of the time period.	Equivalent to the middle 30% of scores
D	Poor	The indicators measured meet few of Ethe benchmark values for some of the time period.	Equivalent to the next 15% of poorer scores
E	Very poor	The indicators measured meet none of the benchmark values for almost all of the time period.	Equivalent to the worst 5% of scores in the state

With limited turbidity data available, Roper et al. (2011) was only able to assess Manly Lagoon using the Chlorophyll-a water quality indicators. Their findings graded Manly Lagoon as poor for this analysis. Since this initial investigation, the MER program has commenced and there is now considerable data for comparing estuaries. Northern Beaches Council has collected turbidity and chlorophyll-a data in Manly Lagoon since 2011. This data has been compared to the grading criteria outlined by OEH (2016) and is shown in Figure A.13 and Figure A.14 for turbidity and chlorophyll-a, respectively.



A.13: Grading of turbidity within Manly Lagoon as compared to other NSW estuaries



A.14: Grading of chlorophyll-a within Manly Lagoon as compared to other NSW estuaries

Review of the turbidity and chlorophyll-a data for Manly Lagoon shows the following trends:

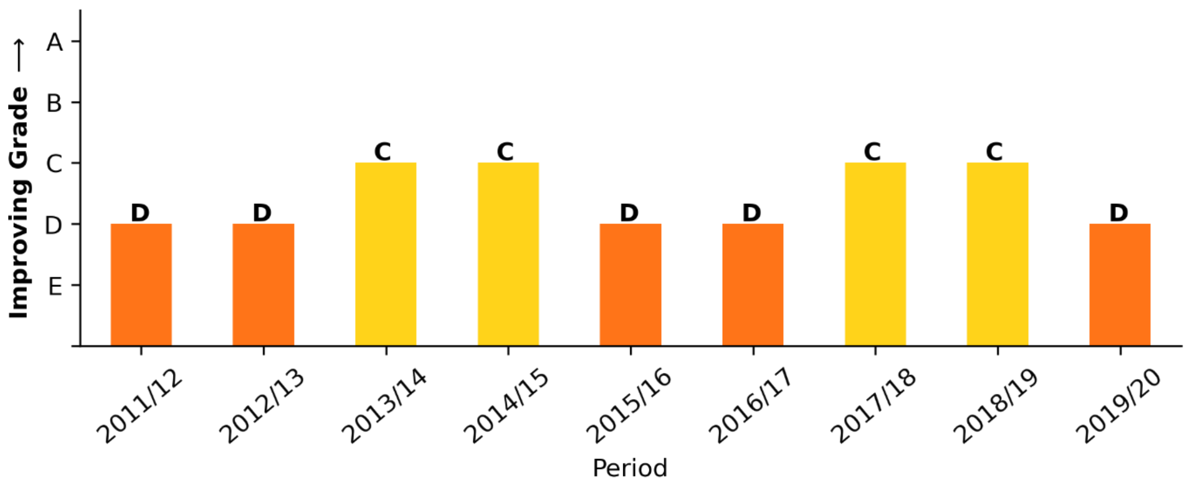
Turbidity:

- The turbidity levels within Manly Lagoon grades from good to poor
- The grade of turbidity has been decreasing in the long term
- Turbidity declines following catchment inflows
- Turbidity is linked to rainfall with good water quality being linked to low rainfall

Chlorophyll-a:

- The chlorophyll-a levels within Manly Lagoon grades from poor to very poor
- Higher levels of chlorophyll-a are observed further away from the entrance of the lagoon to the ocean
- High chlorophyll-a levels are suspected to be caused by high levels of nutrients in the lagoon
- In the long term, chlorophyll-a levels in the lagoon have remained stable

The overall score for Manly Lagoon is shown in Figure A.15.



A.15: Overall grading for Manly Lagoon as compared to other NSW estuaries

Manly Lagoon has been consistently graded as fair to poor over the last 10 years meaning it typically has worse water quality than 50% of all other estuaries in NSW. No distinct long-term trends (either improving or worsening) in water quality have been observed.

Turbidity and chlorophyll-a were used to assess the water quality of NSW estuaries. As part of their study, Roper et al. (2011) also assessed the condition of NSW estuaries based macrophyte and fish data (in addition to turbidity and chlorophyll-a) and the pressures faced by NSW estuaries based on the following indicators:

- Cleared land
- Population
- Sediments
- Nutrients
- Freshwater flow
- Disturbed habitat
- Tidal flow
- Fishing

Each estuary in NSW was then given both a condition rating and a pressure rating. Manly Lagoon was given a very poor condition rating and pressure rating of high. In comparison out of 101 estuaries assessed for condition (there was insufficient data for 83 estuaries), only three were given a very poor rating and out of 184 estuaries assessed for the pressures they face, only 11 were given a high rating.

In addition to monitoring turbidity and chlorophyll-a, Northern Beaches Council has also consistently monitored for the following water quality parameters during its MER program since 2011 (unless otherwise specified):

- Temperature
- Salinity
- Dissolved oxygen (since 2016)
- pH (since 2016)
- Blue green algae (since 2016)
- Fluorescent dissolved organic matter (fDOM) (since 2016)
- Nutrients (ammonia phosphorus, NOx, total dissolved phosphorus, total dissolved nitrogen, total phosphorus and total nitrogen) (since 2007)
- Silica (2007 – 2017)
- Urea (2016 - 2019)
- Enterococci (since 2014)

A4 Flooding

Understanding the risk which Manly Lagoon floodplain is exposed to through flooding allows for appropriate planning and risk mitigation measures to be put in place for the catchment. The Manly catchment is highly urbanised with many residential and commercial developments located on the banks and floodplain surrounding the lagoon that are susceptible to flooding. A number of investigations have been completed to assess flooding in the catchment, including:

- Manly Lagoon flood study – Manly Hydraulics Laboratory (MHL, 1992a)
- Manly Lagoon flood study – BMT WBM (Lyons and Eggleton, 2013)

- Manly Lagoon floodplain risk management study and plan – WMA Water (Harrison et al., 2018)

During each of these studies, numerical models were developed to simulate flooding conditions. MHL developed a one-dimensional (1D) model of the lower lagoon during their study. This investigation highlighted that the connection of Manly Lagoon to the ocean plays a key role in influencing flooding in the catchment. It was also determined that the control of peak flooding levels could be driven by either raised ocean levels (as might occur due to storm surge etc.) or by catchment inflows. The antecedent levels of Manly Dam were also identified as an influencing factor on flood levels.

The flood study completed by MHL (1992a) was superseded by a two-dimensional (2D) numerical model created by Lyons and Eggleton (2013). This model encompassed the entire Manly Lagoon catchment (including upstream sections of Curl Curl Creek, Burnt Bridge Creek and Brookvale Creek), as well as the complex urban drainage network that services the area. As the entrance of the lagoon to the ocean was identified as a key control on flooding, Lyons and Eggleton (2013) incorporated simulations of the changing sand berm and its influence on flows into the model. A number of climate scenarios were also modelled to assess the impacts of sea level rise and changes to the intensity of rainfall. Key findings from this investigation included:

- Flood levels were slightly higher than previously estimated (believed to be due to the way the entrance was modelled)
- Catchment runoff events tend to cause more severe flooding than flood events controlled by increased ocean levels
- Flood waters tend to rise rapidly at the beginning of flood events
- The management of the entrance to Manly Lagoon (i.e. opening schedule) can influence flooding
- Events with a 20% annual exceedance probability (AEP) will cause significant inundation
- The critical storm duration to cause maximum flooding was found to be between two to nine hours
- Climate change is expected to make flooding worse

Harrison et al. (2018) updated the numeric model to assess a number of flood mitigation measures (38 in total) for reducing the impact of flooding in the Manly catchment. Their model incorporated an updated urban stormwater network and an approximation of entrance conditions. Reanalysis of flooding found that the critical storm duration was two hours for the entire catchment. It also found that the peak flood levels in Brookvale and Manly Vale commercial areas were less due to changes in modelling of the urban drainage.

Of the flood mitigation measures proposed, 15 were recommended for implementation based on economic, social and environmental criteria. Of these a number revolved around planning and management changes, while changes to infrastructure was limited to:

- Construction of a 90 metre long levee at Clearview Place
- Changes to the operation of Manly Dam

MHL (1992a) and Lyons and Eggleton (2013) concluded that the entrance of the lagoon was a key control that influenced flood levels. MHL also noted that the Stuart Somerville Bridge was a control during flood conditions. Modelling by Harrison et al. (2018) considered dredging of the lagoon entrance upstream and downstream of the bridge to improve drainage efficiency, however, due to the scale of inflows it was found that there was minimal change to flooding. An option was also considered to lower the rock weir at the entrance of the lagoon by 0.4 m to improve drainage efficiency. This option was also found not to be effective with only small reductions in water levels downstream of the Pittwater Road bridge.

Harrison and Rayner (2019) also assessed the implications of reducing the height of the rock weir at the entrance to Manly Lagoon. Using an approximate model it was found that decreasing the level of the weir could alleviate impacts from more frequent flood events. It was noted however that decreasing the weir also resulted in higher tides within the lagoon and that further modelling specifically addressing flooding should be completed to assess this option.

In recent years there have been a number of large scale projects that have begun planning or have been completed in the Manly Lagoon catchment. These include:

- Northern Beaches Hospital
- Northern Beaches Hospital road connectivity and network enhancement
- Beaches Link

All of these projects are located in the upper catchment and have had an environmental impact statement (EIS) completed for them. Included within this is an assessment of whether flooding will be impacted. It was found that the Northern Beaches Hospital would not impact on flooding due to the use of water sensitive urban design (WSUD) strategies (Stone, 2014). Investigations of the impact of Northern Beaches Hospital road upgrade project on flooding found that due to an increase in impervious areas an increase in flows (less than 10%) could occur in the upstream sections of Manly Creek. It was found that the scale of these inflows were unlikely to have any significant impact on flooding (GHD, 2015). The Beaches Link project involves the construction a bridge from Northbridge to Seaforth that will connect with Wakehurst Parkway and the Burnt Bridge Creek Deviation. Construction has not yet begun on the project however the EIS had assessed the impacts of the proposed work on flooding. It was found that, provided a number of flood mitigation measures are incorporated as part of the project, then flooding would not be impacted for any events with an annual exceedance probability (AEP) of less than 1% (Lyall and Associates, 2020). Note, the investigation also found that in some instances the impact of flooding on the Manly Lagoon catchment may be reduced.

A5 Bathymetry

Bathymetric surveys completed for Manly Lagoon have been summarised in Table A.5.

A.5: Summary of bathymetric surveys of Manly Lagoon

Surveyor	Survey date	Notes
D. Cheng	1985	Scattered depth measurements throughout the lagoon. No datum specified. Measured to water level estimated to be approximately 0.3 m AHD (PBP, 1995)
Manly Hydraulics Laboratory	1992	14 cross-sections from Lagoon Park to Nolan Reserve used for input to a flood model (MHL, 1992a)
Patterson Britton and Partners	1992	Scattered depth measurements taken throughout Manly Lagoon during soil sampling, not referenced to a datum (PBP, 1995)

Surveyor	Survey date	Notes
UNSW Water Research Laboratory	2001	King et al. (2002) collected bathymetry data to supplement existing field measurements for the development of a numerical model.
Bee and Lethbridge	2002	Lagoon entrance only (CMS, 2015)
Bee and Lethbridge	2006	Lagoon entrance only (CMS, 2015)
Astute Surveying	2011	Converted to a digital elevation model (DEM) for sections between the entrance and Kentwell Road (provided by Northern Beaches Council)
CMS Surveyors	2015	Lagoon entrance only (CMS, 2015)
UNSW Water Research Laboratory	2019	103 cross-sections from the entrance to 250m upstream of Kentwell Road (Harrison and Rayner, 2019)

In 2015, CMS completed a survey that focussed on the entrance of Manly Lagoon. The purpose of the survey was to identify the location of bedrock at the entrance and also compare changes in bathymetry with previous surveys. Bedrock at 0.2 m AHD was determined to be the flow control across the entrance. Comparison of bathymetric surveys since 2002 found the following:

- 2002 to 2006: General accretion of sediment on the south and scour of sediment on the north of the entrance channel
- 2006 to 2011: Accretion in the northern section of channel
- 2011 to 2015: Erosion of sand across the entrance opening (with a net loss of approximately 1,134 m3). Total volume of sand in the entrance as of 2015 was approximately 7,040 m^3

Cross-section measurements taken by MHL (1992a) have been compared to those measured in 2011 and provided by Northern Beaches Council. The following observations can be made:

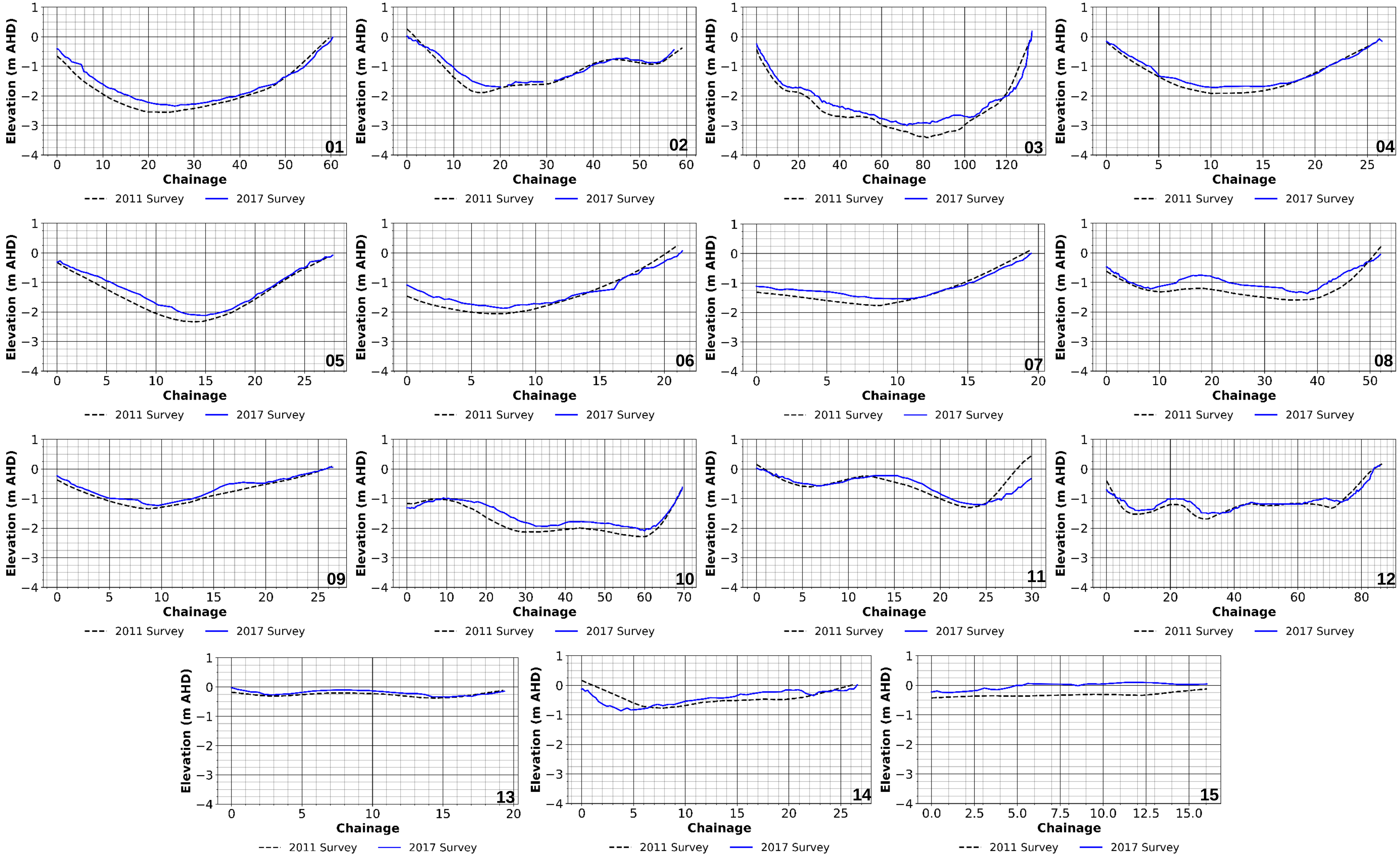
- Between 1992 and 2011 there was a general accretion of sediment from the lagoon entrance to Riverview Parade
- The banks of Manly Lagoon on Hinkler Park have been eroded since 1992
- There has been minimal change in the sediment between Riverview Parade and Passmore Reserve
- Upstream of Passmore Reserve there has been a general accretion of sediment

Bathymetry measured in 2011 has also been compared to recent measurements taken in 2017 by Harrison and Rayner (2019). Figure A.16 shows the cross-section locations where bathymetry data has been compared and Figure A.17 shows the comparisons between the two datasets. Note, measurements were gathered using an echosounder which can only take measurements underwater so the banks of the lagoon are not shown in Figure A.17.

A.16: Location of cross-sections where 2011 and 2017 data was compared

The following observations can be summarised from comparison of the datasets:

- There was generally an increase in sediment between 2011 and 2017 throughout the lagoon
- At cross-sections 11 and 14 there was some erosion near the banks



A.17: Comparison of bathymetry measurements between 2011 and 2017 (see locations in Figure A.16)

A6 Influence of the entrance

Manly Lagoon connects with the ocean on the southern side of Queenscliff headland. There is a natural rock weir that is located at approximately 0.2 m AHD which controls water levels in the lagoon. Sand also accretes on top of this underlying bedrock to create a berm that can build up to prevent the ocean from flowing into the lagoon during high tides.

Low-flow pipes have been constructed on the northern side of the lagoon entrance. These allow tidal water to flush the lagoon when the sand berm is at a high level. Two 1.8 m diameter pipes with an invert of -0.71m AHD were originally constructed in 1916 connecting a channel on the upstream side with an invert at approximately 0 m AHD to the ocean on the downstream side (PBP, 1995; Harrison and Rayner, 2019). The pipes originally had a drop board structure on the downstream side that could be closed to prevent the build-up of sand within the pipe structures (PBP, 1995).

In 1999 the floodgates were removed and the low-flow pipes extended to the end of the ocean pool through the construction of an additional rectangular culvert section. The purpose of this was to prevent the build-up of sediment and blockage of the low-flow pipes (MHL, 1992b). It was noted by PBP (1995) that the blockage of the pipes would impact flooding in the lagoon (as water levels would increase) and water quality (as there would be reduced tidal flushing).

In addition to the low-flow pipes, Northern Beaches Council maintains a channel along the beach that can be broken out in the event of a flood (Figure A.18) (Lyons and Eggleton, 2013; Harrison and Rayner, 2019). Historically, the protocol for this channel was for the berm on the beach to be excavated should the lagoon water levels reach 1.4 m AHD, however, this protocol has been modified and opening of the lagoon is now determined using the Manly "LagoonWatch" system (Lyons and Eggleton, 2013). This system incorporates data gathered from lagoon water levels with rainfall and flood predictions to determine the optimal time to open the lagoon. This generally occurs when the water levels in the lagoon are between 1.0 and 1.4 m AHD and there is a difference between the lagoon and ocean water levels greater than 0.6 m (Lyons and Eggleton, 2013).

The impact of the entrance conditions on water quality in Manly Lagoon has been assessed on a number of occasions (PBP, 1995; WRL, 2016). In their review, PBP (1995) noted the following recommendations had been made for the entrance to improve water quality:

- Improve the connectivity of the lagoon to the ocean through modifications to the low-flow pipes
- Improve mixing within the lagoon by modifying and upgrading culverts under Pittwater Road to the south of Hinkler Park
- Permanently opening the main channel of the lagoon to the ocean to increase connectivity with the ocean

These options were suggested to improve water quality through:

1. Increasing tidal exchange which would dilute poor water within the lagoon with ocean water
2. Promoting mixing in the lagoon to prevent stratification and further build-up of poor quality water

Note that since these recommendations, the work to extend the low-flow pipes has been completed.

The effectiveness of the low-flow pipes at improving water quality has been monitored on a number of occasions, however, evidence of an improvement in water quality has been inconclusive (PBP, 1995;

WRL, 2016). It is clear that rainfall events have a significant impact on the highly variable water quality within the lagoon and that the low-flow pipes do have an effect to moderate the variability of water quality (WRL, 2016).

A.18: Channel across the beach used for flood mitigation (21/01/2021) (source: Nearmap)

Harrison and Rayner (2019) completed an investigation to determine how excavating sand in the entrance of the lagoon and lowering the rock weir would impact water levels in the lagoon. During their field investigations they found that approximately 0.3 m of sediment had accreted on top of the bedrock at the entrance creating a weir at approximately 0.5 m AHD. Using this as a base case they then used a numerical model (RMA) to simulate lowering the weir to 0.2 AHD (i.e. the level of the rock weir) and then further to -0.2 m AHD (requiring excavation of rock). Their study quantified the following findings:

- Lowering the weir from 0.5 m AHD to 0.2 m AHD would result in the volume of water that enters the lagoon from the ocean increasing from approximately 11% to 33%
- Lowering the weir would result in lower water levels across the lagoon and has potential to expose mudflats
- Lowering the weir would decrease the time it takes for salinity to enter back into the estuary following a flood event (where it is flushed with fresh water)
- Lowering of the weir could result in additional scour and mobilisation of bed sediments
- If the weir is lowered when the lagoon is open to the ocean across the beach there is an increased tidal range
- Lowering the weir would likely reduce the flood peak during small catchment events (e.g. 63% AEP events), but would not have a large impact on overall drainage times

Harrison et al. (2018) utilised a flood model to identify opportunities to reduce the impact of flooding in Manly Lagoon. They identified two options for modifying the lagoon entrance:

1. Extend the concrete channel upstream of the low-flow pipes to upstream of the Stuart Somerville Bridge
2. Lower the rock weir at the entrance from 0.2 m to approximately -0.2 m AHD

Using a numerical model (TUFLOW) they assessed the impacts of these options for a 5% and 1% AEP event. They found that by extending the channel upstream of the low-flow pipes that a reduction in the flood peak of up to 0.02 m would occur. There was negligible changes to the flood peak observed by reducing the rock weir.

Investigations into the effectiveness of dredging the entrance of Manly Lagoon for improving water quality have been completed by Wiecek et al. (2006) and Wiecek and Floyd (2007). These investigations analysed tidal harmonics to find that dredging open the entrance at Manly Lagoon was only effective at increasing flushing of the lagoon when large volumes of sediment were removed (>6,000 m^3) and the entrance channel across the beach opened to allow additional tidal inflow. It was also observed that breakouts from the lagoon caused by flooding had a similar impact on tidal flushing of the lagoon (i.e. opening the additional channel across the beach). These investigations show that the sedimentation at the lagoon entrance has limited impact on the operation of the low-flow pipes.

In recent years studies across the lagoon have also been assessing the effects of the entrance conditions on the nutrient and carbon cycles within the lagoon. Filippini et al. (2019) recently compared the bacterial diversity in Manly Lagoon to other intermittently closed and open lakes and lagoons (ICOLLs) on the Northern Beaches of Sydney. They found that Manly Lagoon, which is generally open to the ocean due to the low-flow pipes, had a high bacterial diversity postured to be a result of its constant connection with the ocean and high nutrient loading.

A7 Nutrient and carbon cycling within estuary sediments

Nutrients such as nitrogen and phosphorus are important for the growth of organic material in estuaries. This is because the level of nutrients often limits the growth of plants due to its lack of availability (Smith et al., 1999). When there is a sudden high abundance of nutrients in an estuary, such as nitrogen and phosphorus, this can lead to the excessive growth of plants known as eutrophication. This can have negative impacts on the environment such as (Smith et al., 1999; ANZECC and ARMCANZ, 2000):

- Growth of toxic microorganisms
- Reduced water clarity and decreased aesthetic value
- Increased likelihood of animal mortality
- Depletion of oxygen
- Increased pH levels
- Accumulation of toxins in aquatic food consumed by humans

Linked to the nutrient cycle is the carbon cycle. As plants grow, in addition to the uptake of nutrients, they sequester carbon dioxide during photosynthesis. This carbon, along with nutrients, can then be transferred to sediment through the roots of plants or through their decomposition (Bauer et al., 2013). Subsequently, understanding the carbon and nutrient cycling within the sediments of an estuary is an important factor for understanding the nutrient loading of the waterway.

Sediment samples within Manly Lagoon have been collected on a number of occasions. Early sampling focused on the identification of sediment particle type and also contaminants within the lagoon (such as heavy metals) (PBP, 1995). Data presented by PBP (1995) outlining these early investigations looking at the sediments of Manly Lagoon found that high levels of organic nitrogen (i.e. from organic matter) was present in lagoon sediments and that a lack of oxygen in the sediment prevented nitrification, the process where these nitrogen compounds are converted back into nitrogen gas (N2). Overall the levels of nitrogen observed were considered moderate to high in comparison to phosphorus which was only measured in low quantities within sediment.

Eyre and Ferguson (2002) completed a detailed study assessing the transport of nutrients and carbon into and out of sediments from plants in an estuary. When plants decompose in the sediment of the estuary the nutrients are released. It was found that generally phosphorus was trapped within sediments unless the sediments were deprived of oxygen (i.e. they became anoxic). On the other hand, nitrogen would either be converted to nitrogen gas (N2) which is stable and generally cannot be used by plants or converted into nutrients that plants could utilise to grow (e.g. ammonium/NH4). Eyre and Ferguson (2002) found that when there was larger ratios of carbon being decomposed, this would result in nitrogen being released in the form that provides nutrients for plans. This shows how the carbon cycle within the estuary can have an impact on eutrophication, particularly for Manly Lagoon which was found to have the highest concentrations of carbon, nitrogen and phosphorus out of all coastal lagoons assessed.

Using a different approach, Filippini et al. (2019) studied the impacts of the nutrient cycle on bacteria living in the sediments of Manly Lagoon. These bacteria were then compared to others in the sediments of further ICOLLs located on the Northern Beaches of Sydney. It was found that the high nutrient levels within Manly Lagoon corresponded to a diverse range of bacteria in the sediments. Narrabeen Lagoon, a much larger ICOLL that is not open to the ocean as often as Manly Lagoon, had similar diversity. This indicated that it is possible that the link to the ocean could also drive a high diversity of bacteria in lagoon sediments. Despite this, Manly Lagoon showed other trends that correlate to a system that is in the latter stages of eutrophication with the diversity of bacteria decreasing further from the entrance. The rational for this was that in extreme environments (i.e. high nutrient loading in the sediments) only a few types of bacteria can tolerate the conditions. Other observations made by Filippini et al. (2019) found that Manly Lagoon was generally more degraded than other ICOLLs. This observation was made as certain types of bacteria, such as ones that thrives in anaerobic (i.e. no oxygen) conditions, were more abundant in Manly Lagoon sediments, which generally occurs when there is an abundance of organic matter breaking down.

Filippini et al. (In Prep.) furthered this work by gathering sediment samples from Manly Lagoon to analyse the carbon and nutrient cycles in the lagoon sediments. They found that Manly Lagoon is under high stress with high levels of carbon present in the lagoon sediments. They also found that the lagoon sediments are generally anaerobic (i.e. there is no oxygen) and bacteria in the sediment feed off carbon (or organic materials). The source of this carbon was found to be from local eucalyptus and exotic platanus leaf litter. Under these conditions phosphorus and nitrogen (in the form of ammonia NH3+) is released back into the estuary exacerbating any eutrophication. Filippini et al. (In Prep.) concluded that the urbanisation of catchments, like what has occurred for Manly Lagoon, stresses the waterway by contributing to nutrient loading further highlighting the importance of the nutrient and carbon cycles for the health of the estuary.

A8 Catchment runoff and surface water quality

Manly Lagoon is the receiving water body for three separate catchment areas, all of which influence the water quality within the lagoon:

- Burnt Bridge Creek
- Curl Curl Creek, Manly Dam and Manly Creek
- Brookvale Creek

Historically there have been a large number of investigations that have measured water quality within Manly Lagoon and also the catchments that feed into it. Where this data has been available it has been collated, summarised and presented in Table A.6. There are a number of studies that are not publicly accessible and include data on catchment and lagoon water quality. Note literature reviews which have assessed and summarised the findings of these studies were completed by PBP (1995), UWS (2004) and Dykman (2017).

The following overarching trends in water quality have been observed during the review of available literature for Manly Lagoon and its catchment (Table A.6):

- High levels of nutrients exceeding environmental guideline levels have continuously been measured in the catchments with multiple sources speculated including: stormwater, sewage overflows and fertilisers
- Heavy metals have been measured in the catchment above guideline levels (including lead, copper iron and zinc)
- Water quality within Manly Lagoon has consistently been rated as poor based on a range of water quality measurements

In addition to the monitoring that has been completed for the Manly Lagoon catchment, DEC (2006) developed water quality objectives (WQOs) for the lagoon and also catchment upstream of Manly Dam. These objectives were designed to set out long-term goals for community values of the waterways. For Manly Lagoon, this strategy aims to protect:

- Aquatic ecosystems
- Visual amenity
- Secondary contact recreation
- Aquatic foods (cooked)

In the upstream catchment of Manly Dam the objectives also seek to protect primary contact recreation. Guidance is provided for meeting these objectives in terms of trigger levels for various analytes which are generally based upon the ANZECC and ARMCANZZ (2000) guidelines.

There are a number of other programs that are relevant for assessing the water quality in Manly Lagoon, with different focuses, including:

- Beachwatch water quality program
- Streamwatch
- Monitoring, evaluation and reporting (MER) program (see Section A3)

The beachwatch program was established in 1989 at Queenscliff Beach to monitor the quality of ocean water for the purpose of recreation (DPIE, 2021). Note, this is the site where Manly Lagoon discharges. The program assessed the likelihood of contamination of ocean water being contaminated with sewage based on daily environmental conditions and water samples (taken every six days) which are tested for enterococci. In the most recent assessment of yearly conditions, Queenscliff Beach was given a rating of good indicating it is generally unsuitable for swimming for up to one day following heavy rain (DPIE, 2020b).

The Streamwatch program was a historically run citizen science program that collected water quality data at six sites across the Manly Lagoon catchment between 2000 and 2015. Data collected included: temperature, phosphate, dissolved oxygen, pH, turbidity, nitrate, nitrite, ammonia and Escherichia coli. Note, often only the physical parameters were monitored. Sites monitored included Burnt Bridge Creek at Balgowlah Golf Course, Clontarf Street, Kitchener Street and Manly West Park as well as in Manly Lagoon at Keirle Park and the entrance to the ocean.

A.6: Review of available water quality data for Manly Lagoon

Source	Data location	Dates collected	Data type	Summary
Higgs and Johnson (1982)	Manly Dam; Tributaries of Manly Dam.	21/07/1981; 15/09/1981; 19/10/1981.	Ammonia, nitrite, nitrate, phosphorus	Large amounts of nitrate and phosphate were found in Curl Curl Creek sourced from the Aquatic Reserve Baseball Park (possibly from a leaking sewer), a sewage transfer station depot on Aquatic Drive, and a light industrial area on Aquatic Drive. Nutrients are diluted during wet weather conditions
Cheng (1992)	Manly Dam	Not specified	Orthophosphate, total phosphorus, total inorganic nitrogen, ammonia, turbidity, total suspended solids, pH	Locations responsible for high phosphorus and nitrogen runoff include: Wakehurst Golf Club, Allambie Heights, North Balgowlah and the western section of the upper catchment. These areas are generally more built up. Wakehurst Golf Club was determined to have the most direct effect on Manly Dam. Concentrations of nutrients were higher during wet weather sampling events.
PBP (1995)	Manly Lagoon	Various	Various	A detailed literature review outlining previous water quality investigations completed in Manly Lagoon and its catchment. Some of the data is presented within this report. It was determined that the main influences on water quality included: nutrient inflows following events from Brookvale and Burnt Bridge Creeks, stratification, lagoon entrance conditions, quality of coastal waters and sewage overflows.
Lim et al. (2001)	Manly Dam	Various	Various	A compilation of university research from UTS projects investigating water quality in Manly Dam. The studies found that heavy metals in sediments were below guideline values (with the exception of lead), water quality in the dam can be rated as fair to good based on fauna

Source	Data location	Dates collected	Data type	Summary
				surveys, management of nutrient runoff from Wakehurst Golf Club has improved, constructed wetlands across the upper catchment have varying degrees of success in treating runoff, and no adverse impacts were observed on wetland vegetation surrounding the dam.
Tate et al. (2003)	Manly Dam, Manly Lagoon	20/03/1992 – 01/05/2002	Ammonia, chlorophyll-a, dissolved oxygen, faecal coliforms, inorganic suspended solids, organic nitrogen, orthophosphate, oxidised nitrogen, pH, salinity, Secchi depth, temperature, total inorganic nitrogen, total nitrogen, total phosphorus, total suspended solids, turbidity, volatile suspended solids	This study collated existing water quality monitoring data and developed a database and reporting tool for water quality data within Manly Dam and Manly Lagoon. For the year of 2000 in Manly Lagoon it was found that pH and total phosphorus has an increasing trend. Ammonia, dissolved oxygen, orthophosphate, oxidised nitrogen, total nitrogen and total phosphorus levels were also rated as very poor for the year of 2000 when compared to guideline values.
Appleton (2004)	Curl Curl Creek, Brookvale Creek	Not specified	Total nitrogen, nitrate, nitrite, total phosphorus, reactive phosphorus, biological oxygen demand, total suspended solids, faecal coliforms	Nutrients and faecal coliforms were measured at levels higher than guideline specifications in Brookvale Creek. Nutrients were measured in Curl Curl Creek at high levels. Allambie Heights and Manly Vale were identified as possible sources of pollutants.
UWS (2004)	Manly Dam, Manly Lagoon	1975 – 2002	Various	Review of water quality monitoring that has been completed in the Manly Lagoon catchment. Nitrogen and Phosphorus have consistently been recorded above guideline values and generally increase following wet weather events. Dissolved oxygen is consistently recorded at levels that are ecologically dangerous within the lagoon.
Pygas (2011a)	Manly Lagoon	31/07/2019 – 7/08/2011	Temperature, salinity, pH, oxidation reduction potential, dissolved oxygen, turbidity, total dissolved solids, suspended solids, arsenic, cadmium, chromium, copper, lead, mercury,	Water quality monitoring was completed to assess whether dredging of lagoon sediment adjacent to Nolan Reserve impacted the health of the estuary. Monitoring found that

Source	Data location	Dates collected	Data type	Summary
			nickel, zinc, ammonia, nitrite, nitrate, total Kjeldahl nitrogen, total nitrogen, total phosphorus, chlorophyll-a, phenolic compounds, polynuclear aromatic hydrocarbons, total petroleum hydrocarbons, organophosphorus pesticides, organochlorine pesticides, enterococci	turbidity levels and ammonia levels spiked during dredging but returned to the background levels following completion. Overall nutrient levels measured throughout the campaign were at high levels.
McManus and Knights (2011)	Manly catchment	Various	Various	A study modelling catchment pollution based on a review of existing catchment input data and numerical modelling. Modelling indicated that 95% of nutrients entering the lagoon were sourced from urban stormwater (as opposed to sewage overflows) predominantly originating from impervious surfaces such as roofs and roads.
Roper et al. (2011)	Manly Lagoon	1994 – 2008	Salinity, temperature, dissolved oxygen, pH, Secchi depth, turbidity, chlorophyll-a total suspended solids, total nitrogen, total phosphorus, ammonia, oxidised nitrogen, dissolved inorganic nitrogen, dissolved inorganic phosphorus dissolved organic nitrogen, dissolved organic phosphorus, silicon	Water quality within Manly Lagoon was compared to that of other estuaries in NSW. Manly Lagoon was given a condition rating of “very poor” (i.e. in the worst 3% of all NSW estuaries assessed) and a pressure rating of “High” (i.e. in highest 6% of all NSW estuaries assessed).
GHD (2015)	Upper Manly Dam catchment	12/11/2014 – 10/03/2015	pH, redox potential, dissolved oxygen, temperature, phosphate, conductivity, total dissolved solids, total suspended solids, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, zinc, total recoverable hydrocarbons, BTEX, PAHs, major cations and anions, ammonia, nitrate, nitrite and phosphorus	Monitoring found that levels of copper, iron, zinc and nitrate were above guideline values. Exceedances in guideline levels for pH on two occasions were also noted.
WRL (2016)	Manly Lagoon	Various	Various	A literature review was completed to assess the impacts of dredging at the lagoon entrance on water quality. It was determined that there was limited evidence to support that dredging improved water quality, however, water quality was observed to degrade following rainfall events.

Source	Data location	Dates collected	Data type	Summary
				Flushing through the low-flow pipes was shown to moderate the variability of water quality in the lagoon.
Dykman (2017)	Manly catchment	Various	Various	A literature review was completed identifying and summarising previous investigations completed that collected water quality data within the Manly Lagoon catchment.
Filippini et al. (2019)	Manly Lagoon	Not specified	Temperature, salinity, turbidity, pH, dissolved oxygen, incidental radiation	Water quality parameters were measured during sediment sampling to assist in analysis of sediment data. They reviewed data collected by Roper et al. (2011) and found that bacterial communities can also be an indicator of estuary health.
WRL (2019)	Manly Lagoon	20/03/2019 – 25/03/2019	Temperature, dissolved oxygen, conductivity, pH, oxidation reduction potential, calcium manganese, sodium, potassium, sulphide, sulfate, alkalinity, nitrate, nitrite, ammonia, total dissolved Kjeldahl nitrogen, total Kjeldahl nitrogen, total dissolved nitrogen, total nitrogen, reactive phosphorus, total dissolved phosphorus, total phosphorus	Water quality measurements were taken at seven sampling locations across Manly Lagoon at the surface and bottom of the water profile following a large rainfall event (196 mm in 5 days). All nutrients sampled were well above guideline values for aquatic ecosystems.
DPIE (2020a)	Manly Lagoon	2011 – 2020	Ammonia, BGA-PE, chlorophyl-a, dissolved oxygen, enterococci, NOx, Phosphorus, specific conductivity, temperature, total Nitrogen, total Phosphorus, total dissolved Nitrogen, total dissolved phosphorus, turbidity, fDOM, pH	Analysis of data collected during the monitoring, evaluation and reporting (MER) program found that overall water quality in Manly Lagoon decreased from fair to poor between 2018/2019 to 2019/2020. This grading was given based upon statistical analysis of both turbidity and chlorophyll-a data grading as poor.
Jacobs (2020)	Burnt Bridge Creek, Manly Dam, Manly	31/10/2017 – 02/02/2018	Temperature, conductivity, pH, dissolved oxygen, turbidity, chlorophyll-a, total nitrogen, total phosphorus, total suspended solids, arsenic, cadmium, chromium, copper,	Water quality within Burnt Bridge Creek was determined to be poor with multiple parameters outside of guideline levels (dissolved oxygen, copper, zinc, lead, iron nitrogen and phosphorus). The water quality within Manly Dam was

Source	Data location	Dates collected	Data type	Summary
	Creek, Curl Curl Creek.		lead, nickel, zinc, mercury, manganese, iron, organic compounds	determined to be good with infrequent exceedances of guideline values associated with dissolved oxygen and nitrogen. Water quality within Manly Creek/Curl Curl Creek was usually found not to meet guideline criteria with exceedances related to dissolved oxygen, nitrogen, copper and zinc.

A9 Community engagement

A number of community engagement activities that relate to Manly Lagoon have taken place including:

- Recreational use survey (Micromex, 2011)
- The Manly Dam project
- Streamwatch
- Flood study community consultation
- Integrated Catchment Management Strategy (ICMS)
- Northern Beaches Local Strategic Planning Statement (LSPS) (NBC, 2020)

In 2011, Micromex (2011) completed a recreational and user survey for Manly Lagoon. They surveyed residents of the Local Government Area and users of Manly Lagoon to identify their thoughts regarding the following topics:

- Usage of Manly Lagoon
- Water quality and dredging of the lagoon
- The future of the lagoon

Overall, the community identified improvement of the existing recreational areas of Manly Lagoon should be a focus for council. Only 40% of respondents to the survey knew that the lagoon was being dredged, however, the majority of respondents felt dredging would be positive for the lagoon. Respondents generally agreed that the lagoon was not safe to swim in. Despite this the survey indicated that improving the lagoon so it would become a safe place to swim and/or kayak was not a community priority.

In 2019, Northern Beaches Council partnered with the Manly Art Gallery and Museum and WRL to sponsor the creation of eight contemporary artworks. These artworks were inspired by place, history, water management and engineering based on the Manly Dam landscape. They acknowledged the rich Aboriginal cultural significance of the Dam and the area's European history with stories of social and recreational activity.

The Manly Lagoon Streamwatch was a community led citizen science water quality monitoring program that ran from 1995 to 2017 on a weekly basis in partnership with Sydney Water. During this time the Manly Environment Centre community group sampled water quality within the Manly Lagoon tributaries at five sites:

- Burnt Bridge Creek at the Balgowlah Golf Course dam
- Burnt Bridge Creek at Clontarf Street
- Burnt Bridge Creek at Kitchener Street
- Manly Lagoon at Keirle Park
- Manly Lagoon at the ocean entrance

Water quality measurements sampled by Streamwatch at each site included:

- Phosphate
- Dissolved oxygen
- pH
- Electrical conductivity
- Turbidity

- Niotrate
- Ammonia
- Escherichia Coli

As part of the Manly Lagoon flood study Lyons and Eggleton (2012) conducted extensive community consultation involving media releases, an information website, a community questionnaire, an information session and a public exhibition. Throughout this process the Manly Lagoon community was successfully engaged and provided the following feedback (Lyons and Eggleton, 2012):

- There were concerns flood mapping would affect property value and insurance premiums
- Entrance management was identified as a potential mechanism to reduce flood risk
- Dredging was identified as a potential method to reduce flood risk
- Structures were identified as important for impeding flow and controlling flood levels
- There were concerns regarding what is required as part of the flood emergency plan
- There were concerns regarding flood related development controls
- Ongoing consultation regarding flooding was requested
- Bank erosion and drainage maintenance were also identified as problems

UWS (2004) developed 22 strategies for the management of Manly Lagoon based on community values and the previously developed ICMS created by Northern Beaches Council (formerly Manly Council) and Sydney Water. The development of the strategies was heavily based on the review of pre-existing community consultation workshops. Four long-term goals for the management of the catchment were identified (UWS, 2004):

- "*Water quality, velocities and flows, and waterway features that protect ecosystems and sustain community desired values for public health and recreation.*
- *Open space, natural landscape features and waterways can support on-going high quality passive and active recreation and related community education.*
- *Natural resources are managed and conserved to enhance and sustain desired biodiversity, heritage and other catchment values.*
- *To enhance the pursuit of the Goals 1, 2 and 3 through ongoing 'state of the art' integrated and adaptive management of the catchment and its resources".*

UWS (2004) developed nine objectives to achieve these goals with a further 22 strategies defining specific actions to achieve the objectives. These strategies were designed to meet community expectations and also continue the existing ICMS developed by Northern Beaches Council and Sydney Water. UWS (2004) also recommended that ongoing community consultation continue.

In 2020, Northern Beaches Council released its LSPS outlining the 2040 strategy for the local government area (NBC, 2020). A key part of this strategy identifies a number of priorities for the Northern Beaches landscape. The first priority is for healthy and values coasts and waterways. For Manly Lagoon, the protection of aquatic ecosystems and secondary contact recreation are identified as goals with a 5 to 10 year timeframe. Primary contact recreation is identified as a >10 year goal while visual amenity goals of the lagoon have already been achieved.

Northern Beaches Council regularly consults with the community regarding management of the Manly Lagoon. It is understood that an updated survey to identify how the community uses the lagoon is currently being completed. The results of this survey are not publicly available.

A10 Coastal management

Coastal management of the Manly Lagoon has previously been investigated and outlined on two occasions:

- 1995 Manly Lagoon estuary management study (PBS, 1995)
- 2004 Manly Lagoon and catchment ICMS and evaluation (UWS, 2004)

The Manly Lagoon estuary management study, completed by PBS (1995) aimed to:

- "*Protect and conserve estuarine habitats and ecosystems*
- *Prevent future degradation and undertake repair of past damage*
- *Achieve ecologically sustainable use of estuarine resources*
- *Conserve aesthetic values of estuaries and wetlands"*

PBS (1995) completed a detailed investigation into the lagoon processes and identified an extensive list of management actions that would achieve the estuary management aims outlined above. These included actions that targeted pollution at its source, remediated the catchment tributaries and remediate the lagoon. A Manly Lagoon estuary management plan was developed using the study findings, however, this has been superseded and is not publicly available.

In 2004, the ICMS for Manly Lagoon was developed by Northern Beaches Council (formerly Manly Council), Sydney Water and the local community. The strategy aimed to achieve (UWS, 2004):

- Aquatic ecosystem and associate wildlife protection
- Secondary recreational contact in the Manly Lagoon tributaries
- Primary recreational contact in Manly Lagoon

UWS (2004) distilled these into one clear vision:

> *"Water quality in Manly Lagoon and feeder streams that sustains the natural ecosystem and support public health in swimming and recreation"*

Subsequently, UWS (2004) completed an extensive review of the existing Manly Lagoon catchment management. This resulted in four goals, comprising six objectives for how to achieve the vision for Manly Lagoon. Twenty-two (22) strategies were then developed and each of the 482 existing activities that were ongoing across the lagoon were assigned to a strategy. Goals, objectives and strategies outlined in the ICMS for Manly Lagoon are shown in Table A.7. This allowed for clear direction regarding the ongoing management of Manly Lagoon.

In 2006 an implementation plan was developed and specified 84 actions regarding the ongoing management of Manly Lagoon to be addressed by major projects. These were reviewed in 2012 with the following findings:

- 47 activities that were completed or terminated (as the action would no longer achieve the designated strategy/objective)
- 33 activities that were ongoing
- 2 activities that were yet to commence
- 2 activities that were unfeasible

A.7: ICMS goals, objectives and strategies (UWS, 2004)

Goal	Objective	Strategy
Water quality, velocities and flows, and waterway features which protect ecosystems and sustain community desired values for public health and recreation.	To improve and then maintain the quality of water entering Manly Lagoon by long-term improvements in urban runoff and creeks.	More clearly identify sources of pollution.
		Increase resource commitment to enforcement and assessment activities.
		Increase water conservation and water re-use practices to reduce run-off and stormwater flows.
		Reduce erosion and suspended sediment loads within waterways.
		Reduce urban and industrial pollutants including green waste, oils and nutrients in stormwater runoff.
		Reduce sewer overflows, infiltration and exfiltration from sewerage.
	To maintain and enhance waterway features, flows and tidal interchange of the Lagoon.	Improve tidal exchange and water flows within the lagoon.
		Address issues of water quality and flooding in the lagoon.
	To maintain and enhance waterway features and return creek corridors and channels to a more natural state.	Restore environmental flows where possible.
		Restore, to the extent practicable, creek channels to a more natural state in terms of channel form, bank stability, habitat features and pollution assimilation capability (include existing concrete lined drains).
Open space, natural landscape features and waterways can support on-going high quality passive and active recreation and related community education.	To protect catchment values and manage natural settings and open space to facilitate appropriate recreation and tourism and act as an educational resource.	Mitigate adverse impacts of stormwater on all remnant bushland areas.
		Minimise adverse impacts of stormwater management facilities on public safety.
		Improve access and provide facilities to enable appropriate recreational pursuits and educational use.

Goal	Objective	Strategy
Natural resources are managed and conserved to enhance and sustain desired biodiversity, heritage and other catchment values.	To manage and control, where practicable and beneficial, introduced species having adverse impact on native flora and fauna and catchment values.	Control weed sources and feral animals in riparian corridors and the catchment generally.
	To maintain, and rehabilitate where practicable, natural habitats along waterways and throughout the catchment.	Manage and rehabilitate bushland habitats, building corridors between remnants.
		Maintain and enhance riparian corridors, and other freshwater and estuarine ecosystems.
	To manage and enhance native vegetation environment to ensure viability.	Adopt land use and environmental planning measures and practices to minimise adverse impacts on native animals and vegetation, particularly within urban areas.
	To acknowledge and protect Australian cultural values and heritage sites.	Involve Aboriginal community in management and conservation of cultural assets.
		Educate the community on the need to value, protect and support cultural values and heritage features.
To enhance the pursuit of the Goals 1, 2 and 3 through ongoing ‘state of the art’ integrated and adaptive management of the catchment and its resources.	To adopt an integrated and adaptive approach to the management, human use and arising impacts on the values of natural and built resources.	Continue broad based public education and community and industry support in catchment management.
		Pursue and support integrated approaches to catchment management.
		Develop and implement integrated monitoring frameworks for all aspects of catchment management