Tuggerah Lakes Water Quality

Independent Expert Panel Review

December 2020

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Executive summary

Overview

This report details information regarding the water quality of Tuggerah Lakes as undertaken by an independent expert panel appointed by the NSW Minister for the Environment. The information reviewed and incorporated within the report was prioritised based on input and feedback provided by the community, business and government stakeholders. This input focused the review towards (i) how the entrance influences water quality in the lake system, (ii) the water quality and ecological characteristics of the lakes themselves, and (iii) the influence of the adjacent catchment on the lakes' water quality. The findings within the report are based on available scientific information, input from local stakeholders, the expertise of the members of the expert panel, and an understanding of the current and future pressures. The Terms of Reference for this review excluded flooding, although the Tuggerah Lakes Expert Panel (TLEP) hopes that the information provided herein is considered in any updated flood management plan.

The Tuggerah Lakes system, including Tuggerah Lakes, Budgewoi Lake and Lake Munmorah (Figure ES-1) has been the subject of many studies and local scientific interest for decades. As such, the lakes are rich in data, theories and hypotheses regarding their ecological trajectory and water quality functions. Since 2006, the Tuggerah Lakes Estuary Management Plan has been in place to provide an integrated evidence based management plan for the estuary and its catchment. Central Coast Council has progressed many aspects of the plan in consultation with stakeholders. The Coastal Management Program currently underway provides an opportunity to update the existing plans in coordination with government agencies, the community, and stakeholders. This will ensure that actions are transparent and supported by compelling scientific evidence.

This report does not attribute blame for the existing water quality conditions on a single entity or group. Indeed, the TLEP believes that in most cases the actions were well intentioned. The TLEP wish to highlight the extensive works undertaken by the estuary management group within Council in relation to funding scientific investigations and implementing on-ground actions. However, the broader cycle of poor communication resulting in an escalation of tensions, followed by reactive actions, needs to be broken. The TLEP believe that to achieve a strategic plan for ongoing management of Tuggerah Lakes, a communication reset is required between (and within) State and Local Government and the broader community. Further details on the steps towards achieving these outcomes are provided in the community consultation summary below (and in Chapter 2 of this report).

Figure ES-1 Tuggerah Lake, Budgewoi and Lake Munmorah

As part of the communication reset, the TLEP believes that stakeholders should acknowledge that there is no easy or quick fix to address the water quality concerns of Tuggerah Lakes. Multiple studies over numerous years have highlighted that many of the concerns associated with Tuggerah Lakes are part of the natural cycle of the coastal lake system. Indeed, wrack, intermittent opening/closing of the entrance, and a shallow waterbody stirred up by wind waves, are all part of the natural character of the estuary. These characteristics have been recognised for over a century and are known to fluctuate with the broader climate patterns and environmental pressures. Nonetheless, Tuggerah Lakes requires integrated State and Local Government management and consistent funding to address the range of concerns outlined within this review.

Significant increases in the local population over recent decades has influenced the landscape that drains into Tuggerah Lakes. These changes within the catchment are known to have a deleterious effect on water quality and related aspects. In response to these concerns, Tuggerah Lakes has suffered from attempts to treat the symptoms versus the root cause of the problem.

An important outcome of this enquiry is that a permanent ocean entrance is not recommended at The Entrance for water quality purposes. The TLEP believes and science supports that a permanent entrance would not address the issues causing the highlighted water quality concerns, including wrack accumulation, macroalgal growth, sediment accumulation, flushing, or increased nutrients. Indeed, a permanent open ocean entrance is likely to reduce the lakes' average water levels, which may increase the volume of nutrients draining into the lakes via groundwater and result in more pervasive exposure of fringing mud flats and the resulting generation of odours.

Water in these coastal lakes is not readily exchanged with the ocean. Multiple studies have shown that due to the size and shape of Tuggerah Lakes, oceanic flushing is limited to 1-3% percent of the volume of the lake. In contrast, wind mixing plays an important role as the lakes are wide and shallow. The wind can create waves that stir up the bed sediments and accumulate wrack. Understanding these driving forces is very important in developing integrated strategic plans for better managing water quality and wrack. The use of data rich numerical models can assist the development of ground-truthed strategic and operational plans. Further information on how the entrance opening influences water quality and relevant recommendations are provided below (and in Chapter 3 of the report).

It is important to note that water quality in the lakes has improved over recent decades. The replacement of septic systems with sewage systems and the implementation of the Tuggerah Lakes' Estuary Management Plan by Central Coast Council, has reduced water pollution and improved the overall health of the lakes. However, in recent decades the catchment areas have experienced increasing developmental pressures. As such, much of the seagrass that was living in the main basin has been isolated to a nearshore fringing zone. The TLEP recommend that the existing work led by Council is continued and progressed to decouple the fringing seagrass area with the deeper basin zones to improve water exchange between the two areas. Understanding and addressing these factors, including stormwater runoff and groundwater seepage, is of utmost importance in strategically managing the lakes. Further information on the water quality and ecology of the lakes is provided below (and in Chapter 4 of this report).

The influence of the surrounding catchment on the lakes' water quality is of growing concern. Recent catchment development does not appear to have been undertaken using best practice for stormwater or urban water quality design. As the developments are not applying best practice, the resulting stormwater quality from these developments has the potential to add toxic pollutants, turbidity, and nutrients. Several attempts have been made to treat these inflows using, sometimes quite innovative, water sensitive urban design techniques, but both the magnitude of the problem and the financial costs of maintaining these structures is daunting for any Council. This is compounded by the lack of an environmental levy or stormwater levy, which have been utilised with success by other Councils. Further information on how the catchment influences the water quality of Tuggerah Lakes is provided below (and in Chapter 5 of this report).

The developmental pressures in the catchment are likely to be an increasing concern in the near future with an additional 41,500 houses proposed for the region by 2036. These development targets, set by the NSW State Government, will apply significant additional water quality pressures to the region and require multi-layered governmental collaborations. Indeed, the varied governmental agencies involved in providing oversight of the lakes and adjoining waterways introduces additional barriers towards a comprehensive and strategically aligned future plan. The TLEP is highly concerned that without best practice policy and catchment management in place, along with improved funding and State government resources, significant and potentially irrecoverable threats to the water quality of Tuggerah Lakes are likely. It is the hope of the TLEP that the recommendations of this report are considered in the development of the Coastal Management Program to foster collaborative management by all relevant stakeholders.

The following sections summarise the main findings of the independent review. This includes stakeholder consultation, entrance dynamics, water quality and ecology, catchment influences on water quality, and recommendations. A complete list of the report recommendations is provided in Chapter 6.

Community and Stakeholder Consultation

The TLEP consulted with the local community and stakeholders, using a range of techniques that were modified in response to emerging constraints imposed by the COVID pandemic. In total, from the period 20 July to 30 September 2020, TLEP actively engaged with 2,718 stakeholders and reached more than 36,000 people across the catchment of Tuggerah Lakes. There was a total of 4,637 comments, reactions, shares, survey responses and written and oral submissions made throughout the consultation period.

Key consultation techniques included:

- An interactive map using *Social Pinpoint* and hosted on the Panel's website.
- A dedicated Facebook page.
- Online meetings with community members and stakeholders using Zoom.
- An online survey.
- Phone calls and emails.
- Briefings of elective officials.

Communication channels included:

- Posters distributed around the LGA.
- Media releases.
- Facebook Advertising.
- Infographics.
- A dedicated project email address and phone line.

Key issues identified through the consultation included:

- Managing the entrance, including issues around dredging, training, connection with water quality, flooding, opening a second entrance.
- Flooding. Though this was outside the scope of the Panel, the floods of February 2020 meant the issue was top of mind for many stakeholders.
- Water quality, including issues concerning wrack and ooze on the shoreline, along with Council's management thereof.
- The impact of the catchment on the Lakes, including stormwater, urban development, and the impact of activities on the shoreline such as lawn mowing
- Communication and consultation, including where it has been good and not so good.
- The roles and interplay of state and local government
- Defining the Lakes – are they a lagoon, a lake or something else?

These identified issues helped to define and guide the technical review aspects of this investigation.

Three key strategic issues were identified by the TLEP to guide future engagement between Council, the community, and other stakeholders:

1. Designing processes that encourage all parties to move past any firmly held positions and instead seek to learn together. Specifically, to learn about the lakes natural complexity and to learn what actions and processes can make a difference.
2. Designing engagement such that all parties can work together to understand the range of issues that together comprise the lakes' management dilemmas. Understanding the holistic suite of challenges from all perspectives and agreeing on that shared understanding of the lakes' management dilemmas in order to allow solution finding.
3. Focussing on building trust across the system. That is, working to build trust between Council, the community, other local stakeholders, state agencies and elected representatives.

The Panel's overarching recommendation for future engagement is to take a highly collaborative approach to working with the community and stakeholders. This means using deliberative processes to foster joint learning and co-creation of:

- The dilemma and preferred state for the Lakes.
- Actions and policies for improvement.
- Ways to involve everyone in making recommendations and decisions about actions to take.

As part of this, citizen science and community driven activities should be supported wherever practicable. Further, the regular and open communication of the lakes' water quality via multiple channels is recommended.

Entrance Dynamics

The Tuggerah Lakes estuary comprises three shallow lagoons connected to the ocean by a heavily shoaled entrance that is intermittently closed. Over millennia, the entrance has migrated up and down the beach but most commonly exists adjacent to a rock shelf at Karagi Point (south of the entrance), where it is naturally protected from the ocean waves. During large floods, the entrance scours and widens, but this typically only lasts for a limited time as sand washes into the entrance and the main tidal channel again becomes constrained. Eventually the channel migrates back against the rock shelf. The entrance has never been considered officially 'navigable'.

Over time, there has been a balance between the sand scoured out during floods, and the amount that washes back in as the entrance closes. However, there is significant uncertainty in how the entrance will change as mean sea levels in the ocean continue to rise as a result of climate change. At present, it is believed that sand behind the entrance dunes will gradually be 'reactivated' and more sand will wash in from the ocean to raise sand levels inside the entrance. This would most likely be accompanied by a recession of the sandy barrier further landward into the entrance channel. This may somewhat stabilise the entrance against closure, but higher ocean water levels will also reduce the protection presently provided by Karagi Point. The balance between these two competing future processes is not presently well understood.

Since the 1990's the entrance downstream of the bridge has been dredged, although the effectiveness of this management intervention is very uncertain. It seems unlikely that it improves tidal exchange between the lagoon and the ocean to any significant degree. Typically, the entrance exchanges around 1% of the water inside the estuary with the ocean during each tidal cycle. Water within the three lagoons is generally well mixed except around some of the foreshores, where the growth of algae (seaweeds) and seagrasses form barriers that constrain any exchange between the deeper central basins of the lagoons and the adjacent nearshore areas. Stormwater discharging from small urban catchments fringing the lakes is trapped behind these vegetation barriers. Catchment floods help to overcome these barriers by raising water levels and "re-coupling" the nearshore areas with the broader basins.

The community has shown significant interest in improving the connection of the estuary to the ocean for decades, with options ranging from large scale dredging and training of the entrance to constructing an entrance across the sand barrier between Budgewoi Lake and the Ocean. Several studies over the past five decades have repeatedly concluded that substantial dredging and training walls would be required to increase the tidal exchange from around 1% to around 3%. There are notable limitations in some of these studies, but these findings are consistently reinforced by different researchers using different analytical methods and approaches. A single breakwater of limited extent is unlikely to have any identifiable success at helping to maintain an open entrance and/or enhance tidal exchange.

More recent estimates indicate that large scale entrance works would cost in the vicinity of $70 to $100 million dollars. It would be essential that the full impact and effectiveness of any proposed action is properly understood as training of similar estuaries in NSW (Lake Illawarra, Lake Macquarie, and Wallis Lakes) has created significant problems, some of which continue to affect management of these estuaries more than 100 years after they were trained.

Even with adverse findings from repeated studies over several decades, large scale works (training and dredging) are still advanced by some in the community as a viable solution. There is apparently a breakdown in community engagement on this issue over recent decades and this needs to be addressed. While the impact of such options could be studied more extensively, the

TLEP is extremely doubtful that extensive works will be shown to be viable, even as better scientific understanding of the system is gained.

The so-called Budgewoi sand mass or “big sand” is a large marine sand delta that indicates the past presence of a prior entrance from Budgewoi Lake, directly to the ocean. The available evidence for this site suggests that this area has been closed to the ocean for more than 1500 years. Waves were known to crash over the sand dunes between the Ocean and Budgewoi Lake, but it has been several decades since this has occurred as the dunes have a higher elevation than previously. The TLEP examined several historical sources and cannot find any compelling evidence that there has ever been a clear, sustained second entrance present since the arrival of Europeans.

Despite claims in different reports over several decades that a second entrance at Budgewoi had been numerically modelled to assess its viability, the TLEP found no clear evidence that this has occurred. Although future works to create a second entrance are not supported by the available evidence, more transparency on future analyses undertaken is strongly recommended.

Water Quality and Ecology

The water quality and ecology of Tuggerah Lakes is intricately coupled to the geomorphology of the system, climate and weather patterns, and human pressures. The geomorphology of the system results in distinctly different regions, or “functional zones” that display distinct water quality and ecological processes. These functional zones can broadly be seperated into basin and nearshore zones. Detailed analysis of previously published data and some unpublished data available to the expert panel highlights the importance of several key processes influencing water quality and ecology within Tuggerah Lakes. These can be catergorised into physical forcing affects (e.g. wind, tides and freshwater runoff) and anthropogenic pressures (e.g. storm water runoff, shore line modification, and cathment nutrient and sediment load changes) which influence the different functional zones in varying ways.

Water quality within the lakes’ basin is primarily controlled by the mixing of freshwater runoff from the main rivers and creeks with oceanic water during flood events, and more gradually in response to above- and below-average rainfall periods over seasonal to annual timescales. Wind-driven mixing and resuspension serves to break down any lateral or vertical water quality gradients and can cause significant variations in water quality over hourly to daily timescales (e.g. rapid increases in turbidity during windy days). Tidal flows are estimated to exchange, on average, 1% of the lake volume every day (while the entrance is open), causing a gradual increase in lake salinity during dry periods. However, oceanic water is only apparent in channels of the entrance compartment during flood tides, as wind-driven processes rapidly mix and disperse flood tide flows entering the lake basin.

Much of the community concern regarding water quality, ecology and aesthetics of the lake relate to processes occuring in the nearshore functional zone. The key concerns in this zone relate to wrack accumulation, ooze formation, algal blooms, and odour issues. These processess are intricately linked and the TLEP's review of the data highlights several key factors influencing these processes.

Wrack accumulation is driven primarily by wind direction and velocity as well as seasonal variations in seagrass growth. The formation and dispersal of wrack is a natural and ecologically important process to the Tuggerah Lakes system, providing food and habitat to birds and aquatic life as well as decomposition of wrack driving the return of nutrients to the lakes' ecosystem. However, extensive modification of the shorelines, as well as modification of the water level through entrance management has altered the accumulation rates, where the wrack accumulates, and the way in which the wrack is broken down over time.

A conceptual model regarding how wrack decomposes is provided in Figure ES-2. Under premodified conditions, the wrack was likely accumulated higher in the intertidal zone among the fringing wetland areas. Here it would have served as an important nutrient and food source for the ecological community, and would have broken down naturally over time. Under the current shoreline and water level conditions, wrack can accumulate in barriers along the shoreline, resulting in reduced aestheic qualities of the Tuggerah Lake system, but also impacting water quality through enhancing ooze formation and algal blooms by decoupling the basin and nearshore zones.

There is substantial investment from Central Coast Council in wrack removal programs, and there is a current wrack harvesting strategy informed by historical wind records. This strategy aims to strategically harvest wrack in order to optimise the flushing of the neashore zone in response to seasonal wind patterns. However, wrack harvesting over the past decade has largely been reactive in response to community complaints and has not followed the harvesting strategy. Due to the dynamic nature of wrack accumulation, along with the logistics involved in the wrack removal process and community perceptions, the current harvesting program has not met community expectations.

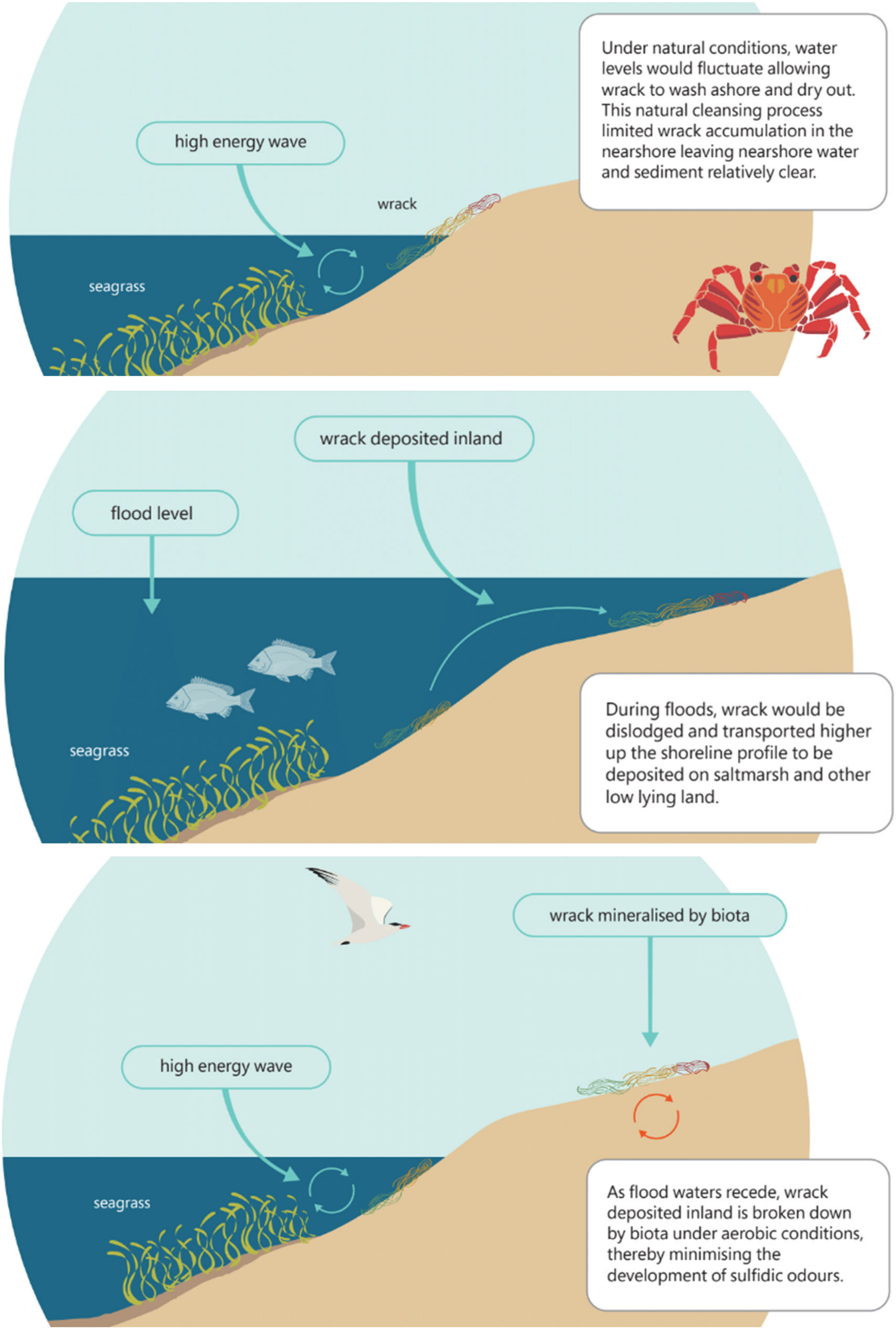

Figure ES-2 Wrack transport, accumulation and decomposition processes on natural shorelines (reproduced with permission of Central Coast Council)

Algal blooms in the nearshore are driven by the input of nutrients via stormwater, overland flow and groundwater. The blooms are exacerbated in areas where there is decoupling of water mixing between the basin and the nearshore zone, as nutrients are retained in the nearshore zone and not dispersed into the basin. Wrack accumulation in barriers adjacent to the shoreline can enhance macroalgal blooms through hydraulic decoupling. The ability of water from the main basins to alleviate poor water quality in the nearshore zones is greatly limited by this decoupling.

Ooze formation is influenced directly and indirectly by wind speed and direction, as well as hydraulic decoupling. When wind energy is high in the nearshore zone, the fine sediments that forms the matrix for ooze formation are resuspended and dispersed, limiting the accumulation of ooze. At intermediate wind intensity, the accumulation of wrack can form barriers preventing the disturbance of fine sediments in the nearshore zone, and facilitating ooze formation. Ooze formation also requires a supply of fine sediments. When combined with nutrient inputs, the presence of the ooze helps faciltate algal blooms. Stormwater input provides both nutrients and fine sediments, and ooze formation often occurs where stormwater inputs and the decoupling of the nearshore and basin areas through wrack barriers coincide.

In contrast to the nearshore zone, the lake basins appear to be currently resilient to the anthropogenic stressors that have an obvious affect on water quality in the nearshore zone. Data suggest that nutrients and algal biomass in the basin are primarily controlled by wind driven mixing and resuspension of sediments, with a relatively undetectable effect associated with large floods. The lack of detectable response of the lake basin to runoff events suggests that a significant portion of the nutrients delivered to the basin are trasported directly to the ocean. This is supported by visual observation of sediment plumes that extend across the lake, through the entrance and out to the ocean. The algal blooms that occur throughout the nearshore zone are typically not apparent in the basin, likely due to the lower availability of light due to sediment resuspension, as well as lower nutrient availability. While it is likely that sediment resuspension has long been a feature of Tuggerah Lakes (i.e. prior to widespread catchment development), the loss of seagrass from the deeper areas of the system has likely resulted in higher rates of sediment resuspension.

Tuggerah Lakes supports a diverse ecological community including bird and aquatic life, which holds significant value for the local community. Phytoplankton, seaweeds and seagrasses form an important ecological base to the system and contribute signficantly to water quality, while also providing food and habitat for macroinvertebrates and fish. Bird life on the Central Coast is also highly diverse with approximately 63 species having been sighted on or around Tuggerah Lakes. Many of these bird communities are supported by floating and deposited wrack as well as wetlands around the foreshore.

The ecological health of Tuggerah Lakes is tightly coupled with water quality and there have been notable declines in biodiversity over the past century. Notable items include an 80% decine in seagrasses and 85% loss of saltmarsh. Biodiversity losses have also impacted recreational and commercial fisheries with declines in macroinvertebrates and fish resulting in the closure of fishing businesses and reductions in landings. While there is no recent data to compare with bird sightings prior to urban growth around the lakes, it is likely that bird communities have been directly impacted by the foreshore developments replacing natural habitats and poor water quality reducing food availability.

Catchment influences on water quality

The Tuggerah Lakes catchment has undergone significant changes since the arrival of Europeans, with widespread clearing of the valley and floodplains for rural, urban and industrial land uses. These changes have resulted in increased flows and pollutant loads to receiving waters, directly impacting on water quality in Tuggerah Lakes.

Scientific studies have identified that urban stormwater is a key contributor to current poor water quality and the degradation of catchment waterway and wetland health, through increased pollutant loads and changes to natural flow regimes. Of particular note, the impact of fringing urban catchments that discharge concentrated urban runoff directly to nearshore areas of the Lakes has been recognised as having a significant impact on water quality within these near shore areas.

Historical clearing for agricultural land use has also altered stormwater runoff, increasing flow generation and turbidity, while reducing infiltration. This, in addition to stock access to waterways, has led to accelerated riparian bank erosion.

The *Central Coast Regional Plan 2036* identifies significant population growth pressures in the region with an additional 41,500 households planned for by 2036. This growth presents a key pressure to future water quality. Future planned development around Lake Munmorah discharges directly to the Lake, and substantial areas of future development in the Porters Creek catchment drain to Porters Creek wetland, a wetland of State significance that provides an important water quality buffer to Tuggerah Lakes. Current development planning controls do not ensure that the future water quality in Tuggerah Lakes will be maintained or improved.

Other key future pressures to water quality from development include poor erosion and sediment control practices, handover of poorly functioning stormwater treatment devices to Council, and limited funding and resources to maintain new stormwater treatment assets. Single dwelling developments exempt from water quality treatment also present a risk to water quality, particularly those in nearshore areas draining directly to the Lakes.

Conceptual figures have been developed to illustrate how European settlement has significantly altered the natural water cycle, and illustrate the key catchment pressures to receiving water quality as a result. Figure ES-3 illustrates stormwater generation in a natural (i.e. forested) catchment, versus current/future catchment pressures to water quality in Tuggerah Lakes.

Council have undertaken a number of actions to address catchment pressures and improve water quality in Tuggerah Lakes, however key knowledge gaps remain around quantifying catchment pollutant loads and the performance of current treatment measures. Despite these gaps, it is clear from the pressures identified that effective catchment management is critical for improving water quality in Tuggerah Lakes.

Recommendations

Tuggerah Lakes are at a crossroads. Based on the consultation and detailed scientific review undertaken for this study, Tuggerah Lakes requires coordinated plans, broad engagement, and transparent actions to improve existing lake management and plan for a sustainable future. To this aim, the TLEP has proposed multiple recommendations for consideration. The recommendations are focused across the broad topics of communication, planning, engagement, and actions. Where relevant, the TLEP has suggested potential funding pathways to implement the proposed recommendations. A short discussion of the main recommendations is provided below with the full list of recommendations provided in each chapter and summarised in Chapter 6 of this report.

Strategic and measurable plans are required or need to be implemented for dredging, wrack management, nearshore water quality, stormwater management, entrance flood management and sustainable catchment development. These plans need to be integrated within the Coastal Management Program so that the development controls, stormwater actions, and entrance management (to name but a few) are aligned and supportive of a healthy and biodiverse coastal lake ecosystem. Furthermore, the plans need to be transparent, well communicated and openly discussed with the community in a proactive manner.

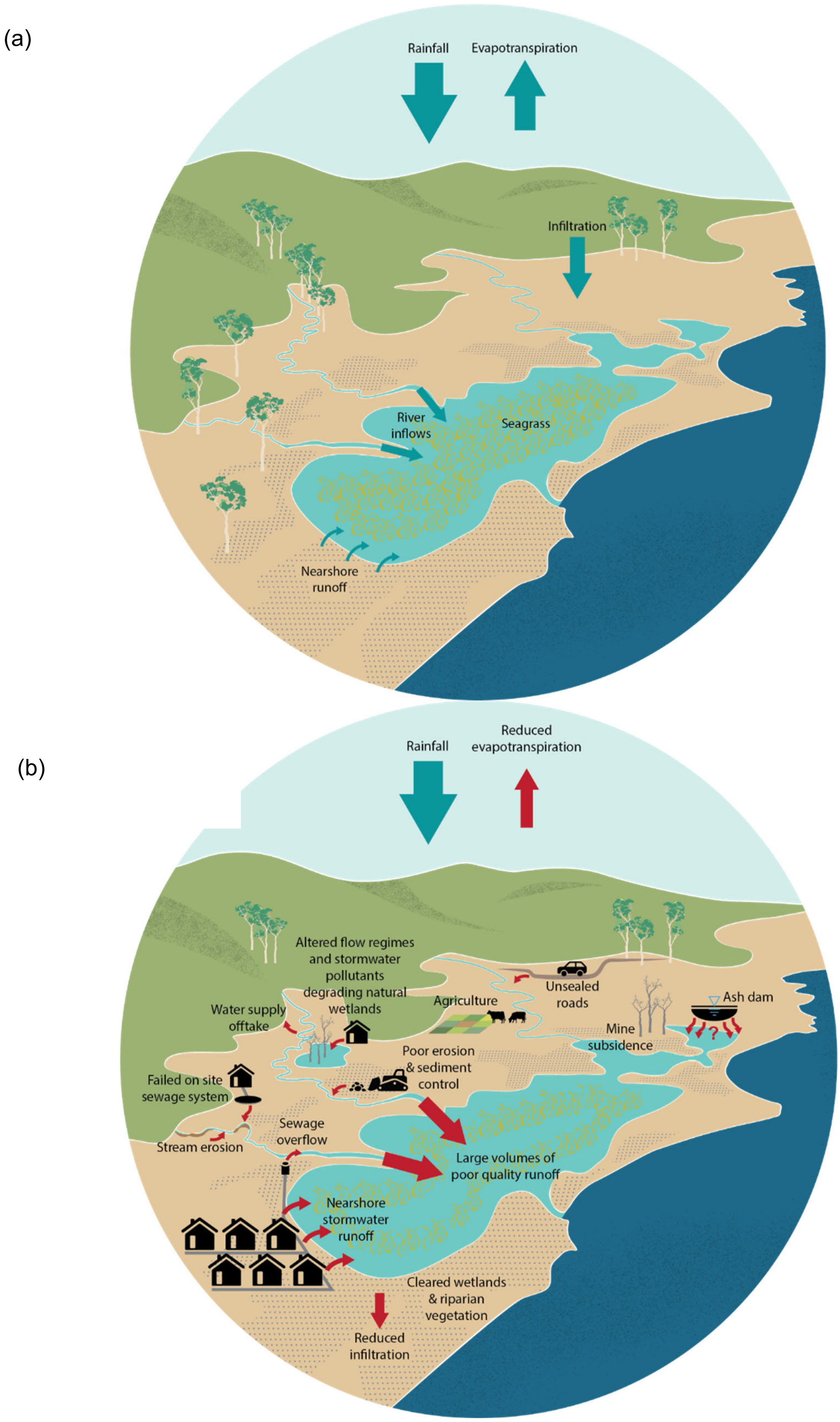

Figure ES-3 Conceptual catchment model highlighting (a) natural and (b) existing or future pressures to water quality (adapted with permission from Central Coast Council)

The TLEP recognise the research, leadership, scientific investment and on-ground actions undertaken by the estuary management group within Council. This investment in resources has aimed to apply best practice across the waterway and to facilitate an exchange of information with the community. Many of these practices should be recognised as best practice in Australia. However, the estuary management group within Council cannot and should not be solely burdened with the responsibility of managing the Tuggerah Lakes ecosystem. A fully integrated Council, supported by funding and resources from the State and Commonwealth governments, with a focus on total catchment management is required if these lakes are to prosper in the future.

To support Council's efforts, the TLEP believe that a *Catchment Coordinator Taskforce* should be established for a 5-year period, with review after 3 years, to assist in implementing the recommendations of this review and to provide a supporting role as Council develops and begins implementation of its Coastal Management Program for Tuggerah Lakes. This new taskforce can play an important role in providing a circuit breaker on discussions between the local stakeholders and government officials, and to address potential concerns with upcoming developmental pressures in the catchment. In addition, the Taskforce could assist in bringing together multiple stakeholders to ensure that the responsibility of managing Tuggerah Lakes is apportioned to those with the delegated legal authority. This should better reflect the various NSW State Government authorities who play a critical role in catchment, waterway, fisheries, environmental, transport, and planning for the region.

The proposed Taskforce could be similar in nature to the Wamberal Beach Taskforce and report directly to the NSW Minister for Planning or an appropriate steering committee of delegates. The Taskforce should aim to undertake an independent audit of water sensitive urban design practices, including erosion and sediment control practices, within Central Coast Council, with regards to receiving water quality impacts. This audit should be used to develop recommendations for future integrated water sensitive urban design practices that are focused on improving water quality in Tuggerah Lakes. The Taskforce should engage with community stakeholders in a collaborative and shared approach, as per TLEP recommendations, to establish water quality targets based on community values *and* a shared vision for the future of Tuggerah Lakes.

The TLEP recognise the current financial pressures on Central Coast Council. Therefore, the TLEP believes the Taskforce should be funded by the NSW State Government in a similar manner to the Wamberal Beach Taskforce or this enquiry. Further, the TLEP recommends that an environmental levy is implemented to secure a continual baseline funding source for Council and to help avoid the current reliance on ad hoc State or Commonwealth grants. Many other Councils in the region have benefitted significantly from an environmental levy and the TLEP is concerned that Tuggerah Lakes will fall significantly behind other similar systems without adequate funding. Further, with significant upcoming developmental pressures, it is the opinion of the TLEP that a stormwater levy should be implemented to progress the related recommendations, to undertake audits of existing and proposed water sensitive urban design infrastructure and sediment control measures, and provide Council with a sustainable means to maintain stormwater infrastructure. It is proposed that the Catchment Coordinator Taskforce provide an interim and immediate role until (i) these proposed levies have been established within Council, (ii) sufficient progress has been made on the development and implementation of proposed strategic plans, including the Coastal Management Program, and (iii) there is substantial progress in community consultation and the establishment of a shared vision for Tuggerah Lakes.

The TLEP supports the development of a detailed dredging management strategy that outlines where, when and, most importantly, why dredging should be undertaken in the entrance channel. It currently appears that dredging is conducted in response to community concerns and any proposed dredging should be strategically informed, providing a better chance of sustainably achieving the values that the community desires at The Entrance. Further, the development of dredging plans should be based on a conversation with the community stakeholders and the best available science, with results reported back to the relevant stakeholders at prescribed intervals.

In addition to these overarching recommendations, individual recommendations arising from each chapter of the report are summarised in Chapter 6. The success of this enquiry is ultimately dependent on whether these recommendations are adopted and implemented.

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1. Introduction

Located on the central coast of NSW, Tuggerah Lakes consists of three connected coastal lakes including Tuggerah Lake, Budgewoi Lake and Lake Munmorah (Figure 1-1). Since records have been available, and likely for millennia before, these lakes have been a highly valued resource for the local community providing a variety of ecosystem services and related amenities. Due to these natural values, Tuggerah Lakes have also been an increasingly popular location for development, with tourism and settlements growing quickly over the past 50-70 years. Unfortunately, these developmental pressures have also influenced the water quality of these coastal lakes.

Multiple studies have been undertaken to examine the water quality of Tuggerah Lakes. In response, numerous on-ground actions have been undertaken with varying levels of success. Concerns with these initiatives, as well as the broader management of the lakes and predicted future pressures, have led to public debate and, in some cases, community polarisation. In response to these concerns, the NSW State Government announced the formation of an Expert Panel focused on the water quality of Tuggerah Lakes on February 20th 2019, with the Tuggerah Lakes Expert Panel (TLEP) subsequently formed in July 2020. This report presents the findings of the scientific review by TLEP.

As per the Terms of Reference, TLEP has been tasked to consider existing information, previous actions to address water quality, and the available science as they relate to the management of water quality in Tuggerah Lakes. TLEP have also been asked to collaborate with the community, government agencies and the Central Coast Council to provide guidance to the Government and the Tuggerah Lakes community to formulate appropriate strategies and actions regarding water quality. As an independent panel, the advice provided by TLEP may encompass strategic, operational scientific and technical advice. A full description of the Terms of Reference, Code of Ethics, and Public Interest Disclosure for TLEP can be found at:
https://www.environment.nsw.gov.au/topics/water/estuaries/protecting-and-managing-estuaries/tuggerah-lakes-expert-panel.

Members of the Ministerial appointed Tuggerah Lakes Expert Panel are detailed in Table 1-1.

Figure 1-1 Tuggerah, Budgewoi and Munmorah Lakes

Table 1-1 Appointed members of the Tuggerah Lakes Expert Panel

Member	Affiliation	Role
Associate Professor William Glamore	Academic at UNSW Sydney	Chair
Mr Stuart Waters	Private Consultant	Member
Dr Katherine Dafforn	Academic at Macquarie University	Member
Dr Angus Ferguson	Scientist at NSW State Government	Member
Professor Damien Maher	Academic at Southern Cross University	Member
Ms Sian Fawcett	Private Consultant	Member
Ms Nicole Ramilo	Principal Environmental Engineer at BMT Consulting	Member
Dr David Wainwright	Principal Coastal Engineer at Salients	Member

1.1 Report approach

Once formed, TLEP aimed to undertake a methodological study into the historical, current and future issues influencing water quality across Tuggerah Lakes. A detailed community and stakeholder engagement process was initiated at the commencement of the study to seek input on the local issues, to gain expertise from various stakeholders, and to better understand the different aspects of any scientific debate. The public consultation was undertaken during the early stages of the COVID19 pandemic and, as such, the majority of the engagement techniques were online and/or virtual. Further information on this process is provided in Section 2 of this report.

Based on community and stakeholder feedback, historical studies, and expert knowledge, subsequent scientific investigations were focused on the entrance dynamics (Section 3), the water quality and ecology within the lakes (Section 4), and the influence of the catchment on water quality (Section 5). As detailed within this report, a scientific, evidence-driven approach was undertaken to describe the key processes influencing water quality based on a collation and review of existing information. Where relevant, knowledge gaps are noted and the implications of these knowledge gaps on the findings and recommendations are discussed.

While this report is scientific in nature, it is designed to be read by anyone with an interest in the water quality of Tuggerah Lakes. It is worth noting that there has been considerable debate and confusion regarding the use of the terms “lake” and “lagoon”. Estuarine classification is based on physical and/or biophysical characteristics and terminology may vary between scientific communities. Throughout this report the term “lake” is used to reflect the three interconnected coastal waterbodies commonly referred to as Tuggerah Lakes, and defined by Roper et al (2011). Further, the enquiry was not asked to assess flood management or flood planning in the Central Coast Council region. Where applicable, the influence of floods on water quality in the lakes is discussed.

The Tuggerah Lakes Expert Panel wishes to acknowledge the First Nation’s land on which Tuggerah Lakes exists. We wish to show our respect for the traditional custodians of the land and to acknowledge previous, current and emerging members of the Darkinjung, Guringai and Awabakal tribes. There are many lessons to be learnt from their stewardship of these coastal lakes for millennia.

TLEP also wishes to acknowledge the generosity of the community and local stakeholders for providing their input to this enquiry. TLEP members are grateful for their input and we hope that this report sufficiently acknowledges the extensive local knowledge provided by the community. The future of the Tuggerah Lakes system rests with the community and their actions.

2 Communication and stakeholder engagement

2.1 Introduction

This chapter outlines the methods and findings from the communication and stakeholder engagement undertaken as part of the Tuggerah Lakes Expert Panel (TLEP) enquiry. Over several decades there has been various management intervention to address water quality at Tuggerah Lakes. It is a challenging issue, suggesting there would be a high risk of consultation fatigue and mistrust among stakeholders. As part of the review, a Communication and Stakeholder Engagement Plan (CSEP) was prepared in July 2020 to guide the communications and engagement activities and seek input from the community about Tuggerah Lakes, while mitigating the risks of community fatigue and mistrust. The CSEP incorporated a combination of online and offline methods with a focus on openness and transparency.

The CSEP provided background information, including details of significant events, documents and activities that have been undertaken to address the issue of water quality at Tuggerah Lakes, strategic stakeholder and communications management considerations and proposed key strategies and tools for seeking input from stakeholders. Protocols were established for creating and distributing communications and strategies to keep stakeholders informed about TLEP activities and a mapping tool developed to identify stakeholders, their interests, risks and issues. A spreadsheet was created to collect and record stakeholder interactions, allow enquiries and complaints to be progressed and closed out, identify trending issues or opportunities, enable the implementation of strategies to mitigate community fatigue and mistrust, and maintain accurate contact details for stakeholders.

This chapter has been divided into 5 sections. Details of the methodology followed to communicate and engage with stakeholders are presented in Section 2.2. Section 2.3 summarises the results of the consultation process, attempts to address criticisms and describe challenges faced during the process, identifies key issues and community values and defines what success may look like to the community. A discussion follows in Section 2.4, with key recommendations regarding future communication and engagement addressed in Section 2.5.

2.2 Methodology

Key Points
The methodology initially developed in the CSEP incorporated both online and offline methods of stakeholder engagement and communication.
The COVID-19 pandemic led to the cancellation of pop-up stalls and intercept surveys, with face-to-face meetings held online instead.

The methodology initially developed in the CSEP incorporated both online and offline methods of stakeholder engagement and communication. However, the evolving COVID-19 situation in late July 2020 led to the cancellation of pop-up stalls and intercept surveys at shopping centres and parks across five locations. Additionally, face-to-face site visits with stakeholders were reconfigured as a series of online meetings using the Zoom platform to protect the health, safety and wellbeing of all participants. Online activities continued as scheduled and included an interactive map, survey and discussion forum, with written and verbal submissions received via email and phone.

2.2.1 Communication

Communication materials were developed to promote consultation opportunities, provide updates about TLEP activities and respond to enquiries. A summary of the activities and level of response for stakeholder communication tools is presented in Table 2-1, with details provided in the following sections

Website
https://tuggerahlakes.mysocialpinpoint.com.au/expert-panel
The TLEP website was hosted on the online engagement platform Social Pinpoint. It included a landing page with links to an interactive map, communication survey, registration form for the online meetings and discussion forums. The platform also included an infographic detailing the consultation strategy, media releases, project documentation, member profiles and photos, a project timeline and a news page.

Table 2-1 Communication activities and tools used by TLEP

Tool	Timing	Stakeholder groups	Response
Website	20 July 2020 to 30 September 2020	All	7,592 site visits 1,979 stakeholders
Facebook page	20 July 2020 to 30 September 2020	All	286 followers 27,864 reach 3,016 engagements
Facebook advertising website and interactive map	24 July 2020 to 9 August 2020	Facebook users aged 18-65+ who live in Central Coast Council local government area	36,112 people reached 714 clicks
Facebook advertising - survey	5 – 15 August 2020	Facebook users aged 18-65+ who live in Central Coast Council local government area	28,944 people reached 487 clicks
Infographic	20 July 202 to 30 September 2020	All	NA
Media releases	20 July 2020 7 August 2020 19 August 2020 17 September 2020	Media MPs Central Coast Council Local Aboriginal Land Councils Business groups	
Posters	24 and 31 July 2020 deliveries	Businesses Residents Visitors	300 posters distributed in the catchment area
Project phone line	23 July 202 to 30 September 2020	All	6 calls
Project email	20 July 2020 to 30 September 2020	All	15 emails

Facebook page

https://www.facebook.com/TuggerahLakesExpertPanel

Facebook is a social media platform that allows individuals to create personal profiles as well as allowing profiles for businesses, special interest and community groups and pages to share media and content. The Tuggerah Lakes community is very active on social media, predominantly Facebook, with many interest groups creating groups and pages specific to Tuggerah Lakes. A Facebook page was launched to share information about its activities and consultation opportunities. Despite initially encouraging stakeholders to provide input using the interactive map and survey, the discussion and comments on the Facebook page itself became valuable information and have been included as part of overall stakeholder input.

Facebook advertising

Social media advertising is an extremely cost-effective promotional tool. Two Facebook advertising campaigns were run; one to promote the interactive map and one to direct traffic to the online survey.

Infographic

A one-page infographic (included in Appendix A) was prepared to outline the consultation strategy and timeline. This was made available for stakeholders to print and download from both the TLEP website and Facebook page.

Media releases

Media releases are official statements delivered to members of the news media for the purpose of providing information, an official statement, or making an announcement. Media releases (included in Appendix A) were used to promote consultation opportunities and detail the consultation strategy and timeline.

Posters

Posters had not been part of the original communication plan but became necessary when plans for pop-up stalls and site visits were cancelled in response to COVID-19. A3 posters (included in Appendix A) were developed and distributed across small businesses, cafes, restaurants, clubs and pubs in the catchment area. The posters included a QR code for stakeholders to scan with their phone or device for quick access to the TLEP website. The poster was also made available on the website in A3 and A4 format for the community to download and print.

Project phone line

A dedicated project phone number was established.

Project email

A dedicated project email was established to manage written correspondence.

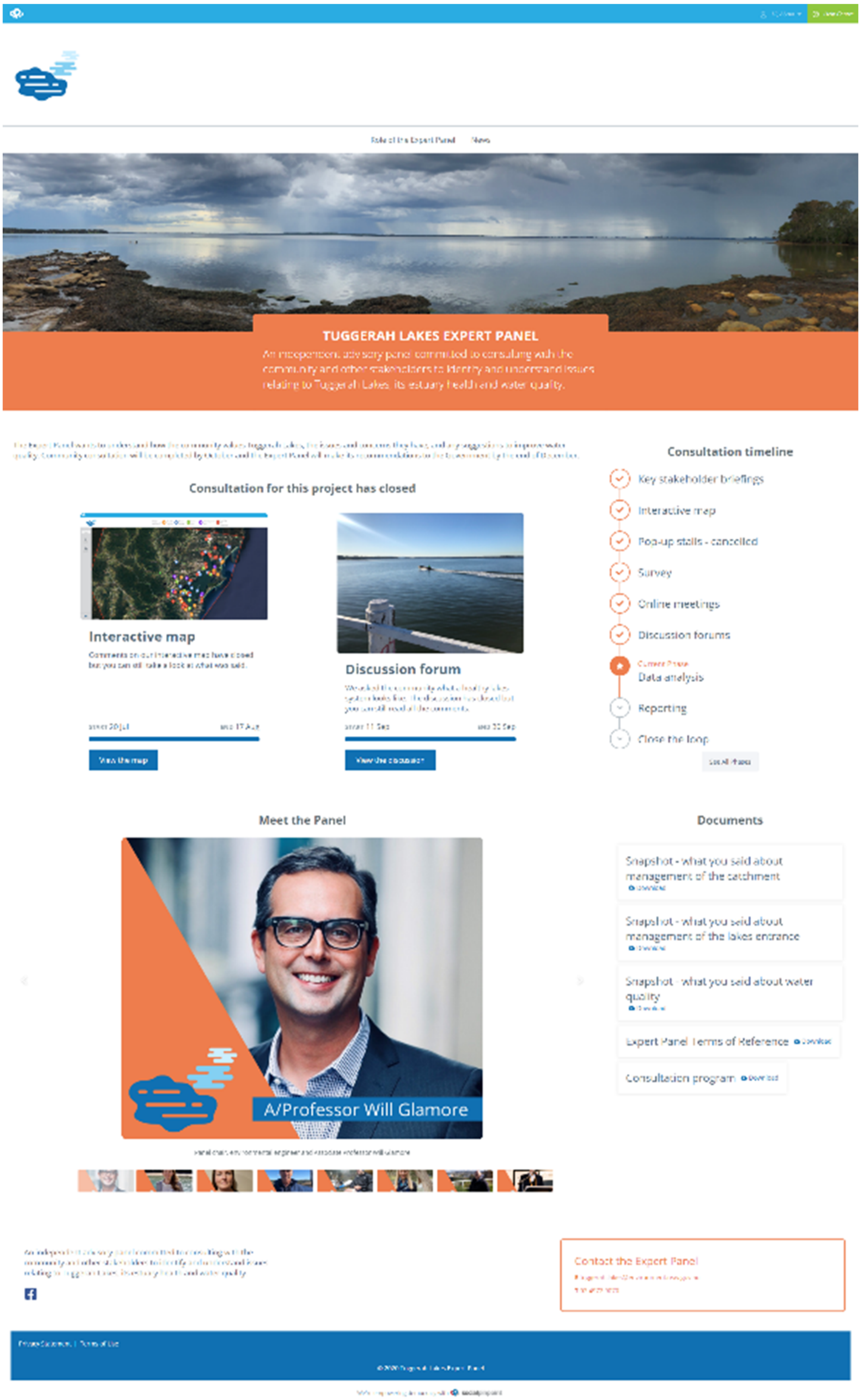


Figure 2-1 Screen capture of website home page

2.2.2 Stakeholder engagement

A summary of the activities and level of response for stakeholder engagement activities supported by the communications materials is presented in Table 2-2, with details provided in the following sections.

Table 2-2 Engagement activities undertaken for community consultation process

Tool	Timing	Stakeholder groups	Response
Phone calls	20 July 2020 to 30 September 2020	MPs Councillors Special interest groups Businesses	9 calls to stakeholders
Interactive map	20 July 2020 to 17 August 2020	Residents Businesses Visitors	445 comments 719 reactions
Survey	20 July 2020 to 17 August 2020	Residents Businesses Visitors	389 responses
Pop-up stalls	Cancelled		NA
Site visits	Reconfigured as online meetings		NA
Online meetings	25 August 2020 9 September 2020 17 September 2020	Residents Businesses Special interest groups	18 participants
Online discussion forum	10 September 2020 to 30 September 2020	All	23 comments
Councillor briefing	29 September 2020	Central Coast Councillors	6 Councillors 1 staff member
Written submissions	20 July 2020 to 30 September 2020	All	18 submissions

Interactive map

An interactive map was hosted on the TLEP website. Stakeholders were encouraged to drag one of several categorical markers onto the map and provide a comment and/or photo relating to that particular location. The interactive map used Google Maps satellite view as a base and was bounded by the Tuggerah Lakes catchment area. Users who tried to leave markers outside this boundary received an error message.

The categorical markers allowed users to identify areas they like, areas they are concerned about, areas or activities they value, and ideas and suggestions for improvement. Users could also view feedback and photos left by other respondents and annotate, “like” or “dislike” to agree or disagree with previous comments. Comments were tagged and coded into themes that could be heat-mapped to help identify areas of particular concern or interest (see Figure 2-2). The results are discussed in Section 2.3.2 of this report.

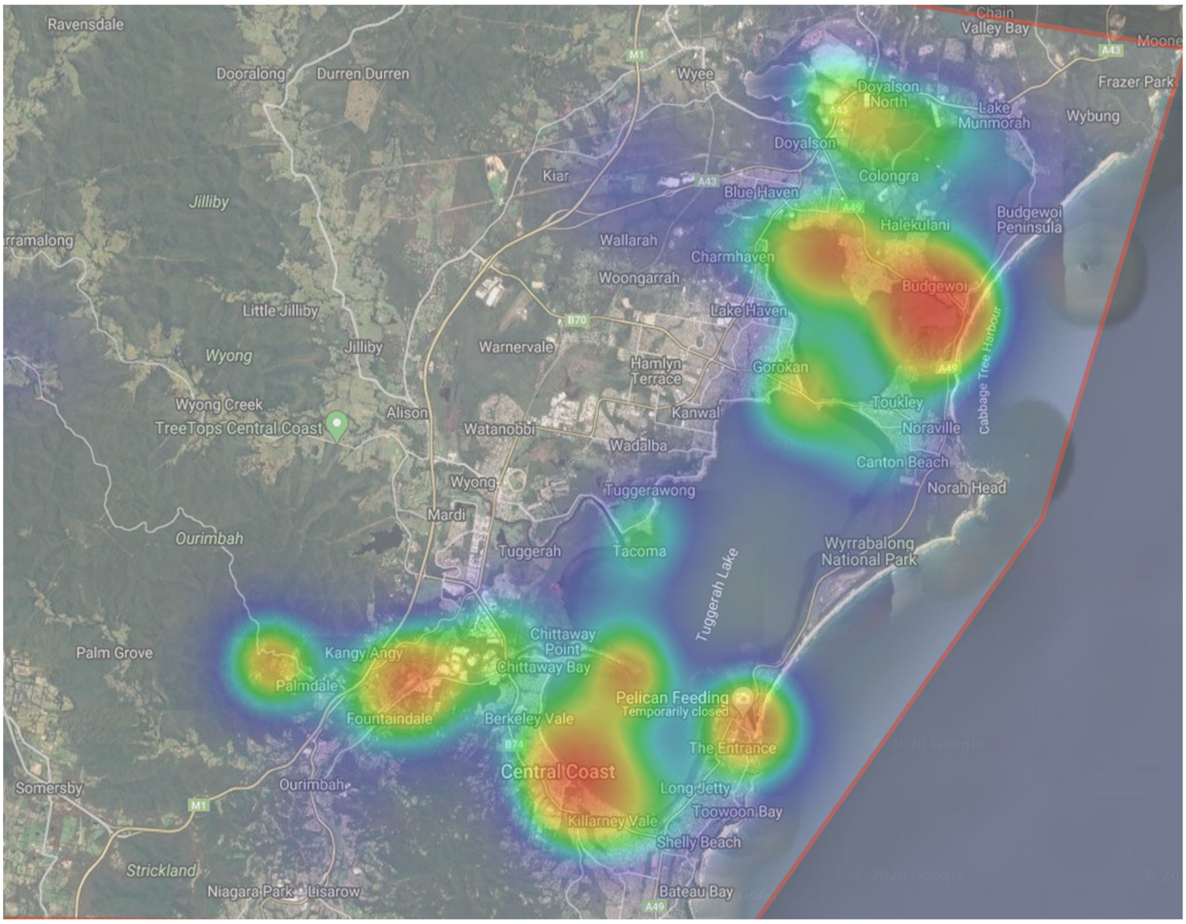


Figure 2-2 Heat map indicating areas where stakeholders identified water quality concerns

Survey

At the commencement of the enquiry a survey was developed to canvass feedback on stakeholder communication preferences, consultation experiences and how information about the Lakes is received and trusted. Intercept surveys using iPads were part of the original engagement plan but could not be undertaken when the pop-up stalls were cancelled. The survey had a 73% completion rate and took about five minutes on average to complete. A copy of the survey questionnaire is included in Appendix A.

The opt-in survey received 389 responses. Based on the population of 344,000 in the Central Coast Council (Council) Local Government Area (2019) (Council, 2020d), a representative random sample size with a 95% confidence level and a +/-5% margin of error is 384 responses.

The survey results are included in Appendix A. Comments were tagged and coded into themes, as discussed in Section 2.3.2 of this report.

Online meetings

A series of online meetings were facilitated using the Zoom platform to provide a COVID-safe environment. Stakeholders were invited to register for a meeting via the TLEP website, with options to register by phone call or email also provided. Each meeting was hosted by an appropriately qualified member of TLEP and allocated a theme:

- Water quality management, including wrack and ooze,
- Management of the entrance channel, and
- Catchment management.

Participants were allocated 20 minutes to discuss their concerns and the TLEP representatives were able to ask questions and hear directly from stakeholders. The meetings were recorded with the participants' consent for the purpose of further analysis and reporting. These recordings will not be made public.

Discussion forum

An online forum was hosted on the TLEP website to facilitate an open discussion guided by a series of questions or topics. The forum was used to ascertain the stakeholders' perception of "good" by inviting stakeholders to cast forward 10 years and imagine that a wide range of actions had been undertaken to improve water quality in the Lakes. The prompt was designed to inspire stakeholders to think about how they would perceive improvements in water quality.

Councillor briefing

A briefing with Councillors from Council was held via the Zoom platform to inform them of TLEP activities. Time for discussion and questions about Tuggerah Lakes was included.

Phone calls

The evolving COVID-19 situation resulted in the cancellation of scheduled community pop-ups and site visits. To facilitate discussion, various stakeholders that had been identified during development of the CSEP were contacted directly. Conversations varied in length and where relevant, stakeholders were referred to specific TLEP members for more detailed conversations about particular issues or concerns. Discussions were informally recorded and captured in the consultation database.

Written submissions

Written submissions were accepted throughout the consultation period. These were predominantly received via email.

2.3 Results

Key Points
A total of 2,718 stakeholders engaged in the community consultation process between 20 July and 30 September 2020, which reached more than 36,000 people across the Tuggerah Lakes catchment.
Low engagement levels were largely attributed to high likelihood of consultation fatigue and stakeholder frustration with the extended history of concern regarding Tuggerah Lakes, although there were criticisms regarding the cancellation or modification of face-to-face activities as a consequence of the COVID-19 pandemic, with a number of respondents having some difficulty with the on-line engagement tools.
Over one third of survey respondents receive most of their news and information about Tuggerah Lakes from social media, not managed by Central Coast Council, followed by personal experience.
Low levels of trust in Councillors, local MPs and Central Coast Council staff are largely attributed to a history of inaction by Council or State Government, misinformation, politics, lack of transparency, information contradicting personal experience, and the perception of an ad hoc approach to management of Tuggerah Lakes.
There is a need and demand for education about the Lakes' ecosystem and how the community can change their behaviour to improve water quality.
Stakeholder expectations for water quality in Tuggerah Lakes are not being met. The use of the word "lakes" rather than "lagoons" can lead to false expectations for how the system should look, smell and be used.
Management of the channel at The Entrance, where Tuggerah Lake opens to the sea, was the most common issue raised by the community. It is widely believed that keeping an entrance to the Lakes open would encourage "flushing", improve the health and water quality of the Lakes' system and reduce wrack and black ooze. There was considerable comment regarding dredging and breakwalls.
There is a widespread and popular belief that there was once a "gap" at Budgewoi, and that this should be reinstated to provide a second opening to the Lakes.
The issue of flooding was raised consistently during the consultation period.

Key Points
There is a perception that water quality has deteriorated over the past 20 years. Good water quality was primarily defined using recreational values and broadly regarded as clear water (when you can see the lake bottom), with a sandy bottom, free of or only with a small amount of weed, plenty of fish, active and diverse bird population, and deep enough to swim in.
Wrack and black ooze were the second most common issues and concerns raised by stakeholders during consultation suggesting a high level of dissatisfaction with wrack management.
The community value diversity in marine and surface ecology, especially bird life and recreation opportunities.
There is widespread understanding among stakeholders that improving water quality in the Lakes starts in the catchment and a strong desire for a catchment-based approach to improving water quality.
Many stakeholders note the impacts of development in the catchment area and recognise the importance of wetlands and reserves as natural filters to prevent nutrients entering the Lakes' system. There are concerns about stormwater management and industrial pollution.

Over the period 20th July to 30th September 2020, the community consultation process engaged a total of 2,718 stakeholders and reached more than 36,000 people across the catchment of Tuggerah Lakes. There were 4,637 comments, reactions, shares, survey responses and written and oral submissions made throughout the consultation period. This input has been coded and categorised into issues in Section 2.3.2 of this report.

The number of actively engaged stakeholders is statistically low when compared to the population of the catchment, though higher as a proportion of those living in what was the Wyong Shire, which has a long history of concern regarding the Lakes. For the purposes of this engagement, the population catchment has been assumed to be that of the Central Coast Council Local Government Area (approximately 327,000), but in reality those with an interest in the health of the Lakes' system likely extends beyond this due to the Lakes' popularity as a tourist attraction and holiday destination.

Low engagement had been expected given the high likelihood of consultation fatigue and stakeholder frustration with the extended history of this issue, as evidenced by many stakeholder comments on the TLEP Facebook page, in the communication survey and in the conversations online, by phone or email. This is further addressed in Section 2.3.2 of this report.

2.3.1 Criticisms and challenges of the consultation methodology

While the consultation process was intended to be responsive and flexible to stakeholder needs in delivering consultation activities, the evolving COVID-19 situation required the cancellation or modification of all face-to-face activities. This drew some criticism from participants who felt more could have been done to facilitate offline engagement, especially to cater to older residents.

However, of those people who engaged with the TLEP Facebook page, 19% were aged 65 and older. This is on par which population estimates for the Central Coast Council Local Government Area which report that the population aged 65 and older in the 2016 Census was 20.9%.

There were some complaints early in the consultation period that the Social Pinpoint survey would not submit or auto-populate responses. This was addressed by rebuilding the survey on an alternate (Survey Monkey) platform which remained accessible through the same link. Survey responses as a result jumped from 79 to 389 by survey close, achieving a representative sample size of 95% confidence with a margin error of +/- 5%.

It is acknowledged that some respondents found the interactive map to be cumbersome and not mobile-friendly. The 445 comments and 719 reactions received, however, appear to have adequately covered community sentiment, issues and concerns about Tuggerah Lakes. Additional responses, while still valuable, would have likely produced an over saturation of data.

There was also some criticism that comments had been turned off or hidden on the TLEP Facebook page. The reason for this was two-fold:

- Historically the issue of Tuggerah Lakes has been a passionate one and there were no available resources to moderate online debate after hours.
- To assist data analysis and reporting by encouraging stakeholders to provide feedback through the interactive map and survey.

After several weeks monitoring comments on the Facebook page, and in response to calls for greater transparency, all comments were opened to view. Since launching the page on 20 July 2020, only five comments have been removed from the page as they contained profanity. The Facebook page and all its comments will remain available to view until TLEP is dissolved.

A very common misconception during the consultation period was that TLEP was engaged or funded by Central Coast Council. As discussed in Section 2.3.2, this led many stakeholders to express frustration or reluctance to engage based on either previous experiences or their sentiment toward Council, Councillors or Council staff.

Finally, there was criticism about the facilitation of the online meetings via Zoom. Some believed that 20 minutes was not long enough to discuss their concerns, while others thought the technology did not allow stakeholders to adequately express their passion and sentiment. Many stakeholders registered for more than one session and several had the opportunity to speak with TLEP on more than one occasion. Others were also able to speak one-on-one with specific TLEP members, depending on the issues they wished to discuss. The majority of, feedback from those who did speak during an online meeting suggest stakeholders appreciated the opportunity.

2.3.2 Key issues

During this consultation process the community rightly noted that many issues with Tuggerah Lakes are linked and cannot be discussed in isolation. While it is acknowledged that many of the issues discussed below are connected, they have been grouped into primary issues for clarity of reporting.

Figure 2-3 Word cloud illustrating key issues raised by the community during consultation

Where appropriate, stakeholder comments have been used to demonstrate issues and concerns, however these are by no means all the comments received. The selected comments do not necessarily reflect the views of TLEP and may not be factually correct. Comments are presented as they were submitted, although spelling has been corrected to aid reading.

Communication and engagement

An online survey was conducted over a four-week period focused on understanding how stakeholders obtain and trust the news and information they receive or hear about Tuggerah Lakes, their awareness of and faith in TLEP and what has influenced their perceptions about communication, information and consultation. This feedback was supplemented by input from the interactive map, written submissions, Facebook comments and online meetings with key stakeholders.

There is significant evidence to suggest that the community wholly or in part mistrust the information and news they receive about Tuggerah Lakes. Distrust in local government practices and projects is not unique to Central Coast Council or the Tuggerah Lakes. Communication and consultation is invariably one of the most significant issues raised during any community engagement program. There is an almost insatiable demand and expectation by communities that councils and governments can always communicate and consult better.

However, despite that being the case, the issues raised about communication, education and consultation regarding Tuggerah Lakes are significant enough to warrant attention. It is of concern that more than one third of survey respondents received most of their news and information about the Lakes from social media, not managed by Council, followed by personal experience. Respondents also said that they trust their personal experience the most, followed by consultants/experts, then family and friends and that they trust Central Coast Councillors, local MPs and Central Coast Council staff the least.

> "*Information received from official sources ie CCCouncil always appears to be in contradiction to of our personal observations."* **Resident of 10-15 years, aged 65-74**

> *"The council managed the February floods very badly and then lied to cover up their incompetence. Council can not be trusted. I would not trust anyone or any information they provide regarding Tuggerah Lakes."* **Resident of 20+ years, aged 55-64**

Of those respondents who had received written communication about the Lakes, 43% said they could believe it about half the time and 22% said they usually can't believe it.

Respondents who said they believed it less than half the time, were asked why they felt that way. One quarter said it was because of a history of inaction by Council or State Government, 24% said there was too much misinformation in the community and 16% said politics. Other reasons were lack of trust, lack of transparency, information contradicts personal experience, and the ad hoc approach to management of Tuggerah Lakes.

> *"I have lived here over 60 years and so much money had been wasted on consultants reports with no action. I have no faith in local council after a personal experience 30 years ago."* **Resident of 20+ years, aged 65-74**

> "*The Council is our conduit for information and action however this process is flawed because Council's management and staff will find excuses when they don't own the asset. Council's expertise is sometimes lacking and they will invariably rely on grants and consultants to find solutions."* **Written submission**

> *"Council also produce an occasional Waterways Report Card. The report card does not record previous year's results and the failure to present this comparative data makes the information less useful than it might otherwise be."* **Written submission**

> *"Not enough hard facts hitting the streets. Lack of good quality information and complete lack of communication lead to lots of gossip and lies."* **Resident 20+ years, aged 25-34**

Consultation fatigue is also a major issue. Of those who had participated in a previous consultation about Tuggerah Lakes, 43% said they rarely or never felt listened to. The reasons given included that their feedback had not being acted on, the decision had already been made, those listening seemed disinterested in what they had to say, that their feedback was not acknowledged and that the issue was political.

> *"Over twenty submissions submitted in 2019-2020 on an array of development issues without a thank you."* **Resident of 10-15 years, aged 65-74**

> *"Nothing discussed was enacted, or it was done differently to what was discussed."* **Resident of 5-10 years, aged 55-64**

> *"My view may have been repetitious, or echoing others views however the receiver seemed disinterested and was not informative or committed to having a conversation regarding concerns."* **Resident of 20+ years, aged 45-54**

"The council really, I'm sure everyone knows what's happening with the council, they never seem to want to do anything, and I'm worried that everything that kind of happens and nothing ever gets done. And that's probably the annoying part and it feels that nothing ever gets achieved." **Online meeting participant**

It is not surprising then that 37% of survey respondents were not sure if TLEP would make a positive contribution to the future management of Tuggerah Lakes and 41% said it was unlikely or highly unlikely. The main reasons, as illustrated in Figure 2-4, were:

- A history of inaction on previous studies, panels and reports
- Concern that TLEP lacked the right expertise/knowledge
- TLEP has no power or authority to implement change
- TLEP recommendations were not backed by funding and politics.

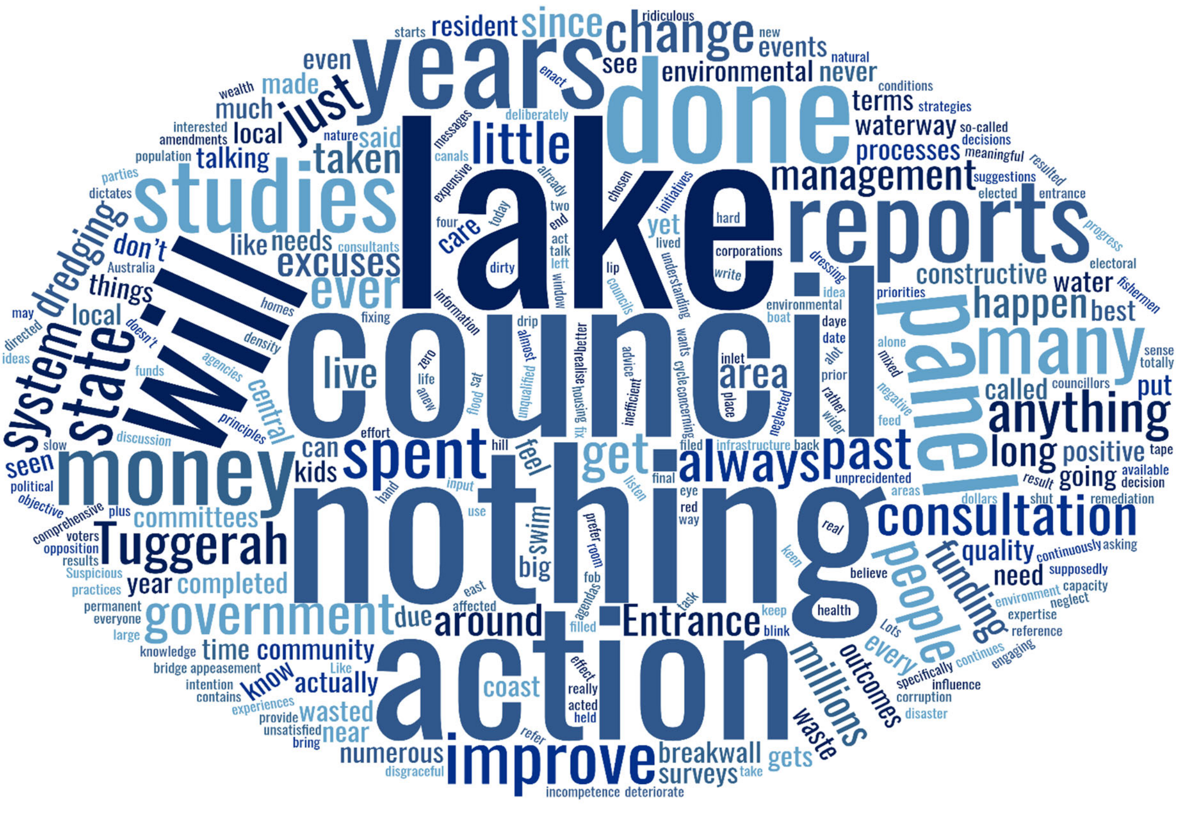


Figure 2-4 Word cloud illustrating community perceptions about the effectiveness of TLEP

"There have been many consultation activities and expert reports over several decades. Whilst your intention is commendable, I don't believe you have the support of government and the necessary financial support for meaningful outcomes. If you can make one or more political

parties commit to funding works, you may actually make a difference." **Resident 20+ years, aged 45-54**

"This expert panel: Who are they, what is their so-called expertise and who selected and appointed them. This stinks of forgone conclusions and grubby money." **Facebook comment**
"My first thought was why does an expert panel need our help? What possible knowledge could I offer the likes of environmental scientists, aquatic ecologists, biogeochemists, et al? If you're after the opinions of residents that have identified issues to the councils for the last century only for it to fall on deaf ears, why would we think this will end up any differently?" **Facebook comment**

"What concerns me most is that the Expert Panel will reiterate information similar to Worley Parsons with no future policies or strategies to be implemented. We have had Estuary Management Plans but with no clearly defined targets that will measure achievements and provide accountability." **Written submission**

"If they are expert why do they need help. Is it because they really have no idea." **Facebook comment**

"Trouble with an advisory panel is they can't implement anything. And being appointed by the government, they will be pressured to come up with a "cheap" option to "maybe" improve the lakes." **Facebook comment**

"*There has been numerous studies and surveys in the past which has not resulted in any positive action being taken."* **Resident of 10-15 years, aged 65-74**

***"**No funding to back outcomes. Initiatives chosen to progress will be at the mercy of external funding priorities and/or political whims."* **Resident of 20+ years, aged 35-44**

***"**Once you hand your recommendations over to Central Coast Council it will be filed in the room that contains the other 10,000 reports and recommendations that have been sourced over the past 50 years and never acted on."* **Resident of 20+ years, aged 55-64**

"Local groups such Toukley Sailing Club, Toukley Cycle Club, Toukley Kayak Club or Landcare volunteers would provide a wealth of first-hand info. that armchair theorists desperately need to formulate a balanced report." **Facebook comment**

"I have grave concerns with the legitimacy of this and other panels that have been politically appointed by the NSW government. Very little is getting out to the communities or those passionate about our environment and having active maps and surveys do not convey those concerns of the shareholders of the Central Coast." **Written submission**

"Where does the expert panel sit in the current council dynamics though ... I mean ultimately what is the scope of your group's capabilities once all information is collated I believe many are concerned once the information and recommendations are put forward continued council inaction and false claims will again occur ..." **Facebook comment**

Education

There is a need and demand for education about the Lakes' ecosystem and how the community can change their behaviour to improve water quality.

"Inform residents residing by the lakes to cease mowing down to the water's edge and not to use fertilisers containing phosphates on their lawns." **Resident of 20+ years, aged 75+**

"*I've done a lot of research but most people prefer to get information off people that spread misinformation to serve their own agenda."* **Resident of 20+ years, aged 45-54**

"This might sound like a very small issue that I have noticed in residential areas. When I see a majority of people mow the grass particularly on the nature strip, they do all the edging first and then blow it onto the road, then mow the grass and then blow more onto the road. Sometimes on our street there is so much leaf and grass on the road that ends up in the gutter, drains and then into the waterways so more nutrients, weeds and fertiliser into the lake and river system. A lot of these people have boats and fish but unknowingly pollute the very water ways they enjoy. My son is also an active volunteer tester of water quality in our local water catchment. So have been educated to edge first blow back all my edging material back onto the grass and mow the lot up, compost or dispose in bins. So what education is planned to make people change their ingrained habits that impact our waterways?" **Facebook comment**

"EDUCATE, EDUCATE, EDUCATE the public forever. Every new generation at school or people who move in to the area will have to be educated as to the workings of this Intermittent Opening and Closing Lagoons (ICOL) system or the toxic politics will remain and forever dam all who try to fix the issue. It will be used as a wedge at election times, not to repair the lagoons but to win and entrench their power." **Written submission, a commercial fisherman of almost 50 years**

“We need a balanced perspective and an education strategy targeting different sectors of the community based on their beliefs. It's not one size fits all and audience research is vital in developing an educational communication campaign.” **Resident, aged 45-54**
“*More communication is best. Educating the public is the start of them having a better connection and understanding of the natural environment. Especially with ongoing flooding events occurring in the estuary system the residents in the flood zone impacted areas must acknowledge that by choosing to live in these areas flooding is going to happen.”* **Catchment employee, aged 25-34**

“*Need for community education, streamwatch, behavioural change. Placement of treatment devices is only one element of the solution.”* **Comment on interactive map**
“Would love to be kept up to date with management practices and procedures involving the Lake, particularly regarding any expectations of us as residents, or how we might be able to be involved - particularly regarding environmental issues, what can we do (or not do!) To help.”
Resident 5-10 years, aged 75+

Council and State Government management

The majority of stakeholders who provided input believe that responsibility for water quality lies with Central Coast Council followed by State Government. Some stakeholders also suggested community education has a role to play but that a single body still needed to take overall responsibility. There was overwhelming evidence that the community is frustrated with previous and current management of Tuggerah Lakes.

“*Since the amalgamation of councils there seems to be a large proportion of funds spent in liberal state gov areas.”* **Catchment employee, aged 65-74**

“I have lived at north entrance since 1970 and have had a boat moored at the end of Hargraves St for 35 years which requires me to inspect it and the lake regularly. As to why the lake is in the state it is in, no one person or section in council has had the position of keep (sic) the entrance open. It has always just some engineer employed in another position to take on the extra duties to dredge. It needs someone in a permanent position that can be held responsible for management of all the lake.” ***Comment on interactive map***

“Nobody sits in council with a job and says my job is to keep the lake open. they’re all engineers, they’re civil engineers. They haven’t got the expertise and they don’t want it because it’s an extra job for them. Nobody sits in there with that job.” **Online meeting participant**

"This channel has needed dredging for 10 years. Council know it's a navigation hazard as well as a flood issue but have done nothing to rectify the problem. Maritime say it's not their problem. Seems to be an argument between Fisheries who manages the weed and Crown Lands who manages the bed of the lake. Just another couple of buck-passing state government departments." ***Comment on interactive map***

"*The only information I hear is the blame game and all the reasons why we can't do anything."* **Resident, aged 55-64**

"Council has been negligent about its responsibility and passes the buck!" **Resident of 20+ years, aged 65-74**

"Apparently the Central Coast Council managers the lake however we have not seen any evidence of it over the years that we have lived in Charmhaven. It seems to us that any funds spent on the lake system is only spent where tourists visit e.g The Entrance, Canton Beach etc but not for the locals that live around the lakes that pay higher rates for 'the privilege'!" **Written submission**

But not everyone thinks that local or state government is at fault.

"Let's promote the facts. More than $35M has been invested in improving the health of the estuary and there have been many great achievements and improvements. Council should bring the community on a journey through the Coastal Management Program development process ... and ensure accurate information on water quality, entrance management etc. Community need to stop pointing fingers and look at their individual/cumulative impacts on stormwater and the estuary itself." **Resident of 2-5 years, aged 35-44**

"They're not lakes. They're actually designated as tidal lagoons and I don't even know whether the maritime and all them have got any jurisdiction in there. They don't worry about Wamberal Lake. They don't worry about Terrigal Lagoon. When was the last time you seen the Fisheries run around Terrigal Lagoon or Avoca Lagoon giving orders. So that's the whole problem. Nobody owns them, nobody takes responsibility. It should be some committee that looks at all these situations up and down the coast, not give it to the council." **Online meeting participant**

Several people suggested a single authority needs to be appointed to oversee management of the Lakes' system separate to Council and State Government.

"After the recommendations are handed over to Central Coast Council will there be any follow ups from the Expert Panel to see whether any of the recommendations are acted on and if so will the results be monitored and recorded. Similar to Lake Illawarra an authority needs to be formed to keep a close watch on improvements and detractions." **Resident of 20+ years, aged 55-64**

"Who should pay? NOT THE COUNCIL. They have enough on their plate to take on the lake and do not have the staff. Staffing and people to my mind is the reason why the lakes are in the state they are in .the council over the years have been given millions of dollars to fix the lakes at one time a minister told council in no uncertain words that he was feed up given the council money to fix the lake without see much progress. Keeping the channel open a removing the weed in some one's second job and is not responsible for it Proof the It appears the mayor had to give permission to open the lakes. As there is a large number of outlets to the sea along the NSW coast with the same problem - one body state or federal or both funding it, not local council, with their own employees being able to tackle and solve the same problems up and down coast." **Written submission, resident 50+ years**

"*Tuggerah Lakes needs its own authority. One person in charge, who would be responsible and accountable for the management of the lakes. Council has "dropped the ball" badly in managing the health of the lakes. There seems to be a culture of no accountability on how the lake is mismanaged. Millions of dollars have been spent on trying to remedy the situation of the lakes, but the money has not been spent in a cost effective and efficient way to get best value. Council has done some good work in the catchment areas of the Lakes, to improve the health of the lakes, but their wrack management strategy and The Entrance channel management have been a total and dismal failure."* **Resident of 5-10 years, aged 65-74**

Lakes or lagoons

Overall, stakeholder expectations for water quality in the Lakes' system are not being met. Several explanations for this came out during consultation.

Firstly, stakeholders base their expectations for water quality in Tuggerah Lakes on their experiences and perceptions of other waterbodies, particularly Lake Macquarie and Lake Illawarra.

"The North side of the lake is so badly silt up the lake foreshore (sic) is now mud, it was once yellow sand. Because the water flow is so poor the lake edge is choked with weed. Compared to Lake Macquarie's well flushed lake system with its clear blue water especially at Swansea the back end of Lake Munmorah is almost a swamp. I believe the Entrance needs to be opened

more or another channel to the ocean in the back end of the lake is needed.” **Comment on interactive map**

“We have recently returned from a north coast trip, Camden Haven, North Haven, Port Macquarie, Yamba, Iluka, Brunswick Heads and Tweed Heads on the way up and Evans Head Harrington on the way back. They all have breakwalls and have a constant flow from the sea to keep the waterways flushed and improve water quality.” **Comment on interactive map**

Secondly, the use of the word “lakes” rather than “lagoons” sets up some false expectation for how the system should look, smell and be used.

“We don't effectively educate the public about the lagoon system, they expect it to function like Lake Macquarie, won't accept its natural weather system and want to turn back the clock before the State Government and Council allowed all of the development around the shoreline, removing vegetation and salt marsh and habitats.” **Catchment employee, aged 65-74**

“Most people don't understand the ecology, history, issues, etc. Most people expect TL to be something it never was.” **Resident of 20+ years, aged 55-64**

“*The name of the system leads to unrealistic expectation by the public. They assume and believe that the Tuggerah Lakes is like Lake Macquarie or the Brisbane Waters. They believe that, if the mouth was open they would be able to bring in deep draught yachts. They don’t realise that the average depth of the water is 1.7 m. Renaming the Tuggerah Lakes to the Tuggerah Lagoons should happen.”* **Written submission, a commercial fisherman of almost 50 years**

“We need to clarify if we are treating TL as recreational lakes or an estuary. People need clarity so they don’t have false expectations of what the lakes should or should not be.” **Comment on interactive map**

The following exchange between two stakeholders on the TLEP Facebook page, shows how the name of the Lakes’ system may affect community feelings about and expectations for water quality.

“*They are called lakes it’s called Tuggerah lakes not Tuggerah lagoons council changed the name without public notice because lagoons are easier to manage than a lake.”* **Facebook user 1**
“*No, they have always been shallow coastal lagoons. They are known as lakes but scientifically they have always been classified as lagoons.”* **Facebook user 2**

“I spent half a million on a lake front on Tuggerah lakes nowhere in my contract does it say Budgewoi lagoon have I been misled if so by who because real estates are selling lake front homes on Tuggerah lakes.” **Facebook user 1**
“You can't change the fact that they are officially classified as shallow coastal lagoons. Tuggerah Lakes are geographical names not a classification.” **Facebook user 2**
“Is Lake Macquarie the same or is it a real lake?” **Facebook user 1**
“It's a real Lake. Lakes and Lagoons are classified by depth, geological and hydrodynamic features.” **Facebook user 2**

As a result, people relate poor water quality to how it restricts their use of the Lakes recreationally.

“I can’t even use my boat in the water it is so bad. Or go for a swim at the entrance. Or fish you guys should be ashamed of yourself for letting it get this bad.” **Resident of 15-20 years, aged 25-34**

“*The lakes desperately need HELP. They are such a wonderful part of our local area and should be treated that way. So many people want to use the lakes for swimming, picnics, kyacking, (sic) water sports such as water skiing etc.”* **Resident of 20+ years, aged 55-64**

Then there are people who do not believe the Lakes are lagoons at all.

“*It is NOT a lagoon I can assure you of that once upon a time long long ago it had two outlets to the sea. One at Norah Head near lakes beach which disappeared as Toukley and Norah Head and the Toukley golf course were developed and the road from Noraville to budge would was constructed. The other was the existing channel which was deeper and wider and faster running than it is today. It is like it is today because back in the sixties the frontal sand dunes from North Entrance were bulldozed into the channel to stop the fish from being washed out in the current flood at the time. I know because I sat in the reclamation area off Ocean Parade and watched in horror.”* **Facebook comment**

This is important because understanding community expectations to use the Lakes for recreation and business leads much of their dialogue about what is “wrong” with the Lakes’ system. A fisherman bases his expectations on his ability to fish, a swimmer to swim and a boater to boat. If they can’t undertake these activities, they perceive something to be “bad”. This isn’t to dismiss the real and varied issues with water quality at a scientific level, but the basis for most community stakeholders’ perceptions is what they see, smell and how it impacts their immediate ability to enjoy the Lakes.

The Entrance

Management of the channel at The Entrance, where Tuggerah Lake opens to the sea, was the most common issue raised by the community. There were more than 140 comments left on the interactive map that related to management of the channel covering a wide range of suggestions from retaining a permanent opening at The Entrance to creating or (reopening) a second channel at Budgewoi Lake.

Figure 2-5 Heat map showing distribution of comments about the channel at The Entrance

A common belief among stakeholders was that keeping an entrance to the Lakes open would encourage "flushing" of the Lakes. Many believed this was critical to the health and water quality of the Lakes' system and would reduce wrack and black ooze.

> *"Personal observations indicate that when the channel has been wide open, after a flood event, that there is improvement in the water quality in the lake. Besides the water quality there has also been a lot of bird activity following the fish that have made their way into the lakes. The initial flushing of the lakes from the rainwater is followed with flushing from the ocean water*

through the channel. I feel that there is little understanding by Council on the dynamics of the channel, sand berm and ocean tides." **Written submission**

Figure 2-6 Word cloud illustrating stakeholder views about management of The Entrance

"*A permanent opening would be the logical solution. A sea wall like Swansea has would be the best solution. I don't understand dredging, but if this is also required the council will need to invest in machines that run day and night all year round to keep up. Making the lake deeper is not the answer it needs to flow, "breath" which is why I urge you to consider an opening."*
Written submission, Halekulani resident

"Having grown up seen the lake, seen the lake degrade, and most particularly since I've been living here, it's one of the most key parts of the whole lake system is getting that mix. So obviously with urban development, fresh water all getting drained into the system, it needs to have that mix of salt water coming in." **Online meeting participant**

"Having lived here for 20 or so years, I have noted the increase in sludge under foot, and resulting odour when walking in the river. It has silted up considerably. I assume as a result of run off from upstream and increase in urbanisation and drainage into the catchment area. My logic suggests to combat, the flushing of the lake is vital, as I have noted after the 2007, 2015 and 2020 flood events the water quality & fishing improves considerably." **Comment on interactive map**

Some stakeholders believe this can be achieved through dredging or a more frequent dredging program. 76% of survey respondents were interested in receiving more information about dredging.

"Ensure it is stipulated within Local & state government policy to dredge every 12months, and if EPA issues present take corrective action." **Comment on interactive map**

"Need for ongoing year-round or even seasonal dredging as minimum - loss of lakes = loss of local business and struggling economy. Relocate dredged sand to local foreshore reclamation and rejuvenation long jetty, Killarney vale etc. Overview upper lakes and ascertain water quality and current and ongoing impact of power station ash dumping, introduce DPI fish management and fingerling release to improve lakes. Without the lake we lose a lot Business already struggling." **Comment on interactive map**

"No matter what you come up with, you're going to have to dredge, because the sand comes in with the tide and that's what causes all the problems. The problem is the council have never been given enough money to dredge on a regular basis." **Online meeting participant**

Other stakeholders see dredging as either part of the problem or only a short-term solution. They want a permanent solution, such as a breakwall or twin breakwalls. There were more than 55 comments received about breakwalls across all consultation tools.

"Widening or dredging of the lakes' entrance will not help with the exchange of water within the lagoon system, again it's a false expectation, but it will change the ecology of the lake. Altering the mouth of Tuggerah Lakes will affect a body of water either north or south and ruin it instead for no benefit to either system." – **Written submission, commercial fisherman of 50 years**

"A properly constructed break wall is what's needed. Sure, there's always an example that people can draw on where there's been a small negative impact but these same people that cry when fire protection measures get completed. They would draw on the fact you live near trees. Twin break walls and dredged properly to a depth of 5.5 metres to Pelican Island. Southern

break wall could house a small marina like Port Stephen which would encourage boat traffic. This would breathe life into The Entrance.” **Comment on interactive map**

“Mostly I agree with the opening comment however dredging is never enough! It is a band aid fix to a long-term problem. We need a permanent opening at The Entrance where little maintenance involved. If it is not made permanent every new council or state government will change the rules of management and nothing will get done.” **Comment on interactive map**

“I’m very strong in the belief that if that entrance was, well the mouth the opening, had a breakwall there and properly dredged that would breathe every tidal change, every seven hours, water change, water improvement.” **Online meeting participant**

“We need a permanent opening such as breakwalls at The Entrance Channel so once established they should be relatively maintenance free. If the channel is left to council to maintain such as dredging then they can change the frequencies as they have done in the past and look how well that as turned out for flooding and the general health of the lakes. Since the inception of CCC the lakes are worse than ever. They have not completed one successful dredging campaign and little weed harvesting.” **Comment on interactive map**

“If we don't build a permanent breakwall council and state government will just stuff around for another 100 years and there will be no lakes for discussion. Over the last 50 years the foreshores have become weed ridden and stinking black ooze infested. The water is captured from the heads of the creeks to fill the dams so there is not as much coming in from the catchment to flush the lakes regularly. Our only hope is to introduce more sea water.” **Comment on interactive map**

“There is a firm view held by many in my community that construction of breakwalls at The Entrance and provision of a trained channel is the single most important thing that can be done to improve the health of the Lake. I invite the Panel to address this point in terms of whether a trained channel and breakwalls, alone, is all that need be done to ensure the health of the Lake.” **Written submission**

However, other stakeholders warned against breakwalls.

“I think that a lot of people would like to see breakwalls because wherever you see breakwalls you associate them with clean clear water. Breakwalls can be a solution to some areas, but they can also create their own problems, which could result in a worse outcome. All that is required at The Entrance channel is the opening of the channel whenever a flood event is looming and

secondly, maintain a berm which is very low, to allow maximum water exchange with the ocean, which improves water quality.” **Comment on interactive map**

“Keeping open, does not need a breakwall. We have a "rock shelf" which protects the Bay area and Tuggerah lakes from damaging swells that must be protected. Any damage to the rock ledge, would cause catastrophic consequences to the bay area and Tuggerah lakes.” **Comment on interactive map**

“Be very careful with entrance breakwalls. The estuarine hydraulics are complex and few engineers understand them. They can have significant long-term consequences, both positive and adverse. Further, they can change coastal alignments. Breakwaters at Brunswick River wiped out the village of Sheltering Palms and, at Newcastle, Stockton Beach. This is well-supported in scientific publications.” **Comment on interactive map**

“The concept of a breakwall at The Entrance has been discredited by so many scientific studies that it's not an option that should be considered. Breakwalls along the NSW coast have caused many problems: the loss of sand nourishment to neighbouring beaches and the loss of prawns in Lake Illawarra are just a couple of examples. The primary concern should not be tourism and business, nor flood mitigation but rather the health of the system from the headwaters of the rivers and creeks to the sea.” **Comment on interactive map**

Some stakeholders suggested geo-textile bags could be an alternative option to a permanent rock breakwall.

“Explore Geotextile Sand Bags to ensure the Entrance Channel is not silted/closed at the Northern end where the Rock Shelf is deeper, and subsequently allows the lake water to self-scour when significant rainfall occurs and escape the lake. This would significantly reduce flood risk to some 5000 buildings surrounding the lake & improve water quality.” **Comment on interactive map**

“The beauty of the sandbags is if they don’t work, you can pull them apart again. It’s no big deal. But there are sandbags, you’ve seen sandbags, they use them up north.” **Online meeting participant**

Some stakeholders believe the depth and narrowness of The Entrance channel is a safety issue.

“The 4 knot markers can only be moved east if the channel is dredged or otherwise navigation of the channel will become more hazardous than it already is.” **Comment on interactive map**

“The channel is dangerously shallow for boats and jet skis when the lake is below 250mm AHD. Locals accelerate to ensure that their vessels can negotiate this hazard. Tourists often get stranded. RMS maritime services have been advised but there is still no action. Council have advised that it is too expensive to dredge again. The sediment build-up since the Feb 2020 flood is very noticeable. A strategy to dredge and place the material back in the lake is required.” **Comment on interactive map**

Others said the mouth of the channel can’t be too big, otherwise it becomes dangerous.

“The thing you’ve got to take into consideration is the mouth can’t be too big. If it’s too big and too open, it’s too dangerous over Christmas. We’ve already lost people to sea when the mouth used to be open wide. And also if you just put one channel down the middle, and have it dredged off, that’s also dangerous because we also go prawning at Christmas-time and we have lost prawners when that dredge, when they’ve only had a shorter dredge.” **Online meeting participant**

A second entrance “the gap”

Complementing the perception that the Lakes need to be “flushed”, there is a popular belief among stakeholders that a second opening to the Lakes is needed. Many believe there is evidence to suggest there was once a “gap” at Budgewoi, where Budgewoi Lake met the sea, illustrated in Figure 2-7.

“The 'Big Sand' in Budgewoi Lake was created by thousands of years of sea water washing over the low dune here. The influx of fresh sea water helped maintain the lake system health. Wyong Council raised the dune and stopped the overflow. This 'gap' must be reinstated and an elevated section of road built over it.” **Comment on interactive map**

“I honestly believe that The Gap used to exist, and think a raised roadway like this would be the best way to have fresh sea water wash into the lakes again on big seas, to flush the lakes out.” **Comment on interactive map**

“Need to re-open the gap just north of the Lakes Beach SLSC. The lake once had this second opening which in large seas allowed the ocean to wash over and flush the lake. Was filled with debris by Council to form artificial sand dunes to protect the road.” **Comment on interactive map**

Figure 2-7 Heatmap showing the location of the Budgewoi "gap"

Others suggested if not the Budgewoi gap, a second opening using pipes under the roadway at the same location would help flush the lake.

> *"Flushing to reduce nutrient build-up is the answer but let us not drain the lake - maybe a second opening at the same level would allow flushing without draining the lake? This is something the qualified experts must decide after thorough investigation."* **Comment on interactive map**

> *"The best way to improve water quality in the lake system is to get more water flushed through it. This happens when it rains but could also be helped by allowing water from the ocean into the top lakes via 2m pipes with flap valves to close at ocean low tide but open with ocean high tide allowing nett flow into the top lakes. This then would force the water to flow in from the Pacific Ocean under the Toukley bridge and out The Entrance (exit) flushing the whole system."* **Comment on interactive map**

> *"If stormwater pipes between Budgewoi Lake & the Ocean were put at the high tide level then twice a day fresh water from the ocean could have a net flow into the lake system. Only in times of excessive flooding would water flow out. Possibly a second opening at the right level would do the same?"* **Comment on interactive map**

“Need a second opening to circulate water. boat ramps throughout the lakes are virtually unusable. Marine Rescue NSW are the first responders on the lakes and rivers. River and Creek mouths are silting up. Tumbi Creek is a drain more or less. economically tourism is very poorly handled Crime and drug use-age needs to address Picnic and seating areas along the lake shorelines needs to be welcoming roads need to have speed humps as they are narrow and winding around beaches and lakes Sunsets!” **Comment on interactive map**

Flooding

The issue of flooding was raised consistently during the consultation period, with areas of concern highlighted in Figure 2-8. This had been anticipated after an East Coast Low in February 2020 resulted in significant flooding around the Lakes which saw community members attempt to open the channel at The Entrance, using shovels and an excavator. This was accompanied by widespread media coverage and calls for dredging to mitigate flooding. Flooding is outside the current Terms of Reference, however, many stakeholders took the opportunity to share their concerns about flooding during consultation. Some stakeholders believe the severity of this year’s flooding was caused by the Lakes not being opened to the ocean.

“We had very bad flooding in February. Council ignored our cries for the channel to be opened causing lots of anxiety!! Finally opened it up and the water was able to recede immediately!! Not good enough.”
“If council keeps the entrance channel open my house won’t flood. If the muppets at council let it close up my house will flood again.” **Resident of 20+ years, aged 45-54**

“Continually maintain The Entrance channel and sand bars, so as lake flooding is kept to a minimum at all times! (A bit like maintaining the harbour bridge, it's ongoing!) **Comment on interactive map**

“We are very concerned about the serious flooding caused by the lake not being opened enough to the sea. The amount of sand that builds up from the ocean currents does not help either. This sand must be continually monitored and dredged on a regular basis to prevent further flooding. We and most residents of Chittaway Point and Chittaway Bay were very badly flooded in February 2020 because of Council’s failure to keep the opening of the lake to the ocean large enough to prevent flooding.” **Comment on interactive map**

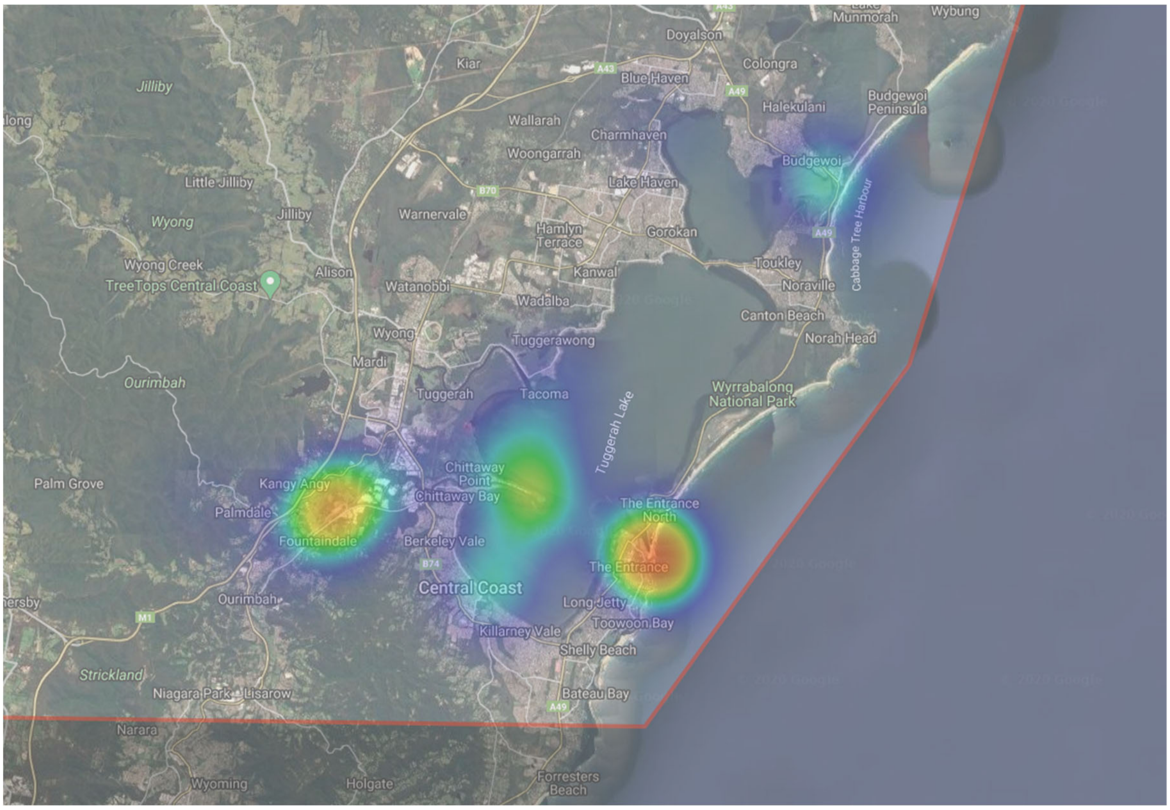


Figure 2-8 Heat map highlighting areas where stakeholders are concerned about flooding

But not all agree the Lakes opening is the cause of flooding. Some stakeholders suggested that industrial and other development in the catchment was contributing to increased flooding around the Lakes. They believe development is encroaching on flood-prone land, upsetting the natural flow and storage for flood waters, forcing flood water into the Lakes and surrounding urban areas.

> *"Tell people that opening the channel will NOT stop low lying areas (eg Chittaway Point) from flooding. AND tell them why!!!"* **Resident of 20+ years, aged 65-74**

> *"This whole Kangy Rail site was mapped as flood prone and flood storage prior to construction. Locals provided photos and testimony of flooding of the site. Something of the order of 200,000 cubic metres of fill have been dumped on the site. This changes the flood characteristics and flow both up and downstream by blocking channels for water flows and storage. More water passes through a narrower channel. This impacts on erosion and flooding of areas previously not flooded."* **Comment on interactive map**

> *"Flooding has been a natural way for the Lake system to flush itself but development around the Lake and flood mitigation works will tend to reduce this effect. Again, I suggest the only way to*

maintain the Lakes ability to flush is with dredging and channel maintenance." **Written submission**

"The removal of 4000 Melaleuca Biconvexa from a flood storage area, filling the land, then expecting the Detention/Retention basins to adequately cope with the amount of rainfall received has been very poorly thought through. Time will tell what filling 50 acres of flood storage land will have. Was the worsening of flooding around Chittaway & Berkeley Vale in February 2020 as a result of this construction? In Orchard Rd Kangy Angy the February 2020 flooding was not as bad as June 2007 flooding." **Comment on interactive map**

Survey respondents said they wanted more information about flood mitigation, more consultation with residents about flood management and for their consultation to be acted on.

"On several occasions I have spoken at council meeting with warnings about the flooding that would occur if flood mitigation was not taken seriously by council and the usual happened. NOTHING, which caused 5700 homes and businesses to be inundated by flood waters which saw many homes to have sewage floating through them." **Business owner, aged 45-54**

"The Feb 2020 floods and poor wrack collection are good examples of finger pointing, poor technical knowledge, inadequate strategies and community frustration." **Written submission**

"I would as a lake front house love to receive more information on what is being done to help the situation of lake health and flood warning systems. I feel as if I and my neighbours were failed as we were under water for a whole week all because the lake entrance was blocked." **Resident 1-2 years, aged 45-54**

While some stakeholders believe flooding is affecting their property values others said it improves the quality of water in the Lakes' system.

"We live on Budgewoi lake. Since the flood and artificial widening of the channel the lake level has dropped significantly. Now our waterfront that we paid dearly for (because it was not flood affected)looks more like a swamp and the algae that flourished this year due to the more shallow water is now producing a sickening stench. I know people who purchased cheaper flood affected blocks are pleased with the result, but I feel it is unfair that our property has been devalued. I think nature should left alone re the channel and we should be concentrating on stopping pollution run off into the lake. Perhaps the residents whose house values have been negatively impacted by the loss of water should start their own class action." **Written submission**

"I've seen first-hand, particularly after the 2007 event, that water quality was just remarkable for the next couple of years, we didn't have any significant east coast lows to block the channel up quickly, the dredging program that was continuing on an annual basis at that stage kept it clear getting to the actual mouth to the entrance, and the fish, the aquatic life, boomed, it really did." **Online meeting participant**

Water quality

During consultation, poor water quality was broadly defined as when the water is dirty (not clear to see to bottom), full of weed, smells, lacks diversity of aquatic and birdlife, stagnant (not being flushed) and shallow.

"It stinks, the water quality is horrid and it's not open to the ocean in the right spot." **Comment on interactive map**

"Please address the issues with the channel, dredging, weed etc as soon as possible so we all don't get inundated with water again, improve the health of the lake and help increase water quality." **Comment on interactive map**

"The lake is extremely shallow, its water quality is poor and dirty, it's weed ridden, it stinks and its lacking fish species." **Comment on interactive map**

Good water quality was broadly perceived by stakeholders as clear water (when you can see the lake bottom), with a sandy bottom, free of or only with a small amount of weed, plenty of fish, active and diverse bird population, and deep enough to swim in and enjoy recreational activities.

"There's two things; a lot of the things that I've read, it's the clearness of the lake is important to the right algae, right plant life to grow in the lake, it's that natural thing, so that's one. So, being out on my boat, being able to see clear water. I can see the sand on the bottom. Number two is seeing the fish. Now obviously when you've got more fish, you get more birds, so the area is just more vibrant, just by that quality of the lake." **Online meeting participant**

"When I was a young kid these lakes were beautiful and clean with sandy bottom that you could swim in at any spot in the lakes teaming with fish (commercial fishing needs to end in these lakes), these lakes need to be restored to their former glory." **Comment on interactive map**

"As a resident on Lake Budgewoi, it would be great to see it flourish once again. Being able to swim in the lake while enjoying the natural wildlife would be amazing." **Comment on interactive map**

There is a perception that water quality overall has deteriorated in the past 20 years or so. Some stakeholders shared anecdotes of when they visited the Lakes as children and recall clear, sandy lake beds.

“We use (sic) to swim in the lake as kids but there is no way I would ever let my kids swim in there, it’s so dirty.” **Comment on interactive map**

“My father’s family holidayed at Budgewoi from the mid 1920's. The family built a holiday home in the 1950/1. In 1956 we moved to Budgewoi to live. I was 12 years old, and at 76 still here. It is heart breaking to see how the Tuggerah Lakes have changed in my lifetime.......” **Comment on interactive map**

“I’ve lived here just shy of 50 years and it’s nowhere near the quality it was when I was a child. The entrance channel needs to be permanently open.” **Comment on interactive map**

“Cast your mind back, not 10 years, but 20, to when the Boat Shed at Long Jetty, wasn't in disrepair, but in use, paddle boats being hired, at Saltwater there was the waterski club house, and yes, people water skiied on the lake. I came to live on the Coast in 1989, but spent every Christmas holidays as long as my memory at Two shores caravan park North Entrance. The water was clear, we fished, we swam. The worst we got was pelican itch. After moving here, we waterskiied. The carpark at Saltwater would be full of boats and trailers, families, competitors.” **Facebook message**

Wrack and ooze

Almost 70% of survey respondents said they would be interested in receiving more information about wrack management. Wrack and black ooze were the second most common issues and concerns raised by stakeholders during consultation suggesting a high level of dissatisfaction with wrack management (Figure 2-9).

“The wrack is a complete disgrace and spending $1.5m per year on an ineffective and inefficient paddle boat and tank rake is a complete waste of money. We need to solve the problems and not just waste money on removing the wrack every 10 weeks.” **Resident of 1- 2 years, aged 45-54**

“*I wish they would remove the wrack it would be so much more beautiful to enjoy … last night was the worst. The stench was like Eastern Creek rubbish tip.”* **Comment on interactive map**

Figure 2-9 Word cloud illustrating community perceptions about wrack and ooze

> "*Council has done some good work in the catchment areas of the Lakes, to improve the health of the lakes, but their wrack management strategy and The Entrance channel management have been a total and dismal failure.*" **Resident of 5-10 years, aged 65-74**

Many stakeholders suggested that increased "flushing" of the Lakes with ocean water would reduce the growth and accumulation of wrack and eradicate black ooze by removing excessive nutrients from the Lakes' system that causes excessive wrack growth and eutrophication.

> *"Flushing is necessary to reduce nutrient water content which causes excessive growth, eutrophication & consequent Ooze. Rain into the catchment helps together with many nutrient traps around the lake system- but they are not enough, partially due to the shallow nature of the lagoon system compared with the drowned-river-valley inlets seen up and down the coast.*

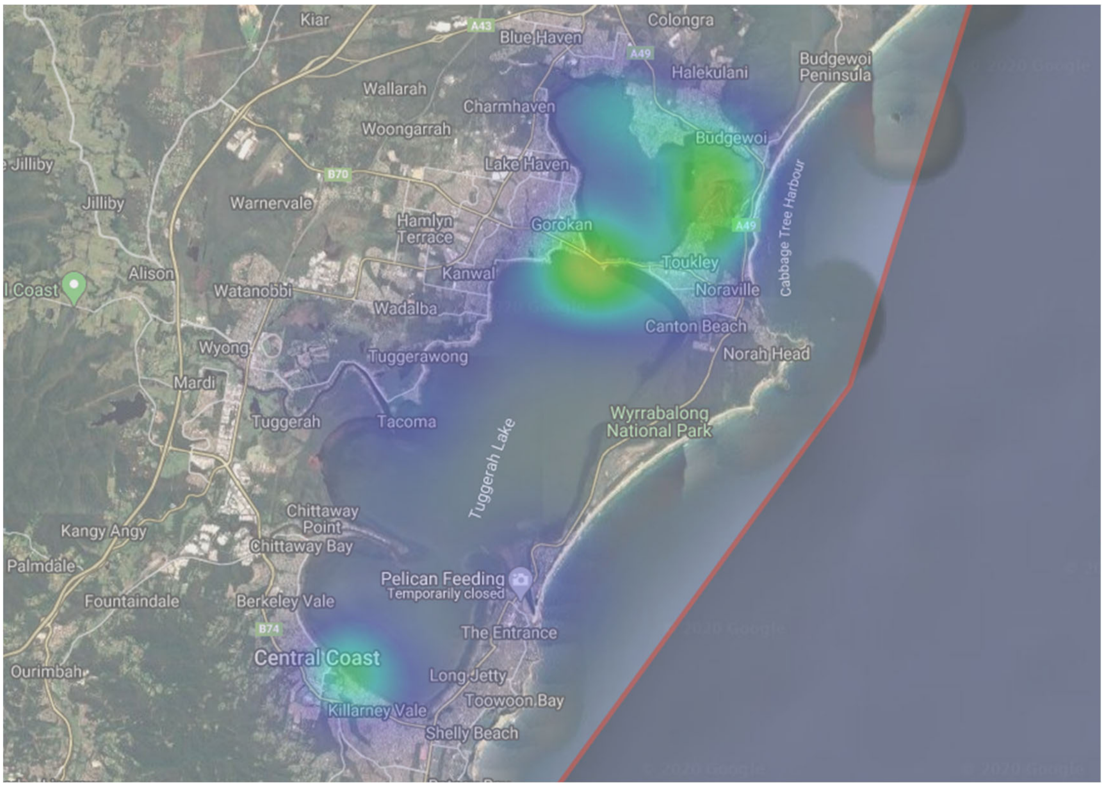


Figure 2-10 Heat map indicating where stakeholders identified wrack as a concern

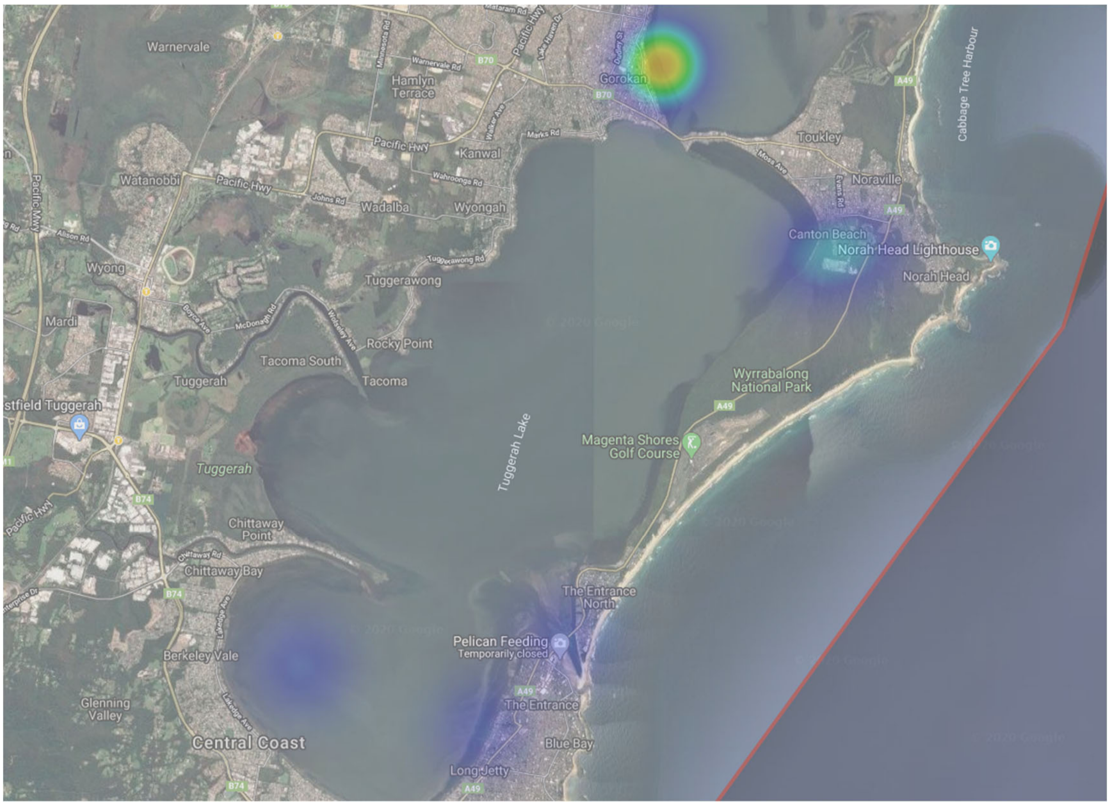


Figure 2-11 Heat map indicating where stakeholders identified black ooze as a concern

Ocean water delivered into the top lakes is a cost-effective way of returning to the sandy beaches in the lake system of the past." **Comment on interactive map**

> *"Having more fresh salt water would help control the wrack problem."* **Comment on interactive map**

> *"The water quality as well as the ongoing degradation of the Lake shore due to weed infestation seemed to improve when the Entrance was opened up recently due to flood mitigation. For a short time while water flowed freely through the entrance and small tidal changes occurred the water quality seemed to improve."* **Comment on interactive map**

Many stakeholders demonstrated an understanding that ooze develops from wrack and the importance of wrack to the lakes' ecosystem, highlighting areas of concern as indicated in Figure 2-10 and Figure 2-11. Those that understood tried to educate and inform others by responding to comments left on the interactive map.

> *"Eutrophication is where excessive nutrients cause excessive growth which can stop oxygenation. Without oxygen life dies creating the ooze that we all hate. As a sailboarder I see first hand the excessive weed in the lakes. I have to use a weed fin (45 deg) on my boards."* **Comment on interactive map**

> "*So many of these comments are very anthropocentric; when the real concern should be around restoring a healthy ecosystem where wrack plays its role in ecosystem processes."* **Comment on interactive map**

> *"The seagrass is a mixture of 14 or more different seaweeds, seagrasses, and algae, all very important parts of the ecosystem probably second to the water itself and probably the most important living part, without the growing and floating seaweeds, grasses and algae there would be next to no living marine animals at all in the lake, the weed is not the problem and wouldn't be a prob if we had not interfered with the habitat, many different things have coursed the prob all can be easily reversed."* **Comment on interactive map**

There is a perception among stakeholders that the current wrack removal program is not frequent enough, damages the edges and beds of the Lakes or does not collect enough wrack to make a significant impact on water quality. Many perceive manual removal as more eco-friendly than machine.

"Canton beach and boat ramp is a disgrace. It is always covered in weed which stinks and limits the use of the beach area. The contractors that collect the weed chew up the beach and make more mess than cleaning the beach." **Comment on interactive map**

"The more wrack that is removed the less stinking black ooze we are left with. Wrack removal should be programmed and ongoing." **Comment on interactive map**

"There isn't enough guys working the wrack collection, they barely collect every 4-6months around the foreshores, as soon as they clear canton beach they fail to go along the foreshore to collect the rest towards the bridge, within a day or two its back to bulk weed bc is washes along as they have to attend other areas. We need more operators to get on top of the wrack to make it manageable, they need the 2nd machine back in action!! minimal staff/ minimal machines = minimal work done!! OBVIOUSLY." **Comment on interactive map**

"It is not difficult to collect the wrack around the lake in an environmentally safe way by using a rake, but there seems to be an aversion by contractors/council on using manual labour. If they cannot use machinery, which wreaks havoc on the shoreline, lake and marine life, then it is not done." **Comment on interactive map**

Some stakeholders suggested that targeting the source of nutrients in the catchment (run-off from stormwater, industry, fertilisers etc) that was causing the excessive wrack needed to be done in conjunction with wrack collection.

"The large amount of wrack that gets trapped in certain areas of the lake, prevents nutrients that enter the water, from mixing with the lake water. Consequently, algae and sludge is the end result. Huge areas of shoreline along Charmhaven and Gorokan suffer from this problem due to the shape of the shoreline and also because there is no wrack collection in those areas by council or contractors." **Comment on interactive map**

"Golf courses in or near the lakes and waterways concern me. No controls to stop nutrient pollution from polluting our lake." **Comment on interactive map**

"The lakes look and smell putrid at times. Years ago, people could swim and go prawning. I wouldn't put a toe in the water now. Constant weeding of sea grass is a waste of time. Need intelligent, scientific, well-engineered solutions. Houses should not have been built so close to lake and ocean. A local population education re run off toxins into lakes needs to be organised. There must be alternatives that won't harm the water life so much. Should mangroves exist along parts of this lake, to help keep the waters in balance? A multi skilled and knowledgeable

group needs to be employed to bring life and sustainability back to the lake system. I see tonnes of water rushing into the lake during rains taking our toxins to the lake. Has any consideration been given to this? Could there be some holding ponds in which the runoff can be purified prior to entering lake?" **Facebook comment**

"*According to information on the Council website, saltmarsh was responsible for eliminating the majority of wrack, but now there is only 15% of the saltmarsh remaining. If this is the case, then it stands to reason that there is 85% of excess wrack within the lakes system, which is not being eliminated/broken down naturally. The wrack remains to rot along the shoreline. Now add in all the nutrients that flow into the lake and we have the situation we face today with a positive feedback loop of nutrients creating more weed, stench and more wrack."* **Written submission**

Catchment

There is widespread understanding among stakeholders that improving water quality in the Lakes starts in the catchment, from the headwaters and creeks that run into the Lakes' system to the human behaviours that impact on them.

"The primary concern should not be tourism and business, nor flood mitigation but rather the health of the system from the headwaters of the rivers and creeks to the sea." **Comment on interactive map**

"The issues are that we know the simple little things we can do. We don't start at the bottom of the lakes system. We start at the headwaters if we're going to solve these problems. We do little increments of things; we make planning more sustainable. Let's not just let developers go in and build 500 or 600 homes and cram them in." **Online meeting participant**

"*The primary goal for caring for the lake is ensuring the ecological health of the system from the headwaters of the feeder streams to the lake and the sea. This must be determined by science not opinion. Opinions from real estate agents and developers, tourism operators, political interests, business owners and most others are generally overly simplistic and/or self serving."* **Resident of 20+ years, aged 65-74**

"If we're seriously going to look at catchment, we've got to look at what's outside of the catchment, the direction the waters are flowing, the soil types, the wind, you name it. We can't just look at, oh, we've got wrack around the edge of the lakes, or we need to do a bit a dredging here because the fish aren't biting anymore. They're tokenistic things." **Online meeting participant**

There is a strong desire for a catchment-based approach to improving water quality reflected in the 110 catchment related comments left on the interactive map. Additionally, 66% of survey respondents said they would be interested in information about stormwater management, 48% said they would be interested in information about things they could do to improve the Lakes and 45% said seagrasses and saltmarshes.

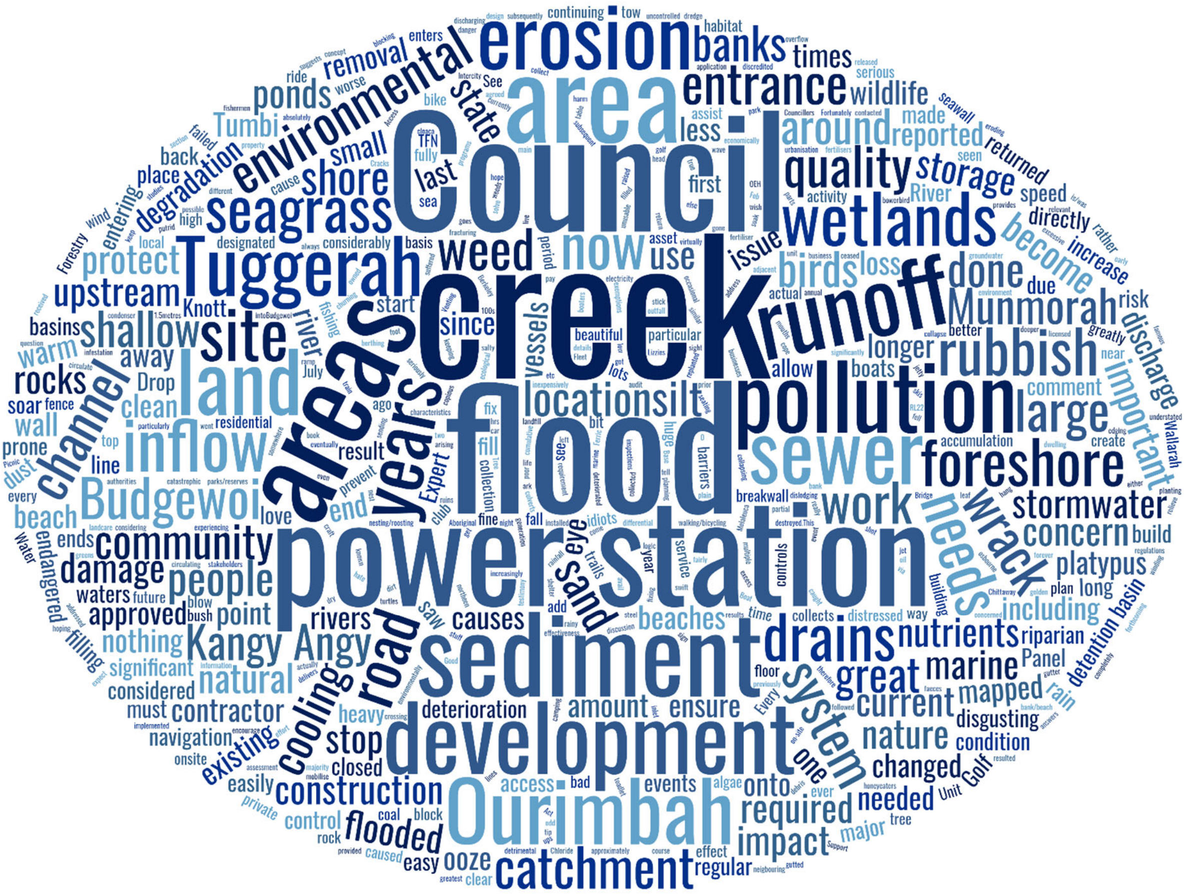


Figure 2-12 Word cloud illustrating community views about catchment management

Stakeholders recognised that catchment issues have been caused by human behaviour or decades of human intervention on a natural system.

"To regain the beautiful lakes we had in the northern half of the system, we need to reverse the damage done by humans when they built dunes to build the road to Toukley and when they reversed the flow of the lake for the power station." ***Comment on interactive map***

"The more we can return to its original condition the better chance nature has. Everything the power station did had an impact, many have not been addressed and it has been left to nature to fix nature eventually will fix theses man-made changes but it will take thousands of years without help." ***Comment on interactive map***

"The lagoon system has suffered since white man came to the area. Logging, mining and power generation has impacted immensely, yet over-development is its greatest threat. The 30 odd stormwater drains that lead into the lagoon are continuing to wreak havoc on water quality, as there are answers to the problem that I have raised several times with Councillors and Council. You do not start at the bottom of an estuary to solve the problems, it must start at the headwaters. A complete audit is needed." ***Comment on interactive map***

Stakeholders recognise the importance of wetlands and reserves as natural filters to prevent nutrients entering the Lakes' system.

"The Porters Creek Wetlands are an important ecological reserve and empty into Tuggerah Lakes. It is important to monitor land use directly upstream from the wetlands and encourage land use which steers clear of high intensity industry on paved concrete. The current 90% grassed airfield is perfectly placed to protect the wetlands, as it has done for over 47 years." ***Comment on interactive map***

"This point was white sand and was covered and reclaimed when they made the power station this could easily be made into a wetland swamp area like Colongra swamp." ***Comment on interactive map***

"The importance of riparian trees along rivers and creeks is generally not well understood by the urban community. More information and restrictor regulations and penalties by Council are required. Good reasons need to be given for removing any riparian trees on public and private property along our rivers and creeks. Tree replacement rules are generally not followed up by Council." ***Comment on interactive map***

"Pioneer dairy is a great asset to the lakes with areas for waterbirds and replanted areas providing corridors for wildlife. it also acts as a sponge to soak up some of the runoff before it hits the lakes." ***Comment on interactive map***

"After more than 20 years of hard work by the local community. The Pioneer nature reserve and bird sanctuary is a great natural asset for the Central coast." ***Comment on interactive map***

Development

Many stakeholders note the impacts of development in the catchment area, both in terms of physical encroachment on the lake edges, wetlands and increased urban run-off.

> *"The Water Act was meant to protect riparian areas and catchments from development. The government has gutted its effectiveness by granting exemptions to 'dwellings'. Great environmental harm will be done by a dwelling approved at this location claiming this exemption. This is just one example. This exemption allows unsuitable activity in riparian areas across the Tuggerah Lakes catchment and across the state."* **Comment on interactive map**

> *"Houses that have been built where they shouldn't, should be removed and the land re-established as sloping at 1% with salt marsh."* **Written submission, a commercial fisherman of 50 years**

> *"It's a gradual thing that happens with that development. But when I look back and I think back and I start reflecting on when I first bought here [Chittaway Point] one of the things that appealed to me as I walked out to the waterfront and looked down, it was the amount of fish there. And then when I was there with the kids, and there used to be things we called killer prawns, so they were a big prawn that had a long pincer – I don't see them any longer. We used to see stingrays all the time. Now it's once in a blue moon. Those sort of things have changed and that, on balance, obviously it's an increase in urban run-off and the management of the lakes."* **Online meeting participant**

> *"The continual increase of multiple occupancy development in the area will only add to the degradation of the lake system."* **Comment on interactive map**

Further to development, some stakeholders have concerns about the number of new homes planned for the catchment area over the next 15-20 years.

> *"I have been very critical of the state government coming up with what they call the Central Coast Regional Plan 2036 … I as a resident didn't have any say in that, and neither did the 350,000 other residents as well … Whereabouts is the 40,500 extra homes going in the northern region of the Central Coast? The current plan, which was the North Wyong Structure Plan 2019 was only talking about between 17,000 and 20,000 extra homes. All of a sudden, somebody's found an extra 20,500."* **Online meeting participant**

"We can't stop development, development's going to happen no matter what but let's make it truly sustainable." **Online meeting participant**

Stormwater

Stakeholders are particularly concerned about run-off from rain events and the management of stormwater, including drains, culverts and gross pollutant traps.

"Council and Govt should be testing these drains on a regular basis. This is a major source of nutrients. 10 or more years ago the community (Waterwatch) identified the detention basin and drains from the Shelley Beach Golf course as a major source of nutrients." **Comment on interactive map**

"Looking at filtering storm/water run-off, looking at any of the drains running in to the lake from Tumbi through to Chittaway end are full of dirt gravel and storm run-off. I would if thought they need cleaning out on a regular basis." **Comment on interactive map**

"The natural vegetation in this swale appears to be working to reduce the discharge of nutrients into the lake. Does Council have operating data to prove the design works? More stormwater drains of this type should be provided around the foreshore." **Comment on interactive map**

"As far as I can find out our council has no plan to complete drainage (gutters) on most of the streets leading to the lake , this run off water and dirt etc has raised the bottom of the lake over the years." **Written submission, Gorokan resident**

"The Large Culvert (at the end of Shaw Street) no longer has a 'Drain Gate' to catch any rubbish before it enters the Lake System. There used to be one, which caught a lot of debris, but it is no longer there. This needed replacing. Also, it would be great if Council could come along and clear out those stagnant culverts on a regular basis. Many of them are absolutely putrid, full of rubbish and rotting 'green waste'. Not a pretty sight while walking/bicycling along the Lake." **Comment on interactive map**

"This creek use to get maintained by council. Now the banks are eroding away that bad a large tree now fell into the creek and the fence lines of all the houses that back onto the creek are about to fall in. The council needs to shore up the shore line with rocks to prevent further erosion and runoff into the lake. Every runoff point to the lake is so shallow cause of this uncontrolled runoff." **Comment on interactive map**

“The real solution is to prevent any further siltation through gross and fine pollution traps around all sources of water entry to the lakes.” W**ritten submission, a commercial fisherman of 50 years**

Pollution

Several stakeholders identified run-off and discharge from industrial areas as a cause of concern, specifically the Kangy Angy Rail Maintenance Facility and the now-closed power station. They suggest they are a source of nutrient, chemical and heavy metal pollution into the Lakes’ system.

“The book Tuggerah Lakes way back when states that Munmorah Power Station put 4-5 tonnes of Ferric Chloride each year into Budgewoi Lake. That 100 tonnes of iron stays in the lake sediment for ever. Does this have a significant impact on the Lakes ecology in particular the formation of black ooze?” **Comment on interactive map**

“Obviously water seepage from these ash dams will make its way into the Tuggerah Lakes system and impact on the water quality. Perhaps the panel can investigate the amount of contaminants and the effect on water quality that seepage from the ash dams have on the lakes and possible solution/remedies.” **Comment on interactive map**

“The local community have not been fully informed on the water quality that is discharged from the detention basins of the Kangy Angy Rail Maintenance Facility. The contractor made a poor start to controlling sediment into Ourimbah Ck. The amount of runoff from this facility during a major flood is a major concern for water quality. Are there environmental standards and controls that are reported Council?” **Comment on interactive map**

“Toukley Golf club has been pumping their excess water into the lake forever this must stop this water is contaminated with chemicals, fertilisers, nutrients and fine grass clippings from the greens. This water is pumped directly into Budgewoi lake and feeds the weed in lake. This happens every time it rains. The golf club also pump lake water into the ponds from the lake to keep them full during dry times. The ponds are saltwater (Lake water) and full of dying marine animals.” **Comment on interactive map**

“Whenever there is heavy rain, stormwater runoff in this industrial area causes oil, toxins, metals and sediment to discharge into Ourimbah Ck. Have the stormwater drains and creeks been tested for pollutants?” **Comment on interactive map**

"The development of the rail maintenance facility has decimated important habitats, wetland and natural filters." **Comment on interactive map**

"The whole site for the Kangy Rail Facility was mapped as flood prone and flood storage. As can be seen in the aerial shot, there are holding ponds during construction and the plan is to have holding ponds during operation. Any flood of the magnitude of the 1992 or 2007 flood will overtop these ponds and spew contaminated water and sediment into Tuggerah Lakes." **Comment on interactive map**

"Flooding of Bangalow Creek at Turpentine Road underpass is a regular occurrence. TfNSW has located the train wash facility for the Intercity Fleet Maintenance Facility adjacent to Bangalow Creek. The concern for all manner of pollution to now enter the creek & therefore Tuggerah Lake at this location is now another reality." **Comment on interactive map**

However, there is some disagreement about how the power station may have impacted the Lakes.

"Munmorah PS ceased operation about 2006 and the large circulating pumps no longer discharge warm cooling water into Budgewoi Lake. This lack of circulation has resulted in large algae plumes to develop in the outfall canal. During major rain events this large amount of algae discharges into the lake. This has been reported to Council but no results have been forthcoming. The top end of Budgewoi Lake no longer has the benefit of cooling water circulation from the Power Station." **Comment on interactive map**

"It did not discharge warm cooling water it discharged warm, warm water and the Power station has not really run since 1990 since it was last on full power. The power station is what damaged the lake. The lake is 1000 times better now than in 1990. It was at its worse in 1990 because of the Power station." **Comment on interactive map**

"The Munmorah Power Station did put large quantities of saw dust into the cooling water to block holes in the condenser tubes. The method was to put a lot amount of saw dust into the water so that a small splinter would lodge into the hole and allow the unit to continue full operation. A cheap solution with some environmental consequences that were considered minor at the time. The Expert Panel should comment on the long-term environmental consequences of this practice." **Comment on interactive map**

"The entire structure of the two Northern Lakes was changed to facilitate the power station. New channels were formed and the Lake edges modified to enable cooling water for the generators. Now the power station has closed what effect has this had on Budgewoi and Munmorah Lakes in

terms of flow, temperature etc. Also there has been no cumulative study (that I know of) regarding the use of chemicals and sawdust to manage leaks in the boilers and pipes? These issues need a study of their own." **Comment on interactive map**

There are also concerns about the potential for pollution from nearby coal mines.

"The potential for pollution arising from Wallarah 2 is high. One issue is the salty groundwater they intend (after treatment) to discharge into a creek just upstream of the lake. A much bigger risk is pathogens and nutrients released from the dislodging and fracturing due to differential movement of all of the on-site sewage treatment systems at houses and businesses in the overlying floodplains. In addition, the movement of the sediments over the mine footprint may mobilise nutrients." **Comment on interactive map**

"I am worried about pollution entering the system from new coal mine." **Comment on interactive map**

In general, stakeholders are concerned about any pollution entering the waterways and making its way into the Lakes.

"Budgewoi creek is full of shopping trolleys and other rubbish it needs divers to clean it up." **Comment on interactive map**

"Amount of pollution, dead plant material that washes into the lake from this area causes issues." **Comment on interactive map**

"The state of this location is nothing less than disgusting. The rubbish that is deposited in this area by flood waters is a navigation hazard and an eye soar." **Comment on interactive map**

"Vehicles dumped in creek here." **Comment on interactive map**

"Some of the pollutants that I see coming into the lake by the small creeks that are the run-offs of the industrial area up there, is a concern. If you live on the water you see it on a boat, but obviously where I am at the end of Ourimbah Creek, you see it float by." **Online meeting participant**

"It appears that water from the car wash enters the creek here unfiltered." **Comment on interactive map**

They are also concerned about the discharge of sewerage into the Lakes with some suggesting illegal stormwater connections also need to be investigated.

"The smell of sewer from the foreshore sewer pumping stations (100s of pumping stations) may indicate that there is sewer discharging into the water table. Does Council have an annual sewer pollution report of the problems and durations that would assist the Expert Panel?" **Comment on interactive map**

"Agreed, the Sewer overflow vent that runs into Ourimbah creek to relieve the holding tanks at the sewerage plant during rainy weather has filled this channel with so much faeces and silt it rivals the cloaca maxima." **Comment on interactive map**

"*I hope you can convince council to improve our sewer system, these leak into our lakes during flooding. I would like to see every house that floods to have a screw lid fitted to the inspection opening, usually found at the rear of the house tap. Preventing flood waters from entering our sewer system should stop, slow the overflow of sewer into our lake, like happened during the February 7 catastrophic storm event."* **Facebook comment**

"*We may have many illegal stormwater connections, into our sewer system, that must be investigated and remedial work done."* **Comment on interactive map**

"*You are correct, I also wonder how much raw sewer enters our lakes during storms, due to illegal stormwater connections.?"* **Comment on interactive map**

"*Sewer overflows have caused closure of the lake for short periods after some storms. Pls have a look at the system capacity and alternate overflow points. The temporary closures have a negative impact on many peoples permanent view on lake health."* **Comment on interactive map**

Figure 2-13 Heat map of the western side of Tuggerah Lake indicating where stakeholders have concerns about sewerage entering the water

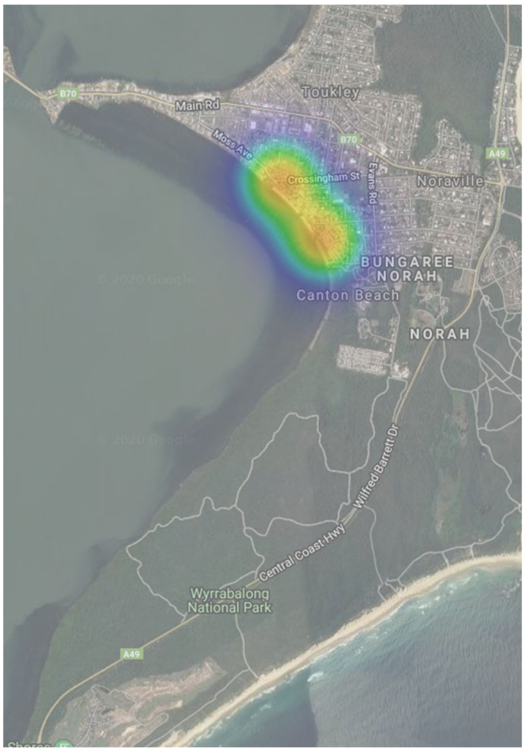


Figure 2-14 Heat map of the north-eastern part of Tuggerah Lake indicating where stakeholders have concerns about sewerage entering the water

2.3.3 What the community value

The community value diversity in marine and surface ecology, especially bird life and recreation opportunities.

"Waterhole is an underground spring which runs through Lakeside Leisure Village then into lake. Where it comes into the lake weed grows in the shallow water and the swans congregate there at end of breeding season with juvenile offspring and they feed on the weed. So this waterhole and spring plays an important role for bird ecology on the lake." **Comment on interactive map**

"The ocean water that was pushed into the lakes by strong winds on 22-24th May, cleaned much of my shoreline ooze. I also had a lot of new "Bladderwrack, which has an important symbiotic relationship with mussels", these are in good health and now abundant. These are vital to health of our water, filtering 20+ Litres a day. Somewhere washed onto my shoreline, where I returned them to the lake. Council allows these to die & taken to the tip. This must be stopped. Bladderwrack health is vital." **Comment on interactive map**

"Canada Drop Down Creek is known platypus habitat. It provides clean water to the Lakes via Ourimbah Creek. The creek and its banks provide shelter to many species like wallabies, wombats, antechinus, snakes, lizards, turtles, many frog species, as well as birds like the lyrebird, regent bowerbird, golden whistler and many more. It is especially important after so many animals were lost in the catastrophic bushfires last summer. These areas are a wildlife ark preserving our animals and birds." **Comment on interactive map**

"Kayaking Ourimbah Creek & seeing platypus, water dragons, eagles a bass." **Comment on interactive map**

"This is a significant estuary and it should be celebrated... too much focus on negatives!" - **Comment on interactive map**

"The combined cycle/pedestrian path along the foreshores is a beautiful place to exercise and unwind in beautiful surroundings with trees and views across the lake." **Comment on interactive map**

"*The boat shed is an icon of The Entrance, the state of the lake is what we rely on to stay open. For far too long this beautiful estuary has been neglected and passed over. We need answers as to how to fix the issues permanently."* **Comment on interactive map**

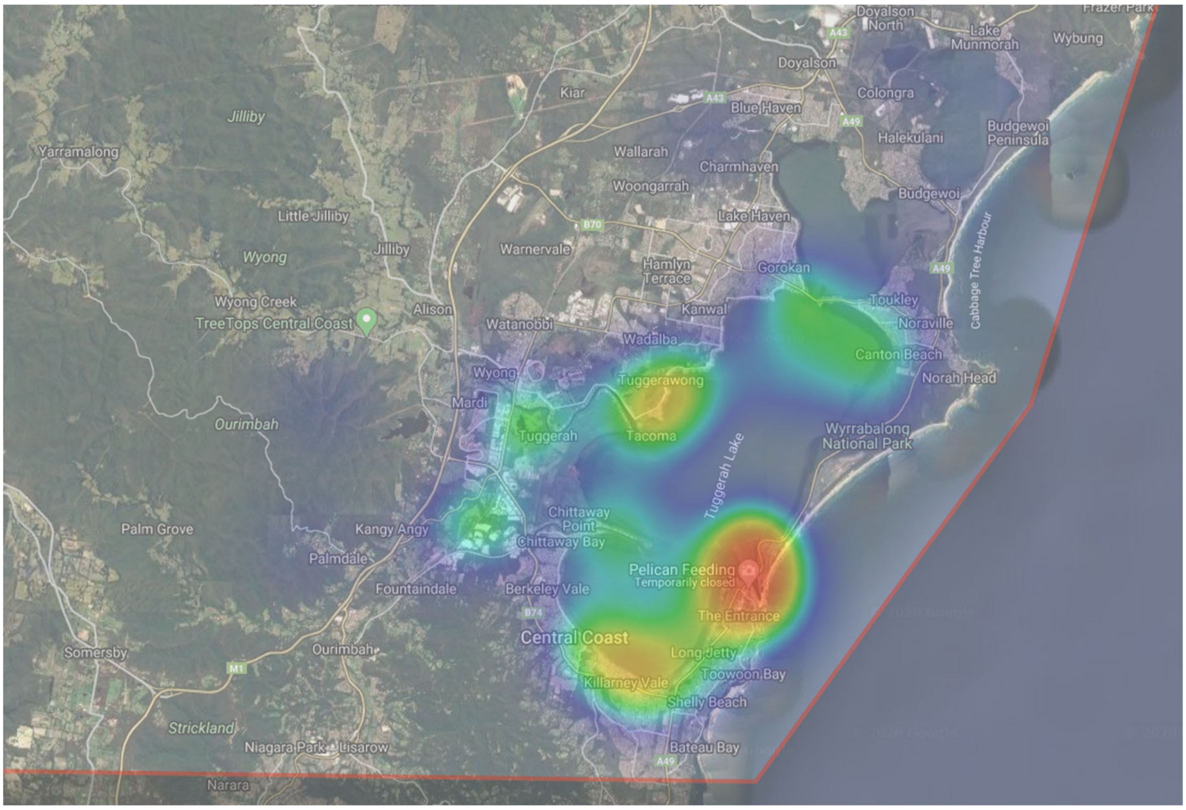


Figure 2-15 Heat map showing where stakeholders identified places and activities they value on or around Tuggerah Lakes

"It's sometimes smelly but always beautiful. I greatly appreciate the public and accessible foreshores alongside the beauty." **Comment on interactive map**

"My grandchildren and I love to fish." **Comment on interactive map**

"Love visiting the raised pathway to observe lake ecosystems and bird life in area." **Comment on interactive map**

"Love this spot for walks and bird watching close to the cafes. Sunsets are beautiful. Would love to have more of this style of seating on the foreshore, no need for a beach, no one uses it. But the seats are always full, hard to get a spot, impossible in school holidays. Love the paperbarks along here, would like more shade trees on the foreshore for picnics in summer. I miss the Long Jetty festival." **Comment on interactive map**

"Having a paddle around Canton Beach on a quiet day." **Facebook comment**
"I love to kayak." **Comment on interactive map**

“Great recreational spot perfect for sunset.” **Comment on interactive map**

“The lakes perfect, it’s beautiful, has the most bird life of any of the coast estuaries!!” **Facebook comment**

“We use and appreciate this boat ramp and cleaning table, however the whole lake could benefit from more frequent Dept fisheries inspections particularly during holiday periods.” **Comment on interactive map**

“This very beautiful natural rock shelf, swimming area, beach and playground is being ruined by excessive wrack accumulation.” **Comment on interactive map**

“I value this area because of the serenity and peaceful quiet, the swans, pelicans and fish, the view is magnificent.” **Comment on interactive map**

2.3.4 What does success look like to the community

At the tail-end of the consultation program, the community was asked what “good” looks like or how they would know that water quality has improved in the Lakes’ system. For the purposes of the consultation, the community was asked to imagine what the Lakes would be like in 2030. Perception of good water quality was, for the most part, linked to how the community could enjoy the Lakes recreationally. Second to this was a Lakes’ system teeming with bird and aquatic life.

“In 2030 it would be good to be able to swim, kayak and fish the lakes. All these activities have virtually disappeared.” **Online discussion forum comment**

“A healthy lake system means children can safely swim in the water and toddlers can safely sit on the white sandy beach and enjoy the splash of gentle waves on a hot day.” **Facebook comment**

“A healthy lake system means that the lake can be used by everyone, visitors and residents alike. It means money to the communities that rely on the visitors coming to our towns for their livelihoods. It means the fish, the birds and all water reliant creatures have a healthy ecosystem to live in.” **Facebook comment**

“To enjoy watching the fish swim between the sandstone rocks at the water’s edge and the small crabs scurrying by, past against a backdrop of a yellow sandy bottom, with minimal decaying wrack and debris.” **Online discussion forum comment**

“I want to stand on Saltwater bridge and look down when the water is clear and not see debris, dumped rubbish, council cones, shopping trolleys etc in the water. I want to see just the fish! Imagine, a flash back, look at historic images of what the lake looked like. THAT is what we want back again.” **Facebook message**

“*What I would like to be able to do in my lake No 1 prawn in the summer. Be able to access the lake with small beach from the lakes entrance to the bridge on the western side along the walk way. Then same on the beach side.”* **Written submission**

For others, it was also about what they could immediately see, smell and hear – less weed, clearer water, sandy lake bottoms and lots of human and marine life.

“I would expect to see tidal water running in and out of the lake, much cleaner water in the lake, less weed and smell around the shoreline, fish and prawns, as before, so we can get back to fishing. A bit more depth in the lake so we can see more boats on the water, clean beaches around the lake so kids and people can get back to swimming.” **Written submission**

“The lake will have a sandy bottom near the shore instead of mud like it did 35 years ago. Less weed as well. San Remo at the end of Emu Drive used to be a lovely sandy clean area to swim in then and if it was like that again I would say it was clean.” **Online discussion forum comment**

“I hear kids having fun, wildlife singing and water flowing. I smell fresh cut grass, salt water, fishing and chips. I would like to see a break wall with pedestrian path, barricaded swimming areas at picnic spots for kids. Wildlife and sea life thriving from fresh flowing waters and consistent tidal changes. The seaweed healthy with a sandy bottom lake of breeding and natural corals coming to life.” **Online discussion forum comment**

“The water will be clean and full of life - a variety of fish, prawns, birds, other marine animals. The tide will rise and fall. The edge of the beach will be sandy. There will be no overgrowth of weed or alga, the lake won’t smell. People will be using the lake a lot more - swimming, sailing, kayaking, fishing. There will be regular monitoring of water quality and biomass of lake.” **Online discussion forum comment**

For others, it was about knowing the water quality was being monitored and appropriately resourced and managed.

> *"I would like to see Improved water quality/clarity up in Lake Munmorah, less weed build up and rotting on the foreshore, a return to sandier bottoms instead of the sludge that results from decaying weed. I just expect better monitoring of the runoff into the lake systems."* **Online discussion forum comment**

> *"In 2030 it would be good to know that Council have the resources to continually improve water quality and not be in catch up. The short and long term plans need to be resourced and communicated to the community. Grants and funding year on year is old school."* **Online discussion forum comment**

> *"It would be good to know that Tuggerah Lakes was a leader in water quality management. The 2019 Coastal Conference demonstrated that other coastal communities are doing better."* **Online discussion forum comment**

> *"It would be good to know that the Tuggerah Lakes catchment had a Waterwatch program and health report program similar to the Molongolo River in ACT."* **Online discussion forum comment**

One suggested it would be when locals showed "pride" in the Lakes and it would drive an economic upswing.

> *"Locals are proud of the "new lakes" clean, fresh, full of fish."* **Online discussion forum comment**

> *"Locals and tourists will want to return to water sports and recreation on the lakes, bringing economic upturn to the upper Central Coast."* **Online discussion forum comment**

2.4 Discussion

Key Points
Much of the public discourse relating to the management of the Lakes reflects the strongly-held positions, beliefs and opinions of all those with an interest in the issues.
While communications and engagement is dominated by positions, beliefs and opinions it is likely that disagreement will grow and trust will fail.
Future engagement processes should be designed to encourage all participants, including Council and state agencies, to go beyond their positions. Engagement should support learning and joint exploration of issues, and allow the whole community of interest to build a shared understanding of the full range of interests and values across the community and other stakeholders.
There is a significant gap in the collective understanding of Tuggerah Lakes management dilemmas. Every organisation, agency and individual sees a piece of the problem but the holistic picture is not shared collectively.
Future engagement processes should be designed to grow a common and deepening understanding of the full range of dilemmas that must be addressed in order to improve water quality and related issues.
Dilemmas include aspects of governance and the extent to which Council and the State Government do or don't work together. These are critical aspects of what makes managing the Lakes more challenging.
A rich and richly-shared understanding of the dilemmas will allow the community, Council and others to work together to find potential solutions.
Trust is low among those individuals, groups, organisations and agencies with an interest in Tuggerah Lakes. Low trust makes it much more difficult to tackle complex problems such as those that manifest across the Lakes system.
In order to make a lasting improvement to the health of the Lakes, it is essential that future engagement processes are focussed on building trust.
Good engagement alone cannot rebuild trust across the Tuggerah Lakes community. It is important that local and state representatives, including elected representatives, prioritise trust-building as a central part of any Lakes Management strategy. Trustworthy governance and leadership is essential to the future wellbeing of the Lakes.

From the large amount of community feedback through the consultation program it is clear that the community are somewhat frustrated and concerned about the state of Tuggerah Lakes and care deeply about their future. It is also clear that many in the community are prepared to invest a great deal of time and effort into improving the Lakes. Stories were told of do-it-yourself weed-cleaning programs, experiments with weed management, investigations of tidal flows and detailed historical research. To improve the Lakes, people sit on committees, write letters and volunteer. They love their Lakes.

People also derive their business from the Lakes, and they spend recreational and leisure time on and about the Lakes. These waterbodies play a central role in the life of the local community. It is therefore not surprising that community members were keen to have their say through the consultation process. Conversations were held with numerous stakeholders and messages exchanged with many others, facilitating the compilation of a wide range of perspectives from a wide range of people. Three overarching conclusions were drawn from all of this communication, with important implications for future engagement and communication:

1. Opinions, 'positions' and assumptions dominate the discourse, when all would be better served by a focus on learning rather than telling and exploring rather than fixing.
2. There is no holistic understanding of the problem or problems to be tackled together. Many put forward 'solutions' but the true nature of the problems to be solved is very unclear.
3. Trust among all parties is very low, making it more difficult to meaningfully resolve the first two issues.

This discussion will look at these three interrelated issues in more detail before presenting a number of recommendations regarding future communication and engagement.

2.4.1 When opinions, positions and assumptions dominate

What is a position? A position can be thought of as a statement that might be made at a public meeting, in a letter to the editor or in a post on Facebook. A position is typically introduced by a phrase such as "here is what I think…", or "here is what I think about what you think…".

During the community engagement process, many clearly articulated positions were presented on a range of issues, including statements along the lines of: *it is obvious that we need to build twin breakwalls*, or *breakwalls aren't the answer*, or *dredging to 5m is essential* or *we mustn't dredge* etc. These genuinely-held positions are expressed in good faith and represent understandable beliefs. But taken as a whole they don't always represent the best wisdom of the community and they aren't particularly helpful for decision makers or the community at large. The community is capable of real wisdom and insight regarding the management of the Lakes, but only if engagement processes provide pathways for all stakeholders to explore beyond each other's opinions and positions to reveal and explore underlying interests and values.

The two triangles in Figure 2-16 represent people with two quite different positions. A consequence of any conversation that takes place at the level of position, quite noticeable through this engagement process, is that a focus on positions can drive polarisation and finger-pointing. Focussing on positions increases the potential for dialogue to degenerate into an argument about which position is right or better than the other rather than exploring the issues underlying the stated positions and providing an opportunity to discover common values. If we go beyond stated positions to explore what sits below, we find common ground about what really matters to us both.

It is important that future engagement processes focus not on hearing more positions but on giving all stakeholders the opportunity to explore why those positions are held, and what is felt to be most important about the future of the Lakes. A conversation about "I believe we need a breakwall" should ideally become a conversation about how we want to experience the Lakes, and then on to what is and isn't possible in terms of the future of the Lakes. This can then inform a conversation about the many actions that might be taken.

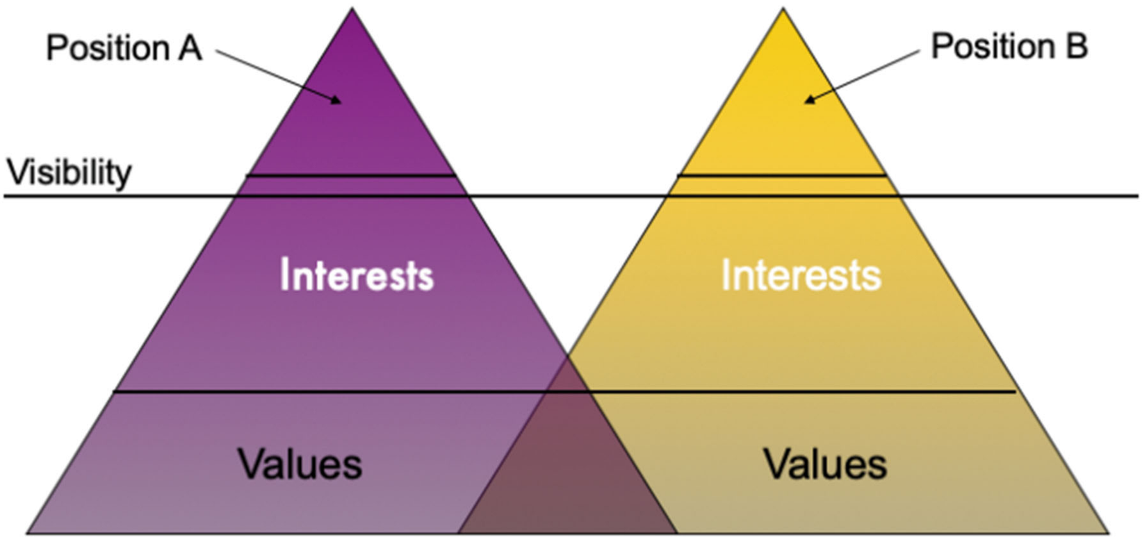


Figure 2-16 A foundation of common ground

2.4.2 The vicious cycle for decisions makers

Elected representatives, with good intention, will ask their constituents for input on the future management of the Lakes, and unsurprisingly, their constituents will tell them. Yet if the question is along the lines of 'what do you think we should do?' they may unintentionally invite a range of positions that simply demonstrate to everyone how little agreement there is. Unsurprisingly, elected representatives and local leaders struggle to make sense of this input and find themselves unable to provide responses that can satisfy the community or provide a consensus position.

Processes that do little more than obtain multiple positions based on opinion can at worst leave those in power with little choice but to pick and choose the positions they want to acknowledge, or try to please everyone – an impossible task - or do nothing, or ask people again what they want to do, which encourages more positions. Nobody feels listened to and the management of the Lakes' system becomes harder as relationships are further damaged.

This common dynamic leads to general frustration, the widespread sense that community engagement isn't helpful and a growing dissatisfaction with 'Council' and 'Government' and the lack of progress. It is worth mentioning that the common engagement tagline 'have your say' is deserving of criticism, as it tends to be an invitation to do just that. What is needed, rather, is an invitation to start listening and developing an understanding of our collective disparate viewpoints. That is, move from positions into interests and values.

2.4.3 A shared management process

Both state and local government are involved in managing the Lakes and neither level of government is immune from taking 'positions' about, or in spite of, the other. Yet in order for all parties to move past their own positions it is very important that all levels of government actively support each other in that effort. If one branch of government, or an elected representative, is giving oxygen to specific positions while the other is trying to encourage people to move past those positions to learn together, this ultimately does harm to the standing of both state and local government. The perception among the community that leaders are 'playing politics' is toxic to successful community engagement, so it is very important to the future management of the Lakes that both levels of government help each other to do quality engagement and foster wise conversations.

In summary, the many differing opinions and positions relating to the past, present and future of the Lakes have been well heard. For future engagement it is important to bring the community and staff and elected representatives past adopted positions into a shared exploration of what really matters to the local community and environment and what is really going on. Elected representatives and other leaders should avoid falling into the trap of soliciting, supporting or actively responding to positions. Instead they must support the system to be wise together through best-practice engagement processes.

2.4.4 When we ‘know what the answer is’ but we aren’t clear about the question

A high percentage of the positions heard during the community consultation process were presented as being the necessary solution to the Lakes’ problems, such as build a breakwall, get a different sort of weed raking machine, dredge here, or don’t dredge here, open a second entrance - to paraphrase a small selection.

The glaring gap in the public discourse is a collective understanding of the problem for which these ‘solutions’ are proposed. Everyone sees a piece of the problem and a potential solution to that piece. But the underlying holistic set of Lakes’ management problems tend not to be clear and are not agreed among all stakeholders. Until the management dilemma is clear and agreed to in a holistic, complex sense everyone is trapped in an unproductive effort to push their proposed solution to the problem as they see it.

2.4.5 Problems or dilemmas?

The consultation process revealed many perspectives on the various issues associated with Tuggerah Lakes . For example, is the problem *how to rebuild the local fishing and tourism industries* or *how to return the Lakes to their natural state*? Perhaps it is a more complex dilemma such as *how to move towards a more natural lake management regime in a way that fosters recreation, tourism and leisure*?

Is the problem *how to prevent future development in the catchment* or *how to reduce urban runoff*? Or is it *how to meet state government growth targets while reducing urban impacts on the waterways*? Is the problem *how do we keep the entrance open* or *how do we make sure “I” don’t get flooded again*? Or is it *how do we best manage the system to minimise the risk of future catastrophic flooding*?

Is the problem *how do we get the Lakes to look and feel like Lake Macquarie* or *how do we support the lake system to keep itself healthy*? Or is it *how do we support natural processes and dynamics in a way that maximises the amenity for residents and users, and minimises the risk of flooding*?

Is the problem *how do we get this weed out of the lakes*? Or is it *how do we stop weed piling up on the edge of the shallows and forming a dam*? Or is it *how do we manage the lakes as a system so that we get less black ooze?*

Without a doubt the real complex Lakes' management dilemma is an unstated mix of all the above and more. It is critical for the success of future engagement on the Lakes that all stakeholders are provided the opportunity to understand and clarify the Lakes' management dilemmas together. This will not only help everyone go beyond positions and 'solutions', it will also inspire a range of smart management actions, informed by a more holistic understanding of what is really going on.

Importantly for engagement, neither a panel, nor Council nor State Government – nor indeed anyone else – is the holder of all knowledge about the dilemmas facing the Lakes. The full diversity and richness of the dilemma can only be developed from the input of a wide diversity of experiences and knowledge. This means future engagement processes must seek to maximise the diversity of voices in defining the dilemma.

2.4.6 A dilemma of process, governance and politics

The Lakes' management dilemma is not only about ecological and physical processes. As with many coastal management issues, the situation is made more complex by the nature of governance and political context. Each part of the governance system therefore is part of what makes 'solving' the Lakes difficult. So in the state government context, the perennial difficulty of getting the various agencies into the room and aligned on what needs to be done is undeniably part of the Lakes' management dilemma. In order that future engagement processes are credible, it is very important that relevant state agencies recognise and acknowledge their part in the holistic management dilemma and take an active, positive role in any engagement in solution-finding processes.

Elected representatives are also part of the system and the same process applies. Politics is an unavoidable part of the context. Elected representatives can support good engagement by acknowledging the role they can play, both as part of the complexity of the situation and in working constructively across political boundaries to help find ways forward. To put this another way, State Government and its representatives cannot expect Council to engage their stakeholders on the management of the Lakes without acknowledging the part they (the state) play and the need from them to be in the room and an active, transparent and positive part of any engagement process. State Government is unavoidably a part of the system, so it must be a part of the solution.

Similarly, Council and its processes are part of the Lakes' management dilemma. For example, those in coastal management often find that one part of Council is not aligned with another in terms of management strategies and actions. Once again, this is a process and governance aspect of the Lakes' management situation that must be acknowledged and recognised as one of the things that makes managing the Lakes more difficult. It is an unavoidable part of the complexity of the situation.

The implications of these organisational and process dilemmas for engagement is that to genuinely make progress to improve the Lakes, all stakeholders have to work together to tackle what is really going on, including politics, organisational silos, state/local relationships and processes. An authentic engagement process must involve all parties being up front about these things as otherwise, the engagement risks being a token effort, delivering little real progress and driving more cynicism.

In summary, the Tuggerah Lakes are a complex biophysical and social/political/economic system. In this context any proposed solution, such as *build a breakwall,* or *implement the weed management strategy* can never be <u>the</u> sole solution. At best, most so-called solutions may go some way to resolving some issues, while perhaps having a range of unintended consequences elsewhere across the system. For future engagement processes to be useful they therefore have to focus on building the collective understanding of the systemic nature of the Lakes – including natural and human aspects. That is, the community of interest must find a way to better understand the holistic Lakes' management dilemma and then together explore actions that are likely to have some benefit in that context. It is challenging engagement work but, in this way, the full wisdom of the whole community of interest can be accessed.

2.4.7 Trust: the oil in the problem-solving machine

The survey of residents undertaken for this study indicates a deficit of trust across the system, with respondents naming State Government departments, Council staff, State MPs and elected Councillors as the four least trusted groups or institutions. Trust is the oil in any problem-solving 'machine' and where trust is low, working together on hard problems becomes more difficult. Low trust among survey respondents isn't particularly unexpected or unusual, but in the context of resolving long term problems with the Lakes, it has real implications.

When trust is low we retreat to safety, doing less engagement with those we don't trust and preferencing those who we expect to think and act more like us, such as 'friendly' action groups, those we identify with, our political allies, workmates, neighbours etc. It becomes harder to seek out and genuinely listen to 'others'. Formal engagement processes can go some way to tackling this bias with thoughtful planning and careful implementation, but all the other conversations and interactions that take place across a community can easily suffer.

A lack of trust makes us reluctant to meet and talk with ‘them’. It makes it hard to listen to and validate their perspectives. Low trust makes it very challenging to explore and learn together. We are prone to finger-pointing, to blame and to a retreat to ideology, which further reduces trust. We retreat to our ‘positions’. We seek evidence of failure or inaccuracy in their position. The relationships spiral downwards.

There is evidence of this dynamic at play across the Tuggerah Lakes community of interest. Among technically-minded stakeholders, including Council staff, external experts, residents and others, low trust drives a retreat to the data and the belief that “if I give them enough evidence they will see it my way”. Engagement then becomes an exercise in educating, telling and convincing them about the rightness of my data.

But where trust is low the usefulness of even the best data, science and evidence is much reduced. If the receiver doesn’t trust the messenger, why would they trust the message? As the saying goes “I need to know you care before I care what you know”. In other words, I need to know that you are listening to me, that you have some empathy for my position and my interests at heart before I give any credit to your data. Of course, the more we try to convince others about our data the less listening we do and the less reason they have to trust us.

So for engagement on complex coastal issues, the prime objective must be to build trust among stakeholders so that together everyone is more able to have the often difficult conversations that matter.

2.4.8 Building trust

So how to build trust? This question has implications beyond Council’s engagement team, going to the way both state and local government ‘walk the talk’ as trustworthy institutions. Building trust requires:

- Transparency: The willingness to be open about all aspects of decision-making regarding Lakes’ management.
- Ability to admit mistakes: The willingness to admit where things have gone wrong and perhaps are still going wrong.
- Asking for help: the willingness to admit that “we can’t do this without you”.

- Focussing on relationships: the willingness to listen, to genuinely empathise with how people are feeling and where they are at.
- Following through with commitments: taking actions and getting things done as agreed.
- Sharing control: Allowing everyone to get their fingerprints on the process, to help design the engagement and to help co-define the dilemmas and understand what is going on.
- Do with, not to: To the maximum extent possible, making decisions about the Lakes with the community of interest, rather than to them, or even for them.

2.4.9 Leadership, trust and engagement

Politics was often cited as a reason the community mistrusted the institutions of power. As the COVID pandemic has clearly demonstrated, voters like to see those in power working together for the interests of all. Our trust in government increases when we see those in power doing a good job and doing it collaboratively.

Conversely, we are all very sensitive to signs of politics at play. Those who seek evidence that politics is in the way of good governance can usually find this evidence. Such evidence – whether real or imagined – undermines people's trust in the system, which in turn makes life harder for everyone, elected representatives included.

This is a key issue for engagement, which always take place in the social and political context. Neither Council nor State Government representatives can expect anyone to engage the community in a way that builds trust if political and bureaucratic leaderships appear to be demonstrating a lack of trust in each other, those same community stakeholders, or the process. Trust-building engagement can only work in a trust-building organisational and leadership culture.

In summary, 'good engagement' starts at the top and even the best-planned engagement process can only be as credible as the political and organisational commitment to that process. Trust is the oil in the machine and it is essential that engagement is designed such that it builds trust across the system. To make this possible, elected representatives and officials in both local and state government must ensure the governance context for that engagement is also something the community of interest can trust, achieved through transparency, openness and the extension of trust to stakeholders in return.

2.5 Recommendations

One way to look at the recommendations offered in this section is illustrated in Figure 2-17, which suggests that relationships are built through conversation, allowing challenging actions and transactions to then be agreed together. In other words, progress on long-term Lakes' management solutions is achieved via conversations and relationship building. At their most fundamental, the recommendations regarding community engagement can be summed up as 'go slow in order to go fast'. Invest time and energy in building relationships and trust across the system so that hard conversations about potential management actions can be usefully had, leading to effective decisions.

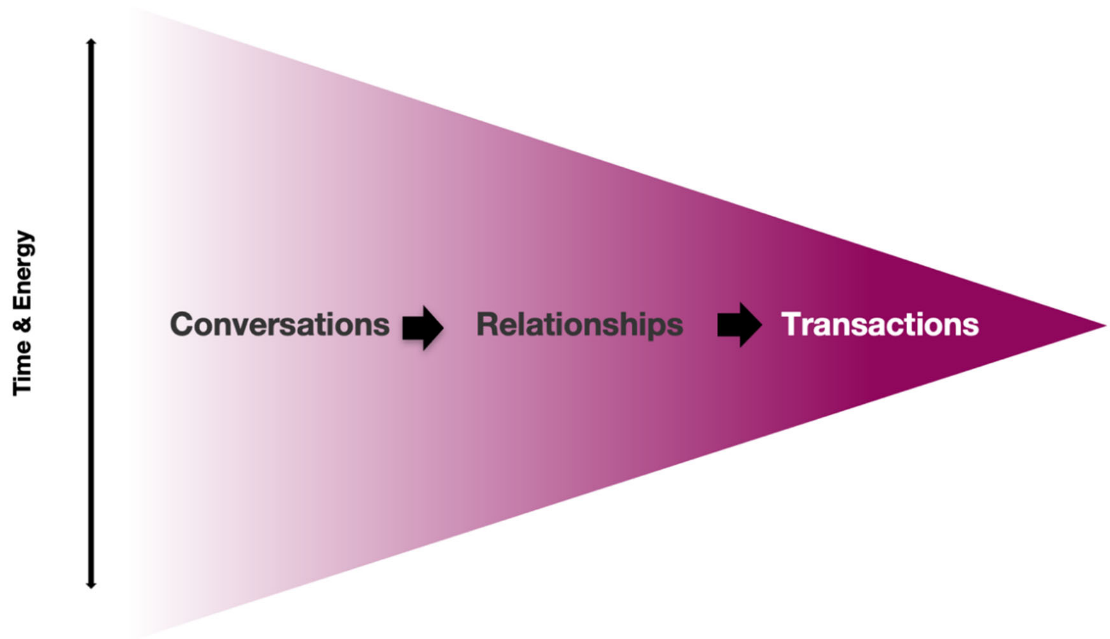


Figure 2-17 Using conversations to build relationships

2.5.1 Community engagement and communication recommendations

The following recommendations are made regarding community engagement and communication:

1. Focus engagement on learning together rather than solving 'the problem' or 'fixing' the Lakes. Work with the community to:
    a. Explore the physical dynamics of the system to build (or at least understand) a conceptual model of the Lakes' system including nutrient and energy inflows and outflows, sand movements, wave actions, flooding and the entrance etc.

b. Set the community up as scientists and researchers and support them to design and conduct small-scale experiments together.
c. Test the various theories put forward by community members, such as those concerning an ocean connection via 'the gap', weed management, tidal flows etc.
d. Focus on building a shared understanding of how the Lakes work. Take time to do this as a joint project, admitting that we don't have all the science already.
e. Seek and acknowledge community knowledge, beliefs and understanding. Seek to understand and help others in the community do the same. At the same time, be clear about what the science is saying.
f. Communicate all of the above broadly with the community.

2. Work with the community to grow a shared understanding of the Lakes' management dilemmas – what is actually going on and what makes managing the Lakes so difficult.
    a. Be clear about constraints, such as financial, resources, urban growth targets, skills and knowledge. Be up front about the role of politics on governance. Acknowledge the complexity of the context and the physical systems. Acknowledge the risks of unintended consequences of any actions.
    b. Agree with stakeholders on the key aspects of the dilemma – thereby describing the problem(s) to be addressed (not necessarily solved).
    c. Communicate all of the above broadly with the community.
    d. Integrate this understanding within the Coastal Management Program framework, which has a legal imperative for collaboration.
3. Build on the dilemma work to co-create a shared picture of the realistic and preferred outcomes for the Lakes.
    a. For example, an outcome could include: water quality that is no worse than current standard, or; a lake that people feel comfortable to swim in.
    b. Then use this shared sense of the desired future to inform actions and interventions and evaluations.
4. Work with the community to design and agree to a decision-making process to determine potential and prioritised management actions, and to implement them. Establish a group to do the work together, with their role including:
    a. to devise and agree a set of criteria to guide decisions about options and actions,
    b. to oversee the design and running of the ongoing series of 'experiments', pilots and other investigations,
    c. to oversee the development and dissemination of messages for the broader community,
    d. to oversee the development of potential actions emerging and their assessment against the criteria,
    e. to oversee additional studies as warranted, such as cost benefit analyses,

f. to make recommendations about large and small actions,
g. to oversee the implementation of actions, and
h. to monitor and learn from lake management actions taken.

Based on the CSEP and recommendations provided above, the following chapters outline our scientific understanding of how the lake functions in terms of the entrance dynamics, the water quality and ecological dynamics and the role the catchment plays in the lake's water quality. Further, the recommendations provided above are used throughout this report as a filter to guide decision making and in developing other recommendations.

3 Entrance processes, hydrodynamics and mixing

3.1 Introduction

This chapter details the existing scientific understanding of the lakes' oceanic entrance and how this connection to the ocean influences water quality within the main lake waterbodies. Past reports, historical records and results of the community consultation described in Chapter 2, have all shown that dynamics of the entrance channel and issues associated with flushing and mixing between the ocean and the three Lakes, have been of persistent interest to the community for decades. Many specialized scientific and engineering studies have been completed to investigate aspects of these dynamics alongside options that could be considered to address water quality problems in the lakes. Each report has its own focus and reports have often been commissioned in response to a specific demand from the community. As noted above in Chapter 2, a commonly expressed sentiment is that enough studies have already been done, and that there should be enough understanding to "do something" to "fix problems" with the entrance. However, different reports can sometimes provide conflicting information about different aspects and this results in understandable confusion.

A key aim of this chapter has been to review the previous studies on or influenced by the lake's entrance, providing assessment and critique. The overriding concern has been to assess our understanding about a variety of management strategies that have been promoted, including dredging, breakwaters, second entrances, pumping of seawater and others. Key gaps in understanding are highlighted, and where we can provide a suitably informed comment on feasibility or appropriateness, this has been documented. With coastal entrances, it may well be possible to engineer a solution that achieves some of the desired objectives, but this is often at a considerable expense. Of course, how much something costs is not the only determinant of feasibility; the costs need to be balanced against the benefits that the community obtains from the solution. Many of these benefits can only be robustly assessed by specialist economists and social scientists and via collaborative engagement with many stakeholders.

This chapter aims to summarise the existing scientific understanding of the entrance effects on water quality (versus undertake new scientific investigations). The next section provides a summary of the key reports available for the review. Subsequently, Section 3.3 discusses the long-term evolution or 'geomorphology' of the lakes, explaining their formation over millennia, and changes since the arrival of Europeans. Sections 3.4 and 3.5, respectively, discuss flow within and through the existing entrance channel and mixing within and between the three main lakes. Building on the preceding sections, and specific assessments completed by others, Section 3.6 discusses management options that have been put forward and what others have concluded. Section 3.7 provides a critical summary of the existing understanding, including:

- Any shortcomings or key gaps in understanding.
- How our present understanding varies from a myriad of opinions or positions promoted within the community and the reasons why, if apparent.

Importantly, water quality is affected by more than entrance and mixing processes alone – inflows from the catchment and other processes at work inside the lagoons themselves (ecological, chemical, human intervention) also need to be considered. The recommendations made here have been carried forward elsewhere in this report and considered alongside the findings of other chapters in formulating a combined suite of recommendations.

3.2 Key references

A landmark report was produced by the NSW State Government in 1979 and only a few reports prepared prior to 1979 have been reviewed in detail. However, historical accounts and photographs have been sought and used, where relevant.

The key reports reviewed as part of this study are presented and briefly described in Table 3-1. A review of these documents has been supplemented by information submitted by community members through online and follow up consultation, including one on one interviews and telephone conversations. Interviews were also undertaken with Central Coast Council (Council) staff to understand Council's approach to entrance management, and independent research undertaken to confirm the veracity of historical information and provide perspective regarding the different points of view which were promoted by various stakeholders. Professional experience and knowledge of similar systems in NSW has also informed the report.

Table 3-1 Reviewed References on Tuggerah Lakes Entrance and Hydrodynamics

Reference	Description
Roy (1971). *Dredging in Budgewoi, Geological Considerations.*	This report was prepared by the Geological Survey of NSW in response to a proposal to dredge the eastern parts of the Budgewoi sand mass to fill adjacent land to the north of Toukley Golf Course. The report contains numerous sediment drill logs and a description of likely geomorphological formation of the sand mass.
Roy and Peat (1973). *Estuarine Investigation – Tuggerah Lake. The Bathymetry and Bottom Sediments of Tuggerah, Budgewoi and Munmorah Lakes, and the Subsurface Stratigraphy of Tuggerah Lake.*	The report appears to have been completed in support of the 10-year Tuggerah Lakes Study, which was reported on in 1979. It contains the results of seismic reflection profiling and drilling in Tuggerah Lake, and bathymetry and surficial sediment sampling in all three lakes, along with interpretation of the geomorphic evolution of the present-day estuary.

Reference	Description
Inter-Departmental Committee (1979). *Tuggerah Lakes Study Report.*	This was a wide-ranging 10-year study of scientific and environmental matters, undertaken internally by the NSW state government but led by the Public Works department. It appears to have been prompted by concerns about preservation of the lake in the light of rapid development of the catchment in the preceding decades (and proposals for further urbanisation) and ongoing problems with siltation, pollution, weed control and "general deterioration". Reflective of concerns at the time, the overall aim seemed to be to "optimize the enjoyment" of the lakes by the public due to their "high potential for recreational use".
Public Works Department (1987). *Jet Pump Systems for Maintaining Tidal Entrances (PWD 87051).*	This study was requested by Wyong Council to investigate jet pumping, which was an emerging technology at the time. The aim was to provide preliminary assessment of the feasibility of such technology to help maintain the entrance. The option was found to be undesirable at the time.
Patterson Britton and Partners (1988). *Tuggerah Lake Entrance Improvements Entrance Restraining Wall Concept Design Report (PWD 88069).*	This was a report commissioned by Wyong Shire Council, outlining the conceptual design of a sand filled geotextile tube wall to restrain the entrance channel from moving southwards and closing. It was argued that this would stop the entrance channel from becoming "perched" on the rock shelf which weakened tidal currents. It was considered favourable due to aesthetics and supposed ease of removal.
Lawson & Treloar (1994). *Tuggerah Lakes Flood Study (No. J1112/R1497).*	This was a flood study completed under the Floodplain Risk Management Process which existed in NSW at the time.
Patterson Britton and Partners (1994). *Tuggerah Lakes, Entrance Training Walls: Technical Discussion (No. J1816/R1005).*	This report was commissioned by Wyong Shire Council to provide a technical review of the feasibility of establishing training walls at the entrance. At the time, the entrance had been maintained using a mobile dredger for one year. That dredger is the same machine which has been recently decommissioned.
Hunter (1996) *Estimates of the Flushing of Tuggerah Lakes*	This brief report presents a simplified "One-Box" type model for estimating flushing times of the Estuary and provides indicative time scales for the complete horizontal and vertical mixing within the lagoons.

Reference	Description
van Senden (1996) *Lake Hydrodynamics, Transport and Ecology Models*	This brief report provides some indication of the time scales for wind mixing. It also provides a limited description of a three-dimensional hydrodynamic model of the Lakes system, prepared using software published by CSIRO. The report was prepared as part of the Adaptive Environmental Assessment and Management (AEAM) Program for the Tuggerah Lakes system.
Scott, A. (1998). *The Ecology of the Tuggerah Lakes. An Oral History.*	The aim of this study was to *"obtain reliable anecdotal evidence that provides a long-term picture of ecological changes in the lakes".* It contains results from interviews of over 40 residents, dating back to the early 1900s. It notes that there were few scientific studies of the lakes prior to 1960 and that qualitative information is therefore useful. The study provides an indication of the distribution of opinions surrounding different issues, including entrance behaviour and management.
Lawson & Treloar (1999). *Recalibration of Tuggerah Lakes Model and Evaluation of The Entrance Dredging Impacts.*	The model developed for the Flood Study in 1994 was upgraded and calibrated to measured tides (20/03/1996 – 06/04/1996) based on a more comprehensive data set. The apparent purpose was to assess the feasibility of a proposed fast ferry service between Sydney Harbour and the Central Coast, and the impact of three different entrance dredging configurations were considered.
Wyong Shire Council (2001). *Tuggerah Lakes Estuary Process Study.*	An Estuary Processes Study completed under the prior Estuary Management Process, where it preceded an Estuary Management Study. The aim was to describe the physical, chemical, and biological patterns and processes operating within the estuary.
Roberts, D.E., Dickinson, T.G. (2005). *Tuggerah Lakes Estuary Management Study*.	The Estuary Management Study followed from the preceding Processes Study under the prior Estuary Management Process in NSW. Its key aim was to assess a range of management options to address issues and conflicts within the Estuary. The preferred options were ultimately compiled into an Estuary Management Plan, which is due to be superseded by an Estuarine Coastal Management Program, under new legislation, in the next few years.

Reference	Description
Dickinson, T.G., Roberts, D.E., Geary, M., McPherson, R., Dye, A., Muston, R. (2006). *Tuggerah Lakes Estuary Management Plan.*	The Estuary Management Plan follows from the Estuary Management Study and comprises a set of actions to be completed in the holistic management of the estuary.
WorleyParsons, (2009). *The Entrance Dredging Project Review of Environmental Factors.*	Maintenance dredging of the entrance channel had been undertaken since 1993. To undertake maintenance dredging, a permit from NSW Fisheries is required. At the time of this report, a prior permit had expired, and an environmental assessment (this report) was required to obtain this approval, alongside a license from NSW Crown Lands, which owns the bed of the channel.
Brennan, K., Sanderson, B., Ferguson, A., Weber, T., Claus, S. (2010). *Tuggerah Lakes Estuary Modelling.*	The (then) NSW Department of Environment, Climate Change and Water (DECCW) were engaged by Wyong Shire Council to fill knowledge gaps associated with water quality in Tuggerah Lakes. A series of models were developed, with some developed from scratch (i.e. not using pre-existing modelling software) to predict nutrient and sediment loads entering the lakes and the likely effects on the ecosystem.
SMEC (2011). *Longshore Sand Transport and Tidal Inlet Stability Study for The Entrance and The Entrance North.*	The report provides a partially quantitative assessment of coastal processes, alongshore transport and sediment movement in and around the entrance to Tuggerah Lakes. It is closely related to the companion Umwelt Report (see next) with both forming appendices to the Wyong Coastal Zone Management plan from 2011.
Umwelt (2011). *Entrance Dynamics and Beach Condition at The Entrance and North Entrance Beaches.*	This study relied heavily on information provided by SMEC, 2011, but extended the analysis to *"clarify sediment transport linkages between The Entrance channel and North Entrance Beach and to identify and evaluate potential options for managing sedimentary processes…"*. The analysis presents a broader, geomorphological assessment of the entrance dynamics.
Cardno (2013). *The Entrance Morphodynamic Modelling - Entrance Beach Management Investigations (No. LJ2985/R2791).*	Following the modelling study, Cardno was engaged by OEH to examine a range of management options for the beaches to the north and south of the entrance. Options included beach nourishment, groynes and/or training walls, to determine whether these would be of benefit to beach amenity.

Reference	Description
Cardno (2013). *Tuggerah Lakes - The Entrance Morphodynamic Modelling.*	Cardno was commissioned by the NSW Office of Environment and Heritage (OEH) to develop a numerical model of the lakes' system to independently assess the potential effectiveness of entrance training walls in addressing water quality issues. The impact of various entrance wall configurations on flood behaviour was also assessed.
Erskine, W.D. (2013). *Flood-tidal and fluvial deltas of Tuggerah Lakes, Australia: Human impacts on geomorphology, sedimentology, hydrodynamics and seagrasses. Deltas: landforms, ecosystems and human activities. IAHS Publication 159–67.*	This academic paper on the Tuggerah Lakes Estuary provides useful information on the flood tidal deltas of Tuggerah Lakes, including the presently active one at The Entrance, and the flood tide delta relating to an ocean entrance into Budgewoi Lake which it argues was closed following a sea level fall of around 1.5m from around 2000 years ago.
Weston, C. (2013). *Report on the Safety of Navigation Should Training Walls be Established at the Barway Entry to the Entrance in New South Wales.*	This report discusses issues associated with potential navigability of the entrance should, for example, training walls be constructed. It was provided as an Appendix to the Entrance Beach Management Investigation by Cardno.
WMAwater (2014). *Tuggerah Lakes Floodplain Risk Management Study and Plan (Final Report).*	The report prepared by WMAwater represents stages 2 and 3 of the management process followed under the NSW State Government's Floodplain Risk Management Policy. The underpinning flood study used was the 1994 study by Lawson & Treloar which was around 20 years old at the time.
Cardno (2015). *Additional Morphological Modelling The Entrance (No. 59915021/R001).*	This report was commissioned by Wyong Council to examine what would happen if the rock shelf at The Entrance were to be removed. At the time, the consultants were advised by Wyong Council that the main interest expressed by the community was with increasing navigational opportunities through the channel. As per the investigation by Weston, the existing channel is known to be non-navigable. Cardno noted that they did not assess the feasibility of rock removal (i.e. through blasting, saw cutting and/or other methods).
Department of Primary Industries - Crown Lands (2016). *Review of Environmental Factors for The Entrance Rock Groyne.*	This REF relates to the construction of the "Short Groyne" investigated in Cardno, 2013b. The basis of design and justification for the project is presented. The groyne was eventually constructed in 2017/2018.

Reference	Description
Waddell, D. (2018). *To flush or not to flush? Can an artificial channel help save the Tuggerah Lakes?*	Waddell's publication is a prize-winning essay which takes a historical perspective of the understanding of the Lakes, including its geological formation and post European settlement, different assessments of potential entrance management options and the political dimension.
GHD (2019). *The Entrance Channel Dredging Operations Feasibility Review.*	After some 26 years of permanent service, the Dredger employed by Central Coast (ex. Wyong Shire) Council, was requiring more regular maintenance. GHD were engaged to assess the associated environmental, financial, and reputational risks.
Central Coast Council (2020). *Marine Pde - The Entrance Existing Channel Mouth Rock Levels January 2020.*	Council has provided a plan showing spot levels in the vicinity of the entrance channel and rock platform, collected during January 2020 prior to the major flood in February of that year.
Manly Hydraulics Laboratory (2020). *Tuggerah Lakes catchment February 2020 flood summary and historical comparison.*	Presents rainfall and water level data associated with the February 2020 event.
Turnbull, A. (2020). *Coastal Management advice re The Entrance.*	This letter comprises advice given to Council, by Royal Haskoning DHV, associated with actively closing off a shallow southern channel which persisted after a flood in February 2020.

3.3 Geomorphological and historical evolution of the lakes

Key Points
The three lakes are shallow and slowly filling up with sediment from the catchment. At historical rates, it may take more than 2000 years to completely infill, subject to how climate change affects the process.
The connections between lakes are constrained, particularly between Budgewoi and Munmorah.
The entrance channel has migrated over thousands of years to locate itself to the north of the rock shelf at Karagi Point.
Areas upstream of the Central Coast Highway bridge are reasonably stable and do not change much, but areas downstream of the Bridge are active and most often contain mobile shoals of sand.
After a flood, these shoals scour out and the northern spit (Dunleith Point) washes away as the entrance opens. Normally sand washes back in and the entrance shoals up again quite quickly.
The entrance has completely closed historically, including around 10 times in the 100 years to 1980.
Regular dredging of the entrance commenced in 1993 and it has tended to not close since then.
The sand in the Budgewoi sand mass is of marine origin, meaning that this area was once directly open to the ocean.
While the history of the way the Budgewoi sand mass formed is not completely understood, it is highly unlikely that this area has had a direct and persistent connection to the ocean during the past 1500 years.
There are numerous eyewitness accounts of waves breaking over the Barrier at "The Gap" many decades ago, however this would have been relatively infrequent.
Changes have been made to "The Gap" with activities including dune restoration following sand mining in the late 1950s and the addition of sand from channel dredging in Budgewoi Lake. There are also reports that Council placed tree stumps to help the dunes build higher and prevent over-wash of waves at some time in the past.

3.3.1 Geomorphological setting

The present-day NSW coastline has been strongly influenced by sea level patterns, particularly since around 20,000 years before present (BP). Between 20,000 and around 7,000 years BP, sea levels rose some 130m to sit approximately 1m higher than at present along the NSW coastline according to recent research (Dougherty et al., 2019). It is generally understood that mean sea level stayed around this elevation for around 5,000 years before falling from around 2,000 years ago. There has been a recent reversal of this general falling trend, with mean sea levels rising during the past couple of centuries because of climate change.

As sea levels rose until around 7,000 years BP, the coastline moved westwards some 30 km, mobilising sand from the continental shelf which was eventually reshaped to form the sand "barriers" which now sit between the Tuggerah Lakes estuary and the ocean. This results in one classification regarding the Lakes as a Wave Dominated Barrier Estuary (Roy et al., 2001). Roy et al. (2001) also noted that estuaries which are prone to being closed to the ocean have been more recently called Intermittently Closed and Open Lakes and Lagoons (ICOLLs) and, even though attempts have been made to keep it in an open state since 1993 through dredging, Tuggerah Lakes fits into this category.

Coastal barriers (or "beaches") along the NSW coast are controlled by local geology. A series of rock outcrops / headlands control the shape of the coastline and barriers enclosing the lagoons (refer Figure 3-1 for locations). These are:

1. Rock outcrop and associated reef complex to the south of The Entrance and exposed along the coast as far south as the northern end of Shelley Beach ("South Entrance Outcrop").
2. Norah Head.
3. A rock outcrop which occurs along the northern foreshore of Budgewoi Lake, but to the west of the bridge which carries Scenic Road over the channel between Budgewoi and Munmorah Lakes ("Budgewoi Outcrop").
4. Wybung Head.

Tuggerah Lake is largely enclosed from the ocean by a barrier between the outcrop to the south of The Entrance and Norah Head. Budgewoi and Munmorah Lakes are now enclosed by a continuous barrier which extends between Norah Head and Wybung Head.

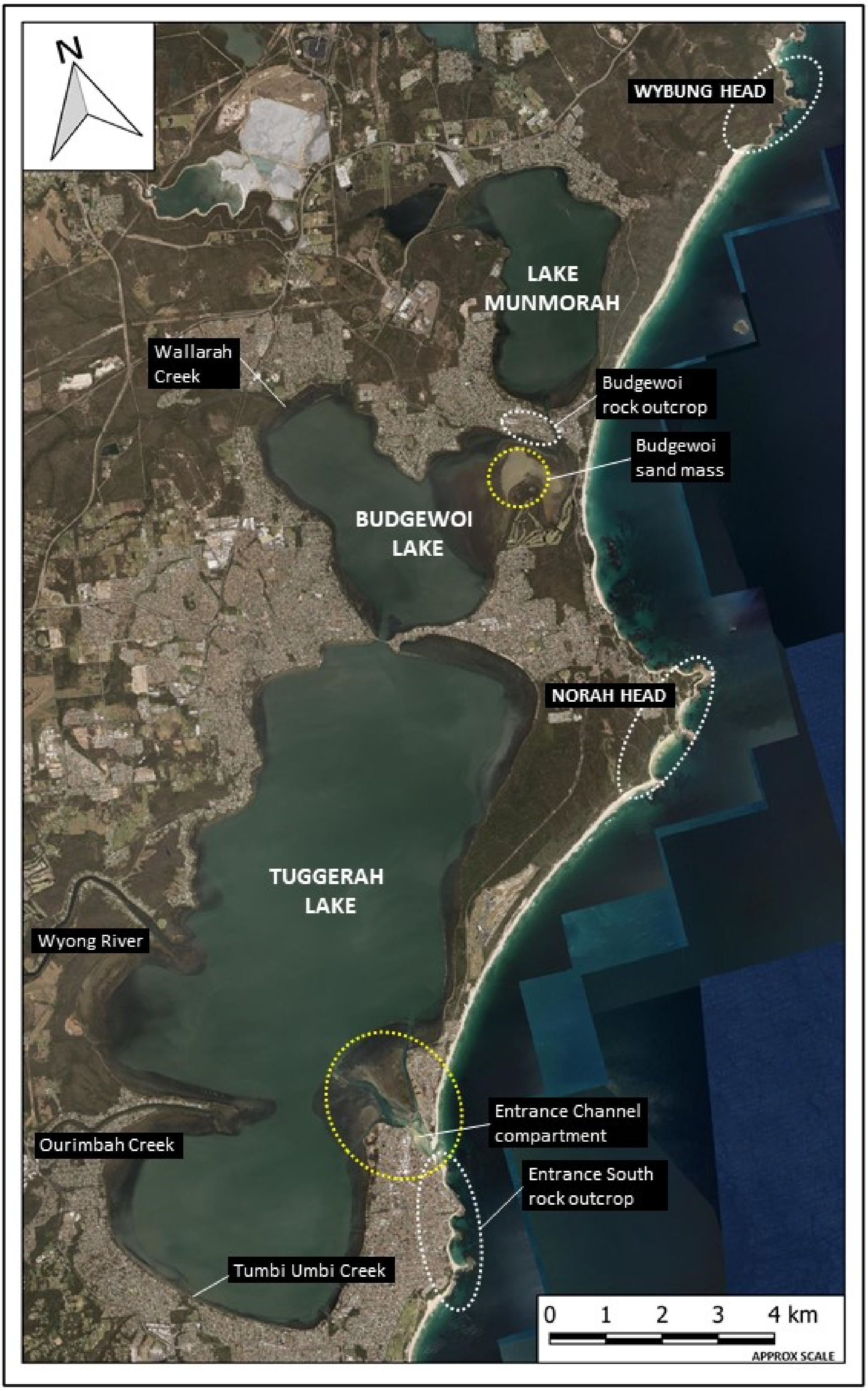


Figure 3-1 Geomorphological features

It was argued by Roy (1971), that barriers which sat further landward probably existed during some prior time in the past 12,000 years. These stretched between Norah Head and the Budgewoi outcrop (separating Budgewoi Lake from the ocean), and between the Budgewoi outcrop and Wybung Head (separating Munmorah Lake from the ocean), with Munmorah Lake's ocean entrance most likely to the north of the Budgewoi outcrop. This past behaviour (likely thousands of years ago) helps to explain the origin of the Budgewoi sand mass, as discussed in Section 3.3.4.

3.3.2 Physical characteristics of the Lakes

The Tuggerah Lakes system includes three interconnected waterbodies, as shown in Figure 3-1. The lake has a total waterway area of some 80 km^2 and a catchment area of around 715 km^2. From south to north the surface areas of the lakes are: Tuggerah Lake: 58 km^2, Budgewoi Lake: 11.2 km^2 and Lake Munmorah 7.8 km^2 (Inter-Departmental Committee, 1979).

When filled to a level of 0.6 m AHD, the lake has an estimated average depth of 2.4m and a volume of 193,230 ML, or 193.23 x 10^6 m^3 (Roper et al., 2011). However, "normal" lake water levels over the past year have been between 0.3 - 0.4m AHD. Therefore, normal storage volumes in the lake, while variable, are around 10% less (approximately 172 x 106 m^3).

The most recent but readily accessible and comprehensive bathymetric map of the lakes was published in Roy and Peat (1973). This map is reproduced as Figure 3-2.

The connections between the three lakes are constrained. A 180m wide but relatively short gap exists between Tuggerah and Budgewoi Lakes. The bridge between Gorokan and Toukley carries Main Road across this gap. The 700m long (35m wide at its narrowest point) Budgewoi Creek connects Budgewoi Lake and Munmorah Lake. The Central Coast Highway crosses this channel at Budgewoi.

Being shallow, the three interconnected 'lakes' which form the Tuggerah Lakes estuary are geomorphologically classified as "coastal lagoons". Cursory inspection of the three lakes in Figure 3-2 shows that Munmorah is the deepest (typical depths around 3.0m) followed by Tuggerah (typical depth around 2.5m). Western Budgewoi Lake (excluding the Budgewoi sand mass) is shallowest (typical depth around 2.0m). The relative shallowness of the lakes is a balance between their surface area and the rate at which sediment is being carried into each of the lakes from the catchment, by the tributaries which flow into them.

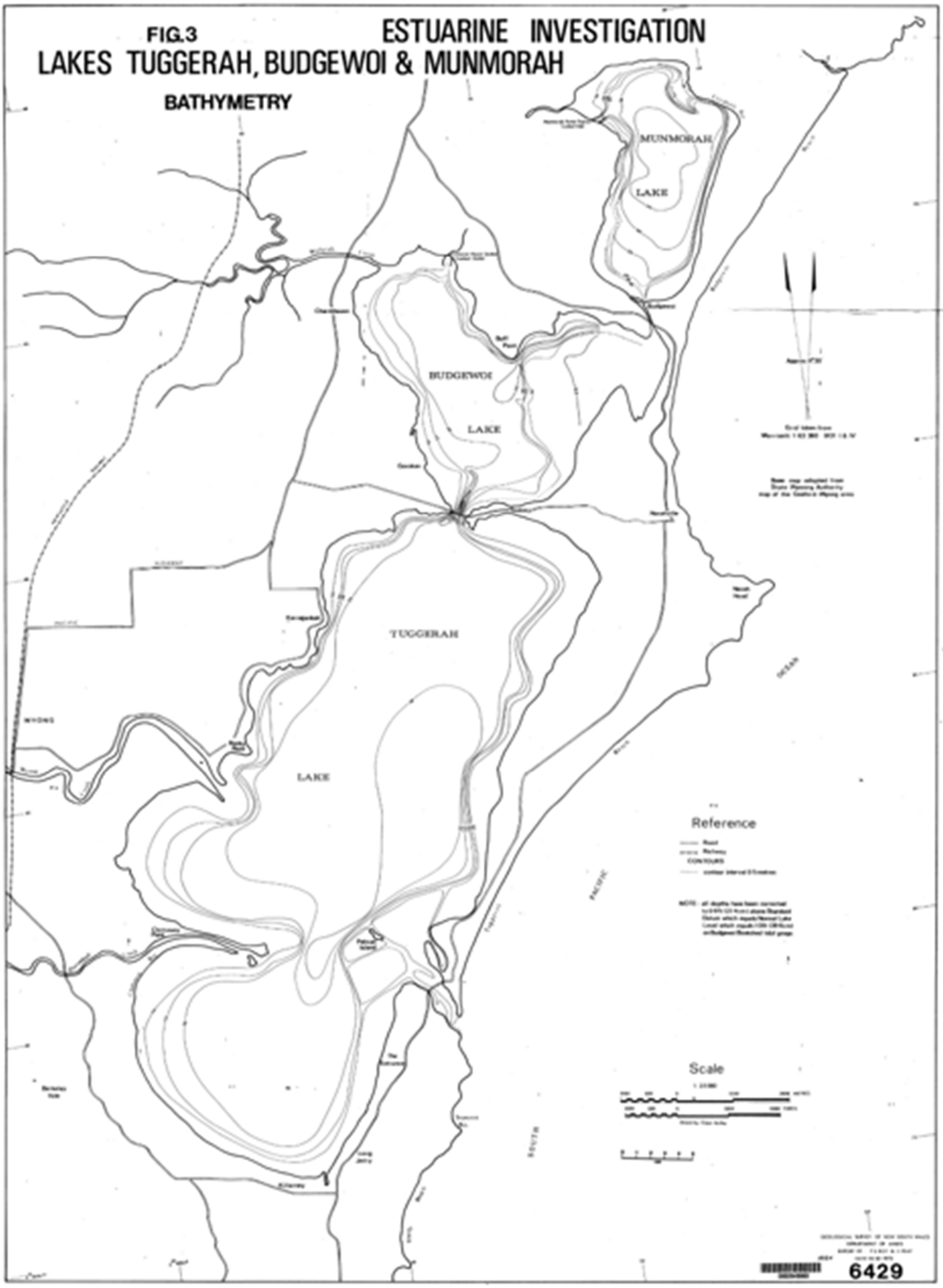


Figure 3-2 Bathymetry (Roy and Peat, 1973)

The lakes are dynamic and ever changing. The three lakes are infilling slowly with sediment delivered from erosion of the catchment via waterways such as the Wyong River, Ourimbah Creek, and Wallarah Creek. Noting that there is presently minimal infeed of marine sediment to the main lake basins from the ocean, Budgewoi Lake has filled faster than the other two over recent millennia due to its small size. In comparison, Munmorah Lake has filled relatively slowly as its contributing catchment (sediment load from that catchment) is small.

Shallow deltas have formed where waterways flow into the lakes. Calls for dredging follow from this ongoing process. However, much of the sediment delivered to the lakes is fine-grained and carried much further into the deeper parts of the lakes where it is deposited as estuarine mud.

The nature of sediments across the bed of the lakes have been mapped by several authors (Erskine, 2013; Inter-Departmental Committee, 1979; Roy and Peat, 1973). While the maps are all broadly similar, the map from Roy and Peat (1973) is reproduced in Figure 3-3, noting that this map is more detailed and informative.

Broadly speaking, the sediments along the eastern fringe of all lakes are sandy and of <u>marine</u> origin (i.e. Quartzose), having been placed directly by tidal action, by wind blowing sand from the coastal dunes and/or the subsequent mixing of these sands with muddier sediments and organic material. The bed in the middle of the lakes comprises muddier material, which is carried from the catchment tributaries and settles in the deeper parts of the estuarine basin. In these deeper areas, the sediment is less easily suspended and moved away by wind waves although wind driven currents can resuspend the sediments, resulting in turbid water.

In comparison, the sediments along the western fringes are derived from erosion of the catchment (i.e. classified as “Lithic”) and delivered to the lakes primarily from the larger tributaries and the movement of those sediments by waves and currents along the foreshores.

The average infill rate was estimated to be 1.42 mm/yr by Roy and Peat (1973). This means that the lakes would infill within around 2,000 years. While the hydro-survey techniques described in the Estuary Processes Study (Wyong Shire Council, 2001b) hint that the resulting analyses may be inaccurate, a comparison of depth changes in different areas indicates that significant shallowing is present in the vicinity of the main catchment discharge locations to Tuggerah Lake, but that depths are increasing in the northern parts of the lake system, most likely due to mine subsidence. At the present time, however, the most dynamic area of the entire lake system is the entrance channel downstream of the bridge.

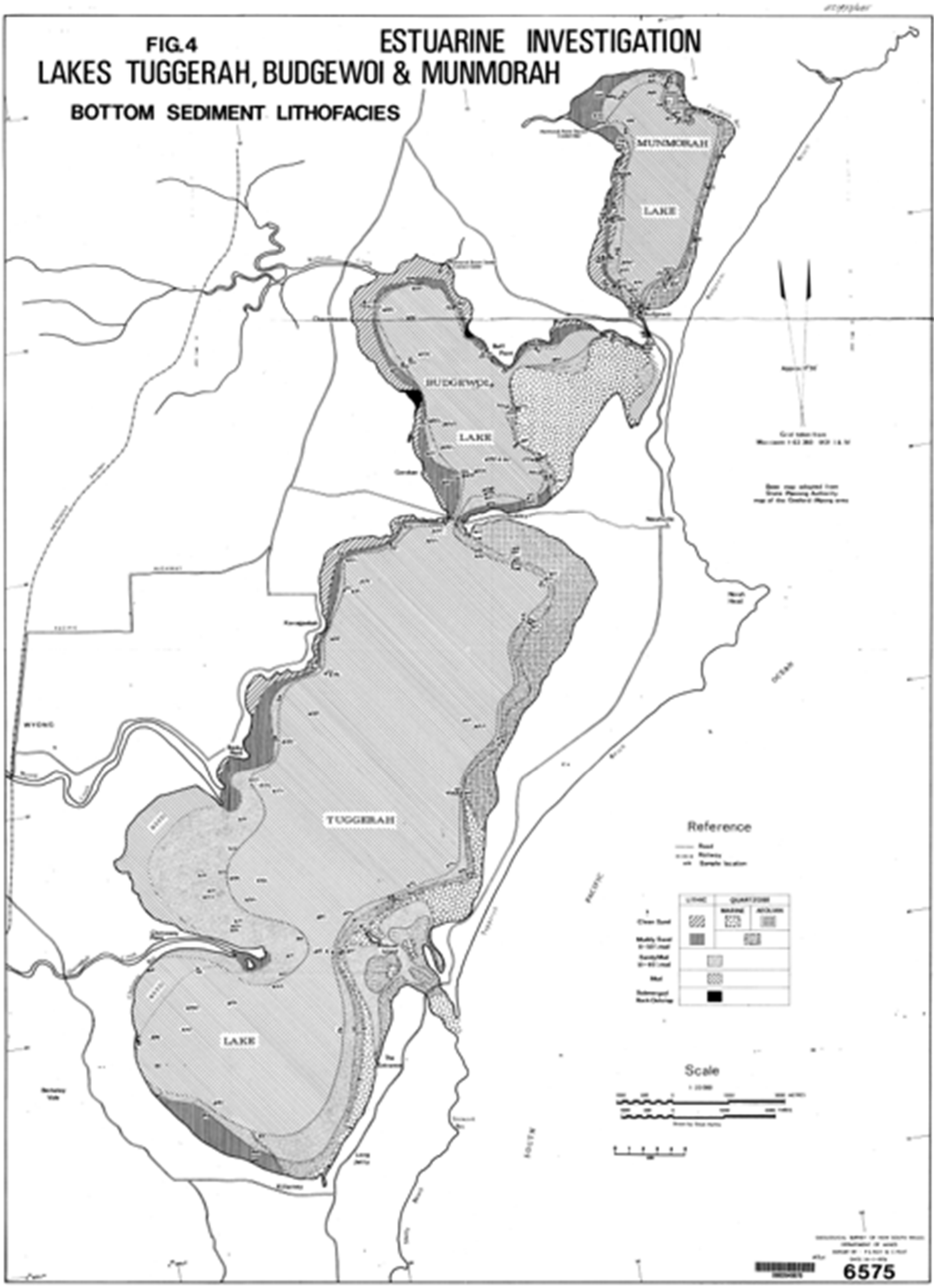


Figure 3-3 Sediment character (source: Roy and Peat, 1973)

3.3.3 Characteristics of The Entrance

Actual net infeed of sediment to the lakes from the coast is presently very small. Most of the bathymetric change occurs within “The Entrance”, downstream of the bridge, but is relatively balanced over the medium term. This means that there is (typically) a circulation with sand washing into the entrance when it is open, causing it to become more constrained (tending to hold the tides out of the lake) over time, and then being flushed out by large floods from the catchment. Processes such as dredging, open coast beach erosion and structures alter sediment dynamics and make the processes more complex.

The tidal delta (or “entrance compartment”) comprises marine sand (quartz) from the open coast, stirred up by waves and carried by tidal currents into the entrance where they settle out onto shoals. The entrance compartment is shown in Figure 3-4. Areas of bare, active shoals occur almost exclusively in the compartment downstream of the bridge. Notably, however, active sand is also able to move upstream beyond the bridge along the southern side of the channel, interfering with business operations at the boat shed in that location.

While areas of the entrance compartment upstream of the bridge are no longer active, they once were, and the sand which is present upstream of the bridge has also been carried in and placed in these locations by tidal action. In Figure 3-4, the entrance is shown in a state of near closure. After a flood, the entrance can grow to be 300 - 400m wide with sediment washed out into the ocean. In this open state, the entrance acts as a ‘sink’, rapidly filling up with sand from the coast, causing tidal channels to shallow and continually change course. This is reflected by the deposition of successive lobes (shoals) of sand which are washed into the entrance by waves and tides, most commonly along the southern side of the entrance downstream of the bridge.

Based on an examination of aerial photographs, the Public Works Department (1987) found that the channel from the entrance to the bridge is some 800m long with a maximum width of around 350m, although typically less than 40m wide. There is normally one principle channel and up to three minor channels.

Aside from the infeed of sand, the location where sand is most active at any given time is relatively random. The area most active is affected by the amount of sand already present inside the entrance, the shape of the entrance spit (Dunleith Point) and shoals, the direction and timing of waves, timing of the tides (spring/neap cycles), whether any additional flood events occur and/or whether there are any events that cause elevated water levels (storm surge, coastal trapped waves

Figure 3-4 Features of The Entrance

and other processes). The amount of time that the entrance stays open after a flood is entirely at the mercy of weather and is random in nature.

Eventually, the sand spit at Dunleith Point grows southwards and pinches the entrance channel against the rocky bluff and associated offshore reef (Karagi Point). At this point in the cycle, the entrance is at risk of closing.

Erskine (2013) described the entrance compartment as a "well-developed delta… ensconced on bedrock at its mouth and, except for dredging is largely inactive between floods". Erskine seems to imply that the mouth being 'ensconced on rock' makes the entrance somehow less stable. However, this view is limited in its appreciation of the effect of the rock shelf. While this will be discussed in more detail in Section 3.4, the presence of the rock shelf provides <u>protection</u> to the entrance from the dominant south easterly wave climate of the New South Wales coast. Therefore, over millennial time scales, the entrance has migrated to locate itself against the northern side of this rock shelf. It is a very common behaviour for coastal lakes and lagoons that are prone to closure in NSW to 'find' a suitably sheltered location such as this. If the entrance does close, a simplistic consideration might conclude that the rock shelf is a key cause of this closure. This is not a reasonable interpretation.

Since 1993, the entrance has (for the most part) been kept open by dredging. However, it is important to recognise that the entrance to Tuggerah Lakes would naturally close from time to time. This is reflected in several historical accounts:

> *"The entrance opened on 24th April through the heavy sea breaking over, and there was a very large entrance up till the end of the year, but it has since closed up considerably and is likely to close altogether if rain does not soon come"*
>
> *(Charles Gordon, Assistant Fisheries Inspector, 11 January, 1898, from Interdepartmental Committee (1979))*

Long term residents of the Lakes area were interviewed by the Electricity Commission in 1962, with the results reprinted in the Tuggerah Lakes Study Report (Inter-Departmental Committee, 1979). One interviewee offered up the following:

> *"Lake was <u>Closed</u> in the times of the big drought late 1940 to early 1943, and my father said that in the period 1890-1910 it was normally closed every summer. 1910-1925 it only closed every 2*

or 3 years and from 1925 to 1939 it did not close once. Periods of water level rises of 2 or 3 feet seem to be more common and frequent over the past 25 years – probably more rain cycle".

In more recent decades, a better understanding of the variable climate patterns across Australia has been gained and periods of closure would tend to result from extended and or extreme drought conditions. During these times, less rainfall means less discharge from the catchment and less tendency for flood flows to clear the entrance of sediment.

During the past decade, the dredging frequency targeted by Council seems to have been reduced from annually to once every two years. The most recent major dredging campaign (in 2018) was halted due to concerns raised with the NSW Environment Protection Authority. Combined with the dry conditions experienced in NSW leading up to and throughout 2019, the entrance was effectively closed in early 2020.

Aside from opening and closing, there are other, more permanent changes that have been made by humans in and around the entrance compartment. Channels were dredged upstream of The Entrance from early in the 1900s to allow holiday makers to be transferred from the railway station at Wyong to The Entrance, where there were guest houses on both the south and north side of the channel (Scott, 1998).

Prior to the 1930s there existed a channel, known as the "Southern Channel", around the base of the slope to the rear of present-day Memorial Park. During the 1930s, this area was reclaimed to form the Park. Parts of Memorial Park are low lying (~ 1.5m AHD) and prone to inundation.

Artificial islands, including Pelican Island, were created from dredged spoil during the early 1960s alongside additions to the southern end of Terilbah Island, where a channel was dredged to try and encourage flow along the eastern side of the Island. By the early 1970s, reclamation of parkland at Picnic Point to the west of Tuggerah Parade had begun.

Umwelt (2011) completed a rigorous review of aerial photographs over the period from 1941 through to 2006. Anthropogenic changes since the 1970s are notable as follows:

- Prior to 1970, wind-blown sand across the area now occupied by Curtis Parade and Terilbah Place fed sand across the dunes and into the lakes to the north of the entrance compartment. Wind driven waves were then able to carry this sand southwards around the inner edge of the tidal delta. With construction of properties in this area, this movement of sand has ceased, and the inner edge of the tidal delta is now covered in vegetation.

- The shoals across the tidal delta upstream of the bridge seem to have been more active prior to 1970. In combination with the removal of the windblown sand from around Curtis Parade, it is possible that deeper, dredged tidal channels have reduced the movement of sand across the shallows upstream of the bridge. This has apparently allowed for almost the entirety of the shallow areas of the tidal delta upstream of the bridge to be colonised by vegetation.
- As part of the Tuggerah Lakes Restoration Project, substantial reclamation was undertaken around the Entrance. This included further reclamation around Picnic Point by the mid-1980s, with the area of reclamation extending for around 1,500m south along the foreshores of the Lake by 1990.
- In the early 1990s, Terilbah Reserve was reclaimed from the Lake, with that area presumably filled using dredged spoil from the channel to the east of Terilbah Island. Since the early 1990s there has been a reasonably clear navigation channel in this location, although navigation further downstream (east of the Bridge) is often blocked by marine sand.
- By the mid to late 1990s the reclamation at Terilbah Reserve and the foreshore south of Pelican Point had been finalised and, since that time, the reclaimed areas have been stabilised with grass and trees.

The most notable development of the entrance in the past few years has been the construction of a groyne across the rock platform at Karagi Point, to the south of the channel. The reasoning provided for construction of this groyne by NSW Crown Lands was to increase the retention of any sand which was present on The Entrance Beach (south of the channel). The groyne was constructed in 2017, and sand from the dredging campaign in 2018 was pumped from the entrance compartment to nourish The Entrance Beach.

3.3.4 Characteristics of the Budgewoi sand mass

An aerial photograph of the Budgewoi sand mass is shown in Figure 3-5. The area is only marginally above mean sea level, which means that it can be exposed and covered for extended periods, particularly in response to the “fortnightly tides” in the lakes (refer to Section 3.4.4).

Figure 3-3 and other available maps of sediment clearly show the Budgewoi sand mass as being derived from marine sources. More specifically, the majority of the Budgewoi sand mass is considered to be the remnant of an old tidal delta and barrier (Erskine, 2013; Roy, 1971), meaning that Budgewoi Lake was indeed directly open to the ocean at some time in the past.

Figure 3-5 Budgewoi sand mass

Roy (1971) states:

> *"The dune-covered sand spit* [referring to the current location of the Toukley Golf Course] *that forms the western side of the embayment is believed to be a remnant of a largely continuous barrier that originally connected Norah Head in the south to the bed-rock outcrop at Budgewoi township in the north. During this time, the barrier was breached by a tidal inlet connecting the lake to the sea. The movement of tidal currents through the inlet washed sand into the lake to form a tidal delta. (A similar tidal delta occurs in Tuggerah Lake to the south.) The extensive sand flats in the eastern part of Budgewoi Lake comprise this old tidal delta deposit as well as remnants of the old dune barrier which was subsequently redistributed by wave action"*

Roy's assessment is based on extensive drilling and sampling across the Budgewoi sand mass. The drilling results show that the eastern fringe of Budgewoi Lake is characterised by a layer of black mud (typically 0.3 to 1.0m thick), overlying sandy muds to muddy sands. There is some limited evidence of sand being washed over the narrowest part of the beach barrier from the east, although this is localised and the intermixing with mud indicates that there has been a fringe of mud adjacent to the rear of the barrier here for some time. As Roy noted in 1971, transport of sand across the Budgewoi sand mass is presently dominated by west to east directed wind waves. At the time Roy was writing, the west to east transport was also enhanced by a unidirectional circulation established by pumping from Munmorah Lake and discharge into Budgewoi Lake by the Munmorah Power Station (refer to Section 3.5.6). The power station is now closed.

Sampling and dating of sediments across the sand delta could help to further understand the timing of different sediments being laid down by different processes over the past 12,000 years (known as the Holocene Epoch). However, the scientific evidence strongly indicates that there has not been an active tidal delta across the Budgewoi sand mass for around the past 2,000 to 1,500 years. Erskine (2013) states that:

> *"This delta atrophied during the late Holocene, probably due to a 1.5m sea level fall after 2000 cal BP".*

The estuary processes study for Tuggerah Lakes also states:

> *"This sand body is a relic Pleistocene tidal delta formed at the mouth of the entrance channel, which once connected Budgewoi to the sea approximately 1,000 to 2,000 years ago"*. [Note that the use of the word "Pleistocene" is inconsistent with the dates stated and the word "Holocene" should have been used].

While definitive data are not available, based on a preliminary interpretation of coastal bathymetric and elevation data collected on behalf of the NSW State Government in 2018 (Fugro, 2019), it seems that the most likely location for any more recent tidal connection to the ocean would have been further to the south, near a rock reef present offshore and south of the present day Lakes Surf Life Saving Club. At this location, the presence of the reef would have provided some protection to a coastal entrance from infilling by waves. Over millennia, coastal entrances in NSW have tended to migrate to a location where they are most protected from waves. Exposure to waves tends to stir sediment from the bed and make it available to be carried into an entrance, assisting it in closing.

The beach barrier between Budgewoi Lake and the ocean is narrowest at a location which has been historically referred to as “The Gap”. There are a variety of observations and opinions that have been put forward regarding the more recent history of this length of barrier and whether management intervention, such a second ocean entrance to the lakes, is warranted.

A range of historical accounts are available, including the recollections of five long standing residents from interviews undertaken by the Electricity Commission in 1962 (Inter-Departmental Committee, 1979) and the detailed study of Scott (1998). Many of these deal with the various opinions regarding The Gap and Budgewoi Lake. Relatively few accounts claim the existence of a stable channel between Budgewoi Lake and the adjacent ocean, since the arrival of Europeans, although there are some:

> *“…Mrs. Elizabeth Hargraves reported when she first arrived in the area as a child bride, a shallow entrance to the lake still existed at ’The Gap’. During enormous storms, massive amounts of sand were washed into the lake to form the sand-flat that stretches from the sand hills to Buff Point. (Gordon Browne)”*
>
> *“Older tales of fishermen say this was a second entrance to the sea in grandfather’s time, but of course many say also this wasn’t true” (Electricity Commission Interview, 1962).*

However, the source of these stories seems likely to have been passed from the stories of First Nations People:

> *“Well, I support the old story handed down by old timers, i.e. they say aborigines told their parents that Budgewoi was also open to the sea. The opening appears to have been much wider than the Entrance opening but apparently not as deep, and had a large reef extending out into the ocean making the area an ideal fishing spot. I do know that the area between the Lake and the sea has always been very low lying and flat.” (Electricity Commission Interview, 1962)*

"Old residents say that the blackfellows told their parents that there was a sea entrance in Budgewoi in times past and rock reef extended right from Budgewoi out to the sea, but the reef became covered with sand and the entrance closed up by the sea action" (Electricity Commission Interview, 1962)

These accounts are more consistent with the evidence from drill logs, the interpretation of geomorphologists and the conclusion made above that the entrance is more likely to have flowed to the ocean near the extensive rocky reef offshore of Lakes Beach.

The weight of evidence from historical recollections seems to point towards the barrier being much lower in the past and susceptible to waves crashing across here from time to time. However, any connectivity between the ocean and Budgewoi Lake here was short lived:

“From the lake to the sea at the Budgewoi end is but a few hundred metres and the dunes were very low, often the wave tops could be seen while driving past the area which was named The Gap. Wyong Shire Council dumped large amounts of tree stumps along the dunes in recent years so wind blown sand would build up over them to form a higher dune. Previously heavy seas occasionally broke over the low dune, washing large amounts of sand onto the roadway.” (Gordon Browne)”

“In my lifetime there has never been a second entrance to the lakes. When the rutile mining went through this area, no evidence of a second entrance showed up. Back in about 1932 the sand dunes were very low in height and the seas came over the sand dunes into the lake during a big storm with strong easterly winds. This occurred about where the Lakes Surf Club is today.” (Keith Southwell)

“There were two big floods in the mid 50s and also a flood in 1990. During one of the floods in the 50s there was a bad storm and a small amount of water from the ocean came over the sand dunes into Budgewoi Lake” (Albert Asplet)

“If anybody tells you there was another inlet at Budgewoi Lake - it never was. The only time water came in there (it floods along there) was heavy seas used to wash across it.” (Ernie Quinton)

“Pop came here when he was 2 yrs old and they used to live at Canton Beach. His first job was to build a lighthouse. He said a big sea would wash across, but he could never remember a distinctive channel. A lot of people say they have. He can’t remember it. He was 90 old when he

died. He died about 10 years ago. ... It is built up there now. To this day, if it was flat there, it would still come across." (Elizabeth Denniss)

"When you go along just north of where the Toukley golf course is, that was very low and in big seas the water would come over there and after they mined it they made sure they built the dune up higher. .... And before that the Council used to put logs down to try and stop the road washing away in floods." (Clarrie Wynn)

It seems clear that the sand dunes could be overtopped in the past. However, any detailed recollections only refer to this happening irregularly. Interviewees of the Electricity Commission in 1962, when asked: *"Has the sea ever reached the sandhills just north of Budgewoi, so that waves have broken into Lake Budgewoi near the large sand bar"* replied with mixed messages:

"No, not really - waves have broken over the road and some water may have reached the lake but it would have been very small"

"Yes. Several times in the last 15 - 20 years"

"Not really - it did break over a bit and some residents started to dig a channel but were stopped. Extremely rough seas occasionally drain a little water to the lake but it is very rare and not very often."

"Not to my knowledge, although some say that it has but even if this was so then it must have been of a very short deviation indeed since only very few people support the view"

"Yes. I believe so, on several occasions, although I have never actually seen it."

However, the relationship between overtopping behaviour, sand mining and other changes made to the landscape by people is unclear. Mining records from the NSW coastal geomorphology dataset (Troedson et al., 2016) indicate that sand mining leases over the area were active from 1957 through to 1979, and it appears that mining through the area along Lakes Beach (directly east of Budgewoi Lake) was completed earlier than the areas along Budgewoi Beach to the north. Sand mining would have lowered the barrier in this location, and it was common practice to rehabilitate the coastal dunes (building them back up and adding vegetation). The recollections of the community that Council placed tree stumps here to help the dunes build higher may reflect these activities occurring post sand mining. However, the reasons attributed to Council's actions by the community are to prevent flooding of the road. This has not been confirmed as no official account of road flooding being a particular concern has been located.

1941

1950

Figure 3-6 Extracts from historical aerial photographs of Budgewoi sand mass

What is clear, from very early aerial photography, is that the barrier was relatively clear of sand and mobile, with windblown sand drift approaching and affecting the road prior to any official dates of sand mining. Historical aerial photos were sourced from DPIE and these are shown in Figure 3-6. The current road is not present on these photos, having been constructed sometime between 1952 and 1961.

In summary, it seems that the sand barrier along this narrow section was unvegetated prior to 1960 and some wind-blown sand would have made its way into Budgewoi Lake. Furthermore, on occasion, a severe coastal storm would have carried some sand across the barrier and into the lake. In recent centuries, however, neither of these would have been processes large enough to significantly affect the distribution of sand, nor the movement of water in Budgewoi Lake.

These conclusions do not mean that management actions associated with "The Gap" or adding a second entrance should not be considered. Those management actions that have been put forward are discussed in more detail in Section 3.6.

Beyond 1960, other changes seem to have been made and additional aerial photographs are provided in Figure 3-7. For example, in 1965, it seems obvious from the aerial photograph that sand has been placed along the foreshore to the west of the existing road, and some of the wetlands on the eastern side of the southern end of Budgewoi Creek have also been reclaimed. This sand comprised spoil from dredging around the northern end of the Budgewoi sand mass and into Budgewoi Creek. The dredging was completed to allow free flow from Budgewoi into Munmorah Lakes to accommodate the circulation induced by operation of the Munmorah Power Station (commissioned in the late 1960s).

The photograph from 1975 (Figure 3-7) presents strong evidence that sand from the dredged channel was also placed at the end of the spit, to the north of Toukley Golf Course. Bare piles of dredged spoil have appeared and there are linear features leading northwards from here that suggest discharge pipelines were laid across the sand mass from the dredged channel along its northern edge. By 1975, vegetation is beginning to establish along the dunes to the east of the road. It seems highly likely that this is the result of "dune rehabilitation" works that followed sand mining of the 1950s and 1960s. While it is often claimed that Wyong Shire Council completed these works, it was also common for the State Government (i.e. Soil Conservation Service) and mining companies to undertake these rehabilitation activities (NSW Department of Land and Water Conservation, 2001).

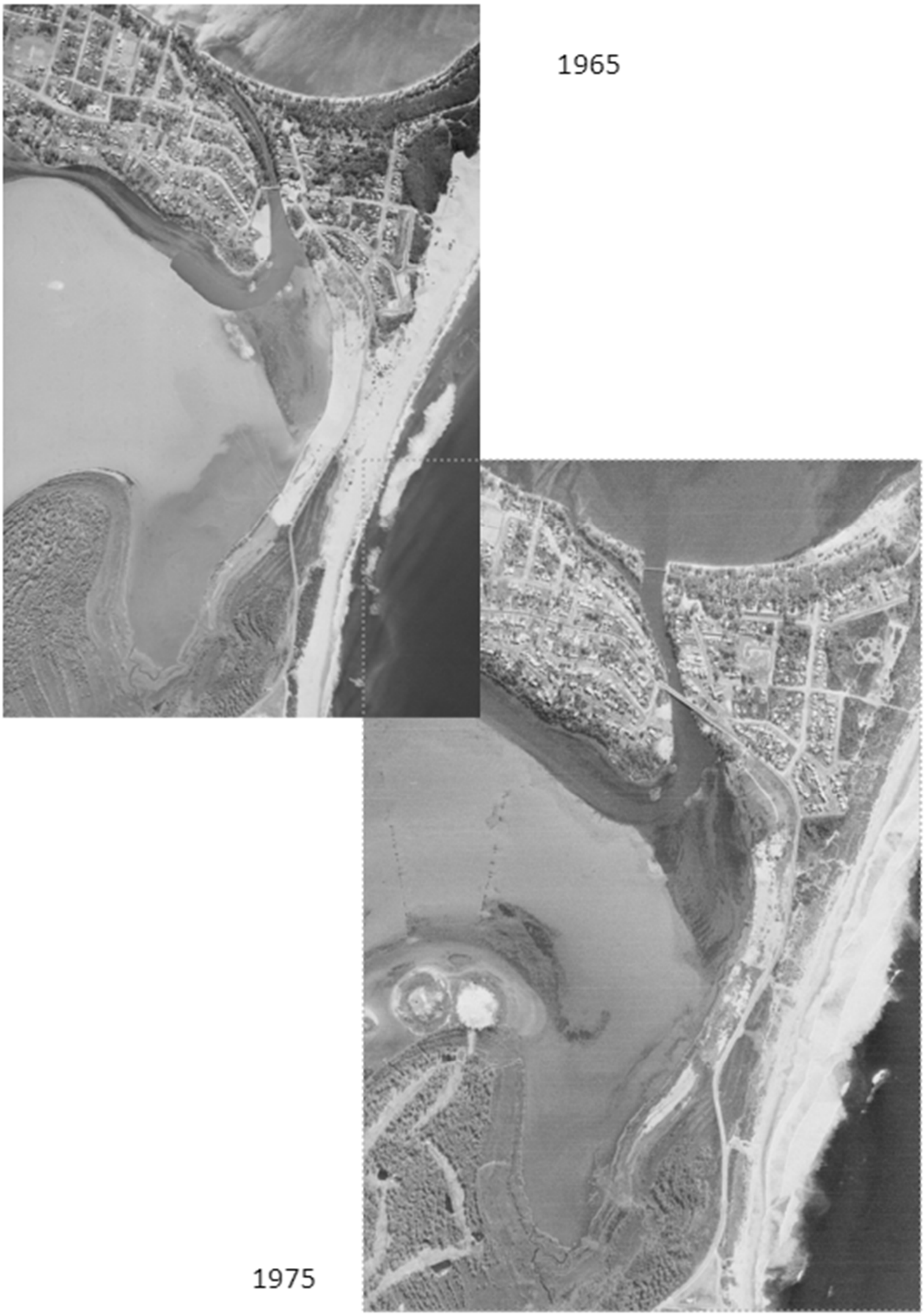


Figure 3-7 Extracts from historical aerial photographs of Budgewoi sand mass

3.4 Hydraulics of the entrance channel and lakes

Key Points
The entrance channel is naturally variable and has never been considered formally ‘navigable’.
There is no way to accurately ‘predict’ how the entrance will behave over periods of weeks to months as it varies due to the combined actions of waves, currents and changing water levels.
An approximate long-term ‘equilibrium’ exists where the amount of sand scoured out during floods balances the amount that is washed in by the ocean after the entrance opens. This equilibrium is likely to be modified by climate change.
The most common configuration for the entrance channel is to be 25-35m wide, about 2m deep and adjacent to the rock associated with Karagi Point to the south of the entrance. A rock platform here seems to assist in keeping the entrance open to the ocean.
The entrance has closed many times in recorded history. This is most strongly associated with periods of drought (no flood flows to scour the entrance) and north to north-east waves pushing sand southwards to completely close the entrance.
During large floods, the entrance scours and the main outlet channel widens to hundreds of metres. The current extent of Dunleith Spit means that the entrance can adjust effectively to convey the flood waters.
During 2020, the entrance has been primarily open and tides in the lakes of up to 8 cm have been measured. This is larger than has been typically reported historically.
The lakes are also subject to fortnightly tides when open to the ocean, and these variations are larger than the variations caused twice per day by the ocean tides.
When the entrance is wide open, the average water level tends to be lower than when the entrance is shoaled and narrow. This can expose wide shallow areas around the fringes of the lakes for extended periods during the lower stages of the fortnightly tide when the entrance is open.
Entrance and tidal behaviour in a naturally opening and closing coastal estuary, particularly a large one such as the Tuggerah Lakes, is naturally variable and future behaviour is difficult to predict, except in an average sense.

3.4.1 The changing entrance

Historically, the entrance channel has been highly constrained by sand shoals. The Inter-departmental Committee (1979) stated:

> *"…the connection to the ocean is restricted to a small channel at the entrance. The channel is in a continuous state of change due to the deposition and subsequent destruction of various sand bars and spits"*

While dominated by periods of restricted connection, the entrance channel still experiences extended periods of being relatively open and, before the 1990s, would also close relatively frequently. Since the 1990s, the entrance channel has been dredged.

Over a 24 month period (1977-1978), the Inter-departmental Committee (1979) found that the size of the most constricted cross section (or 'throat') of the entrance varied between 26 and 150 m^2 (below mean sea level) and this type of variation was considered 'typical'. At no point historically has the entrance been considered 'navigable'.

Floods tend to open the entrance and, in the absence of additional flood events, the time it remains open is controlled by coastal processes. The coastal processes have been reasonably well described, particularly by the work of Patterson Britton and Partners (1994), SMEC (2011) and Umwelt (2011).

SMEC (2011) correctly note that the movement of sand around tidal inlets is complex, being related to combined actions of variable waves and currents superimposed on highly variable bathymetry with constantly changing water levels. Even so, over long time scales, the total amount of sand stored in the dynamic entrance system would attain a reasonably constant volume, providing the entrance is "in equilibrium" with the coastal processes climate. This is argued to be the case for the entrance to Tuggerah Lake. SMEC (2011) present a qualitative conceptual coastal processes model for the entrance and this is shown in Figure 3-8, with the processes of importance described in the following paragraphs.

Patterson Britton and Partners (1994) have noted that, when the entrance is wide open, there is a tendency for the sand from the entrance bar (ebb tide shoal) to be moved into the entrance with the ebb tide. This sand is mobilised by waves and currents, carried through the entrance throat, and deposited at the upstream end of the active channel (commonly downstream of the bridge). Inspection of imagery captured after the February 2020 flood, from an elevated fixed camera managed for Council to the south of the entrance, indicates that this movement of sand is quite

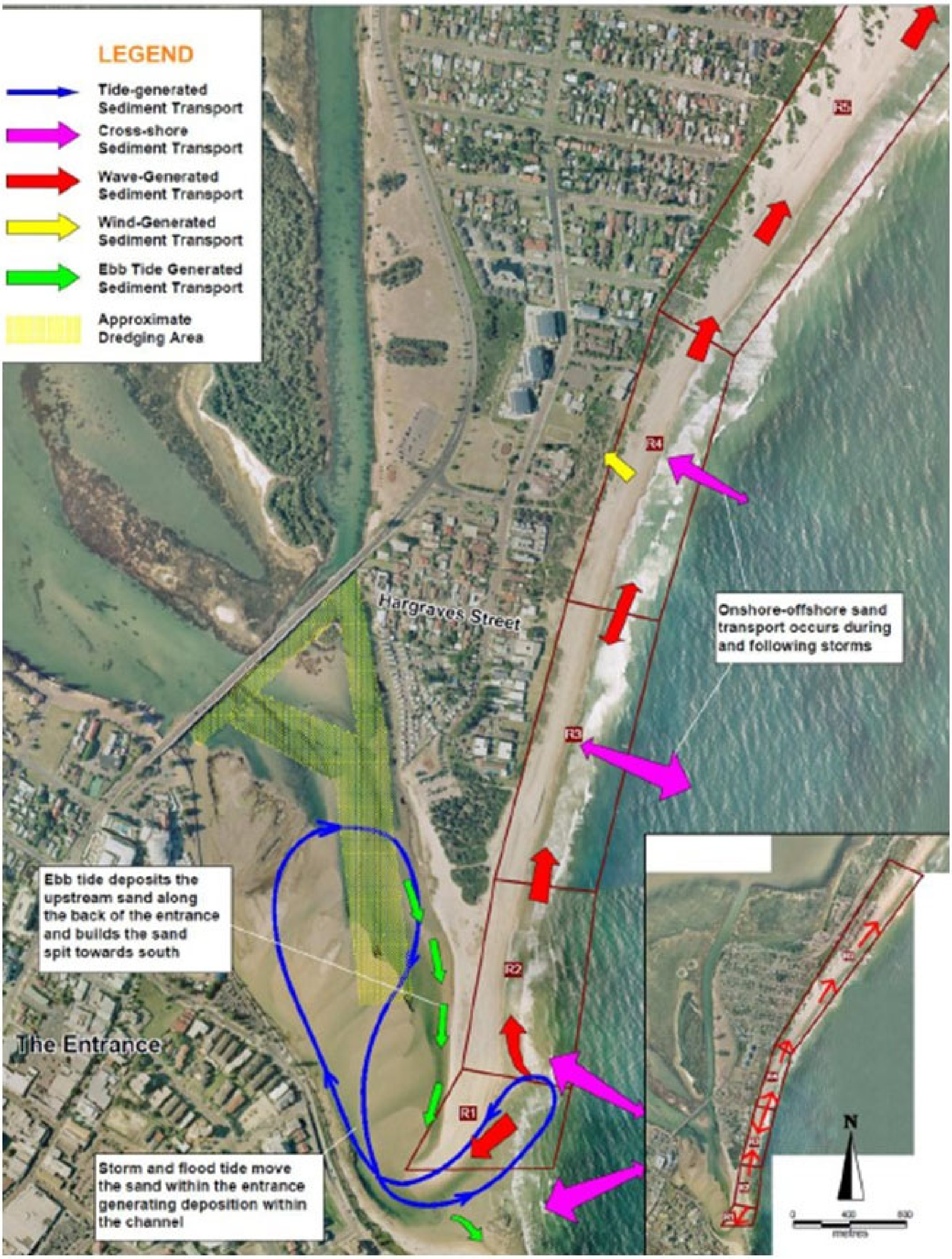


Figure 3-8 Conceptual coastal processes model (SMEC, 2011)

rapid initially. The sand moves in consecutive pulses, individually moved into the entrance over several tidal cycles.

Conversely, the ebb tide tends to transport sand out of the entrance, along the landward edge of Dunleith Spit. The ebb tide transport is less effective than the flood tide transport, partly because there are no ocean waves to assist with suspension of the sediment and partly because the ebb tide velocities tend to be slower.

Eventually, the entrance becomes throttled as more sand is carried into the entrance than out. The entrance reaches a dynamic equilibrium with tides, but tidal exchange is typically very small. The typical throat dimensions are between 25-35m with about 2m depth at mid tide (Patterson Britton and Partners, 1994).

Due to protection of the southern end of North Entrance Beach and Dunleith Spit from offshore waves approaching from the south east (typical wave climate for NSW), the typically northward sand movement along the beach is reversed along Dunleith Spit. There is a theoretical 'null point' along the North Entrance Beach where the sand transport direction reverses. Worley Parsons (2009) noted that the actual location of the null point can vary several hundred metres up or down the coast, in the vicinity of Hargraves Street.

Towards the north, sand is transported along the beach, ultimately ending up closer to Norah Head, where it accumulates, and high sand dunes have formed. The beach at this location is more aligned to face the typical incoming wave climate. As the alignment of the beach changes with the distance north, the tendency for northwards transport reduces. Umwelt (2011) noted that North Entrance Beach has been receding at between 0.2 to 0.5m per year over the past few decades. They argue that recession may be associated with losses from strong flood flows out of the estuary depositing sands in depths of 10 to 20m, with those sands sufficiently deep that they are not readily mobilised by normal waves to build the beach.

A rock revetment seawall was installed to protect properties along this length of foreshore following severe storms in July 2020. Until the 1970s, sand was also lost over the beach barrier carried into the lake by the action of wind, in the vicinity of Curtis Parade, as discussed in Section 3.3.3.
At the end of Dunleith Spit, sand washed out of the entrance is partly moved onshore and southwards resulting in an elongation of the spit. The entrance channel narrows as the end of the spit grows toward the rock platform at Karagi Point. As the spit extends southwards, it may also migrate westwards into the entrance (Public Works Department, 1987).

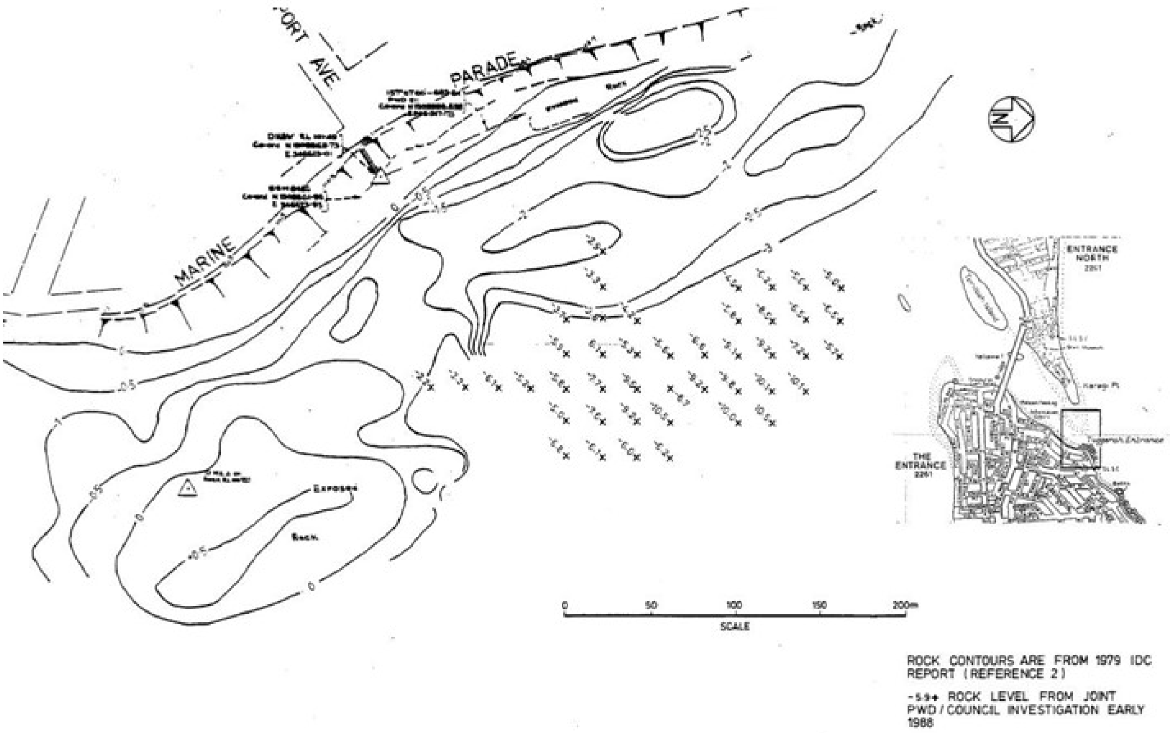
The bedrock forming the rock shelf and adjacent offshore reefs dips downwards towards the north, meaning that rock below the sand is deeper further away from the southern edge of the channel. Clearly the rock shelf does work to control flows, and some elevation information exists (see Figure 3-9), although that appears to have been collected opportunistically, is incomplete, and there seem to be some inconsistencies between different data sets (Council, 2020c; Inter-Departmental Committee, 1979; Patterson Britton and Partners, 1988). The presence of the rock shelf seems to enhance stability of the entrance channel.

Several sources note that the rock shelf acts like a broad crested weir at low tide, and this is clear from photographic evidence (Figure 3-10). This tends to enhance the ability of the ebb tide to scour sand from the entrance and keep it clear by both holding tides back (lengthening the period the ebb tide operates) and generating turbulence which stirs sediment and enables currents to carry sand further offshore. Even so, this process is clearly not sufficient to completely prevent closure of the entrance, and alongshore transport southwards along Dunleith Spit eventually narrows the entrance to the extent that tidal currents become too weak and an entrance cannot be maintained.

Figure 3-10 also illustrates a tendency, present in many historical aerial photos, for the tidal channel to bend towards the north as it exits to the ocean. This is partly affected by the shape of the rock platform but is also a feature of the way that sand scoured from coastal entrances in NSW tends to deposit following a flood or entrance breach event. For example, following the flood of February 2020, there were periods when the exit channel ran in a gutter parallel to the beach for hundreds of metres extending in front of properties along North Entrance Beach.

Recent construction of the groyne across the rock platform south of the entrance may have contributed in a small way to keeping the entrance open. The groyne acts to retard the northward movement of sand from The Entrance Beach towards the entrance throat. Brief perusal of aerial photography available from Google indicates that, since construction of the groyne in 2017/2018, the supratidal rock shelf to the north of the groyne has remained relatively free of sand. By reducing the amount of sand build up on the rock platform and along its northern edge, the speed with which the entrance tends to close has likely reduced, although this effect is most likely to be small and only realised some of the time.

Extract from Figure 2.3 of Manly Hydraulics Laboratory (1988)



Extract from Central Coast Council (2020)

Figure 3-9 Rock shelf elevation and location

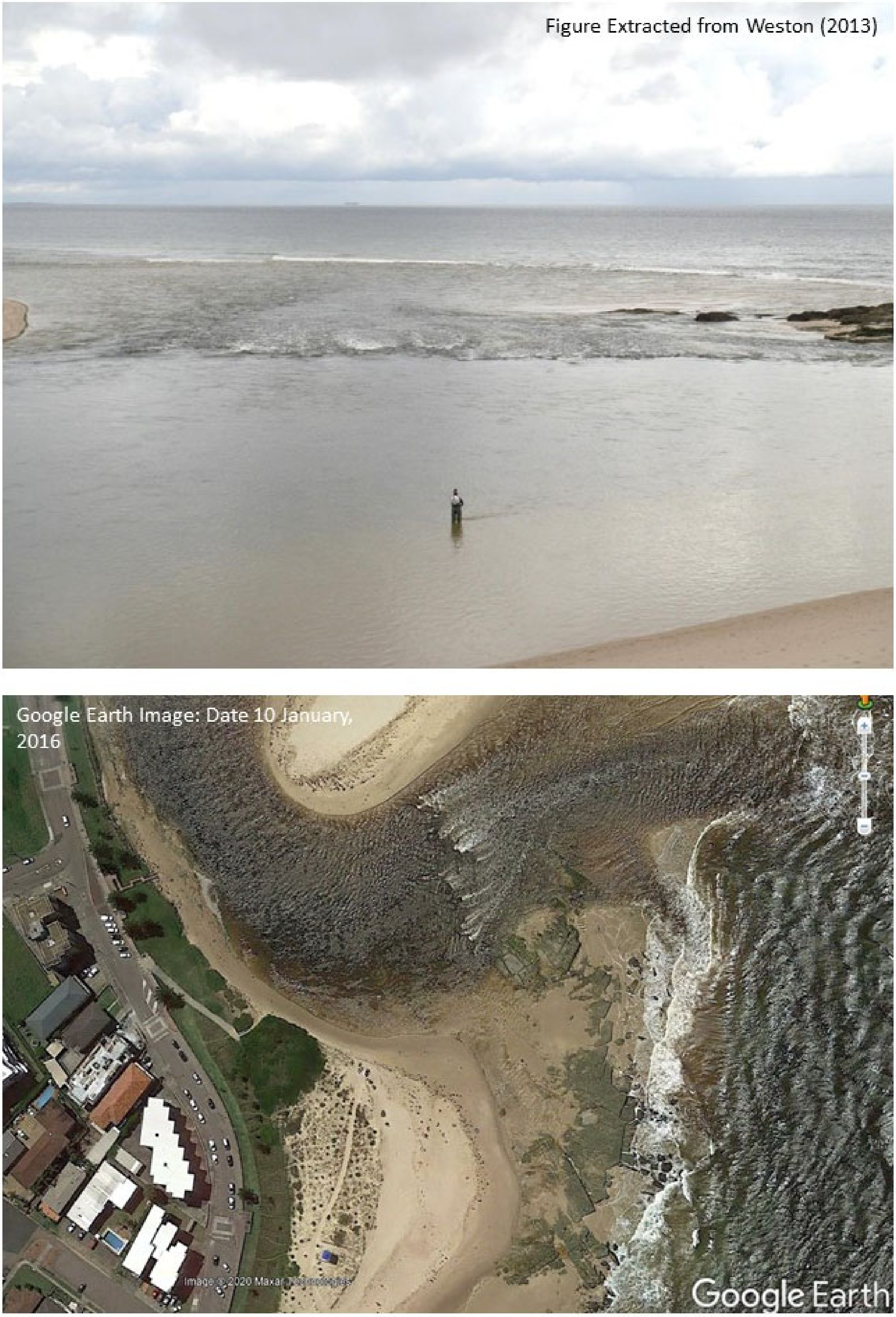


Figure 3-10 Rock shelf at low tide

3.4.2 Entrance closure

The entrance is naturally prone to closure. Umwelt (2011) notes that periods of low rainfall with north to north-east waves directing sand southwards along the beach can eventually form a berm which builds across the entrance, eventually cutting off tidal exchange.

Based on historical recollections, Scott (1998) noted that:

> *Under natural conditions the channel would slowly block up and could remain closed for up to a year or more.*

The Inter-Departmental Committee (1979) claimed that, in the preceding 100 years, there had been nine occasions when the channel was completely closed for at least a few tidal cycles, with no flow of sea water into the system. NSW Public Works Department (1987), highlighted that entrance closures in the 1980s seemed to be more common and persistent, arguing that this may have been due to a lack of major rainfall events in the early 1980s, or the practice of Council at the time, which opened the entrance artificially using bulldozers when the water level in the lake reached only 1m AHD.

While the channel would open and close intermittently, climatic variability seems to have also resulted in long periods where the entrance could stay closed. Based on the weight of evidence from historical recollections, Scott (1998) notes:

> *"In the late 30s and early 40s the channel is reported to have been closed for much of the time"*

It is instructive to note that entrance closure has seemingly been rare since regular dredging commenced, with a notable exception occurring in 2019 and early 2020. However, there does not seem to be a reliable and meaningful measure of entrance closure employed to inform management at the present time.

3.4.3 Floods and entrance opening

The management of risk to life and property arising from floods is not within the terms of reference for this study. However, the effect of floods in opening the entrance, the resulting increased exchange with the ocean, and any flow on effects to water quality are of interest.

Umwelt (2011) notes that, following closure of the entrance, catchment runoff can cause water levels behind the barrier to rise until the barrier is eventually overtopped (or the entrance is artificially opened by cutting a relief channel with earthmoving equipment). Sand is then scoured and deposited in the nearshore zone with the entrance channel widening to 300 to 400m, depending on the magnitude of the flood.

Scott (1998) noted that, historically:

> *"Eventually a large flood would burst over the sandbars and scour out the channel. This was often expedited by local residents who lived in low lying areas around the lake shores (e.g. Tacoma) and whose houses were being flooded. They would come across to The Entrance with shovels and dig a small channel until the water cut through and rushed out. The sudden release of water during these floods would wash all of the sand out of the channel and for a while the entrance channel would be much wider and deeper than usual"*

Scott's report contains several long-term historical accounts of dry times when the entrance was closed, followed by floods which would fill up the lake such that the community (or the council responsible at the time) would work with shovels, machinery or horses to open the lake artificially. The entrance has been artificially opened since at least the late 1800s to alleviate flooding.

Some long-term residents have also recalled observations which reflect multi decade climatic variations that have only begun to be well understood by scientists in the past few decades:

> *"In the 1920s, 30s and 40s flooding would occur, but since 1954 and the last major flood, only much smaller floods which is not sufficient to prevent sand infilling the entrance. (Arthur Clouten)"*

Recollections of the behaviour of the entrance after a flood and during normal periods also reflect the current understanding of the variability of the entrance described above:

> *"In the average seasons the Tuggerah Lakes can only support an entrance of 40-50 yards and 6-8 feet deep, but in the major flood season you need 200-300 yards to get the flood water away after which the entrance would return to 40-50 yards wide." (Arthur Clouten).*

Patterson Britton and Partners (1994) make the very important point that, in its current state, "*the entrance is able to adjust to all storm and flood events*". This needs to be considered when looking to alter the entrance say, by constructing breakwaters, as such changes will have impacts on how efficiently the entrance is able to discharge floodwaters. A photograph from the June 2007 flood is shown in Figure 3-11 (Erskine, 2013). The speed at which a flood exits the lake is dependent on how far the entrance can widen (for example by eroding the tip of the Dunleith spit, shown to the right of Figure 3-11). Similarly, breakwaters and dredged channels will change the efficiency with which storm surge can get into the lakes and this also needs to be considered.

Figure 3-11 2007 flood discharge (from Erskine 2013)

Experience in NSW has shown that sand tends to accumulate against the northern edge of a northern entrance breakwater (example sites are the entrances to Lake Macquarie and Wallis Lake). The beach adjacent to the entrance tends to widen, grow in height, and become vegetated. This effectively forces flow between the breakwaters. At present, when the barrier is low or short, storm surge can readily make its way into the entrance compartment by overtopping the barrier. This process would be altered by forcing flood flows through a gap between breakwaters.

The dynamics of the entrance opening are important. The Tuggerah Lakes Flood Study (Lawson & Treloar, 1994) noted that:

"The entrance condition is the single most important aspect controlling flood behaviour in the lakes"

Similarly, the Floodplain Risk Management Study (WMAwater, 2014) noted that:

"the extent of flooding is influenced by the level of the beach berm at the entrance and whether elevated ocean levels in the Pacific Ocean can overtop the berm and enter Tuggerah Lake or restrict the outflow of floodwaters".

Surprisingly, the Estuary Processes Study (Wyong Shire Council, 2001b) indicates, somewhat differently:

"The difference between peak flood heights with the entrance channel partially opened or fully closed would be small".

It may be that this last quote relies on previous information and that the full context is not given. Unfortunately, statements such as this, if used to guide floodplain risk management, are likely to exacerbate flood risk. It is fundamentally clear that a higher beach barrier at the entrance to a closed coastal lake or lagoon during the onset of a catchment flood will cause water levels to rise higher before the barrier is overtopped. Given the right circumstances, artificially opening the entrance with earthmoving equipment can help alleviate the flood risk but any alleviation of flood risk needs to be balanced against the potentially deleterious effects that long term modifications to entrance behaviour will have on environmental and ecological processes within the lake.

For reference, the design flood levels used in the most recent floodplain risk management plan for Tuggerah Lakes (Lawson & Treloar, 1994; WMAwater, 2014) are presented in Table 3-2.

Table 3-2 Design flood levels for Tuggerah Lakes

Event	Flood Level (m AHD)
PMF	2.70
1% AEP	2.23
5% AEP	1.80
20% AEP	1.36
50% AEP	0.91

Sources: Lawson & Treloar (1994), WMAwater (2014)

3.4.4 Tides

It is often claimed that tides in the lakes are negligible (approximately1% of volume exchanged), although this does not represent a complete understanding of how the entrance behaves. The 1% figure seems to stem from a tidal gauging exercise undertaken in October 1975 by the NSW Public Works Department (reported in Inter-Departmental Committee, 1979). Based on field measurements, it was estimated that around 1% of the total volume of water within the lakes moves from the ocean into the lakes during a typical semi-diurnal (twice per day) tidal cycle. Of course, these measurements were only specific to measurements over a particular tidal cycle and, given the variability of the entrance, the amount of water that exchanges can also vary. The tidal range in the lakes when the measurements were made was 25mm, which seems to be a reasonably typical value based on other reports.

The Inter-Departmental Committee also noted that winds which blow towards the ocean act to push water levels up on the eastern side of the lakes, with this "wind set-up" acting against flooding tides but enhancing ebbing tides.

Other data from the gauging exercise in 1975 indicated that "*most of the head loss …. occurs within a couple hundred metres from the sea*". This refers to <u>attenuation</u> of the tide. Attenuation means that the size of the tides (difference between low and high tides) gets smaller with distance upstream. In the case of the 1975 gauging, most attenuation (80%) occurred within 200m of the entrance (roughly along the channel length downstream of Beach St/Fairport Ave).

An overly simplistic assessment may conclude that this means managing the channel in the immediate vicinity of the entrance will efficiently open the lakes to the ocean tides. This is not the case. The entrance channel is much longer than this 200m length, and removal of the constriction here, while it will reduce overall attenuation, will not reduce it by 80% as there will be comparable increases in attenuation at other locations along the channel. Substantial increases in tidal exchange in the lake would require increases in efficiency throughout the entrance compartment, including areas upstream of the bridge.

Several reports have noted the limited amount of tidal exchange through the entrance to the lake. WMAWater (2014) assessed historical tidal ranges in the Lake and assessed it as being "*effectively nil*" (i.e. less than 50mm).

There is a relationship between the effectiveness with which tides can flow in and out of the lake from the ocean and the average water level inside the lake. Typically, the mean lake level is higher than mean sea level in the ocean. The tidal range in the lake decreases as the entrance becomes more constrained, but at the same time, the mean lake level increases. Several reports have discussed mean lake water levels. WMAWater (2014) noted that mean lake water levels were *"normally in the range of 0.2m to 0.4m AHD"*. The NSW Public Works Department (1987) found that the water levels were *"tidally super-elevated 0.2m above MSL*". Based on analysis of water level data from between 1964 and 1973, the Tuggerah Lakes Study (Inter-Departmental Committee, 1979) found that the lake was typically superelevated 0.3m above mean sea level. Patterson Britton and Partners (1994) found that mean lake levels are typically superelevated 0.2 to 0.3m above the ocean but can drop to 0.1m above the ocean after a flood (i.e. when the entrance is more 'open').

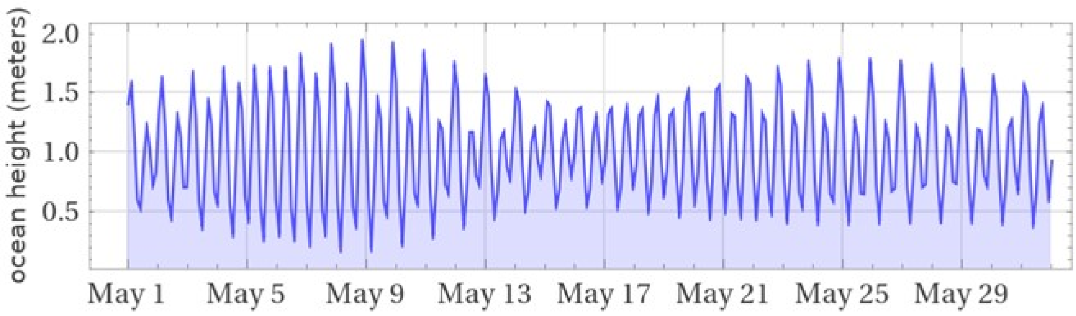
To better illustrate these processes, data from late 2019, when the entrance was effectively closed, and data from mid-2020, following a flood in February and subsequent storm/rainfall events that caused the entrance to open, were compared. The analysis also considers the effect of entrance closure on fortnightly variations of water levels in the lake.

So called "fortnightly tides" inside coastal lakes and lagoons (when open) occur in response to neap/spring tidal cycles in the ocean. Ocean tides vary over a period of around 15 days between larger (spring) tides and smaller (neap) tides. During spring tides, a process known as "tidal pumping" traps water in the upper reaches of an estuary, causing average water levels to be higher than they are during neap tides. Representative ocean and estuarine water levels are shown in Figure 3-12. However, unlike the bottom frame in Figure 3-12, which is for tides inside a river estuary, the fortnightly tides in a coastal lake with a heavily constrained entrance can be much larger than the daily tide variation.

Two recorders are available in Tuggerah Lake at Long Jetty (south) and Toukley (north). Focusing initially on June 2020, charts for Long Jetty (Figure 3-13) and Toukley (Figure 3-14) are provided. The figures show the actual tidal variation, including a 'smoothed' line which highlights the fortnightly variation at the two sites (top frame), alongside the tidal variation relative to the fortnightly variation (bottom frame). The two sites are qualitatively and quantitatively similar, showing that, for this 'open' entrance condition, fortnightly tide variations of up to 0.2m are present, compared to a maximum variation during spring tides of around 0.08m. The tidal response is clear (varying up and down around twice a day and showing differences through the spring/neap cycle) and the variation of up to 80mm exceeds that reported by others (see above). There are also variations which last for less than a tidal cycle that arise from wind events. These are discussed in more detail below.

Corresponding figures for December 2019, representing an extremely constrained condition are shown in Figure 3-15 (Long Jetty) and Figure 3-16 (Toukley).

Tides in Sydney during May 2020, to ISLW. Sourced from Wolfram Alpha https://www.wolframalpha.com



"Fortnightly tide" response of mean water level inside an estuary – smoothed line represents the variation of the average water level around which the tides oscillate (from NSW Government, 1990).

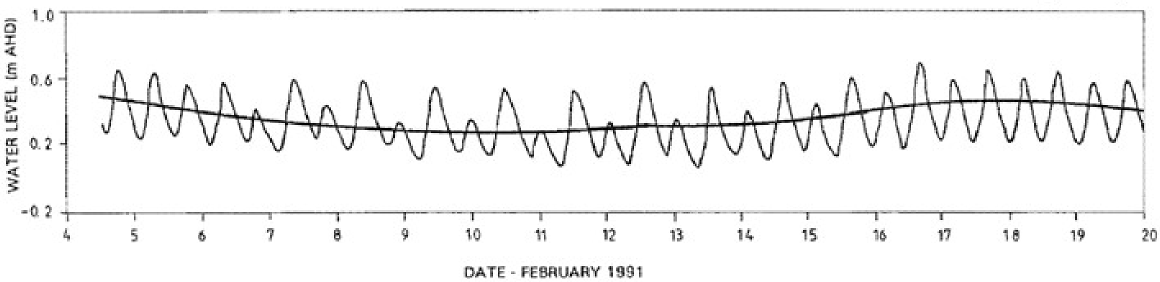


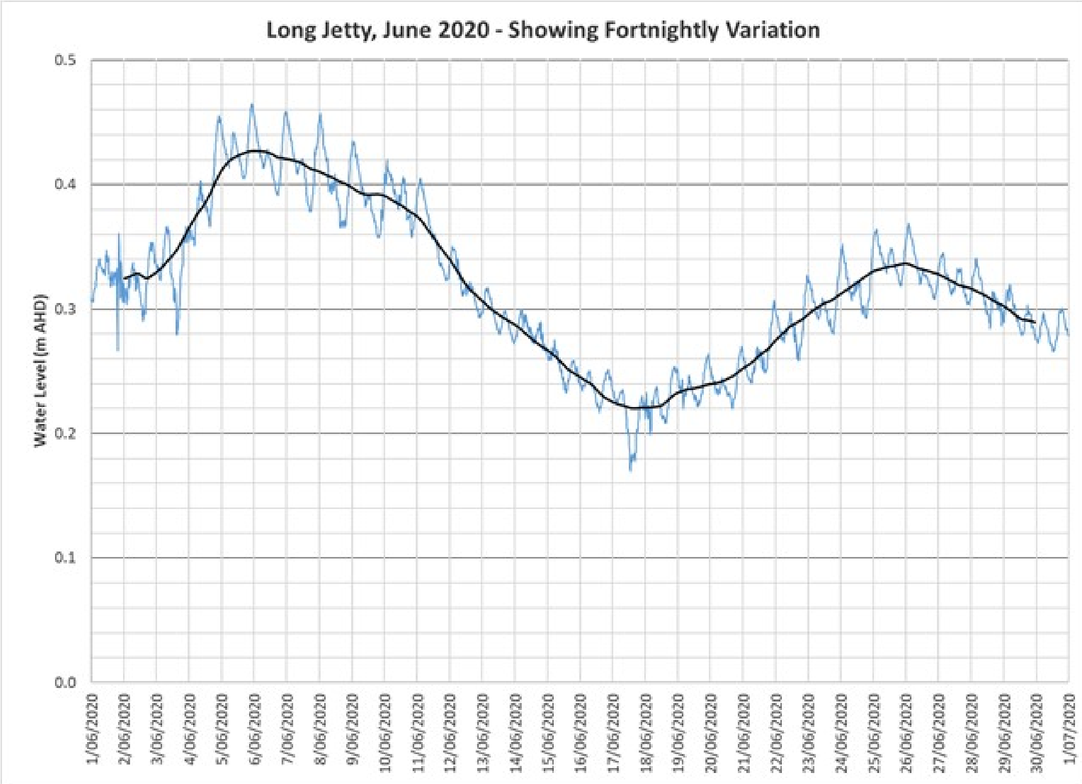
Figure 3-12 Neap, spring and fortnightly tides

The difference between the closed and open situation is marked. When the entrance is closed there are two things that are notable:

- There is no coherent fortnightly variation in mean lake water level.
- While water levels vary from day to day, it is not possible to identify a tide 'signal' inside the lake. It is notable that the largest spring tides during the year occur during December (around the solstice), and the impact of these is not visible on the plots.

It can be assumed here that the entrance was closed to ocean tides, and examination of preceding months (not presented here) indicates that this was the case for at least several months prior. A closed entrance excludes both daily tidal variations and fortnightly tides from the lakes. Given the above, some surprising statements are made such as the following from Worley Parsons (2009), which found the:

> *"tidal range generally, is small in magnitude and does not appear to vary markedly in response to the range of entrance conditions at times when the entrance is open"*



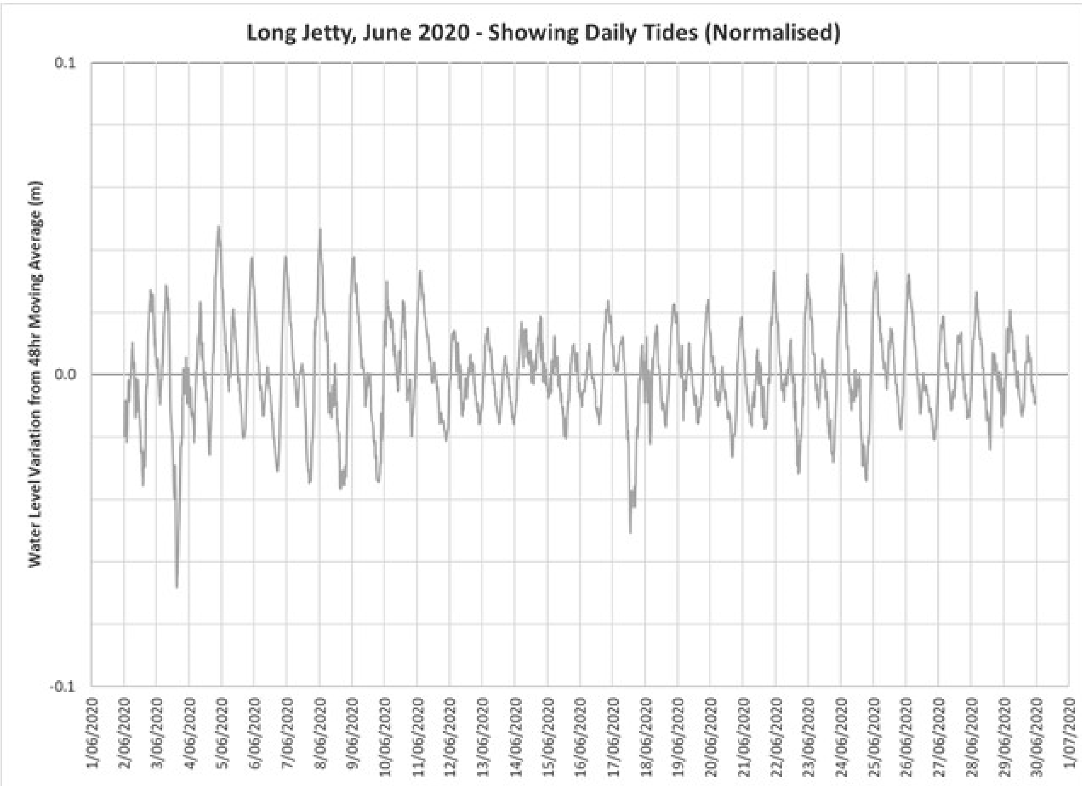
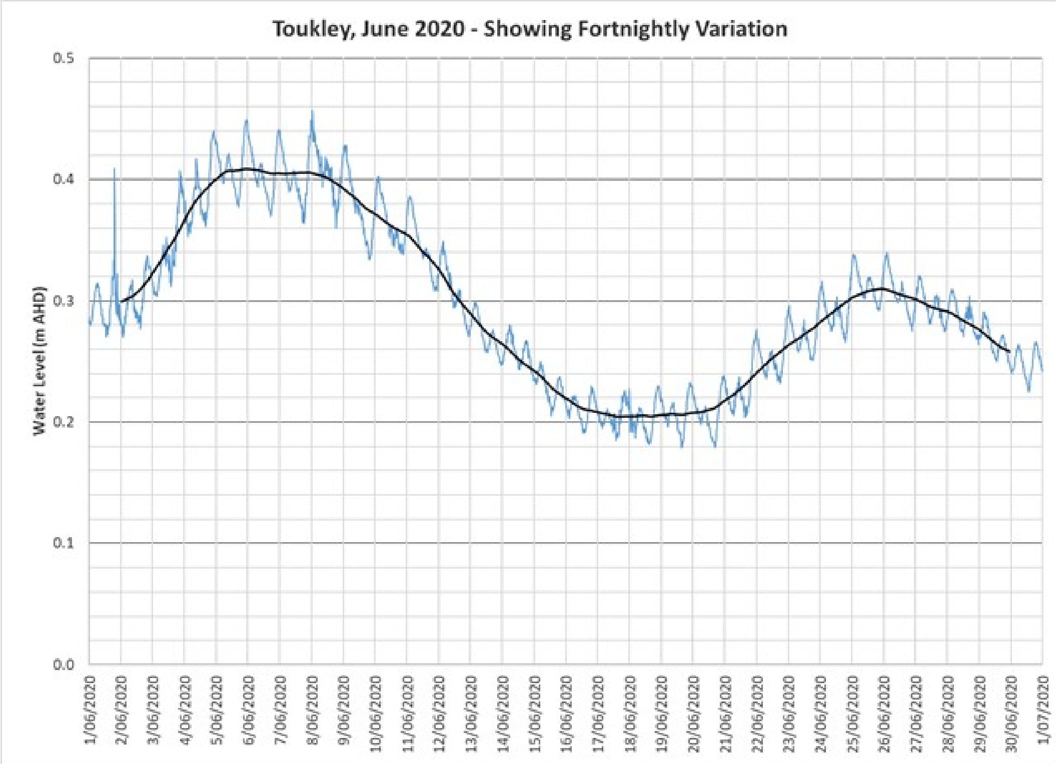


Figure 3-13 Long Jetty tides, June 2020



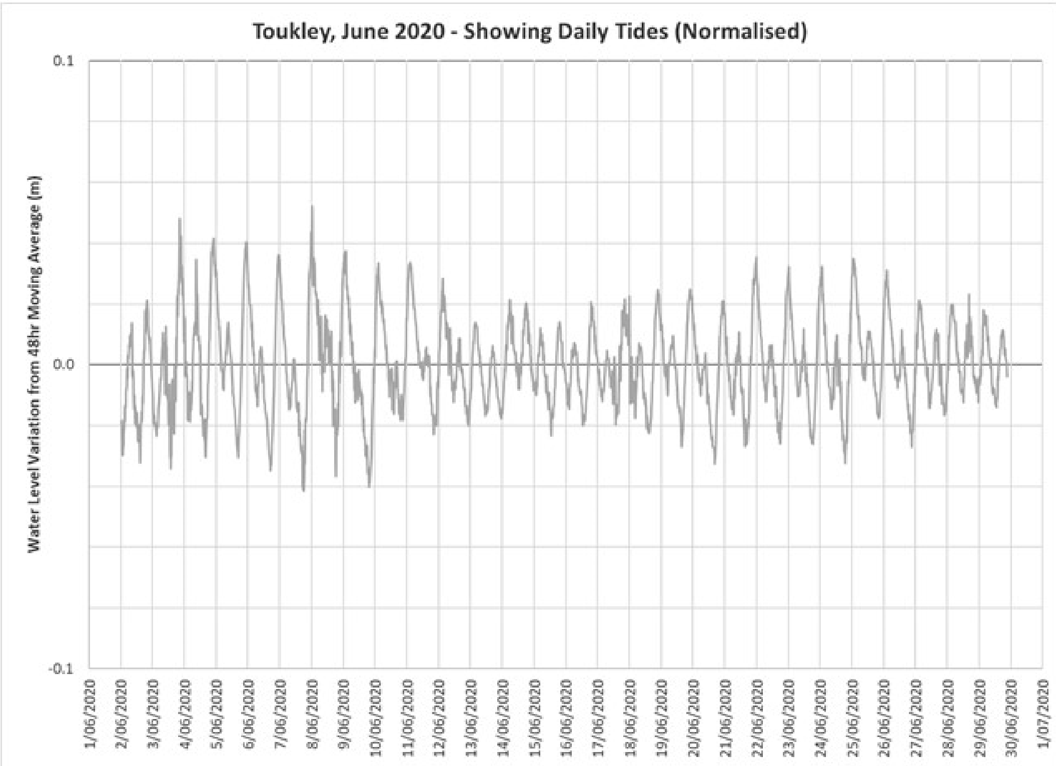
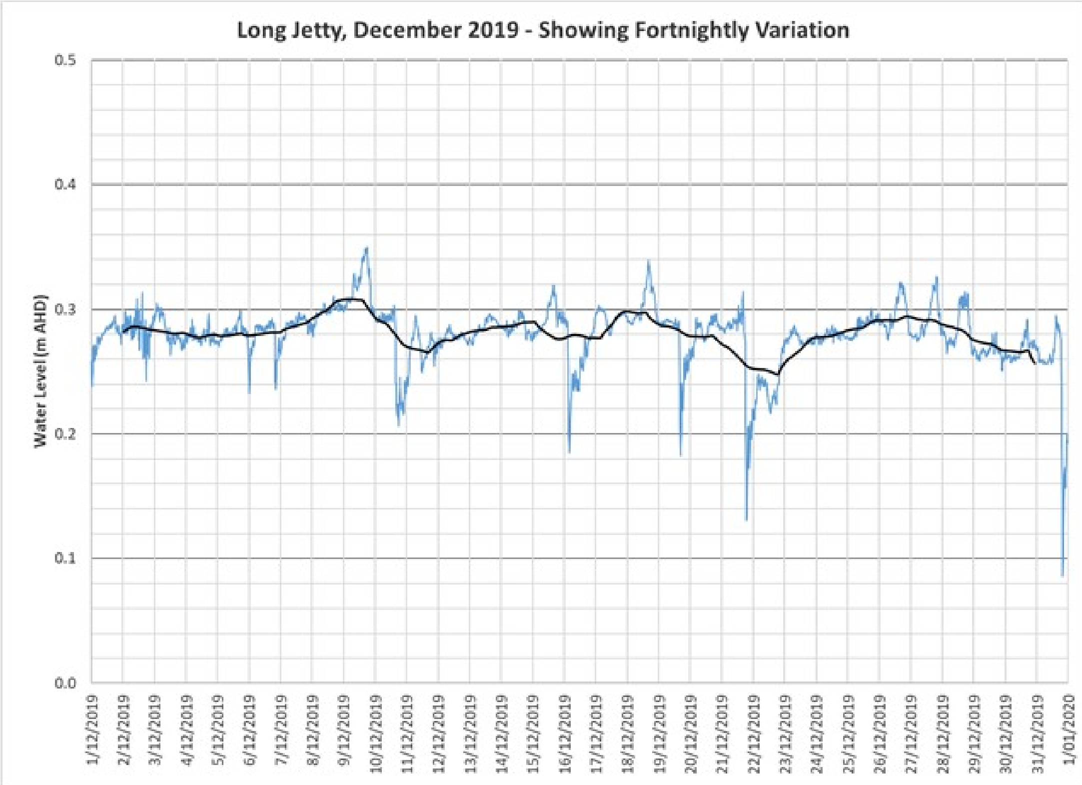


Figure 3-14 Toukley tides, June 2020



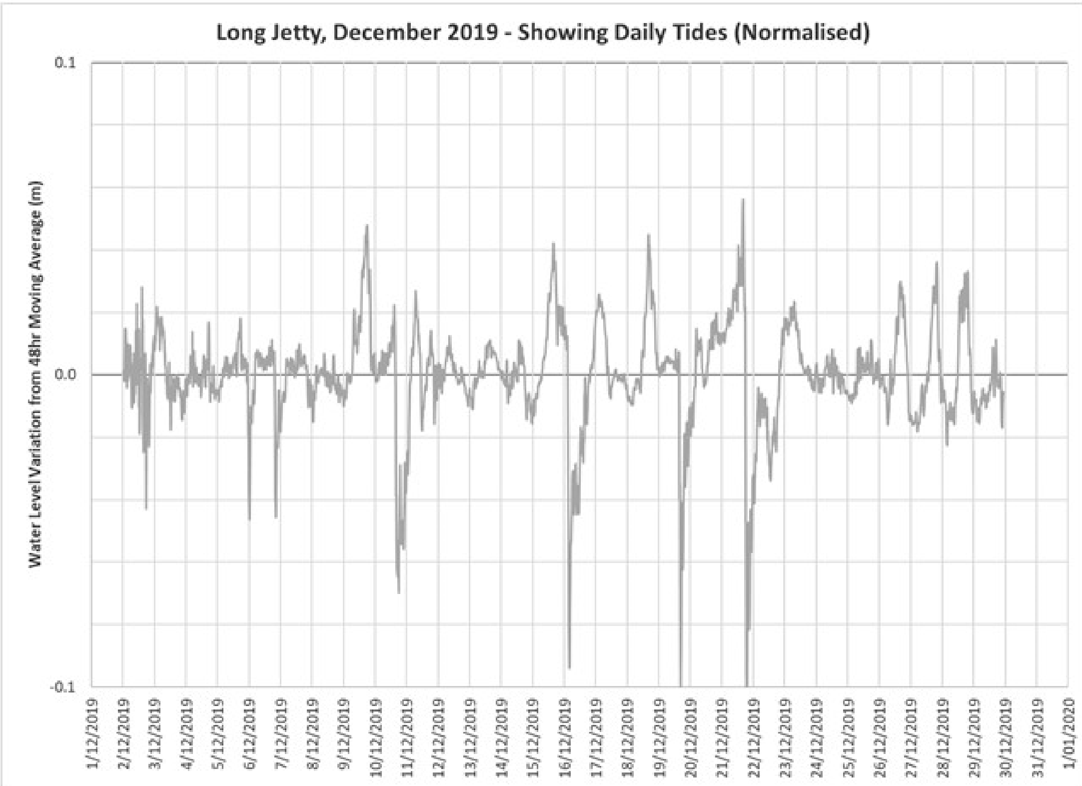


Figure 3-15 Long Jetty tides, December 2019

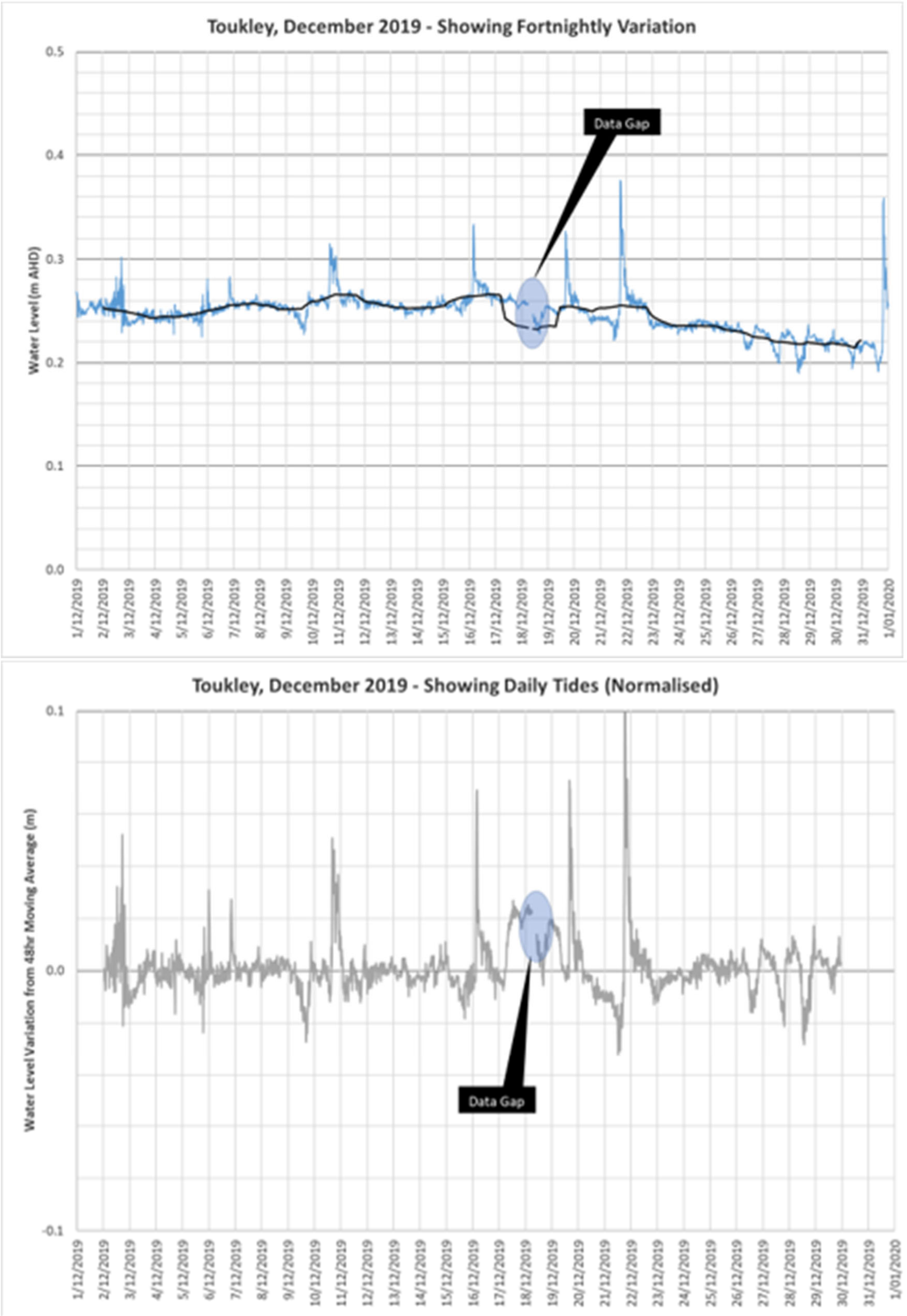


Figure 3-16 Toukley tides, December 2019

Conversely, the NSW Public Works Department (1987) found that the tidal range varies with the condition of the entrance channel, although they indicated that the range is typically around 20mm.

An effect of wind is illustrated in Figure 3-17 which compares water levels at Toukley and Long Jetty. It should be highlighted that the data plotted indicates that there is a mismatch of around 4cm between the surveyed levels of the two recorders. During periods where there is minimal wind and a flat lake surface (e.g. 23 December on Figure 3-17), the two sites should plot on top of each other. For illustrative purposes though, the data are useful.

In the evening of 21 December 2019, a strong southerly wind change which is common during summer months on the NSW Coast (a “Southerly Buster”) acted on the lakes, pushing water from the south (Long Jetty) towards the north (Toukley) of Tuggerah Lake. The wind change appears to have acted for around an hour before relenting. After that time, the lake acted somewhat (simplistically) like a bathtub that sloshes backwards and forwards in a motion known as a “seiche”. This backwards and forwards (and up and down) motion repeated every 1.5 hours or so for a further six to eight hours, gradually diminishing with time similarly to the motion of a sloshing bath coming to rest. The natural period of the seiche in Tuggerah Lakes is around 1.5 hours. There were at least six wind driven seiche events in Tuggerah Lake in December 2019, typically initiated by southerly winds in the evening or very early morning. The action of wind events such as these, including circulation currents that are generated by the wind and wind waves that move towards the foreshore, are important processes that promote mixing in the lake, as discussed in more detail in the following section.

Umwelt (2011) makes the point that dredging of the entrance from the 1990s has resulted in a “*marked decreases in water level and waterway area variation in the lakes*”. This seems true when considering that complete closure and subsequent filling of the lakes behind the sand barrier has been rarer, but during the more ‘typical’ condition of the entrance being open but heavily constrained by sand, it seems doubtful that the impact of dredging has been particularly significant.

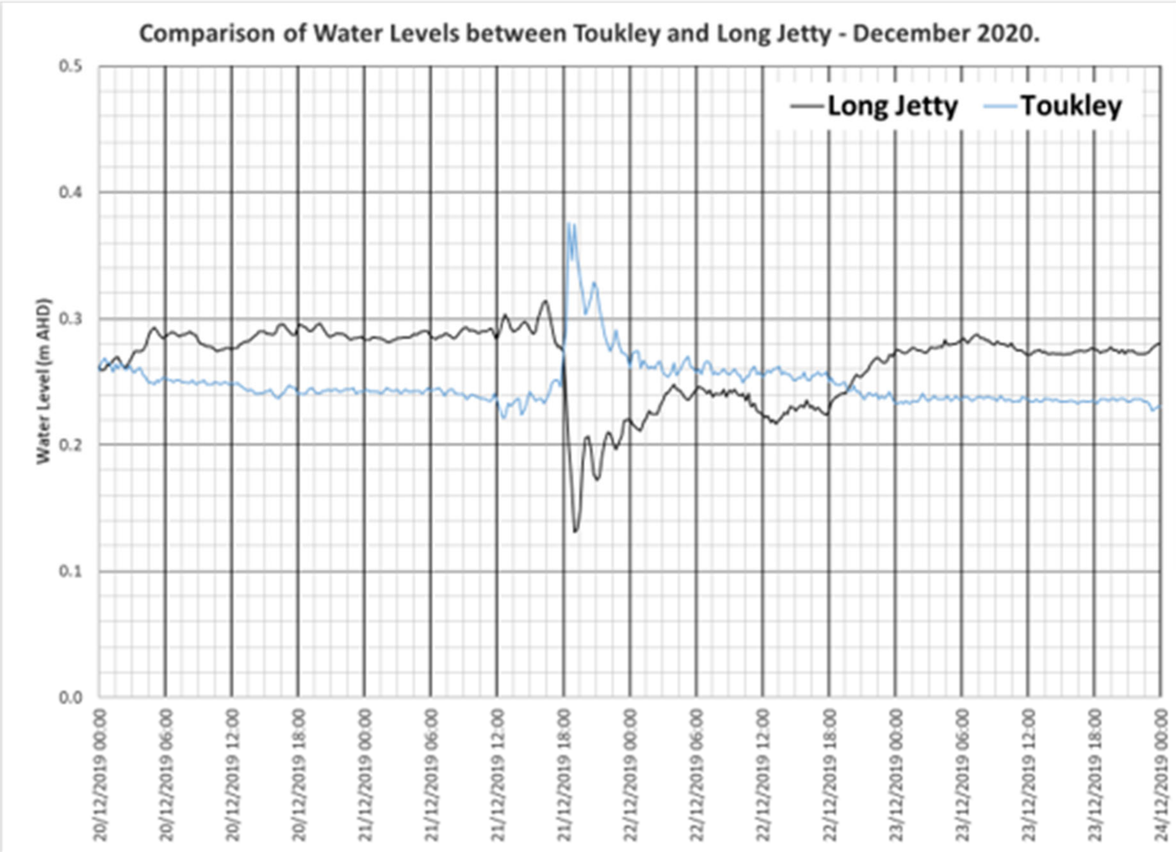


Figure 3-17 Example response to wind events

Part of the tidal behaviour is affected by perching of the entrance outlet channel adjacent to or upon the rock shelf. During consultation undertaken as part of this current study (refer to Section 2.3.2), several community members expressed a concern that the rock shelf should be maintained in place. Their concern stems from the observation that the rock shelf tends to hold water back in the lakes and several community members quite strongly oppose any modification to the rock shelf.

Following the flood and subsequent events in February 2020, the entrance channel remained north of the rock shelf until at least the time of writing (end of October 2020). As noted above, in this location, a deeper channel can scour as the rock is deep below the sand. During this period, it was noted that the lakes were draining to a much lower level, presumably as reflected in the fortnightly tide variation. One submission highlights the difficulty in introducing any management strategy that could result in a “more open” entrance:

"Since the [February 2020] flood and artificial widening of the channel the lake level has dropped significantly. Now our waterfront that we paid dearly for looks more like a swamp and the algae that flourished this year due to the more shallow water is now producing a sickening stench……. I think nature should left alone re the channel and we should be concentrating on stopping pollution run off into the lake."

This shows that, while the entrance may be open with more water exchange during each tide, other effects (lowering of the water level) can have severe negative aesthetic impacts on some of the residents around the lakes.

3.5 Mixing processes within and between the lakes

Key Points
The immediate “Entrance Area” around Memorial Park tends to be well flushed if there is any tidal connection with the ocean.
Clean marine sand tends to be washed out of the entrance by floods and replaced by clean marine sand carried back in by the tides.
During normal conditions, tidal exchange with the lagoon is slow and tidal currents contribute little to circulations within the Lake. Estimates of flushing of the estuary are in the order of hundreds of days. Flows from the catchment contribute more to flushing than tides (on average).
Stratified conditions are not common, except during particularly still conditions.
Vegetation accumulating in the nearshore zone creates barriers that resist flows and may also protect the water surface from wind stress, impeding movement and trapping stormwater discharges from urban catchments fringing the lakes in stagnant and shallow nearshore zones. This creates a potential for poor water quality conditions to arise.
The action of catchment floods in particular seem to have the capacity to reset the conditions around the foreshores of the lakes by overcoming barriers that otherwise inhibit the exchange of water and sediments between main lake basins and nearshore areas.
The deeper estuarine basins of the lakes are well mixed, both horizontally and vertically, by wind and tend towards being turbid because of the interactions of wind driven currents with the muddy bed sediments. In isolation, this mixing does not remove pollutants from the lakes.
Although connections between the three lakes are constrained, slow changes to water levels through flooding and tides propagate throughout the system such that water levels across all three lakes are approximately ‘flat’.
In some circumstances, wind generated seiching will assist exchange by temporarily establishing water surface gradients which force water between the constrained connections between lakes.
A unidirectional current flowing north through Budgewoi Creek was present while the Munmorah Power Station was operating. Before this, Budgewoi Creek was particularly constrained, and exchange between Munmorah Lake and Budgewoi Creek would have been less than today.

3.5.1 Introduction

Section 3.4 has highlighted that exchange between the ocean and the lakes is small (limited to around 3% of volume during more open conditions, but typically around 1% when the entrance is constrained but not closed), to the extent that some classify the lakes as 'non-tidal'. This section focuses mainly on mixing processes from the catchment (Section 3.5.4), exchanges between the nearshore and deeper parts of the lagoons (Section 3.5.5), and between the three lakes that comprise the estuary (Section 3.5.6), although some consideration of exchange from the ocean and the immediate entrance (around the Bridge and further downstream) is warranted and a brief discussion is provided in Sections 3.5.2 and 3.5.3.

3.5.2 Flushing of "The Entrance"

The immediate entrance, around the community and tourism focal point of Memorial Park and further downstream is normally well flushed when the entrance is open. While the build-up of sand shoals and shallowing of the area adjacent to the southern foreshore may be a concern from a tourism perspective, this is not an indication of poor water quality, as long as the entrance maintains a reasonable degree of tidal connectivity.

Inspection of aerial photography indicates that the area downstream of the bridge almost always comprises bare, clean, mobile sand shoals intersected by variable channels of differing sizes across most of this compartment.

When the entrance is heavily constrained or effectively closed there is greater tendency for vegetation, including seagrasses and saltmarsh, to establish on the shoaled areas, and this is particularly the case in the areas immediately downstream of the bridge. However, a flood and subsequent infill of the entrance with sand tends to either scour or smother the shoals and remove any vegetation that has established.

The situation across the inner tidal delta (i.e. upstream of the bridge) is notably different, with less shoal mobility and more permanent vegetation being present. If complete closure were to occur for more extended periods, a degree of stagnation, more established vegetation, and an increase in the amount of wrack washing up on the foreshore could be expected to occur. However, since the onset of regular maintenance dredging in the early 1990s, this does not appear to have been the situation downstream of the bridge.

3.5.3 Oceanic flushing of the lakes

Wyong Shire Council (2001b) concluded that tidal flushing contributes very little to circulation and mixing patterns inside the lakes. This can be largely attributed to the lakes having a large surface area which is only connected to the ocean by a narrow entrance. Estimates of "*flushing*" build on the work of several other researchers:

- Hunter (1996) using a simple "Box" model, which considered the estuary as being a single well-mixed basin with freshwater inflows in addition to oceanic exchange. Hunter defined *"flushing time"* as the time it would take for tidal flows and river inflows to fill the estuary from empty to its typical level (more commonly referred to as "*Residence Time"*). Based on this simple model, it takes around three times the "*flushing time"* for 95% of the original water in the lakes to exchange with the ocean, noting that the proportion of original water exchanged reduces exponentially over time. The 95% value was calculated at 320 days, based on annual average conditions of inflow. This means that it is a 'typical' value and there may be substantial variation around this value depending on how open or closed the entrance is.
- van Senden (1996) established a model with nine boxes and provided an estimate of flushing time using the definition of *"time for an instantaneous change in concentration to recover by 37%"*. We note that this appears to refer to an 'e-folding time' which is in fact reduction in the instantaneous change by 63%, or the time for around 63% of the original water to be exchanged. An estimate of flushing time was provided, varying from around 50 days for catchment inflows of around 1000 ML/day (approximately 11.6 m^3/s) up to around 1000 days for catchment inflows of around 50 ML/day (approximately 0.6 m^3/s). The results are at least comparable to the findings of Hunter (1996) who adopted an average inflow of 7.5 m^3/s. Similarly to Hunter, van Senden appears to have adopted an 'average' condition for the entrance representing minimal exchange.

Neither author quantitatively assesses the relative importance of tidal exchange compared to catchment inflows. However, taking Hunter's approach the following can be estimated:

- Doubling the tidal exchange would reduce the estimated *total flushing time* (i.e. the 95% reduction time) from 320 days to around 230 days.
- Tripling of tidal exchange would reduce the estimated *total flushing time* from 320 to around 170 days.

Based on mathematical modelling undertaken by the Inter-Departmental Committee (1979), tidal currents are negligible everywhere except for the immediate entrance channel. Within the model, which would have been state of the art in the 1970s but very coarse by today's standards (2D representation of lakes, grid size in excess of 300m; 1D in the entrance channel), a simulation was executed with the entrance flow area increased by lowering the bed by 0.5m. It was found that this did not alter peak tidal current patterns significantly.

Some attention is given in the Estuary Processes Study (Wyong Shire Council, 2001b) to gravitational circulations associated with denser (colder, more saline) flood tide flows entering the main body of the lake and sinking, such that a *stratified* scenario arises where the denser tidal inflow sinks below fresher lake water. The process was replicated by Sanderson (2009) using a hydraulic (three dimensional) computer model. However, due to the mixing processes described in the following section, stratification is unlikely to persist for significant periods, except during extremely still conditions, and the process is unlikely to be particularly relevant to tidal exchange.

Tidally generated currents continually introduce salt water into the lakes. However, the Inter-Departmental Committee (1979) reported that the lakes vary from hyper saline (41ppt) conditions during droughts down to brackish conditions (8ppt) during floods. A more typical salinity within the lagoons tends to be around 20ppt. Due to the relative efficiency of the mixing processes described below, salinity tends to be relatively consistent throughout the main lake basins, although Wyong Shire Council (2001b) reports that salinity can be higher in Tuggerah Lake than the two northern lakes. Differences in salinity would be most pronounced when the entrance is open (wet conditions), with salinity being more uniform when the entrance is closed (dry conditions).

3.5.4 Water from the catchment

The ‘average’ inflow conditions utilised by Hunter (1996) and van Senden (1996) perhaps over simplify the real contributions of different flushing processes to water quality. It is accepted that exchange with the ocean is presently relatively ineffective in its contribution to flushing. However, inflows from day to day are not constant and vary depending on rainfall.

Water flowing into the lagoons from the catchment tends to be warmer and fresher (i.e. less dense) than more saline water in the lagoons. Depending on conditions, the catchment discharges may flow as a stratified ‘lens’ over the top of the saline water, persisting for some time before being mixed into the water column by other processes.

The movement of water from the estuary to the ocean is significantly influenced by catchment flooding events, which tend to occur during autumn and early winter (Wyong Shire Council, 2001b). Most of the catchment inflow enters via Ourimbah Creek and Wyong River into Tuggerah Lake; and Wallarah Creek into Budgewoi Lake (Inter-Departmental Committee, 1979). Significant catchment floods are typically accompanied by coastal storms, such as east coast lows along the central NSW coast. These are characterised by tight low-pressure systems with strong winds that generate significant wind waves inside coastal lakes and lagoons. Therefore, depending on the response time of the lake (time to reach peak flood level) and whether the entrance is closed to the ocean at the time, wave stirring and breaking at elevated water levels, full mixing of the incoming water vertically through the water column and dilution of the water around the lake through horizontal circulation (see below for a discussion on these) may contribute to the following:

- Dislodgement of settled vegetative matter from around foreshore areas and redistribution to other locations, including into the deeper parts of the lake or onto backshore areas where it settles and dries out after the flood recedes.
- Recoupling of shallow nearshore and deeper parts of the lakes (described below).
- Stirring of fine-grained silt and 'ooze' from foreshores and distribution of this material further offshore and into the water column.
- Extensive mixing of any suspended material throughout the waterbody.
- Carriage of some suspended matter to the ocean via the entrance channel as the flood passes.

These processes seem to accord with both historical and recent recollections of the lakes seeming 'cleaner' following a flood event, however, much would depend on the precise conditions that occur during a flood event and the relative magnitude of the processes and their timing.

Conversely, more frequent runoff and catchment inflow conditions tend to not have as marked an impact. These events may be insufficient to overcome some of the barriers to water movement, such as deltas at the mouths of the main tributaries or accumulated vegetation in nearshore areas, and instead contribute to any problem areas by introducing further pollutants.

In summary, large floods seem to 'reset' conditions around foreshores of the Lakes to some extent, whereas small inflows may exacerbate problems with water quality and siltation. The processes involved are described in more detail in Section 3.5.5.

3.5.5 Water movement by wind and mixing between nearshore and deeper parts of the lakes.

As exchange between the lake and the ocean is limited for most of the time, other mixing and exchange processes within the lakes become particularly important. The Tuggerah Lakes Study (Inter-Departmental Committee, 1979) noted that natural currents inside the lakes were generally less than 0.3 m/s and generated by winds. Even so, currents which induce mixing inside the lakes are not capable, in isolation, of transporting pollutants out of them, although they do act to reduce any stagnation or "dead" water which may contribute to poor water quality.

Currents generated by tides were limited to the immediate vicinity of the flood tide delta.
With respect to wind driven currents, Hunter (1996) noted that:

1. Horizontally, currents tend to flow in the direction of wind in shallow water and against the wind in deeper water (circulating flows).
2. Vertically, currents tend to flow in the direction of the wind near the surface and against the wind near the bottom (overturning flows).

The currents are qualitatively reproduced by Sanderson (2009) using a three-dimensional hydraulic computer model. Hunter argued that the horizontal circulations dominate wind driven currents in Tuggerah Lakes with a typical circulation time of 12 days. Where currents are generated, their interaction with the bed also generates turbulence which enhances mixing through the water column (vertically). Hunter (1996) calculated that a typical time of vertical mixing is about three hours.

Broadly, Hunter provides a good first order approximation of the importance of mixing processes. The vertical water column in the lake tends to be very well mixed (in the order of three hours) when compared to the horizontal circulations (in the order of 12 days). Similarly, the lake tends to be very well mixed horizontally when compared to exchange with the ocean (320 days, see above).

It has been noted that a build-up of vegetation can create a barrier which severely limits exchange by currents or the effect of other mixing processes such as wind waves. Determination of the magnitude of this effect was referred to as the *"mixing question"* in the 2006 Estuary Management Plan (Dickinson et al., 2006) and was the subject of a subsequent study of the related processes (Brennan et al., 2010).

The effect of these barriers is clearly shown in the top frame of Figure 3-18. The central basin of southern Tuggerah Lake is well mixed by currents that interact with the bed, generating turbidity in the water column. In comparison, there is limited evidence of exchange with the shallow fringing areas. This limited mixing has been witnessed by several members of TLEP. As discussed above, the separation may be alleviated through the actions of large enough catchment floods (particularly if accompanied by strong wind currents and wind waves). Wyong Shire Council (2001b) reported that "flushing times" between the shallow fringing areas and deeper waters were estimated to be around 5 to 10 days, although the source of this estimate is unclear. Even so, these shallow and relatively stagnant areas may respond very quickly to daily temperature and stormwater inflows and while the reported flushing is relatively quick (compared with ocean exchange), it may not be quick enough to prevent water quality problems from arising.

Figure 3-18 Aerial oblique photographs (courtesy Central Coast Council)

The hydrodynamic modelling informing the estuarine modelling effort of Brennan et al. (2010) is detailed in several background reports by Sanderson (including 2009, 2013). Sanderson (2013) attributed the effects of vegetation build up in trapping nutrient-rich waters at the edges of the lakes to:

1. Direct frictional drag of vegetation on currents.
2. Reduction of the wind stress acting on the wind column when vegetative accumulations extend to the surface and absorb some of the wind energy.

Sanderson noted that the second mechanism was unproven but was able to develop a model which provided predictions of 'hot spots' for eutrophication for varying wind speeds and directions.

3.5.6 Movement between the Lakes

The Tuggerah Lakes Study (Inter-Departmental Committee, 1979) noted that connections between the three lakes were constrained. For the most part, however, the changes in water levels such as tides and major floods, happen slowly and tend to propagate relatively quickly to the other lakes (within a few hours). Water levels across all three lakes tend to rise and fall at around the same time.

As described in Section 3.3.4, a deep connection channel was dredged around the northern edge of the Budgewoi sand mass (see Figure 3-18) during the mid-1960s to encourage circulation from Budgewoi Lake to Munmorah Lake to support the operation of Munmorah Power Station.

The power station had four generators with all four operational until 1992, and the remaining two decommissioned in 2012. It extracted water from Munmorah Lake and discharged it to Budgewoi Lake. Through this process, it generated a unidirectional current that flowed northwards along Budgewoi Creek. This current would have been significant in mixing water between Budgewoi and Munmorah Lakes, but has ceased with decommissioning of the power station.

Prior to dredging of the channel around the Budgewoi Sand Mass, the Budgewoi channel was apparently shallow and often closed off, as relayed by Scott (1998):

> "*in the evening we used to dig our way in to Lake Munmorah and in the morning we'd have to dig our way back out. If you got a north east wind it would block it off at the top end. That was deepened when they were building the Power Station. They also deepened from Buff Point all the way round to the channel at Budgewoi; that section was always deep enough for the boats but they deepened it too". (Mick Asquith)*

“When the Power Station was constructed, they dredged a big channel from Buff Pt around to Munmorah Lake. Before that was dredged, we had a job getting into Top Lake from here because there used to be a ford across the channel at Budgewoi, and it only had about 3 inches of water across it.” (Pat Clifford)

When compared to Budgewoi Creek (connecting Munmorah and Budgewoi), which is elongated and narrow, the connection between Tuggerah and Budgewoi is short. Revisiting the wind set-up and seiching event in Tuggerah Lakes introduced in Section 3.4.4, it is interesting to investigate how Budgewoi Lake responded to the same event. This is shown in Figure 3-19 which compares water levels at the recorder in Wallarah Creek. (around 1km upstream from Budgewoi Lake proper) and Toukley. The wind elevated water level at Toukley drives water through to Budgewoi Lake, and the seiche propagates as a (long period) wave across Budgewoi Lake into Wallarah Creek. The water level in Wallarah Creek peaks around an hour later than at Toukley and then falls, exhibiting some of the effects of the seiche felt in Tuggerah Lake.

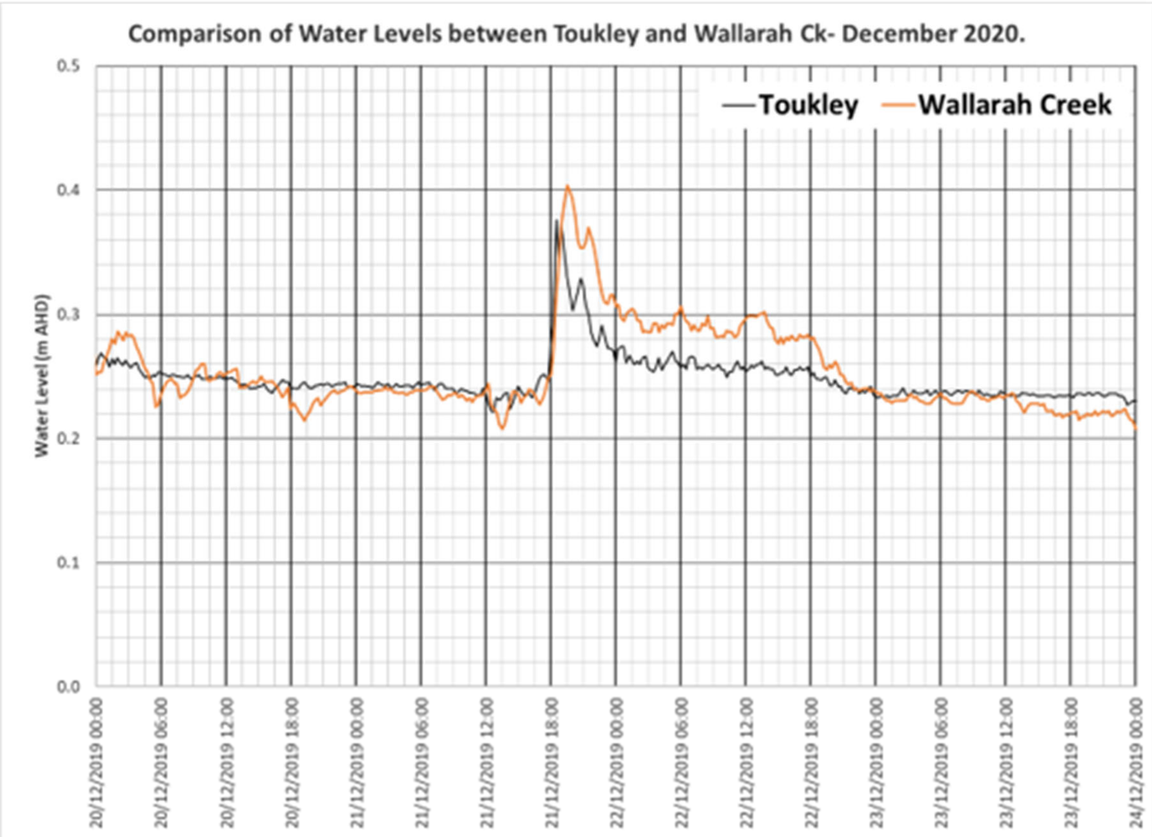


Figure 3-19 Budgewoi Lake response to wind events

There are further local wind effects on the surface of Budgewoi Lake which, combined with the geometry of Wallarah Creek, causes the water level to “pump up” higher than the water level at Toukley. Additional water is forced into the upper reaches of the creek and it takes a while (a further 24 hours or so) before that water level returns to be around the same as that in Tuggerah Lake. A similar effect would also be felt through into Munmorah Lake and the relatively slow drainage of the water forced into the northern reaches of the system also has an impact on water levels as measured at the Toukley recorder.

In summary, the water level interactions between the different lagoons can be complex from time to time, but for the most part the water levels across all three are very similar.

3.6 Potential management options

Key Points
Options for managing the ocean connections to the lakes in a manner which increases flushing to “improve water quality” involve balancing competing values and intervening in a system that is not perfectly understood. Potential costs may be very high and the outcomes will still be uncertain.
Dredging and construction of breakwaters at The Entrance have been studied extensively.
There remain gaps in understanding of the purpose and impact of regular dredging, which has occurred since 1993, particularly due to a lack of follow up interpretation of available monitoring data. Regular dredging has tended to cost Council around $0.7M per year more recently.
Breakwaters have been considered in several reports at different times (Cardno, 2015, 2013a; Inter-Departmental Committee, 1979; Patterson Britton and Partners, 1994, 1988; SMEC, 2011). Overwhelmingly, the findings have not been favourable, primarily due to the high cost, but also due to the unknown side effects and uncertainty about the positive benefits that could arise.
The cost for full training of the entrance with twin rock breakwaters that effectively prevent closure is in the vicinity of $50M.
Typical deepening scenarios considered in the past, alongside training works, are simulated to increase tidal exchange from around 1% for existing ‘normal’ conditions up to 3% for extensive dredging. This would be accompanied by a fall in ‘mean water level’ and, most likely, an increase in the fortnightly variation of water levels experienced inside the estuary. Shallow mudflats around the fringes of the lakes would be exposed more often and for longer periods. Dredging to achieve 3% exchange would cost in the order of $30-50M.
Extensive training works and dredging have the potential to increase salinities inside the lakes by around 5ppt.
Based on the recent experience gained from training Lake Illawarra, a system which is similar in size and shape to Tuggerah Lake, we note that training works are highly likely to have unexpected negative impacts (e.g. runaway scour of the entrance, as has also been recorded at other similar locations in Wallis Lake and Lake Macquarie). The expected ‘water quality’ impacts inside the estuary have generally not been realised. Water has become clearer within the entrance compartment to Lake Illawarra, which is similar in size to that at The Entrance.

Key Points

Structures from sand filled geotextile containers have the potential to be much cheaper than rock structures in some locations. However, the individual containers (up to 2.5 m^3 in size) are limited to relatively low energy locations and aren't generally found on the open coast in NSW. Larger units (approximately 4.5 m^3) have started being used recently in Australia, but there is currently limited evidence of performance or laboratory testing. A single breakwater of limited extent, constructed from stacked geotextile containers either to the north or south of the main tidal channel, has been proposed in the past Such a structure would cost in the vicinity of $1M providing that an experienced contractor can be found to complete the work.

Single breakwaters, whether intended to train the northern or southern side of the exit channel have typically failed to control sand from moving into entrance channels in NSW, particularly when they don't extend well out into the surf zone. A recent example is that of Lake Illawarra in the early 2000's.

A limited, single breakwater to the south of the entrance (argued to prevent the entrance channel from 'perching' on the rock shelf) would do very little to arrest the main process that delivers sand to a closing entrance, the alongshore transport of sand southwards along Dunleith Spit.

Jet Pumps, which sit in a cone shaped depression and are used to pump sand through a discharge line, delivering to an alternative location to protect against erosion, have been considered in the past. Other options involving trapping sand, using machinery to create a slurry from the sand and backpassing the slurry through a discharge pipeline could also be considered, potentially in conjunction with a sand filled geotextile container wall. A similar arrangement has been installed at Winda Woppa Spit by MidCoast Council recently, for a cost of some $4M, costing around $120,000/yr to run. That system, however, is in a more sheltered location and is designed to pass around 10,000 m^3/yr.

The extent of prior attempts to assess a second entrance at Budgewoi seem to have been repeatedly overstated with limited evidence that any real consideration of this option has been made. There is no doubt that this would be an extraordinary intervention to the system with potentially broad impacts, some negative and some positive. The history of such expansive interventions along the New South Wales coast has often resulted in very poor environmental outcomes.

Based on the example of construction of the Dawesville Channel in Western Australia in 1994, a second entrance to the lakes is likely to cost in excess of $100M and is unlikely to be a panacea for the multitude of perceived problems with the estuary.

Key Points
Several less extensive options for introducing some connection between Budgewoi Lake and the ocean have been advanced. These should be investigated in developing the Coastal Management Program for the estuary.
Unless the potential impacts from large scale training and dredging works are understood, acknowledged, and mitigated against, such works at The Entrance cannot be recommended.

3.6.1 Introduction

The different management options that have been considered and discussed in various reports have been categorised here, with findings compared and evaluated. By far, the options that have received the most formal investigation are dredging and/or the construction of various breakwater configurations at The Entrance. Maintenance dredging of The Entrance has been carried out since 1993. Prior to that time, the entrance was typically allowed to close and then artificially opened to relieve flooding around the lakes.

Several options have been put forward for introducing more ocean water directly to Budgewoi Lake, ranging from "Bringing back the Gap" by lowering the barrier between Budgewoi Lake and the Ocean to opening a second entrance. These options have not been investigated and/or reported robustly in the past.

Management options are discussed separately in the following sections. Where possible a preliminary idea of costs involved is presented.

3.6.2 Managed barrier at The Entrance

A 'managed' barrier at the entrance appears to have been the historical approach to addressing flooding in Tuggerah Lakes. While water quality was known to deteriorate, historical accounts point to flooding of low lying properties and homes as being the main driver that would lead either to Council initiating and artificial breach, or residents taking matters into their own hands (Scott, 2002). The community response to the flood in February 2020 can be taken as an example.

The Estuary Management Study (Roberts and Dickinson, 2005) considered the potential option of 'Dune Shaping', whereby the entrance is allowed to close, but the height of the barrier is 'carefully trimmed' to a set level so that the entrance breaches at a controlled level. Underpinning this option is a desire to make the system behave more ‘naturally’. We note that this option was put forward to address the risk of flooding and this issue is strictly beyond the scope being considered by TLEP. Estuary entrances need to be managed by balancing a range of issues including water quality, flood risks and ecological impacts, among others.

Experience with maintaining a ‘notch’ in the barrier at other locations in NSW has proven difficult and becomes even more so if the notch elevation can be easily reached by regular wave runup processes on the beach face. Wave runup is the process by which beach barriers are built and if the notch is to be maintained at a low level, the frequency of maintenance of the level can become impractical. In the case of The Entrance, the notch elevation would be below commonly reached runup levels.

Such a strategy can be augmented by artificial breaching as described above. One result of letting the water level rise before breaching is that the greater amount of water released can scour more sand from the entrance, re-establishing more effective tidal exchange. This accompanies the ‘reset’ that seems to accompany elevated water levels in the lagoon (refer to Section 3.5.4)
We understand that a formal entrance management strategy, aimed at managing flood risk is presently being prepared for Council.

3.6.3 Dredging at The Entrance

In a review of historical management and community involvement, Waddell (2018) noted that:

> *“Over the years, many have proposed that the solution lies in the construction of a permanent, deeper, wider artificial mouth of the southern channel at The Entrance, designed to flush the Tuggerah Lakes of their detritus”*

This is reflected in the number of times different dredging schemes have been assessed, often accompanied by breakwaters, training walls, groynes or “restraining walls” which are described in more detail in the next section.

The Tuggerah Lakes Study (Inter-Departmental Committee, 1979) presented results from hydrodynamic modelling which examined the impact of “deepening the entrance”. The results indicated that tidal amplitude could be increased to around 200mm (from around 20mm) by deepening by 3m. Whether a uniform deepening across the entire tidal delta was simulated is unclear, but it seems likely that was the case. The modelling indicated limited change to tidal velocities and circulation currents beyond the tidal delta. Within the tidal delta, it was argued that the area exposed to ‘dangerous’ tidal velocities (defined as those over 0.8 m/s) could expand upstream to cover a length of 400m along the channel. At the time, a length of around 100m near the entrance was exposed to such currents. Of course, a substantial flood also increases areas exposed to these larger tidal velocities.

The model developed by the NSW Public Works Department for the study was sophisticated for the time but only simulated Tuggerah Lakes, reflecting the limitations on computational capacity in the 1970's.

In approximate terms, the entrance delta has an area of around 2 km^2, and dredging by 3m would involve the removal of some 6 x 10^6 m^3 of sand. In comparison deepening by 1m would involve removing around 2 x 10^6 m^3 of sand. Assuming \$15-25/m^3 this smaller dredging effort would be in the order of \$30-50M but could increase tidal amplitude by around a factor of around 3, based on the numbers presented in the report (reproduced as Figure 3-19). Figure 3-19 indicates that 'normal' water levels in Tuggerah Lake were simulated to fall a few centimetres for a 1m bed deepening, and around 15cm for a 3m bed deepening. Of course, fortnightly variations around a 'normal' water level can be around 20cm for a scoured condition (Figure 3-14).

The Tuggerah Lakes Study noted that major entrance works could result in mud flats which were normally submerged being exposed. This issue has arisen from a scoured entrance during 2020. It has also been experienced persistently at Lake Illawarra, following dredging (and training) of that entrance in 2007, and subsequent runaway scour. In the case of Lake Illawarra, it has been argued that the shallower fringes of Lake Illawarra are more easily disturbed by wind waves and currents and that the lake is now more turbid (Wiecek et al., 2016).

Other impacts inferred from the modelling reported by the Inter-Departmental Committee were that there would be an overall increase in salinity in the lakes and more 'flushing' of the intertidal zone (presumably due to the larger variation in tidal water levels).

Patterson Britton and Partners (1994) wrote that "judicious dredging" of the entrance could help the entrance stay open for much longer periods. At that time, Wyong Shire Council had just commenced regular dredging operations for this purpose. Patterson Britton noted that dredging sometimes needed to be completed at discrete locations with reconfiguration and appropriate adjustments made, as necessary. The dredger employed by Council at the time had been configured to relocate around 60,000 m^3 over a 12-week period. Capital (purchase of the dredger) and ongoing (dredging operations and maintenance of the dredger) costs, inflated to present day, were priced at around \$2M and \$400,000/yr. Periodic and regular dredging of the entrance was also an initiative of the *Tuggerah Lakes Restoration Project* which ran between 1988 and 1993.

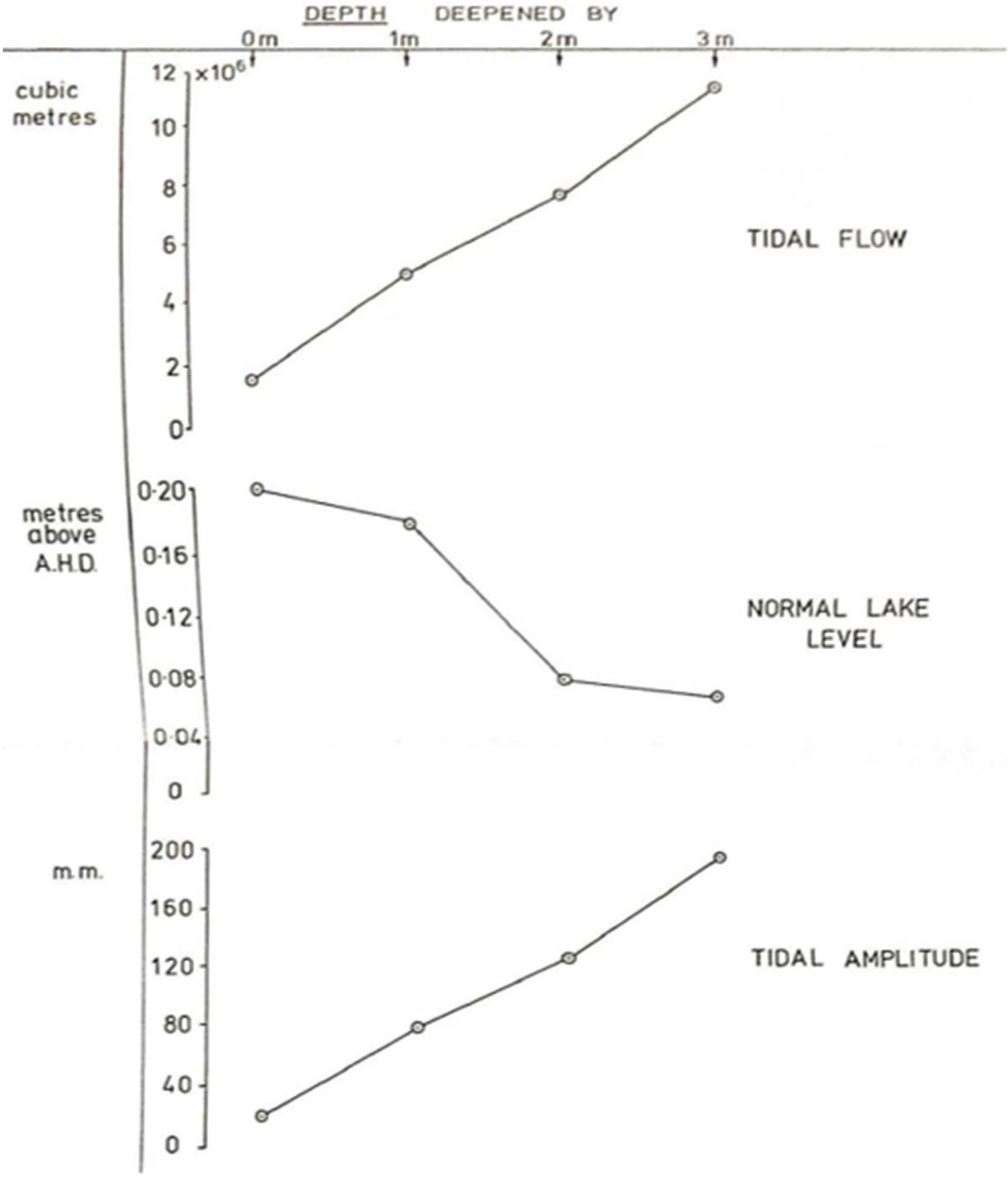


Figure 3-20 Modelled effect of entrance deepening (Inter-Departmental Committee, 1979)

Patterson Britton and Partners were generally supportive of maintenance dredging, noting its flexibility in being able to be relocated to different locations where needed, the ability to plan to avoid peak periods, and that it didn't have a significant impact on the overall sand balance between the coast and entrance compartment. Over time, a few shortcomings in the process have evolved:

- Expertise is required to direct dredging appropriately; this often requires the use of specialised consultants.
- Monitoring of the impact of dredging appears to have been limited. There does not seem to have been a concerted effort to assess the outcomes in terms of reasonably basic responses such as tidal exchange and water level variations.
- Related to the above point, the dredging results in money being spent without a means of showing what has been achieved. If monitoring data can show effectiveness, it can be used to keep the community informed and to justify ongoing expenditure.

Nevertheless, the entrance has been dredged with reasonable regularity since the early 1990's. There have been some historical concerns addressed (from Scott, 1998):

> *The Council currently has a small inadequate dredge. They are dredging the channel because it keeps silting up as it has always done for thousands of years..... They are pumping the sand from the channel, through a pipeline, over to the beach. But the way they are doing it, it will end up back in the surf and then back into the channel! (Allan Whitham)*

While seen as a flaw by some, this is how the strategy was designed. Placement of dredged spoil on the North Entrance Beach was meant to intentionally be to the south of a *"null point"* to ensure that sand was moved in a southerly direction along Dunleith Spit towards the entrance. In this way, the balance of sand circulating from the beach, into the entrance and back out again (either by floods, ebb tides, or dredging) was to be maintained and the overall coastal processes not changed in ways that could have unexpected impacts on the entrance (such as overall recession of the entrance barrier, reactivation of shoals upstream of the bridge).

However, a parallel objective of sand placement has been to provide a store of sand in front of properties threatened by coastal erosion in the vicinity of Hargraves Street and Hutton Road. It is unclear how decisions have been made regarding where sand is placed in relation to that *"null point"*, noting that its location can change from year to year by hundreds of metres. Umwelt (2011) agreed that there was such a null point but that that it should only be considered "as an indicative outcome of longshore movement north and south along the beach, in response to daily changes in wave angle, beach face condition and other factors". In other words, the null point is not fixed, but variable.

In 1999, Lawson and Treloar completed computer simulations of a variety of dredging options, apparently in response to a proposed fast ferry service between Sydney and the Central Coast. The context around the modelling is reported in two letters to Wyong Shire Council dated 15 February and 6 May (Lawson & Treloar, 1999) which presented results based on 1996 and 1993 entrance surveys respectively. The proposed channel was to be 45m wide with deepening as follows:

- Option A: deepened to ~ - 2.5m AHD
- Option B: deepened to ~ - 3.9m AHD
- Option C: deepened to ~ - 4.9m AHD.

Key results were as shown in Table 3-3. They show a varied response, but this can be partly explained by understanding that the entrance had been recently dredged prior to the 1996 survey being undertaken. In that case, the impact on dredging was less pronounced.

Table 3-3 Simulated tidal response to dredging of a 45m channel from entrance to bridge

Scenario	**1993 Bathymetry**		**1996 Bathymetry**	
	Mean Lake WL (m AHD)	Tidal Range (m)	Mean Lake WL (m AHD)	Tidal Range (m)
Base	0.14	0.016	0.17	0.026
-2.5m AHD	0.09	0.041	0.15	0.031
-3.9m AHD	0.09	0.060	0.13	0.033
-4.9m AHD	0.08	0.072	0.12	0.042

Source: Lawson & Treloar (1999)

There are some inconsistencies between the results from the two dates which don't seem to be readily explainable. However, the simulations indicate that most of the expansion of the tidal range caused by dredging results from the lakes being able to drain more efficiently. This indicates that dredging would tend to make low tides in the lake even lower without affecting high tides as much. It may be that the shape of the 1993 bathymetry resulted in the simulated ebb tide drainage of the lakes being particularly efficient, therefore accentuating the low tide more than for the 1996 case.

The Estuary Processes Study (Wyong Shire Council, 2001b) stated that further exploration of the implications of periodic dredging of the tidal delta at The Entrance would be required as part of the subsequent Estuary Management Study. That subsequent study (Roberts and Dickinson, 2005) does provide a few pages describing preceding research. This summary highlighted additional points including:

- Maintenance dredging at the time was normally occurring around September in the lead up to Christmas and costed around $350,000/yr (inflated to 2020 values).
- That ‘clean’ marine water around The Entrance makes the area more attractive to tourism.
- That the amount of flushing delivered by the entrance, based on modelling by van Senden (1997)[1] was ‘questionable’ and limited to the immediate area around the entrance.

Overall, the Estuary Management Study does not really provide much additional information relating to the efficacy of dredging at The Entrance. Surprisingly, given the supposedly ‘questionable’ benefits of entrance dredging, Roberts and Dickinson (2005) did still identify that entrance dredging was a priority. It may be that this recommendation was tied to the alleviation of the effects of flooding in low-lying areas alongside the amenity benefits outlined above. They state that:

> *“The entrance to Tuggerah Lakes is currently kept open by a dredging programme. This is done to minimise the risk of flooding, retain the tourist appeal of The Entrance channel and existing patterns of flushing within the estuary.”*

And that:

> *“A closed entrance would change the water quality in the channel, making it similar to the water quality in the main body of the entrance”*

The implication here is that the entrance dredging is not presently intended to improve water quality in parts of the estuary upstream of the immediate entrance. However, a subsequent review of environmental factors for The Entrance dredging program (WorleyParsons, 2009) surprisingly states that it *“prevents a degradation of water quality in the Tuggerah Lakes”* and that dredging had resulted in a *“reduction in nutrient levels in the estuary taking it from a eutrophic to mesotrophic state”*. Limited evidence seems to be provided for this statement.

As an aside, WMAwater (2014), in preparing a floodplain management plan for Tuggerah Lakes, noted that the REF of Worley Parsons (2009) mentions a reduction in flood risk several times, without providing a quantitative assessment of the supposed benefits while simultaneously stating that dredging is *“not likely to significantly impact peak flood levels in the lake”*. WMAwater was sceptical of the benefits of dredging to flooding, particularly given the lack of any technical study to try and quantify the benefits. They said:

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[1] We have not reviewed this report as part of our study.

> *"In the absence of any technical study, it is considered that the dredging regime will have no negative impacts on flooding but only minor positive benefits (an indicative assessment is less than a 30mm reduction or maybe 6 hours reduction in duration of inundation".*

WMAwater argued that the only benefits to flooding would arise from dredging near the beach berm and that dredging further upstream of the bridge would be of extremely limited value for flooding purposes. However, in discussions with Council staff during preparation of this report, the presence of the rock shelf was noted as a factor making it difficult to dredge close to beach berm in the vicinity of entrance. The overall assessment of WMAwater (2014) on potential flood benefits is sound.

WMAwater also commented that Council needs to be clear with the community on the reasoning behind dredging, including the difference between managing to mitigate against floods, and management for other reasons, such as tourism or ecological benefits. Based on the differing accounts from different sources, the reasoning behind dredging at the entrance is not transparent and this seems, in part, to be due to the absence of monitoring to determine whether the objectives of dredging are being met.

Returning to the Estuary Management Study, Roberts and Dickinson (2005) did recommend that ongoing investigation of physical, chemical and biological processes should be undertaken, including the development of flood, safety and ecological triggers for dredging. It appears that dredging has continued, alongside additional investigations, but that the identification of triggers for dredging has not been given much attention since this time. The Estuary Management Plan (Dickinson et al., 2006) recommended that a "small" amount of additional funds (some $360,000) be set aside to understand the *"positive and negative impacts that the current dredging program may be having"*. This does not seem to have happened.

The Estuary Management Plan refers briefly to an "amplitude model", which is not described in the Plan (nor the preceding Estuary Management Study). A letter appended to a Review of Environmental Factors (REF) for Dredging (WorleyParsons, 2009) sheds some light on this, noting that a *"decision support tool"* based on the "M2 tidal constituent" was available. This tidal constituent represents the major effect that the moon has on tides in the ocean and can also be monitored inside the lake to see how much it is throttled by the entrance. The description provided in the letter appended to the REF indicates that the decision support tool is useful, and that *"it would be useful for council to update, and continue to update, the temporal pattern of the M2 tidal constituent and dredging history…..and review this over time"*. We have not seen evidence that this has occurred and consider it would be useful to pursue the required analysis as tidal response is a key indicator of the degree which the entrance is open at any given time.

Ultimately, Worley Parsons (2009) opined that observations of the entrance conditions were the best decision support tool for the initiation of dredging, and suggested trialling the following 'triggers':

1. The throat [narrowest cross section] of the channel at the entrance reduces to an estimated width of less than 15m measured at mid tide level; and/or
2. The flood tide sand shoals threaten to block the ebb tide dominant channel along the northern/eastern side of the entrance area; and/or
3. The flood tide sand shoals threaten to block the main channel east of the bridge.

Based on discussions with various Council staff members over the course of this investigation, it seems that decision making has been mostly based on the first criterion. No formal records of the monitoring and assessment having being undertaken, nor any attempts to re-evaluate these 'triggers' have been identified. Admittedly, Worley Parsons (2009) did not provide guidance on how the triggers might be re-evaluated.

The Worley Parsons REF does provide a solid summary of the way dredging had been undertaken up to that time. Dredging campaigns typically took around 3-4 months to complete, on an as-needs basis, and involved extraction of around 30,000 to 80,000 m^3 annually. Dredging focused on two channels as illustrated in Figure 3-21, which also shows placement areas, including North Entrance Beach, The Entrance Beach, and a beach along the eastern side of Dunleith Spit. The channel was intentionally directed towards the rock shelf at Karagi Point as this where the entrance channel is naturally forced due to southerly growth of the Spit. Worley Parsons (2009) noted that:

> *"The existence of the rock shelf in fact assists in maintaining the entrance channel open by training the flows on one side"*

Dredging was designed to enhance the ebb tide flow and tended to progress from upstream to downstream. A dredged sump on the eastern side of the bridge was designed to capture sand before it could be transported further upstream as the entrance filled after scouring. The location where dredged sediments are placed was determined based on "visual inspection", although typically the North Entrance Beach was nourished annually and The Entrance Beach every 5 years or so.

During a dredging campaign in 2018, following complaints from the community, the NSW Environment Protection Authority required that dredging operations cease as discoloured water was being discharged to the beach and ocean at North Entrance Beach. A range of additional factors,

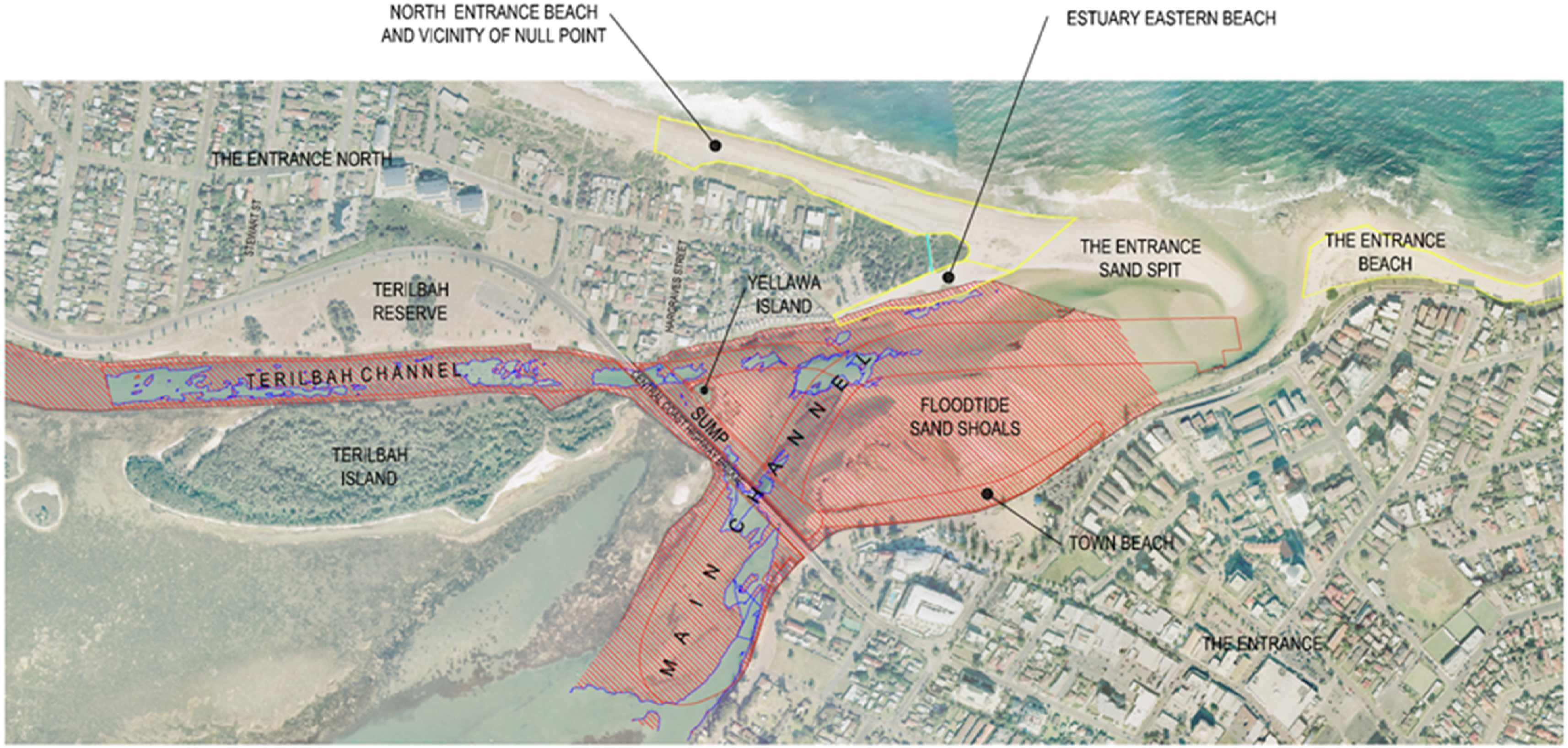

Figure 3-21 Maintenance dredging extents (Worley Parsons, 2009)

including decommissioning of the dredger and an ongoing drought seem to have contributed to the entrance almost completely closing to the ocean after this time.

Umwelt (2011) concluded that the existing dredging strategy was an appropriate interim management action, although they recommended that a water level monitoring station be established at The Entrance. Umwelt also highlighted that the volume of sand dredged is a small fraction of that which can be scoured from the entrance in occasional major floods. The dredging effort at the entrance was dwarfed by the amount of sand scoured from the entrance during the February 2020 flood.

GHD (2019) reviewed the dredging program and their report tabulates the dredging campaigns that had been undertaken since 1993. The report shows that dredging tended to occur annually before 2008, but then was reduced, with campaigns in 2010, 2012, 2015 and 2018. GHD claimed that the reduction in frequency was due to a recommendation of the REF (WorleyParsons, 2009) to undertake less frequent dredging operations and remove more material during each campaign. We have been unable to locate any such recommendation in the REF, which is worded as if the works were to continue as required, based on the three triggers outlined above. It may be that those triggers resulted in less frequent dredging but, as noted above, there seem to have been no attempts to evaluate those triggers – something which could have been completed alongside monitoring of the efficacy of dredging.

GHD's analysis found that operations were costing around $650,000/yr, with an additional $60,000 for maintenance. The order to stop dredging by the NSW Environment Protection Authority in 2018 led GHD to conclude that, with the ocean discharge of return waters being deemed unacceptable, the beach nourishment operations would become unfeasible. Council's dredger was subsequently decommissioned, and the most recent dredging campaign (second half of 2020) was carried out by an external contractor.

3.6.4 Breakwaters at The Entrance

Within the Tuggerah Lakes Study (Inter-Departmental Committee, 1979), it was argued that any benefits from breakwaters at the entrance would be accompanied by considerable environmental disturbance, noting that the:

> *"financial and environmental cost of permanent, "hard", training works appears to greatly exceed the benefits from such a construction program. Major entrance works are not recommended"*

In 1988, following an investigation into the feasibility of jet pumps (described in Section 3.6.5), a further investigation was completed into the construction of a complementary ‘restraining wall’ from sand filled geotextile tubes (Patterson Britton and Partners, 1988). During the early 1980’s the entrance had seemingly been increasingly prone to closure. The restraining wall concept is presented in Figure 3-22. The geotextile tubes were seen by Wyong Shire Council as being a ‘softer’ and more aesthetically pleasing than rock and estimated to have a service life of some 10 to 15 years. It is also argued, even today, that if a sand filled geotextile structure doesn’t perform its function, the ‘bags’ or ‘tubes’ can be easily removed. This may be true in a physical sense, but it is our experience that authorities have been reticent to remove failing geotextile sandbag walls. A more common outcome seems to be to ‘double down’ and try to bolster or modify the structure.

Sand filled geotextile containers do have several benefits:

- lower cost, particularly if an experienced contractor can be engaged to do the work
- less likely to cause lacerations and more easily trafficable (except where fouling by marine growth and ‘slime’ may cause slipperiness)
- improved geotextiles now have more resistance to vandalism (although they can seemingly be damaged by flame)
- substantial reduction in the number of truck movements required to deliver materials to site (when compared to a more traditional rock-based structure).

At the time of the 1988 report, the structure was estimated to have a capital cost of some $580,000 (which inflates to approximately $1.4M equivalent in 2020) and maintenance cost of around $7,000/yr ($20,000/yr inflated to 2020). There has been substantial experience gained in Australia over the past 30 years with sand filled geotextile containers, alongside improved materials. It’s likely that the cost today would be closer to around $1M. Patterson Britton and Partners’ report states:

> *“Construction of the wall by itself is an appropriate entrance management strategy, as it is anticipated that by restraining the channel from migrating south over the rock reef, the condition of the entrance channel will be improved”*

The statement is surprising, as a subsequent report by the same authors (Patterson Britton and Partners, 1994), considers experience gained at several entrances in NSW, noting that:

> *“Irrespective of whether the walls have been placed updrift or downdrift of the estuary mouth, the walls have trapped littoral deposits and the entrance bar is generally shallow, very mobile and treacherous to navigate.”*

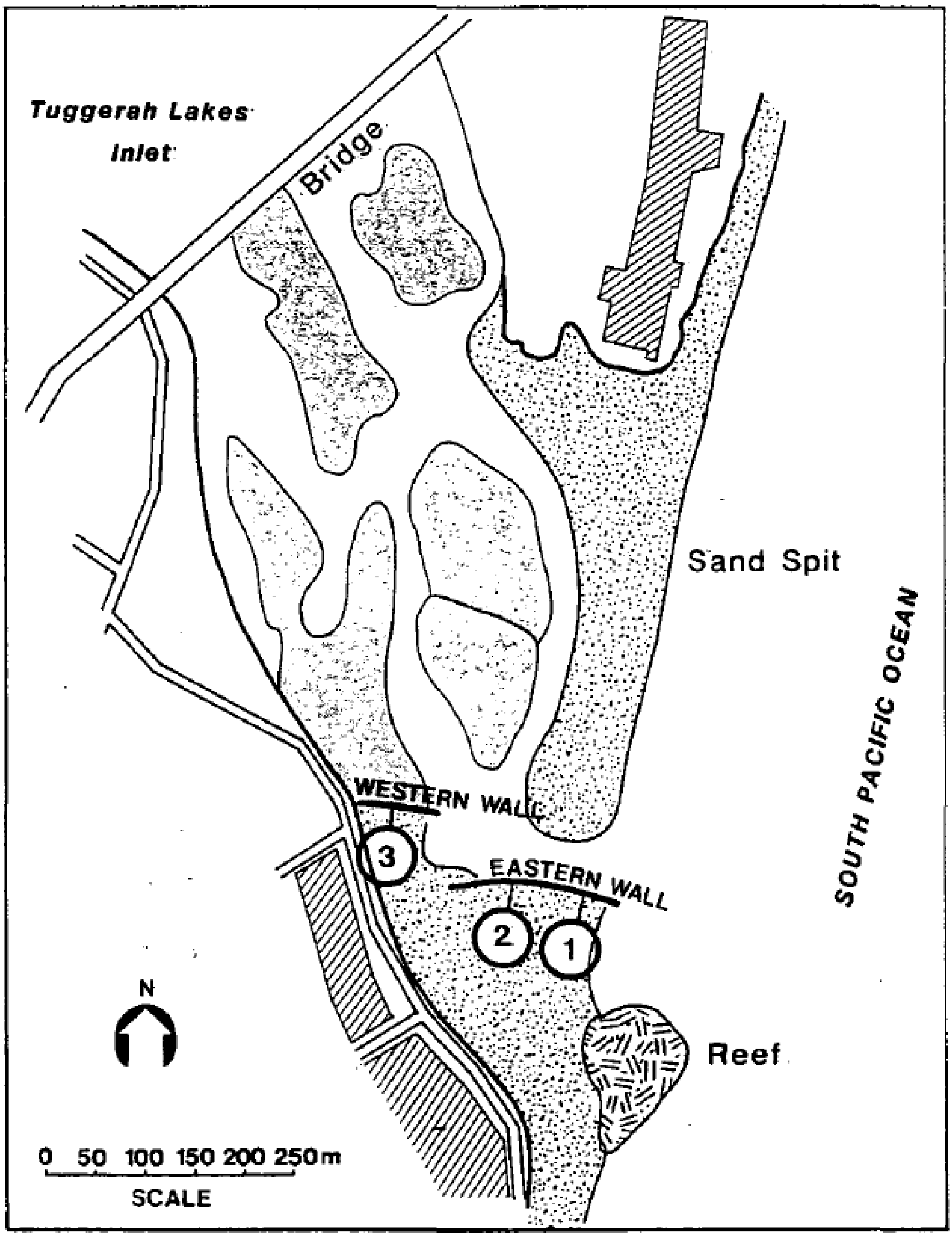

Figure 3-22 Restraining wall concept (Patterson Britton 1988)

The argument provided is that when the entrance perches on the rock shelf, tidal flows weaken and thus allow the entrance to block. It is argued that training the flows is more efficient and scour is encouraged. However, the discussion of the rock shelf, presented in Section 3.4.1, based partly on the inspection of aerial and satellite imagery of the entrance, concludes that the rock shelf is more likely to provide a stabilising effect on the location of the entrance ebb tide jet. Once the entrance has moved this far south, it is already prone to closure from a variety of processes, including closure via littoral transport further inside the entrance (say, in the vicinity of Fairport Avenue).

More recently, attempts to train the entrance to Lake Illawarra with a single training wall in the late 1990's and early 2000's failed. Lake Illawarra is an ICOLL located south of Wollongong which bears remarkable similarities to Tuggerah Lake and its entrance. Figure 3-23 illustrates the initial attempt at building a single southern breakwater and associated tombolo at Lake Illawarra, which was designed to stabilise the entrance to the north of Windang Island and to provide an entrance which was efficiently scoured by the tides, avoiding closure. Within a few years the entrance was already showing a tendency to close. Subsequently, the entrance was more comprehensively trained with twin breakwaters. Failure of the initially proposed entrance stabilisation works were followed by substantial public pressure to spend further and "do the job properly". We note that this training has reportedly not eliminated the growth and accumulation of algae in areas distant from the entrance to Lake Illawarra[2], nor improved water quality to the extent originally expected.

The key function of training walls is to force the bar at the entrance far enough seawards and to stop littoral drift from getting into the entrance. While the above quotation from Patterson Britton and Partners (1994) is presented in the context of navigation, it is clear that a single restraining wall to the south of the entrance will not alter the processes which contribute to wave-stirred sand being carried into the entrance on a flood tide from both the ebb tide shoal (entrance bar) and through alongshore transport from the north along Dunleith Spit. A close read of the two Patterson Britton and Partners' reports (1994, 1988) indicates that the single, relatively short training wall (aka 'restraining wall') option was expected to accompany the installation of jet pumps, which are described in Section 3.6.5.

Whether a restraining wall would have any detectable effect is very difficult to say. However, based on the schematics presented in reports dealing with this option, it is likely that the structure would need to extend much further seaward and into deeper water than shown to be effective at pushing the ebb tide shoal far enough offshore to arrest any entrance closure event.

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[2] https://www.illawarramercury.com.au/story/421875/blooming-weed-chokes-lake-illawarra/, accessed 1 November, 2020.

9/04/2002, Post construction of initial training works and tombolo

9/04/2006, Exactly 4 years later, showing closure by a continuous barrier and evidence of some wave overtopping. The wave overtopping process is the means whereby the barrier builds and is one of the final stages of complete closure of an ICOLL to the ocean.

Figure 3-23 Initial attempts to train Lake Illawarra

The key function of training walls is to force the bar at the entrance far enough seawards and to stop littoral drift from getting into the entrance. While the above quotation from Patterson Britton and Partners (1994) is presented in the context of navigation, it is clear that a single restraining wall to the south of the entrance will not alter the processes which contribute to wave-stirred sand being carried into the entrance on a flood tide from both the ebb tide shoal (entrance bar) and through alongshore transport from the north along Dunleith Spit. A close read of the two Patterson Britton and Partners' reports (1994, 1988) indicates that the single, relatively short training wall (aka 'restraining wall') option was expected to accompany the installation of jet pumps, which are described in Section 3.6.5.

Whether a restraining wall would have any detectable effect is very difficult to say. However, based on the schematics presented in reports dealing with this option, it is likely that the structure would need to extend much further seaward and into deeper water than shown to be effective at pushing the ebb tide shoal far enough offshore to arrest any entrance closure event.

A longer and deeper structure, aside from being more expensive, exposes the filled geotextile bags to larger wave forces. With enough distance offshore (and resulting depth), the units most used in the Australian market (approximately 2.5 m^3 in size) become exposed to wave breaking forces that exceed their capacity to remain stable. We note that larger units (around 4.5 m^3) have recently been applied in Australia, but that experience is limited.

Furthermore, a longer structure, depending on its arrangement and alignment would not necessarily protect the entrance from closure at the throat, which can be forced by southward littoral drift along Dunleith Spit. Patterson Britton and Partners (1988) even noted this, stating:

> *"A significant mechanism for closure of the channel following flood scour is an alongshore supply of sand from the north, hence locating the channel further south may assist in achieving a more permanent entrance."*

This suggests the expected relative ineffectiveness of a single restraining wall to prevent closure from alongshore drift in isolation (i.e. without jet pumps).

SMEC (2011) provided a preliminary assessment of the option of providing a single training wall on the "northern" side of the Entrance. The purpose here would be to limit the movement of sand southwards along the North Entrance Beach, intercepting that sand and preventing it from forcing closure. SMEC argued that, presumably if designed and constructed robustly, this would create a strong ebb jet that would force the ebb tide shoal offshore.

As a result, sand deposited on the shoals inside the entrance would be greatly reduced, although the increased tidal currents would likely reactivate areas of the tidal delta further upstream. The additional scour would increase the tidal range and prism and the possibly initiate runaway scour requiring extensive foreshore protection works further inside the entrance compartment, as has happened at Lake Macquarie and Lake Illawarra. This would need to be acknowledged and planned for, including accounting for the likely costs of future works. A training wall would be required to extend upstream along the entrance channel to the bridge to prevent breakthrough of the Dunleith Spit during a large flood event.

As has been experienced at many other trained entrances in NSW, a fillet of sand would accumulate on the northern side of a northern breakwater, and it is important for the break wall to extend far enough into the ocean to prevent sand from being washed around the end. The further into the ocean the breakwater extends, the more likely it is that it could effectively trap sand.

Patterson Britton & Partners (1994) also considered a broader array of entrance training wall options, beyond a single 'restraining' wall, although their conclusions were based on 'broad experience' at other sites. They noted that considerable site-specific coastal processes and geotechnical data are needed to properly investigate options and that modifications to the entrance would need to consider changes in the overall character of the entrance, claiming that its 'natural state', comprising shifting and extensive shallows and shoals, is of particular importance to the local community. Construction of a deep, permanent channel will exclude the possibility for community members to wade from one side of the entrance to the other.

Extensive training walls have been requested by some sections of the community for at least the last 50 years. For example (from Scott, 1998):

> *"The next step I would take is to build Breakwalls where the channel is on the southside and another to the Northeast, 300 metres long to hold back the sand. My ideas would result in a clean healthy lake with a minimum of dredging as is the case with Wallis Lake and coastal tidal rivers such as the Hastings and Manning." (Arthur Clouten's diary)*

This view, particularly the comparison to other estuaries that have been trained in NSW, has been expressed during community consultation undertaken by TLEP and there are a couple of things worth noting. The Tuggerah Lakes estuary is fundamentally different hydraulically from coastal rivers such as the Hastings or the Manning (or the Clarence, Tweed, or Brunswick). To provide a fair comparison, similar coastal lake systems that have been trained, such as Wallis, Macquarie, Illawarra and Wagonga can be examined.

Patterson Britton & Partners (1994) noted that effective training walls, whether to prevent littoral drift from getting into the entrance, or to create a navigable entrance would need to extend beyond the surf zone present during storm conditions. They estimated that training walls would need to extend to a bathymetric contour which is around 2.0 to 3.0m below lowest tide levels. Using available recent hydro-survey data, this could be around 200m offshore of the rock platform at Karagi Pt. Patterson Britton argued that, when internal training walls are also considered, structures of around 500m long would be required. By limiting spacing of the training walls to 100 to 130m ebb tide flows are able to scour efficiently and maintain the ebb tide shoal (or 'entrance bar') at a reasonable depth and distance offshore of the beach to appropriately minimise the amount of sand coming in to the entrance.

Patterson Britton indicated that the impact on lake levels, due to widening and deepening of the entrance would be quite noticeable, even initially. However, this is at odds with modelling which has been undertaken subsequently. Deepening throughout the entrance compartment would be required to have a noticeable impact, and it is unlikely that this would compare, for example, to the impact of the February 2020 flood and follow up events, as discussed in Section 3.6.4 and illustrated in Figure 3-13 through to Figure 3-16.

Patterson Britton also noted that construction of training walls would result in a loss of the 'flexibility' which is otherwise present during natural conditions, or during management by dredging as and where required. To be reliable and robust, the entrance training walls must constrain all flows to occur between the walls. This means that the catchment flood flows would also be constrained to the 100 to 130m gap between training walls and the entrance would not be able to scour to widths of 300 to 400m as would occur naturally during a flood. It is likely that this would have some impact on flood levels, but subsequent work by Cardno (2013a) indicate that this would be reasonably small.

A further issue with substantial rock structures is the disruption caused by truck movements (estimated to be between 10,000 and 20,000 movements over 12 to 18 months). Igneous rock is required by the current Australian Standard and the closest sources for this rock are quarries to the west of Port Stephens. Capital cost for full training works was estimated by Patterson Britton and Partners at around $40M (inflated to 2020 values), with a need for maintenance works of around $2-3M every 10 years (also inflated). If dredging of the entrance were included in the management strategy, comparable capital and ongoing costs would be $56M and $3-5M every 10 years.

Finally, Patterson Britton and Partners noted that, in conjunction with a reduction of sand moving from the ocean into the entrance, the additional tidal currents inside the entrance would gradually begin to scour the shoals inside the entrance, and due to differences between the flood and ebb tide stages, that sand would be carried upstream, eventually reactivating the tidal delta upstream of the bridge and resulting in sand being deposited at a ‘drop over’ into the deeper part of the lake. The development of ‘unstable scouring’ has been witnessed at several comparable coastal lakes along the NSW following training, including Wallis Lake, Lake Macquarie, and Wagonga Inlet. Perhaps most dramatically, it has also occurred at Lake Illawarra since full training in 2007.

The Estuary Management Study (Roberts and Dickinson, 2005) highlighted that any training walls constructed would need to be maintained by the owners, and that responsibility could fall on the State and/or Council. Ongoing dredging is still likely to be required and they estimate around $100,000/yr would still be require (around $130,000 inflated to today’s values). They also noted that increased tidal flows could lead to greater erosion. They did, however, see potential benefits relating to ocean related tourism and recreation, and some additional marine water exchange, although they expected this to be insignificant.

Umwelt (2011) concluded, following a review of background information that:

> *“Council should not construct training walls at The Entrance. None of the investigations to date indicated that construction of training walls would benefit the lake or North Entrance Beach. High volume dredging, removing the berm and driving the lake entrance to a permanently wide open condition is also not supported. Enhanced wave penetration into the estuary and increased lake water levels, now and as sea level rises, both have significant risks for lake ecology and flooding”*

Importantly, opening the entrance widely exposes areas inside to greater risks from ocean water levels (affected by storms, sea level rise and other processes). With ongoing sea level rise. Umwelt (2011) stated that, if the entrance were extensively widened (approximately 250m), so as to reduce peak 1% AEP flood events, this would have significant shortcomings:

- the requirement for either costly ongoing dredging or breakwall construction
- unknown effects on the environment, including lower overall water levels and the exposure of shallow mud flats
- no improvements to recreational boating in the lakes
- major scouring of entrance shoals, high velocity tidal currents and the possibility (even likelihood) of undermining the road bridge.

In subsequent, detailed modelling studies, Cardno (2015, 2013a, 2013b) considered a range of different entrance configurations including:

- existing case

- a single training wall to the north of the rock platform
- twin training walls spaced at 100, 150 and 200m.

The model used is representative of the type of model that is presently applied in practice in NSW. The model files were obtained and inspected as part of our review. The model could be upgraded/adapted for use in further investigations as required.

Cardno simulated the impact different structure configurations would have on a 1% AEP flood, including the simulation of scour from the bed of the entrance (down to the underlying bed rock). The scenario with 100m wide training walls caused an increase in the peak flood level of around 8cm, and those water levels remained elevated for several days longer than other scenarios. The 100m option was subsequently disregarded. The other options had minimal effect on peak flood levels.

The 150m and 200m wide entrance simulations were continued for a period of six weeks to examine how sand movements might be affected. It was assessed that the entrance would not continue to self-scour and would continue to shoal. This indicates that maintenance dredging would need to continue, even if the entrance were trained.

However, this is dependent on the conditions that follow a flood event, which can affect how long the entrance stays open, as seen following the recent February 2020 flood. The rate at which sand washes back into the entrance is also affected by the length of the training walls, and this was not varied in the simulations. If the structure protrudes further into the ocean, the chance that sand will be washed around the end of the structure is reduced.

Cardno (2013a) also completed water quality simulations to investigate the effects of training walls and a more 'open entrance' on flushing capacity inside the lakes. To do this, they took the scoured bathymetry which existed at the end of the flood simulation and 'fixed' it at that configuration before executing a 13-month simulation with morphology (simulation of sand movement and shoal migration) switched off.

There are practical reasons for this. Morphological simulations are complex, sensitive, and often subject to interpretation. Leaving morphological updates switched on can add significantly to the amount of time the computer simulations take to complete, particularly when they extend out to year long time scales.

The results of leaving the morphology switched off is that the entrance was simulated as remaining open for an abnormally long period of time. In reality, sand would tend to wash back in between the breakwaters and shoal up the entrance. Cardno argued that *"these simulations represent unrealistic 'Best Case' scenarios"*, with the implication that the modelling accentuates any positive impact that could be expected in flushing the Lakes. Cardno subsequently found that all the entrance training wall cases *"would lead to virtually no change in lake water quality"*.

However, there is an apparent bias that has been introduced in Cardno's approach. One role of a traditional breakwater is to prevent sand from being washed back into the entrance and, if designed sensibly, they should help to keep the entrance open. By fixing not only the bathymetry of the simulations including breakwaters, but also the bathymetry of the 'base case' (existing conditions), it appears that they have not accounted for the increased tendency of the entrance to shoal up under existing conditions (beyond 4 days after the peak of the flood, when the bathymetry was 'fixed'). The modelling and subsequent interpretation seems to have downplayed the impact that a more rapidly closing entrance for the base case tends to have on throttling tidal exchange.

In other words, while the training wall simulations may show unrealistically good flushing behaviour, the same (even more so) can seemingly be said for the 'base case' simulations. This would tend to reduce the apparent positive impact of training wall scenarios. In fact, Cardno stated in their report that the existing condition has the deepest post-scour channel.

The long-term morphological behaviour of the entrance is of further interest. It has been well established that entrance training walls tend to result in runaway entrance scour of large coastal lakes and lagoons in NSW (Nielsen and Gordon, 2008; Wiecek et al., 2016). Neither Cardno, nor any other researchers have modelled this behaviour although the model system used by Cardno, Delft3D, does have capabilities in this regard.

Cardno undertook subsequent modelling at the request of Wyong Shire Council (Cardno, 2015). In this case, they limited the simulations to examine what would happen if a channel navigable for small vessels were created. To do this, the rock shelf below the entrance would need to be excavated. This would doubtless be very expensive, but the question of costs was not assessed by Cardno in their report as this was seemingly excluded from their scope of works.

Simulations were completed with the rock shelf either retained or removed to - 1.5, - 2.5, - 4.0 or - 5.5m AHD. The simulations were executed for both trained and untrained entrances. The key findings were:

- that dredged channels would begin to fill immediately from both the upstream and downstream ends

- the rate of time to infill from downstream is slowed by the training walls.

One aspect that seems to be missing from this set of analyses is how much the training walls would need to be lengthened to achieve a stable entrance. The rate at which the channel between the breakwalls tends to fill indicates that they do not protrude far enough into the ocean to achieve their design objectives. Of course, longer breakwaters require more money to be spent.

Regarding water quality, Cardno (2015) found:

- that if dredged channels were also incorporated, this would increase tidal exchange and increase lake salinity
- dredging in the simulations was limited to the area downstream of the bridge, so the tidal delta shoals upstream of the bridge still presented a tidal constriction. For this reason, tidal benefits diminished with dredging below - 2.5m AHD
- the dredged channel schemes would decrease mean lake level by up to 10-20cm

The 'fixed bed' simulations completed by Cardno (2015) did not, apparently, have the same issue of bias present in their 2013 modelling study. Impacts of the removal of rock to a depth of up to - 2.5m AHD included:

- an increasing in the tidal prism by a factor of 3 to 4
- an increase in typical lake salinity by around 5 ppt.

Beyond dredging to - 2.5m AHD, the changes are relatively insignificant.

A third report by Cardno (2013b) examined a range of works around the entrance, but these were primarily assessed on their ability to provide benefits to the beaches north and south of the entrance. Cardno did, however, provide cost estimates for two training options of interest:

1. a substantial "northern training wall" and training wall around the inside of Dunleith Point. A total of some $31M capital cost was estimated with an ongoing need to nourish South Entrance Beach (around $50,000/yr, undertaken maybe once per five years). It was estimated that around 8,000 truck movements would be required to transport the rock to site.
2. a fully trained entrance which added a southern training wall to Option 1, resulting in a capital cost of some $45M, including initial nourishment of South Entrance Beach.

These options do not consider the potential need to dredge between the breakwaters and additional cost would need to be factored in to deepen the channel and get any benefit from additional tidal exchange. This would most likely involve removing rock.

3.6.5 Jet pumping at The Entrance

At the request of Wyong Shire Council, jet pumping, which was a relatively new technology at the time, was investigated as a means of keeping a permanently open tidal entrance to the lakes (Public Works Department, 1987). Council's desire was then driven partly for the following reasons:

> *"to increase tidal flushing in an effort to improve water quality"*
>
> *"to provide as pleasant and environment as possible for its residents and to attract tourists and tourism related development"*
>
> *"to reduce the need for artificial opening with the attendant complaints and criticisms that are raised when the entrance closes".*

At the time, Council did not support extensive training works due to the cost, aesthetic impact (including loss of sandy shoals) and inflexibility of the works.

The option works by installing jets at the bottom of a series of craters in the sediment, with an onshore pump forcing water through the jet nozzles to stir up sediment and suck it into an outlet pipe, from where it is pumped elsewhere as a slurry, typically for beneficial reuse (i.e. to prevent erosion). The effectiveness is dependent on the installed jets being able to maintain the craters. The depth and number of jets required depends on the depth at which the bed is to be lowered and the extent of required bed drawdown.

At the time, there were several identified shortcomings with jet pumping:

1. Blockage with kelp or other neutrally buoyant materials and resultant safety issues with clearance operations. Perhaps of more concern though is denser material such as rocks, bricks and other rubbish which settle in the base of the crater but can't be passed through to the discharge line. Ultimately, it is likely that cranes would be required to remove the jet pumps to enable maintenance and maintenance could be required many times per annum.
2. Uncertainty about the location/depth of the rock shelf and concern about whether the jet pumps could be installed at the required depth without having to excavate rock.
3. Wear of the jet nozzles.

The costs estimated by the Public Works Department for installation and maintenance (approximately inflated to 2020 values) were $2M and $130,000/yr.

Since the 1987 report, additional experience has been gained in Australia with jet pump technology, including several decades of the Nerang River bypassing system on the Gold Coast and operation of the Tweed River Sand Bypassing system since the late 1990's. Various bypassing and back-passing systems are operational around Australia and several of the problems indicated in the Public Works Department Report have been overcome. A back-passing system has recently been installed by MidCoast Council at a more sheltered location inside Port Stephens. Capital costs of $4M and ongoing costs of around $120,000/yr are involved in passing around $10,000 m^3/yr.

Ultimately, the Public Works Department study found that jet pumps, in isolation, would not be able to maintain the location of the untrained tidal inlet. They indicated that a restraining wall would be required to fix the channel location. It was argued that a mobile dredger could provide the same functionality, but without the inflexibility. This has not fundamentally changed in the past few decades.

The findings triggered a subsequent investigation into construction of a "Restraining Wall" to hold the entrance channel in place. (Patterson Britton and Partners, 1988), which has been described in Section 3.6.4.

3.6.6 Second entrance at Budgewoi

The Tuggerah Lakes Study (Inter-Departmental Committee, 1979) reported that mathematical modelling of an ocean outlet at Budgewoi Lake would have the same effect (on flood levels) as increasing flow through The Entrance by the same quantity. It is difficult to understand how this was achieved, as the model did not include a complete representation of Budgewoi Lake. However, as part of that study, it was concluded:

> *"Because of the technical problem of adequately by-passing littoral drift sand past an outlet channel in the middle of a long exposed beach, such as Lakes Beach and because of the huge capital cost of providing and additional ocean outlet, further investigation of this proposal is not considered necessary".*

While there have been improvements in some of the technology surrounding sand by-passing and in the understanding of coastal processes, these technical and cost obstacles still exist.

The Estuary Processes Study (Wyong Shire Council, 2001b) stated that the practical implications of a second entrance to alter estuarine mixing and flushing would require further exploration. The Estuary Management Study (Roberts and Dickinson, 2005) provided around a page of text regarding this matter and claimed that modelling by Walkerden and Gilmour (1996) had *"clearly demonstrated that a second entrance situation in Budgewoi Lake would not result in any major benefits to its water quality and, in fact, there could be major ecological impacts"*

"The AEAM project was used to model these scenarios and found that these options would not have the desired 'flushing' effects"

This misrepresents what Walkerden and Gilmour (1996) had to say about the second entrance, a few examples of which are:

[the following is a description of uncertainty associated with a second entrance, Table 9 of the report*] "There are substantial uncertainties around the impact of major entrance changes on the system. Experience elsewhere has shown that even after major engineering studies there is still a relatively high probability of the hydrodynamic system performing in unexpected ways. The ecological impacts are much more difficult to quantify, with precision, than hydrodynamic impacts, although major shifts in abundance of differing species are likely if the Lakes become much more tightly integrated with the ocean."*

"Some management proposals are likely to have large impacts which are difficult to predict in detail (e.g. constructing a second entrance) so they should be approached with considerable caution"
"If the judgment is that catchment changes will flow through too slowly and/or will be too modest, then the options available are major flushing changes:.creation of a second entrance"

"Areas where research programs should be developed include: ……an investigation of the flushing characteristics under a variety of environmental conditions be undertaken. This would help throw further light on….the potential impacts of a second entrance"

Therefore, Walkerden and Gilmour (1996) mainly expressed uncertainty about the impacts of a second entrance, with an implication that those impacts would be significant. Indeed, the models ultimately developed by the AEAM project (Walkerden and Gilmour, 1996) would not have been capable of properly assessing the hydraulic and mixing characteristics of a second entrance to any reasonable degree.

The Estuary Management Study (Roberts and Dickinson, 2005) claims that *"The construction of a second entrance to the lakes would only have a limited (near-field) effect with regard to improving water quality"*, which does not seem to have been backed up by any modelling and seems to contradict the potential *"major shifts"* in ecological impact that were indicated as possible by Walkerden and Gilmour.

It can only be concluded that the Estuary Management Study did not really consider a second entrance as required by the Estuary Processes Study in any robust manner. The Estuary Management Study does note that, following construction of a second entrance at Budgewoi, *“There would not be a circulation current established as has been popularly touted in the past”.* This is most likely, essentially correct, but as far as we can determine, this was not supported by any modelling or analysis. They do note, however that the entrance would need to be cut through a sensitive area containing saltmarsh and wetlands in the near vicinity of coastal wetlands and an important habitat for migratory waders. Roberts and Dickinson (2005) concluded that the option of a second entrance should be given a low priority.

A second entrance to the Lakes at Budgewoi has long been promoted by the community as a potential solution to water quality issues within the Tuggerah Lakes estuary (mentioned in interviews dating from the early 1960’s in Inter-Departmental Committee, 1979). The Dawesville Channel, which was constructed in 1994 as a second entrance to the Peel-Harvey Estuary, some 80 km south of Perth, is often put forward as an example of the benefits that would flow from a second entrance.

The Peel-Harvey Estuary is around 135 km^2 in size, with an average depth of 0.5m. Historically, the estuary had a single connection to the ocean, an approximately 5 km long channel that flows to the ocean at Mandurah.

Due to the excessive use of fertilizers by agriculture in the catchment, the water quality was severely degraded by the 1980’s, with “hypereutrophic” conditions and “extreme” algal blooms (Valesini et al., 2019) experienced. Based on these accounts, it seems the health of the estuary was substantially worse than has yet been experienced in Tuggerah Lakes and it subsequently became a political issue. A variety of catchment-based solutions were trialled in the lead up to the decision being made to construct the second channel into the estuary. Valesini et al. (2019) noted that:

> *“In concert with State elections in the early to mid-1980’s, rising public frustration at feeling left out of decision-making and the slow response in “fixing” the problems, large-scale engineering projects were conceived. That which gained most momentum was the Dawesville cut, a 2.5km long, 200m wide and 4.5-6.5m deep channel connecting the northern Harvey Estuary with the sea to increase tidal flushing”.*

The reported cost of the channel and associated works was around $64M[3] (inflates to around $110M in 2020). The works included a sand bypassing system which comprises pipelines installed underneath the constructed channel and a sand trap. Alongshore drift is captured by the sand trap and intermittently excavated using standard earthmoving equipment. From there, sand is fed into a mobile screening and bypassing plant which creates the slurry that is pumped through the pipelines underneath the channel.

An important difference between the Peel Harvey Estuary and Tuggerah Lakes is that rainfall along the south western coast of Western Australia is seasonal, with minimal rainfall occurring during summer months. Furthermore, the catchment soils are very sandy and less able to absorb nutrients. Therefore, the catchment seems to have more readily exported nutrients to the estuary, resulting in the reported hyper-eutrophication. Prior to construction of the Dawesville Channel hypersaline conditions tended to develop further from the ocean entrance during summer, and fresher conditions occurred during winter.

Construction of the Dawesville Channel caused the following:

- Approximate tripling of the tidal range (and tidal exchange).
- A notable increase in winter salinities.
- An increase in periods of stratification in the main basin (accompanied deoxygenated water at the bed).
- A rapid fall in nutrient concentrations in the water column (indicative of improved flushing of the estuary), but not in the underlying sediments.

Interpreting the response of the estuary to construction of the Dawesville Channel is difficult as there has been a well-documented, climate change driven decrease in rainfall in the area during the past few decades.

It is acknowledged that eutrophication still occurs in the downstream reaches of tributaries that feed the main bodies of water that comprise the Peel Harvey Estuary, i.e. further away from the Channel. The response to the Dawesville Cut has not been universally positive and the community continues to have problems in the estuary[4,5]

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3 https://www.parliament.wa.gov.au/Hansard/hansard1870to1995.nsf/83cc4ce93b5d4e0b48257b33001cfef6/8E848A1AED7ED8D248257B550008E384/$File/19940407_Assembly.pdf, accessed 31/10/2020.

4 https://thewest.com.au/news/wa/peel-harvey-estuary-a-toxic-mess-ng-ya-355786, accessed 31/10/2020

5 https://www.mandurahmail.com.au/story/6462410/getting-worse-bouvard-resident-calls-for-action-as-seaweed-builds-up-on-estuary-edges/, accessed 31/10/2020

3.6.7 Other types of connections to Budgewoi Lake

Parts of the community have been interested in some connection between the ocean and Budgewoi Lake for many decades. Noting the potential expense of a full ocean connection with sand bypassing, several cheaper and less expansive alternatives for more limited exchange between Budgewoi Lake and the ocean have been advanced by the community.

These have not been considered in detail here, but an initial, qualitative assessment has been made. There is merit in providing a more formal investigation as part of development of the forthcoming Coastal Management Program. In some instances, there have also been calls to install similar connections to Munmorah Lake, in addition to connections at Budgewoi.

Lowering Barrier at Budgewoi

The idea of lowering the barrier at Budgewoi seems to stem from a desire to reverse the increase in height that has occurred here during the past century, following sand mining and dune rehabilitation works. There also seems to be a belief, by some, that waves which historically overtopped the low barrier are the source of the Budgewoi sand mass. However, a review of available scientific information raises strong doubts that this is true (see Section 3.3.4).

Based on historical accounts, it appears that overtopping events may have occurred very infrequently, at most maybe once every five years or so. At this frequency it is expected that overtopping would probably have been limited to a few hours around high tide for maybe two consecutive tides during a storm. The volume of water that would flow over the barrier into the estuary would have been very small compared to other flushing effects.

Lowering of the barrier is unlikely to result in sufficient overtopping volume to ‘flush’ the estuary to any substantial extent. However, more formal analysis should be completed to confirm or disprove this belief.

Tidally Limited Connection at Budgewoi

The idea of providing pipes through the barrier, set at an appropriate level, has been proposed. The idea here is that typical water levels in the lakes are only slightly above mean sea level whereas tides reach elevations above the mean sea level in the lagoon. If the pipes are set at an appropriately high level (above lagoon water level) then flow could occur through the pipes from the ocean to the Budgewoi Lake.

Setting aside questions relating to pipe capacity, it would seem most feasible to provide a buried pipeline across the narrowest width of the beach barrier. At that location, the beach is completely sandy and installation of a pipe inlet on the beach face at this location would be subject to the following issues:

- The pipe inlet would almost certainly need to be located in the swash zone during some stages of the tide and this means that it will be prone to the build-up of sand and almost certainly would clog with sand and/or kelp to an elevation above mean sea level. Maintenance operations would need to be considered carefully. We note that existing stormwater outlets across beaches in NSW tend to be self-scouring, but in that situation, the water is flowing in the opposite direction and tends to wash sand out of the pipeline or culvert.
- Being present in the swash zone during normal conditions, and in the area subject to dynamic change because of coastal storms and recovery, the structure would need to be substantially robust.
- Considering the above two points, there are potential engineered variations where a pipeline is carried out into deeper water to avoid sand washing into the pipe. There are doubtless solutions that would physically work but would most likely require significant maintenance.
- Maintenance requirements to manage ongoing marine growth and subsequent clogging may render this option infeasible.
- The aesthetic impact on Lakes Beach would needs to be considered very carefully as the structure is likely to be visually intrusive.

Pumping from the Ocean at Budgewoi

Put forward by some as an alternative to a piped connection is a piped connection augmented with pumping. In this instance, a more robust solution to potential blockage with kelp and/or sand needs to be found. It is considered unlikely that a pipeline under the narrow barrier at Budgewoi is likely to be feasible. Often, infrastructure which aims to either take water from, or deliver water to, the ocean aims to do so near a stable rock platform, or cliff, or at considerable depth. The closest location that might be feasible is the rocky reef offshore of Jewfish Point (south of Lakes Beach Surf Club) and a pipeline that is long enough to enable discharge to Budgewoi Lake to occur at a suitable location would need to be constructed.

It is possible that the intake would need to be located even further south. Again, solutions for this type of structure can be engineered, but development of a robust pumping system which continues to operate given the harsh environmental conditions, tidal variation, variable bed levels and crashing waves would likely come at substantial cost. In addition, an assessment of the amount of water that would need to be delivered to have an impact would need to be made, alongside the ecological and environmental impacts of delivering marine water into an estuary that tends to have salinity levels which are somewhat lower than the ocean.

3.7 Summary and recommendations related to entrance dynamics

The Tuggerah Lakes estuary comprises three shallow lagoons connected to the ocean by a heavily shoaled entrance that is intermittently closed. Over millennia, the entrance has migrated up and down the beach but most commonly exists adjacent to a rock shelf at Karagi Point (south of the entrance) where it is naturally protected from the ocean waves. During large floods, the entrance scours and widens, but this typically only lasts for a limited time as sand washes into the entrance and the main tidal channel again becomes constrained. Eventually the channel migrates back against the rock shelf. The entrance has never been considered officially ‘navigable’.

Over time, there has been a balance between the sand scoured out during floods, and the amount that washes back in as the entrance closes. However, there is significant uncertainty in how the entrance will change as mean sea levels in the ocean continue to rise as a result of climate change. At present, it is believed that sand behind the entrance dunes will gradually be ‘reactivated’ and more sand will wash in from the ocean to raise sand levels inside the entrance. This would most likely be accompanied by a recession of the barrier further landward into the entrance channel. This may somewhat stabilise the entrance against closure, but higher ocean water levels will also reduce the protection presently provided by Karagi Point. The balance between these two competing future processes is not presently well understood.

Since the 1990’s the entrance downstream of the bridge has been dredged, although the effectiveness of this management intervention is very uncertain. It seems very unlikely that it improves tidal exchange between the lagoon and the ocean to any significant degree, but it does improve the clarity of water and flushing of the area downstream of the bridge. However, as noted in Section 4 of this report, clear water is not the same as good water quality.

Typically, the entrance exchanges around 1% of the water inside the estuary with the ocean during each tidal cycle. Water within the three lagoons is typically well mixed except around some of the foreshores, where the growth of algae (seaweeds) and seagrasses form barriers that constrain any exchange between the deeper central basins of the lagoons and the adjacent nearshore areas. Stormwater discharging from small urban catchments fringing the lakes is trapped behind these vegetation barriers. Catchment floods help to overcome these barriers by raising water levels and “re-coupling” the nearshore areas with the broader basins.

The community has shown significant interest in improving the connection of the estuary to the ocean for decades, with options ranging from large scale dredging and training of the entrance to constructing an entrance across the sand barrier between Budgewoi Lake and the Ocean.

Several studies over the past five decades have repeatedly concluded that substantial dredging and training walls would be required to increase the tidal exchange from around 1% to around 3%. There are notable limitations in some of these studies, but these findings are consistently reinforced by different researchers using different analytical methods and approaches. A single breakwater of limited extent is unlikely to have any identifiable success at helping to keep the entrance open and/or enhance tidal exchange.

More recent estimates indicate that large scale entrance works would cost in the vicinity of $70 to $100 million dollars. Before spending this amount on entrance training/dredging works, it would be essential that the full impact and effectiveness of any proposed action is properly understood. Training of similar estuaries in NSW (Lake Illawarra, Lake Macquarie and Wallis Lakes) without fully understanding the implications has created significant problems, some of which continue to affect management of these estuaries more than 100 years after they were trained.

Even with adverse findings from repeated studies over several decades, large scale works (training and dredging) are still advanced by some sectors of the community as a viable solution. There is apparently a breakdown in community engagement on this issue over recent decades and this needs to be addressed (See Section 2 for relevant recommendations). The continued argument for such works is typically based on simplistic explanations for processes that are far more complex than most people understand. While the impact of such options could be studied more extensively, we are extremely doubtful that extensive works will turn out to be viable, even as better scientific understanding of the system is gained.

The so-called Budgewoi sand mass or “big sand” is a large marine sand delta that indicates the past presence of a prior entrance from Budgewoi Lake, directly to the ocean. The available evidence for this site suggest that this area has been closed to the ocean for more than 1500 years. Waves were known to crash over the sand dunes between the Ocean and Budgewoi Lake, but it has been several decades since this has occurred as the dunes have a higher elevation than previously. The TLEP examined several historical sources and cannot find any compelling evidence that there was a clear, second entrance present since the arrival of Europeans.

Despite claims in different reports over several decades that a second entrance at Budgewoi had been modelled to assess its viability in the past, the TLEP have found no clear evidence that this has occurred. Although future works to create a second entrance are not supported by the available evidence, more transparency on the science undertaken thus far, is recommended.

Based on the information presented in this chapter, the following recommendations are provided in relation to the entrance dynamics and water quality.

Entrance Training Works: Based on available information, the existing entrance should not be trained, nor extensively dredged. The existing studies indicate that there would be a minor increase in tidal exchange and that the potential impacts on water quality and ecology are not well understood. Potential adverse impacts include:

- If the entrance were opened permanently, it is highly likely that the average lake water levels would fall, exposing shallow fringing areas of the lakes during fortnightly neap tides and resulting in the generation of poor odours and groundwater seepage. This was experienced in 2020, following the floods in February and subsequent rain and storm events that caused the entrance to remain open for an extended period.
- Experience with entrances to other large coastal lagoons in NSW, has shown a tendency for the entrance to enter an unstable scouring mode with increasing activation and movement of sand through the entrance and ongoing excessive erosion of the entrance channel foreshores. This long-term geomorphic process has not been assessed by any of the modelling studies completed to date and may result in significant ecological and engineering implications.
- As sea levels continue to rise offshore of NSW, the issue of flooding around the fringes of estuaries as a result of ordinary astronomical tides and coastal storm surge will become increasingly important. Opening the entrance more broadly and permanently will exacerbate flooding from this process. The absence of a mapped coastal vulnerability area within *State Environmental Planning Policy (Coastal Management) 2018* in relation to the tidal inundation hazard means that this is not presently understood.

Coastal Vulnerability Mapping: The Coastal Vulnerability Area, relating to the tidal inundation hazard should be analysed and mapped, with a subsequent Planning Proposal put forward as part of the Coastal Management Program to be prepared for the Estuary.

Dredging assessment: In the medium term, dredging of the entrance should continue, however the following actions are recommended:

- Install a permanent water level recorder in the entrance compartment: downstream but in the vicinity of the bridge. This will provide information to inform future management.

- Collate the dredging history, all water level, flood and coastal information from inside the estuary, including available footage from the fixed camera to the south of the entrance. Use this information to analyse the degree to which past dredging programs have affected tidal exchange between the ocean and the coastal lake.
- Collect regular and consistent clarity data (secchi disc or turbidity probe) from selected locations around The Entrance to better understand how dredging affects entrance clarity.
- Undertake a socio-economic and tourism study to understand, and quantify wherever possible, the benefits derived from a clear and flowing entrance channel around The Entrance.
- Using the above steps, ascertain whether dredging represents a reasonable ongoing investment. If so, develop and implement a practical and transparent monitoring program with improved dredging triggers (most likely based on tidal response at the above recommended permanent water level recorder) and negotiate with relevant authorities to develop a protocol which enables rapid response and dredging when required.

We note that entrance dredging may also be implemented to assist with flood management and the above processes should be integrated with Council's flood risk management procedures. This work may be funded via the Coasts and Estuary Grant's program, if noted as a priority within the Coastal Management Program study for Tuggerah Lakes.

Dredge Program Funding: Council and relevant government agencies are recommended to examine past expenditure on entrance dredging and to agree upon a clear and reliable funding structure for future dredging over the medium term. Reliance upon contestable grants programs is unlikely to provide the required certainty of funding. The arrangement should be revisited once a final decision is made regarding the continuation of dredging as per Recommendation 3.5.

Second Entrance Consideration: A collaborative community guided process into examining potential management options for a second connection to the ocean at Budgewoi Lake is recommended. We recommend the following approach:

- Development of different potential concepts or options
- Consideration of overall viability (engineering, acceptability, effectiveness of a range of options)
- Development of cost estimates
- Assessment of concepts and, if warranted, selection of a preferred option (or options)
- Numerical modelling of preferred options.

If viable options are available for consideration, potential funding opportunities and the assessment of environmental impacts could be completed. It will be important that appropriate community members are selected to participate in this exercise. The exercise should be facilitated by Council and/or state government representatives. We note that several options have been examined partly in the past, and they all seem to have quite significant limitations. Regardless, all community and government participants should aim to approach the exercise with an open mind and consultative nature. We recommend that all participants be required to adhere to a code of conduct, which requires engagement in the process with good faith.

4 Water quality and ecological status

4.1 Introduction

This chapter details the water quality and ecological status of Tuggerah Lakes. Past reports, historical records and consultation undertaken by the Tuggerah Lakes Expert Panel (TLEP) have identified key issues and concerns about water quality and ecology in the three main lakes of the Tuggerah Lakes system. These include poor water clarity, overgrowth of macrophytes, reduced biodiversity, wrack accumulation and ooze formation.

Significant scientific evidence relating to the natural variation in processes operating within the lakes has been collected in Council and State Government reports as well as in peer-reviewed international journals. A key aim of this chapter has been to review previous published work and recent unpublished data, providing an evidence-based evaluation of the ecosystem processes affecting the historical and current water quality and ecology of the lakes. This information has then been used to assess the relative contributions of natural (e.g. climate) and anthropogenic factors (e.g. Munmorah Power Station) to water quality and ecology in the lakes.

Based on this information, management actions in the nearshore and lake basins are critiqued, including the large scale removal of macrophytes and ooze, wrack harvesting in response to community requests, and saltmarsh restoration and rehabilitation. Key gaps in scientific evidence are highlighted, along with recommendations for future management actions that could be implemented at different scales.

Importantly, the health of the lakes is a reflection of interactions between pressures and processes including ecological and biogeochemical processes, climate and hydrology, geomorphology, and human activities (e.g. catchment runoff and hydrological modifications). However, community perceptions of the health of the lakes appear to be significantly influenced by personal and cultural experiences. Indeed, the Tuggerah Lakes system is often compared to other estuaries such as Lake Macquarie, Brisbane Water and Lake Illawarra, despite scientific evidence that suggest different biogeochemical, climate and hydrologic processes. Furthermore, there is a disconnect between community perceptions that ecosystem processes within the lakes, such as entrance openings, flooding and wrack formation should be controlled and maintained through intervention rather than an understanding of the natural variability that is essential to maintaining water quality and biodiversity in ICOLLs such as the Lakes' system.

This chapter has been divided into 7 sections. A summary of the key literature and datasets reviewed follows this introduction. Subsequently, Section 4.3 introduces the functional zones within the lakes, explaining differences in water and sediment quality between the lake basin and nearshore zones. Section 4.4 synthesises the current understanding of groundwater influences in the nearshore, while Section 4.5 provides an overview of ecological communities and interactions within the Lakes. Building on these sections, Section 4.6 discusses the outcomes of management activities in the Lakes and Section 4.7 proposes future strategies to be implemented.

Recommendations in this chapter should be considered in the context of findings from other chapters of this report.

4.2 Key References

The key literature and datasets reviewed as part of this study are presented and briefly described in Table 4-1.

Table 4-1 Reviewed references on Tuggerah Lakes water quality and ecology

Reference	Description
Higginson, F.R. (1965). *The distribution of submerged aquatic angiosperms in the Tuggerah Lakes system*.	This study provides a baseline survey of the aerial distribution of seagrasses *Zostera capricorni, Halophila ovalis* and *Ruppia megacarpa* in Tuggerah Lakes in the 1960s.
King, R.J. and Holland, V.M. (1986). *Aquatic angiosperms in coastal saline lakes of New South Wales. II. The vegetation of Tuggerah Lakes, with specific comments on the growth of* Zostera capricorni *Ascherson.*	This study provides a baseline survey of the aerial distribution of seagrasses *Zostera capricorni, Halophila ovalis* and *Ruppia megacarpa* in Tuggerah Lakes in summer 1985.
Batley et al (1990). *The Ecology of the Tuggerah Lakes System. A Review: with Special Reference to the Impact of the Munmorah Power Station.*	This study reviews the hydrology and flow, distribution and abundance of aquatic macrophytes, sources of heavy metals, and nutrient dynamics in the Tuggerah Lakes system with reference to the Munmorah Power Station, which was commissioned in 1967.

Reference	Description
Batley, G. and Brockbank, C.I. (1992). *Environmental studies of Munmorah Power Station.*	This is a follow up study addressing the recommendations from Batley et al. 1990 to collect more data on metal concentrations in sediments and aqueous discharges to the lakes.
Scott, A. (1998). *The Ecology of the Tuggerah Lakes. An Oral History.*	Described in Chapter 3.
Allison, J. and Scott, A. (1998) *The Ecological History of Tuggerah Lakes: What the Newspapers Said...*	A collection of newspaper stories about the ecological history of Tuggerah Lakes. Provides some similar context about issues to do with wrack and ooze as well as a stories about potential pollution sources such as sewerage, catchment development and the Munmorah Power Station
Wyong Shire Council (2000). *Tuggerah Lakes Estuary Process Study.*	An Estuary Processes Study completed under the prior Estuary Management Program, where it preceded an Estuary Management Study. The aim was to describe the physical, chemical, and biological patterns and processes operating within the Estuary. The study was done to identify gaps and key estuarine processes to understand how the estuary works.
Wyong Shire Council (2001). *Tuggerah Lakes Estuary Process Study.*	An Estuary Processes Study completed under the prior Estuary Management Program, where it preceded an Estuary Management Study. The aim was to describe the physical, chemical, and biological patterns and processes operating within the Estuary. The study was done to identify gaps and key estuarine processes to understand how the estuary works.
Chapman, M.G. and Roberts, D.E. (2004) *Use of seagrass wrack in restoring disturbed Australian saltmarshes*.	Experimentally manipulated covers of wrack in saltmarsh and measured changes in saltmarsh biomass, diversity, macroinvertebrates, organic content and sediment carbon/nitrogen. They found a rapid increase in biomass of *Sarcocornia quinqueflora,* but limited responses in other variables. This may increase protection for smaller saltmarsh plants to aid in restoration/rehabilitation efforts.
Wyong Shire Council (2005). *Tuggerah Lakes Estuary Management Study.*	Reviews the Estuary Process Study to identify principles and objectives for the Tuggerah Lakes Estuary, and priority issues relating to each principle. These were consolidated into priority programs to be actioned through the management plan.

Reference	Description
Wyong Shire Council (2006). *Tuggerah Lakes Estuary Management Plan.*	Describes the Estuary Management Plan developed by Wyong Shire Council in partnership with the Department of Natural Resources. This is the final action framework that builds on the 2001 Estuary Process Study and 2005 Estuary Management Study. Developed 27 programmes, grouped under 4 Action Plans (water quality, ecology, socio-economics, knowledge and management) to address the issues identified in the Estuary Management Study for application over 5 years.
Wyong Shire Council (2008). *Saltmarsh rehabilitation strategy for selected sites in the Tuggerah Lakes estuary.*	Provides a strategy for rehabilitation of saltmarsh in the Tuggerah Lakes estuary, which was identified as a high priority in the Estuary Management Plan. Includes a review of best practice rehabilitation, methods for selecting rehabilitation sites and recommendations for different stages of rehabilitation e.g. implementation and timing, education and community consultation etc.
Wyong Shire Council (2009). *Passive saltmarsh rehabilitation and management plan.*	Developed as a follow up to the saltmarsh rehabilitation strategy to develop plans and a program of works for passive rehabilitation of saltmarsh in the Tuggerah Lakes. Includes a background review, field verification and mapping of existing saltmarsh communities as well as a condition assessment, identification of management actions and priorities for investment.
Cocco, G. (2010) *Research to assist management of a controversial estuarine resource: Seagrass-Wrack.*	Thesis from University of Sydney contributing information on the distribution of wrack in Tuggerah Lakes and processes affecting this distribution. Experiments were used to test rates of wrack arrival onshore, wrack departure, movement in the lakes and fate once stranded onshore (rate of breakdown). Overall, no clear effects of urbanization, prevailing winds, seasonal effects, types of sediments or armouring on patterns and processes of wrack distribution.
NSW Office of Environment & Heritage (2013). *An assessment of Tuggerah Lakes Restoration Project as a shoreline restoration strategy*.	Reviews the objectives of the Tuggerah Lakes Restoration Project as a strategy for ooze management with a short-, medium- and long-term assessment of effectiveness. TLRP is discussed as a flawed strategy that likely compounded the issue of macroalgal blooms and contributed to long-term issues of wrack trapping in the nearshore.

Reference	Description
NSW Office of Environment & Heritage (2013). *Recommendations for Management of Ooze in Tuggerah Lakes.*	Provides a background to the problems of ooze, management strategies implemented by the Council, and recommendations including stormwater management, saltmarsh rehabilitation and wrack harvesting.
NSW Office of Environment & Heritage (2013). *Restoration of Tuggerah Lakes through Improved Water Quality Management.*	Overview report from four years of investigations in Tuggerah Lakes to develop integrated catchment, hydrodynamic and ecological response models.
NSW Office of Environment & Heritage (2013). *Wrack Harvesting Strategy.*	Reports on spatial variation in wrack accumulation and ooze formation in Tuggerah Lakes. Suggests a rationale and harvesting strategy (methodology, timing, locations) to reduce the development of ooze in the nearshore.
Wyong Shire Council (2013). *Tuggerah Lakes Monitoring, Evaluation, Reporting and Improvement Project: Saltmarsh Rehabilitation.*	Report on from three and a half years of data collection following a 'Beyond BACI' (Before, After, Control Impact) approach to determining the effectiveness of saltmarsh re-establishment projects in Tuggerah Lakes. Describes the active rehabilitation sites in Berkeley Vale, Long Jetty, Lake Munmorah and Tuggerah Lake where shorelines were lowered and planted. Successful growth was observed in the upper shore at most locations while Long Jetty, Berkeley Vale and Lake Munmorah were considered rehabilitated relative to reference sites.
NSW Office of Environment & Heritage (2018). *Impact assessment of Berkeley Vale Subcatchment Pollutant Loads.*	This report focuses on Berkeley Vale because of issues identified that include eutrophication and resulting macroalgal blooms, wrack accumulation and ooze build up in the nearshore zone. Factors contributing to eutrophication are identified and management recommendations provided based on assessed pollutant inputs and surveys of drains, nearshore water quality and groundwater influence.
NSW Office of Environment & Heritage (2018). *Tuggerah Lakes Nearshore Data Synthesis.*	Synthesis of data compiled from regular monitoring of Tuggerah Lakes system by NSW OEH to assess changes in water quality in the nearshore and lake basins between 2012 and 2017. Identifies priority catchments for on ground works to reduce sediment and nutrient inputs e.g. Tumbi, Lake Haven, Tumbi Creek, Ourimbah Creek, Wallarah and Lake Haven.

Reference	Description
Central Coast Council (2019). *Review of Wrack and Algal Collection Program: Final Report.*	Report by GHD on wrack and algal collection operations, including options for disposal and reuse of rack, a review of existing collection resources and future needs as well as costs for new equipment and contractors. Challenges in wrack management identified by the report include the cost of aging equipment, variability in wrack collection requirements, enviro-socio conflicts, and compliance issues. Highlights the need to first make stormwater quality improvements and reduce catchment wide runoff. Following recommendations include increase the rate of wrack collection and purchase new machinery for this purpose, and engage and educate the community on the importance of wrack with relevant case studies.
Central Coast Council (2020). Tuggerah Lakes Estuary Management Plan: Summary of Implementation 2008-2020.	This report provides a summary of the implementation of Tuggerah Lakes Estuary Management Plan with key achievements regarding catchment, hydrodynamic and ecological response modelling, ongoing water quality monitoring, wrack collection, and saltmarsh rehabilitation and restoration projects.
Datasets	**Description**
NSW DPI (2020). *Tuggerah Lakes landings.*	Commercial wild harvest landings reported for Tuggerah Lakes 1987/88 to 1996/97 (prior to Restricted Fisheries).
Central Coast Council (2020). *Wrack Collection Report PN19/220.*	This dataset includes information about the location of wrack collection, collection date, material, volume and method of collection between 01/07/2019 - 30/06/2020. This data has been compared to advice on strategic wrack harvesting provided by DPIE.
NSW DPIE groundwater quality data set.	This dataset includes physicochemical, nutrient and radon (a natural groundwater tracer) data for bores located in transects along the Berkley Vale shoreline, as well as nearshore radon, nutrient and physicochemical data collected during boat-based surveys.
Birding NSW Central Coast Group, (2016). *Central Coast Bird Report for 2009 and 2010.*	Records from the Central Coast Field Ornithologists Club listing birding highlights from 2008 and 2009 as well as a comprehensive species list of sightings with some location and abundance data.

4.3 Water and Sediment Quality in Tuggerah Lakes

Key Points
Prior to large-scale development, Tuggerah Lakes estuary was considered nutrient poor (oligotrophic). From the 1950s to the 1990s, human pressures contributed to increasing nutrient loading in the lakes leading to a eutrophic state. Nutrient loading has since been reduced and the Tuggerah Lakes estuary is now generally classified as mesotrophic (apart from in the nearshore areas).
A barrier of seagrass wrack and algae along some sections of shoreline result in hydraulic decoupling of the basin and the nearshore zone. The means that the lakes effectively have two zones; one in the main basin and one in the nearshore zones.
The decoupling of the nearshore zone and the basin results in nutrient and sediment loads delivered by storm water being retained in the nearshore zone.
These high nutrient loads result in eutrophication, with extensive seasonal macroalgal and phytoplankton blooms in the nearshore zone.
The algae fuel poor water quality and amenity decline in the nearshore zone through ooze formation, deoxygenation and hydrogen sulphide (rotten egg gas) formation.
Studies by CSIRO concluded that physico-chemical conditions in Tuggerah Lake were relatively unchanged by the operation of the power station apart from minor temperature and salinity changes. Some metal (Cu, Pb, Zn) enrichment was observed in sediments with higher clay/silt fractions, but there was no evidence of enrichment of dissolved metal concentrations or significant accumulation by seagrasses or sediment-dwelling infauna.
Poor sewage management in the past has contributed to water quality issues in the lakes, but since development of a reticulated sewage system and ocean outfalls, many of these problems have been resolved. Beachwatch has identified sites at Canton Beach and Lake Munmorah that continue to perform poorly with regards to faecal contamination and research continues to identify the source.
The delivery of catchment sediments to the lakes has been significant and is contributing to the shift in grain sizes in the nearshore from muddy to sandy. Overall, the lakes are not experiencing significant sedimentation with variation at depth increases and decreases at different sites.

4.3.1 Functional zones in the Tuggerah Lakes

Classification

The Tuggerah Lakes estuary system (comprising Tuggerah Lake, Lake Budgewoi and Lake Munmorah) is classified as a coastal lake (Roper, 2011). The system also belongs to a broader sub-type of estuary known as Intermittently Open and Closed Lakes or Lagoons (ICOLLs) due to the tendency for the entrance to periodically close. ICOLLs account for approximately 60% of the 184 estuaries along the NSW coast, with systems tending to fall into two main groups: those whose entrance is open for more than 80% of the time (including Tuggerah Lakes); and those whose entrance is closed for greater than 80% of the time. While the entrance is closed or restricted, water levels vary widely according to the balance between freshwater inputs and evaporation. While the entrance is open, semi-diurnal tides tend to be suppressed and tidal water level variation tends to be dominated by fortnightly tides as a result of spring-neap variation in tidal amplitude. This variation in water level over monthly to seasonal timescales controls a defining aspect of ICOLL function: the inundation and drainage of fringing wetland habitats, which has a raft of implications for biogeochemical and ecological function (Ferguson et al., 2020).

The Tuggerah Lakes system comprises six main functional zones: 1) open lake basins; 2) soft sediment nearshore zones; 3) rocky nearshore zones; 4) entrance compartment; 5) estuarine river channels; 6) fringing wetlands (Figure 4-1). An introductory overview of these zones is provided below, with more detailed analysis of the interactions between environmental drivers (e.g. wind, rainfall, lake level) and the biogeochemical/ecological function detailed in subsequent sections of this report.

Open lake basins

The main lake basins are shallow (1.5 to 3m deep), open waterways, with fine-grained organic-rich sediments. Water quality is primarily influenced by freshwater inputs from the main rivers and wind-driven circulation and resuspension of bed sediments, which tends to breakdown lateral and vertical water quality gradients such that there is little variation among sites within the lakes on any given day. There is historical evidence that parts of the lake basins once supported extensive areas of seagrass, however, there has been a progressive migration of seagrass to the nearshore zone since the 1940s.

Soft-sediment nearshore zones

The lake nearshore zone (from the shoreline to approximately 100-250m offshore) is extremely shallow (0.5-1.5m deep) and water tends not to mix readily with lake basin water due to a barrier effect created by seagrass and macroalgae (‘hydraulic decoupling’). The majority of the nearshore zone is dominated by sandy to silty-sand sediment substrates, with the relative proportion of the silt

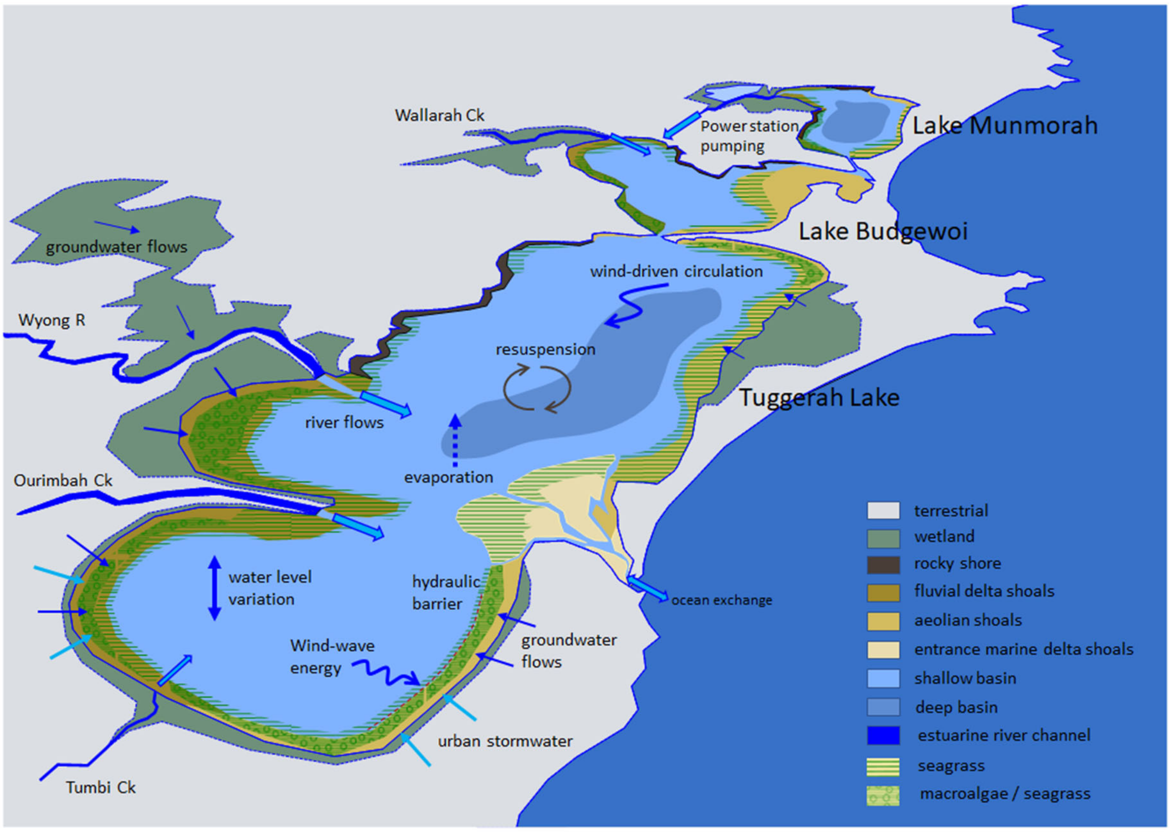


Figure 4-1 Functional zones of Tuggerah Lakes

and sand fractions depending on exposure to wind-wave energy. Seagrass wrack accumulations regularly occur along the nearshore zone, with severity of accumulations depending on prevailing winds. Water level variations create important biogeochemical/ecological linkages between the inter-tidal and sub-tidal zones. Water quality in the nearshore is primarily influenced by localised urban stormwater inputs and groundwater seepage. Nutrient enrichment primarily due to stormwater pollution has resulted in excessive growth of macroalgae which is a major contributor to the formation of 'ooze'. Historical photographic evidence suggests that large stretches of the nearshore zone (e.g. at Long Jetty and Tumbi) were devoid of seagrass and macroalgae prior to the 1950s. However, it is likely that the nearshore zone was naturally a place of high productivity relative to the lake basins, influenced by similar processes as observed today (e.g. hydraulic decoupling and wrack accumulations).

Rocky nearshore zones

A smaller percentage of the lake nearshore zone is dominated by rocky shores and sub-tidal reefs interspersed with some soft-sediment substrates. Similar processes operate in this zone as in the soft-sediment nearshore, however the hard shoreline imposes different interactions between the sub-tidal and inter-tidal zones. The rocky substrates provide a wide range of ecological niches for aquatic plants, invertebrates and fish.

Entrance compartment

This zone is defined as extending from the entrance berm to the western limit of the marine delta shoals at Pelican Island. The entrance compartment is dominated by shallow, mobile marine delta sand shoals and shifting channels downstream of the bridge, and immobile shoals colonised by seagrass with stable channels to the west of the bridge. Water quality in the entrance compartment is the only part of the lake system that is influenced by oceanic water during flood tides.

Estuarine river channels

The Wyong River, Ourimbah Creek, Tumbi Creek and Wallarah Creek all discharge to the lake system via relatively deep (>3m) estuarine channels with fine-grained, organic-rich sediments. The channels are steep-sided, with overhanging vegetation. Water quality is dominated by lake water during periods of low freshwater inflows, and becomes highly stratified during wet weather as freshwater inflows form a lens on the surface of the denser brackish lake water.

Fringing wetlands

Large areas of the lake system are surrounded by low-lying shoreline and wetlands that become periodically inundated when lake levels rise in response to freshwater inflows and spring high tides. The alternate inundation and drying phases in this zone facilitate an important ‘self-cleansing’ function in the lake whereby seagrass wrack is transported inland and allowed to decompose under aerobic conditions, supporting a rich invertebrate fauna. The development and infilling of low-lying foreshores, in combination with entrance management practices, has served to reduce the area and inundation patterns of the fringing wetlands.

4.3.2 Water quality drivers

Water quality in Tuggerah Lakes is controlled by the interaction among the various functional zones (known as ‘drivers’) presented in Figure 4-1. Broadly, the Lakes’ system is defined as a type of ‘estuary’, which is a waterway where freshwater runoff from the land mixes with ocean waters (Pritchard, 1967). However, water quality throughout the lakes is also influenced by internal physical processes such as the stirring up of sediment by wind-waves, and biological processes such as the growth of algae and seagrass. These internal processes are important for determining how the lake system responds to pollutant inputs, and can often overwhelm apparent effects on water quality due to freshwater inputs and tidal exchange. This section provides an overview of the main water quality drivers, highlighting the temporal and spatial variation in drivers and how this impacts on community perceptions of water quality and lake processes (e.g. wrack and ooze).

Rainfall and freshwater inputs

Pollutants (e.g. sediments and nutrients) are delivered to the Tuggerah Lakes via freshwater streams, groundwater seepage, and direct rainfall. The timing and location of these inputs are determined by interactions between catchment topography / geology and seasonal variations in rainfall and evaporation.

The Tuggerah Lakes region receives on average approximately 1400mm of rainfall annually, with a high degree of interannual variability due to the influence of climatic drivers such as the Southern Oscillation Index and the Interdecadal Pacific Oscillation. The highest rainfall tends to occur during the late summer to autumn period, with a winter minima. However, large falls can occur at any time of year, particularly during late autumn in association with the occurrence of East Coast Lows. Coastal storms during late spring to early summer can also result in localised heavy falls, particularly in the urbanised catchments around the lake.

The timing and duration of rainfall events has a bearing on the discharge volumes realised within the stream network. During extended dry periods, shallow groundwater levels and baseflows are greatly reduced due to evapotranspiration. Runoff rates in response to rainfall during these conditions are reduced due to higher infiltration rates to the soil profile. In contrast, rainfall during extended wet periods results in relatively greater runoff due to saturated soil profiles and high groundwater levels. The exception to these general rules is within urbanised catchments that have a high percentage of impervious surfaces (e.g. roads, concrete etc.), resulting in elevated rates of runoff with a rapid response time to rainfall events.

Catchment modelling is a technique used to quantify freshwater and associated pollutant inputs from the various sub-catchments draining to Tuggerah Lakes in response to rainfall and landuse (See Chapter 5 for more details on land-use). In a broad sense, the models answer the questions "*how much goes in and from where".* Catchment modelling undertaken for Wyong Council in 2009 (BMT WBM, 2010a) estimated that the bulk (85%) of freshwater enters via three main water-courses: Wyong River (55%); Ourimbah Creek (24%); and Wallarah Creek (5%) (Figure 4-2). The smaller fringing catchments contribute significantly less overall inflow, however their discharges are generally spread across many small stormwater outlets along the Lakes' foreshore. These inflows, combined with the poorly flushed nature of the nearshore waters, tends to concentrate the impacts from these smaller catchments (see Section 4.3.6 for further details). Freshwater also enters the Lakes via groundwater seepage pathways around the lake margins, however, data on these inputs is very limited and it is not possible to quantify their importance to the system.

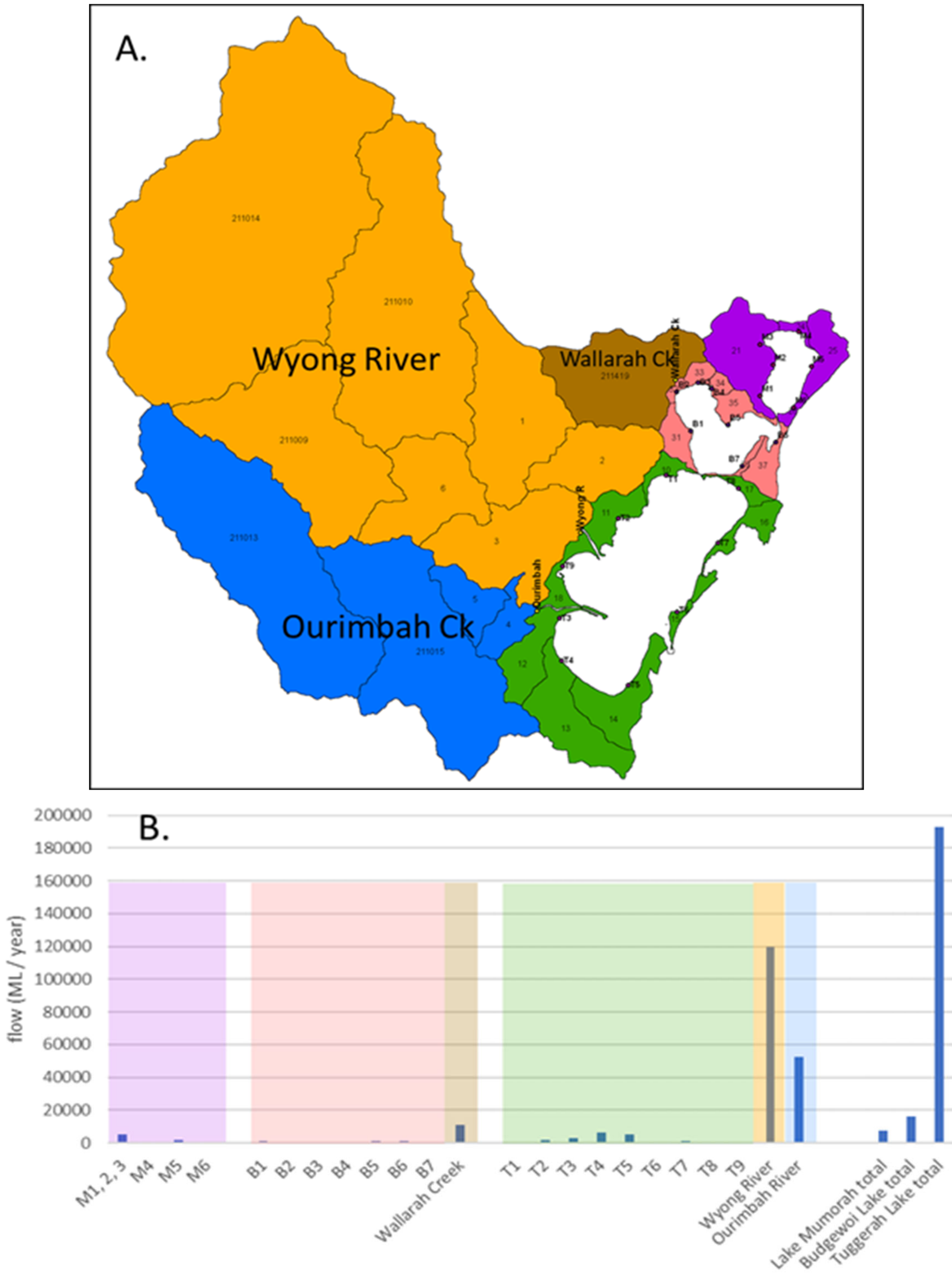


Figure 4-2 A) Major sub-catchments draining to Tuggerah Lakes

B) Estimated yearly discharges from sub-catchments.

Impact of dry weather flows on lake water quality

For the majority of the time, most freshwater runoff occurs as stream 'baseflows', which are orders of magnitude smaller than flood event flows. In the case of the larger rivers and creeks (i.e. Wyong River, Ourimbah Creek, Whallarah Creek) the freshwater baseflow (and associated pollutant loads) are mixed with lake water and processed within the tidal reaches of the river channels before entering the lake basin. This means that water quality in the tidal reaches of these larger waterways is mostly indistinguishable from the receiving waters of the lake basins.

Impact of floods on lake water quality

The majority of freshwater inflows occur during large rainfall events that can cause significant lake level rises and conspicuous freshwater plumes from the main rivers and creeks to extend across the surface of the more saline basin waters[6] (Figure 4-3). Floods tend to scour channels through the entrance compartment, with a large percentage of the floodwater volume discharged through the entrance to the ocean (if open). As the hydraulic head between the lake and ocean reduces in response to a combined decrease in runoff and drainage of floodwaters through the entrance, a residual amount of freshwater (and its constituent suspended sediment and nutrient loads) is retained within the lake. Wind-driven mixing of this residual freshwater input after the rainfall event causes a rapid breakdown in stratification resulting in a general reduction in salinity (Figure 4-4).

Figure 4-3 Flood plume from Wyong River discharging into Tuggerah Lake

[6] This phenomenon, known as 'stratification', is caused by density differences between the less dense freshwater flood waters and the more dense brackish lake water

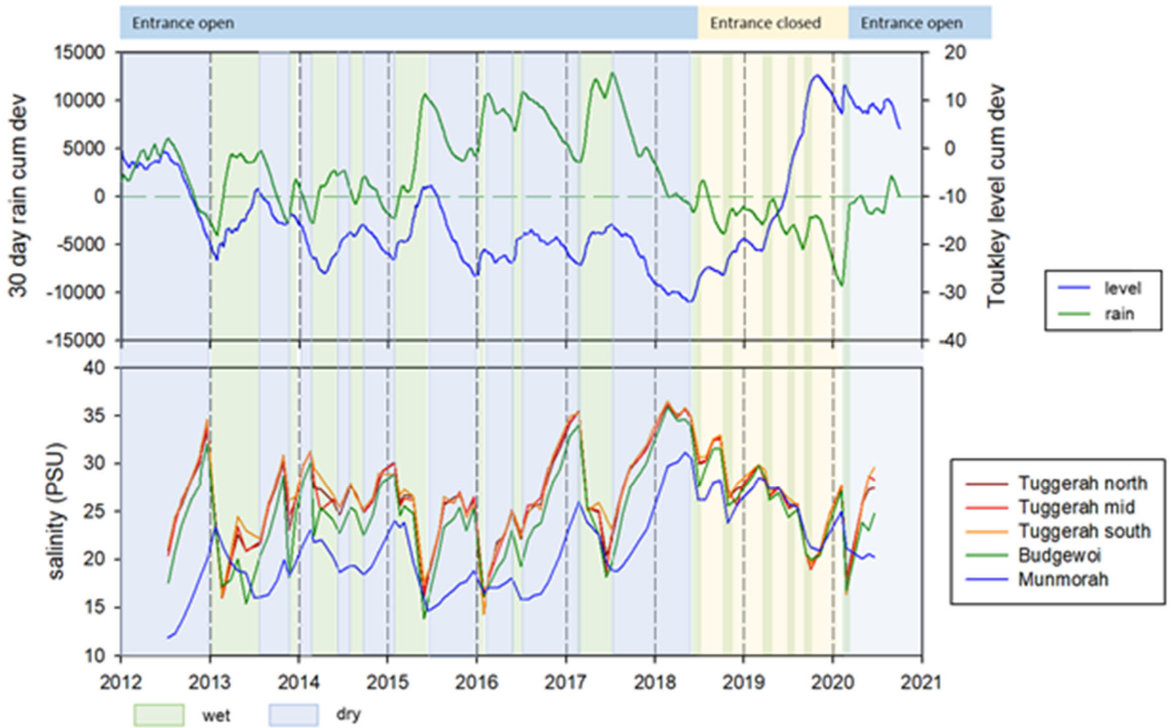


Figure 4-4 Trends in rainfall and water level (expressed as cumulative deviation from the mean) and salinity.

Freshwater inputs and average lake levels

Lake water levels rise in response to rainfall events large enough to result in freshwater runoff to the creeks and rivers draining to the Lakes' system. The magnitude of the water level rise is related to the rainfall totals over the preceding fortnight (refer to Figure 4-5), with the drop in levels after the rainfall event dependent on the efficiency of the entrance channel (i.e. the extent of shoaling in the entrance compartment) and whether there is follow up rainfall (Figure 4-6). In addition, there is feedback between the size of the rainfall event, the lake water level rise, and the degree of scouring of the entrance channel. Large flood events will cause greater channel scour and thereby drain faster and to lower levels than smaller events where scour is less and outflows are impeded by the size and invert level of the entrance channel or by shoals within the entrance compartment of the channel (Figure 4-6).

The coupling between water level and freshwater inputs is reflected in seasonal variation of mean levels within the lakes. Seasonal wet periods (characterised by roughly 6 month periods of above average 30 day rainfall totals) result in a slight rising (or pumping up) of water levels, followed by decreasing levels during subsequent below average rainfall periods (Figure 4-7). During normal or above average wet seasons, the entrance channel remains well scoured and the low excursion of lake levels is controlled by ocean levels (see Chapter 3).

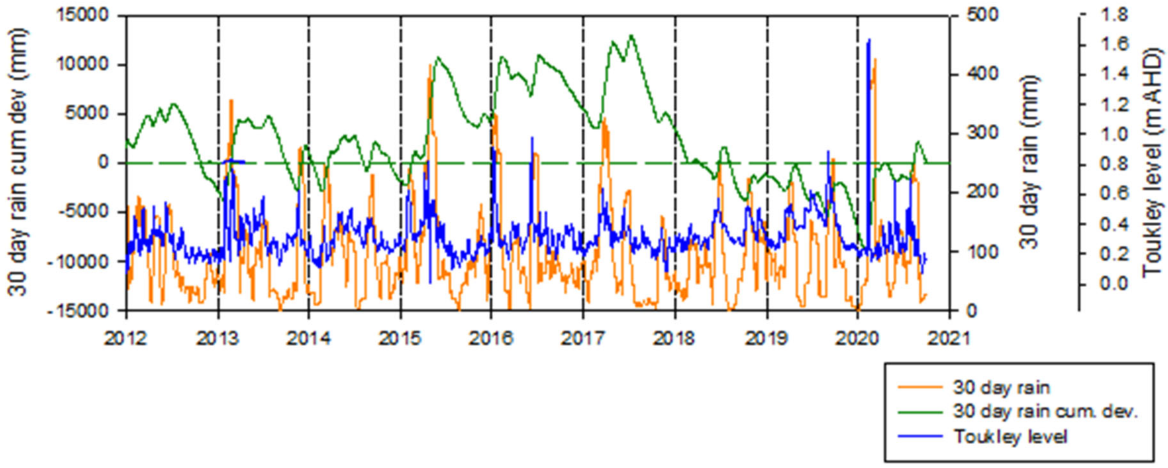


Figure 4-5 Comparison of Toukley water level and 30 day rainfall totals since 2012

(Note; the green line indicates the cumulative deviation from mean rainfall, which highlights periods of above average rainfall (rising line) and vice versa.)

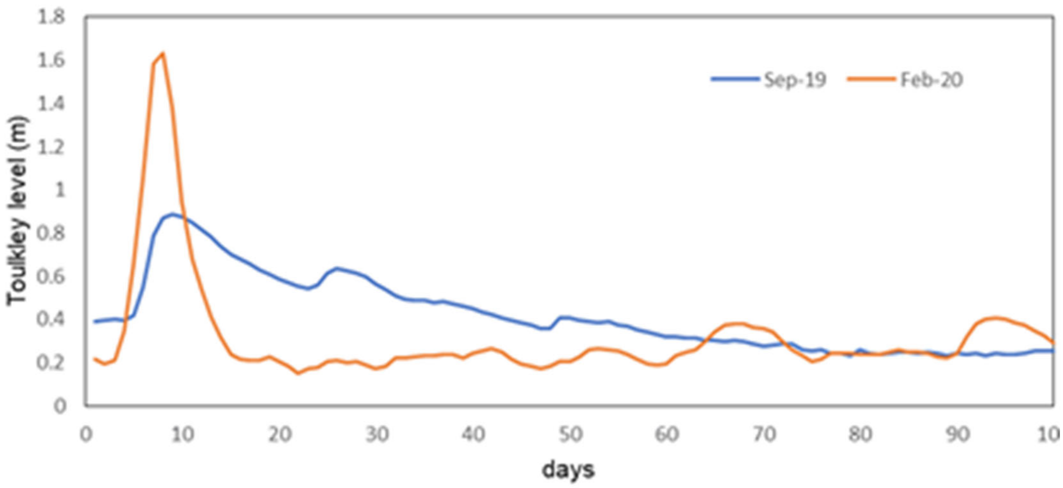


Figure 4-6 Comparison of water level variation in response to two freshwater runoff events.

(Note; The longer drainage time after the September 2019 event when the entrance channel was significantly blocked by shoaling.)

Conversely, over extended periods of below average rainfall (i.e. smaller and less frequent rainfall events), the entrance can become progressively clogged due to ongoing sand inputs from the ocean in the absence of significant scouring events. During these periods, post event drainage becomes less efficient over time resulting in a rise in average water levels in response to smaller rainfall events. This was observed between mid-2018 and mid-2019, when the tidal signal disappeared from the lakes' water level before rising by approximately 10cm. This period also coincided with a progressive drop in salinity in the lakes despite the below average rainfall.

Tidal exchange

There is a strong community perception that tidally-driven exchange of lake water with ocean water can improve water quality in the lake system and alleviate problems associated with ooze formation in the nearshore zone. The fact that the lake system is brackish (i.e. salinity varies between approximately half and full seawater over inter-annual timescales) is evidence that tidal exchange has an impact on lake water quality. The inflow of ocean water during flood tides results in obvious changes in water quality in the entrance compartment as far as Pelican Island. However, the effect of tidal exchange in the main lake basin is slow relative to other processes impacting on water quality and is therefore unlikely to result in perceptible improvements, especially along the nearshore where exchange is further impeded by 'decoupling' (see Sections 4.3.1 and 4.3.6).

The long-term monitoring of lake salinity provides a clear indication of the effects of tidal exchange (increase in salinity) balanced against freshwater inputs (decreases in salinity as shown Figure 4-4). Periods where 30 day rainfall totals are below average (i.e. a downward trajectory in the cumulative deviation from the mean as per Figure 4-4) coincide with an increase in salinity in the lake, indicating the gradual influx and mixing of oceanic water during open entrance conditions. Hydrodynamic modelling of tidal exchange (Sanderson, 2009) entering the lake during flood tides tends to flow under the less saline lake water into the deeper basin. Wind-driven mixing rapidly breaks down this temporary stratification, resulting in a gradual increase in overall salinity.

Salinity measurements can be used to quantify the likely tidal exchange over a defined dry period using a simple salt balance model which mixes ocean water (with a salinity of 36 PSU) with lake basin water (salinity set at measured value at the start of the simulation period). at a constant daily rate. This model shows the likely rate of daily tidal exchange during two dry periods in 2016 and 2017 (Figure 4-7) is approximately 1% of the lake basin water is exchanged every day while the entrance is open, which accounts for the observed gradual increase in salinity during these periods. It is notable that this rate of change would be imperceptible throughout the lake, with the only obvious impacts of tide being observed within the entrance channels during flood tides.

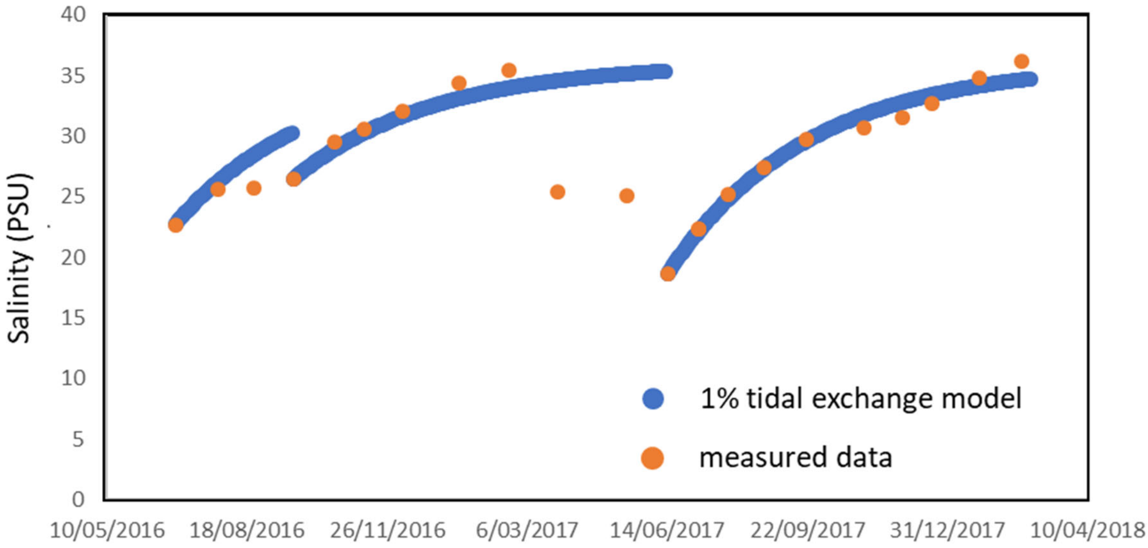


Figure 4-7 Comparison of measured data and modelled salinity assuming 1% daily exchange with ocean water during open entrance conditions

Evaporation

Evaporation is another significant driver of processes in Tuggerah Lakes, affecting both water levels and water quality. The Tuggerah Lakes' system is particularly prone to evaporative losses due it being broad and shallow, and exposed to all prevailing winds (Brennan et al., 2010). Based on pan evaporation rates for Sydney (source BOM), the maximum potential annual evaporation in the lake system is equivalent to approximately 34% of the average total annual freshwater inputs. This is in line with estimates for Australian lakes and reservoirs, with rates expected to increase by up to 15% by 2070 due to climate change (Helfer et al., 2012). As indicated in Figure 4-8, evaporation can exceed rainfall and potentially cause a decrease in water levels and increase in salinity during periods when freshwater inputs are small and entrance efficiency is low. In extreme cases, salinity in the lakes can exceed seawater ('hypersalinity') as was recorded during the drought experienced in the early 1990s.

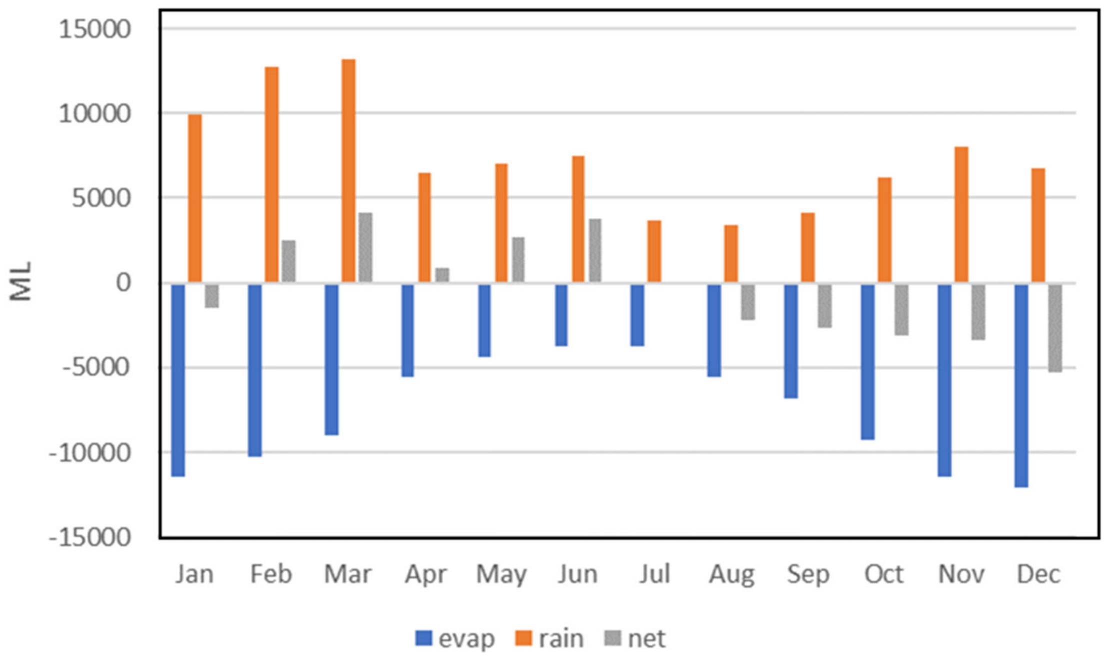


Figure 4-8 Median monthly inputs of freshwater via direct rainfall to the lake surface, median losses due to evaporation and net water balance

Wind-driven mixing

Wind data for Norah Head shows that winds are dominated from the north easterly and southerly directions for much of the year, with a shift towards the western quadrants during winter. Wind speeds are greatest during the afternoons, with highest average wind speeds during summer. The relatively low-lying surrounding topography combined with a broad, shallow waterway area means that Tuggerah Lakes system is exposed to winds from all directions. Wind shear stress across the water surface sets up circulation currents (Figure 4-9, also refer to Section 3.5), with surface currents reaching about 4% of the wind speed travelling in the direction of the wind. Wind driven currents result in ‘seiching’ (i.e. the setting up of a standing wave across the lake basin; see Section 3.5) which causes a return current at depth in the opposite direction to the wind. The net effect of these processes is to mix the water column both vertically and laterally on considerably shorter timescales (hours to days) than the timescales of ocean water intrusion due to tides (weeks). This means that, outside of the entrance channel compartment as far as Pelican Island, there are no apparent gradients in water quality within the lakes at any time due to tidal exchange.

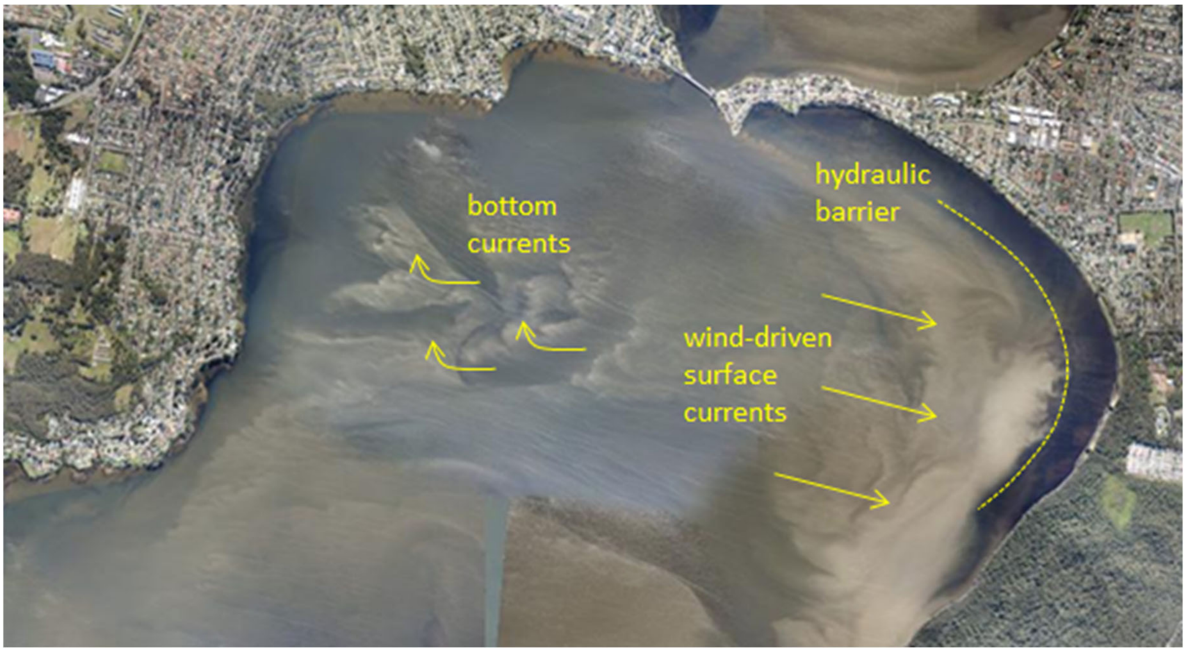


Figure 4-9 Nearmap image of turbidity plumes in Tuggerah Lake caused by a strong north west wind event

Wind-driven bed shear stress

The long wind fetches across the lake basins also allow the rapid development of wind waves which enhance vertical mixing, and cause significant bed shear stress and resuspension of bed sediments. This mechanism is responsible for the rapid rise in turbidity across the lake during windy days (Figure 4-9). The magnitude of bed shear stress at any point in the lake depends on wave height and water depth. Wave height is, in turn, dependent on wind strength, duration and fetch, therefore spatial patterns of bed shear stress across the lake are driven by seasonal variation in wind direction and strength (Figure 4-10). The increase in average wind speeds during summer causes an overall concomitant increase in average bed shear stress across the lake basins, which is closely related to seasonal increases in turbidity (Figure 4-11, Figure 4-12 and Figure 4-13). Lake Munmorah experiences lower wind-driven turbidity due to its smaller area and deeper basin which limits wind wave development and associated bed shear stress.

It is notable that extreme wind events can occur at any time of the year, resulting in a more stochastic (unpredictable) temporal pattern in the 99th percentile bed stress with no clear seasonality and high inter-annual variability (Figure 4-11). The timing and duration of these events may be important drivers of lake processes, especially in the nearshore zone. For example, high wave energy associated with strong wind events can dislodge wrack offshore accumulations, either forcing the material onshore or alternatively making it available for transport to other areas of the lake via wind-driven circulation currents. These processes are responsible for the rapid changes commonly observed in wrack accumulations along the lake shorelines, despite wrack harvesting efforts by Council which operate over longer timescales.

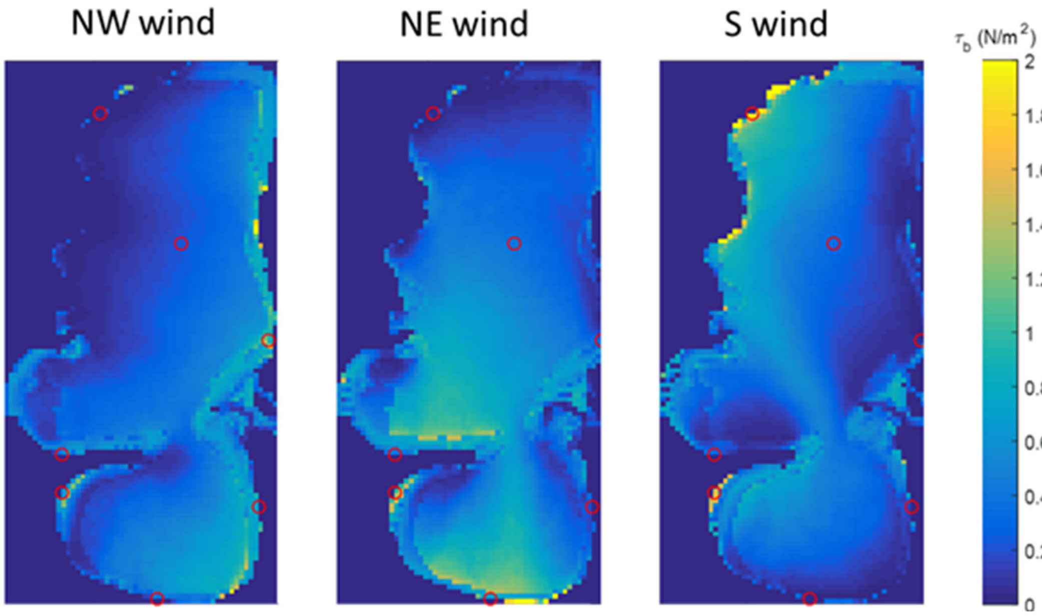


Figure 4-10 Bed shear stress across Tuggerah Lake under three different wind directions

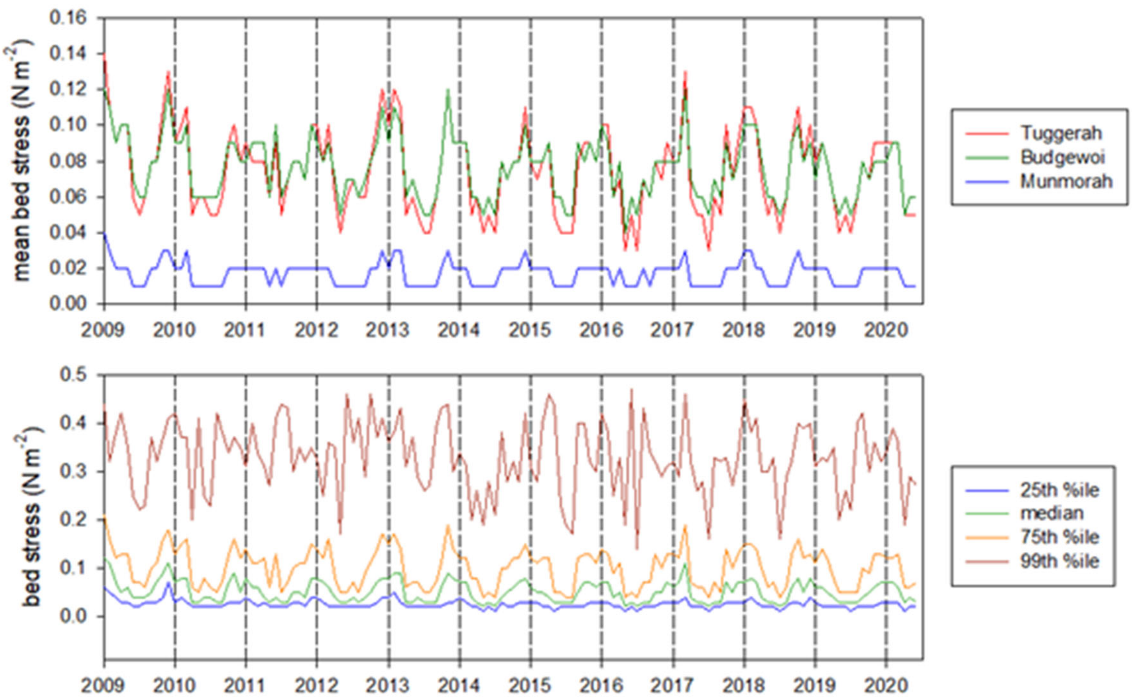


Figure 4-11 Mean bed shear stress in the three lakes (top panel); and bed shear statistics for Tuggerah Lake (bottom panel)

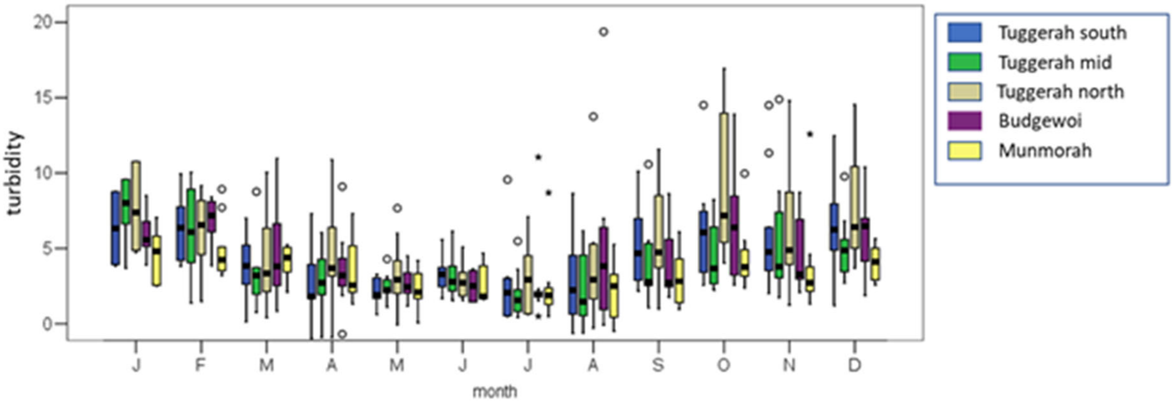


Figure 4-12 Seasonal variation in turbidity in the three lake basins (2009-2020)

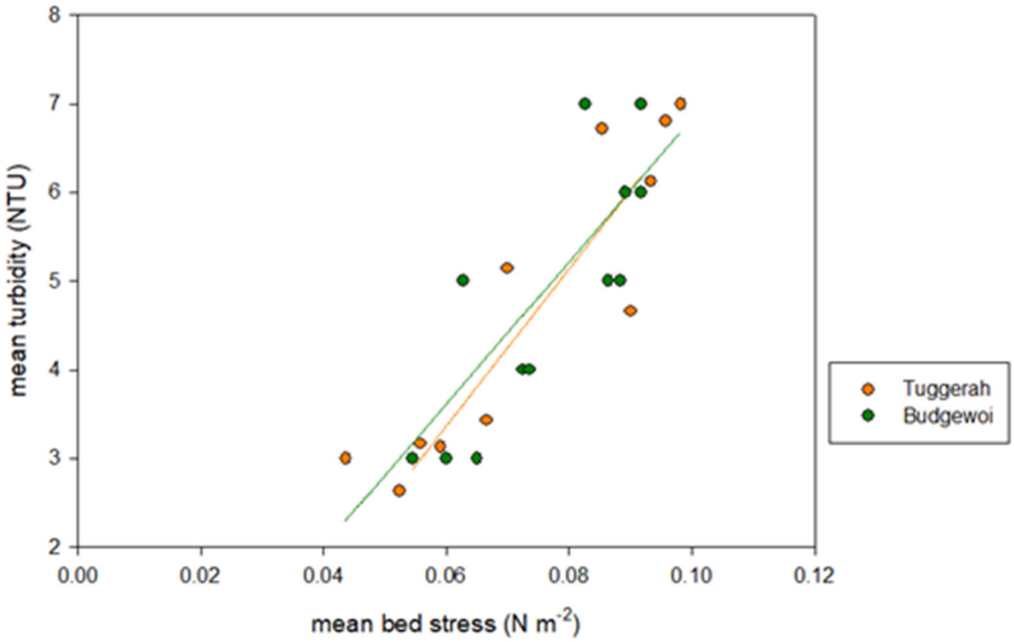


Figure 4-13 The relationship between mean monthly bed shear stress (2009-2020) and mean monthly turbidity (2012-2020).

Strong wind events also cause downwind water level rises due to seiching which may overcome the hydraulic barrier that decouples the basin from the nearshore in some instances. This can cause turbid basin water to impinge along the shoreline and also result in dilution of nutrient-rich nearshore water.

4.3.3 Sediments and sedimentation

The main sources of sediments to the lakes come from the surrounding catchment and erosion of land-based materials (Roberts, 2000). This has increased over time as a result of increased urbanisation and development around the lakes. Stormwater runoff in particular is a major source of sediments to the lakes, with contributions dependent on the size and amount of disturbance within catchments. Patterns of sediment accumulation and erosion within the lake have likely been affected by dredging, construction of weirs and stormwater drains that have changed natural flows.

Sediment grain sizes (i.e. the relative proportions of clays, silts and sand) throughout the lakes are linked to energy that determines areas of settlement of resuspension of particles (Roberts 2000). Accumulation zones are characterised by fine silts and clays with high organic content, while particles range from muds to sands in transportation zones and erosion zones tend to be dominated by coarse particles. In general, submerged aquatic vegetation slows water movement, which allows particles to settle, while large flood and wind events result in resuspension that shift significant amounts of sediments. There is also some evidence that nearshore sites have become muddier over the past few decades (Roberts, 2000) and this has been attributed to development in the catchment increasing delivery of sediments to the lakes via runoff (Roberts, 2000).

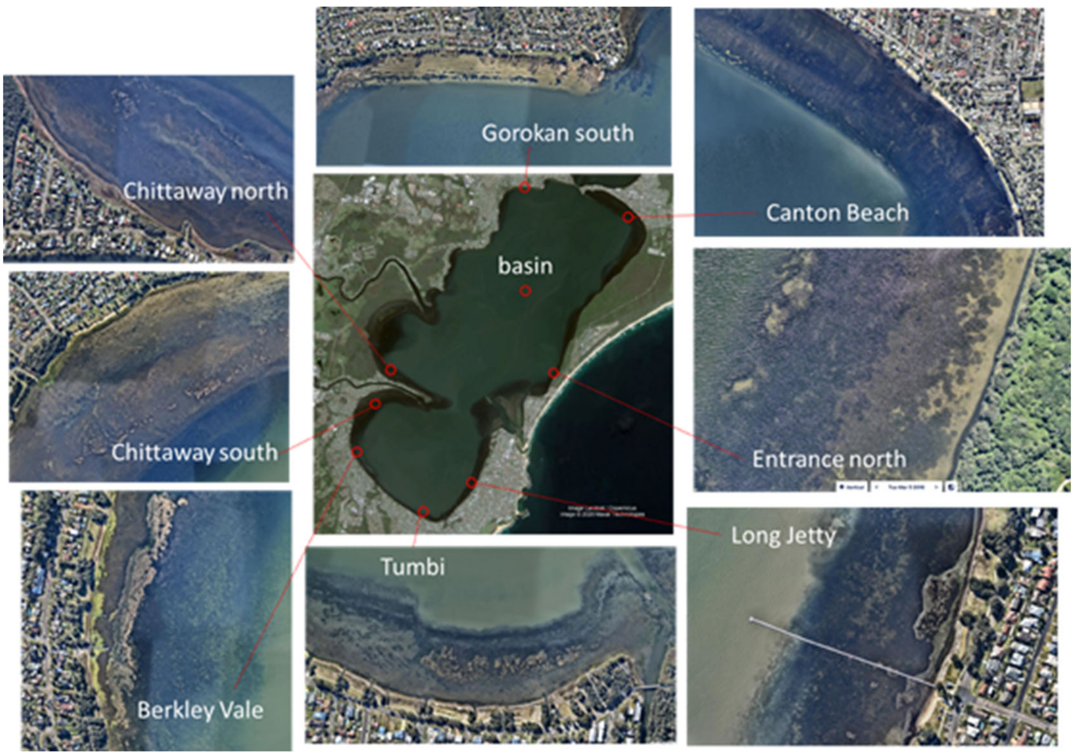
Spatial variation in the quality of sediments along the lake nearshore zone is largely determined by the aspect of the shore which controls its exposure to wind-wave energy (Figure 4-14). Protected shorelines (e.g. Berkeley Vale) tend to accumulate fine sediments, while shorelines exposed to large wave energy (e.g. Gorokan south) are dominated by sands. The presence of significant seagrass / macroalgae barriers also impacts on wave energy and therefore sediment type. For example, the presence of extensive macroalgae accumulations along Long Jetty has resulted in higher fine sediment contents relative to the shoreline north of the entrance, despite both sites having similar aspect and wind-wave exposure. The deeper lake basins are largely depositional zones that accumulate fine sediments deposited during freshwater inflows and winnowed from lake margins due to wind-wave energy.

Despite these trends in sediment particle size distributions, the 2000 Estuary Process Study reported that Tuggerah Lakes is not experiencing significant sedimentation. Significant depth increases were reported in northern Lake Munmorah (1 m) and in the north west of Budgewoi Lake (0.5 m), while significant depth decreases were observed in Tuggerah Bay (0.3-0.5 m, occurring at a rate of ~13-22 mm/yr) and Chittaway Bay (0.5 m, occurring at a rate of ~22 mm/yr). Reversal of natural water flow and increased flows from Munmorah Power Station were linked to increased depths in the northern edge of Budgewoi Channel, Budgewoi sand mass and Munmorah inlet (Roberts, 2000).

Sediment organic matter

The quantity and quality of sediment organic matter has a large bearing on biogeochemical and ecological processes, and the amenity values experienced by the community. Sediment organic matter contents tend to be highest in low-energy depositional areas with high fine sediment contents. The makeup of sediment organic matter comprises a mix of 'labile' or highly reactive material (i.e. can be readily broken down by microbes; e.g. macroalgae), to 'refractory' or low reactivity material (i.e. are broken down slowly by microbes; e.g. terrestrial leaf litter). Organic matter quantity and quality is important for determining the rates of sediment microbial activity and whether ooze will form at any given site (Swanson et al., 2013).

The contributions of different organic matter sources to sediments around the nearshore zone is highly variable in space and time, reflecting a combination of proximity to stormwater inputs (e.g. nutrients and terrestrial organic matter), and wind-wave exposure which controls the movement and accumulation of seagrass wrack. Shorelines most predisposed to ooze formation are characterised by fine sediments and high contributions of relatively labile organic matter (Figure 4-15). A study by NSW DPIE has indicated that macroalgae detritus is a main contributor to ooze formation, and while seagrass wrack is not considered labile, it can contribute to ooze formation by trapping other labile organic material (e.g. phytoplankton) and reducing water exchange (Figure 4-15; Swanson et al., 2013).



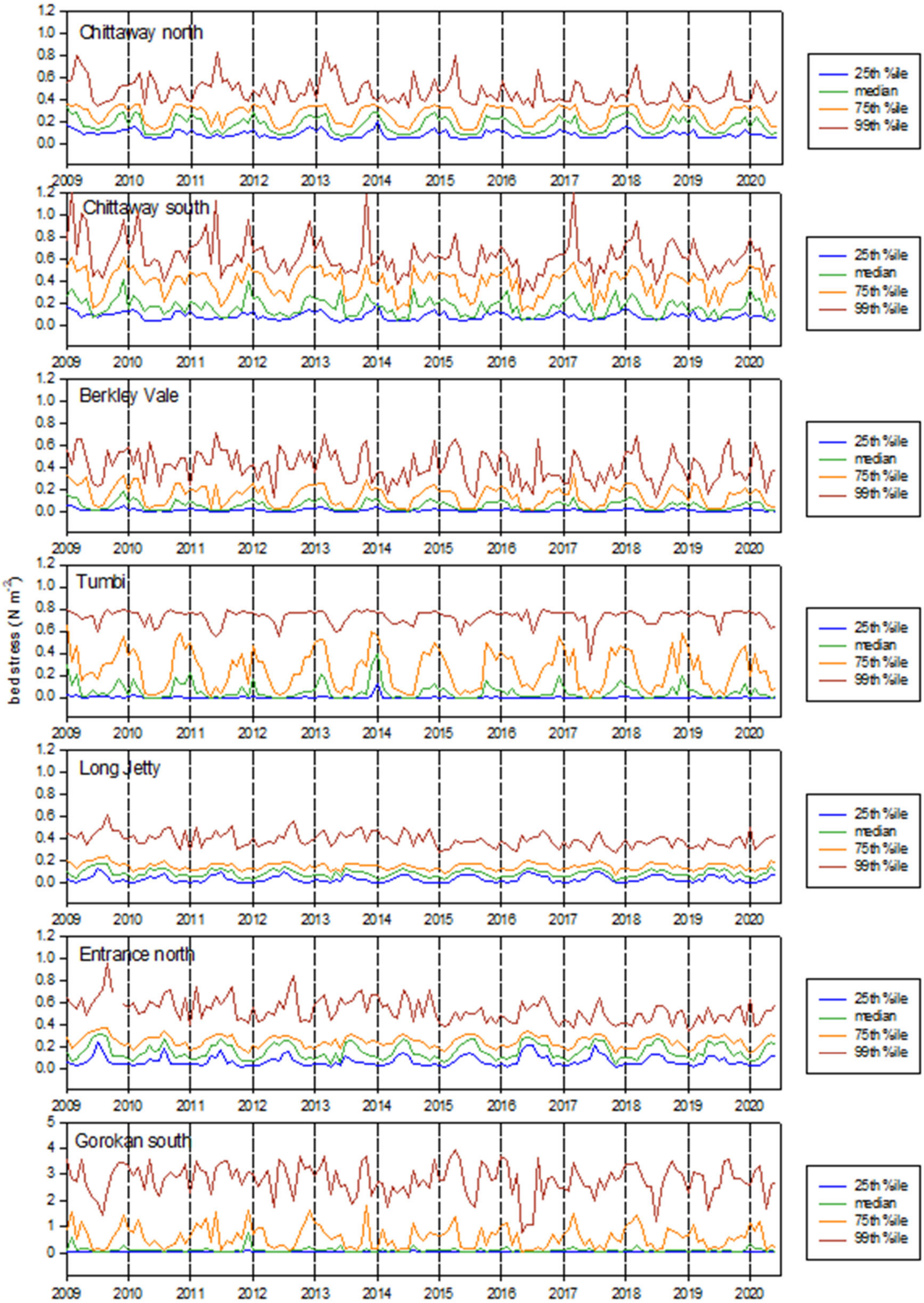


Figure 4-14 Bed shear stress statistics for different locations around the lake system. Locations are shown on page 188.

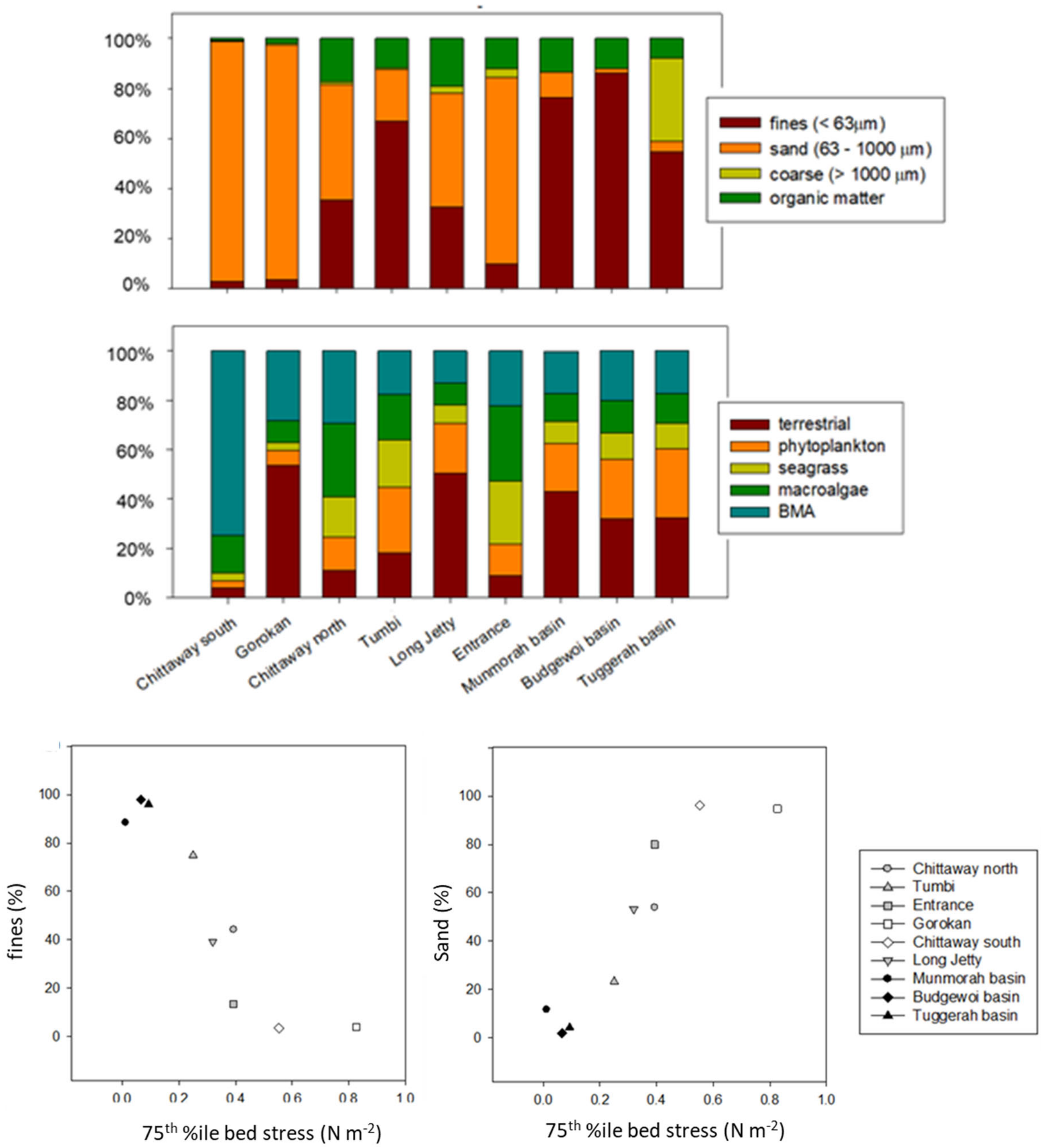


Figure 4-15 Sediment grain size distributions (top panel), organic matter sources at various nearshore sites and the main lake basins (middle panel), and the impact of bed shear stress on sediment grain size (bottom panel).

4.3.4 Nutrient dynamics – lake basins

Nutrients (i.e. nitrogen and phosphorus) are essential elements for the growth of aquatic plants which form the base of many aquatic food webs. Australian waterways are generally characterised by low nutrient concentration, with aquatic ecosystems evolving strategies to tightly recycle and conserve available bio-available nutrients (Harris, 2001b). Increased nutrient supply (e.g. due to urban stormwater pollution) can upset this balance by causing excessive aquatic plant growth, resulting in the build-up of organic matter and a cascade of associated negative impacts (e.g. low dissolved oxygen, sulfidic ooze formation; a process known as 'eutrophication' (Cloern, 2001).

Prior to large-scale development, Tuggerah Lakes estuary was considered fairly nutrient poor or oligotrophic (Roberts et al., 2005), which is a natural state for many NSW estuaries (Harris, 2001a). After development in the 1950s and until the 1990s, human pressures contributed to increasing nutrient loading in the lakes leading to a eutrophic state (Roberts et al., 2005). Since improved catchment management and completion of the sewerage scheme, nutrient loading has been reduced and the estuary is now generally classified as mesotrophic or medium nutrient status, apart from some areas of the developed foreshore where blooms still occur (Roberts, 2000).

Nutrient inputs and internal cycling

Nutrients within the lakes system exist in the water column and the sediments, with dynamic exchange between these two compartments occurring via the resuspension/settling of particulate forms, and diffusive fluxes of dissolved forms (Figure 4-16). In general, dissolved inorganic forms comprise between 10-40% of total nutrient inputs during high flow events (Brennan et al. 2011) and are considered bio-available, while the remaining particulate and dissolved organic forms must be broken down by microbes to release bio-available inorganic nutrients to the environment. The majority of nutrient inputs during floods are exported to the ocean, with a relatively small residual retained within the lake system.

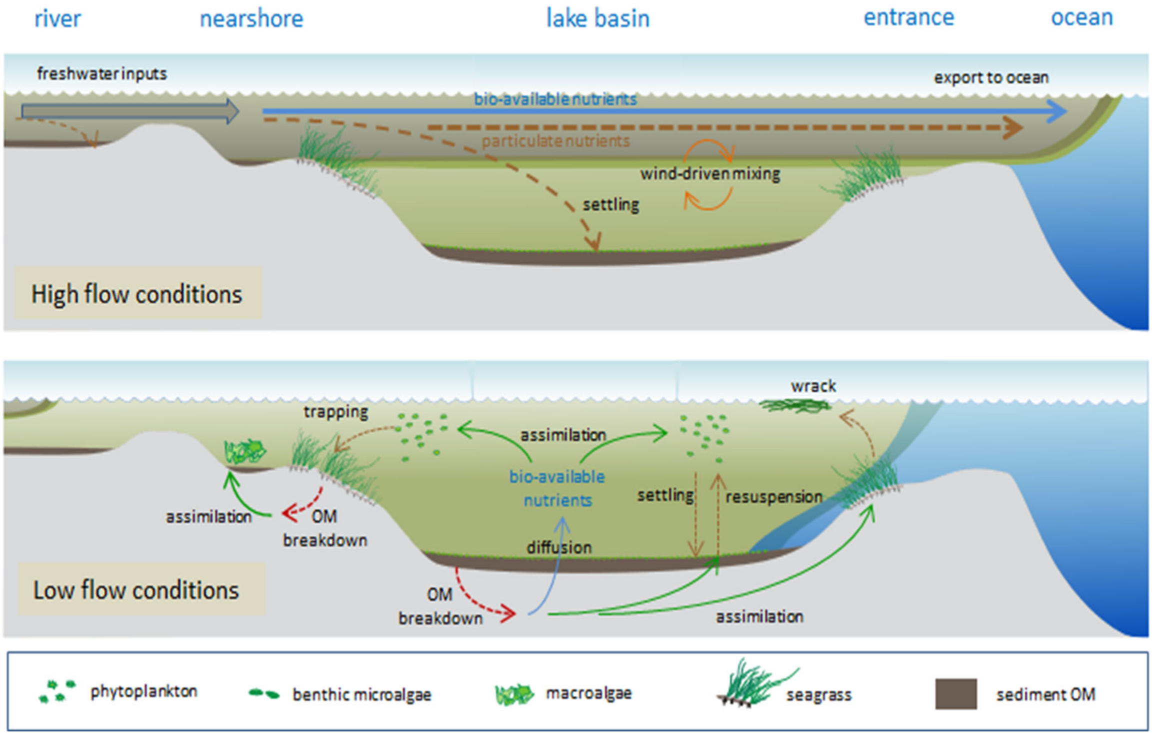


Figure 4-16 Conceptual model of the processes impacting on the transformation of nutrients in the Tuggerah Lakes system during high and low flow conditions

Monthly observations of nutrient concentrations in the lake basins since 2009 reveal strong seasonal trends in both total nitrogen and phosphorus concentrations, with summer maxima and winter minima (Figure 4-17). Nutrient fractions within the lake are dominated by particulate and dissolved organic forms, with bio-available (dissolved inorganic) forms generally accounting for less than 2% of total concentrations (Table 4-2). This indicates that the productivity of aquatic plants in the lake basins is nutrient-limited and must be sustained by internal biogeochemical recycling processes.

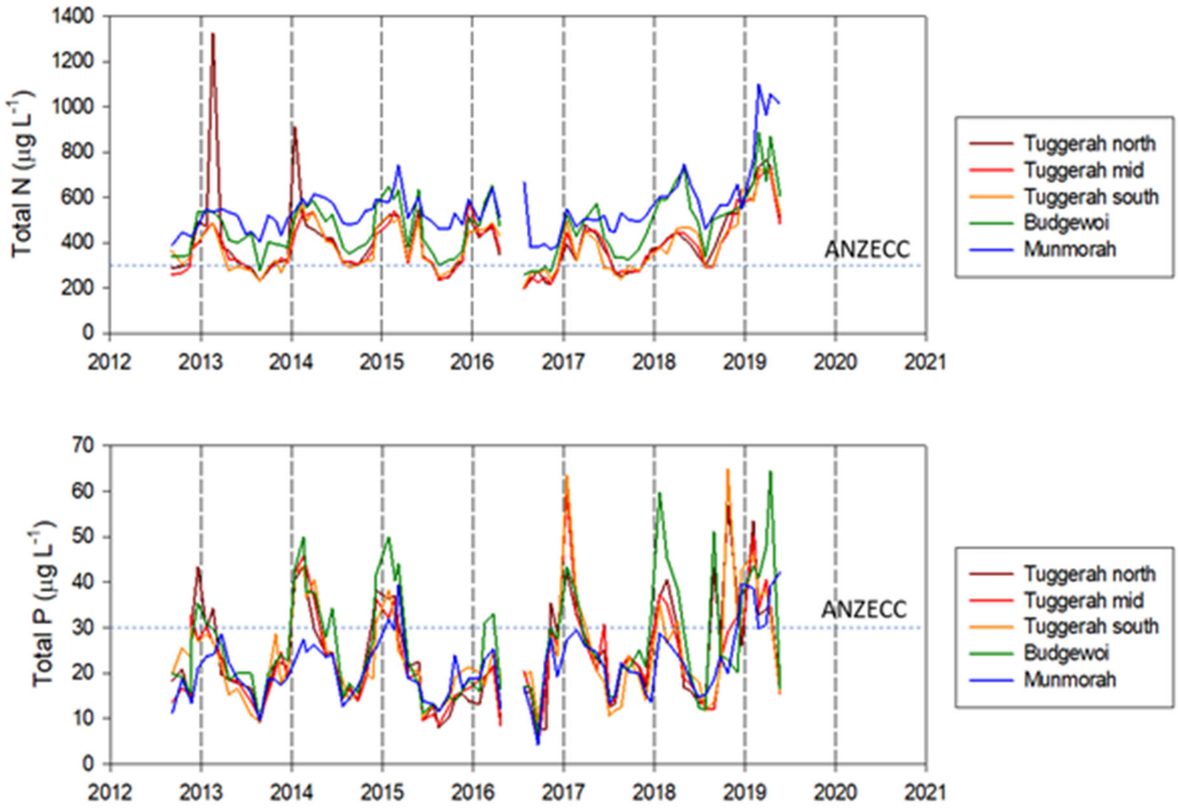


Figure 4-17 Total nitrogen and phosphorus concentrations in the lake basins between 2012 and 2020, showing ANZECC guidelines for the protection of aquatic ecosystems

Nutrients enter the lake system primarily via nutrient-rich freshwater runoff and rainfall, which is then diluted by nutrient-poor ocean water in the lake basin. Salinity can be used as a conservative tracer of the ocean water concentration in a sample since it is unaffected by biological or geochemical transformations. In contrast, nutrient concentrations can be affected by internal sources or sinks due to a wide variety of processes within the lake. By plotting nutrient concentrations as a function of the sample salinity it is therefore possible to assess the net effect of internal nutrient processes (Figure 4-18). If there is simple mixing of fresh and ocean waters with no internal sources or sinks (i.e. 'conservative mixing'), then nutrient concentrations will plot along a straight line as a function of salinity. Samples plotting above this theoretical mixing line imply internal sources and vice versa.

Table 4-2 Percentage of dissolved inorganic nitrogen and phosphorus (DIN and DIP), dissolved organic nitrogen and phosphorus (DON and DOP), total particulate nitrogen and phosphorus (TPN and TPP)

	DIN:TN	DON:TN	TPN:TN	DIP:TP	DOP :TP	TPP:TP
Tuggerah Lake	2%	75%	22%	6%	33%	62%
Lake Budgewoi	2%	75%	22%	5%	34%	61%
Lake Munmorah	1%	77%	20%	6%	48%	58%
Wyong River	4%	71%	24%	12%	27%	62%
Ourimbah Creek	5%	70%	25%	5%	27%	69%
Wallarah Creek	6%	73%	21%	4%	33%	63%

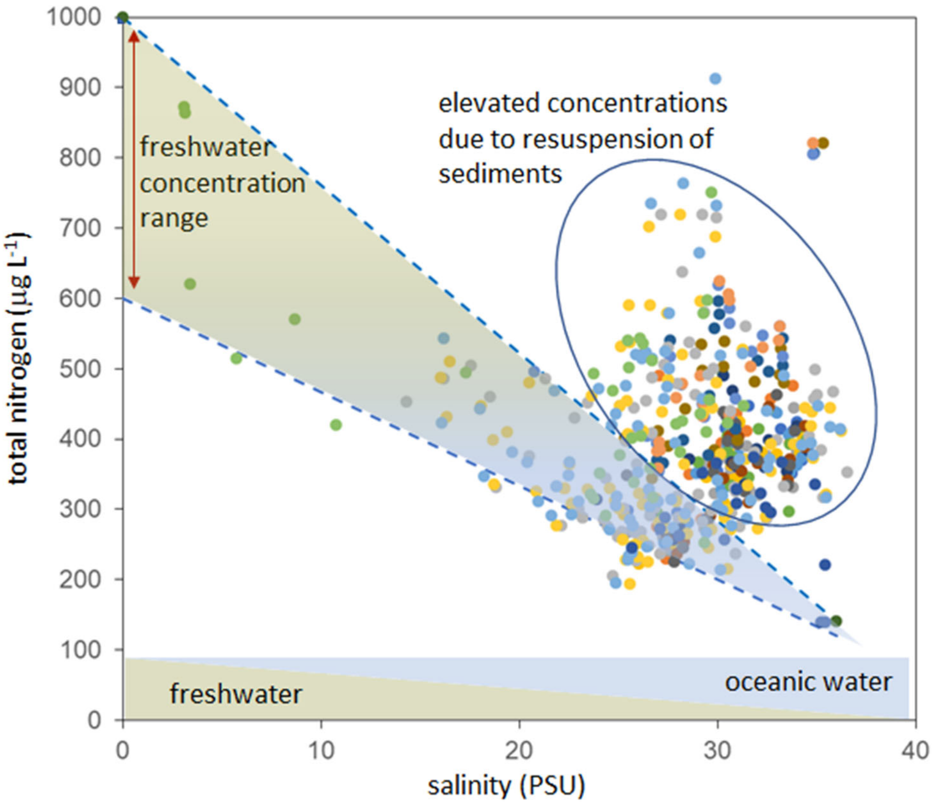


Figure 4-18 The relationship between salinity and total nitrogen concentrations. The envelope bounded by the dashed lines show the expected TN concentrations assuming the straight mixing of freshwater inputs (TN = 600 – 1000g L-1) and ocean water (TN = 150g L-1)

There are no clear linear relationships between nutrient concentrations and salinity as may be expected if freshwater inputs mix conservatively with nutrient-poor ocean water (Figure 4-19). The majority of observations plotting above the conservative mixing line indicates that internal sources control nutrient concentrations within the lake system, increasing concentrations and potentially availability during summer months. These trends suggest three main potential mechanisms:

1. *Wind-driven resuspension of lake sediments* – As discussed in section 4.3.2, there is a general increase in wind-driven resuspension within the lakes during summer. Strong positive relationships between nutrient concentrations and turbidity suggest that wind-driven resuspension of particulate nutrient fractions may be an important internal driver. This hypothesis was supported by ecosystem modelling (Brennan et al., 2011), which found that observed nutrient concentrations over time could only be accounted for by invoking wind-driven resuspension and settling of particulates.
2. *Increased nutrient regeneration with higher temperature* – Temperatures covary with wind speeds, hence it is possible that a proportion of the observed increase in nutrient concentrations during summer is due to nutrient release arising from elevated microbial breakdown of organic matter in sediments at higher temperatures.
3. *Interactions with microalgae* – Strong relationships between chlorophyll-*a* (an indicator of phytoplankton biomass), turbidity and nutrient concentrations, as well as the very low concentrations of bio-available nutrient forms suggest that the fate of nutrients is closely controlled by rapid microalgae assimilation within the lakes. Modelling of benthic light climate (i.e. the amount of light reaching the sediments; Brennan et al., 2010) indicates that photosynthetic production by microscopic plants on the sediments (‘benthic microalgae’) is important and may account for significant assimilation of regenerated bio-available nutrients in the sediments. Resuspension of benthic microalgae (microscopic plants growing on the sediment surface) during wind events may also contribute to the observed chlorophyll-*a* concentrations in the water column. This suggests that the distinction between phytoplankton (microscopic algae in the water) and benthic microalgae may be blurred in Tuggerah Lakes.

4.3.5 Chlorophyll-a

Overview

Chlorophyll-*a* concentrations provide a proxy for microalgal biomass in the water column, which comprises a mixture of phytoplankton and resuspended benthic microalgae. Chlorophyll-*a* is a commonly used indicator of aquatic system health, since excessive phytoplankton growth and biomass (i.e. high chlorophyll-*a*) can occur due to nutrient pollution. This can potentially result in organic enrichment of the system leading to a cascade of negative impacts such as large diel swings in dissolved oxygen, sulphide toxicity and ooze formation. This process is known as ‘eutrophication’.

Chlorophyll-*a* concentrations in the Tuggerah Lakes system are indicative of low to moderate nutrient enrichment (exceeding ANZECC guidelines for the Protection of Aquatic Ecosystems during summer months (ANZECC, 2000), however the likely influence of resuspended benthic microalgae on measured concentrations may be overestimating the degree of enrichment. It is likely that system attributes (bathymetry etc) and forcing processes (hydrodynamics) serve to buffer the lake basin against eutrophication.

Seasonal variation

There was a strong seasonal trend in chlorophyll-*a* (Figure 4-19a), with highest concentrations recorded during the summer-autumn period, and a secondary peak during late autumn. These trends most likely arise from complex interactions between a number of drivers:

1. *Light and temperature* – an increase in primary productivity and biomass during summer is consistent with greater incident light and higher temperatures, however increasing incident light during spring – summer is offset to an extent by wind-driven resuspension which increases turbidity and hence light attenuation in the water column.
2. *Resuspension of benthic microalgae* – good water clarity during winter – early spring results in high potential productivity by benthic microalgae (Brennan et al., 2011), with subsequent increases in wind-driven resuspension of benthic microalgae during early summer influencing water column chlorophyll-*a.* A positive correlation between turbidity and chlorophyll-*a* indicates the potential influence of resuspended benthic microalgae, however seasonal peaks in chlorophyll-*a* (late summer-autumn) lagged the seasonal peak in turbidity (late spring-early summer), suggesting that light and nutrient impacts on phytoplankton productivity are an important driver of observed biomass.
3. *Nutrient availability* – episodic inputs of bio-available nutrients to the lake basin during rainfall events are in themselves not sufficient to support the observed biomass of phytoplankton throughout the year (Brennan et al., 2011). Most bio-available nutrients delivered during freshwater inflows are rapidly assimilated after the event, meaning that productivity in subsequent dry periods must be sustained by the recycling of nutrients from the breakdown of organic matter deposited in the lake sediments during antecedent freshwater inputs. This creates a lag of approximately one to two months between freshwater inputs and phytoplankton growth (Figure 4-20).

Inter-annual variation

Chlorophyll-*a* observations from 2009 indicate variation in the timing and magnitude of seasonal concentration peaks (Figure 4-19b), giving rise to significant inter-annual variation. It is not possible to unravel the exact mechanisms behind this variation within the scope of this report, however it is likely due to complex interactions among the timing and magnitude of various drivers (e.g. light, temperature, wind, and rainfall). It is clear however, that inter-annual variation in climatic drivers on 3-5 year timescales results in very different conditions within the lake which are independent of incremental changes in land use happening over longer timescales. The dynamics of inter-annual variation in chlorophyll-*a* could be better understood by utilising ecosystem response modelling.

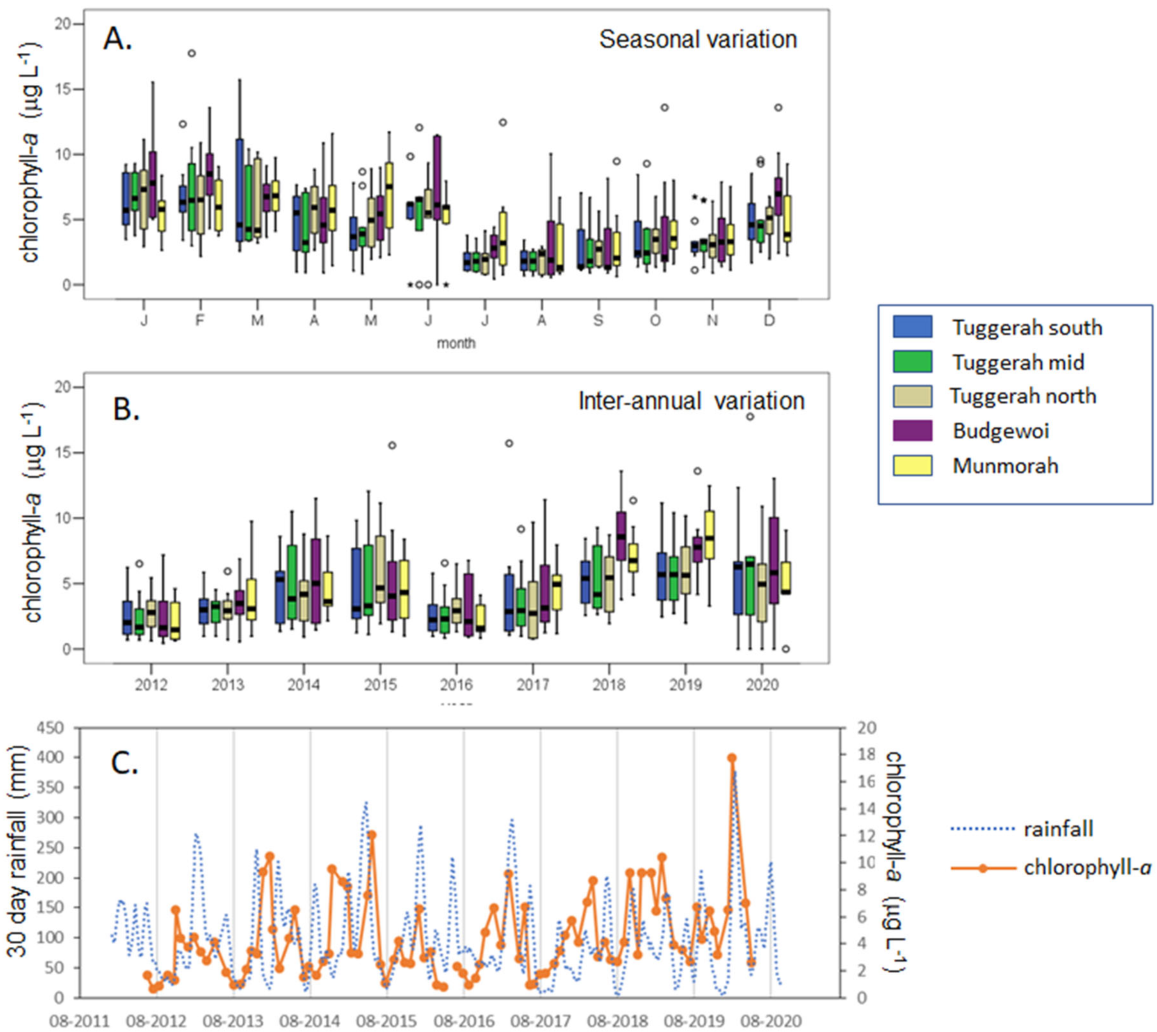


Figure 4-19 Seasonal (A) and inter-annual (B) variation in chlorophyll-a in the three lake basins (2012-2020) with (C) a comparison between chlorophyll-a in Tuggerah Lake (Gorokan) and 30 day rainfall totals

4.3.6 Nutrient dynamics – nearshore zone

Nutrient concentrations in the lake nearshore margins are observed to be consistently higher than lake basin sites, with considerably higher proportions of bio-available nutrient forms (it is notable that nearshore samples were taken from boat at the outer fringe of the nearshore zones therefore they are likely to underestimate the nutrient concentrations within the seagrass / macroalgae barriers). This supports the hypothesis of 'decoupling' between the nearshore and lake basins (see Sections 4.3.1), and also indicates significant nutrient enrichment of the nearshore. Nutrient enrichment in the nearshore may arise via two mechanisms:

1. *The trapping of nutrient-rich urban stormwater within the nearshore zone* – sampling of urban stormwater runoff in Tuggerah Lakes and nearby Lake Macquarie shows much higher concentrations of bio-available nutrients compered to diffuse runoff from rural and forested catchments which enters the lakes via the main rivers/creeks. Assimilation of these stormwater nutrient loads by micro and macroalgae within the nearshore serves to retain a large proportion as organic-bound nutrients which can be recycled when plants die and are broken down by bacteria in sediments. This process is a major contributor to 'ooze' formation along the lake shorelines.
2. *The trapping of organic-bound nutrients from the lake basin* – The quelling effects of seagrass and macroalgae on wave energy and currents in the nearshore allows the trapping and settling of particulate nutrients (e.g. phytoplankton biomass and resuspended sediments) from lake basin waters. This mechanism would contribute to the concentration of nutrients within the nearshore sediments, further exacerbating feedbacks associated with ooze formation.

Similar to the lake basin, there were increases in nearshore nutrient concentrations during summer. In contrast however, the higher proportion of bio-available nutrient forms (e.g. ammonium) suggests that summer peaks along the nearshore are more likely due to increased microbial activity with higher temperature and less likely to be associated with resuspension events.

Eutrophication and decoupling of nearshore zone and basin – a contributor to ooze formation
Along with wind driven processes that lead to fine sediments and wrack being accumulated around the lake nearshore zone, metabolism plays an important role in the production of ooze (see also Section 4.5.3). Metabolism is essentially the combination of primary production (seagrass, and algae growth), and respiration (the decomposition of plant material), and the balance of these processes is controlled by nutrients and physical conditions such as light and temperature. Under elevated nutrient conditions, eutrophication can occur, which results in the accumulation of plant material, primarily algae.

The formation of nearshore barriers of seagrass wrack and macroalgae (Figure 4-20), coupled with shoreline modification, result in limited flushing of the nearshore area with the lake basin. This is illustrated in Figure 4-21, which shows a marked variation in water clarity between the basin which is turbid due to wind-driven resuspension, and the nearshore zone (where seagrass beds are still visible).

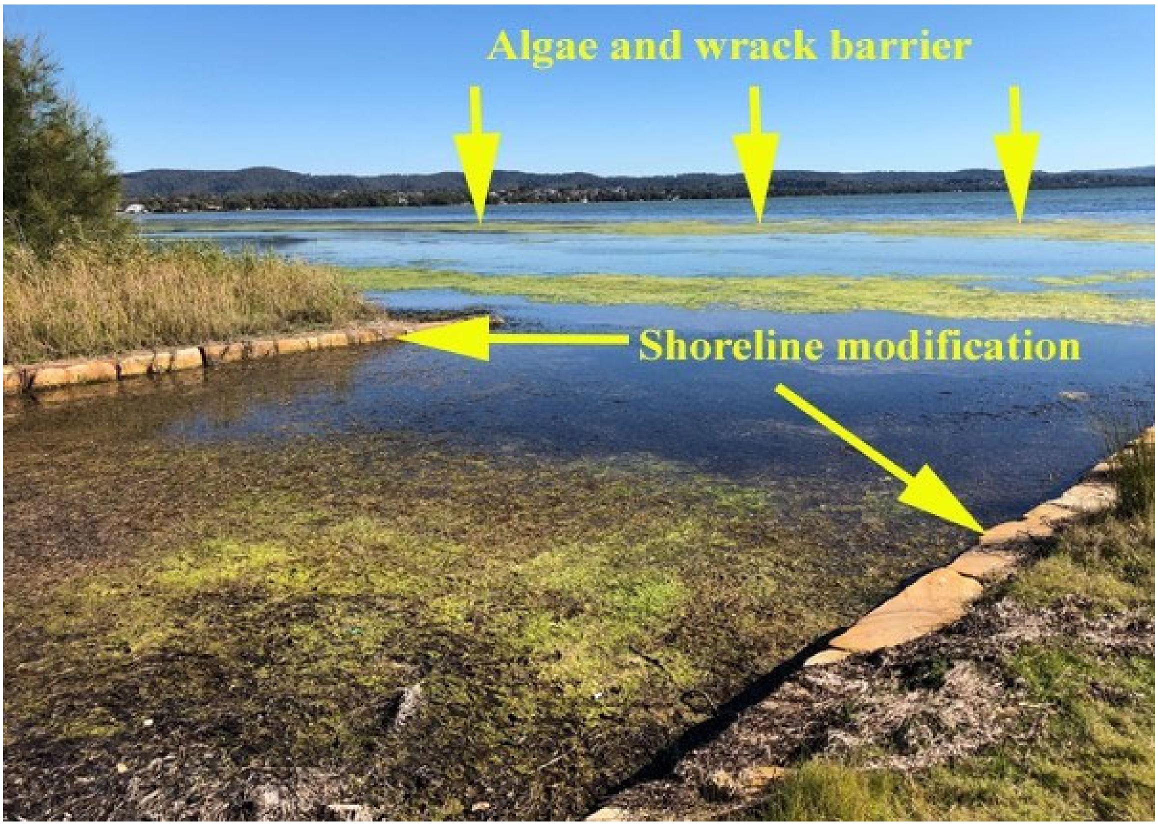


Figure 4-20 Example of shoreline modification and algal/seagrass wrack barrier

Evidence of decoupling and limited mixing between the nearshore zone and the basin can also be demonstrated through the measurement of oxygen concentrations through survey techniques and time series experiments at stations within the nearshore zone, and the adjacent basin. If the conditions were well mixed between the nearshore and basin areas, it would be expected that concentrations and concentration ranges would be similar across the two zones. However, this is not the case, with significant changes in oxygen concentrations in space (Figure 4-22) and time (Figure 4-23). These data highlight limited mixing between the nearshore and basin zones. Long term time series data of dissolved oxygen saturation at nearshore sites displayed large swings between super saturation and hypoxia compared to the relatively stable oxygen conditions in the lake basin. This indicates ongoing eutrophication in the nearshore, and highlights the high degree of inter-annual variation in the condition of different shorelines around the lake.

Figure 4-21 Southern Tuggerah Lake during high winds resulting in sediment resuspension

Note the seagrass beds are still visible on the western shoreline, highlighting the decoupling between the basin and nearshore zone.

Long term time series data of nutrient concentrations also highlight distinct differences between the nearshore zone and the basin (Figure 4-24). Concentrations in the basin do show seasonal variability, however the range over 6 year study period is ~ 300 µg L^{-1}, while the concentrations in the nearshore sites vary from ~ 200 to 1600 µg L^{-1}. Interestingly there are no obvious spikes in TN concentrations in the basin following significant rainfall events, suggesting that catchment loads of nutrients that are delivered to the basin are rapidly mixed and diluted and/or are transported as a buoyant freshwater plume out to sea if the entrance is open during this events. Conversely, the large spikes in TN at the nearshore sites suggest that catchment and storm water inputs to the nearshore exert a strong control over nutrient concentrations in this zone.

As a result of the limited flushing of the near shore zone as demonstrated by the data highlighted above, along with optimal light conditions and a supply of nutrients from both stormwater and groundwater, extensive algal blooms can occur in the nearshore zone (Figure 4-25). Macroalgae and phytoplankton blooms can contribute to declining water quality through extreme shifts in dissolved oxygen concentrations driven by metabolism.

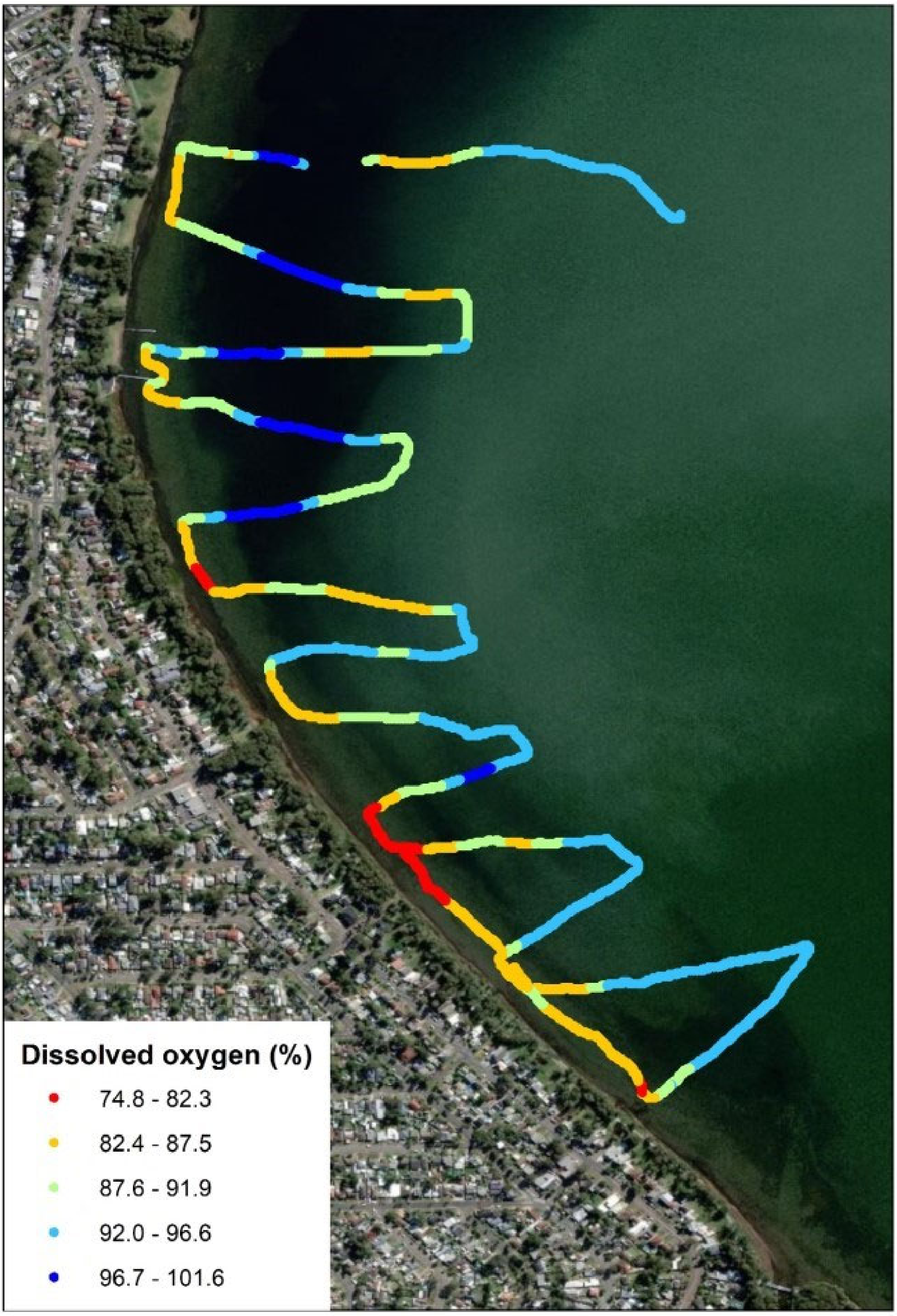


Figure 4-22 Survey data of dissolved oxygen saturation along the Berkley Vale coast line. Note the distinct gradient from the nearshore to offshore zone. Unpublished data.

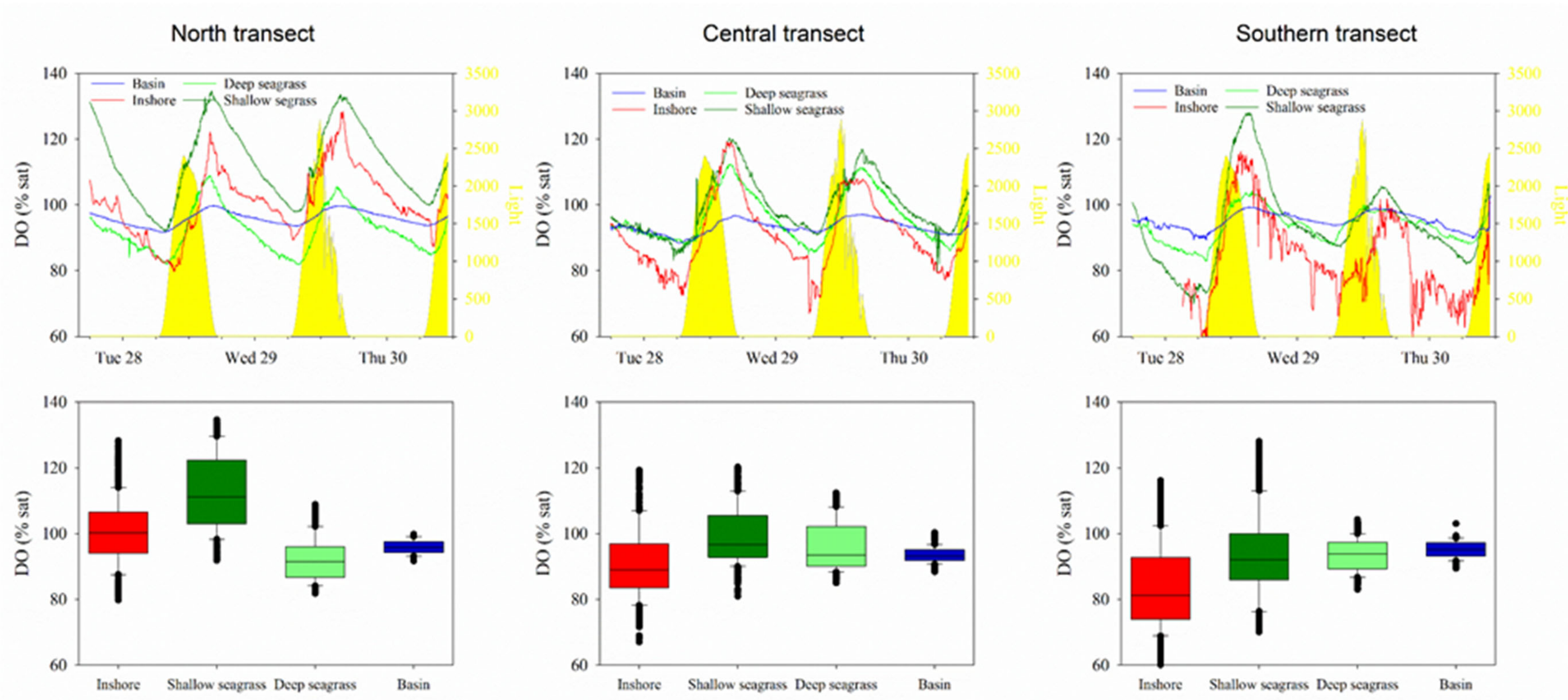


Figure 4-23 Time series observations of dissolved oxygen along three transects in the Berkley Vale area. Note the distinct variability between the inshore and basin regions. Unpublished data.

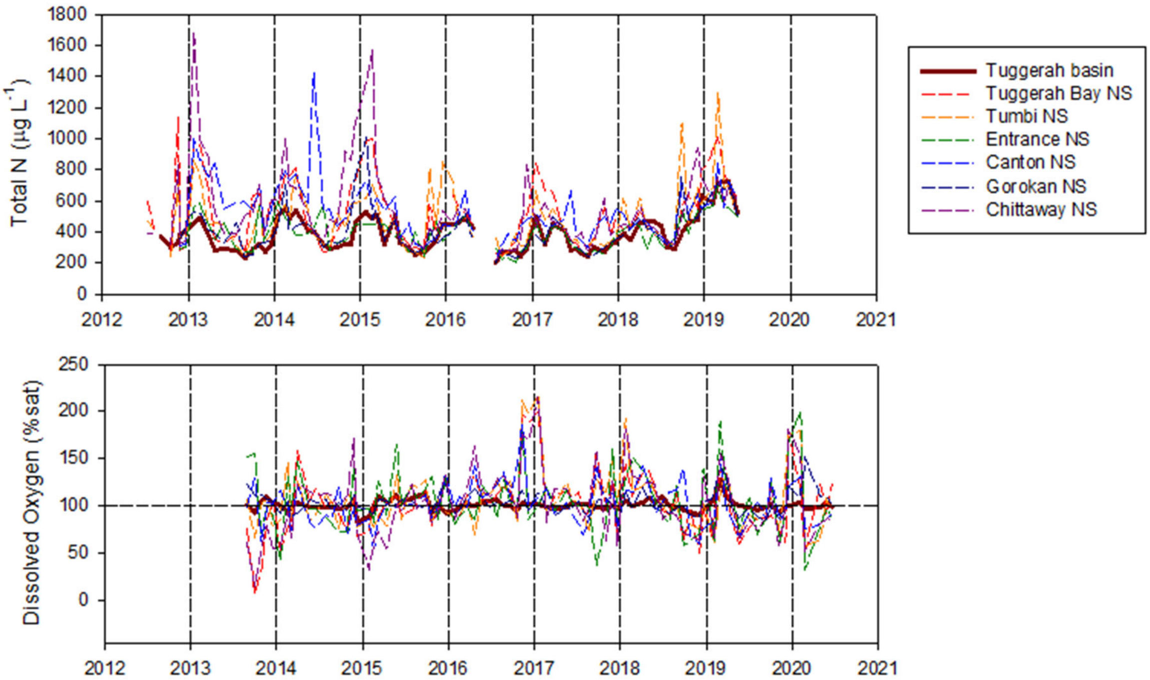


Figure 4-24 Total nitrogen concentrations (top) and dissolved oxygen saturation (bottom) from various nearshore sites (dashed lines) and Tuggerah basin zone (solid line)

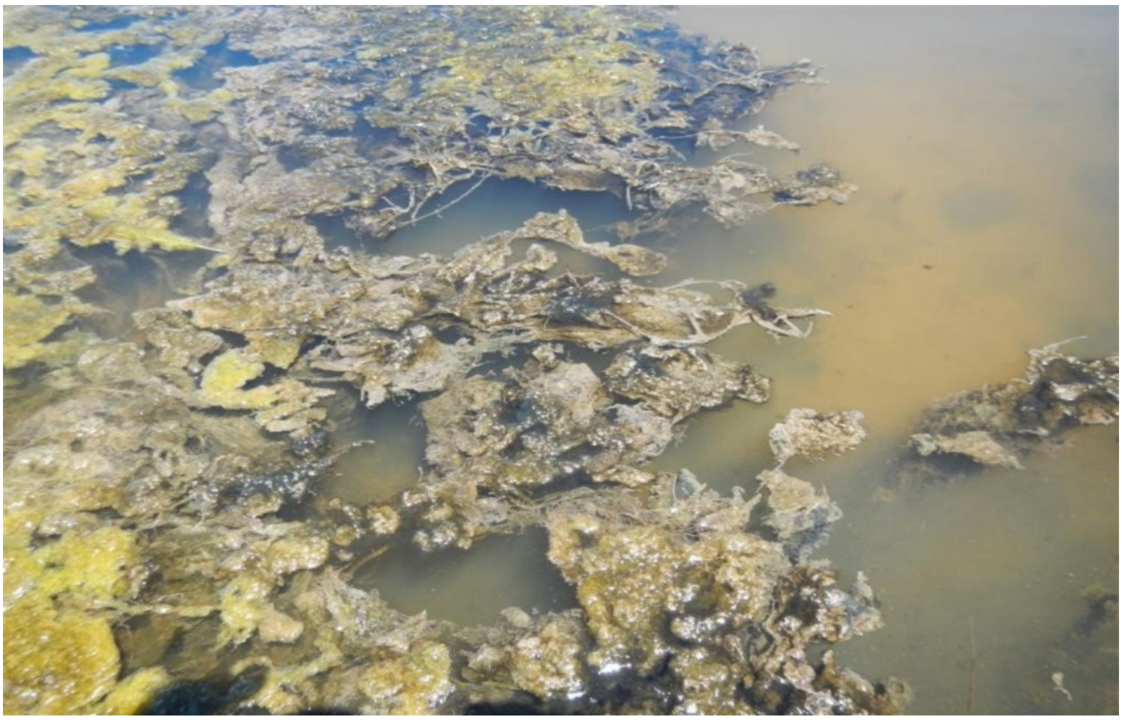


Figure 4-25 Macroalgae rafts found at Berkley Vale

Further, excessive algal blooms can smother seagrass, resulting in declining habitat and biodiversity (see Section 4.5). Under extreme conditions, macroalgae blooms can result in anoxia, as the material is broken down by bacteria which rapidly consume all the available oxygen (Rutten et al., 2006).

In the estuarine environment of Tuggerah Lakes, this breakdown or decomposition process follows a series of different microbial reactions as detailed in Table 4-3. When there is oxygen available the aerobic decomposition process dominates, as there is more energy produced during this process. As oxygen is consumed and no longer available, a series of anaerobic (i.e. without oxygen) processes occur. Among these anaerobic pathways, sulphate reduction is often the dominant pathway in organic rich estuarine sediments due to the high availability of sulphate (seawater has very high sulphate concentrations) (Burdige, 2011). One of the products of this reaction is hydrogen sulphide. This gas is what leads to the distinct "rotten egg" smell that often accompanies macroalgal blooms. The decoupling of the nearshore and basin areas further exacerbates the potential for the formation of rotten egg gas. The basin waters are generally well oxygenated (Figure 4-21), and if hydraulically connected to the nearshore zone, would provide the oxygen required to prevent the production and release of hydrogen sulphide gas.

Table 4-3 Main respiration processes and standard state free energy changes

Process	ΔG° (kJ/mol C)
Aerobic respiration – $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 138O_2 \rightarrow 106CO_2 + 16NH_4 + H_3PO_4$	-471
Denitrification - $CH_2O + 0.8NO_3^- + 0.8H^+ \rightarrow CO_2 + 0.4N_2 + 1.4H_2O$	-444
Manganese reduction - $CH_2O + MnO_2 + 4H^+ \rightarrow CO_2 + Mn^{2+} + 3H_20$	-397
Iron reduction - $CH_2O + 4Fe(OH)_3 + 8H^+ \rightarrow CO_2 + 4Fe^{2+} + 11H_2O$	-131
Sulfate reduction - $CH_2O + 0.5SO_4^{2-} + 0.5H^+ \rightarrow CO_2 + 0.5HS^- + H_2O$	-76
Methanogenesis - $CH_2O \rightarrow 0.5CH_4 + 0.5CO_2$	-49

Adapted from Kremins et al. (2013) and Burdige (2011). Note the order relates to the energy production for the microbial community, with aerobic respiration being the most favourable process, and methanogenesis the least favourable process

The algal blooms formed in the nearshore zone also contribute to the formation of ooze, by providing excess organic matter to the bacterial community (Section 4.5). The macroalgae also acts as a physical trap for any fine sediments that may be delivered to the nearshore zone through erosion, catchment run off or storm water flow. A conceptual model of the key processes associated with algal blooms and the link to decoupling and ooze formation are presented in Figure 4-26.

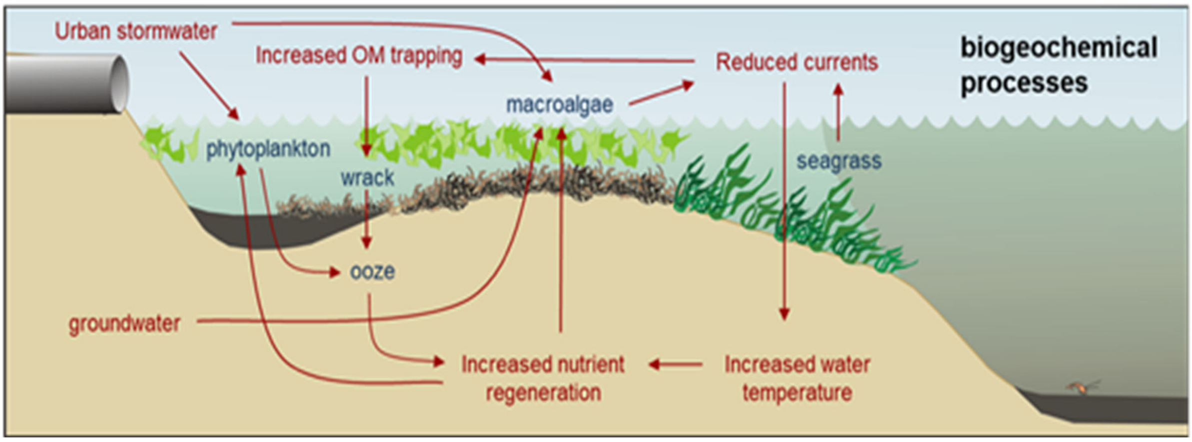


Figure 4-26 Conceptual model of key process for algal blooms and ooze formation

4.3.7 Contaminants in the sediments and waters

Dissolved metals entering the water column and metals adsorbed to sediment particles in the seabed can be bioaccumulated by local flora and fauna with potential ecological impacts on e.g. survival, growth and reproduction (O'Brien et al., 2019). Heavy metals in the sediments and waters of the Tuggerah Lakes system are thought to have increased as a result of industrial activities (i.e. Munmorah Power Station) in the surrounding catchment as well as historical overflows from septic tanks and urban stormwater runoff (Batley et al., 1990). The following section discusses investigations into contaminants from the power station and historical sewerage issues (refer to Chapter 5 regarding stormwater contaminants).

Munmorah Power Station

Munmorah Power Station was established in 1967 and continued operation until decommissioning in 2014. The power station has been investigated several times for potential metal contamination and other environmental change leading to harmful effects on the ecology of the Tuggerah Lakes system (Batley et al., 1990; Batley and Brockbank, 1992). During operation, Munmorah Power station would draw cooling water from Lake Munmorah near Colongra Creek and then discharge water via an outlet canal into Budgewoi Lake near San Remo. These discharges, which included overflows from the nearby ash dam and coal settling basins together with stack emissions of ashes dispersed over the Lakes through wind and runoff, were the main potential sources of metals from the power station.

Studies by CSIRO in 1990 and 1992 concluded that physico-chemical conditions in Tuggerah Lake were relatively unchanged by the operation of the power station, however some heating effects were observed in Munmorah Lake and Budgewoi Lake (~0.8 degrees higher on average) as well as salinity changes up to 3 ppt (Batley et al., 1990; Batley and Brockbank, 1992). These temperature and salinity changes were deemed relatively small when compared to daily and seasonal temperature changes in the lakes as well as changes to physico-chemical conditions resulting from rainfall and runoff events.

Ash content was found to be up to 12% higher in Lake Munmorah sediments compared to the rest of the lakes, and some metal enrichment was observed in sediments with higher clay/silt fractions. Specifically, copper, lead and zinc concentrations were enriched by up to 60-100%, but there was no evidence of enrichment of dissolved metal concentrations or significant accumulation by seagrasses or sediment-dwelling infauna. Furthermore, there were no differences in macroinvertebrates observed near the power station discharge compared to the other areas of the lakes (Powis, 1975). Together, this suggests that ecological impacts from metal contamination would have been unlikely. Elutriate tests also indicated that arsenic and selenium could have been released into lake waters through ash leachates although at very low concentrations due to dilution.

Sewage and faecal contamination

In the past, sewage release and septic tank overflows may have contributed to issues of water quality in the Tuggerah Lakes. Specifically, from the 1960s-1970s, seepage from septic tanks and greywater into drains and the lake system were a major source of faecal contamination and nutrients that increased with the growing population and associated development (Scott, 1998). These issues have largely been eliminated since the development of a reticulated sewerage system and the shift in sewage treatment pond discharges from Tuggerah Lake near Canton and Wyong River to an ocean outfall.

Central Coast Council (Council) continues to monitor and report on the water quality at 32 swimming sites, including several within the Lakes' system. Beachwatch sampling is also done at Canton Beach and in Lake Munmorah. Samples target *Enterococci* which are bacteria common to the faecal material from animals and indicate stormwater and/or sewage contamination at a site. In 2018-19, all estuary beaches on the Central Coast, including Canton Beach and Lake Munmorah were graded poorly for faecal contamination. It should be acknowledged it isn't always possible to determine the source of contamination, the *Enterococci* could have been introduced from bird and dog faeces washing into the lakes. Council is currently working with universities to understand sources of microbial contamination in the lakes and work towards source tracking (Central Coast Council, 2020f). Results are not yet available but will assist in management to improve water quality.

4.4 Groundwater

Key Points
Groundwater can be an “invisible” source of nutrients to coastal lakes.
It is important to account for groundwater inputs when assessing the efficacy of management strategies.
Groundwater may provide a continuous supply of nutrients to the nearshore zone even when surface water (e.g. storm water) inputs are negligible.
Legacy effects of restoration project may include enhanced groundwater nutrient inputs, due to nutrient rich dredged materials. Detailed data to assess this hypothesis are not available.
Preliminary data suggest that groundwater may be a locally important source of nutrients to the nearshore zone of Berkeley Vale. Further research is recommended.
Opening strategy will likely have an effect on groundwater discharge due to changes in tidal amplitude.

Management focus on improving water quality in Tuggerah Lakes has been directed towards improving stormwater quality, and catchment inputs via surface water runoff through strategies such as bank stabilisation and wetland remediation and installation of stormwater quality improvement devices (SQIDs). However, groundwater inputs of nutrients may also contribute to poor water quality, particularly in the nearshore zone where mixing is limited. Historically, reports of macroalgae blooms in the Canton Beach area during the 1980’s were believed to be associated with groundwater inputs of nutrients associated with on-site septic systems. Macroalgae blooms in the area declined following the implementation of a central sewer system in the area.

The factors controlling groundwater inputs to coastal waters are varied (Figure 4-27), however, if there is a head differential between the groundwater table and surface water level there will be some flow of groundwater due to the hydraulic gradient. In Tuggerah Lakes, the primary drivers of groundwater input are likely the terrestrial hydraulic gradient, and tidal pumping and wave setup (particularly when the entrance is open).

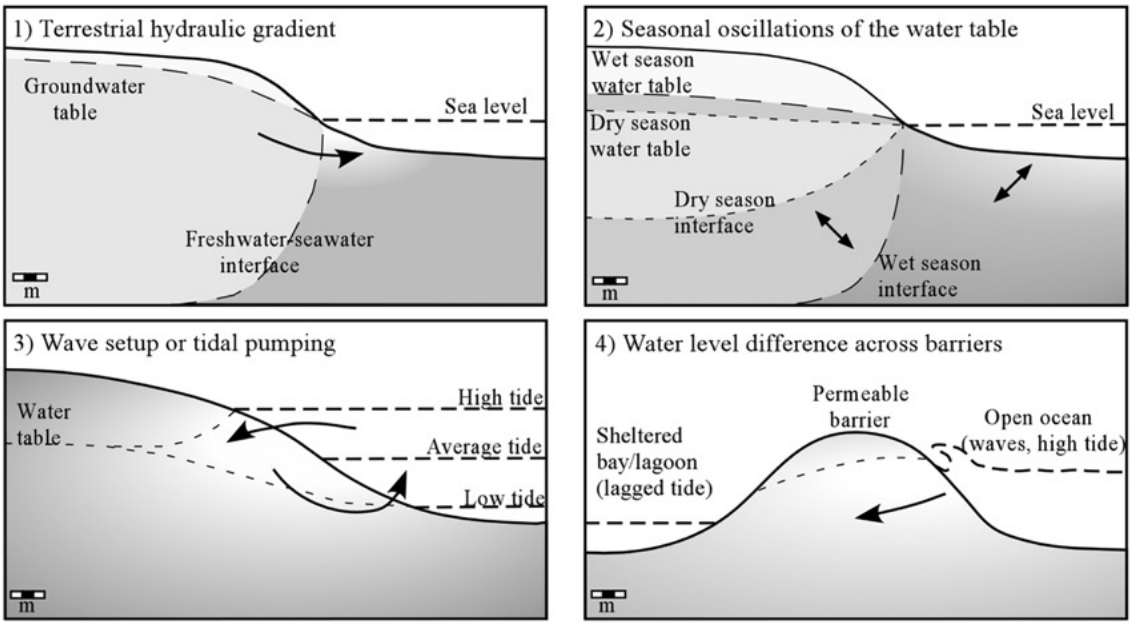


Figure 4-27 Conceptual models of the key processes driving groundwater inputs to Tuggerah Lakes (Santos et al., 2012)

Groundwater often has much higher concentrations of nutrients and other contaminants (e.g. heavy metals) than surface waters. Research in the nearby Avoca Lake, suggested that groundwater inputs were a significant source of nitrogen and phosphorus that stimulated macroalgae blooms (Maher et al., 2019). Indeed, that study showed that groundwater supplied approximately 16 times more nitrogen and 85 times more dissolved phosphorus to the lake than surface water. While the geology, topography, land use and geomorphology of Avoca Lake is different to Tuggerah Lakes, these results highlight the potential for groundwater to be an overlooked “invisible” source of nutrients.

To date there have only been preliminary studies undertaken on quantifying groundwater inputs to Tuggerah Lakes, although anecdotal evidence of freshwater springs along the lake have been documented (Scott, 1998). A review of satellite imagery also indicates areas of groundwater discharge in the Canton Beach, Chittaway Bay and the Budgewoi areas (Figures 4-28 - 4-30). Areas with distinct tannin-stained plumes are often indicative of groundwater discharge.

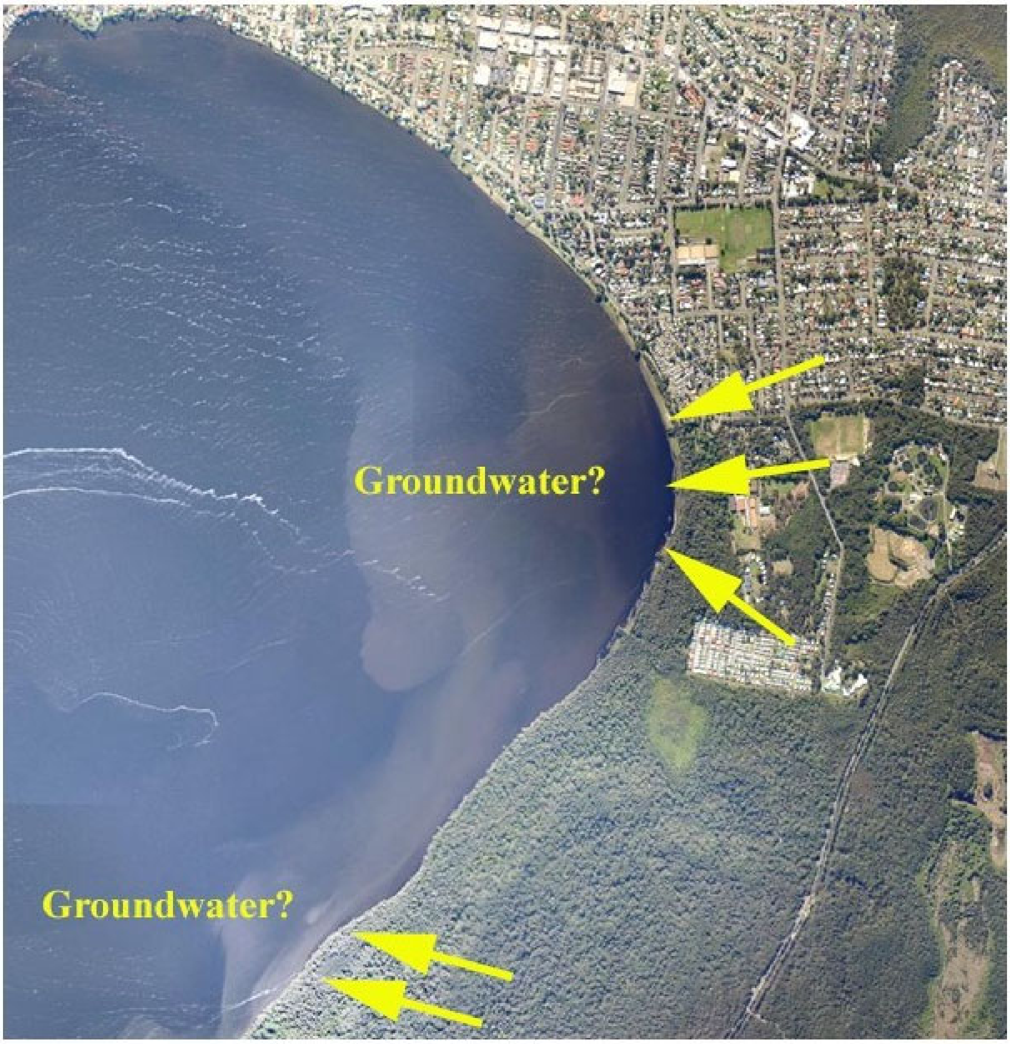


Figure 4-28 Satellite imagery highlighting potential groundwater plumes at Canton Beach

Figure 4-29 Evidence of possible groundwater seepage channels at Chittaway Bay

Figure 4-30 Groundwater seepage plumes as evidenced by dark tannin-stained water at Budgewoi

Current sampling by NSW DPIE in collaboration with SCU is focused on determining whether groundwater seepage to the nearshore zone of Berkeley Vale may contribute to nutrients that fuel macroalgae blooms, and subsequent ooze and odour issues. This work has included the establishment of groundwater monitoring bores along the Berkeley Vale shoreline, and measurement of groundwater tracers and nutrients concentrations in both groundwater and the nearshore zone of Berkeley Vale.

Preliminary data suggest that shallow groundwater in the Berkeley Vale area has very high concentrations of nutrients, with the ratio of groundwater to surface water concentrations ranging from 4 to 4000 depending upon the nutrient form (Figure 4-31). These high nutrient concentrations in shallow groundwater suggest that inputs of groundwater can contribute to nutrient loading.

Determining groundwater discharge rates to coastal waters is not a simple process. One method that has become increasingly popular is the use of natural tracers. One such tracer is radon, a

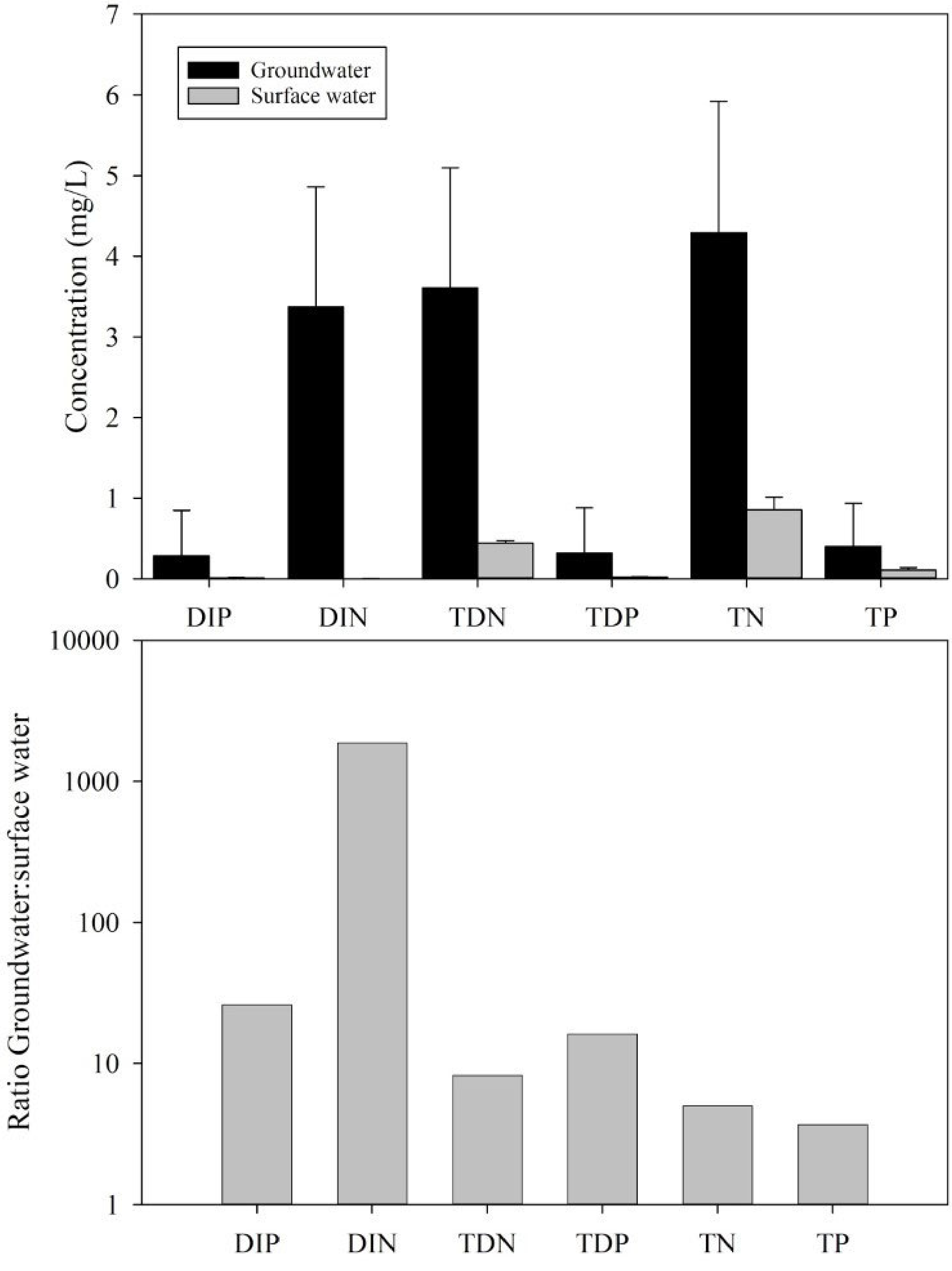


Figure 4-31 Groundwater nutrient concentrations (top, black bar) and nearshore lake water nutrient concentration (grey bars) from the Berkley Vale region, March 2020

naturally occurring gas that is produced in soils through the radioactive decay of naturally occurring minerals (Burnett et al., 2006). By measuring radon concentrations in the groundwater and in the receiving estuarine waters, a model can be used to estimate how much groundwater is discharged, as well as provide insights into where that groundwater is being discharged to (Figure 4-33).

Boat-based surveys of the groundwater tracer radon suggest that there may be hotspots of groundwater seepage along the Berkley Vale shoreline. Using radon (a groundwater tracer) and a mass balance model (as described by (Maher et al., 2019)) groundwater discharge rates were estimated during March 2020. The results indicate a groundwater discharge ranging from 0.43 to 2.35 cm/d (or 4.3 to 23.5 $L/m^2/d$).

By combining the volumetric groundwater discharge rate, with the concentrations of nutrients measured in the groundwater the input of nutrients via groundwater flow can be estimated. The calculated groundwater discharge rates can replace around 23% of the observed total dissolved phosphorus concentrations, and 47% of the observed total dissolved nitrogen concentrations in the nearshore zone of the Berkeley Vale area daily during the study period (March 2020). The groundwater nutrient discharge rates suggest that groundwater may supply a constant feed of nutrients to the nearshore zone following rainfall events. Rainfall events increase the hydraulic head (i.e. the height difference) between the groundwater table and the estuary water level due to recharging the aquifer. This height differential is one of the key factors controlling the rate of groundwater discharge (see Figure 4-27). This extended input of nutrients into the decoupled nearshore zone via groundwater discharge likely sustains macroalgae blooms after surface runoff of nutrients has ceased. As a result, groundwater may further exacerbate eutrophic conditions in these nearshore areas, contributing to both ooze and odour problems.

The high concentration of nutrients in groundwater surrounding the Berkley Vale shoreline may be related to the extensive Tuggerah Lakes Restoration Project, which included land reclamation using dredged material from the lake bottom. These lake sediments typically have high nutrient concentrations, which may help sustain the high concentrations of nutrients observed in the groundwater of Berkley Vale shoreline. Any legacy effect associated with this process are unknown, but warrants further investigation.

Groundwater discharge may also be influenced by entrance opening condition, through changes in the head differential between lake waters and the groundwater table. This mechanism, known as tidal pumping, can be a dominant driver of groundwater exchange in tidal systems. When open, the tidal signal in Tuggerah Lakes actually reflects more of the spring-neap cycle than the typical semi-diurnal (twice daily) tides observed in the nearby ocean (Figure 4-32). This tidal frequency may affect nutrient inputs via groundwater through two mechanisms:

1. Water that infiltrates the sediment during the higher tides has a longer residence time in the soils, enhancing the time for nutrients to accumulate,
2. The extended low tide period allows a greater volumetric discharge of water to the lake, increasing the total groundwater derived nutrient inputs.

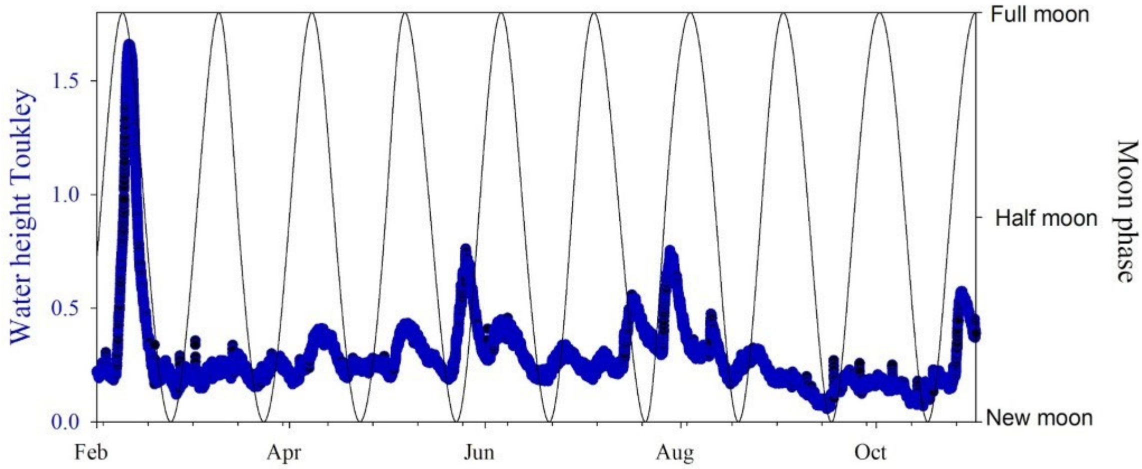


Figure 4-32 Water level height measured at Toukley during 2020 (blue line), and moon phase (black line). Note the greater influence of spring-neap cycles (fortnightly) to water level than semi diurnal (twice daily) cycles.

The two processes described suggest that if groundwater is a major source of nutrients to the nearshore zone, any management decisions leading to permanent entrance opening (e.g. installation of training walls) may enhance nutrient delivery to the nearshore zone. This in turn could exacerbate macroalgal blooms and the formation of ooze.

Management of groundwater inputs of nutrients is a difficult task, particularly if there are legacy affects associated with historical enrichment of nutrients within the aquifer which can take decades to reach surface waters (Shishaye et al., 2020). Further, the diffuse nature of groundwater-surface water exchange can complicate "end-of-pipe" type solutions. However, some success has been achieved where groundwater inputs are localised through microbial remediation techniques such as bioreactors.

Figure 4-33 Groundwater discharge rates determined along the Berkley Vale shoreline using a natural groundwater tracer technique

Bioreactors use microbial processes to transform nutrients from a bioavailable form to a more inert form. Nitrogen can be transformed from bioavailable ammonium and nitrate to dinitrogen gas (that is released to the atmosphere) through a series of microbially-mediated pathways including Nitrification, which transforms ammonium to nitrate, and denitrification, which transforms nitrate to dinitrogen gas. Denitrification is the key process that removes nitrogen from the system, as the nitrogen form is changed to an unreactive gas and is lost to the atmosphere. While the efficacy of bioreactors in various setting remains to be determined, bioreactors are one of the few treatment options available for groundwater nutrient contamination. Other options are excessively expensive, and could have unintended environmental impacts. For example, some success with PFAS remediation has been achieved through extraction and treatment of groundwater. However such methods are not economically feasible for treatment or nutrients in shallow groundwater due to the widespread (diffuse) nature of the problem.

There currently is not enough information on the importance, or the distribution of groundwater-derived nutrient inputs to Tuggerah Lakes to provide clear management recommendations. Further studies would help identify the relative importance of groundwater nutrient inputs, as well as the spatial and temporal variability. This information could the inform management of whether options such as strategically located bioreactors in groundwater discharge hotspots may provide some benefit in reducing nutrient inputs to Tuggerah Lakes.

4.5 Ecological communities and interactions

Key Points
Seagrasses and seaweeds are important ecological communities contributing to water quality in the Tuggerah Lakes system, however seagrasses have declined by ~80% in recent decades resulting in a switch to a seaweed dominated system.
Seagrass surveys highlight an overall decline in spatial coverage and yet excess wrack production continues to be linked to ooze.
The species considered to be a nuisance in the Lakes are those that occasionally bloom to form large floating mats and accumulate in the nearshore where ooze can develop. These include *Enteromorpha*, *Chaetomorpha* and *Rhizoclonium.* The increasing occurrence of algal blooms supports that the Lakes system has been shifting from a mesotrophic to increasingly eutrophic state and overall has shifted from a seagrass dominated system to a seaweed dominated system.
The processes contributing to ooze formation are primarily occurring in the nearshore zone, and these are decoupled from the lake basin. Therefore the problems of wrack accumulation and ooze development cannot be fixed by increased oceanic exchange through entrance management.
Tuggerah Lakes supports a diverse bird community both on the lakes and around the foreshores, and has been recognised as a globally important bird area. 379 bird species have been recorded in the Central Coast Region between 1970-2010 and approximately 63 of those have been sighted on or around Tuggerah Lakes.
Bird communities have likely been directly impacted by foreshore development replacing natural habitats, poor water quality impacting on the abundance and quality of food as well as wrack harvesting removing habitat and food.
Macroinvertebrates and fish have supported important recreational and commercial fisheries in Tuggerah Lakes although fishing businesses and landings have been declining over the past four decades. Fisheries landings between 1987-2018 report 131 fish, 8 cephalopod and 24 other macroinvertebrate species.
Saltmarsh is listed as a threatened ecological community under the EPBC Act 1999, but 85% of saltmarsh has already been lost from Tuggerah Lakes. The Central Coast Council has been restoring or rehabilitating saltmarsh sites around the foreshore with over 30 ha completed so far.

Tuggerah Lakes supports a rich food web from the benthic microalgae living on the seabed and phytoplankton in the water column to the larger fish and birds that may be transitory residents (Figure 4-34). The dominant macrophytes include seagrass and seaweeds and despite their ecological importance, many are considered nuisance species. Part of this negative perception is evident in the use of “weed” for many of the common names. The growth of microalgae and aquatic macrophytes such as seagrass and seaweeds is affected by a number of natural factors including temperature, nutrients, salinity, light, and the presence of herbivores. Rarely do these natural factors act in isolation and it is difficult to separate their effects from anthropogenic stressors arising due to rapid urbanisation of the catchment, recreational use of the waterway, as well as siltation the resulting high turbidity.

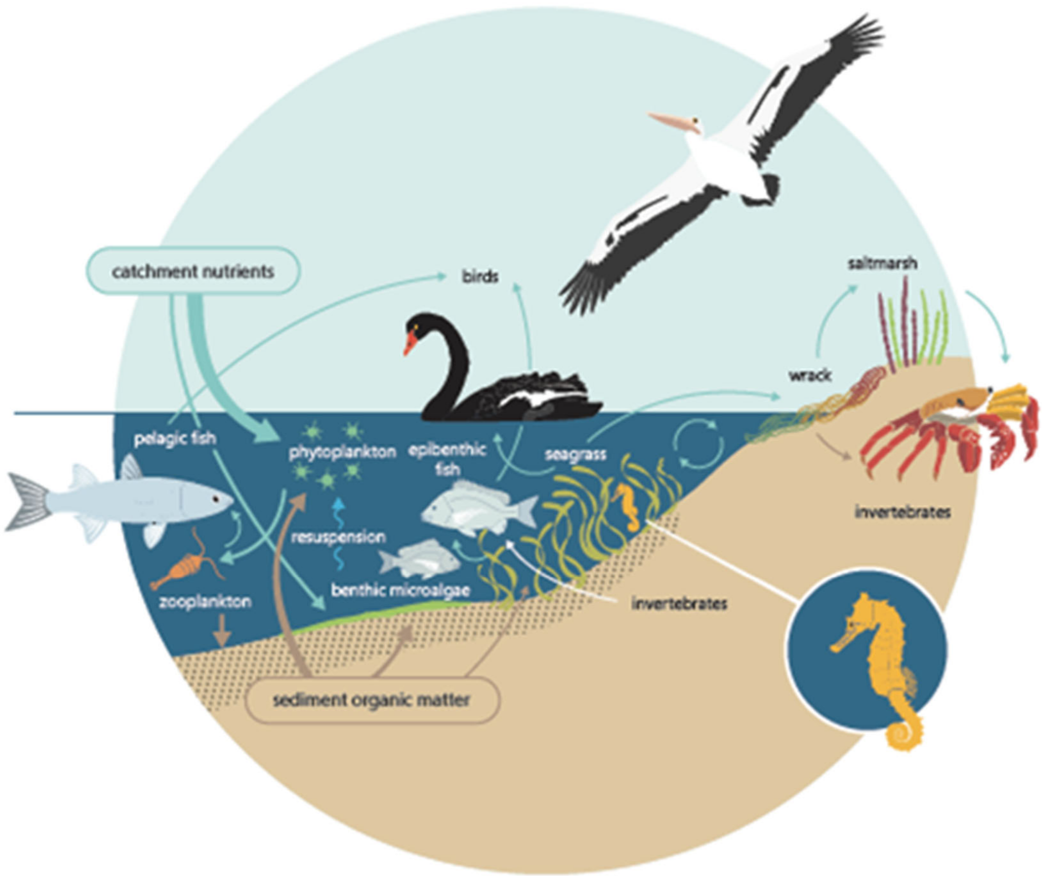


Figure 4-34 Interactions between the Tuggerah Lakes food web and nutrient cycling (reproduced with permission of Central Coast Council)

4.5.1 Seagrasses

Seagrass beds provide critical environmental (wave and storm buffering, enhancing water quality) and socio-economic services (support recreational and commercial fisheries) (Mtwana Nordlund et al., 2016). Seagrass are efficient primary producers (Duarte and Cebrian, 1996). As such, they play an important role in carbon dioxide sequestration, which can reduce the effects of ocean warming and acidification (Duarte et al., 2013). They also provide substrate for many marine organisms including epiphytes (microalgae) and small marine animals (e.g. protozoans) as well as food and shelter for fish and crustaceans (Scott, 1998). Seagrass meadows also help to reduce foreshore erosion by dissipating wave energy (Ondiviela et al., 2014). Loss and damage of seagrass beds across Australia has led to the long-term degradation of estuarine ecosystems (Orth et al., 2006). It is estimated that approximately 80% of seagrass has been lost from the Tuggerah Lakes system, with the majority of loss occurring since the 1960s (Roberts, 2000; Dickinson et al., 2006).

Three species of seagrass are found in Tuggerah Lakes; *Halophila ovalis*, *Ruppia megacarpa* (stack weed) and *Zostera capricorni* (ribbon weed). In the 1920s-1930s, anecdotal reports suggest that *Ruppia megacarpa* covered the deeper parts of Budgewoi Lake and southern parts of Tuggerah Lake, reaching lengths of up to 3m (Scott, 1998). Reports from the late 1930s-1940s document a die off of seagrass including *Ruppia megacarpa* and *Zostera capricorni*, with some linking this loss to a period when the entrance was blocked (Scott, 1998). Seagrass was then observed by fishermen to have generally increased in the nearshore between 1950s-1960s making the use of hauling nets difficult. The hauling nets and scythes used by prawn fishermen were actually thought to be helping keep eastern shores of Tuggerah Lakes free of weed (Scott, 1998).

Residents talk about a significant weed resurgence in the late 1960s, and this has been linked to temperature increases from the power station operation, increasing nutrients entering the lakes from urban runoff and sewage pollution (Scott, 1998). However, this resurgence was short lived as the increased nutrients led to macroalgal blooms, and sediment loads entering the lakes reduced the amount of light available for photosynthesis (Roberts and Dickinson, 2005). Surveys done in the 1980s found that the aerial coverage of *Zostera capricorni* in particular had halved since the 1960s although there was a significant increase in *Halophila ovalis* extent (Higginson, 1995) (Table 4-4). Despite these declines, excess seagrass wrack production has been linked to problems of ooze on the foreshores of Tuggerah Lakes and this has been a major driver of management actions (Dickinson et al., 2006).

Table 4-4 Seagrass cover in Tuggerah Lakes (km^2)

	Zostera	Halophila	Ruppia	Total
1980-1985 (King and Hodgson, 1995)	8.66-16.69	4.10-13.36	1.76-8.24	14.52-38.29
1986 (King and Hodgson, 1995)	9.69	6.24	10.82	26.75
1988 (King and Hodgson, 1995)	8.97	8.98	6.81	24.76
1991 (King and Hodgson, 1995)	12.31	5.38	9.10	26.79
2009 (Creese et al., 2009)	*	*	*	17.32

* indicates species were present, but individual data not available

4.5.2 Seaweed

Seaweed forests are among the most productive habitats on Earth (Smale et al., 2013) and are believed to export over 80% of their primary production as detritus (Krumhansl, 2012). This export has great consequences for connectivity among habitats, as well as secondary productivity in adjacent and remote habitats (Filbee-Dexter and Scheibling, 2014). Seaweeds also contribute to stabilising sediments, nutrient cycling, energy capture and flow, and elevated secondary production through the provision of habitat (Smale et al., 2013).

The main species of seaweed documented from Tuggerah Lakes include *Chaetomorpha linum* (rope weed), *Enteromorpha intestinalis* (green or bait weed), *Cladophora* spp. (goat weed), *Sargassum* sp. (bladder wrack), *Chara* sp., *Cystophyllum muricatum*, *Dictyota* spp., *Polysiphonia mollis*, G*racilaria verrucosa*, *Lyngbya majuscula*, *Rhizoclonium implexum*, and *Lamprothamnium papulosum.* The species that are considered to be a nuisance in the lakes are those that occasionally bloom to form large floating mats and accumulate in the nearshore where ooze can develop. These include *Enteromorpha*, *Chaetomorpha* and *Rhizoclonium* (King, 2010).

Anecdotal reports suggest that seaweed has always been present in the Lakes, but that coverage varies with season and inter-annually. For example, very little seaweed was observed in the 1940s compared to the 1960s (King, 2010). Distributions of seaweed within the Lakes has also appeared to have shifted from the deeper basin to the nearshore where blooms occurred in the 1970s, 1980s and 1990s (Scott, 1998). These patterns initiated an investigation into whether the Munmorah Power Station could be a cause of excessive seaweed growth, leading to blooms. However, this has been largely disproved since the heated water only affected Lakes Budgewoi and Munmorah yet the blooms also occurred in Tuggerah Lake. Further, the power station was operating for over 20 years before many of the blooms occurred (King, 2010). The increasing occurrence of algal blooms supports that, at that time the Tuggerah Lakes system had been shifting from a mesotrophic state to increasingly eutrophic (Roberts, 2000) and overall has shifted from a seagrass dominated system to a seaweed dominated system (Swanson et al., 2013).

4.5.3 Wrack and ooze

Wrack describes the plant materials that have become dislodged from sediments or rocky shore substrates and are moved about by wind. Seaweeds and seagrasses are the primary contributors to wrack in Tuggerah Lakes (Ferguson and Scanes, 2013). Wrack formation can occur due to seasonal die back and natural disturbances such as bird feeding activities, or due to anthropogenic disturbances such as propeller action from boats. Wrack remains floating for a period of time, but can form large mats and eventually washes up onto beaches or becomes lodged in foreshore vegetation such as saltmarsh (Scott, 1998). Detritus such as wrack provides habitat to beach macroinvertebrates, food for fish and bird species, and breakdown of wrack releases essential nutrients back into the system.

The accumulation of wrack on shorelines is determined by the location and supply of wrack sources as well as factors such as wind and prevailing currents that determine transport and fate (Ferguson and Scanes, 2013). The shoreline aspect determines the exposure of different locations to wind and wave energy, and therefore the sediment type and likelihood of wrack arrival at the beach. The grade of the shoreline and features such as shoots, roots and cobbles will then determine whether the wrack accumulates and remains on the beach to decompose or is translocated on the next tide. Natural flooding and changes in water levels in the lakes would have previously helped to shift wrack up the shoreline to be mineralised by biota as the flood waters receded (Swanson et al., 2013). Steeper beaches, less water level variation due to entrance management and shoreline armouring have reduced the transport of wrack up the shoreline and this, together with shoreward migration of seagrass, has contributed to wrack and dissolved nutrients being trapped in the nearshore zone (Figure 4-35 and Figure 4-36). These factors are contributing to the development of ooze.

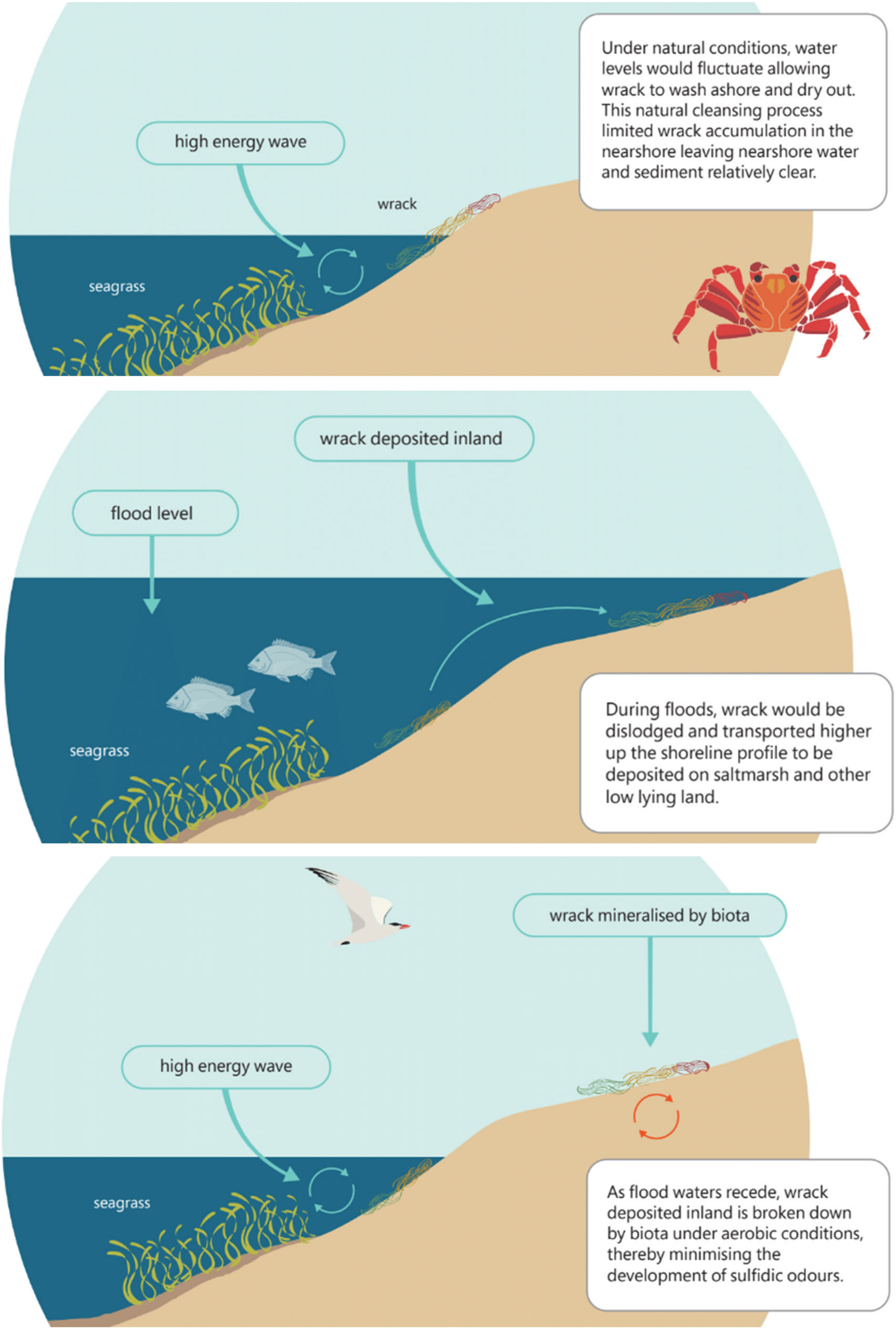


Figure 4-35 Scenarios illustrating the natural processes of wrack transport, accumulation and decomposition on shorelines (reproduced with permission of Central Coast Council)

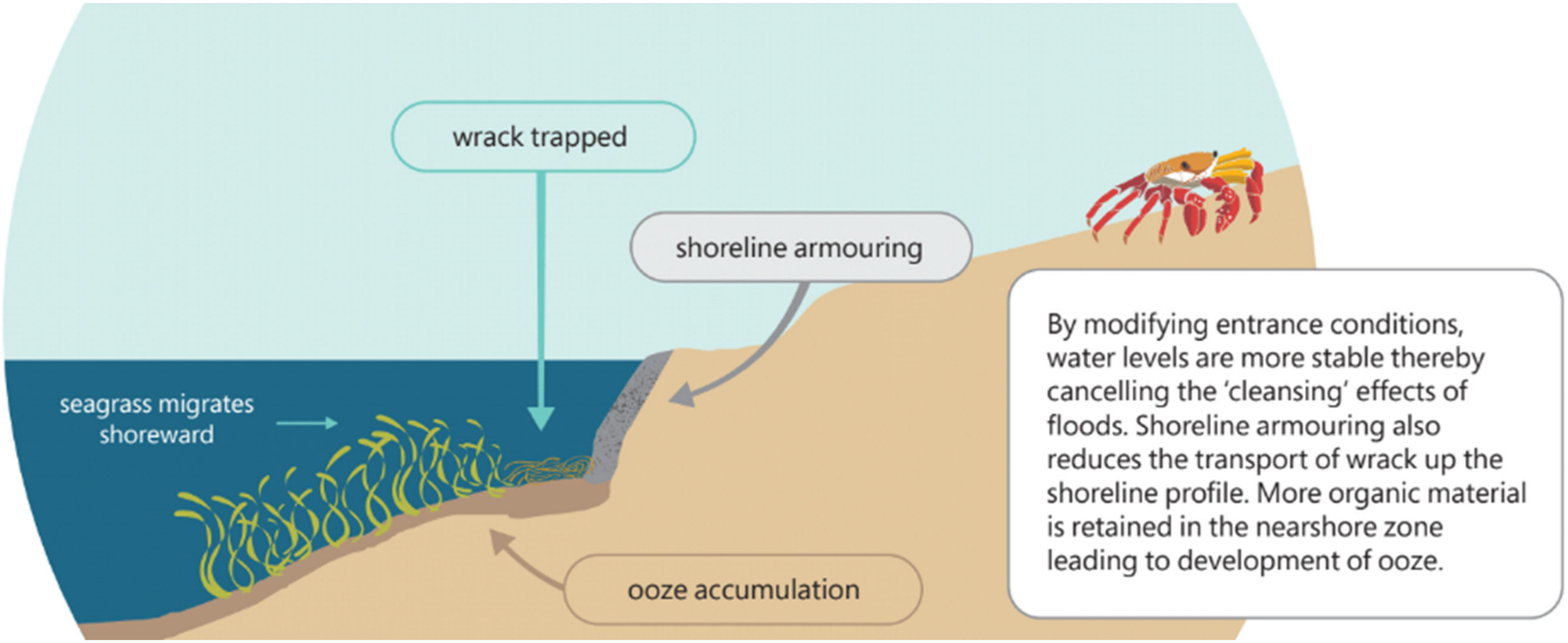


Figure 4-36 Scenario illustrating the changes that occur to wrack processes when a shoreline is modified with armouring (reproduced with permission of Central Coast Council)

‘Black ooze’ is a term used to describe sediments in various stages of nutrient and organic matter enrichment (Swanson et al., 2013). Ooze tends to form when increased nutrients and organic matter in sediments cause the microbial nutrient cycling to switch from aerobic (with oxygen) to anaerobic (without oxygen) metabolism. This drives production of sulfidic compounds like H_2S, which cause a rotten egg smell if disturbed. This has become a major issue for management in Tuggerah Lakes because ooze reduces the amenity of the foreshores and has reduced accessibility of the lake basin for recreational activities.

The primary drivers of increased nutrients and organic matter include stormwater and groundwater inputs as well as reduced mixing of nearshore waters with basin waters (Swanson et al., 2013). This results in macroalgal blooms that lead to accumulating organic matter forming a barrier to oxygen penetration in the nearshore zone and fuel ooze formation. Seagrass wrack makes up a minor (15%) proportion of the organic matter in oozes compared to trapped macroalgae, microalgae and organic material from storm drains (Ferguson and Scanes, 2013). Macro- and microalgae are labile organic matter sources that promote higher rates of organic matter activity. Finer sediments also contribute to the formation of ooze by providing a rich organic matter source for microbes to break down. The Tuggerah Lakes have become increasingly over the last century due to high sediment loads entering from the catchment (Swanson et al., 2013). Since the processes contributing to ooze formation are primarily occurring in the nearshore zone, and these are decoupled from the lake basin, the problems of wrack accumulation and ooze development cannot be fixed by increased oceanic exchange through entrance management (Ferguson and Scanes, 2013).

Tuggerah Lakes residents report that the issues of ooze are not new (Scott, 1998). Some nearshore areas that were described as sandy between the 1920s-1940s were observed to slowly shift from the 1960s onwards to mud and ooze. Some nearshore areas have always had mud and weed, although residents claim that the depth of the ooze has increased. Reports from the 1960s and 1970s highlight the shoreward creep of macrophytes in the lakes with ‘weed’ growing in shallow areas that were previously sandy. From the 1980s to 1990s, algal mats began appearing along edges of the lakes (Scott, 1998). Anecdotes link the appearance of algal mats to warming from the power station or input of nutrients from urban development, although some link mat declines to flood events.

4.5.4 Bird life on the lakes

Tuggerah Lakes supports a diverse bird community both on the lakes and around the foreshores, and has been recognised as a globally important bird area (Central Coast Council, 2020c). The Birding NSW Central Coast Group has recorded 379 bird species in the Central Coast Region between 1970-2010 and one of the most abundant species (over 6000 individuals recorded) is the black swan (Carpenter, 2016). In the most recent report from the Birding NSW Central Coast Group, 63 bird species had been sighted on or around Tuggerah Lakes (Table 4-5).

Some key species supported by the lakes include the Little Tern, Bar-tailed Godwit and migratory shorebirds from Asia and North America (Central Coast Council, 2020c). Important bird habitat on the lakes includes mudflats and shallow sandbars, where wading bird species include spoonbills and stilts (Scott, 1998). Many bird species are also supported by the wetlands, creeks and swamps around the foreshore (Scott, 1998). Osprey and sea eagles have also been associated with fringing riparian and estuary vegetation (Scott, 1998).

Bird life on the lakes has been threatened directly in the past by human activities with the hunting of waterbirds and terrestrial birds common between the 1920s and 1940s (Scott, 1998). Development around the lakes has also replaced much of the habitat that would have supported waterbirds in the past, although no consistent records exist to map and quantify this change. Anecdotally, musk ducks are thought to have decreased in numbers while wood ducks have increased (Scott, 1998). Removal of wrack also has the potential to be detrimental to birdlife since some species use wrack as habitat and a food source. For example, the endangered bush stone-curlew has been observed sheltering in wrack during the day, while herons and wagtails have been observed feeding on invertebrates in stranded wrack (Wyong Shire Council, 2013). More extensive bird surveys done with spatial and temporal replication would be needed to quantify and understand these threats.

Table 4-5 List of bird species (Carpenter 2016)

Common name	Scientific name	Classification
Black Swan	*Cygnus atratus*	Common
Australian Wood Duck	*Chenonetta jubata*	Common
Australasian Shoverler	*Anas rynchotis*	Uncommon
Grey Teal	*Anas gracilis*	Common
Chestnut Teal	*Anas castanea*	Common
Northern Mallard	*Anas platyrhynchos*	Common
Pacific Black Duck	*Anas superciliosa*	Common
Great Crested Grebe	*Podiceps cristatus*	Rare
Australasian Darter	*Anhinga melanogasters*	Common
Little Pied Cormorant	*Phalacrocorax melanoleucos*	Common
Great Cormorant	*Phalacrocorax carbo*	Common
Little Black Cormorant	*Phalacrocorax sulcirostris*	Common
Pied Cormorant	*Phalacrocorax varius*	Uncommon
Australian Pelican	*Pelecanus conspicillatus*	Common

Common name	Scientific name	Classification
Australasian Bittern	*Botaurus poiciloptilus*	Rare
Eastern Great Egret	*Ardea alba*	Common
Intermediate Egret	*Ardea intermedia*	Uncommon
White-faced Heron	*Egretta novaehollandiae*	Common
Little Egret	*Egretta garzetta*	Common
Australian White Ibis	*Theskiornis molucca*	Common
Royal Spoonbill	*Platalea regia*	Common
Eastern Osprey	*Pandion haliaetus*	Rare
White-bellied Sea Eagle	*Haliaeetus leucogaster*	Common
Pied Oyster Catcher	*Haematopus longirostris*	Uncommon
Black -winged Stilt	*Himantopus himantopus*	Common
Pacific Golder Plover	*Pluvialis fulva*	Uncommon
Red-capped Plover	*Charadrius ruficappillus*	Uncommon
Black-fronted Dotterel	*Elseyornis melanops*	Uncommon
Masked Lapwing	*Vanellus miles*	Common
Bar-tailed Godwit	*Limosa lapponica*	Common
Common Greenshank	*Tringa nebularia*	Common
Red Knot	*Calidris canutus*	Uncommon
Red-necked Stint	*Calidris ruficollis*	Common
Sharp-tailed Sandpiper	*Calidris acuminata*	Common
Curlew Sandpiper	*Calidris ferruginea*	Common
Little Tern	*Sterna albifrons*	Common
Gull-billed Tern	*Sterna nilotica*	Uncommon
Caspian Tern	*Sterna caspia*	Common
Whiskered Tern	*Childonias hybridus*	Uncommon
Common Tern	*Sterna hirundo*	Common
Crested Tern	*Sterna bergii*	Common
Silver Gull	Larus *novaehollandiae*	Common
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	Common
Striped Honeyeater	*Plectorhyncha lanceolata*	Uncommon
Willie Wagtail	*Rhipidura leucophrys*	Common
Magpie-lark	*Grallina cyanoleuca*	Common
White-winged Chough	*Corcorax melanorhamphos*	Uncommon
Musk Duck	*Bizura lobata*	Uncommon
Red-necked Avocet	*Recurvirostra novaehollandiae*	Rare
Great Knot	*Calidris tenuirostris*	Uncommon
Pink-eared Duck	*Malacorhynchus membranaceus*	Uncommon
Hoary-headed Grebe	*Poliocephalus poliocephalus*	Uncommon
Striated Heron	*Butorides striatus*	Common

Common name	Scientific name	Classification
Nankeen Night Heron	*Nycticorax caledonicus*	Uncommon
Whistling Kite	*Haliastur sphenurus*	Common
Buff-banded Rail	*Gallirallus philippensis*	Uncommon
Baillon's Crake	*Porzana pusilla*	Rare
Australian Spotted Crake	*Porzana fluminea*	Rare
Spotless Crake	*Porzana tabuensis*	Rare
Bush stone-curlew	*Burnhinus grallarius*	Rare
Azure Kingfisher	*Alcedo azurea*	Uncommon
White-breasted Woodswallow	*Artamus leucorhynchus*	Common

4.5.5 Macroinvertebrates, fish and fishing

The macroinvertebrate and fish communities in Tuggerah Lakes are important ecologically as well as for recreational and commercial fisheries. Macroinvertebrates have been well studied in the past, with 32 species being described from the 1970s and 1980s from 58 locations around the Lakes (Table 4-6) (Powis, 1975; Powis and Robinson, 1980). However, much of the data on fish communities relates to fishery catch statistics, which is unlikely to be fully representative of the entire community.

Common residents include small fish, crustaceans, molluscs and polychaetes (Table 4-6) and their distributions within the Lakes are linked to environmental variation in water and sediment quality as well as other natural and human stressors. Many macroinvertebrates and fish are also dependent on the seagrass and seaweed communities in the Tuggerah Lakes for habitat and food, and many will use drifting ephemeral algae and wrack-mats as short-term habitats to escape predation, for food or as egg-laying sites (Casey, 2003) Surveys in the lakes found that seagrass supported more diverse macroinvertebrate communities than unvegetated sediments (Powis and Robinson, 1980). At the same time, macroinvertebrates are essential for the breakdown of floating and deposited wrack (Heck and Orth, 1980; Robertson and Hansen, 1982).

Some species that have been discussed anecdotally in Tuggerah Lakes include small mouth hardyhead, sea mullet, flathead gudgeon, bream, whiting, snapper, jewfish, big tailor and mulloway (Scott, 1998). Blue swimmer crabs and mud crabs have been important to fisheries, but appear to be in decline since the 1990s. Similarly, shellfish, cockles, mussels and pippies may have been declining since the 1970s (Scott, 1998).

Table 4-6 Abundance of sediment macroinvertebrate species from surveys in 1974

Common name	Scientific name	Abundance
Whelk	*Nassarius burchardi*	392
Mussel	*Xenostrobus securis*	353
Polychaete worm	*Owenia fusiformis*	234
Polychaete worm	*Ceratonereis erythraeensis*	193
Clam	*Tellina deltoidalis*	183
Polychaete worm	Capitellidae	181
Clam	*Sanguinolaria onuphia*	173
Clam	*Theora fragilis*	153
Amphipod	Melita sp.	126
Whelk	*Velacumantus australis*	115
Isopod	*Cyathura* sp.	98
Clam	*Notospisula trigonella*	70
Polychaete worm	*Armandia intermedia*	57
Snail	*Austrocochlea constricts*	39
Anemone	Actinozoa	32
Amphipod	Oedicerotidae	27
Amphipod	Eusiridae	23
Amphipod	*Parphoxus* sp.	18
Polychaete worm	*Scoloplos (Scoloplos) simplex*	15
Clam	*Laternula tasmanica*	12
Amphipod	*Exoediceros* sp.	11
Amphipod	*Orchestia* sp.	9
Polychaete worm	*Nephtys australiensis*	7
Crab	*Halicarcinus australis*	5
Nemertean	Nemertinea	4
Polychaete worm	*Marphysa sanguinea*	3
Polychaete worm	*Australonereis ehlersl*	2
Snail	*Polinices conica*	2
Polychaete worm	Magelonidae	1
Polychaete worm	Pilargidae	1
Crab	*Halicarcinus* sp.	1
Snail	*Bedeva hanleyi*	1

Source: Powis and Robinson (1980)

Ecologically significant species such as White's seahorse and pipefish have also been observed (Dickinson et al., 2006). These are protected under the EPCB Act 1999 as well as the Fisheries Management Act 1994 and Fisheries Management (General) Regulation 2020. White's seahorse is also listed as an endangered species on the IUCN red list.

Fishing in Tuggerah Lakes dates back to the earliest settlers. While the 1920s to 1940s were considered good for recreational fishing and prawning, declines in abundance have been reported since the 1970s that are outside of the range of what has been noted as seasonal fluctuations in the past. While it is difficult to make long term comparisons of fisheries datasets due to changes in fishing effort, the decline over the last few decades is thought to be linked to overfishing and human-induced changes to the lakes ecology (Scott, 1998). Fishing businesses reporting landings have declines from approximately 70 to 80 in the late 1980s/90s to around 30 in 2017/18 while total reported landings have declined from 426,507 kg to 328,763 kg in 2017/18 with some fluctuations in between. Fisheries landings between 1987-2018 have included 131 fish species, 8 cephalopod species and 24 macroinvertebrate species (Table 4-8).

4.5.6 Saltmarsh

Saltmarsh are an important ecological community because they contribute to nutrient capture and recycling including dissolved nutrients in land-based run off and the remineralisation of nutrients from trapped wrack along the shoreline. However, 85% of fringing saltmarsh and wetland vegetation has been lost from Tuggerah Lakes (Roberts, 2000). This includes *Sarcocornia quinqueflore, Suaeda Australia, Triglochin striatum, Cotula australis, Spergularia marina* and *Sporobolus virginicus* (Chapman and Roberts, 2004). Historically, saltmarsh communities have suffered as a result of catchment development along the shoreline, residents mowing or removing plants from private property, and general disturbance from human traffic (Chapman and Roberts, 2004). Saltmarsh is now listed as a threatened ecological community under the EPBC Act 1999, which affords a high level of protection, and Council have restored or rehabilitated over 30 ha of saltmarsh around Tuggerah Lakes.

Table 4-7 List of commercial fish species reported from landings between 1987-2018

Fish			
Anchovy	Flounder, Unspecified	Mullet	Silver biddy
Australian Bonito	Garfish, Eastern Sea	Mullet, Fantail	Silverbiddy, Common
Australian Salmon	Garfish, River	Mullet, Pink-eye	Snapper
Australian Sardine	Garfish, Sea	Mullet, Red	Snapper, Crimson
Bastard Red Cod	Garfish, shortbill	Mullet, Sand	Snapper, Rosy
Blue Grenadier	Garfish, Snubmose	Mullet, Sea	Sole (other)
Bream, Black	Garfish, Unspecified	Mullet, Unspecified	Sole, Black
Bream, Yellowfin	Gemfish	Mulloway	Sole, Lemon
Bullrout	Goatfish, Bluestriped	Ocean Jacket	Stingray
Carp	Mullet, Glodspot	Old Maid	Striped Grunter
Catfish, Eeltail	Pigfish, Goldspot	Old Wife	Striped Scat (Butterfish)
Catfish, Estuary	Gurnard, Red	Perch, Eastern Orange	Sweep
Catfish, Forktail	Hairtail	Perch, Ocean Reef	Sweetlip
Catfish, Unspecified	Hardyhead	Perch, Unspecified	Tailor
Cobia	Herring (other)	Pigfish	Tarwhine
Dart	Herring, Southern	Pike	Teraglin
Diamond Fish	Kingfish, Yellowtail	Pike, Longfin	Trevally, Black
Dory, John	Latchet	Rabbitfish	Trevally, Silver
Drummer	Leatherjacket (other)	Bream, Rays	Trumpeter
Eel, Common Pike	Leatherjacket, Black Reef	Red Gurnard	Trumpeter, Bastard
Eel, Conger	Leatherjacket, Rough	Rudderfish	Trumpeter, Unspecified
Eel, Eastern Conger	Leatherjacket, Sixspine	Shark, Bignose	Venus Tuskfish
Eel, Longfin River	Longtom	Shark, Black Tip	Whitebait (Glass fish)
Eel, Pike	Luderick	Shark, Carpet	Whiting, Eastern School
Eel, Short-finned Conger	Mackerel, Blue	Shark, Dogfish Greeneye	Whiting, Grass
Eel, Shortfin River	Mackerel, Unspecified	Shark, Dusky Whaler	Whiting, King George
Eel, Unspecified	Morwong, Blue	Shark, Fiddler	Whiting, Sand
Carp, European	Morwong, Red	Shark, Gummy	Whiting, School
Flathead, (other)	Morwong, Rubberlip	Shark, Sandbar	Whiting, Stout
Flathead, Bluespotted		Shark, School	Whiting, Trumpeter
Flathead, Dusky		Shark, Shovelnose	Whiting, Unspecified
Flathead, Sand		Shark, Unspecified	Wrasse, Crimsonband
Flathead, Sand			Yabby (Saltwater)
Flathead, Tiger			Yellowtail Scad
Flathead, Unspecified			

Table 4-8 List of cephalopod and other macroinvertebrate species reported from landings between 1987-2018

Cephalopods	Other macroinvertebrates	
Bailer Shells	Beachworms	Lobster, Eastern Rock
Calamari, Southern	Bug, Balmain	Nipper
Cuttlefish	Bug, Deepwater	Pipi
Giant Cuttlefish	Cockle	Prawn, Eastern King
Gloomy Octopus	Crab, Coral	Prawn, Endeavour
Gould's Squid (Arrow)	Crab, Blue Swimmer	Prawn, Greasyback
Luminous Bay Squid (Bottle)	Crab, Hermit	Prawn, King
Maori Octopus (South Coast)	Crab, Mud	Prawn, School
Pencil Squid	Crab, Sand	Prawn, Tiger
	Crab, Spanner	Scallop
	Crab, Three spotted	Shrimp, Mantis
	Crab, Unspecified	

4.6 Review of management actions

Key Points
The Tuggerah Lakes Restoration project involved the large-scale removal of ooze and macrophytes from the nearshore zone of the Lakes. Despite considerable effort and cost, the effects of the project were brief before macrophytes and ooze re-established.
The Tuggerah Lakes Restoration Project is largely considered “a “band-aid” solution because it only treated the symptoms (ooze) and not the actual cause of the problem (stormwater pollution).
One of the key activities undertaken as part of the Estuary Management Program has been restoration and rehabilitation of saltmarsh. 29 ha of saltmarsh has been passively rehabilitated while 2.5 ha of saltmarsh has been actively reconstructed. Restoring saltmarsh communities and gently graded foreshores is important to improve intertidal connectivity in Tuggerah Lakes.
Restoring natural foreshore gradients has improved the connectivity of wrack to upper shorelines to support aerobic drying and reduce the rate of organic enrichment that might contribute to ooze formation.
Wrack harvesting and management is done to improve public amenity and improve estuarine health. There is a long history of wrack harvesting in Tuggerah Lakes beginning in the late 1950s. Since around 2013, there have been steady increases in wrack and macroalgae collection in response to community requests.
One of the current barriers to an effective wrack harvesting and management strategy is the demand from the community for removal from specific locations, which has resulted in a reactive approach rather than a proactive strategy-based approach.

Two key management programs were considered in this review. This included the Tuggerah Lakes Restoration Project that was implemented in 1990 and the Tuggerah Lakes Estuary Management Plan that was developed from an Estuary Process Study and Estuary Management Study in preceding years. The Tuggerah Lakes Restoration Project has largely been considered a failure with respect to its original objectives, while the Tuggerah Lakes Estuary Management Plan is still operating with 86% of actions completed or ongoing.

4.6.1 Tuggerah Lakes Restoration Project (1990)

The Tuggerah Lakes Restoration project involved the large-scale removal of ooze and macrophytes from the nearshore zone of the lakes. Around $13 million was invested and this included the purchase of a dredge and weed harvester. Large areas of the lake were bunded and ooze sediments, seagrass and seaweed were dredged along around 15 km of shoreline. The project mostly targeted the lower areas of Tuggerah Lakes including the Entrance, Long Jetty to Tumbi, and Berkeley Vale to Chittaway Bay. Problems arising from the project were compounded by the use of dredge spoil to extend adjacent foreshore areas (Swanson and Scanes, 2013).

Despite considerable effort and cost, the effects of the project were brief before macrophytes and ooze re-established. The efficacy of the project was assessed by NSW OEH using aerial photography of restored and unrestored sites (Swanson and Scanes, 2013). These surveys found that seagrass returned within 18 months and algal blooms continued. Factors contributing to the failure of this project included the community and political pressure to fix eutrophication issues in the estuary without a comprehensive understanding of causes. Thus the Tuggerah Lakes Restoration Project is largely considered “a “band-aid” solution because it only treated the symptoms (ooze) and not the actual cause of the problem (stormwater pollution) (Roberts, 2000; Swanson et al., 2013).

4.6.2 Tuggerah Lakes Estuary Management Plan (2006)

The Tuggerah Lakes Estuary Management Plan developed action plans and programs to address the six primary objectives identified in the Tuggerah Lakes Estuary Management Study (Roberts and Dickinson, 2005):

1. Ensure that the quality and quantity of water meet the needs of the community and lakes and rivers.
2. Ensure that the plants along the banks of rivers, lakes and in wetlands are protected because these are essential to a healthy ecosystem.
3. Ensure that biodiversity and ecological integrity of the lake ecosystem are maintained or enhanced.
4. Ensure that human activities can take place while protecting cultural heritage and enhancing soil, water and ecosystem health.
5. Ensure that the social and economic needs of the community are met while protecting the environment of the coastal zone.
6. Ensure that we continue to improve our understanding of how the estuary works and incorporate this knowledge into management.

The Management Plan was certified in 2007 with a final 27 priority programs across four action plans identified to achieve the above objectives. The action plans included a water quality plan, ecology plan, socio-economic plan, and knowledge and management plan. The Vision identified as a desirable outcome of the Management Plan is summarised below:

- *Water quality:* Current water quality does not deteriorate in the face of new development. Recreational water quality is improved at lake and creek swimming areas.
- *Foreshores:* Healthy foreshore that promotes saltmarsh growth which in turn aids the natural breakdown of seagrass wrack.
- *Public facilities:* Excellent recreational facilities and access points.
- *Rivers and creeks:* Healthy rivers and creeks that connect well with the estuary and provide good habitat for estuarine animals.
- *Ocean entrances:* Existing exchange with the ocean is maintained. A permanent entrance is not a cost-effective solution and will have unknown ecological impacts.
- *Seagrass wrack:* Seagrass wrack will be harvested from locations where it accumulates too frequently to be broken down naturally. Wherever possible, saltmarsh will be used to encourage natural odourless decomposition of wrack on the foreshores.
- *Fish and prawns:* Sustainable fish and prawn populations and habitat that provide long-term recreational and commercial fishing.

A review of the implementation of the Estuary Management Program between 2008-2020 was recently finalised and highlighted that 86% of the actions have been completed or are ongoing. The Water Quality Action Plan focused on catchment and stormwater improvements (see Chapter 5). The Ecology Action Plan focused on maintenance, restoration, rehabilitation, protection and monitoring of foreshore and catchment habitats with most actions still in the stages of assessment and review so their efficacy cannot be determined.

Foreshores: Saltmarsh restoration and rehabilitation

One of the key activities undertaken as part of the Estuary Management Program has been restoration and rehabilitation of saltmarsh. Passive rehabilitation of 29 ha of saltmarsh has been undertaken while 2.5 ha of saltmarsh has been actively reconstructed. Restoring saltmarsh communities and gently graded foreshores is important to improve intertidal connectivity in Tuggerah Lakes. These actions improve the connectivity of wrack to upper shorelines to support aerobic drying and reduce the rate of organic enrichment that might contribute to ooze formation. This has the potential to reduce nearshore eutrophication and anaerobic sediment metabolism (less hydrogen sulphate).

The active reconstruction of saltmarsh in Tuggerah Lakes faces several challenges because the system now lacks natural water level variations. Projects have therefore involved regrading the shoreline, followed by managing contamination issues from acid sulphate soils, active revegetation with saltmarsh plants and mulching with seagrass wrack. Passive rehabilitation has involved excluding damaging activities, controlling weed and using wrack as mulch to assist saltmarsh recovery (Roberts & Chapman, 2003). Adding wrack to restored saltmarsh is thought to promote saltmarsh restoration and rehabilitation by shading soils, reducing physical stress, and providing additional nutrients to nutrient-poor soils (Chapman and Roberts, 2004). Furthermore, wrack breakdown in saltmarsh communities prevents ooze formation in the nearshore (Chapman and Roberts, 2004). Importantly, these projects have also engaged local community groups to maintain existing sites and establish new ones.

Seagrass Wrack: Harvesting

Wrack harvesting and management is done to improve public amenity and improve estuarine health. There is a long history of wrack harvesting in Tuggerah Lakes beginning in the late 1950s to early 1960s with a horse and rake followed by a tractor and rake (Alison and Scott, 1998). In the mid-1980s, wrack was removed by a bulldozer and a prototype weed harvester was developed. The most damaging wrack collection strategy, and possibly least effective, was the dredging involved in the Tuggerah Lakes Restoration Project (see Section 4.6.1). Modifications to wrack collection in the 1990s included a floating weed harvester to reduce the damage associated with tractor removal on the foreshores. Since around 2013, there have been steady increases in wrack and macroalgae collection in response to community requests. The licence for wrack management issued to Council by NSW DPI allowed for an increase in collection from 5145 m^3 in 2013/14 to 14,855 m^3 in 2017/18.

Apart from wrack removal, there are a number of management actions that can reduce the chance that wrack accumulations in the foreshore will contribute to ooze formation. These have been discussed in Sections 4.3.5 and 4.5.3 and include improving flushing of the nearshore zone to reduce eutrophication and trapping of fine sediments, permitting wave energy to penetrate along the shoreline to disperse wrack and macroalgae (Ferguson and Scanes, 2013). Actions to remove wrack should minimise disturbance of other plant and sediment communities as well as impacts on nearby habitat. There also needs to be recognition of the ecological importance of wrack and thus the allocation of 'wrack reserves' where natural accumulations of wrack can occur to support birds, fish and macroinvertebrates without contributing to ooze problems.

One of the current barriers to an effective wrack harvesting and management strategy is the demand from the community for removal from specific locations, which has resulted in a reactive approach rather than a proactive strategy-based approach.

4.7 Recommendations

Key Points

This section provides a summary of key findings from past management and recommendations for future management strategies that could be enacted at multiple scales.

As nearshore water quality and ooze issues are decoupled from the lake basins, entrance management, which primarily affects circulation, will not address the current water quality issues.

Water quality issues have arisen in the nearshore due to eutrophication from stormwater pollution and catchment management practices that prevent natural water level variation occurring. Therefore, management actions in the lakes will not be effective in the long-term without stormwater reduction and treatment zones together with the restoration of natural water level variation in nearshore waters.

There is no clear signal of nutrient enrichment in the basin following heavy rainfall, which suggests that nutrients delivered during runoff events to the basin via the larger rivers/creeks don't have a major effect on the lakes' system. Future development could therefore investigate having runoff directed through appropriate WSUD, then eventually into one of the rivers to reduce catchment nutrient loading.

The Munmorah Power Station caused changes to water flow, temperature and salinity during operation, and introduced some heavy metals to the Lakes. However, these changes were not significant enough to have been a primary cause of eutrophication and were not lasting after decommissioning.

Key recommendations include:

- Continued efforts at source reduction
- Further investigation of groundwater nutrient inputs
- If groundwater is found to be important, investigate the potential to apply bioreactors
- Investigate redirecting stormwater into the rivers and creeks
- Restoration of natural water level variation and shoreline gradients
- Implement strategic wrack harvesting
- Continue saltmarsh restoration at large scales
- Investment in monitoring and adaptive management
- Community education, training and engagement.
- Actively promote and broadcast the Lakes regular (i.e. daily) water quality conditions

Tuggerah Lakes has been significantly influenced by human activities that have cumulatively resulted in issues of water quality and ooze development. These activities impact on the ecological health of the system and reduce recreational amenity such as boating, swimming, kayaking and fishing. This report reviews the major physico-chemical processes operating in the system and links them to variations in water quality and interactions between ecological communities.

This section provides a summary of key findings from past management and recommendations for future management strategies that could be enacted at multiple scales. These consider management actions that have been enacted and build on the previous recommendations from relevant reports. Since the Estuary Management Plan was adopted in 2006, relevant scientific studies have been commissioned and many works have been completed as a result, but the issues in the Lakes will not be resolved in the short-term and require a long-term strategy. Here, recommendations are targeted towards addressing land-based problems together with improving the resilience of the receiving aquatic environment for longer-term effectiveness. Best-practice management for Tuggerah Lakes will be grounded in the linkages between climate, geomorphology, biogeochemistry and ecology, and scientific evidence.

4.7.1 Summary of findings

Key findings of this review of water quality and ecological issues are:

1. Nearshore water quality and ooze issues are decoupled from the lake basins. Therefore, entrance management, which primarily affects circulation in the lake basins, will not address the current water quality issues.
2. Water quality issues have arisen in the nearshore due to eutrophication from stormwater pollution and catchment management practices that prevent natural water level variation occurring. Therefore, management actions in the Lakes will not be effective in the long-term without stormwater reduction and treatment zones together with the restoration of natural water level variation in nearshore waters.
3. Groundwater also appears to contribute to the nutrient loading of the nearshore zone, however there currently is not enough data to provide any indication of the relative importance of this pathway. Without understanding how important groundwater is to the nutrient budget of the nearshore zone, the desired outcomes associated with stormwater management may not be met.
4. The Munmorah Power Station caused changes to water flow, temperature and salinity during operation, and introduced some heavy metals to the lake. However, these changes were not significant enough to have been a primary cause of eutrophication and were not lasting after decommissioning.

4.7.2 Water quality and ecological recommendations

Based on the findings from this chapter, water quality and ecological recommendations are described below.

1. *Further studies to quantify the importance of groundwater nutrient inputs to the nearshore zone* – there is currently very limited information to provide a detailed assessment on what role groundwater may play in driving eutrophication in the nearshore area. The preliminary data suggest that groundwater may be an important nutrient source during some periods e.g. following rainfall events where the head differential between the groundwater table and lake water level are maximal. Due to the reclamation of some areas of shoreline as part of the Tuggerah Lakes Restoration project, there are likely some legacy affects associated with the breakdown of the organic material in the dredged material. Whether this material is continuing to leach nutrients (and potentially other contaminants) through groundwater seepage is unknown, but should be a priority for future studies.
2. *If groundwater is found to be important, strategies such as the use of bioreactors should be investigated for feasibility* - treating groundwater nutrient contamination in not a trivial task. However some success has been achieved with the use of bioreactors, which essentially provide an environment for bacteria to break down nutrients. If future investigations find that nutrients loading via groundwater seepage is a significant source to the nearshore zone, then the trialling of bioreactors in groundwater seepage hotspots is recommended.
3. *Where possible, redirecting stormwater into the rivers and creeks may help alleviate nearshore eutrophication* - data on nitrogen and phosphorus concentrations within the basin suggest that large runoff events do not produce a detectable signal in the long term record. While the detailed modelling required to assess why this may be so is currently not available, it is likely due to dilution in the basin, and/or the direct transport of the freshwater plume to the ocean (when the entrance is open). As there is no detectable signal in eutrophication in the basin (as evidenced by the long term Chlorophyll a data, Section 4.3), then ensuring that nutrients associated with runoff are shunted to the basin, rather than trapped in the nearshore zone will likely lead to improved water quality.
4. *Large-scale re-engineering of shorelines* – Shoreline realignment should be considered to restore the natural gradient of the shorelines and address the legacy issues that remain from the steeper shoreline gradients that were introduced during the Tuggerah Lakes Restoration Project. Remodelling the lake shorelines has many potential benefits including improvements to stormwater and groundwater treatment, improved nearshore processes, support for the rehabilitation and restoration of intertidal and supratidal habitat such as saltmarsh, and improved

amenity. Reducing the shoreline gradient will help to transport wrack onto the shore to dry aerobically and reduce the anaerobic processes that contribute to ooze development and bad odours.

5. *Implement strategic wrack harvesting* - Effective implementation of a strategic wrack harvesting program has been somewhat impeded by several factors including reactive management rather than improved understanding of where wrack is likely to accumulate and develop ooze. However, this could be improved by using the evidence base developed by DPIE for strategic wrack harvesting (Swanson, 2013). Specifically, strategic wrack harvesting would be driven by science to adapt to wind-driven transport with a focus on locations where wrack collection would improve nearshore circulation (by removing offshore wrack barriers) and public amenity. Wrack should be allowed to remain in locations where aerobic drying can occur. Further, the rate of removal by the contractor currently doesn't match the amount of wrack deposited. This capacity issue should be addressed with upgrades to machinery as well as improved methodologies to harvest in shallower waters of the nearshore as well as offshore (e.g. seining). These efforts should be complemented by a community education and engagement program (see Recommendation # 8) around wrack processes that may enable Council to be more proactive in their response to wrack accumulation and ooze.
6. Continue rehabilitation and restoration of wetland habitat in the waterways that discharge to Tuggerah Lakes on a large scale (refer to Chapter 5).
7. Ongoing monitoring and adaptive management - All of the recommendations provided above should be included in an adaptive management plan, whereby monitoring and evaluation of the effectiveness of actions provides the evidence to continue with the status quo or to make adjustments and improvements. Wherever possible, monitoring should follow a Beyond BACI (Underwood, 1991) approach whereby information is collected before any management action is implemented at a site as well as afterwards, and from additional sites that are not being targeted by management. At the same time, the extensive water quality and ecological datasets that have been collected in the various reports commissioned by Council should be compiled into one repository and made openly available. This will firstly allow the data to be used in long-term models of the Lakes' system and improve predictive capacity for management actions, but will also create a resource that can continue to be updated and improved to assist in adaptive management.
8. Community education and engagement - Future water quality improvements in the Lakes will require educational programs to address incorrect community perceptions of the characteristics of a healthy ICOLL. Furthermore, relevant stakeholders including the Council and the community need to work together to understand how the Lakes operate as an entire system to appreciate the allocation of management priorities. This could be aided by the development of a

web-based conceptual model of the functional zones, processes and communities in the Lakes that is hosted through a Council website. Regular communication is essential and could be facilitated through social media channels, providing a daily water quality report through wide-reaching media such as radio or television, as well as engaging communities around the Lakes in citizen science. Projects such as community wrack harvesting for Council collection (Swanson et al., 2013) should be expanded while preventing disturbance of sediments or damage to living seagrass communities. The community could also be engaged in wrack monitoring programs through the capture of high-resolution images of seaweeds and seagrass distributions around the lakes using drones where available. Data management could be incorporated into the current apps that the Council maintains.

9. Importantly, the information collected during this review process could be distilled down into a visual product that is accessible to all. Options might include an update to the book Tuggerah Lakes – Way Back When that becomes an essential addition to residents' coffee tables.

5 Catchment pressures

5.1 Introduction

The chapter details how developmental pressures in the catchment have and will continue to influence water quality in Tuggerah Lakes. The Tuggerah Lakes catchment is recognized to have undergone significant changes since European settlement, with widespread clearing of the valley and floodplains for rural, urban and industrial land uses. These changes have resulted in increased flows and pollutant loads to receiving waters, directly impacting on water quality in Tuggerah Lakes. Community consultation undertaken by TLEP indicates that there is widespread understanding in the community that improving water quality in the lakes starts in the catchment, from the headwaters to the creeks and rivers that flow into the lakes. The Tuggerah Lakes Estuary Management Study (Bio-Analysis, 2005) identified sediment and nutrient loads from existing land use and new development as well as streambank erosion as priority issues impacting on water quality. Numerous scientific studies and management plans have subsequently been undertaken to better understand and manage these impacts (Storm Consulting, 2007a, 2007b, 2008; Cardno Lawson Treloar, 2008, 2008a; Sinclair Knight Merz, 2010; Australian National University, 2010; BMT WBM, 2010a; DECCW, 2010; NSW OEH, 2011; NSW OEH, 2018).

As referred to in previous chapters, a key role of TLEP is to review existing information and previous actions as they relate to the management of water quality in Tuggerah Lakes, making recommendations for improvement based on science and best practice management. As such, Sections 5.3 and 5.4 of this chapter documents the current and future catchment pressures to water quality in Tuggerah Lakes respectively, and the information available to quantify and understand these pressures and their impacts. Section 5.5 then presents conceptual drawings illustrating our understanding of natural catchment conditions, key existing and future catchment pressures to water quality, and best practice catchment management to improve water quality in the lakes.

Review of the work done to estimate existing and future catchment loads, and the modelling framework developed to help inform our understanding of nutrient and sediment loads into Tuggerah Lakes and the likely impact on ecological function is summarised in Section 5.6. Section 5.7 provides a review of current management actions in the Tuggerah Lakes Estuary Management Plan for improving water quality, informed through review of technical reports and discussion with Central Coast Council (Council) staff. Key gaps in information regarding current understanding of catchment pressures have been identified in Section 5.8, along with recommendations for improving catchment management and receiving water quality in Section 5.9. Lastly, two case studies have also been undertaken to review catchment pressures on water quality. These case studies include the Berkeley Vale urban catchment in Section 5.10 and the Porters Creek Wetland catchment in Section 5.11.

5.2 Key references

Key reports reviewed as part of this study are presented and briefly described in Table 5-1.

Table 5-1 Reviewed references on catchment pressures to Tuggerah Lakes

Reference	Description
Wyong Shire Council (2001). *Tuggerah Lakes Estuary Process Study.*	An Estuary Processes Study completed under the prior Estuary Management Program, where it preceded an Estuary Management Study. The aim was to describe the physical, chemical, and biological patterns and processes operating within the Estuary. The study was done to identify gaps and key estuarine processes to understand how the estuary works.
Bio-Analysis (2005). *Tuggerah Lakes Estuary Management Study.*	Reviews the Estuary Process Study to identify principles and objectives for the Tuggerah Lakes Estuary, and priority issues relating to each principle. These were consolidated into priority programs to be actioned through the management plan.
Bio-Analysis (2006). *Tuggerah Lakes Estuary Management Plan.*	Describes the Estuary Management Plan developed by Wyong Shire Council in partnership with the Department of Natural Resources. This is the final action framework that builds on the 2001 Estuary Process Study and 2005 Estuary Management Study. Developed 27 programmes, grouped under 4 Action Plans (water quality, ecology, socio-economics, knowledge and management) to address the issues identified in the Estuary Management Study for application over 5 years.

Reference	Description
Storm Consulting (2007). *Saltwater Creek Streambank Rehabilitation Plan.*	Geomorphic and riparian condition assessment of Saltwater Creek. Identified erosion hotspots and recommended management techniques.
Storm Consulting (2007). *Tumbi Umbi Creek Streambank Rehabilitation Plan.*	Geomorphic and riparian condition assessment of Tumbi Umbi Creek. Identified erosion hotspots and recommended management techniques.
Cardno Lawson Treloar (2008a). *Ourimbah Creek Streambank Management Plan.*	Geomorphic and riparian condition assessment of Ourimbah Creek. Identified erosion hotspots and recommended management techniques.
Cardno Lawson Treloar (2008b). *Wyong River Streambank Management Plan*	Geomorphic and riparian condition assessment of Wyong River. Identified erosion hotspots and recommended management techniques.
Storm Consulting (2008). *Spring and Wallarah Creeks Streambank Condition and Conservation Report.*	Geomorphic and riparian condition assessment of Spring and Wallarah Creeks. Identified few erosion hotspots and recommended management techniques and conservation strategies.
Australian National University (2010). *Tuggerah Lakes Catchment Modelling – Inflows, TN, TP and TSS exports to Tuggerah, Budgewoi and Munmorah Lakes.*	Summarises the data, analyses and modelling (IHACRES and MUSIC) work that has been undertaken to generate catchment flows and pollutant loads from the Tuggerah Lakes catchment.
BMT WBM (2010). *Tuggerah Lakes Catchment Scenario Assessment: Final Report*	Describes Source catchment modelling undertaken to estimate pollutant flows and loads from Tuggerah Lakes in natural conditions, existing conditions, future conditions with unmitigated development as well as a number of scenarios investigating mitigation measures to address the impacts from both the future and existing urban lands.

Reference	Description
DECCW (2010). *Tuggerah Lakes Estuary Modelling, Final Report.*	Summarises results of integrated catchment, hydrodynamic and estuary response models developed to represent the Tuggerah Lakes catchment.
Sinclair Knight Merz (2010). *Stormwater Improvement Strategy for Tuggerah Lakes.*	Stormwater quality improvement strategy developed to improve lake water quality, supporting objectives of the Estuary Management Plan. Included a prioritised program of works that included predominantly new bioretention basins, as well as saltwater wetlands and existing wetland expansions.
NSW OEH (2011). *Tuggerah Lakes Ecological Response Project Stage 1.2 Final Report.*	Chapter 5 Streambank Rehabilitation of this report was reviewed. It uses previous technical assessments and modelling results to provide a comparison between predicted modelled sediment export rates from subcatchments and the potential erosion rate estimated by the streambank management plan studies.
EOS Ecology Ltd (2013). *Restoration of Tuggerah Lakes through Improved Water Quality Management.*	Overview report from four years of investigations in Tuggerah Lakes to develop integrated catchment, hydrodynamic and ecological response models.
NSW OEH (2013). *Sediment and Nutrient Generation from Sealed and Unsealed Rural Roads In Wyong Shire, New South Wales.*	Presents the methodology and results from a monitoring study on Footts Road Ourimbah that quantified total suspended solids concentrations in run-off from sealed and unsealed road sections and used these in combination with rainfall data and run-off coefficients to determine generation rates at the roadside scale.

Reference	Description
Wyong Shire Council (2013). *Wyong Development Control Plan.*	Provides detailed planning and design guidelines to support the planning controls in the Local Environment Plan. This includes site specific stormwater quality objectives to be achieved for future development in key locations, along with water sensitive urban design elements proposed to achieve these objectives.
NSW Government (2016). *Central Coast Council Regional Plan 2036.*	Provides an overarching framework for accommodating proposed population growth from approximately 339,550 to approximately 415,050 in the Central Coast Region.
BMT WBM (2017). *Porters Creek Wetland Catchment Water Management Strategy 2016*.	Describes an alternative Water Management Strategy to the stormwater harvesting scheme for Porters Creek catchment to assist with reducing the cost of the scheme to a financially sustainable level whilst also protecting Porters Creek Wetland.
Central Coast Council (2018). *Civil Works Specification Design Guidelines. Roads, Transport, Drainage and Subdivisions Design and Construction.*	Section 11 of this report was reviewed, which details water sensitive urban design and MUSIC modelling guidelines to be applied for future development in the region.
NSW OEH (2018). *Impact assessment of Berkeley Vale Subcatchment Pollutant Loads.*	This report focuses on Berkeley Vale because of issues identified that include eutrophication and resulting macroalgal blooms, wrack accumulation and ooze build up in the nearshore zone. Factors contributing to eutrophication are identified and management recommendations provided based on assessed pollutant inputs and surveys of drains, nearshore water quality and groundwater influence.

Reference	Description
Swanson, R. (2018). *Tuggerah Lakes Nearshore Data Synthesis.*	Synthesis of data compiled from regular monitoring of Tuggerah Lakes system by NSW OEH to assess changes in water quality in the nearshore and lake basins between 2012 and 2017. Identifies priority catchments for on ground works to reduce sediment and nutrient inputs e.g. Tumbi, Lake Haven, Tumbi Creek, Ourimbah Creek, Wallarah and Lake Haven.
Central Coast Council (2019). *Central Coast Waterways Report Card 2017-2018.*	Presents the ecological health data for Tuggerah Lakes from data collected throughout 2017-18, providing a performance grade for each site. It also provides an indication of water quality trends at each site since monitoring commenced in 2011-12.
Central Coast Council (2019). *Greater Lake Munmorah Structure Plan*	Provides a framework to guide the future growth around Lake Munmorah from approximately 8,500 people to approximately 13,500 people.
Central Coast Council (2020). *Tuggerah Lakes Estuary Management Map.*https://centralcoastcouncil.mysocialpinpoint.com/tuggerah-lakes-estuary-management#/	Mapping that provides a summary of physical works completed as part of the Tuggerah Lakes Estuary Management implementation program.
Central Coast Council (2020)	Dataset providing 2018/19 freshwater sub-catchment grade scores.

5.3 Existing catchment pressures on water quality

Key Points
Increasing urban development in the region from high growth rates implemented by State Government has resulted in altered and increasing stormwater flows and pollutant loads. Urban stormwater has been identified as a key contributor to poor water quality and the degradation of catchment waterway and wetland health.
The impact of fringing urban catchments that discharge concentrated urban runoff directly to nearshore areas of the Lakes has been recognised as having a significant impact on water quality.
Poor erosion and sediment control practices have been raised by both the community and Council as having impacts on water quality.
Poor design, construction and establishment of water quality treatment assets has led to asset failure, and better guidelines and development approval conditions are needed to ensure that water quality treatment assets are being handed over to Council in good working condition.
Historical clearing for agricultural land use practices has altered stormwater runoff, increasing flow generation, reducing infiltration and altering the catchment water - sediment ratio. This, in addition to stock access to waterways, has led to accelerated bank erosion of waterways including the Wyong River and Ourimbah Creek.
Streambank erosion alone is estimated to contribute to equivalent or double the sediment loads generated by the catchments. This demonstrates the importance of managing streambank erosion for managing sediment loads.
Stormwater is typically high in bacterial and other contamination from catchment sources (rather than sewage sources), which is why lake swimming sites are closed for three days following rainfall. Poor water quality at Canton Beach is currently being investigated to identify the source, noting that it is not necessarily from sewage.
Modelling investigations in 2010 indicated that town water supply extractions at that time from Wyong Weir and Ourimbah Weir could cause flows from the weirs to cease, such that inflows to the lakes are only from areas downstream of the weirs and fringing catchments. At these times, urban runoff would be the dominant source of inflow to the lake and although small could contribute to eutrophic conditions.

5.3.1 Introduction

Increasing development in the region from high growth rates implemented by State Government has placed significant pressures on catchment management and water quality over the years, with altered and increasing stormwater flows and pollution repeatedly identified as a key pressure in State of Environment (SOE) Reports dating back over the past 20 years (Wyong Shire Council, 2000a, 2001a, 2004b, 2005a, 2006, 2007, 2012).

Development in the coastal lowlands and floodplains has resulted in the loss of bushland and soils (through poor erosion and sediment controls), impacts to natural wetlands (that provide important nutrient cycling and water quality treatment among other benefits), and increased generation of stormwater pollutants (nutrients, sediments, microbial contamination, heavy metals, toxicants) impacting on the ecology and recreational uses of receiving waters and ultimately Tuggerah Lakes. Other existing pressures in the catchment include sewage overflows from aging infrastructure and ensuring environmental flow needs are met while accommodating demands from human use.

Catchment modelling investigations and other scientific studies have identified key differences in impacts to water quality from catchment runoff from the upper catchments versus runoff from nearshore urbanised areas that discharge directly to the lakes (ANU, 2010; DECCW, 2010; EOS Ecology, 2013; OEH, 2018).

Modelling shows that the upper areas of the catchment deliver the majority of runoff, sediment and nutrients during large rainfall events from the Wyong River and Ourimbah Creek. During these events, the large flow volumes and buoyancy effects of fresh water on top of the saline water result in a large proportion of catchment derived nutrients and fine sediment passing through the lake and out to sea. During large events, sediment from floods are also deposited in the lake basin, where it can smother seagrass and be resuspended by the wind and waves (due to the shallow nature of the lake), affecting turbidity in the lake lakes. Turbidity and reduced light penetration in the main basins presents a key pressure on water quality due to the impacts on seagrass (refer to Section 4.5.1).

The fringing urban catchments deliver more frequent and concentrated urban runoff directly to the lakes due to large areas of impervious surfaces connected to the lakes via the stormwater drainage network. Although the loads may be comparatively small to overall catchment loads, reduced flushing in the nearshore zones in some areas (refer to Section 4.3.6) results in eutrophic conditions and water quality issues (such as the formation of ooze).

Key existing pressures on water quality in the Tuggerah Lakes catchment have been identified as:

- Landuse practices
- Streambank erosion
- Unsealed Roads
- On site sewerage systems
- Sewage overflows
- Water supply offtakes

Existing information and technical studies have been reviewed to describe these pressures in more detail in the following section.

5.3.2 Land use practices

Stormwater runoff from land use practices is a key source of diffuse pollution placing pressure on receiving waterways. The concentrations of pollutants in stormwater are highly variable, however in a study by Fletcher et al (2004) some typical export rates for NSW were calculated for key pollutants and land use types based on a literature review of monitoring data and MUSIC modelling. These estimates are reproduced below in Figure 5-1 to Figure 5-3 for TSS, TN and TP, respectively.

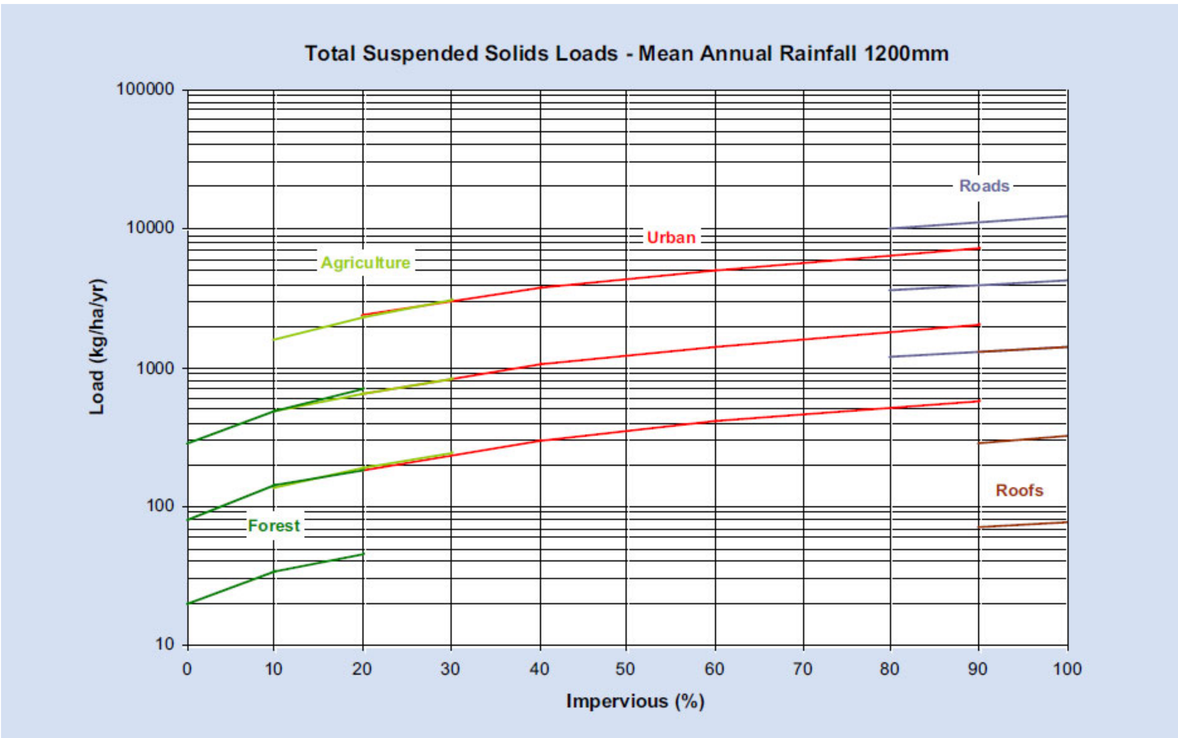


Figure 5-1 Total suspended solids loads for mean annual rainfall of 1200 mm (Fletcher et al., 2004)

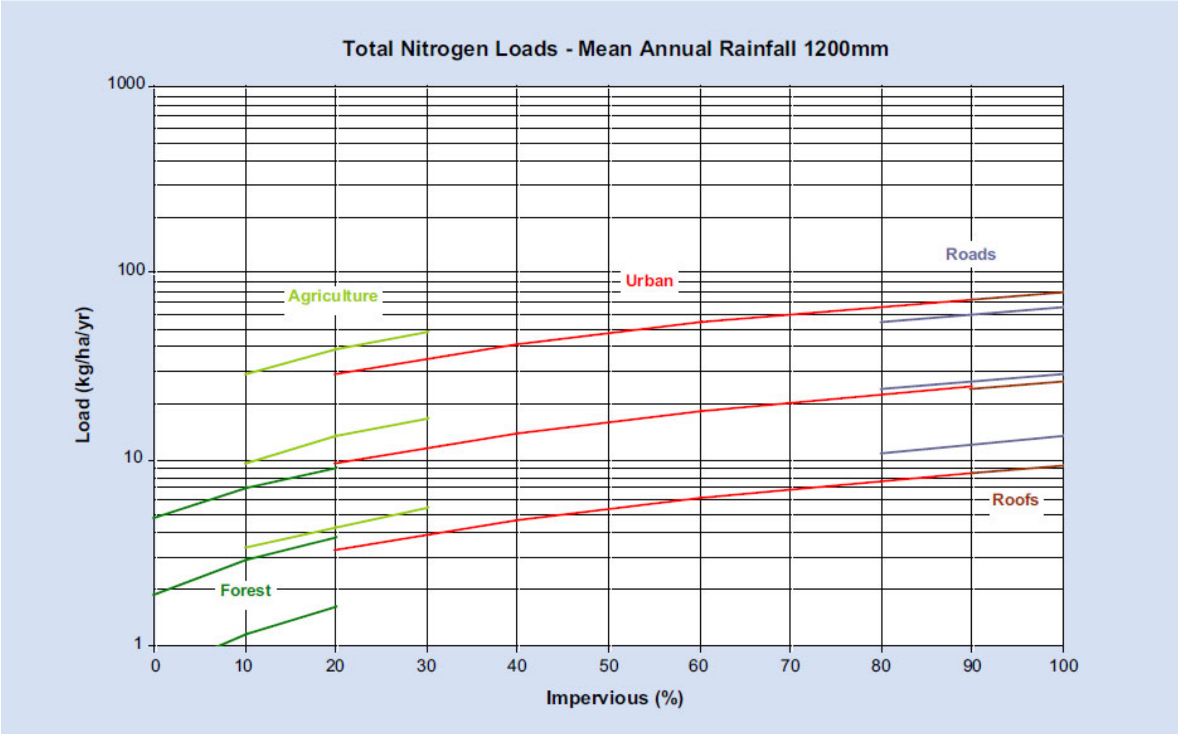


Figure 5-2 Total nitrogen loads for mean annual rainfall of 1200 mm (Fletcher et al., 2004)

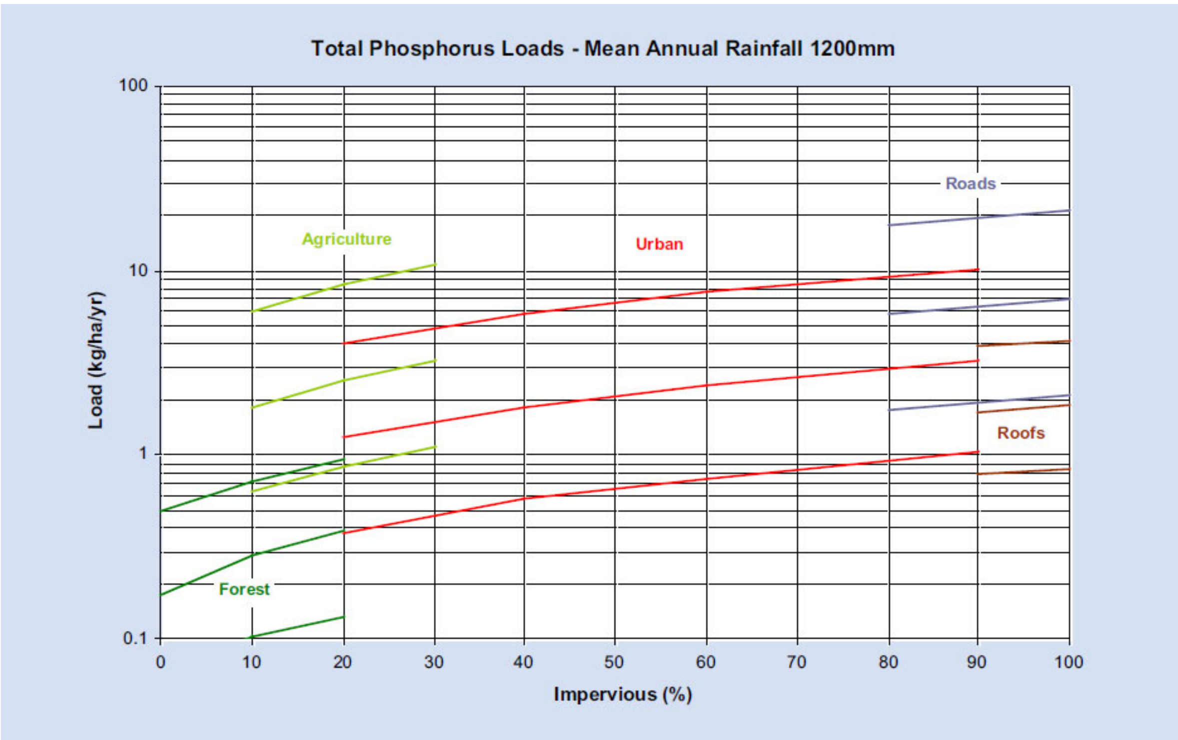


Figure 5-3 Total phosphorus loads for mean annual rainfall of 1200 mm (Fletcher et al., 2004)

The following section outlines pressures to water quality from key land use practices in the catchment including:

- Urban Development
- Agriculture and farming
- Forestry
- Mining
- Munmorah Ash Dam

Urban Development

Urban development in the region is concentrated around the lakes and lower estuarine sections of the creeks, with expanding suburbs to the west.

Urban development has resulted in the widespread clearing of land in the catchment, including the loss of riparian vegetation and wetlands, and significant increases in impervious areas. Increasing impervious areas significantly alters catchment hydrology, reducing natural infiltration and groundwater recharge, and resulting in increased stormwater flows and frequency, as well as increasing stormwater pollutant loads to receiving waters (Wong et al., 2000).

Key pollutants typically contained in urban stormwater are identified in Table 5-2, along with a summary of potential catchment sources and impacts to water quality (including environmental and use values of waterways).

Historical water quality monitoring, waterway and wetland assessments have all indicated that urban development pressures and stormwater are likely key contributors to poor water quality and the degradation of the ecological health of waterways and wetlands in the catchment (Storm Consulting, 2007a, 2007b; Cardno Lawson Treloar, 2008, 2008a; Australia Wetlands, 2009; Sinclair Knight Merz, 2010). Furthermore, recent results of freshwater monitoring provided by Council show most urbanised sub-catchments receiving grades of D or E during the 2018/19 reporting period.

During community consultation, several sites were identified where stormwater quality management practices on private sites were potentially causing pollution of waterways (e.g. golf courses, industrial sites). Discussion with Council compliance officers indicated that due to resourcing constraints, proactive assessment of stormwater quality management practices on private sites are not undertaken unless local residents lodge formal complaints with Council for further investigations to be undertaken (and are encouraged to do so).

Table 5-2 Urban stormwater pollutants and potential sources

Urban stormwater pollutant	Potential catchment source	Water quality impact
Suspended solids	Land clearing Poor erosion and sediment control Stream erosion Decomposition of plants/ leaves and garden litter Vehicle wear Industrial runoff	Reduces water clarity and sunlight penetration Smothers benthic organisms and habitat (e.g. seagrass) Releases other bound contaminants and inorganic nutrients into water May increase water oxygen demand (if organic content is high)
Nutrients (nitrogen and phosphorus)	Fertilisers Detergents Grass clippings and plant matter Sewage overflows Contaminated groundwater inflows Vehicle emissions (nitrous oxides) Ash from bushfires	Eutrophication and algae blooms
Toxicants (heavy metals, hydrocarbons, pesticides, ammonia)	Vehicle leaks Fuel spills Pesticides Fertilisers Industrial runoff Contaminated groundwater inflows	Aesthetics Toxic to aquatic species Human health risk
Oxygen demanding substances (organic material, ammonia, hydrocarbons, sulphides)	Grass clippings Other organic plant matter Animal faeces Sewage Overflows	Depletes oxygen of water
Microbial pathogens (enteric viruses, bacteria, protozoa, helminths)	Animal faeces Sewage overflows	Human health risk
Gross pollutants	Litter Vegetation (leaves, twigs etc) Coarse sediment	Aesthetic Harmful to aquatic species, through physical impact and contamination from associated toxicants and oxygen demanding substances
Algal related scums and odours	Response from elevated nutrients	Aesthetic Depletes oxygen of water on breakdown Human health risks

Nearshore impacts

The impact of fringing urban catchments that discharge concentrated urban runoff directly to nearshore areas of the Lakes has been recognised in past investigations as having a significant impact on water quality (EOS Ecology, 2013; DPIE, 2018).

In the fringing urban catchments, the high proportion of impervious surfaces convert rainfall to stormwater runoff (rather than infiltrating soils), which is then quickly transported by urban drainage systems directly to the lakes, and in some instances to urban waterways prior to draining to the lakes. There are approximately 250 stormwater drainage outlets (sometimes referred to as Stormwater Treatment Zones (STZs)) conveying stormwater from predominantly urbanised areas directly to the lakes. The STZs have been found to be ineffective at removing sediment and nutrients (Sinclair Knight Merz, 2010). Due to the large directly connected impervious area of these urbanised catchments, runoff into the lakes is conveyed more frequently than from upstream rural catchments. Furthermore, in some areas of the lakes with sheltered shorelines, there is limited mixing of nearshore waters, trapping polluted urban stormwater in these nearshore regions and impacting on water quality. Refer to Section 3.5.5 for further information on nearshore zone water mixing.

Erosion and Sediment Control

Poor erosion and sediment control (E&SC) practices have been raised by the community as an issue affecting water quality in various locations throughout the catchment, on both private development sites and local government infrastructure works. Sediment generation from poor erosion and sediment control practices can result in significant quantities of sediment being washed into waterways and ending up in the Tuggerah Lakes, where it can impact on water quality and the health of seagrass (refer to Section 4.5.1). Discussion with Council staff have also indicated instances where poor erosion and sediment control practices by developers / builders have damaged water quality treatment assets (with sediment blinding the filter media of bioretention basins). Discussion with Council staff indicates that this is particularly an issue with the lot scale builders. As such, an opportunity exists to address this through education and capacity building initiatives. For example, Healthy Land and Water (HLW) have developed a toolkit for house builders that may be used as a basis:

https://hlw.org.au/download/erosion-and-sediment-control-toolkit-for-house-builders/

Existing Planning Controls for Urban Development

Currently, water quality treatment requirements for the region are located within the Wyong Development Control Plan (WDCP) (Wyong Shire Council, 2013b). The WDCP provides detailed planning and design guidelines to support the planning controls in the Wyong Local Environment

Plan (WLEP). Discussion with Council planning staff however indicate that these requirements have been contested by developers in the past, with cases going to court resulting in less than optimal outcomes for water quality, legal fees and setting a precedent for future developments. If provisions for water quality treatment outcomes are included in the LEP (which is a legal instrument), there is less potential for these requirements to be contested.

Discussions with Council planning staff have also indicated that poor design, construction and establishment lead to failure of water quality treatment assets, and that better guidelines and development approval conditions are needed to ensure that water quality treatment assets being handed over to Council by developers are in good working condition. Another issue raised was insufficient bonds being secured from developers to rectify issues with failing water quality treatment assets when they are identified.

Agriculture and farming

Large areas of agricultural and farming lands exist in the upper catchments, including predominantly grazing as well as orchards, turf farms and smaller hobby farms. Historical clearing of the catchment, including wetlands and riparian vegetation for agricultural land use practices has altered stormwater runoff, increasing flow generation, reducing infiltration and altering the catchment water - sediment ratio. This, in addition to stock access to waterways, has led to accelerated bank erosion of waterways including the Wyong River and Ourimbah Creek (refer Section 5.3.3). However discussion with Council indicates that most properties are now fenced with access to watering points to restrict stock access to waterways.

Agricultural / farming land use practices including the application of fertilisers and pesticides / herbicides can also pollute waterways with excess nutrients and chemical contaminants. No recent specific farming practices were identified as key sources of pollution in the literature reviewed. Discussions with Council staff indicates that a water quality monitoring program is currently under development to better inform how sources of pollution in the upper water supply catchments may be identified.

Forestry

A large proportion of the upper catchment is forested, with key areas covered by Ourimbah State Forest, Olney State Forest (upper Wyong catchment) and Wyong State Forest, as well as Jilliby Conservation Park and forested ranges around Cedar Brush Creek. State forestry lands make up approximate 20% of the catchment area. Currently, operations are only active in Olney State Forest around Kingtree Ridge Road and Walkers Ridge Forest Road around the headwaters of Wyong River (Forestry Corporation, 2020).

Previous investigations and discussion with Council staff have identified that although these areas are largely undisturbed, key pressures to water quality may be from logging tracks used by four wheel drives and dirt bikes causing erosion and sedimentation of waterways (Cardno Lawson Treloar, 2008, 2008a). Similar issues have also been noted in other reserves / waterways / wetlands throughout the catchment (Storm Consulting, 2008; Australian Wetlands, 2009).

The potential impact of active areas of timber harvesting on water quality in the catchment is not known, however a study on the efficacy of Best Management Practice (BMPs) in a small NSW forestry catchment indicated that BMPs were effective at protecting stream water quality from the impacts of forestry (Webb et al., 2007).

Impacts from unauthorised vehicle access and active logging in forestry lands have not been quantified in past assessments or modelling, however it is unlikely to be a key issue, with largely forested catchments generally receiving scores of A or B in the 2018/19 freshwater health assessment, with the few exceptions to this noted to be largely due to poor riparian condition.

Mining

Coal mining is noted in the latest state of the environment report (Central Coast Council, 2020d) as a key land use in rural areas. As a result, the catchment includes large areas zoned as mine subsidence districts, largely located west of the Sydney Newcastle Freeway (Wyong and Hue Hue districts). An exception to this is the Swansea North Entrance mine subsidence district, located around Munmorah and Budgewoi Lakes. No assessment has been undertaken as to the proportion of active / future resource extraction sites. Mine subsidence areas may impact on water quality through disturbance of soils and sediment to waterways. Potential disturbance of on-site sewerage systems could also release nutrients and pathogens to waterways. Limited information was reviewed on the potential risks and impacts of mine subsidence on water quality.

A mine subsidence event was noted to have caused an inflow of saline water into the freshwater lake and surrounds in the Lake Munmorah / Colongra Wetland complex, killing significant areas of vegetation (Australian Wetlands, 2009).

Munmorah Ash Dam

The Munmorah Power Station was a coal fired power station owned and operated by Delta electricity. The power plant was built in the 1960's and stopped operations in 2010 (official closure in 2012). Residual boiler ash (fly ash was transferred to Vale Point) from burning coal at the power plant was disposed of in the Munmorah Ash Dam, known as Colongra Lake. The ash dam is not lined, therefore there may be potential for contaminants to leach into the groundwater and adjacent Tuggerah Lakes' system.

The Munmorah Ash Dam is still regulated by the EPA, with the latest available audit of the site undertaken in 2017. While specific results of the audit for the site were not reported (10 coal ash dam/ emplacements were investigated, including Munmorah Ash Dam), results indicated licensees were complying with 80% of the audited requirements (NSW EPA, 2017).

Currently, there is a NSW State Government enquiry into the costs for remediation of coal ash repositories in New South Wales, which includes investigating (via the NSW Legislative Council):

- adequacy and effectiveness of the current regulatory regime for ensuring best practice remediation of coal ash repositories
- risks and liabilities associated with inadequate remediation including community and environmental health impacts.

Community concern has been raised about the impacts of the Munmorah Ash Dam as well as the Vale Point Ash Dam, both during community consultation and also as a submission to the state government enquiry. While the Vale Point Ash Dam is outside of the catchment, there is community concern about leaching of contaminants such as heavy metals into the groundwater table potentially reaching Lake Munmorah and the Tuggerah Lakes system.

Stands of dead trees are noted to line the margin of the wetland around Colongra Lake and next to Lake Munmorah, however these have been attributed to a mine subsidence event that caused an inflow of saline water into the freshwater lake and surrounds, killing vegetation (Australian Wetlands 2009). Further investigations are beyond scope of this report, however it is recommended that community concerns be reviewed as part of the CMP. Results of the enquiry are also expected to guide appropriate actions to take.

5.3.3 Streambank erosion

Council's EMP (Bio-Analysis, 2006) identified streambank rehabilitation as a priority action for managing erosion and vegetation degradation issues that result in the export of nutrient rich sediment during floods, and the accretion of sediment in the estuary and lakes due to low/ negative river gradient and the influence of denser brackish water. As such, detailed streambank condition assessments were undertaken for key waterways in the catchment.

Assessments of the two major waterways draining to Tuggerah Lakes, the Wyong River and Ourimbah Creek, identified key causes of bank erosion as follows (Cardno Lawson Treloar, 2008, 2008a):

- Altered water-sediment ratio due to land clearing following European settlement (clearing of vegetation results in increased flows and sediment loads)
- Changes in stream flow velocities, and
- Loss of floodplain vegetation.

It is important to note that the middle and lower reaches of Wyong River and Ourimbah Creek (and most coastal streams) are classified as alluvial streams. Alluvial streams are characterised by the ability to change their boundaries reflecting a balance between sediment supply and hydrological regime.

The streambank condition assessments identified and prioritised key erosion sites and management options. Numerous recommendations have been implemented by Council, however no additional studies have been undertaken since this time (10+ years).

A summary of the key findings of the streambank condition assessments are presented below.

Wyong River

The Wyong River is the major waterway discharging to Tuggerah Lakes, with its catchment contributing to approximately 50% of the total catchment area. Land use in the middle reaches of the Wyong River is predominantly national parks and agriculture (mostly grazing). Due to the nature of the deep sandy soils forming the valley floor and the legacy of European activity (i.e. land clearing), middle reaches of the Wyong River are considered to be moderately to highly unstable (Cardno Lawson Treloar, 2008b). The streambank condition assessment identified that the instability of the river banks and bed are primarily characteristic of a natural process (with the creek establishing a new equilibrium between the hydrologic regime and sediment available for transport), but that this process has been accelerated by land clearing. Erosion was generally confined to bank erosion, with bed erosion issues noted along some tributaries, however not within Wyong River.

Other factors contributing to bank instability were noted to be a lack of fringing vegetation (including suitable ground cover species), stock access, wombat burrows and boat wash and wind driven waves in the lower reaches with tidal influences.

Study field investigations noted that many properties had been fenced to prevent erosion issues caused by stock access. Wombats were noted to be active along many reaches, with some burrows in the lower bank contributing to undercutting of the bank. Burrow networks were also noted to be undermining large trees and providing seepage paths for lateral overland flows increasing the risk of bank instability.

The predominant cause of erosion was identified from fretting at the normal water line resulting in bank undercuts (extending up to 500mm into the bank) and weakening of the sandy soil above the undercut. The undercut bank then collapses due to either or both the surcharge load due to trees growing above the undercut or high flows washing away the weakened and slumped soil.

Due to the sandy nature of most eroding banks in the Wyong River, the study identified that strengthening banks through revegetation alone would not be sufficient to prevent erosion. To adequately address the erosion, it recommended techniques to protect the river bank by either shielding the bank and/or by diverting the river current away from the bank.

The streambank management plan (Cardno Lawson Treloar, 2008b) notes bed slope in lower reaches of the Wyong River (approximately 2km inland of the lake) is negative, with erosion predominating upstream of the change in slope, and bed accretion and delta development (from deposition of sediment) predominating downstream. This is also thought to be the case in lower reaches near the mouth of Ourimbah Creek (Cardno Lawson Treloar, 2008a).

While the upper reaches of the catchment were not included in the assessments due to their largely undisturbed catchments, it was noted that there are numerous logging tracks likely to be used by four wheel drives, dirt bikes and horse riding. One site in the Dooralong Valley was noted to have severe localised erosion due to 4WD vehicles and it was considered quite probable (based on aerial photography) that similar situations occur in other locations within the Wyong River catchment that were not investigated.

Ourimbah Creek

Ourimbah Creek is another key waterway draining to the Tuggerah Lakes, with its catchment contributing to over 20% of the total catchment area. The upper catchment is predominantly covered by native forests on steep to undulating sandstone. Floodplains and valley floors in the catchment have been cleared for agricultural land uses including grazing and orchards. Urban development is concentrated in the lower reaches downstream of the Sydney-Newcastle highway.

Like Wyong River, the streambank condition assessment for Ourimbah Creek identified that the instability of the creek banks and bed are primarily characteristic of a natural process that has been accelerated by historical land clearing, with erosion generally confined to banks in the study area. Other factors contributing to bank instability were noted to be a lack of fringing vegetation (including suitable ground cover species), stock access and wombat burrows. Boat wash and wind driven waves were also noted to contribute to erosion in the lower reaches.

Again, the predominant cause of erosion was identified from fretting at the normal water line resulting in bank undercuts and weakening of the sandy soil above the undercut. It was noted that the numerous trails through state forest exist in the upper catchment that may be subject to erosion (e.g. from four wheel drives) and should be investigated further where they are in close proximity to waterways.

Wallarah and Spring Creeks

The Wallarah and Spring Creek catchment consists of predominantly rural land use and bushland, with approximately 75% of the catchment consisting of native vegetation. Spring Creek is the key tributary of Wallarah Creek, with the confluence approximately 1.6 km upstream of Wallarah Creek's outlet to Budgewoi Lake. Both Spring Creek and Wallarah Creek have numerous unnamed tributaries. Urban development covers only about 10% of the catchment, primarily fringing Budgewoi Lake around areas of Blue Haven and San Remo.

Due to the largely undeveloped and natural nature of the catchment the Streambank Rehabilitation Plan (Storm Consulting 2008) identified limited need for rehabilitation throughout catchment streams, with over 65% of streamlines assessed to be in good geomorphic condition. Reaches assessed to be in moderate condition had localised bank erosion and were typically located in rural land use areas with degraded riparian vegetation. The assessment identified only two reaches in poor condition, along the lower reaches of Spring Creek (adjacent urban development near Blue Haven) and in the lower reaches of an unnamed tributary of Wallarah Creek, upstream of the confluence with Spring Creek.

Uncontrolled 4WD access was identified as a key issue along reaches of Wallarah Creek and its tributaries. Commonly occurring issues identified in rural areas of the catchment included gravel road scouring, informal creek crossings, stock access and minor bed/bank erosion.

Erosion was also assessed through field inspections of estuarine reaches of Spring and Wallarah Creeks. High and moderately active erosion was generally limited to the outside banks along Spring Creek and was attributed to a range of processes including boat traffic, urbanisation and public access. In the lower reaches of the Wallarah Creek estuary some moderately active areas of erosion were identified due to a high degree of public access and greater exposure to wind waves generated by the lake.

Tumbi Umbi Creek

Tumbi Umbi Creek has a catchment area of approximately 15 km^2 that includes rural residential lots (predominantly south west of Tumbi Umbi Creek), residential and industrial land uses. Tumbi Umbi Creek discharges into the south eastern corner of Tuggerah Lake. The Tumbi Umbi Creek Streambank Rehabilitation Plan (Storm Consulting, 2007a) identified that Tumbi Umbi Creek and its key tributary Killarney Vale Branch have largely adjusted in response to significant development, however are now considered relatively stable. As such, stream processes are not considered a major source of sediment to Tuggerah Lakes. Minor instream sources of sediment were identified in Tumbi Umbi Creek as bank and bed erosion around the straightened stream adjacent to Aurora Place and bank erosion along the reach extending 500m upstream of Wyong Road.Key sources of sediment were predicted to be from impervious surfaces in the urbanised catchment.

It was noted that dredging activities for removing accumulated sediment from the mouth of Tumbi Umbi Creek were undertaken in 2007. Trial dredging activities were reported to have been monitored with no odour, spoil pH or water quality impacts, however an area of saltmarsh was damaged (despite protection measures) and rehabilitation works were put in place in response (Wyong Shire Council, 2007).

Saltwater Creek

Saltwater Creek is an urbanised catchment with area of approximately 4.3 km^2. Land uses include commercial, residential and industrial. The creek has two arms that meet approximately 100m upstream of the creek mouth, which discharges to the south eastern corner of Tuggerah Lake.

Numerous diversions, alterations and channelisation of Saltwater Creek has occurred through urbanisation of the catchment, resulting in generally poor geomorphic condition assessment. Despite this, some valuable reaches of ecological significance were identified that require protection, and the management plan identified areas with suitable corridor widths for rehabilitation.

The geomorphic assessment identified that many of the freshwater stream reaches had been enlarged and straightened to assist in flood flow conveyance, and act as sediment throughput zones with limited sediment storage within the channels. The tidal area within the flat floodplain is a combination of silt and muds deposited by lateral and vertical accretion, and is noted to be a long-term sediment depositional zone with sediment derived from upstream and reworked by tidal currents.

Due to channelisation most stream sections are considered stable, apart from upper areas of the western arm which was identified as being subject to head cut and bank undermining causing erosion and transport of sediment downstream. Large stormwater outlets were also identified as a significant source of sediment through scouring, as well as the likely transport of sediment (and other stormwater pollutants) from surrounding impervious urban areas.

Quantification of catchment sediment loads from erosion

A study undertaken by NSW OEH (2011) compared predicted catchment sediment generation rates in Wyong River and Ourimbah Creek (from catchment modelling) to predicted potential streambank erosion rates. The streambank erosion rates were quantified using erosion assessment results of priority sites in the streambank management plans (Cardno Lawson Treloar 2008a, 2008b) and unit conversion rates for soil volumes. A summary of the results are document below in Table 5-3, while the catchment locations and priority sites for rehabilitation are shown in Figure 5-4. Results show that the predicted erosion rates are generally equivalent or double the predicted catchment generation rates. This demonstrates the importance of streambank rehabilitation for managing sediment loads (and associated nutrients), particularly to the main basin (Tuggerah Lake) and estuary mouths.

Table 5-3 Relative contribution of streambank erosion to catchment sediment loads

Sub-catchment	Sub-catchment TSS generation (t/yr)[1]	Potential additional streambank erosion (t/yr)[2]	Streambank erosion as % of modelled catchment load
3	600	551	92
6	205	216	105
211009	460	702	153
211010	678	1,4141	208
211014	755	62	8
Wyong River Total	2,699 t/yr	2,945 t/yr	109%
4	154	168	109
5	108	288	267
211013	714	1,1196	167
211015	712	218	31
Ourimbah Creek Total	1,688 t/yr	1,870 t/yr	111%

Source: NSW OEH (2011)

[1] Catchment model output

[2] Results of the Streambank Management Plans (Cardno Lawson Treloar 2008a, 2008b). Units converted using a density of 1.31 t/m^3 (average of dry sand, clay and earth)

Figure 5-4 Wyong River and Ourimbah Creek priority streambank rehabilitation sites (Source: OEH 2011)

5.3.4 On Site Sewage Management systems

Most rural properties in the upper catchments are serviced by On Site Sewage Management systems (OSSMs). The two key types of systems are the traditional septic systems and the Aerated Water Treatment Systems (AWTS). These systems can be a source of ground and surface water pollution, leaching nutrients and facial contamination to waterways if not appropriately managed.

Historically, field investigations had shown high failure rates OSSM systems, and it was identified as a key pressure to water quality (Wyong Shire Council, 1999). In recent times, Council has been concerned over the cumulative environmental impacts and risk to public health that failing or inadequately designed systems may have on the region (Wyong Shire Council, 2013b).

OSSM systems often fail because of the inability of the site to cope with effluent absorption due to impermeable clay soils, overloading of the systems with large volumes of wastewater, inappropriate design and lack of proper maintenance.

It is Council's responsibility to ensure that on site sewerage systems are appropriately installed and maintained, and Council has a proactive program of inspections to work with property owners to improve on site sewerage system performance. Approximately 400 systems are inspected each year. As part of this program, systems may require relocation at the time of upgrade to minimise risks to health and the environment.

5.3.5 Unsealed roads

Unsealed roads have been demonstrated to be a significant source of sediment impacting on water quality (NSW OEH, 2013d). As part of a program aimed at reducing sediment loads from unsealed roads, Wyong Shire Council commissioned NSW OEH (2013d) to undertake a monitoring study quantifying concentrations and generation rates of Total Suspended Solids and nutrients in run-off from sealed and unsealed roads, using a local case study on Footts Road, Ourimbah (adjacent to creek). The investigation found that sealing roads can lead to substantial reductions in sediment generation with little change in nutrient generation. In the case study on Foots Road, it found that sealing the road would reduce sediment loads by approximately 4,100 kg / year, with minor increases in dissolved nutrients (3.2 kg/yr dissolved organic nitrogen and 0.24 kg/ year dissolved organic phosphorus).

Importantly, the generation rates derived in this study can be used as a tool for future modelling scenarios assisting to quantify the impacts of unsealed roads in the catchment and assess the costs and benefits of treatment options.

The study also acknowledged that the increased impervious area from sealed roads can lead to other issues impacting receiving water quality such as increased flows and erosion of streams, and increased contaminants from impervious road runoff (heavy metals, nutrients). It noted that monitoring results also suggested attenuation of nutrients and sediment over increasing distance along the roadside drain, and that maximising the length of roadside drains may also be effective in reducing pollutant loads without increasing runoff volumes.

5.3.6 Sewage overflows

Sewage overflows can occur in dry or wet weather. In dry weather, they would typically occur from a system blockage or pump station failure. Blockages could be caused by damage to pipes (through construction or land subsidence) or through blockages caused by tree root ingress or inappropriate disposal of items (such as wet wipes and sanitary products). Tree root ingress and inappropriate disposal are the main causes of blockages within the Central Coast system (Central Coast Council, 2020e). Pump station failures can be due to equipment failure or interruptions to power supply that cannot be fixed prior to sewage storage volumes at pumping stations being exceeded, causing overflows. Overflows at sewage pumping stations may also be caused as they are undersized due to new development that was not accounted for at the time of planning. Significant growth in future population predications has occurred in the region since the reticulated sewerage network was constructed that is likely putting pressure on the capacity of the existing sewerage network.

Wet weather overflows can be caused by blockages and pump station failures, but are most typically caused when stormwater infiltrates the sewerage system, exceeding its design capacity (which has an allowance for wet weather flows) and causing sewage to back up and overflow through relief points in the system. Overflow locations in the sewerage network usually occur at the lowest point in the system, and are commonly located at pump stations next to waterways at these low relief points. The design intent for overflow locations is generally to ensure sewage does not overflow onto private properties (causing unacceptable health risks).

Key pathways that stormwater can infiltrate the sewerage system are via illegal cross connections (e.g. stormwater downpipe connected to the sewerage system or less commonly sewerage connected to stormwater), when overflow relief gullies on properties are set too low (they should be elevated above ground level), or from cracks in aging / damaged sewerage pipes allowing rainfall infiltrating through the ground and into the leaky pipes.

Sewage overflows can adversely affect water quality resulting in potential health, environmental and aesthetic impacts. Pathogens (including bacteria, viruses, protozoa and helminths) pose the key risk to public health (e.g. via swimming / consumption of affected shellfish). Thermotolerant coliforms and enterococci are commonly used as indicators of pathogen pollution. These indicators are limited however as they do not identify whether the source is from humans, or other faecal contamination (animals etc). Council are using DNA and pharmaceutical analysis in the Terrigal Catchment Audit to better identify whether the source of contamination is from sewage or from the catchment.

Elevated concentrations of nutrients (nitrogen, phosphorus) and high biochemical oxygen demand in sewage present key environmental pressures on water quality in Tuggerah Lakes, contributing to eutrophic conditions and depleting the water of oxygen. A summary of the potential environmental impacts of sewer overflows is outlined in Table 5-4.

Table 5-4 Potential impacts of sewage overflows

Pollutant	Potential impact
Suspended solids	Deposited sediment affects aquatic insect habitat
Turbidity	Reduces water clarity and impacts on fish and aquatic plants such as seagrass
Nutrients (nitrogen and phosphorus)	Stimulates growth of algae and undesirable aquatic plant, micro-organisms and invertebrates (mosquitoes)
Ammonia, metals and pesticides	Toxic to fish and aquatic insects at high concentrations
Organic matter / biochemical oxygen demand	Reduces dissolved oxygen levels, impacting on fish, insects and micro-organism productivity
Gross pollutants	Visually unattractive

Source: NRMCC (2004)

Despite the above, it is noted that in wet weather when most overflows are likely to occur in the catchment, sewage is largely diluted and stormwater contaminant loads are likely to be the dominant source of pollution to receiving waters.

The community has identified sewage overflows possibly caused by cross connections is an issue impacting on water quality and recreational use in Tuggerah Lakes, particularly following rain events. It was observed that beaches in the area are closed following rainfall, presumably due to sewage contamination. It is noted that it is standard procedure by Central Coast Council (and usually other Councils) to close beaches to swimming at lake sites for three days following rainfall. This is done as a precaution to ensure public safety to contaminants carried in stormwater. Although this may include diluted sewage from overflows, stormwater runoff from the catchment also contains typically high concentrations of bacterial contamination that preclude swimming.

A detailed program is currently being undertaken at Terrigal Lake to investigate and remediate the cause of historically poor beach watch and water quality testing results. The program has undertaken CTV inspections and smoke testing to identify issues, and has identified many illegally connected stormwater pipes. Investigations undertaken as part of the Terrigal Catchment Audit have also noted that sometimes water that looks and smells to be contaminated by sewage is in fact from algae blooms and decaying seaweed, which can cause bad odours and looks like brownish slicks (Central Coast Council, 2020e).

Within the Tuggerah Lakes, the Beachwatch Program monitors water quality at Lake Munmorah and Canton Beach swimming areas. An audit has recently commenced at Canton Beach in response to poor results for recreational use. Sampling will be undertaken in the lake, stormwater and sewer network to investigate and identify potential contamination sources, similar to the Terrigal program.

5.3.7 Water supply offtake

Water offtake from Wyong River and Ourimbah Creek for town water supply is managed by the Water Sharing Plan for the Central Coast Unregulated Water Sources 2009. The water sharing plan aims to set rules for accessing water while protecting the health of waterways. While Tuggerah Lakes are not technically in the water sharing plan area, they are recognised as being an important ICOLL connected to water sources in the plan.

Previous investigations (DECCW, 2010) have shown that town water supply extractions from Wyong Weir and Ourimbah Weir can cause flows from the weirs to cease, such that inflows to the lakes are only from areas downstream of the weirs and fringing catchments. At these times, local runoff would be the dominant source of inflow to the lake. Although in absolute terms the inflows were noted to be small, high concentrations of available nutrients typically contained in urban runoff could contribute to eutrophic conditions (see Chapter 4 for more details). However, it is noted that town water extractions may have changed since the time of the previous assessment, and the impact of current extractions and entitlements on flows from the weir are uncertain.

A recent review of the water sharing plan was undertaken by the Natural Resources Commission in accordance with the *Water Management Act 2000*. The review identified a number of areas for improvement, however recommended the current plan be extended until June 2022 to allow the new water plan to take into consideration findings from Council's updated Integrated Water Resource Plan and the revised Lower Hunter Water Plan, which are both due for completion in 2021.

A priority issue to be addressed in the development of a new water sharing plan included the review of provisions to protect the environment to ensure they are evidence based, transparently reported and their implementation monitored. Two key risks of the current water sharing plan were identified as follows (Natural Resources Commission, 2020):

- Ecological assets and their water requirements are not clearly defined.
- Population increases, water scarcity and hydrological stress threaten future utility supply security

Despite the above, it is noted that the Tuggerah Lakes ICOLL itself was assessed by the Plan as having a low sensitivity to low and high flow inflows (NSW DPI, 2016). Based on the limited information provided, further investigations are required to assess if this is a reasonable assessment.

5.4 Future catchment pressures on water quality

Key Points
The Central Coast Regional Plan 2036 identifies significant population growth pressures in the region with an additional 41,500 households by 2036.
Future pressures from urban development are increasing impervious areas, increasing stormwater pollutant loads to receiving waters and altered natural hydrology, which can impact on receiving waterway and wetland health.
Large areas of planned development within the catchment present a key future pressure to water quality from poor erosion and sediment control practices during the construction phase.
Planning controls for water quality within the Development Control Plan vary by location, however only locations within water supply catchments require that neutral or beneficial (NorBE) water quality objectives be achieved.
Where stormwater is directly connected to the lakes, it will be important to manage all future development, and it is noted that currently some forms of development are exempt from complying with water quality standards (e.g. single dwellings and granny flats).
Where urban runoff is discharged to Wyong River or Ourimbah Creek prior to the lakes, impacts to lake water quality may be less pronounced as monitoring in the main basins show reasonable health, presumably due to better mixing than in nearshore areas. However, it is noted that monitoring within waterways draining to the lakes generally showed poor water quality and waterway health, which will likely worsen with increased pollutant loads.
Council requires improved funding mechanisms, resourcing and capacity building to ensure both current and future stormwater quality treatment assets, including streetscape or ‘at source’ solutions are appropriately maintained to achieve optimal treatment performance.
Despite gaining planning approval and consent by the Federal Minister Energy and Environment in February 2019, community concern still exists around the impacts to water quality from the Wallarah 2 Coal Project.

5.4.1 Introduction

The *Central Coast Regional Plan 2036* identifies significant population growth pressures in the region as prescribed by state government, with an additional 75,500 people planned for the region (or 41,500) households by 2036. The following section identifies key future catchment pressures to water quality related to development and population growth within the Tuggerah Lakes catchment.

5.4.2 Development pressures

Development pressures in the Tuggerah Lakes catchment include:

- Development through the northern growth corridor, which follows the alignment of the M1 Motorway and rail corridor between Tuggerah and Warnervale, and includes key development areas around Tuggerah, Wyong River foreshore and Wyong town centre, in addition to extending north to areas within the Warnervale Wadalba land release area (Warnervale Town Centre, Wyong Hospital and Wong Employment Zone and Bushell's Ridge).
- New greenfield development in the Warnervale Wadalba land release area, which are predominantly located in the Porters Creek wetland catchment (and around areas identified in the North Wyong Structure Plan).
- Development around Lake Munmorah, including a mix of new low and low/medium density residential development and employment lands (as identified in the Lake Munmorah Structure Plan).
- Local centres identified with potential for additional infill housing include Toukley, The Entrance and Long Jetty (NSW Government, 2016).

Population growth pressures between 2026-2036 are expected to be generally highest in catchments draining to Lake Munmorah (Munmorah catchment) and Porters Creek wetland (Central Coast Council, 2020b).

Beyond the urban areas, population growth and development pressures are also expected in the rural areas west of the motorway. Subdivision of lots in unsewered areas will result in more OSSM that will need to be managed to ensure surface and groundwater water quality is protected, particularly within the water supply catchments. However, it is noted that in surface and groundwater drinking catchments, Neutral or Beneficial Effect (NorBE) water quality objectives apply (NSW Government, 2016).

Future pressures from urban development are increasing impervious areas, increasing stormwater pollutant loads to receiving waters and altering natural hydrology. Altered flow regimes and increased pollutant loads from urban stormwater can impact on the health of wetlands, and is the key cause of much of the current wetland degradation in the region (Australian Wetlands 2009). Wetlands provide important ecosystem services in catchments, including acting as natural water quality treatment buffers, providing habitat value, and providing flood mitigation and groundwater recharge. Much of the planned future development drains to Porters Creek Wetland, a wetland of national significance. Furthermore, development pressures around Warnervale and Wyong have been noted as existing cumulative impact pressures to Porters Creek and Tuggerah Swamp wetlands (Eco Logical 2020).

5.4.3 Erosion and sediment control practices

Large areas of planned development within the catchment present a key future pressure to water quality during the construction phase. As discussed in Section 5.3.2, sediment generation from poor erosion and sediment control practices can result in significant quantities of sediment being washed into waterways and ending up in Tuggerah Lakes, where it can impact on water quality and the health of seagrass. There also exist areas of dispersive soils in the catchment (e.g. Wadalba) that present a key risk to water quality if not appropriately managed during construction. Poor erosion and sediment control practices during the construction phase can also damage water quality treatment assets, resulting in poor treatment of stormwater (further affecting water quality) and expensive rectification costs.

5.4.4 Planning controls

The standard water quality treatment provisions in the Wyong Development Control Plan (DCP) require 80% reduction of total suspended solids, 45% reduction of Total Nitrogen and 45% reduction of Total Phosphorus from post development loads, in accordance with the A*ustralian Runoff Quality* guidelines (Engineers Australia, 2006). However, location specific development provisions in the DCP can require more stringent treatment requirements. As noted previously, no future development, apart from developments within the drinking water catchments, require neutral or beneficial (NorBE) water quality objectives to be achieved.

Although the impact of increased pollutant loads on water quality from future development has not been comprehensively assessed, and sustainable targets are unknown, it is clear that the current condition of water quality in the lakes is unacceptable to the community, particularly around foreshore areas which are directly impacted by stormwater runoff. During community consultation, stakeholders voiced concerns about the number of new homes planned for the catchment area over the next 15 to 20 years and the impact on water quality.

Where runoff is discharged to Wyong River or Ourimbah Creek prior to the lakes, the impacts may be less pronounced as monitoring in the main basins show reasonable health (receiving Grades of 'B' (Tuggerah and Munmorah) and 'C' (Budgewoi) during the 2018/19 reporting period, and having remained relatively stable since 2012). However, it is noted that monitoring within waterways draining to the lakes generally showed poor water quality when compared to objectives (SKM 2010), which will likely worsen with increased pollutant loads. Recent results of freshwater monitoring provided by Council, also show many urbanised catchments receiving overall grades of D or E during the 2018/19 reporting period. Current sediment loads will also continue to place pressure on water quality and seagrass in the lakes.

Consequently, the capacity of receiving waterways and Tuggerah Lakes to accept additional pollutant loads is questionable, and current planning controls that allow an increase in loads (which may occur with current treatment objectives) are only expected to result in reduced water quality. Furthermore, in those areas where stormwater is directly connected to the lakes, it will be important to manage all future development, and it is noted that currently some forms of development are exempt from complying with water quality standards (e.g. single dwellings and granny flats).

As mentioned in Section 5.3.2, the following existing pressures to water quality are also likely to create future pressures if not appropriately managed:

- Less than optimal water quality treatment outcomes from contested requirements in the DCP
- Handover of poorly functioning water quality treatment assets
- Insufficient developer bonds to rectify issues with water quality treatment devices.

5.4.5 Maintenance

The ownership of water quality treatment devices constructed by developers to manage stormwater quality is transferred to Council to maintain as an asset after the development is complete. The large amount of development planned in the region will see an increase in the number of stormwater quality treatment devices that Council will need to maintain. Discussion with Council maintenance staff indicate that it is challenging to adequately maintain even the current assets with allocated funding, resourcing and knowledge base, particularly since the stormwater levy was abolished.

It was also evident from discussion with various areas of Council that there is some resistance to approving streetscape water sensitive urban design in new developments or through renewal / retrofit works due to the lack of skills and resources to ensure effective construction and maintenance of these assets.

Good maintenance of assets is important to ensure optimal performance and protection of receiving water quality. Therefore, another key pressure on future water quality is the ability of Council to secure the funding, resourcing and capacity required to maintain all types of stormwater quality treatment assets, including streetscape or ‘at source’ solutions.

Stormwater NSW recently submitted a position statement on opportunities for policy reform and improved sustainable funding for stormwater management in NSW. This includes the recommendation that the NSW Government should update the legislation, Local Government (General) Regulation 2005 Section 125AA, regarding the maximum annual charge for stormwater management services (i.e. stormwater levy) to $81 per year for a house (currently $25) with annual CPI increase (Stormwater NSW, 2020).

Furthermore, it is noted that a white paper is currently being written by Stormwater NSW that addresses some of these key issues. The white paper is being developed as a result of two industry engagement seminars hosted by Stormwater NSW and UNSW, and will outline the current status of WSUD adoption in NSW and suggest areas for research and development to further drive sustainable stormwater practices in NSW.

5.4.6 Water supply offtake

Another pressure that may impact on water quality is the ability to meet the environmental needs for water (i.e. to support wetlands and ecological health) with growing human use demands for water in a changing climate. The *State of the Climate 2020* (BOM, 2020) report predicts continued increases in temperatures in the region and cool season (between April – October) rainfall declines that will lead to more time in drought. Increased temperatures are likely to increase evaporation losses from rivers and water storages (reducing supply), while also increasing demands for water.

As discussed in Section 5.3.7, a recent review of the Water Sharing Plan (WSP) identifies that population increases, water scarcity and hydrological stress threaten future utility supply security, and that ecological assets and their water requirements are not clearly defined (Natural Resources Commission, 2020). These issues are to be addressed in a new WSP following updates to Council’s Integrated Water Resource Plan (i.e. update to WaterPlan 2050) that will help to better inform how these issues are addressed.

5.4.7 Sewage overflows

Cumulative infill development has the potential to place pressures on existing sewerage infrastructure, the condition of which is likely to already be impacted by age (i.e. cracks and tree root ingress) considering the area was sewered approximately 30 years ago. Infill development may further reduce the capacity of the system, particularly during wet weather events and may increase the frequency of sewage overflows occurring if not appropriately managed. As previously noted, Council has an ongoing maintenance program to improve reliability, lower the risk of sewage overflows, and accommodate planned future population growth in the region.

5.4.8 Mining

Some community concern was raised about the impacts of the Wallarah 2 Coal project on water quality. The project is an underground coal project extracting coal from beneath the Dooralong and Yarramalong Valleys using longwall mining techniques. The project has received significant community opposition since its inception for posing potential risks to drinking water quality in the catchment. This project was originally refused in March 2011 citing uncertainty around (Wyong Council, 2012):

- Subsidence predictions
- Surface water quality impacts
- Ecological impacts
- Heritage impacts.

After additional investigations and some changes to the project, planning approval was granted in January 2018, with consent granted by the Federal Minister Energy and Environment in February 2019. The project still needs to undergo final feasibility, detailed design and approval processes before the tendering, construction and employment phase can commence (programmed to commence between 2022-2025).

5.5 Conceptual model of catchment pressures to water quality

Conceptual models have been developed in a graphical format to assist in illustrating our current understanding of catchment pressures affecting water quality, and what current best practice management actions could be implemented to help improve catchment and receiving water quality in Tuggerah Lakes.

A summary of the conceptual models are provided below:

- **Figure 5-5 Natural Conditions.** This drawing illustrates the basic water cycle in natural forested conditions. Rainfall is largely infiltrated into soils and recharges groundwaters, or is lost through evapotranspiration. Only a small proportion of rainfall is discharged to the lakes via runoff.
- **Figure 5-6 Existing and Future Pressures to Water Quality.** This drawing illustrates the key existing and future pressures in the catchment that impact on water quality, as described in Sections 5.3 and 5.4. It shows that overall these pressures result in reduced infiltration and evapotranspiration due to widespread clearing of vegetation through the catchment and increased impervious surfaces. In combination with catchment pressures, this results in altered flow regimes and increased volumes of poor quality stormwater runoff to the lakes.
- **Figure 5-7 Best Management Practices.** This drawing illustrates best management practices that could be applied throughout the catchment to address the key pressures identified in Figure 5-6. The management actions focus on promoting infiltration, treatment and reuse of stormwater at the source where possible, to mimic more natural conditions. Best management practices would therefore seek to increase infiltration and evapotranspiration, reducing stormwater volumes and ensuring that stormwater is appropriately treated before discharging to waterways. Although not shown on the conceptual diagram, education and capacity building are integral to the successful implementation of catchment best management practices.

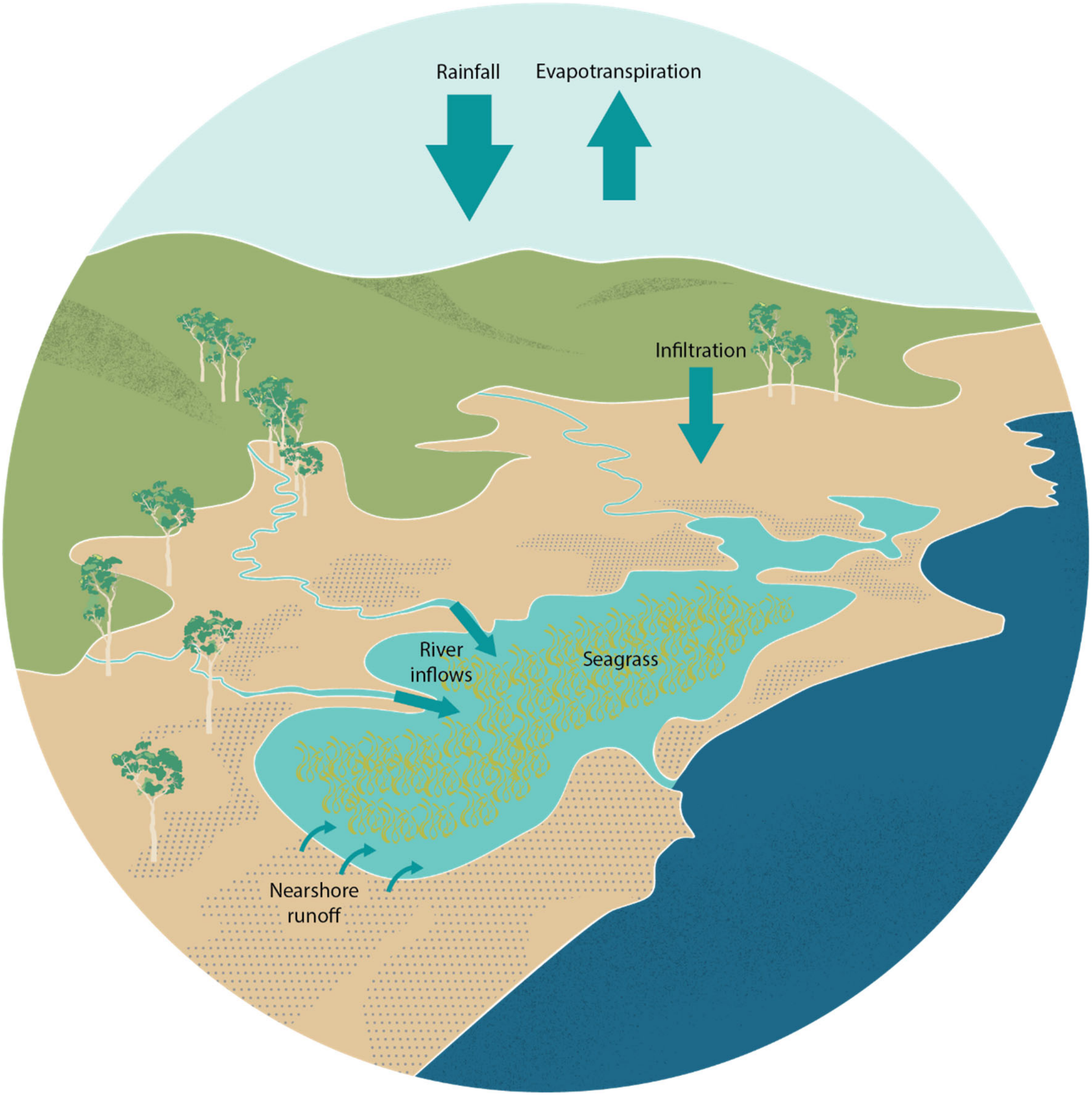


Figure 5-5 Conceptual catchment model – natural conditions

(adapted with permission from Central Coast Council)

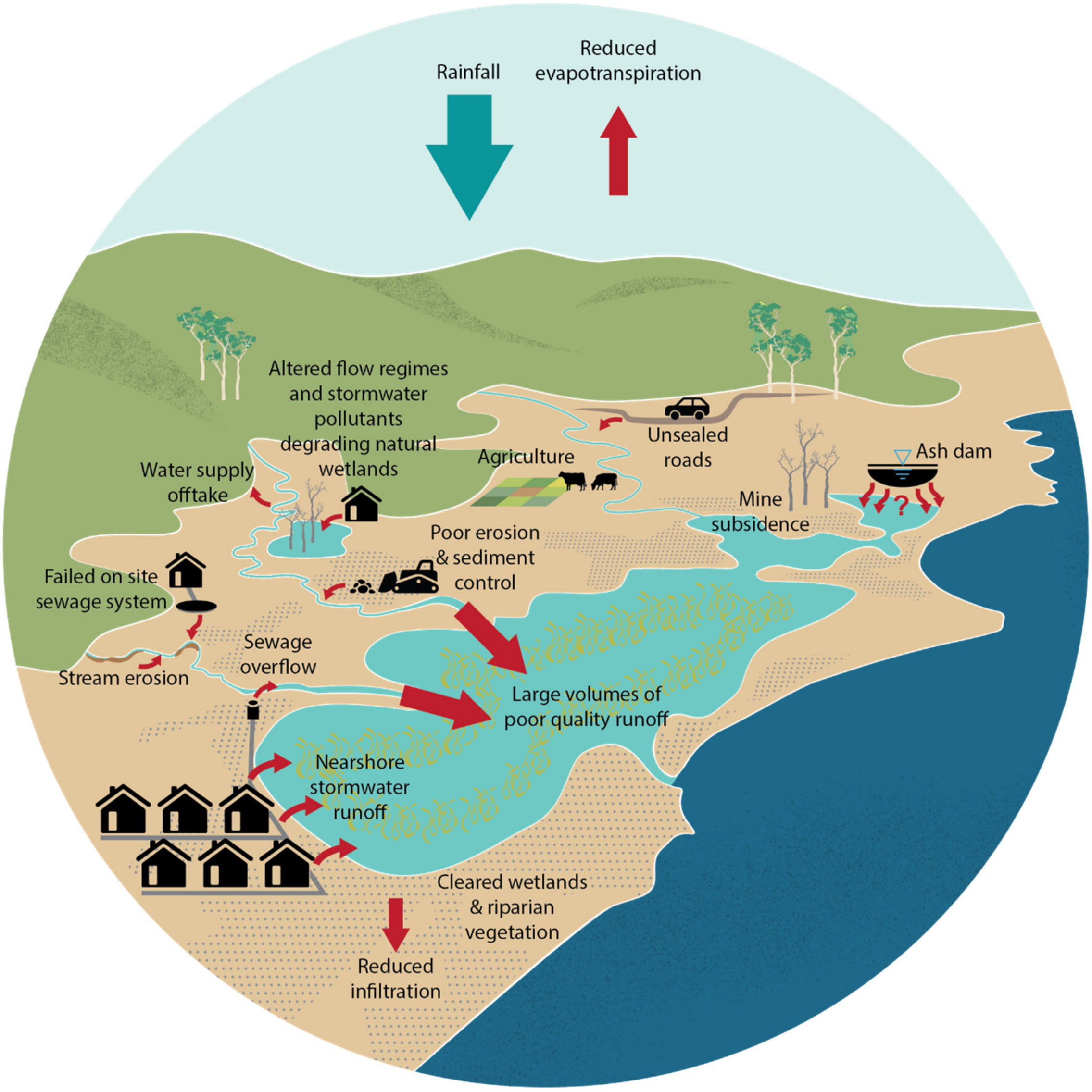


Figure 5-6 Conceptual catchment model – existing and future pressures to water quality

(adapted with permission from Central Coast Council)

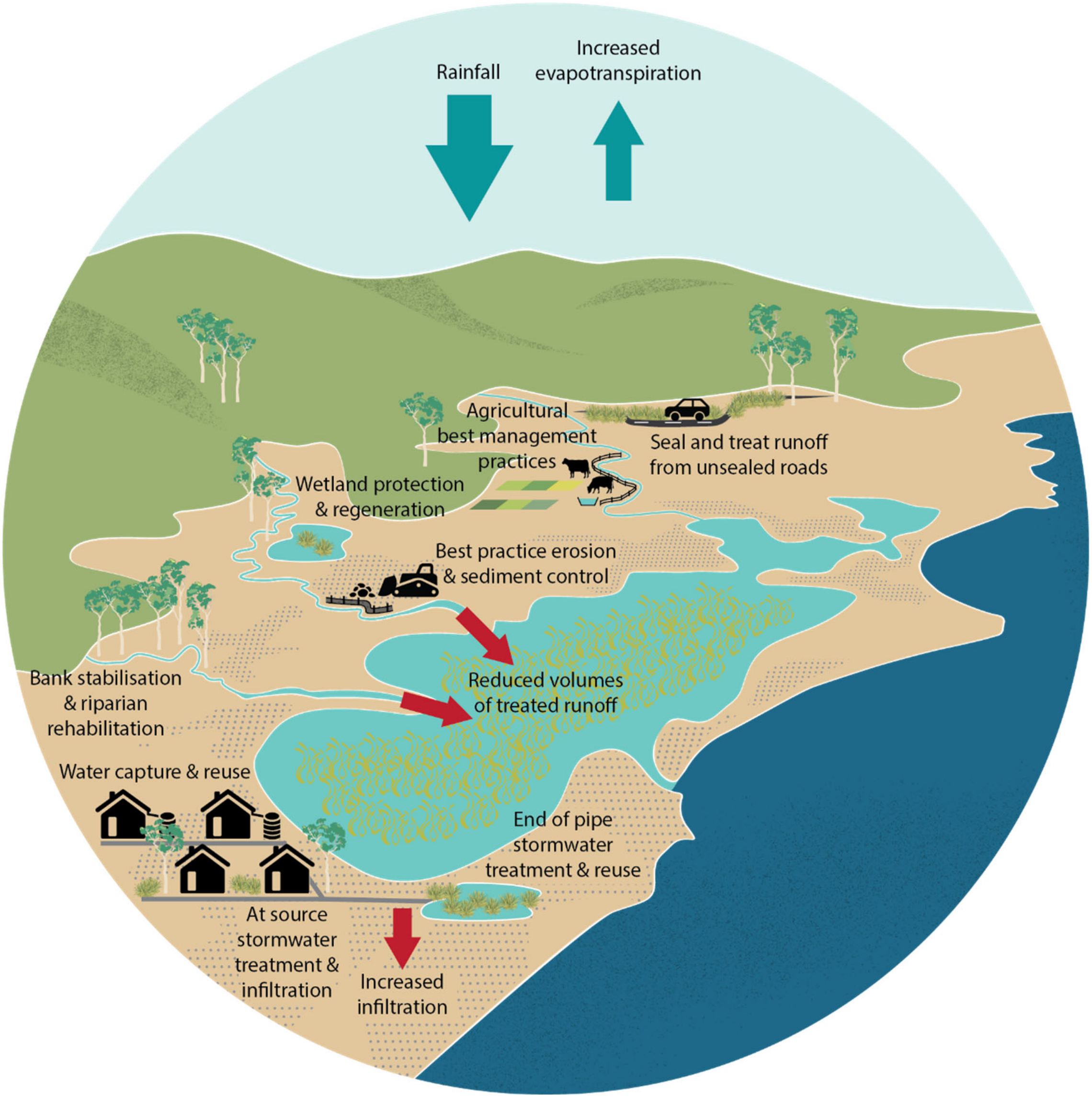


Figure 5-7 Conceptual catchment model – best management practices

(adapted with permission from Central Coast Council)

5.6 Catchment pollutant loads

Key Points
A catchment model was developed by ANU (2010) to estimate current catchment pollutant loads to the Tuggerah Lakes. The model was developed using IHACRES for the predominantly non-urban catchments, and MUSIC for the urban catchments immediately surrounding the lakes.
Water quality monitoring data in non-urban catchments were analysed to estimate average IHECRES catchment pollutant concentrations for TN, TP and TSS. Despite some data limitations, these were used as a basis for estimating average annual existing catchment pollutant loads and to inform hydrodynamic modelling.
For urban catchments modelled in MUSIC, modelling of flows and pollutant loads was undertaken using parameters recommended in the NSW MUSIC Modelling Guidelines (BMT WBM, 2010b), as there were insufficient local long term water quality data sets to derive event and dry weather mean concentrations.
While uncertainties exist about the prediction of absolute quantities of pollutant loads (due to the insufficient information about water quality) the relative differences between catchments are likely to be real.
Catchment modelling identified that while rural catchments generally deliver the largest flows and associated nutrient and sediment loads due to their size, catchments with urban development generate the highest loads of key pollutants on a per hectare basis in the catchment.
Catchment modelling was also undertaken in Source to quantify the increase of current catchment pollutant loads compared with natural conditions, and investigate future management scenarios.
Source catchment modelling indicated that existing urban development areas have increased pollutant loads upwards of 400% in some areas compared to natural catchment conditions.
Catchment management scenarios assessed using Source predicted that applying best practice stormwater treatment of 80% TSS, 60% TP and 45% TN to all future development would result in improved conditions compared to current pollutant loads. However, this is unlikely to be the case, largely due to changes in recent development trends that result in a higher proportion of impervious area for new developments, and subsequent increased generation of pollutant loads. Further assessment is recommended of what the likely impact of future development is on pollutant loads when current Water Quality Objectives are applied.

Key Points

Due to the magnitude of loads from non-urban catchments, management actions would need to be focused on both urban and non-urban land uses in order to provide significant mean annual load reduction to Tuggerah Lakes from current conditions. However, the importance of managing urban runoff in fringing urban catchments that discharge directly to the lakes is recognised for managing water quality in nearshore areas.

The catchment model forms part of a modelling framework developed for the Tuggerah Lakes system to help inform the understanding of nutrient and sediment loads into the estuary and the likely impact on ecological function.

While the modelling framework has improved the understanding of the system, the model is unable to determine sustainable load targets and the potential impacts that future development may have on the lake due to the following key limitations:

- Uncertainty around actual pollutant generation characteristics and groundwater influences
- Hydrodynamic modelling complexities for nearshore processes that are not captured in the current model
- Catchment model resolution needs improvement to better represent nearshore conditions in combination with the hydrodynamic modelling.

5.6.1 Existing catchment loads

A catchment model was developed by ANU (2010) to estimate current catchment pollutant loads to the Tuggerah Lakes. The model was developed using IHACRES for the predominantly non-urban catchments, and MUSIC for the urban catchments surrounding the lakes. MUSIC was used in the highly urbanised areas surrounding the lakes, to enable the model to be easily used for future investigation of management options in these urban areas. However it is noted that urban development areas beyond the lake edges (e.g. around Wadalba, Warnervale, Wyong, Tuggerah and Ourimbah) were not included in the MUSIC model extents. The catchments modelled using IHACRES and MUSIC are shown in Figure 5-8.

Figure 5-8 Catchment modelling in IHACRES (green) and MUSIC (blue) (Source: ANU 2010)

The IHECRES model was calibrated for flow, based on gauged data in the catchment. Available data was used to represent flows from Mangrove Creek Dam to supplement water supply, as well as extraction of water at Wyong River and Ourimbah Creek weirs for town water supply. It is noted that since modelling was undertaken, water supply and extraction is likely to have changed and should be reviewed. Water quality monitoring data in non-urban catchments were analysed to estimate average IHECRES catchment pollutant concentrations for TN, TP and TSS and discharge-concentration relationship for estimating daily input files for use in the Tuggerah Lakes hydrodynamic model. ANU (2010) noted that none of the water quality monitoring data reviewed included flow data and there were issues that made data interpretation difficult (e.g. unclear units, sampling methods, site locations, data inconsistencies). There was also very limited data available for TSS. The investigation attempted to develop land use pollutant export characteristics, but determined that this could not be reliably undertaken with the available data.

Despite the above data limitations, average catchment concentrations were used to estimate average annual existing catchment pollutant loads, by multiplying IHECRES catchment flows by average pollutant concentrations determined from the monitoring data, with some assumptions made regarding catchments with limited data. For fringing lake urban catchments represented in MUSIC, modelling was undertaken using concentrations recommended in the NSW MUSIC modelling guidelines (BMT WBM, 2010b), as there were insufficient local long term water quality data sets to derive Event Mean Concentrations (EMC) and Dry Weather Concentrations (DWC). Adopted values are shown in Table 5-5 and Table 5-6 for EMC and DWC parameters, respectively.

Table 5-5 Land use Event Mean Concentrations for MUSIC Modelling

Pollutant	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Residential Commercial Industrial	141.3	0.251	2.00
Rural residential	89.1	0.219	2.00
Agricultural	141.3	0.603	3.02
Forest	39.81	0.079	0.89

Source: BMT WBM (2010b)

Table 5-6 Land use Dry Weather Concentrations for MUSIC Modelling

Pollutant	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Residential Commercial Industrial	15.8	0.141	1.29
Rural residential	14.1	0.060	0.89
Agricultural	20	0.089	1.10
Forest	6.03	0.030	0.30

Source: BMT WBM (2010b)

Reporting noted that while there were uncertainties about the prediction of absolute quantities of loads (due to the insufficient information about water quality) the relative differences between catchments are likely to be real (ANU, 2010). Results showing mean annual pollutant loads for sub-catchments draining to Tuggerah Lakes are shown in Figure 5-9 in absolute terms, and Figure 5-10 in terms of pollutant generation per hectare. The key finding from the investigations is that while rural catchments generally deliver the largest flows and associated nutrient and sediment loads due to their size, catchments with urban development generate the highest loads of key pollutants on a per hectare basis in the catchment (DECCW, 2010). Furthermore, it was noted that town water supply extractions from Wyong and Ourimbah Weirs can cause flows downstream to cease, such that inflows are only from areas downstream and fringing lake catchments. At these times urban runoff is the main source of inflow to the lakes, although in absolute terms the runoff is small (ANU, 2010). However, it is noted that the flow regime may have changed since this time, due to changes in extraction rates. Catchment modelling was also undertaken in a separate assessment (using Source, refer to Section 5.6.2), to quantify the increase of current catchment pollutant loads compared with natural conditions.

Results are shown in Figure 5-11 and indicate that existing urban development areas have increased pollutant loads upwards of 400% in some areas compared to natural catchment conditions. This was also supported by investigations in the highly urbanised Berkeley Vale catchment, which indicates urbanisation has resulted in a 300% increase in pollutant loads from natural conditions (NSW OEH, 2018a).

Importantly, in a final report presenting the findings of all catchment modelling (DECCW, 2010), it was noted that existing catchment loads would not be reported due to inconsistencies / errors with the catchment model that needed to be resolved. It is assumed that this refers to the difference in pollutant load predictions when the two different modelling approaches were compared (Source Catchment vs IHACRES and MUSIC). No further information could be found about resolving this issue.

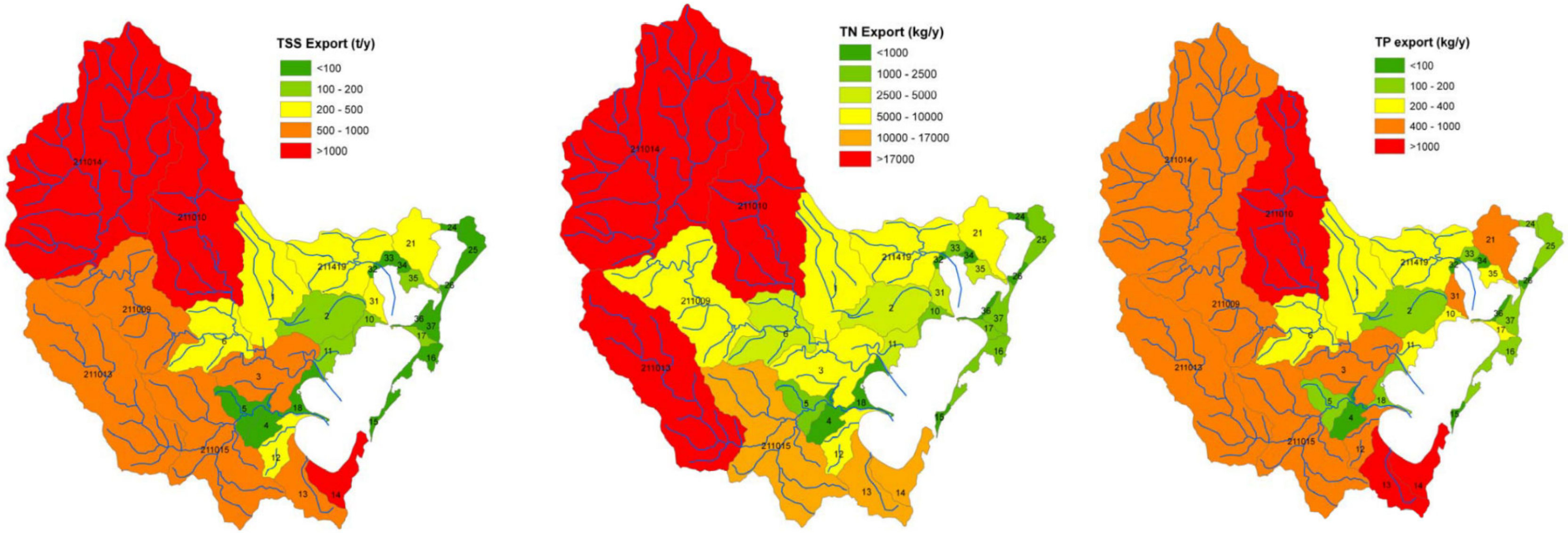


Figure 5-9 Predicted mean annual loads for TSS, TN and TP (Source: ANU, 2010)

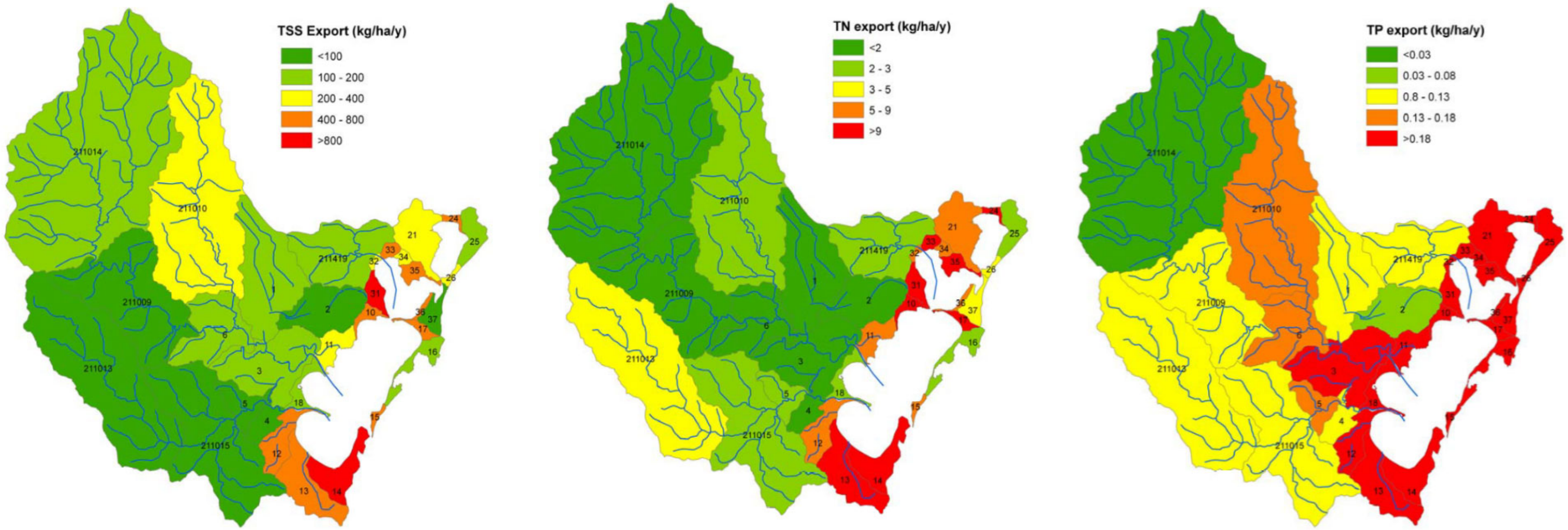


Figure 5-10 Predicted mean annual export rates for TSS, TN and TP (kg/ha/yr) (Source: ANU, 2010)

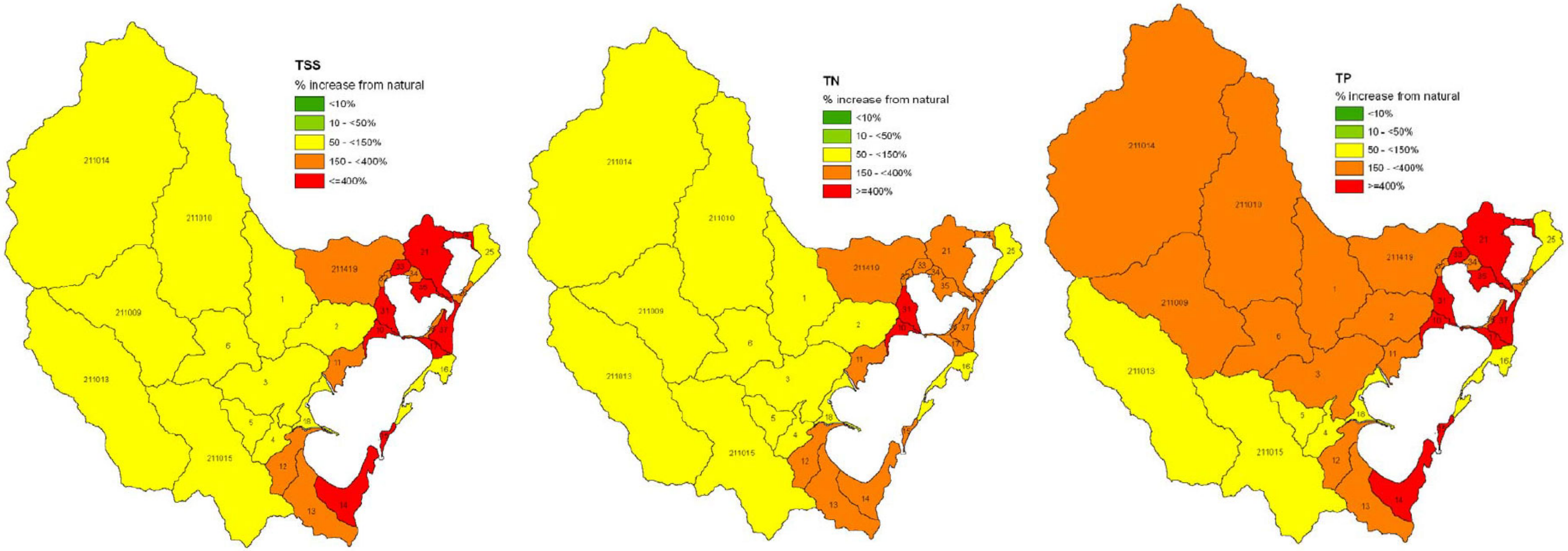


Figure 5-11 Predicted increases in current pollutant loads compared to natural conditions for TSS, TN and TP (Source: DECCW, 2010)

5.6.2 Future catchment loads

NSW DECCW commissioned another modelling study to investigate a number of land use management scenarios using eWater CRC's Source Catchment modelling package (BMT WBM, 2010a). The model was developed in consideration of previous catchment modelling and calibration efforts undertaken by ANU (2010).

Comparison of existing catchment flows and loads between the models showed a good correlation in flows, however a poor correlation in predicted pollutant loads. This is likely due to the fact that the Source catchment modelling adopted all EMC and DWC values to be consistent with those used in the MUSIC model developed by ANU (2010), as no landuse EMCs and DWC were available for nonurban areas. The MUSIC model parameters were based on those recommended in the Draft NSW MUSIC Modelling Guidelines (BMT WBM, 2010b), that had been derived from Fletcher et al (2004). The study by Fletcher et al (2004) was commissioned by the NSW Environmental Protection authority (through their stormwater trust) and includes a comprehensive review of monitoring data (predominantly from NSW) to derive EMCs for typical land use types in NSW.

The difference in pollutant generation rates when comparing these two approaches increases uncertainty around absolute load predictions to the lakes. However, relative comparisons within each model are expected to be reasonable.

The modelling was used to investigate the following key scenarios:

- Pre-European development (i.e. natural conditions)
- Current land use
- Future land use
- Future land use with WSUD applied to future landuse only (assuming 80% TSS, 45% TN and 60% TP reduction in post development loads)

A number of other scenarios were also assessed investigating the impact of future land use with WSUD retrofit (assumed at a streetscape scale) incorporated into various different proportions of existing urban residential lands. Results of the modelling show increases in catchment loads if future development was unmitigated, however it showed that applying 80% TSS, 60% TP and 45% TN treatment to all future development would result in improved conditions compared to current loads. However the modelling assumes treatment standards for Total Phosphorus (65%) that are better than general current standards (45%), and applies the treatment standard to all new development (including infill development which is likely to be exempt from requiring water quality treatment).

It is also likely that the future development areas previously modelled are no longer an accurate description of what is currently planned in terms of the extent and intensity of development. For example, future urban residential development was assumed to be only 35% impervious in the modelling, whereas current development trends are showing low density residential developments (R2) are now expected to be much higher, with Council recommending that single lots between 450 to 700m^2 be modelled using at minimum of 80% impervious area. An example highlighting the nature of these types of new development, including an 80% impervious area (rather than 35% impervious area) is shown in Figure 5-12.

Figure 5-12 Example of low density residential development R2

To test the likely implications of increased impervious areas and reduced treatment requirements on catchment pollutant loads, a simple MUSIC model was developed using parameters in accordance with the *Civil Works Specification Design Guidelines* (Central Coast Council, 2018). Results are shown in Figure 5-13 to Figure 5-15 for TSS, TN and TP, respectively. Percentages indicate the assumed percentage of impervious area modelled. Water Quality Objectives investigated include 80% TSS, 45% and 60% TP and 45% TN reduction in post development loads.

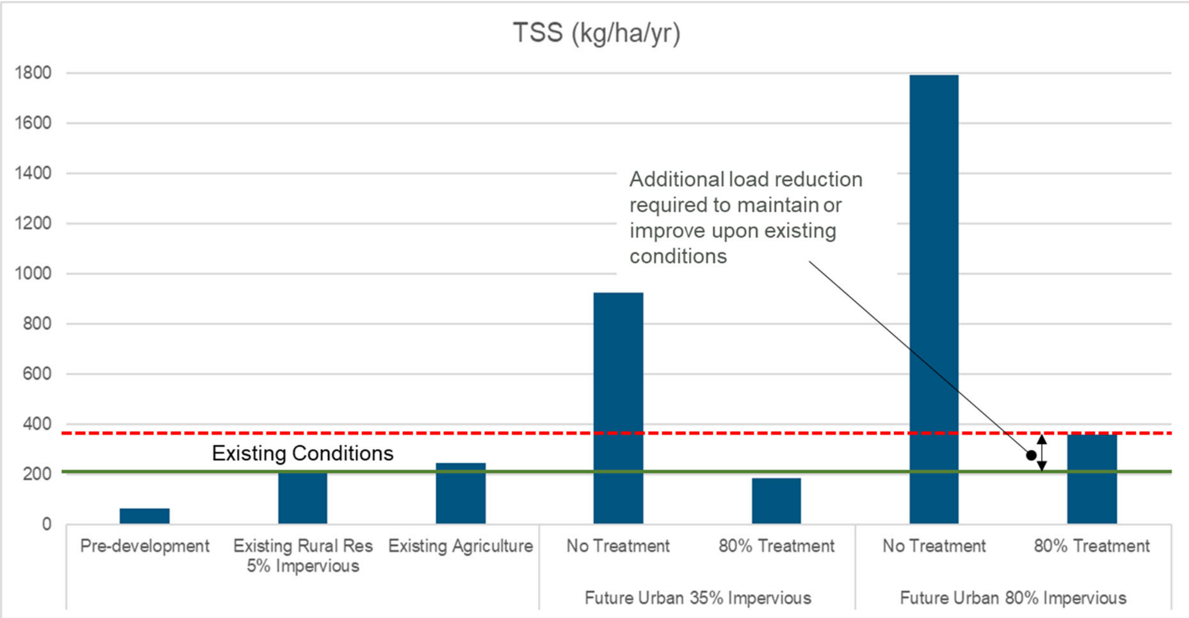


Figure 5-13 Predicted TSS mean annual load comparisons

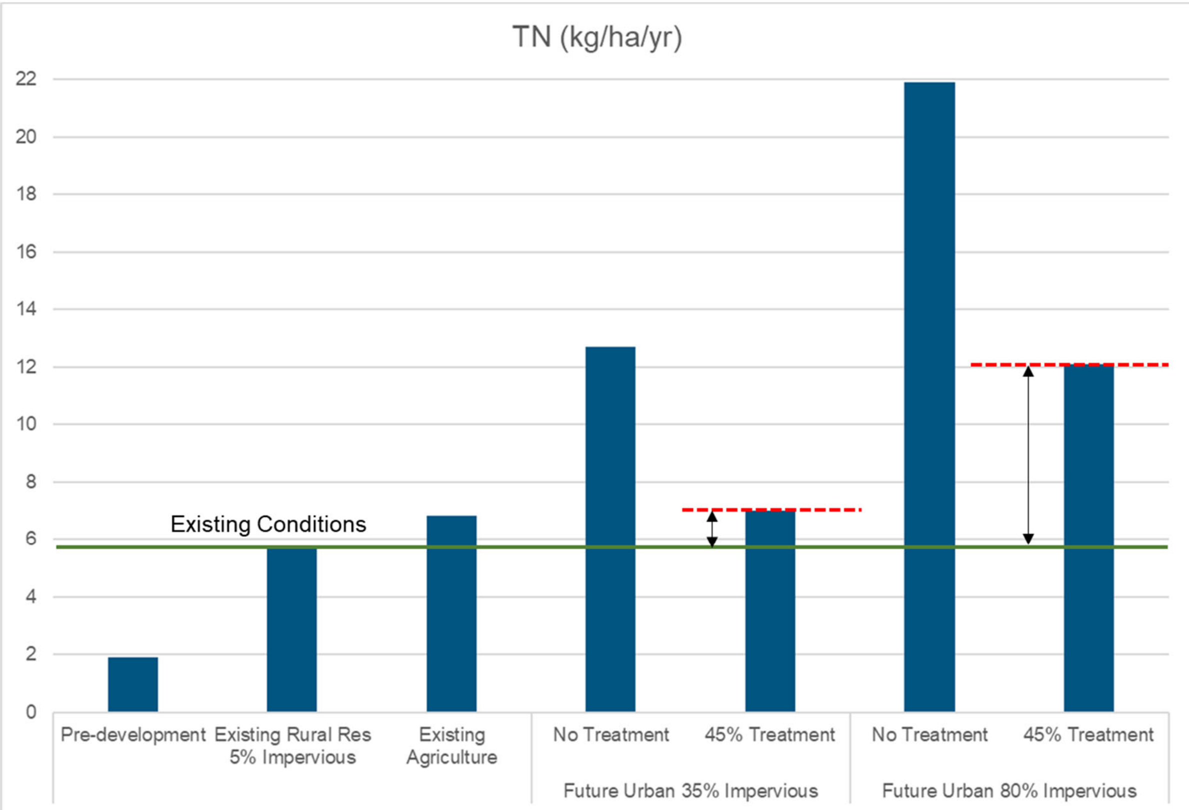


Figure 5-14 Predicted TN mean annual loads comparisons

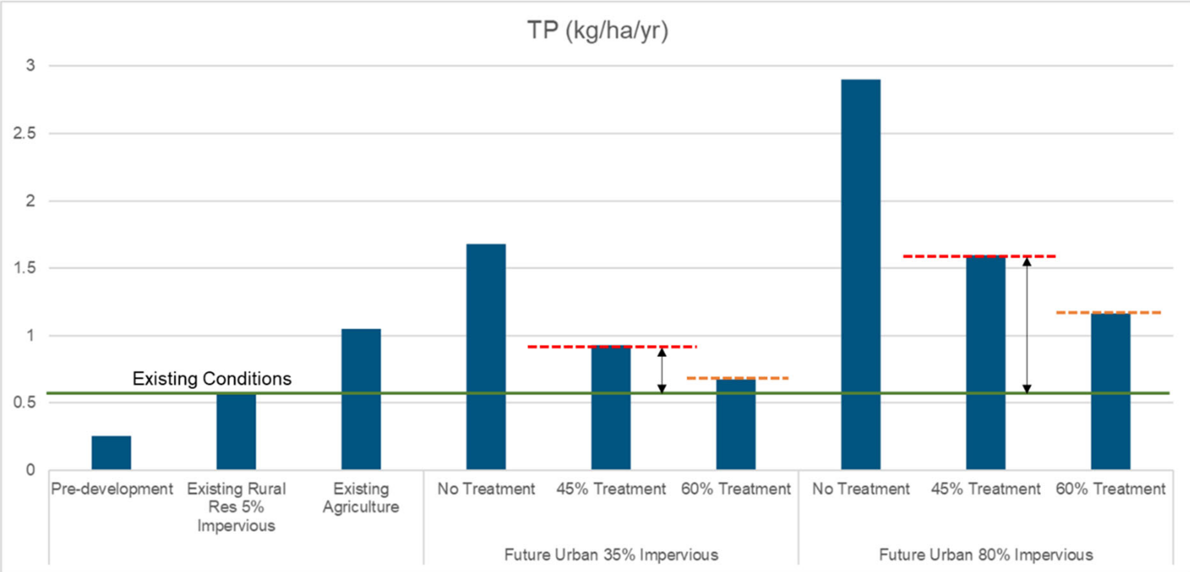


Figure 5-15 Predicted TP mean annual loads comparisons

The results indicate that maintaining existing catchment pollutant loads from future development areas will likely not be achieved from the application of current guidelines in greenfield developments, assuming current land use is mostly rural residential. It also shows that increasing the percentage impervious area from 35% to 80% significantly increases loads after treatment. It is however noted that no flow mitigation has been accounted for (e.g. water losses through stormwater harvesting or rainwater tanks), which would further reduce pollutant loads.

Due to expected changes since the previous modelling was undertaken in 2010 (in terms of the extent and intensity of planned future development), a more comprehensive assessment is recommended to detail the likely impact of future development on pollutant loads when current WQOs are applied.

The results of the catchment modelling undertaken by BMT WBM (2010a) also illustrated the impact that current land use has had on total pollutant loads to the lakes (refer to Figure 5-11). Even with significant investment of stormwater treatment in urban areas (both new and existing), modelling suggests that due to the magnitude of loads from non-urban catchments, management actions would need to be focussed on both urban and non-urban land uses to provide significant mean annual load reduction to Tuggerah Lakes from current conditions. However, it is important to note the importance of managing urban runoff in nearshore zones for managing water quality in the Tuggerah Lakes system (refer to Section 5.3.2).

Further, it is important to note that additional investigations in the catchment (NSW OEH, 2011, 2013) have identified that streambank erosion and unsealed roads are a key source of sediment generation in the catchment. These location specific sediment sources have not been included in the catchment modelling, and it is predicted that sediment generation from eroding banks in Wyong River and Ourimbah Creek (prior to any rehabilitation works) may double predicted sediment loads from these catchments (NSW OEH, 2011) .

5.6.3 Modelling framework

A modelling framework was developed for the Tuggerah Lakes system to help inform the understanding of nutrient and sediment loads into the estuary and the likely impact on ecological function. The modelling framework consists of the following key models:

- Catchment model: predicts mean annual flows and pollutant loads for TSS, TN and TP entering the Tuggerah Lakes estuary. This informs the hydrodynamic model.
- Hydrodynamic model: models the movement of water, sediment and nutrients around the lakes. It helps to determine the resulting concentrations of key pollutant loads throughout the lakes, informing the ecological response model.
- Ecological response model: models biogeochemical processes and seagrass growth within the lakes. Ideally identifies threshold concentrations and loads of sediment and nutrients for management interventions, or 'sustainable load targets' whereby the catchment pollutant loads result in a healthy lake ecology.

The modelling framework has been used to successfully describe how the catchment and estuary interact, mixing and flushing processes, the source and type of major pollutants, how they impact the system and where efforts should be focussed to address ongoing ecological health issues. However the model is unable to determine sustainable load targets and the impact that future development may have on the lake due to the following key limitations to our understanding:

- Actual pollutant loads from the catchments: stormwater quality is highly variable, and therefore local data is needed to help calibrate the models to ensure good predictions of absolute loads. This is essential to help inform accurate ecological responses (in the ERM), and establish how the lakes will respond to future catchment loads, and what absolute load reductions are needed for a healthy ecosystem. This is not a simple process, and presently limited local data exists to accurately inform the catchment model. Furthermore, our understanding of the impacts of groundwater pollutant sources on receiving water quality is limited (refer to Section 4).
- Hydrodynamic modelling complexities: monitoring studies have shown that there is essentially a decoupling of the nearshore area with the main basins (refer to Section 3.5.5). This has an

important impact on the movement of water and impacts on nearshore water quality and lake ecology that are not currently represented in the hydrodynamic model.

Catchment model resolution: the catchment models fringing the lake do not currently provide the resolution needed to appropriately model the impact of the frequent pulses of highly concentrated stormwater flowing to the nearshore areas (e.g. on eutrophication and ooze). This would need to be updated in combination with the hydrodynamic modelling.

5.7 Review of current management actions

Key Points
The Estuary Management Plan (Bioanalysis 2016) identified a number of actions for improving water quality in Tuggerah lakes. Key actions were around streambank rehabilitation, stormwater management in existing and new urban areas, auditing for compliance in the catchment, developing a catchment prioritisation tool, maintaining stormwater services and educating people about stormwater pollution. The implementation and effectiveness of these actions for improving water quality have been reviewed where possible.
The Report Card provides a general report of lagoon and catchment health, however limited monitoring or modelling has been undertaken to quantify the effectiveness of individual actions undertaken in terms of reductions in pollutant loads to improve water quality.
Significant work has been undertaken to complete streambank rehabilitation actions.
Many actions for managing stormwater in new urban areas are partially complete / ongoing. While conditions to improve stormwater have been included in the Development Control Plan, it is uncertain whether these requirements are being implemented on ground, or whether they will result in maintaining or improving water quality
Council has undertaken many actions to improve stormwater management in existing areas, focused on the provision of new or upgraded gross pollutant traps and wetlands. Actions have been limited by available funding.
Barriers to effective implementation of water sensitive urban design include a lack of knowledge, resources and tools for both Council and developers to achieve successful outcomes.
Proactive auditing of private site compliance in the catchment is generally limited to onsite sewage management due to resourcing constraints.
A modelling framework has been developed as a sub-catchment prioritisation tool, in combination with report card monitoring. Further work is required and is currently underway / planned for improved assessment of management priorities.
Actions for maintaining stormwater devices/services are being undertaken, however they are limited by funding and resourcing constraints.
Significant work has been undertaken by Council to educate the community about stormwater pollution.

A number of key themes with supporting actions were recommended in the Estuary Management Plan (EMP) (Bio-Analysis, 2016) for improving water quality. Progress on these actions and their effectiveness have been reviewed as part of this study in the following tables:

- Streambank Rehabilitation: Table 5 7
- Stormwater management – new urban areas: Table 5 8
- Stormwater management – existing areas: Table 5 9
- Audit for compliance in catchment: Table 5 10
- Develop a sub catchment prioritisation tool: Table 5 11
- Maintenance of stormwater services: Table 5 12
- Education people about stormwater pollution: Table 5 13
- Sustainable use of water: Table 5 14.

A summary of key catchment management recommendations as a result of this review is included in Section 5.9.

In terms of the effectiveness that the above actions have had on water quality, there has been limited monitoring or modelling undertaken to quantify the effectiveness of individual actions in terms of reductions in pollutant loads / concentrations. The report card monitoring provides a general report of how the Tuggerah Lakes and individual catchments are responding, however it is difficult to directly correlate this to the performance of individual actions undertaken throughout the catchment. Water quality and report card results are also influenced by preceding rainfall and the amount/quality of catchment runoff (Swanson, 2018).

The recent Central Coast Waterways Report Card for Tuggerah Lakes (Central Coast Council, 2019a) indicates a long term stable trend of 'Good' (B) water quality in the main basins, meeting the monitored benchmarks (turbidity, chlorophyll-a and seagrass depth) for most of the year. The exception to this is Budgewoi Lake, which has a long term stable grade of Fair (C). Wallarah Creek is noted to contribute to poor water quality in Budgewoi Lake, with persistently elevated turbidity and chlorophyll-a. The near shore monitoring site at Lake Haven also indicated elevated turbidity and chlorophyll-a.

Slight long term improvements to water quality from the report card monitoring are apparent at near shore sites within Tuggerah Lake around Gorokan, Canton Beach and Chittaway Bay. However they cannot be attributed to any specific management actions, and may be a result of different rainfall patterns (Swanson, 2018). Long term declines in water quality from the report card monitoring are indicated at the nearshore monitoring site at Tumbi, due to increased frequency of periods of high turbidity (Swanson, 2018). Overall, the report cards provide a broad tool for identifying which catchments to target on ground works and also for communicating results to the community.

Numerous community education initiatives have also been undertaken by Council to help improve water quality (e.g. ibooks, catchment crawls, environmental tours, waterwatch, educational videos, working with schools). Key on ground EMP actions undertaken to improve water quality are summarised below (Central Coast Council, 2020d):

- 40 km rural stream rehabilitation
- 13 km urban stream rehabilitation
- Approximately 10 new or upgraded stormwater quality treatment devices each year (GPTs and wetlands)
- Total of 37 constructed wetlands and 277 GPTs maintained in the catchment
- Approximately 1000 tonnes per year of gross pollutants removed from GPTs
- 374 ha of wetland conservation and rehabilitation
- 2.5 ha saltmarsh reconstruction
- 29 ha saltmarsh rehabilitation.
- Sealing and stabilising of two roads / erosion hotspots
- Fencing and restricting 4WD access and erosion in Spring Creek catchment

It is also recognised that a large amount of development has taken place over the last 10 years in the catchment placing pressure on receiving water quality. While the performance of the above catchment management measures are not quantified (apart from GPTs), they are expected to have increased the resilience of the catchment and lake to water quality impacts, as demonstrated by generally stable report card trends. While not quantified, it is expected that streambank rehabilitation works will have provided substantial benefits to water quality considering that they had been identified as a key source of sediment to the lakes (NSW OEH, 2011).

In addition, recommendations to incorporate water sensitive urban design into new developments have been incorporated within development control plans to varying degrees and include comprehensive requirements for some locations. However, it is noted that there may be barriers to effective implementation of these measures, including a lack of knowledge, resources and tools for both Council and developers to achieve successful outcomes.

Table 5-7 Streambank rehabilitation (PP1)

Action	Review Notes	Comments / Recommendations
1. Prepare creek management plans and identify areas experiencing poor creek condition or streambank erosion (including urban streams).	**Complete** Rehabilitation plans developed include: • Saltwater Creek (Storm Consulting 2007) • Tumbi Creek (Storm Consulting 2007) • Ourimbah Creek (Cardno Lawson Treloar 2008) • Wyong River (Cardno Lawson Treloar 2008) • Spring / Wallarah Creek (Storm Consulting 2008)	• OEH (2011) report using results from the streambank management plans and catchment modelling predicted erosion rates are generally equivalent or double catchment generation rates in Wyong River and Ourimbah Creek. • Above OEH (2011) findings demonstrate importance of rehabilitation for managing sediment loads and water quality, particularly to main basins (to protect seagrass) and to protect water supply catchments.
2. Develop a program of prioritised remediation measures.	**Complete** Included in each of the creek rehabilitation plans	• Review creek rehabilitation plans and prioritisation recommended due to the extent of works completed and changed river conditions since studies undertaken (10+ years). Consider learnings from current program in review.
3. Implement rehabilitation works including bank stabilisation, bush regeneration and limit stock access/ boat wash - $500K p.a.	**Partially complete / ongoing** • Total of 50+ km of streambank rehabilitation completed in priority locations (Federal Grant Funded). • Includes 40+ km of rural streambank rehabilitation • Includes 13km of urban stream restoration (Tumbi Creek and Saltwater Creek) undertaken in 2010-11 • Extensive community engagement and changed land management practices working with LLS • Locations documented on interactive mapping (Social pinpoint) • Anecdotally, most of the riparian corridors in Wyong River and Ourimbah Creek are now fenced from livestock	• Urban areas included community involvement and education initiatives as well • Rural properties included works on private lands, working with local landowners • Council worked with LLS to establish incentive grants for local landowners for revegetation, fencing and provision of off stream watering points. LLS achieved 526 ha improved riparian management on private land. • LLS also ran landholder workshops for sustainable land management practices • Unlikely $500K funding was available to undertake this task each year. Funding options need to be investigated to ensure this action can be successfully implemented.
4. Assess effectiveness of rehabilitation, collate data, present to stakeholders and inform management.	**Partially complete / ongoing** • Stability of sites routinely inspected, recovery generally good • No assessment of nutrient and sediment load reduction	• Investigations by OEH (2011) would suggest that the works undertaken to rehabilitate streambanks would have provided significant benefits to water quality. • Recommend quantifying pollutant load reductions and assessing life cycle costs to determine the cost effectiveness of works. This could be done through a combination of monitoring and modelling investigations and the information could assist in prioritising works.

Table 5-8 Stormwater management - new urban areas (PP2)

Action	Review Notes	Comments / Recommendations
1. Review Stormwater Management Plan to improve strategy for new urban areas including Development Control Plans (DCPs), guidelines and any supporting works	**Partially complete / ongoing** • Stormwater Management Plan referred to: *Urban stormwater quality management plan for the Tuggerah Lakes and coastal catchments*. Wyong Shire Council. July 1999 • This plan (WSC, 1999) specifies: - no worsening at a catchment level - 90% TSS and 50% TN & TP reduction at the subdivision level • More recent stormwater management plan completed by SKM (2010), recommended 80% TSS, 60% TP and 45% TN reduction based on Council's draft WSUD guidelines (no longer available/retracted) • Civil Works Specification Design Guidelines (Council, 2018) include MUSIC modelling guidelines and standard WQOs to be achieved as follows: *80% TSS reduction post development* *45 % TN reduction post development* *45 % TP reduction post development* • The DCP generally refers to meeting WQOs in the above Guidelines (Council, 2018) with some location specific development provisions relating to stormwater quality. • *DCP Chapter 6-1 Key Sites* for 'Iconic Sites' as defined by LEP. Specific strategies relating to improved water quality outcomes include: - Specific objectives of the chapter state '*to ensure any development on land complies with principles of water sensitive urban design*'. - Green Building Design must address stormwater management and demonstrate	• SKM (2010) SMP. Uncertain what actions have been implemented with the information available for this review. Recommend review of implementation undertaken when considering options in the new CMP. • Note a number of different stormwater management investigations have been undertaken for the Porters Creek Wetland catchments. DCP still reflects the stormwater harvesting scheme, which is unlikely to go ahead due to high costs (Wyong Shire Council, 2015). Cost benefit assessment should be undertaken to determine the best option for stormwater management and DCPs updated accordingly. • Recommend modelling to determine the implications of current treatment requirements for future development and assess whether they maintain or improve upon existing (2020) water quality, if implemented. • To ensure WQOs are achieved, include requirements in the LEP (as the DCP is not legally binding). Recommend targets to maintain and improve water quality be adopted consistent with DCP objectives and EMP recommendations (Bio-Analysis, 2016). • If sustainable loads can be determined, translate these findings into WQOs (% reduction of TSS/TN/TP). • Recommend street landscaping should be 'water sensitive'. For example, street trees should be designed with passive irrigation (i.e. through cut out in kerb and channel). • Note discussion with DA officer: - 85/65/45 objectives too difficult to meet - Preference for wetlands and GPTs - Smaller assets too expensive and labour intensive to maintain • Recommend improved and consistent DA/DCP requirements during construction and establishment to ensure handover of good assets. Refer to construction

Action	Review Notes	Comments / Recommendations
	that outcomes are 'superior to that of average building stock in the area'	and establishment guidelines (WBD 2010) and checklists.
1. Review Stormwater Management Plan to improve strategy for new urban areas including Development Control Plans (DCPs), guidelines and any supporting works (cont'd)	- Warnervale Airport (iconic site) shall comply with *Porter's Creek Integrated Water Cycle Management Scheme* • Chapter 6-5 Warnervale South: - Specific objective *to adopt water sensitive urban design that employs best practice in quality and quantity controls* - Balance at source WSUD with end of line treatment to meet targets - Provide cost effective and affordable treatments in consideration with ongoing maintenance costs - To be compatible with the broader Porters Creek IWCM scheme - *To maintain and improve water quality in receiving waters and groundwater systems* - *The criteria for Urban Stormwater runoff quality for areas within the Woongarrah Creek/Porter's Creek Catchments are:* *85% TSS reduction post development*	• Recommend developer bonds be secured by Council to better reflect cost of rectification in the event of asset failure • For Warnervale South and Warnervale Town Centre, the TN and TP targets look to have been interchanged. Confirm what these targets are. Suggest 65% TP & 45% TN. • The DCPs appear to have comprehensive requirements for WSUD (e.g. LRIP) however it is unclear whether these requirements are being implemented. Streetscape and source control measures are recommended, however do not look to be implemented. This may be due to internal push back on these types of systems (due to perceived maintenance burden), or developer push back on the DCP requirements. • Inspection of areal imagery shows wetland storage areas in LRIP are eutrophic. Appears minimal macrophytes in wetland for treatment (and possibly no streetscape for pre-treatment). • Recommend WSUD standard drawings as technical support (currently under development)

Action	Review Notes	Comments / Recommendations
1. Review Stormwater Management Plan to improve strategy for new urban areas including Development Control Plans (DCPs), guidelines and any supporting works (cont'd)	*65 % TN reduction post development* *45 % TP reduction post development* *Retention of litter for up to 50% of 1 yr ARI flow* - *…no runoff leaves the development area other than via water quality control structure* • Chapter 6.17 Warnervale East / Wadalba North West - comprises the suburbs of Woongarrah, Hamlyn Terrace and Wadalba - WQOs as per ARQ: 80% TSS /45% TN /45% TP • Chapter 5-5 Warnervale Town Centre - WQOs for development discharging to stormwater storage to achieve best practice (as per Warnervale South): *85% TSS reduction post development* *65 % TN reduction post development* *45 % TP reduction post development* - WQOs for development discharging to receiving environments (wetlands, Wallarah Creek) to achieve: *90% TSS reduction post development* *50 % TN reduction post development* *50 % TP reduction post development* - IWCM strategy at source, streetscape and end of pipe treatment prior to stormwater storages • Chapter 6.2 Hamlyn Terrace – Louisiana Road Infill Precinct (LRIP): - *85% TSS reduction post development* - *65 % TN reduction post development* - *45 % TP reduction post development* - At source treatment (porous pavement,	• Recommend capacity building in Council to ensure that staff have the appropriate skills to review and approve proposed water sensitive urban design assets through the development approval process, and provide ongoing maintenance.

Action	Review Notes	Comments / Recommendations
	raingardens, rainwater tanks) - Bio swales in streetscapes - Precinct treatment in wetlands and bioretention basins - Storages to maintain hydrologic objectives and facilitate regional stormwater harvesting scheme Council officer discussions: Draft WSUD standard drawings internally released by roads, some push back internally (e.g. streetscape) and comments around improvements (e.g. maintenance access requirements, more details).	
2. Develop and apply an assessment protocol to determine appropriate stormwater interventions (in terms of flow and Water Quality) for new developments.	**Partially complete / ongoing** • This is about determining existing conditions before development to assess effectiveness of measures	• Recommend monitoring program for Porters Creek wetland to establish baseline conditions to inform both stormwater management requirements and monitoring to ensure targets are being met, and treatment can be adapted as required. • Recommend protocol be clearly outlined (in CMP/DCP) (e.g. integrated water management plan and monitoring requirements)
3. Cost stormwater harvesting and stormwater pollution control infrastructure (including ongoing maintenance costs).	**Partially complete / ongoing** • W&CP have some input into design of stormwater pollution control devices in new urban areas. Wyong contributions plan (2015)	• Council undertake a review of infrastructure and maintenance works to determine typical costs for constructing and maintaining various water quality assets. Where information is not available, recommend using costing from other Councils until local data can be collected. • Recommend life cycle costing be undertaken to better

Action	Review Notes	Comments / Recommendations
		inform cost effectiveness of different options and ongoing maintenance requirements. Recommend reinstating Stormwater Levy to help ensure new assets are effectively maintained and optimal treatment is achieved. Future expected maintenance costs and Council resources required should be considered in determining an appropriate Levy.
4. Manage the installation of infrastructure (funding through S. 94)	**Ongoing** • Currently managed through the development of DCPs and stormwater quality management studies, then further information on costs in contributions plan e.g. Wyong Contributions Plan	
5. Assess the effectiveness of stormwater management programmes in achieving objectives and adjust management plans accordingly.	**Pending** (Environment Restoration Fund, 2020-23) • Upcoming study of the performance of two constructed wetlands • Results to inform future development SMP requirements and design / development guidelines	• Recommend review of current developments in terms of achieving the DCP objectives for stormwater management. For example, Hamlyn Terrace – Louisiana Road Infill Precinct which is now largely completed. Help to identify any learnings for future developments and development requirements.

Table 5-9 Stormwater management - existing areas (PP3)

Action	Review Notes	Comments / Recommendations
1. Prepare a 5 year plan for stormwater remediation upgrades focussing on priority catchment first rather than available space	**Completed** • Annual capital works program to retrofit existing devices to maintain asset condition • Program dependent on grant funding	• Recommend catchment audits in collaboration with the community (e.g. community science) to inform / help prioritise upgrades. Use report card monitoring and community concerns to help identify priority catchments. • Use existing catchment models to help undertake cost benefit assessments of options to help further prioritise works • When data becomes available, use calibrated catchment model and improved Ecological response model to better inform the prioritisation of works (which catchments to target for best outcomes) • Identify funding source, may be partly funded by the stormwater levy.
2. Undertake design and construction on a 5 year plan as part of the drainage infrastructure upgrade programme	**Ongoing** • Annual rolling works program • 10 new or upgraded wetlands or GPTs each year with grant funding (Council, 2020d) • Council now has a total of 277 gross pollutant traps & 37 wetlands (Council, 2020d)	• Recommend capacity building in Council to ensure that staff have the appropriate skills to design, construct and maintain water sensitive urban design assets, particularly new streetscape designs. • Stormwater Levy to help fund works
3. Assess the performance of the devices and link back to design and management plans	**Pending** (Environment Restoration Fund, 2020-23) • Upcoming study of the performance of two constructed wetlands	• Recommend monitoring performance of saltmarsh swale and bioretention basin • Recommend using catchment model to estimate and report on the performance of treatment devices. • Recommend GPT removal quantities made publicly available through an interactive map so community can track their performance (similar to report card results). • Consider including assessment of benefits other than water quality treatment i.e. reducing urban heat island effect, CO_2 sequestration, flow mitigation. • Stormwater levy can also be used to partly fund performance monitoring works.

Table 5-10 Audit for compliance in catchment (PP8)

Action	Review Notes	Comments / Recommendations
1. Develop a rationale and criteria for conducting audits	**Complete (Council, 2018)** • Catchment Ecological Health Monitoring Program to provide information on parts of the catchment contributing to poor water quality, this can then assist to target areas to audit • Catchment management officer developing a targeted strategy prior to implementing a monitoring program to identify pollution sources in water supply catchments	• Recommend review of Council's E&SC and audit policy. More proactive approach for E&SC audits, particularly at individual lot level. May need to consider facilitation by third party such as the state government for effective implementation (i.e. with fines) • Recommend privately owned stormwater treatment devices are inspected and maintained in accordance with DA conditions, with annual audits to enforce. A third party auditor could be conditioned in future DAs to reduce the impost on Council.
2. Undertake the audits and provide constructive advice	**Ongoing** • Audit commenced at Canton Beach following poor results for recreational use. Sampling in lake, stormwater and sewer network to investigate and identify potential contamination sources. • Compliance team audit approximately 400 OSSMs / yr to identify any corrective actions needed to protect water quality. • No proactive audits being undertaken in catchment by compliance team for stormwater management on private sites, or for erosion and sediment control, due to limited resources. Compliance responds to community complaints only. • Currently catchment officer conducts inspections with LLS who provide advice to landowners to help manage streambank erosion • When Council identifies key areas impacted by illegal access (e.g. 4WDs), actions are taken to prevent future access. Significant progress in controlling 4WD damage in Spring Creek Catchment. Council and Local Aboriginal Land Council land upslope of Thompson Vale Road has been fenced to restrict 4WD access. Areas of unsealed road sealed and stabilised to reduce erosion (Footts Rd Ourimbah, Chandlers Lane Wyong Creek) • Decommissioned a fire trail /erosion hotspot at Kangy Angy (with subsequent stablilisation and regenerative planting).	• Recommend annual reporting to community on audit results e.g. % of audits compliant with requirements, and % of corrective actions resolved. • Secure resources to undertake a more proactive approach to investigating urban stormwater management on private sites and provide assistance to implement best management practices. Audits of existing sites can be partly funded by the stormwater levy.

Action	Review Notes	Comments / Recommendations
3. Link results from the audits to management planning	**Ongoing** • Currently report card results used to target management actions	• Set targets to review effectiveness of actions e.g. increase in annual % compliance • Important that audit teams communicate result to inform management responses

Table 5-11 Develop a sub-catchment prioritisation tool (PP9)

Action	Review Notes	Comments / Recommendations
1. Develop a process/ system for assessing which catchments are a high priority, and what type of intervention is required	**Complete** • Modelling framework developed and accompanying studies have provided valuable learnings around ecological processes, however it has limitations to use due to the system complexities and data gaps.	• Use existing uncalibrated models (with minor refinements) as a tool for assessing priorities in combination with report card results • Refine and calibrate modelling framework as more data becomes available
2. Collect catchment data and device performance data to improve understanding of priorities and responses	**Ongoing** • Monthly monitoring to inform report card • Monitoring to inform better calibration of catchment model currently underway in Berkeley Vale • Monitoring is planned to better understand the performance of treatment strategies (e.g. wetlands) • Monitoring and investigating the influence of groundwater is currently underway (Berkeley Vale)	• Recommend continued monitoring to improve understanding of catchment pollutant generation and effectiveness of treatment devices. This can be partly funded by a stormwater levy. • Recommend providing continued opportunities for community to be involved in monitoring and evaluation (e.g. waterwatch program). This may also be partly funded by a stormwater levy.
3. Undertake the assessments on an annual basis for prioritising works	**Ongoing** • Annual report card	• Recommend periodic update of the catchment model to also help prioritise catchments (e.g. include updates to development and new treatment initiatives).
4. Use the information for refining planning (Stmw Mgt Plan) and doing drainage upgrades (PP3)	**Ongoing** • Report card monitoring results have driven more detailed investigation around Berkeley Vale.	

Table 5-12 Maintenance of stormwater devices (PP20)

Action	Review Notes	Comments / Recommendations
1. Continue existing maintenance programme	• Noted as ongoing (Council 2020d) • Includes GPTs, wetlands, saltmarsh and STZs • Budget and resourcing limitations noted. Stormwater Levy abolished in Council amalgamation.	• Stormwater Levy to ensure effective maintenance of stormwater quality treatment devices • Recommend that privately owned stormwater treatment devices are inspected and maintained in accordance with DA conditions, with annual audits to ensure this is undertaken. To reduce the impost on Council, a third party auditor could be conditioned in the DA that reports results to Council.
2. Review adequacy of existing devices and retrofit devices where necessary to improve performance and maintainability	• Noted as ongoing (Council, 2020d) • Discussion with staff shows process in place to identify and rectify performance issues • Rectification program in place, however budget limitations	• Suggest quarterly performance reporting on rectification activities (e.g. 10 rectification issues, 9 issues resolved, average resolution time, cost of rectification works) • Communicate rectifications within Council (i.e. at WSUD meetings) to promote learnings and avoid future issues • Ensure maintenance staff are involved in rectification plans
3. Develop a system for handling, processing and disposing of collected material	• Noted as complete (Council, 2020d)	
4. Record data on collected material	• Noted as ongoing (Council, 2020d) • Discussion with staff indicates data collected on GPT clean outs includes weight of gross pollutants, sediment and organics • Data will be used to help better inform clean out frequency and budget costs • Approximately 1000t/yr gross pollutants captured and removed from GPTs (Council, 2020d) • Future monitoring program proposed to assess effectiveness of other treatment devices (constructed wetland)	• Undertake planned monitoring program to assess effectiveness of constructed wetland and bioretention basin. Information will help inform the selection of future treatment devices • Make data cleaned out of GPTs available to community (interactive website)
5. Review data and feed into catchment management decisions and design of future devices	• Noted as ongoing (Council, 2020d) • No supporting information reviewed	• Review quantities of gross pollutants captured to see whether trends indicate educational programs (e.g. littering) are working

Action	Review Notes	Comments / Recommendations
6. Review adequacy of maintenance programmes	• Noted as ongoing (Council, 2020d) • No supporting information reviewed	• Develop audit procedure to review effectiveness of maintenance programs. Consider quantitative assessment where possible. e.g number of failing assets, number of rectified assets, funding available, funding spent

Table 5-13 Educate people about stormwater pollution (PP26)

Action	Review Notes	Comments / Recommendations
1. Identify key groups that need to be targeted	• Noted as complete (Council, 2020d)	
2. Devise and implement the education programme	• Noted as ongoing (Council, 2020d) • Many educational initiatives noted, including: - New website Central Coast Waterways with a lot of educational material including, common concerns and misconceptions, iBooks, tips to help community look after waterways - Free environmental tours on kayaks and bikes - Catchment crawls to learn about the catchment and how to protect it - Citizen science opportunities (e.g. waterwatch). - Educational videos that were played in cinemas - Collaborations with Local Land Services - Working with schools to educate children	• Recognise that Council has undertaken many educational initiatives, however still appears key messages are not being 'heard'. • Continue focus on citizen science and include more community consultation and participation in management of waterways, similar to Council's saltmarsh swale at Long Jetty (identified through citizen science program) • Consider media collaboration (and potential waterway ambassador) • Adopt a raingarden program with schools, environmental groups to help capacity building. • Stormwater levy can be used to assist funding stormwater education campaigns
3. Assess attitudinal and behavioural change through time to determine effectiveness	• Noted as ongoing (Council, 2020d) • No assessment identified.	• Determine a way to assess this, potentially through annual community surveys or quantitative assessment e.g. annual OSSM compliance, incidents of illegal dumping or illegal 4WD access, home raingardens built

Table 5-14 Sustainable use of water (PP27)

Action	Review Notes	Comments / Recommendations
1. Review of innovative schemes and current best practice	**Ongoing (Council, 2020d)** • No supporting information reviewed, apart from WaterPlan2050	• WaterPlan 2050 is currently being revised to develop an Integrated Water Resource Plan. Options should be considered in the context of the CMP and impacts on lake water quality and ecological health.
2. Conduct trial of incentive schemes	**Ongoing (Council, 2020d)** No supporting information reviewed	
3. Implementation of successful trial	**Ongoing (Council, 2020d)** No supporting information reviewed	
4. Review community acceptance, cost impacts and demand changes	**Ongoing (Council, 2020d)** No supporting information reviewed	

5.8 Discussion and information gaps related to catchment processes

Previous sections have identified that there exist a number of current and future catchment pressures to receiving water quality from land use practices, with urban stormwater identified as a key pressure.

Council have a number of planning controls in the Development Control Plan to support water sensitive urban design and mitigate the impacts of urban stormwater quality on receiving waters. However, it is unclear whether these controls are being effectively implemented and whether they will result in improved outcomes for future water quality in Tuggerah Lakes with current development pressures.

Many studies have been undertaken and others are underway in the catchment to better understand and quantify the impacts of catchment pressures on water quality, such as streambank erosion, unsealed roads and urban stormwater quality. A modelling framework has been developed to help quantify catchment nutrient and sediment loads to the estuary and understand their likely impact on water quality and ecological function. However key knowledge gaps exist in quantifying pollutant loads from the catchment and the effectiveness of current treatment measures.

Best practice stormwater management is encouraged to be applied throughout the catchment as illustrated in Figure 5-7 to ensure that water quality in Tuggerah Lakes is maintained or improved in the future. However, an improved understanding of catchment pollutant loads and treatment performance would assist to ensure that suitable targets and treatment options are developed to effectively achieve this.

In undertaking this review, the following key knowledge gaps were noted around current understanding of catchment pressures to water quality:

- Although catchment modelling has been undertaken, there are uncertainties around absolute quantities of existing pollutant loads and future pollutant loads to the lakes.
- Sustainable pollutant load targets (i.e. those pollutant loads that will maintain a healthy lake ecology) are unknown.
- The effectiveness of current water quality treatment devices (apart from GPTs) in the catchment is unknown. Limited modelling has been undertaken to predict performance and limited monitoring has been undertaken to verify performance.
- The likely impact of future development on pollutant loads when current Water Quality Objectives are applied.

- The influence of groundwater on water quality in the lakes (refer to Section 4.4).
- Risks to water quality from mine subsidence.
- While data exists for NSW, there is limited local data characterising the quality of stormwater runoff (i.e. Event Mean Concentration) and impacts from various land uses in the catchment (rural and urban).
- No information was reviewed on the level of adoption of rural BMPs in the catchment, apart from anecdotal evidence that suggests most properties are fenced with offline watering points to prevent stock access to waterways.
- Impact of current extractions and entitlements on flows from the weir. These are likely to have changed from conditions modelled ten years ago.

5.9 Recommendations for catchment management

Key recommendations to improve water quality in Tuggerah Lakes from a catchment management perspective are summarised below:

Funding and Implementation

- To ensure successful delivery of actions in the Coastal Management Program, it will be vital to identify the likely costs and funding mechanisms available.
- Reinstate Stormwater Levy to help ensure new assets are effectively maintained and optimal treatment is achieved. This levy is currently only able to be applied to urban areas where an increased level of service is provided (e.g. retrofit or beyond best practice treatment). Future expected maintenance costs and Council resources required should be considered in determining an appropriate Levy. Furthermore, it is recommend that the NSW government increase the allowable current charge of $25/household/year to better reflect cost burdens to Council and also relax use restrictions to ensure that current level of service requirements are met. There may also be opportunity to remove the levy for households/ business that provide additional on-site treatment of stormwater, or achieve a certain percentage of pervious area. This would provide a financial incentive for improved management of urban stormwater on private sites.
- Recommend life cycle costing of stormwater treatment options to better inform the cost effectiveness of different options and ongoing maintenance requirements, using local data where possible.
- Undertake Water Sensitive Urban Design (WSUD) capacity building within Council, ensuring staff are appropriately trained to ensure successful design, construction and maintenance of WSUD. To ensure integration within teams, create a senior leadership 'WSUD' working group that reviews WSUD implementation opportunities and shares learnings and successes between internal teams.
- Standard WSUD drawings for use in Council infrastructure works (e.g. roads, renewals) as well as by the development industry to ensure consistent standards and requirements are met (noted currently under development in Council).
- Improved education and enforcement of Erosion & Sediment Control (E&SC) practices, particularly at the lot scale. Consider proactive enforcement of erosion and sediment control practices, potentially through a third party (e.g. State Government). A literature review by Taylor and Wong (2002) indicated that education alone is not sufficient to ensure compliance and that enforcement is essential for the successful implementation of erosion and sediment control programs. The literature review suggests that E&SC programs with strong educational and enforcement elements may represent the best performing non-structural BMP for managing

stormwater pollutants. With the large amount of future development planned in the catchment, it will be important to ensure best practice erosion and sediment control practices are implemented and enforced. Healthy Land & Water have recently developed a toolkit for house builders that may be used as a basis to improve E&SC practices at the lot scale:

https://hlw.org.au/download/erosion-and-sedimentcontrol-toolkit-for-house-builders/

Planning

- Adopt a maintain or improve conditions (from existing 2020 conditions) target for all future development until sustainable loads are determined. Note this is already referred to as a goal in various documents (some Development Control Plan chapters, Estuary Management Plan). However, it is unlikely that current performance targets (i.e. 80% reduction of total suspended solids, 45% reduction of total nitrogen and 45% reduction of total phosphorus from post development loads) will result in unchanged or improved conditions. Neutral or beneficial (NorBE) water quality targets are currently required for development in water supply catchments (Regional Plan 2036).
- Adopted water quality treatment targets should be included in the new Local Environmental Plan to give Council greater powers to enforce.
- Introduce planning controls for single dwelling developments to achieve water quality treatment. Two case studies are detailed in Figure 5-18 and 5-19. Examples can be sourced from other local Councils, such as Mid-Coast Council. A case study for Moonee Valley Council can be found here:

  https://watersensitivecities.org.au/solutions/case-studies/moonee-valley-planning-scheme/
- Stormwater management / Integrated Water Management plan for Porters Creek. A number of investigations have been undertaken / are currently underway. A plan should be adopted to ensure development doesn't adversely impact Porter Creek wetlands through changes to flow regimes and increased pollutant loads. The costs and benefits of alternate options should be considered to determine the best triple bottom line outcome. A monitoring program will likely be required to establish and understand baseline conditions in Porters Creek Wetland to then assess future performance against.
- WaterPlan 2050 will be revised to develop an Integrated Water Resource Plan. Options should be considered in the context of the CMP and impacts on lake water quality and ecological health.
- Improved and consistent Development Assessment/Development Control Plan requirements during construction and establishment to ensure handover of good water quality treatment assets. Refer to Construction and Establishment Guidelines (WBD, 2010) and checklists.
- Developer bonds be secured by Council to better reflect cost of rectification in the event of asset failure. Consider third party enforcement of this requirement (e.g. state government).

- Existing modelling framework would likely need significant investment to be able to determine sustainable catchment loads for the lakes. This should be undertaken as a priority, including collecting data to better calibrate and refine models.
- Current models should be used in the interim to set targets for maintaining / improving catchment loads, and assess the impact of development on future catchment loads. For example, while MUSIC and Source catchment models are not calibrated, they would still be able to estimate in relative terms the future increase in pollutant loads and identify the management measures needed to ensure 2020 conditions are maintained or improved.
- The current catchment models could also be used as a basis for investigating the treatment performance and cost effectiveness of:
    a. existing treatment measures
    b. future treatment options, including rural best management practices.

  This could help prioritise works in the catchments more effectively. Key sources of sediment generation, where known e.g. unsealed roads, should also be included.
- Review creek rehabilitation plans and prioritisations due to the extent of works completed and changed river conditions since studies undertaken (10+ years). Consider learnings from current program in this review.
- Current impact to flows and water quality in Tuggerah Lakes caused by water supply offtake be further investigated as part of Council's Integrated Water Resource Planning (i.e. updated Water Plan 2050).

Community education and capacity building

The significant work that Council has been undertaking in collaboration with Local Land Services (LLS) to help educate the community is recognised, and it is recommended that these efforts be continued. The following suggestions are provided to strengthen the current program and help foster ownership and improved understanding of Water Sensitive Urban Design (WSUD) in the catchment.

- Use citizen science and the current Waterwatch program to help identify pollution hot spots in the catchment and suitable locations for treatment initiatives such as raingardens / passively irrigated street trees. Consider using a community selected site as a demonstration project to educate others in the local community (similar to Council's Saltmarsh Swale project).
- Similarly, use citizen science to help monitor the effectiveness of new types of assets in the area such as saltmarsh swale and raingardens, as well as existing devices. This can help to foster ownership and improved understanding of WSUD.
- Melbourne Water's 10,000 Raingardens Program provides a good example of how Council could work with the community to raise awareness about the need to manage stormwater, drive behavioural change and improve water quality through implementation of measures on private

lots. Such a program would also help measure the performance of educational campaigns (Milenkovic et al., 2012). Resources from this program can be found online https://www.melbournewater.com.au/water-data-and-education/environmental-issues/why-weneed-save-water/tips-saving-water/raingardens.

- Consider including a raingarden building workshop in the waterways related events program.

Opportunities

- The current Coastal Management Planning framework only requires an estuary wide approach, limiting treatment options to within the estuary. The review of key pressures to receiving water quality in this chapter has clearly shown that a catchment wide approach is needed to improve water quality in Tuggerah Lakes. It is therefore recommended that a catchment wide approach be adopted for the Tuggerah Lakes Coastal Management Program.
- Look for opportunities to integrate WSUD into Council renewal works (e.g. Lake Haven centre and through the northern growth corridor). All landscaping should consider WSUD e.g. flush kerbs, pervious pavements, raingardens, swales, self-watering street trees. It will be most cost effective to integrate WSUD retrofits through urban renewal projects, so this should be a priority to consider for all infrastructure works. Standard WSUD drawings would also assist to more easily integrate these works.
- In high priority existing urban catchments, work with the community to integrate streetscape systems such as raingardens and passively irrigated street trees upstream of conventional drainage inlets, to treat stormwater prior to entering the stormwater system.
- Consider including passively irrigated street trees in all new developments rather than conventional street trees. They provide multiple benefits including water quality treatment benefits and can be designed to include a range of storage options to help mitigate flows (such as wicking beds and underground storages). Examples are provided in Figure 5-16 and Figure 5-17.
- Review the uptake and effectiveness of rural Best Management Practices through continued partnership with Local Land Services. As the rural lands make up a large proportion of the catchment, this will be important to reduce overall catchment loads.
- In partnership with Local Land Services and NSW Department of Primary Industries, Council to investigate the applicability of bioreactors in the catchment for treating agricultural runoff. Recent studies in Queensland have shown them to be highly effective form of removing nitrate through dentification (Manca et al., 2020). They are a simple to construct, low cost, passive technology with an expected design life of approximately 10+ years. These treatments are best suited to areas with shallow groundwater tables and lateral inflows to waterways, with high concentrations of nitrate.

- Expand the Lakes Festival to celebrate successes. For example, ‘waterway warrior’ awards to recognise significant community group achievements for improving catchment and receiving water quality in Tuggerah Lakes. It could also be used to announce social media competition winners for programs promoting community action for improving waterway health, such as best (as voted) home raingarden or highest social media postings of ‘Take 3’ (picking up rubbish near waterways).
- Use community education centre space (e.g. Marine Discovery Centre) to showcase a raingarden. This could be used to demonstrate how a raingarden works (Figure 5.20) and what it looks like. It could also provide toolkits for teaching the community how to build their own raingarden, and have plant giveaway days or even workshops to encourage people to build their own.

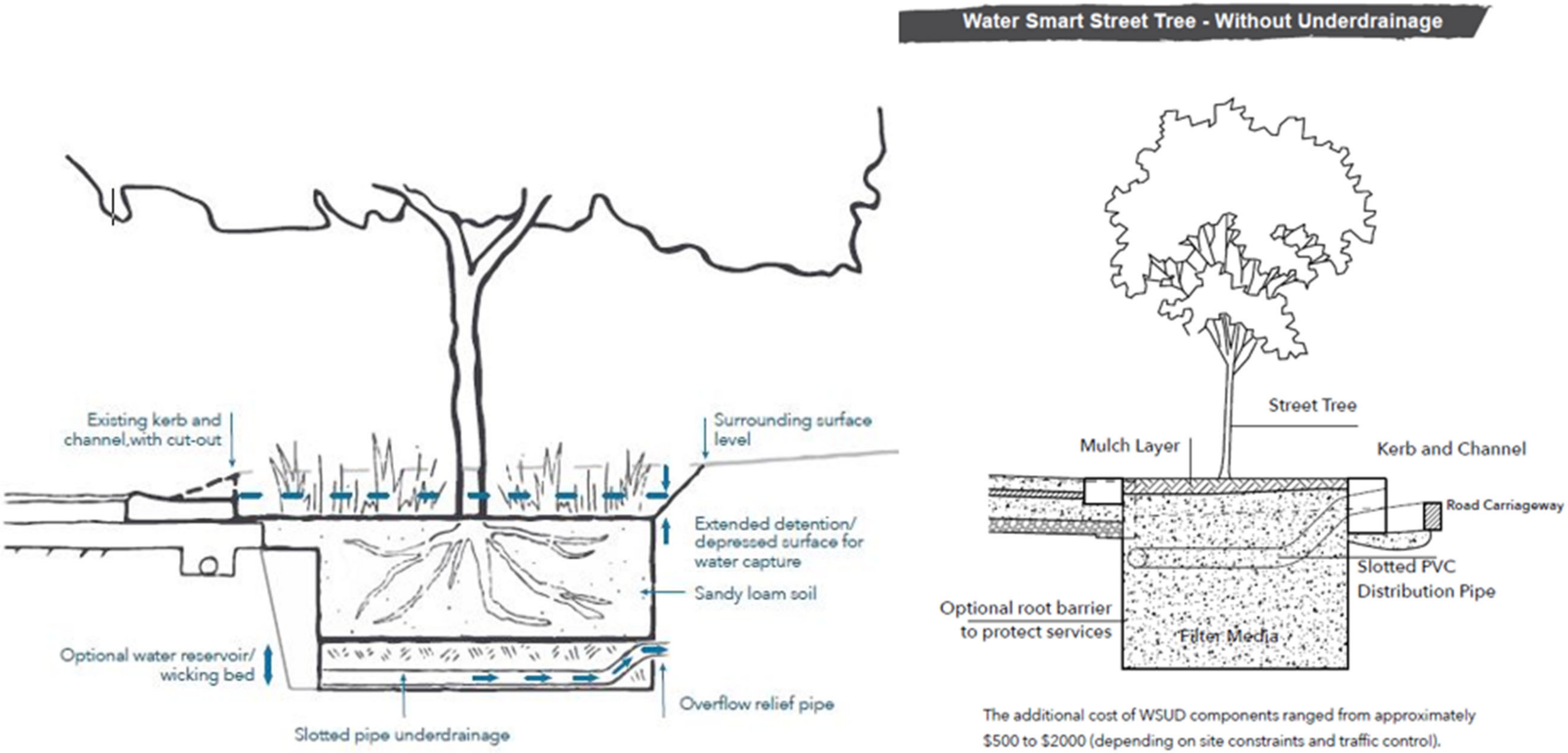


Figure 5-16 Passively irrigated street trees (with and without underdrainage) (HLW, 2019)

Figure 5-17 Examples of passively irrigated street trees

Figure 5-18 Examples of raingardens on single dwelling development (Tucker, 2018)

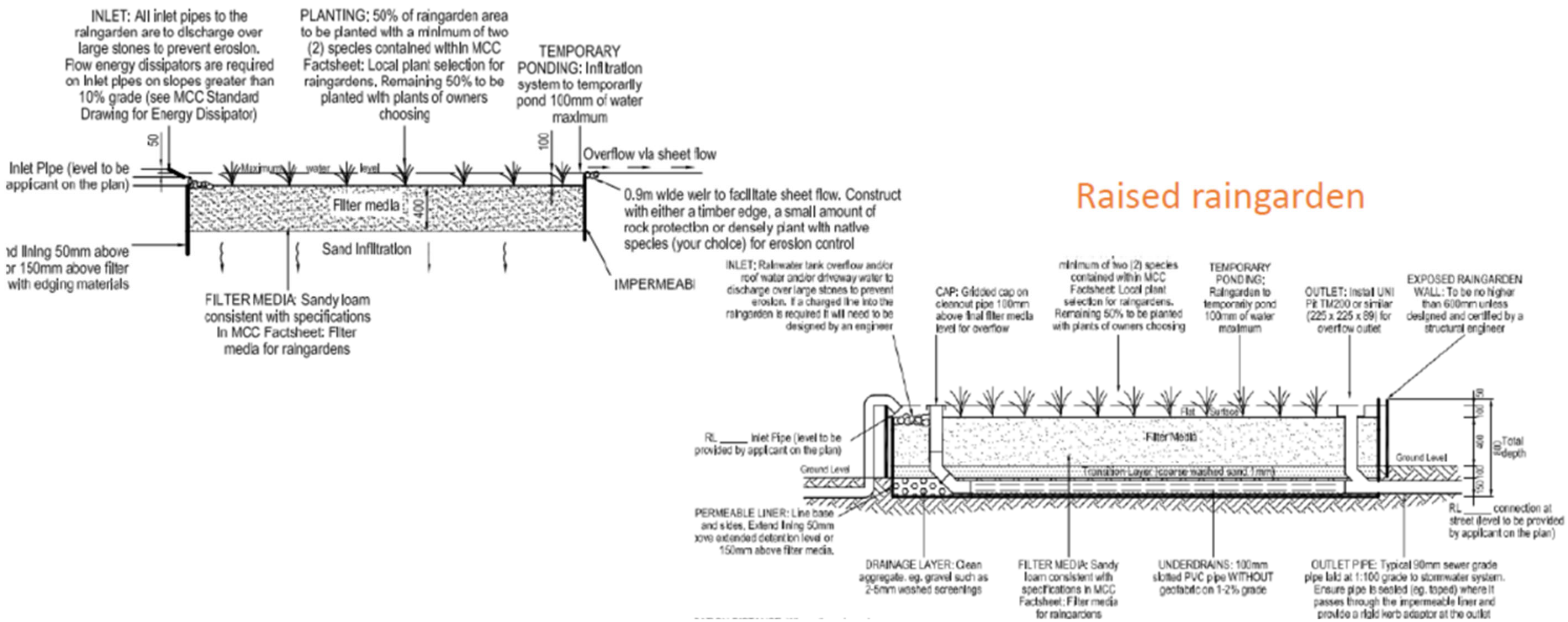


Figure 5-19 Example of standard drawings for single dwelling development (Tucker, 2018)

Figure 5-20 Examples of raingarden demonstrations (Melbourne Water, 2012; Government of South Australia, 2019)

5.10 Case study 1: Berkeley Vale urban catchment

Key Points
Existing urban stormwater runoff in the Berkeley Vale catchment presents a key pressure to fringing lake water quality, with monitoring indicating that nitrate is the key parameter of concern.
Water quality along the foreshore is further affected by restricted mixing of nearshore areas with the main lake basin. This traps stormwater in the nearshore area, where inorganic nutrients cause macroalgae or phytoplankton blooms, which then decompose depleting the water of oxygen and releasing inorganic and organic nutrients back into the water column. Of note, water quality during dry weather monitoring is typically worse than during wet weather due to internal biogeochemical processes such as these.
Groundwater may be contributing to nutrient pollution along the Berkeley Vale foreshore.
Infill development may also present pressures to future water quality, particularly for redevelopment /renovations that increase the impervious area and pollutant generation from the catchment, yet are not subject to water quality treatment requirements.
The open channel drains discharging stormwater to the lagoons were originally constructed as ‘stormwater treatment zones’, however they provide ineffective treatment of stormwater.
Passive and active saltmarsh rehabilitation has been undertaken in areas along the Berkeley Vale foreshore.
Source reduction strategies such as raingardens at both streetscape scale and on private allotments provide a key opportunity for treating stormwater in the catchment.
Working with the community to improve education about the impacts of stormwater on water quality and create behavioural change in the catchment is important for successful outcomes.
NSW Department of Planning, Industry and Environment are currently undertaking a monitoring program for Council that will assist to characterise urban stormwater quality to better calibrate the catchment model and provide more certainty around predicted catchment loads.

5.10.1 Introduction

As a case study, the urbanised catchment around Berkeley Vale draining directly to Tuggerah Lake was reviewed to identify:

- Key existing and future pressures to water quality
- Effectiveness of current management measures for improving water quality
- Information gaps in understanding of water quality pressures / management actions
- Opportunities and recommendations for improving water quality.

Key findings are outlined in the following section.

5.10.2 Catchment description

For the purposes of this assessment, the Berkeley Vale catchment study area was delineated based on previous investigations of the urbanised catchment (NSW OEH, 2018), and the existing stormwater drainage network. The Berkeley Vale catchment study area is shown in Figure 5-21.

The area is approximately 153 ha in size, encompassing urban development predominantly east of Wyong Road that extends from around Grevillea Crescent in the north, down to around Gregory St in the south. The catchment contains largely urban residential development, as well as a school (Berkeley Vale State School) and sporting oval (Kurraba Oval). Small areas of commercial development are also located through the catchment, mostly along Lakedge Avenue.
Most of the roads in the catchment are sealed and although stormwater is generally collected via kerb and channel drainage, there are locations through the catchment where no kerb and channel exist. Low relief close to the foreshore has restricted the construction of conventional piped stormwater drainage in areas.

Stormwater runoff from the catchment is discharged to Tuggerah Lake via approximately 18 stormwater drainage outlets along the catchment foreshore. Rural residential development around the Glenning Valley sub catchments drain to Berkeley Creek and Quondong Gully prior to discharging to Tuggerah Lake to the north of the defined Berkeley catchment and have been excluded from this assessment. NSW OEH (2018) note that inputs from Berkeley Creek tend to be transported north along Chittaway Bay shoreline, however can be transported southward along the Berkeley Vale shoreline in some conditions. Similarly, inputs from Tumbi Umbi Creek (immediately south of the study area) tend to be conveyed into Tuggerah Bay, however some material can become entrained into the Berkeley Vale nearshore zone.

The nearshore zone around the Berkeley Vale region in Tuggerah Lake commonly experiences poor water quality resulting in eutrophication, macroalgae blooms, wrack accumulation and sulfidic ooze build-ups.

Figure 5-21 Berkeley Vale urban catchment

5.10.3 Key pressures

Urban stormwater runoff from the fully urbanised catchment presents a key pressure to lake water quality. MUSIC modelling of the catchment indicates urbanisation has resulted in a 300% increase in pollutant loads from natural conditions (NSW OEH, 2018).

Water quality monitoring of drainage lines undertaken by NSW OEH (2018) during wet weather indicates catchment runoff contributes to elevated concentrations of inorganic nutrients contributing to eutrophication of nearshore waters and macroalgae blooms, with very high concentrations of nitrate (over 250 ug/L) being the key parameter of concern.

Furthermore, the investigations found that water quality in these areas are further affected by restricted mixing of nearshore areas with the main lake basin. This traps stormwater in the nearshore area, where inorganic nutrients cause macroalgae or phytoplankton blooms, which then decompose depleting the water of oxygen and releasing inorganic and organic nutrients back into the water column. Of note, water quality during dry weather sampling was typically worse than during wet weather due to internal biogeochemical processes such as these. Further information and discussion on the biogeochemical processes occurring in the nearshore zone are outlined In Section 4.3.6.

Water quality monitoring and investigations by NSW OEH (2018) also suggest that groundwater seepage may be contributing to nutrient pollution along the Berkeley Vale foreshore (refer to Section 4.4).

Stormwater from the catchment is conveyed to the foreshore predominantly via 15 open channel drains, as well as a 1200m x 450mm culvert and two x 375mm stormwater pipes at the southern extent of the catchment. The community have raised concerns about the visual appeal of the open channel drains.

As mentioned previously, water quality monitoring during wet weather identified elevated concentrations of nutrients at most sites, particularly nitrate. Locations where concentrations of nitrate were particularly high included:

- Site BV9: This drain outlet is located along the foreshore at Erin Avenue. This site recorded the highest concentration of nitrate, and drains a small catchment serving only parts of Erin Avenue, Colleen St, Clare Crescent and Emerald Place. Sampling was undertaken in the drain approximately 3m from the lake shore.
- Drain 2: This drain outlet is located along the foreshore just north of Erin Avenue, and services the largest area in the catchment. Stormwater west of Jubilee Parade in the north down to

Montah Avenue in the south is collected in this drain. Sampling was undertaken in the drain from the footbridge approximately 10m from the lake shoreline.

- BV5: This drain outlet is located along the foreshore at Bundilla Parade, and services a small area of residential development along this street. Sampling was undertaken in the drain approximately 5m from the lake shore.

Pressures to water quality in the catchment may also be from areas of exposed soils immediately adjacent to roads without a defined kerb. These exposed areas are a source of sediment that is quickly transported to the lakes in rain events.

While the area is not within the northern growth corridor, infill development may also present pressures to future water quality, particularly for redevelopment /renovations that increase the impervious area and pollutant generation from the catchment, yet are not subject to water quality treatment requirements.

5.10.4 Current Management Actions and Effectiveness

Six Gross Pollutant Traps (GPTs) are noted to be located throughout the catchment, including two underground Rocla CDS units and other litter boom / trash rack configurations. Inspections of the systems in 2018 (NSW OEH, 2018) indicated variable asset conditions, noting that the below ground GPTs were not inspected. The catchment GPTs generally capture large gross pollutants and organic debris. The CDS units are effective for trapping sediment also.

The short open drains that convey stormwater from the piped network to the lake are referred to as stormwater treatment zones. However assessment of these areas has indicated that they provide ineffective treatment of stormwater (Sinclair Knight Merz, 2010), with water quality monitoring indicating that all drains are highly eutrophic (NSW OEH, 2018). Poor flushing between the lake and drains occur during dry weather due to low grades and minimal tidal range.

No other stormwater quality treatment devices (e.g. wetlands, bioretention systems) are known in the catchment. The uptake of rainwater tanks (which can provide some treatment of nitrogen in addition to reducing flows) in the catchment is unknown.

Passive and active saltmarsh rehabilitation has been undertaken in areas along the Berkeley Vale foreshore. In active areas, the foreshore has been regraded to improve connectivity between land and water, allowing saltmarsh plants to establish. This provides benefits to water quality through filtering of nutrients, capture of sediment and supporting natural breakdown of seagrass wrack. Community engagement activities were also undertaken in conjunction with works, and a viewing platform and interpretive signage has been installed at one location. No known water quality monitoring has been undertaken to assess the effectiveness of such works.

DPIE are currently undertaking a monitoring program for Council that will assist to characterise urban stormwater quality to better calibrate the MUSIC model. Calibrating the urban areas could allow for better understanding of the sustainable pollutant loads and management options if appropriately integrated with the hydrodynamic and Ecological Response Models.

5.10.5 Information Gaps

Key information gaps informing our understanding of catchment pressures on water quality include:

- The influence of groundwater. Investigations undertaken by NSW OEH (2018) indicated that groundwater was likely a contributing factor, however limited investigations were undertaken to understand groundwater influences. In particular, the potential impact of contaminated soil used for shoreline reclamation on groundwater, or aging sewerage infrastructure potentially leaking into groundwater.
- Stormwater quality monitoring was undertaken, however not enough information currently exists to characterise the quality of runoff for use in catchment MUSIC modelling.
- The influence of sewage overflows on water quality. Although it is not predicted to be a significant issue (overflows are only likely to happen occasionally in large rainfall events and be diluted by stormwater), no monitoring has been undertaken that can assess the impact of potential overflows on water quality.
- As discussed previously, the sustainable load targets for ensuring pollutant loads in the catchment maintain acceptable water quality in receiving waters is not known. However it is obvious from water quality monitoring and issues with ooze along the foreshore that the current loads are not sustainable / acceptable to the community.
- Stormwater drainage invert levels were not provided for review, so the integration of conventional raingardens and street trees with the stormwater drainage system could not be assessed.
- Uptake of rainwater tanks throughout the catchment and their influence on water quality.

5.10.6 Future management recommendations

Future management recommendations are generally consistent with recommendations made by NSW OEH (2018), which recommended the following:

1. **Source reduction strategies:** identification of pollutant generation hotspots to allow development of targeted programs aimed at improving the quality and reducing the quantity of stormwater entering the nearshore

2. **Stormwater treatment strategies**: redesign the stormwater treatment zones to enhance their effectiveness and aesthetic appeal
3. **Improvement of nearshore zone resilience:** improve the function of shoreline processes and increase flushing of nearshore waters with the lake to reduce localised impacts of stormwater inputs
4. **Community education and behavioural change:** bring all stakeholders on board in understanding the problem and their roles in potential solutions
5. **Flow-weighted sampling of stormwater quantity and quality:** this was recommended to both identify hotspots of pollutant generation and also provide data for the calibration of the MUSIC catchment model
6. **Review and adaptation of existing hydrodynamic models of Tuggerah Lakes:** this was recommended in order to develop a tool for the testing of various management scenarios aimed at reducing the impacts of stormwater on the Berkeley Vale nearshore zone

Further discussion around these management recommendations is provided below.

Source reduction strategies

Due to space and level constraints throughout the catchment for larger treatment devices, source reduction strategies are considered to provide a key opportunity for achieving stormwater quality treatment. This may be done at the streetscape scale and on private allotments.

Water quality monitoring undertaken by NSW OEH (2018) indicates a few key drainage lines with elevated concentrations of nitrate that would be good catchments to target initially. The following opportunities could be investigated by Council in collaboration with the community at a streetscape scale:

- Integrate streetscape systems such as raingardens and street trees upstream of conventional drainage inlets, to treat stormwater prior to entering the stormwater system. This will be difficult in areas close to the lake where the low relief restricts use of conventional piped drainage systems with kerb and gutter. In these locations, there may be opportunities to integrate self-watering street trees where kerb and channels exist that do not tie into the drainage system. Refer to Figure 5-16 and Figure 5-17.
- The use of pipeless / infiltrating water sensitive urban design measures like raingardens and bioretention swales are recommended where conditions permit. Note opportunities for these systems are likely restricted in poorly drained Wyong soils around the foreshore and south-eastern extent of the catchment, particularly where conventional piped drainage systems do not exist. Refer to Figure 5-19 and Figure 5-23.
- Stabilise exposed soils along roadside verges where there is no kerb and gutter. This may be done by including a kerb and investigating vegetative solutions such as buffer strips and swales (where levels permit) rather than a conventional gutter arrangements.

- Introduce planning controls for infill development /redevelopment /renovations to achieve water quality treatment and reduce flows, through implementation of some of the individual allotment controls discussed below. For example, MidCoast Council has developed a WSUD DCP that has water quality requirements for single dwellings. Water Sensitive Cities has also recently released infill typologies to guide water sensitive designs. There is also comprehensive advice on source control integrating both water quantity and quality objectives provided Argue (2004).

The following opportunities could be investigated on individual allotments, through community education and / or incentive schemes:

- Rainwater tanks:. current uptake in the catchment is unknown, however rainwater tanks provide multiple benefits, including providing a source of water supply, reducing flows and potential flooding impacts, and reducing nitrogen concentrations (from atmospheric deposition on roofs), as well as potentially other pollutants entrained in roof runoff before it reaches the drainage network (particularly along exposed road shoulders).
- Reduced impervious area: this could be encouraged through the use of pervious pavements and increasing vegetated surfaces.
- Raingardens to collect and treat runoff from roofs and other impervious surfaces.
- Downpipe diverters to lawns (or raingardens) to reduce roof runoff and disconnect impervious areas.

Stormwater Treatment Strategies

- Continue to support saltmarsh regeneration where possible along the foreshore
- Investigate rehabilitation of stormwater treatment zones. Further investigate options for this, such as bypassing flows for treatment in saltmarsh swales.
- Investigating the integration of proprietary products that treat nutrients. These may be appropriate at certain constrained locations, however they are likely more expensive options. It is recommended only products that can demonstrate independent verification of treatment performance are considered for use.

Improvement of nearshore zone resilience.

Refer to Chapter 4 for discussion on options to improve nearshore resilience.

Community education and behavioural change

Working with the community to improve education about the impacts of stormwater on water quality and create behavioural change in the catchment is important. Suggested actions to consider to support this include:

- Community science and engagement activities to help prioritise locations of retrofit treatments such as streetscape raingardens. This would also help to create ownership and acceptance of these assets through the catchment.
- Melbourne Water's 10,000 Raingardens Program provides a good example of how Council could work with the community to raise awareness about the need to manage stormwater, drive behavioural change and improve water quality through implementation of measures on private lots. Such a program would also help measure the performance of educational campaigns (Milenkovic et al., 2012). Resources from this program can be found online https://www.melbournewater.com.au/water-data-and-education/environmental-issues/why-we-need-save-water/tips-saving-water/raingardens
- Consider a demonstration project where a raingarden with education signage is integrated into a well-used location, such as the site pictured in Figure 5-22.

Figure 5-22 Potential WSUD demonstration site

Flow-weighted sampling of stormwater quantity and quality

The collection of additional flow-weighted monitoring data would help to provide local information on the quality of urban stormwater that could be used to calibrate the catchment model. This would help to fill an information gap, providing more certainty around predicted catchment pollutant loads.

Review and adaptation of existing hydrodynamic models of Tuggerah Lakes

This action would be recommended once better data has been collected to calibrate the catchment model.

Figure 5-23 Example of streetscape water quality treatment and raingardens

5.11 Case study 2: Porters Creek wetland catchment

Key Points
Urban development and widescale clearing of the catchment for grazing has resulted in changes to the natural hydrological regime, increasing flows and pollutant loads from natural conditions.
Porters Creek Wetland is the largest remaining freshwater wetland on the NSW coast and is recognised as being of state significance. As the wetland has a range of Endangered Ecological Communities protected under the *Threatened Species Conservation Act 1995*, Council has a responsibility to protect it and manage impacts from planned development in the catchment.
The catchment is a key growth area and potential increases in flows and pollutant loads can adversely impact the wetland, which provides an important water quality buffer the lakes.
Changes to the hydrologic regime resulting from urban development were identified as the largest risk to the future health of the Porters Creek Wetland (Sainty & Associates, 2002).
Due to large areas of future development in the catchment, poor erosion and sediment control presents a key risk to receiving water quality during the construction phase.
Ensuring sufficient funding, resourcing and capacity required to maintain future stormwater quality treatment assets is required to protect receiving water quality, but will be a challenge due to the abolishment of the stormwater levy during Council amalgamation, and the current cap on the levy.
The Porters Creek Integrated Water Cycle Management (IWCM) Strategy is a stormwater harvesting strategy previously endorsed by Council to protect the hydrology and ecological values of the Porters Creek Wetland from future development pressures, through replicating pre-development flows. It would also provide a source of town water for the region and improve water quality discharging to receiving environments.
The cost of the stormwater harvesting scheme was estimated to be in the order of $50 million and alternative schemes are currently under investigation by Council to reduce costs while also protecting the ecological values of Porters Creek Wetland.
Council's Development Control Plan contains specific provisions to incorporate water sensitive urban design into most new developments and includes comprehensive requirements for some locations. However, it is uncertain whether these requirements are being effectively implemented.
The predicted impact of the current growth strategy in the Regional Plan on catchment pollutant loads and the health of the Porters Creek wetland is unknown.
A number of opportunities and recommendations for managing water quality in the Porters Creek catchment and filling information gaps are provided for consideration.

5.11.1 Introduction

As a case study, the Porters Creek catchment was reviewed to identify:

- key existing and future pressures to water quality
- effectiveness of current management measures for improving water quality
- information gaps in understanding of water quality pressures / management actions
- opportunities and recommendations for improving water quality.

Key findings are outlined in the following sections.

5.11.2 Catchment description

The Porters Creek Wetland catchment is shown in Figure 5-24 and contains the following sub-catchments:

- Wadalba Woongarrah
- Sparks Road
- Buttonderry Creek
- Upper Porters Creek
- Porters Creek.

The catchment contains a number of existing and future urban development areas, including the Wyong Employment Zone (significant area of future development), Warnervale Town Centre (commenced development), and other areas of urban development around Warnervale, Wadalba and Hamlyn Terrace which are well underway.

The catchment has been extensively modified since 1820. Urban development has significantly increased impervious surfaces (e.g. roads, roofs, car parks and hard landscaping) in the catchment, and clearing of land for grazing (and other rural uses) has reduced the ability of the catchment to adsorb rainfall. These changes have resulted in increased stormwater runoff draining to Porters Creek Wetland. Despite this, Porters Creek Wetland is the largest remaining freshwater wetland on the NSW coast and is recognised as being a wetland of state significance (State Environmental Planning Policy 14 - Coastal Wetlands). It also contains a range of Endangered Ecological Communities protected under the *Threatened Species Conservation Act 1995*. As such, Council has a responsibility to protect Porters Creek wetland and manage any adverse impacts from planned development in the catchment.

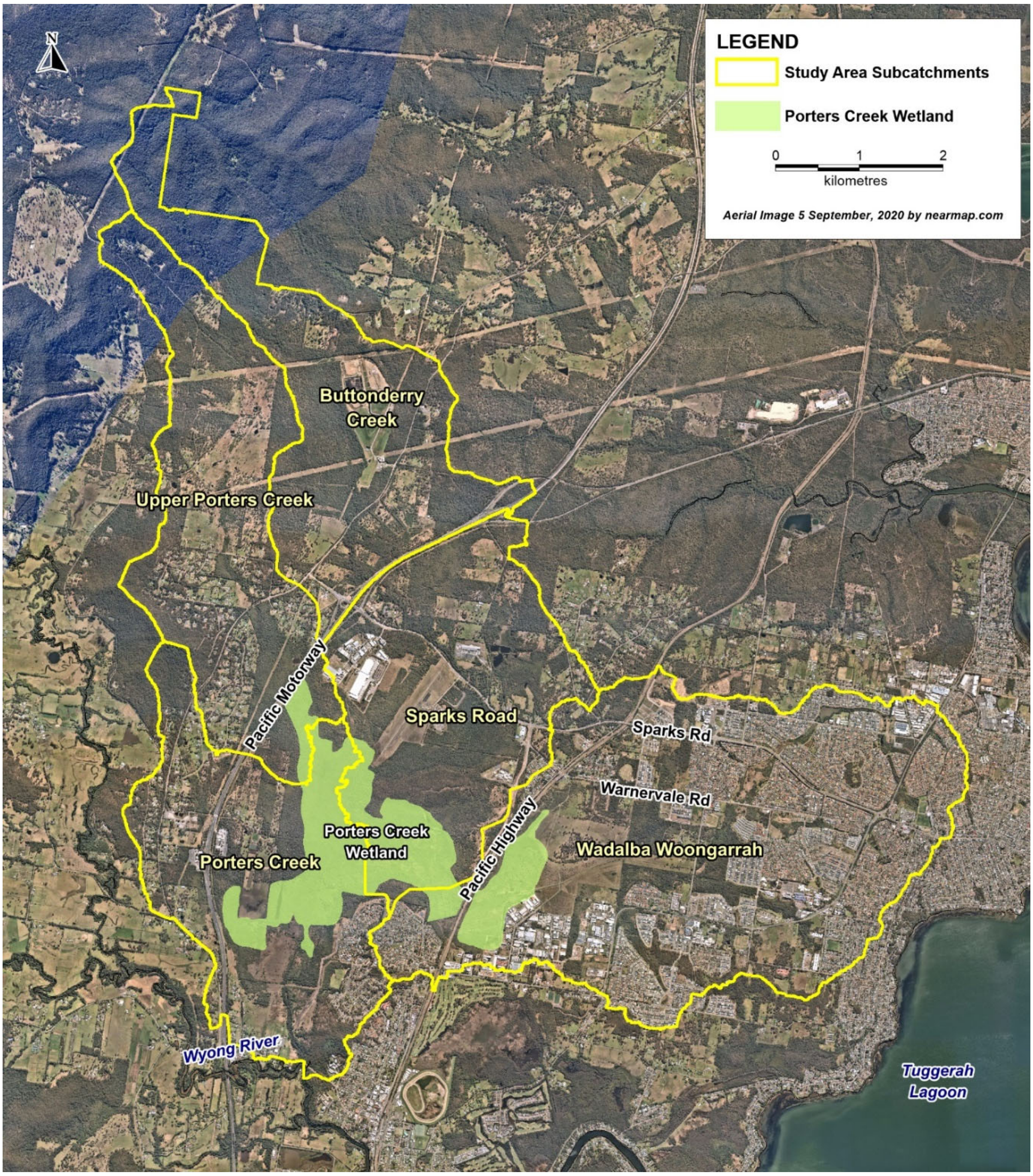


Figure 5-24 Porters Creek Wetland Catchment

5.11.3 Key pressures

Key pressures to water quality in the catchment are summarised as follows:

- urban stormwater from both existing and future development: the catchment is a key growth area and potential increases in both catchment flows and pollutant loads can adversely impact on Porters Creek wetland, which provides an important water quality buffer to Tuggerah Lakes. Changes to the hydrologic regime resulting from urban development were identified as the largest risk to the future health of the Porters Creek Wetland (Sainty & Associates, 2002).
- poor erosion and sediment control during construction: discussion with Council noted there exist high risk areas in the catchment with dispersive soils.
- maintenance of stormwater treatment assets.: Council is expected to acquire a number of stormwater treatment devices as a result of significant development in this catchment. These assets will need to be maintained to ensure optimal treatment performance and protection of receiving water quality. Council has limited capacity to undertaken current maintenance requirements, and will need to secure the funding, resourcing and capacity required to maintain these future assets. This is a challenge due to both the abolishment of the stormwater levy during Council amalgamation, and the current cap on the levy by state government.

For a more detailed discussion on the above pressures, refer to Section 5.3 and 5.4.

5.11.4 Current Management Actions and Effectiveness

Management of water quality in this catchment is primarily managed through Development Control Plans. The development control plans also refer to the Porters Creek Integrated Water Cycle Management Strategy (the IWCM Strategy) for Porters Creek Wetland, which identifies how the hydrology of the catchment can be maintained to protect Porters Creek Wetland. The IWCM Strategy and DCPs are discussed further below.

IWCM Strategy

The Porters Creek IWCM Strategy refers to a stormwater harvesting strategy to protect the hydrology and ecological values of the Porters Creek Wetland from future development pressures, through replicating pre-development flows. The scheme was developed based on detailed investigations undertaken by Ecological Engineering (2006).

The IWCM Strategy was based on the capture, treatment and storage of stormwater runoff, with excess stormwater pumped around Porters Creek Wetland to the Wyong River. The strategy provided the following key benefits:

- Protecting the hydrology and ecological values of Porters Creek wetland

- Providing a source of town water supply for region, particularly in consideration of water supply issues during the millennium drought. It was proposed that this would be done indirectly by maintaining environmental flows downstream of the weir, so that additional water could be taken from upstream of the weir. Alternatively, harvested stormwater could be discharged upstream of the weir to supplement water taken for town water supply (indirect potable reuse).
- Improving water quality discharging to receiving environments (through additional treatment prior to harvesting)

The driver for water supply from the scheme was reduced, however, when the Mardi to Mangrove pipeline was constructed in 2010, improving water supply security for the region.

The cost of the stormwater harvesting scheme was estimated to be in the order of $50 million dollars, $26 million to be funded by future development contributions (Wyong Contributions Plan, 2015). Due to the impact on development costs a revised contributions plan (Wyong Shire Council, 2015) was proposed that removed the stormwater harvesting component, instead adopting a Wetland Diversion Scheme that used a 'central storage facility' to mitigate changes to hydrology. The central storage facility is essentially a cleared wetland / floodplain which is proposed to be rehabilitated (Woongarrah Creek Wetland). This alternative diversion scheme instead adopted an interim cost of $15 million for levying contributions towards this scheme.

Studies have been undertaken to help identify how an alternative stormwater management diversion scheme would be implemented, but no scheme has been formally adopted by Council. The two most recent investigations include:

1. *Porters Creek Wetland Water Management Study* (BMT WBM, 2017). This study demonstrated that hydrological objectives to protect Porters Creek Wetland could be achieved through implementing the following key strategies (within an adaptive management framework):
    a. centralised constructed wetlands to mitigate existing and future planned development, and
    b. rehabilitation of the Woongarrah Creek Wetland ('central storage facility').
2. *Porters Creek Wetland & Catchment Stormwater Modelling, Revegetation Plan and Monitoring Plan* (Cardno ongoing). This study is essentially investigating the option of rehabilitating large areas of vegetation throughout the catchment to provide storage and treatment of stormwater to meet hydrological objectives and protect Porters Creek Wetland. It includes large scale revegetation of the Woongarrah Wetland, in addition to identifying other areas that could be revegetated and act as flood storage and water quality treatment areas.

As constructed stormwater treatment wetlands are becoming a maintenance burden for Council, the Cardno investigation is looking at naturally revegetated areas as a more cost effective solution.

Development Control Plans

As described above, it is noted that a comprehensive stormwater management strategy for the Porters Creek Wetland is yet to be confirmed, the outcomes of which will need to be updated in the DCP chapters. A summary of the water quality requirements in the current development control plans for key urban areas in the catchment are outlined in Table 5-15 below.

As seen in Table 5-15, currently the DCPs in the catchment have objectives to incorporate water sensitive urban design into most new developments and include comprehensive requirements for some locations. However, it is unclear whether these requirements are being effectively implemented. Streetscape and source control measures are recommended, however from limited desktop inspections (via aerial photography and street views) do not look to be widely implemented. This may be due to internal push back in Council for accepting these types of systems (due to perceived maintenance burdens) and / or developer push back on the DCP requirements or failure to implement. An example of a typical newly developed streetscape in Warnervale Town Centre and LRIP is shown in Figure 5-25. This highlights missed opportunities to integrate WSUD such as passively irrigated street trees, raingardens on street corners, permeable paving, roadside buffer strips and swales.

Inspection of recently constructed (< 5 years) stormwater storage /wetland areas within the Hamlyn Terrace Louisiana Road Infill Precinct (through review of aerial imagery only) indicate eutrophic conditions, likely because they are not receiving sufficient pre-treatment by source control measures through the developments or within wetland macrophyte zones (refer Figure 5-26). This suggests that improved guidance may be beneficial for the design, construction and handover of water quality treatment assets to Council.

Table 5-15 also shows variable WQO targets within the DCPs. The 65% reduction target for TN may be an error (as this more closely represents widely adopted best practice target for TP), while 45% treatment of TN is a more commonly adopted target. A simple test of the performance of these targets in maintaining existing conditions was undertaken in MUSIC, with results presented below. These results indicate that the current targets alone do not necessarily maintain existing conditions . It is noted that the performance of these targets do not account for reduced flows (and associated pollutant loads) to meet hydrological management objectives to protect Porters Creek wetland. If flow management is appropriately incorporated into the design it is likely that water quality would maintain existing conditions. A key issue however, is that much development appears to have been constructed in the catchment in the last five years, and it is uncertain as to whether this development has achieved required water quality or quantity requirements in accordance with existing DCPs.

Table 5-15 Summary of DCP WQOs for Porters Creek Catchment

DCP Reference	General Water Quality Objectives	WQO[1]		
		TSS	TN	TP
Chapter 5.5 Warnervale Town Centre	Stormwater to storage (for IWCM scheme)	85%	65%	45%
	Stormwater to receiving environments (wetlands and Wallarah Creek)	90%	50%	50%
	• WSUD is to be adopted throughout the development to promote sustainable and integrated management of land and water resources • Treatment trains to include at source, streetscape and end of pipe stormwater treatment, including: rainwater tanks and harvesting, bioretention systems, bioretention pods within lots and streetscape, permeable paving in carparks and some roads, proprietary GPTs, buffer strips and grass verge treatments • For large retail, commercial and apartments, also consider roof top gardens, WSUD carparks, stormwater harvesting.			
Chapter 6.2 Hamlyn Terrace Louisiana Road Infill Precinct (LRIP)	• At source stormwater treatment (porous pavement, raingardens, rainwater tanks, swales) • Bio swales in street reserve widths of 16m or 18m • Precinct stormwater treatment in wetlands and bioretention basins prior to discharge to 'stormwater storage' •	85%	65%	45%
Chapter 6.5 Warnervale South	• Adopt WSUD that employs best practice in quality and quantity controls • Balance at source WSUD with end of line treatment to meet targets • Provide cost effective and affordable treatments in consideration with ongoing maintenance costs • To maintain and improve water quality in receiving waters and groundwater systems	85%	65%	45%
Chapter 6.17 Warnervale East / Wadalba North West	• Refers to ARQ objectives	80%	45%	45%
Chapter 6.18 Warnervale Business Park (first stage of Employment Zone)	• To promote and encourage the conservation and re-use of stormwater run-off • To minimise the negative impact of stormwater run-off from individual sites on the water quality of Porters Creek and surrounding wetlands system • To ensure that existing baseline water quality in the Porters Creek Wetland area is not affected by the development • Requires compliance with Council's Civil Works Design Guideline and Construction Specification (i.e. ARQ WQOs)	80%	45%	45%

[1] Reduction in post development loads. This is the target to demonstrate compliance requirements when modelling in MUSIC.

Figure 5-25 Streetscape Warnervale town centre and LRIP

Figure 5-26 Example of eutrophic conditions in stormwater storage areas (4 November 2020)

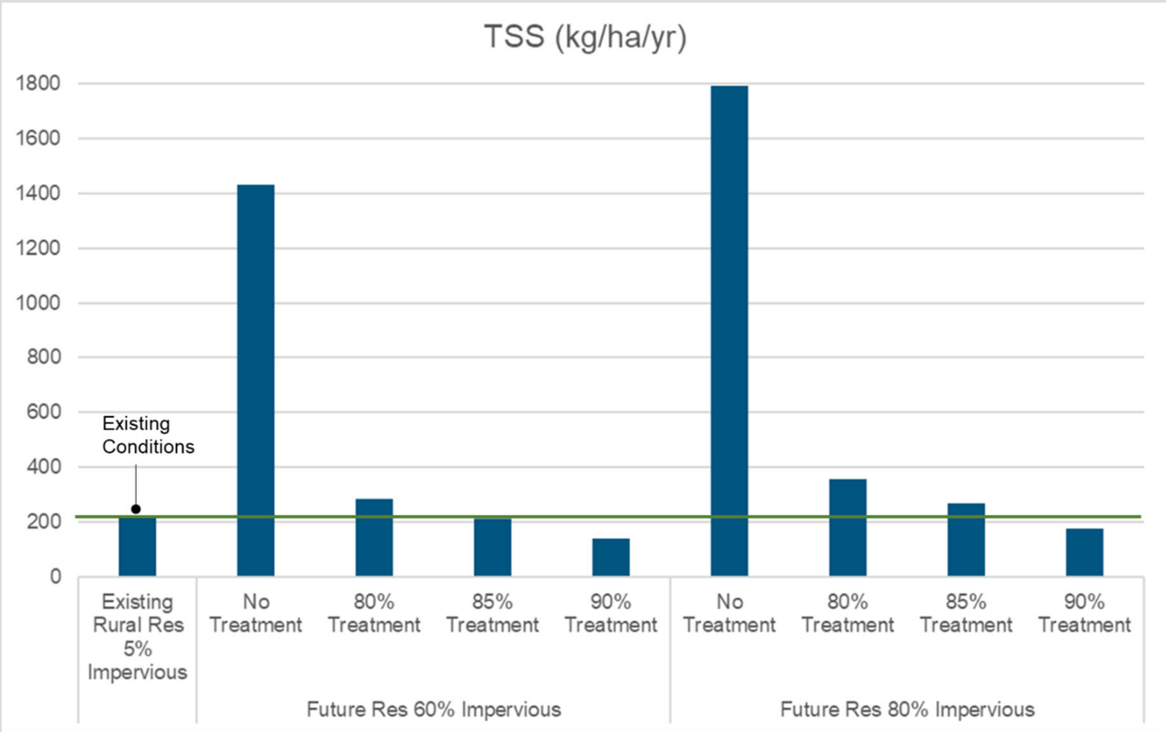


Figure 5-27 Predicted TSS (kg/yr) with DCP WQOs applied

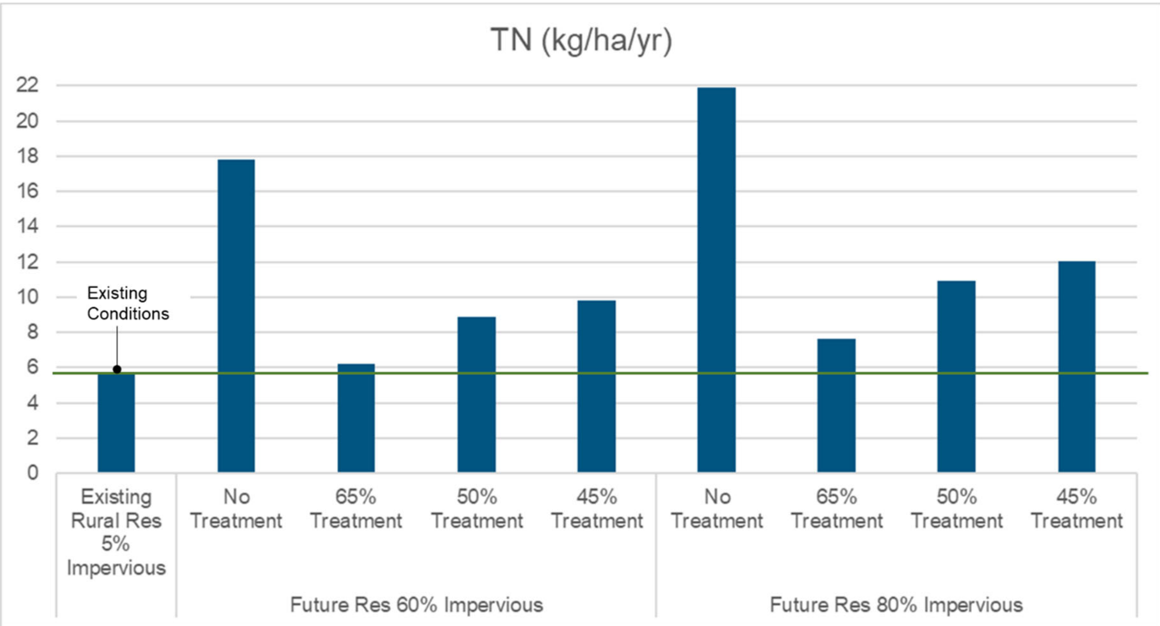


Figure 5-28 Predicted TN (kg/yr) with DCP WQOs applied

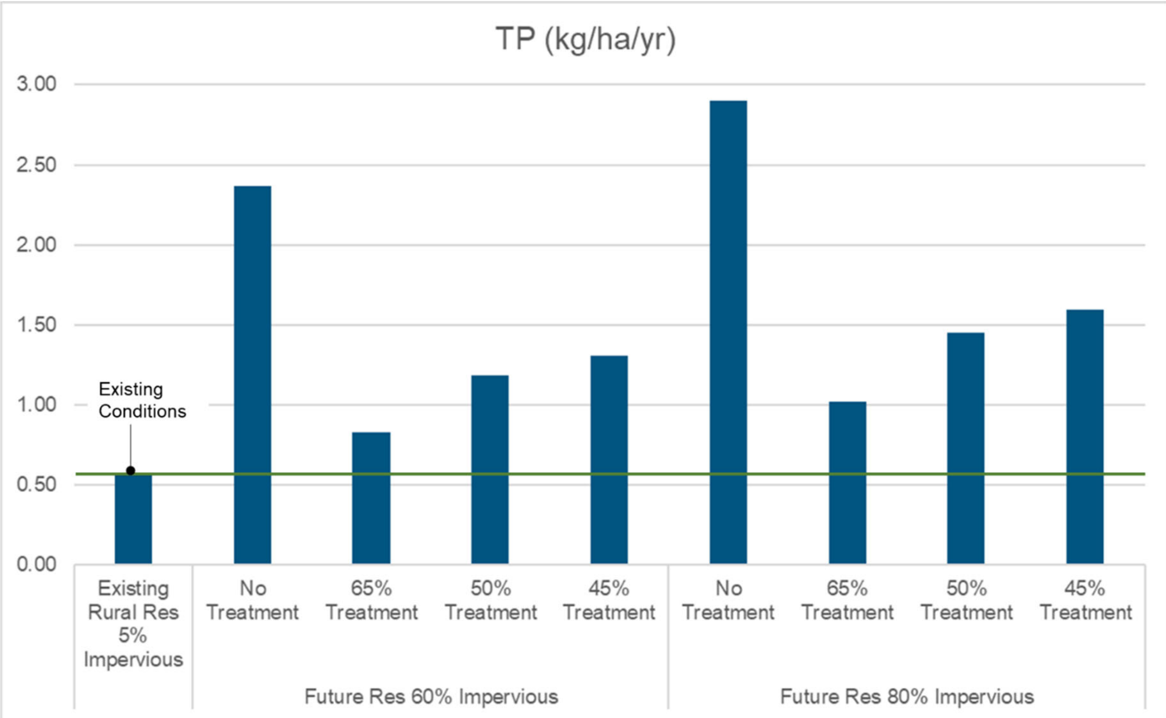


Figure 5-29 Predicted TP (kg/yr) with DCP WQOs applied

5.11.5 Information Gaps

In undertaking this review, the following information gaps were noted:

- Baseline monitoring of hydrology and water quality to establish what current conditions are, and to assess the effectiveness of future catchment management measures (currently under investigation by Council).
- Sustainable load targets for water quality to protect the ecological health of both Porters Creek Wetland and Tuggerah Lakes.
- Revised and approved stormwater management strategy to inform the DCP assuming that Porters Creek stormwater harvesting scheme does not proceed (currently under investigation by Council).
- Locations of all current treatment assets in the catchment. While this information is understood to exist it was not provided as part of this review.
- Monitoring to show the effectiveness of current treatment devices (e.g. wetlands) in the catchment. It is understood that Council has scheduled future works to investigate this further.
- Predicted impact of current growth strategy in the Regional Plan on catchment pollutant loads, assuming current DCP treatment targets are achieved.

- The extent of compliance of development in the catchment with the DCP requirements for water quality treatment. (i.e. have approved developments demonstrated how DCP WQOs will be achieved, and has this been effectively implemented on ground as planned).

5.11.6 Future management recommendations

Opportunities and recommendations for managing water quality in the Porters Creek Catchment and filling information gaps are outlined below:

- Implement a baseline monitoring program to better understand current conditions and set benchmarks for protecting the health of Porters Creek Wetland
- Update catchment modelling to predict the likely impact of future development on hydrology and water quality, and assess whether current Water Quality Objectives (contained in the Development Control Plan) and / or proposed strategies (under investigation) will maintain or improve upon existing (2020) conditions. This will better inform our understanding of the future pressures on water quality from development.
- WaterPlan 2050 is currently being revised to develop an Integrated Water Resource Plan (IWRP) which will present how a sustainable water supply strategy for the future can be achieved. The IWRP should provide a transparent review of the costs and benefits of the Porter Creek stormwater harvesting scheme, with consideration given to valuing the indirect benefits provided by protecting Porters Creek wetland and Tuggerah Lakes.
- Consider undertaking a benefit cost assessment of the various stormwater management strategies developed for Porters Creek Wetland catchment to help identify the best strategy.
- Monitor the performance of treatment devices in the catchment to check their performance against assumed performance and better inform future decision making.
- Investigate apparent eutrophic conditions observed in the storages within the catchment, and assess appropriate actions to rectify (if required).
- Support the use of passively irrigated street trees, with wicking beds where conditions permit. Larger storages could also be investigated for meeting hydrological objectives. Downpipes could also be connected to the street trees. Benefits include protecting water quality, improving air quality, providing urban cooling (and energy savings), increasing amenity and property values and reduced demands on infrastructure (from reduced volume of stormwater). Refer to Figure 5-16 and Figure 5-17 for examples.
- Improved and consistent Development Approval / Development Control Plan requirements during construction and establishment to ensure handover of good water quality treatment assets. Refer to construction and establishment guidelines and checklists (WBD, 2010) for examples of how this may be implemented.

- Improved education and enforcement of Erosion and Sediment Control practices, particularly at the lot scale. Consider proactive enforcement of erosion and sediment control practices, potentially through a third party (e.g. State Government).
- Reinstate Stormwater Levy to help ensure new assets are effectively maintained and optimal treatment is achieved. Future expected maintenance costs and Council resources required should be considered in determining an appropriate levy. It is also recommended that the NSW State government increase the allowable rate for a stormwater levy to support this.
- Life cycle costing be undertaken to better inform the cost effectiveness of different options. It is recommended that monitoring or modelling results of typical treatment performance and actual maintenance costs be used to inform this (e.g. wetlands, bioretention basins, raingardens, passively irrigated street trees, revegetation).
- Capacity building in Council to ensure that staff have the appropriate skills to design, construct and maintain water sensitive urban design assets, particularly new streetscape designs.

6 Summary and Recommendations

6.1 Summary

This report details information regarding the water quality of Tuggerah Lakes as undertaken by an independent expert panel appointed by the NSW Minister for the Environment. The information reviewed and incorporated within the report was prioritised based on input and feedback provided by the community, business, and government stakeholders. This input focused the review towards (i) how the entrance influences water quality in the lake system, (ii) the water quality and ecological characteristics of the lakes themselves, and (iii) the influence of the adjacent catchment on the lakes' water quality. The findings within the report are based on available scientific information, input from local stakeholders, the expertise of the members of the expert panel, and an understanding of the current and future pressures. The Terms of Reference for this review excluded flooding, although the Tuggerah Lakes Expert Panel (TLEP) hopes that the information provided herein is considered in any updated flood management plan.

The Tuggerah Lakes system, including Tuggerah Lakes, Budgewoi Lake and Lake Munmorah has been the subject of many studies and local scientific interest for decades. As such, the lakes are rich in data, theories and hypotheses regarding their ecological trajectory and water quality functions. Since 2006, the Tuggerah Lakes Estuary Management Plan has been in place to provide an integrated evidence-based management plan for the estuary and its catchment. Central Coast Council has progressed many aspects of the plan in consultation with stakeholders. The Coastal Management Program currently underway provides an opportunity to update the existing plans in coordination with government agencies, the community, and stakeholders. This will ensure that actions are transparent and supported by compelling scientific evidence.

This report does not attribute blame for the existing water quality conditions on a single entity or group. Indeed, the TLEP believes that in most cases the actions were well intentioned. The TLEP wish to highlight the extensive works undertaken by the estuary management group within Council in relation to funding scientific investigations and implementing on-ground actions. However, the broader cycle of poor communication resulting in an escalation of tensions, followed by reactive actions, needs to be broken. The TLEP believe that to achieve a strategic plan for ongoing management of Tuggerah Lakes, a communication reset is required between (and within) State and Local Government and the broader community. Further details on the steps towards achieving these outcomes are provided below and in Chapter 2 of this report.

As part of the communication reset, the TLEP believes that stakeholders should acknowledge that there is no easy or quick fix to address the water quality concerns of Tuggerah Lakes. Multiple studies over numerous years have highlighted that many of the concerns associated with Tuggerah Lakes are part of the natural cycle of the coastal lake system. Indeed, wrack, intermittent opening/closing of the entrance, and a shallow waterbody stirred up by wind waves, are all part of the natural character of the estuary. These characteristics have been recognised for over a century and are known to fluctuate with the broader climate patterns and environmental pressures. Nonetheless, Tuggerah Lakes requires integrated State and Local Government management and substantial additional funding to address the range of concerns outlined within this review.

Significant increases in the local population over recent decades has influenced the landscape that drains into Tuggerah Lakes. These changes within the catchment are known to have a deleterious effect on water quality and related aspects. In response to these concerns, Tuggerah Lakes has suffered from attempts to treat the symptoms versus the root cause of the problem.

An important outcome of this enquiry is that a permanent ocean entrance is not recommended at The Entrance for water quality purposes. The TLEP believes and science supports that a permanent entrance would not address the issues causing the highlighted water quality concerns, including wrack accumulation, macroalgal growth, sediment accumulation, flushing, or increased nutrients. Indeed, a permanent open ocean entrance is likely to reduce the lakes' average water levels, which may increase the volume of nutrients draining into the lakes via groundwater and result in more pervasive exposure of fringing mud flats and the resulting generation of odours.

Water in these coastal lakes is not readily exchanged with the ocean. Multiple studies have shown that due to the size and shape of Tuggerah Lakes, oceanic flushing is limited to 1-3% percent of the volume of the lake. In contrast, wind mixing plays an important role as the lakes are wide and shallow. The wind can create waves that stir up the bed sediments and accumulate wrack. Understanding these driving forces is very important in developing integrated strategic plans for better managing water quality and wrack. The use of data rich numerical models can assist the development of ground-truthed strategic and operational plans. Further information on how the entrance opening influences water quality and relevant recommendations are provided in Chapter 3 of this report. Entrance related recommendations are also summarised below.

It is important to note that water quality in the lakes has improved over recent decades. The replacement of septic systems with sewage systems and the implementation of the Tuggerah Lakes' Estuary Management Plan by Central Coast Council, has reduced water pollution and improved the overall health of the lakes. However, in recent decades the catchment areas have experienced increasing developmental pressures. As such, much of the seagrass that was living in the main basin has been isolated to a nearshore fringing zone. The TLEP recommend that the existing work led by Council is continued and progressed to decouple the fringing seagrass area with the deeper basin zones to improve water exchange between the two areas. Understanding and addressing these factors, including stormwater runoff and groundwater seepage, is of utmost importance in strategically managing the lakes. Further information on the water quality and ecology of the lakes is provided in Chapter 4 of this report. Related recommendations are provided below.

The influence of the surrounding catchment on the lakes' water quality is of growing concern. Recent catchment development does not appear to have been undertaken using best practice for stormwater or urban water quality design. As the developments are not applying best practice, the resulting stormwater quality from these developments has the potential to add toxic pollutants, turbidity, and nutrients. Several attempts have been made to treat these inflows using, sometimes quite innovative, water sensitive urban design techniques, but both the magnitude of the problem and the financial costs of maintaining these structures is daunting for any Council. This is compounded by the lack of an environmental levy or stormwater levy, which have been utilised with success by other Councils. Further information on how the catchment influences the water quality of Tuggerah Lakes is provided in Chapter 5. Recommendations are summarised below.

The developmental pressures in the catchment are likely to be an increasing concern in the near future with an additional 41,500 houses proposed for the region by 2036. These development targets, set by the NSW State Government, will apply significant additional water quality pressures to the region and require multi-layered governmental collaborations. Indeed, the varied governmental agencies involved in providing oversight of the lakes and adjoining waterways introduces additional barriers towards a comprehensive and strategically aligned future plan. The TLEP is highly concerned that without best practice policy and catchment management in place, along with improved funding and State government resources, significant and potentially irrecoverable threats to the water quality of Tuggerah Lakes are likely. It is the hope of the TLEP that the recommendations of this report are considered in the development of the Coastal Management Program to foster collaborative management by all relevant stakeholders.

6.2 Overarching Recommendations

Tuggerah Lakes are at a crossroads. Based on the consultation and detailed scientific review undertaken for this study, Tuggerah Lakes requires coordinated plans, broad engagement, and transparent actions to improve existing lake management and plan for a sustainable future. To this aim, the TLEP has proposed multiple recommendations for consideration. The recommendations are focused across the broad topics of communication, planning, engagement, and actions. Where relevant, the TLEP has suggested potential funding pathways to implement the proposed recommendations. A short discussion of the main recommendations is provided below with the full list of recommendations provided in each chapter and summarised below.

Strategic and measurable plans are required or need to be implemented for dredging, wrack management, nearshore water quality, stormwater management, entrance flood management and sustainable catchment development. These plans need to be integrated within the Coastal Management Program so that the development controls, stormwater actions, and entrance management (to name but a few) are aligned and supportive of a healthy and biodiverse coastal lake ecosystem. Furthermore, the plans need to be transparent, well communicated and openly discussed with the community in a proactive manner.

The TLEP recognise the research, leadership, scientific investment and on-ground actions undertaken by the estuary management group within Council. This investment in resources has aimed to apply best practice across the waterway and to facilitate an exchange of information with the community. Many of these practices should be recognised as best practice in Australia. However, the estuary management group within Council cannot and should not be solely burdened with the responsibility of managing the Tuggerah Lakes ecosystem. A fully integrated Council, supported by funding and resources from the State and Commonwealth governments, with a focus on total catchment management is required if these lakes are to prosper in the future.

To support Council's efforts, the TLEP believe that a *Catchment Coordinator Taskforce* should be established for a 5-year period, with review after 3 years, to assist in implementing the recommendations of this review and to provide a supporting role as Council develops and begins implementation of its Coastal Management Program for Tuggerah Lakes. This new taskforce can play an important role in providing a circuit breaker on discussions between the local stakeholders and government officials, and to address potential concerns with upcoming developmental pressures in the catchment. In addition, the Taskforce could assist in bringing together multiple stakeholders to ensure that the responsibility of managing Tuggerah Lakes is apportioned to those with the delegated legal authority. This should better reflect the various NSW State Government authorities who play a critical role in catchment, waterway, fisheries, environmental, transport, and planning for the region.

The proposed Taskforce could be similar in nature to the Wamberal Beach Taskforce and report directly to the NSW Minister for Planning or an appropriate steering committee of delegates. The Taskforce should aim to undertake an independent audit of water sensitive urban design practices, including erosion and sediment control practices, within Central Coast Council, with regards to receiving water quality impacts. This audit should be used to develop recommendations for future integrated water sensitive urban design practices that are focused on improving water quality in Tuggerah Lakes. The Taskforce should engage with community stakeholders in a collaborative and shared approach, as per TLEP recommendations, to establish water quality targets based on community values *and* a shared vision for the future of Tuggerah Lakes.

The TLEP recognise the current financial pressures on Central Coast Council. Therefore, the TLEP believes the Taskforce should be funded by the NSW State Government in a similar manner to the Wamberal Beach Taskforce or this enquiry. Further, the TLEP recommends that an environmental levy is implemented to secure a continual baseline funding source for Council and to help avoid the current reliance on ad hoc State or Commonwealth grants. Many other Councils in the region have benefitted significantly from an environmental levy and the TLEP is concerned that Tuggerah Lakes will fall significantly behind other similar systems without adequate funding. Further, with significant upcoming developmental pressures, it is the opinion of the TLEP that a stormwater levy should be implemented to progress the related recommendations, to undertake audits of existing and proposed water sensitive urban design infrastructure and sediment control measures, and provide Council with a sustainable means to maintain stormwater infrastructure. It is proposed that the Catchment Coordinator Taskforce provide an interim and immediate role until (i) these proposed levies have been established within Council, (ii) sufficient progress has been made on the development and implementation of proposed strategic plans, including the Coastal Management Program, and (iii) there is substantial progress in community consultation and the establishment of a shared vision for Tuggerah Lakes.

The TLEP supports the development of a detailed dredging management strategy that outlines where, when and, most importantly, why dredging should be undertaken in the entrance channel. It currently appears that dredging is conducted in response to community concerns and any proposed dredging should be strategically informed, providing a better chance of sustainably achieving the values that the community desires at The Entrance. Further, the development of dredging plans should be based on a conversation with the community stakeholders and the best available science, with results reported back to the relevant stakeholders at prescribed intervals.

In addition to these overarching recommendations, individual recommendations arising from each chapter of the report are summarised in Chapter 6. The success of this enquiry is ultimately dependent on whether these recommendations are adopted and implemented.

In addition to the above overarching recommendations, detailed recommendations are provided within each Chapter of this report. These recommendations are reproduced below.

6.3 Community engagement and communication recommendations

The following recommendations are made regarding community engagement and communication as per Chapter 2 of this report.

Focus engagement on learning together rather than solving 'the problem' or 'fixing' the Lakes. Work with the community to:

- Explore the physical dynamics of the system to build (or at least understand) a conceptual model of the Lakes' system including nutrient and energy inflows and outflows, sand movements, wave actions, flooding and the entrance etc.
- Set the community up as scientists and researchers and support them to design and conduct small-scale experiments together.
- Test the various theories put forward by community members, such as those concerning an ocean connection via 'the gap', weed management, tidal flows etc.
- Focus on building a shared understanding of how the Lakes work. Take time to do this as a joint project, admitting that we don't have all the science already.
- Seek and acknowledge community knowledge, beliefs and understanding. Seek to understand that we don't have a complete understanding of the processes involved and help others in the community do the same. At the same time, be clear about what the science is saying.
- Communicate all of the above broadly with the community.

Work with the community to grow a shared understanding of the Lakes' management dilemmas – what is actually going on and what makes managing the Lakes so difficult.

- Be clear about constraints, such as financial, resources, urban growth targets, skills and knowledge. Be up front about the role of politics on governance. Acknowledge the complexity of the context and the physical systems. Acknowledge the risks of unintended consequences of any actions.

- Agree with stakeholders on the key aspects of the dilemma – thereby describing the problem(s) to be addressed (not necessarily solved).
- Communicate all of the above broadly with the community.

Build on the dilemma work to co-create a shared picture of the realistic and preferred outcomes for the Lakes.

- For example, an outcome could include: water quality that is no worse than current standard, or; a lake that people feel comfortable to swim in.
- Then use this shared sense of the desired future to inform actions and interventions and evaluations.

Work with the community to design and agree to a decision-making process to determine potential and prioritised management actions, and to implement them. Establish a group to do the work together, with their role including:

- to devise and agree a set of criteria to guide decisions about options and actions,
- to oversee the design and running of the ongoing series of 'experiments', pilots and other investigations,
- to oversee the development and dissemination of messages for the broader community,
- to oversee the development of potential actions emerging and their assessment against the criteria,
- to oversee additional studies as warranted, such as cost benefit analyses,
- to make recommendations about large and small actions,
- to oversee the implementation of actions, and
- to monitor and learn from Lake management actions taken.

It is suggested that these recommendations are applied as a filter for implementing the remaining recommendations below. Initially, it is proposed that the proposed Taskforce lead these initiatives with support from Council and relevant State agencies.

6.4 Entrance dynamic recommendations

Based on the information presented in Chapter 3, the following recommendations are provided in relation to the entrance dynamics and water quality.

Entrance Training Works: Based on available information, the existing entrance should not be trained, nor extensively dredged. The existing studies indicate that there would be a minor increase in tidal exchange and that the potential impacts on water quality and ecology are not well understood. Potential adverse impacts include:

- If the entrance were opened permanently, it is highly likely that the average lake water levels would fall, exposing shallow fringing areas of the lakes during fortnightly neap tides and resulting in the generation of poor odours and groundwater seepage. This was experienced in 2020, following the floods in February and subsequent rain and storm events that caused the entrance to remain open for an extended period.
- Experience with entrances to other large coastal lagoons in NSW, has shown a tendency for the entrance to enter an unstable scouring mode with increasing activation and movement of sand through the entrance and ongoing excessive erosion of the entrance channel foreshores. This long-term geomorphic process has not been assessed by any of the modelling studies completed to date and may result in significant ecological and engineering implications.
- As sea levels continue to rise offshore of NSW, the issue of flooding around the fringes of estuaries as a result of ordinary astronomical tides and coastal storm surge will become increasingly important. Opening the entrance more broadly and permanently will exacerbate flooding from this process. The absence of a mapped coastal vulnerability area within *State Environmental Planning Policy (Coastal Management) 2018* in relation to the tidal inundation hazard means that this is not presently understood.

Coastal Vulnerability Mapping: The Coastal Vulnerability Area, relating to the tidal inundation hazard should be analysed and mapped, with a subsequent Planning Proposal put forward as part of the Coastal Management Program to be prepared for the Estuary.

Dredging assessment: In the medium term, dredging of the entrance should continue, however the following actions are recommended:

- Install a permanent water level recorder in the entrance compartment: downstream but in the vicinity of the bridge. This will provide information to inform future management.
- Collate the dredging history, all water level, flood and coastal information from inside the estuary, including available footage from the fixed camera to the south of the entrance. Use this information to analyse the degree to which past dredging programs have affected tidal exchange between the ocean and the coastal lake.
- Collect regular and consistent clarity data (secchi disc or turbidity probe) from selected locations around The Entrance to better understand how dredging affects entrance clarity.
- Undertake a socio-economic and tourism study to understand, and quantify wherever possible, the benefits derived from a clear and flowing entrance channel around The Entrance.

- Using the above steps, ascertain whether dredging represents a reasonable ongoing investment. If so, develop and implement a practical and transparent monitoring program with improved dredging triggers (most likely based on tidal response at the above recommended permanent water level recorder) and negotiate with relevant authorities to develop a protocol which enables rapid response and dredging when required.

We note that entrance dredging may also be implemented to assist with flood management and the above processes should be integrated with Council's flood risk management procedures. This recommendation may be funded via the Coasts and Estuary Grant's program, if noted as a priority within the Coastal Management Program study for Tuggerah Lakes.

Dredge Program Funding: Council and relevant government agencies are recommended to examine past expenditure on entrance dredging and to agree upon a clear and reliable funding structure for future dredging over the medium term. Reliance upon contestable grants programs is unlikely to provide the required certainty of funding. The arrangement should be revisited once a final decision is made regarding the continuation of the dredging program.

Second Entrance Consideration: A collaborative community guided process into examining potential management options for a second connection to the ocean at Budgewoi Lake is recommended. We recommend the following approach:

- Development of different potential concepts or options
- Consideration of overall viability (engineering, acceptability, effectiveness of a range of options)
- Development of cost estimates
- Assessment of concepts and, if warranted, selection of a preferred option (or options)
- Numerical modelling of preferred options.

If viable options are available for consideration, potential funding opportunities and the assessment of environmental impacts could be completed. It will be important that appropriate community members are selected to participate in this exercise. The exercise should be facilitated by Council and/or state government representatives. We note that several options have been examined partly in the past, and they all seem to have quite significant limitations. Regardless, all community and government participants should aim to approach the exercise with an open mind and consultative nature. We recommend that all participants be required to adhere to a code of conduct, which requires engagement in the process with good faith.

6.5 Water quality and ecological recommendations

Based on the findings from Chapter 4, water quality and ecological recommendations are described below.

- **Where possible, redirect stormwater into the rivers and creeks to alleviate nearshore eutrophication** - data on nitrogen and phosphorus concentrations within the basin suggest that large runoff events do not produce a detectable signal in the long term record. While the detailed modelling required to assess why this may be so is currently not available, it is likely due to dilution in the basin, and/or the direct transport of the freshwater plume to the ocean (when the entrance is open). As there is no detectable signal in eutrophication in the basin (as evidenced by the long term Chlorophyll a data, Section 4.3), then ensuring that nutrients associated with runoff are shunted to the basin, rather than trapped in the nearshore zone will likely lead to improved water quality.
- **Large-scale re-engineering of shorelines** – Shoreline realignment should be considered to restore the natural gradient of the shorelines and address the legacy issues that remain from the steeper shoreline gradients that were introduced during the Tuggerah Lakes Restoration Project. Remodelling the lake shorelines has many potential benefits including improvements to stormwater and groundwater treatment, improved nearshore processes, support for the rehabilitation and restoration of intertidal and supratidal habitat such as saltmarsh, and improved amenity. Reducing the shoreline gradient will help to transport wrack onto the shore to dry aerobically and reduce the anaerobic processes that contribute to ooze development and bad odours.
- **Implement strategic wrack harvesting** - Effective implementation of a strategic wrack harvesting program has been somewhat impeded by several factors including reactive management rather than improved understanding of where wrack is likely to accumulate and develop ooze. However, this could be improved by using the evidence base developed by DPIE for strategic wrack harvesting (Swanson, 2013). Specifically, strategic wrack harvesting would be driven by science to adapt to wind-driven transport with a focus on locations where wrack collection would improve nearshore circulation (by removing offshore wrack barriers) and public amenity. Wrack should be allowed to remain in locations where aerobic drying can occur. Further, the rate of removal by the contractor currently doesn't match the amount of wrack deposited. This capacity issue should be addressed with upgrades to machinery as well as improved methodologies to harvest in shallower waters of the nearshore as well as offshore (e.g. seining). These efforts should be complemented by a community education and engagement program (see Recommendation # 8) around wrack processes that may enable Council to be more proactive in their response to wrack accumulation and ooze.

- **Wetland rehabilitation** - Continue rehabilitation and restoration of wetland habitat in the waterways that discharge to Tuggerah Lakes on a large scale (refer to Chapter 5).
- **Further studies to quantify the importance of groundwater nutrient inputs to the nearshore zone** – there is currently limited information to provide a detailed assessment on what role groundwater may play in driving eutrophication in the nearshore area. The preliminary data suggest that groundwater may be an important nutrient source during some periods e.g. following rainfall events where the head differential between the groundwater table and lake water level are maximal. Due to the reclamation of some areas of shoreline as part of the Tuggerah Lakes Restoration project, there are likely some legacy affects associated with the breakdown of the organic material in the dredged material. Whether this material is continuing to leach nutrients (and potentially other contaminants) through groundwater seepage is unknown, but should be a priority for future studies.
- **If groundwater is found to be important, strategies such as the use of bioreactors should be investigated for feasibility** - treating groundwater nutrient contamination in not a trivial task. However some success has been achieved with the use of bioreactors, which essentially provide an environment for bacteria to break down nutrients. If future investigations find that nutrients loading via groundwater seepage is a significant source to the nearshore zone, then the trialling of bioreactors in groundwater seepage hotspots is recommended.
- **Ongoing monitoring and adaptive management** - All of the recommendations provided above should be included in an adaptive management plan, whereby monitoring and evaluation of the effectiveness of actions provides the evidence to continue with the status quo or to make adjustments and improvements. Wherever possible, monitoring should follow a Beyond BACI (Underwood, 1991) approach whereby information is collected before any management action is implemented at a site as well as afterwards, and from additional sites that are not being targeted by management. At the same time, the extensive water quality and ecological datasets that have been collected in the various reports commissioned by Council should be compiled into one repository and made openly available. This will firstly allow the data to be used in long-term models of the Lakes' system and improve predictive capacity for management actions, but will also create a resource that can continue to be updated and improved to assist in adaptive management.
- **Community education and engagement** - Future water quality improvements in the Lakes will require educational programs to address community perceptions of the characteristics of a healthy ICOLL. Furthermore, relevant stakeholders including the Council and the community need to work together to understand how the Lakes operate as an entire system to appreciate the allocation of management priorities. This could be aided by the

development of a web-based conceptual model of the functional zones, processes and communities in the Lakes that is hosted through a Council website. Regular communication is essential and could be facilitated through social media channels, providing a daily water quality report through wide-reaching media such as radio or television, as well as engaging communities around the Lakes in citizen science. Projects such as community wrack harvesting for Council collection (Swanson et al., 2013) should be expanded while preventing disturbance of sediments or damage to living seagrass communities. The community could also be engaged in wrack monitoring programs through the capture of high-resolution images of seaweeds and seagrass distributions around the lakes using drones or trial cameras, where available. Data management could be incorporated into the current apps that the Council maintains.

- **Visual products** - Importantly, information collected from the community should be captured within a visual product that is accessible to all. In combination with the scientific review, one option is to build upon the book *Tuggerah Lakes – Way Back When* an essential addition to residents' coffee tables.

6.6 Catchment management recommendations

Key recommendations to improve water quality in Tuggerah Lakes from a catchment management perspective as discussed in Chapter 5 are detailed below. Note that site specific recommendations regarding the case studies are provided in Sections 5.10.6 and 5.11.6.

Funding and Implementation

- To ensure successful delivery of actions in the Coastal Management Program, it will be vital to identify the likely costs and funding mechanisms available to implement actions across the catchment (not just the estuary).
- Reinstate Stormwater Levy to help ensure new assets are effectively maintained and optimal treatment is achieved. This levy is currently only able to be applied to urban areas where an increased level of service is provided (e.g. retrofit or beyond best practice treatment). Future expected maintenance costs and Council resources required should be considered in determining an appropriate Levy. Furthermore, it is recommend that the NSW government increase the allowable current charge of $25/household/year to better reflect cost burdens to Council and also relax use restrictions to ensure that current level of service requirements are met. There may also be opportunity to remove the levy for households/ business that provide additional on-site treatment of stormwater, or achieve a certain percentage of pervious area. This would provide a financial incentive for improved management of urban stormwater at the source (versus end of pipe).

- Adopt a policy of life cycle costing of stormwater treatment options to better inform the cost effectiveness of different options and ongoing maintenance requirements, using local data where possible.
- Undertake Water Sensitive Urban Design (WSUD) capacity building within Council, ensuring staff are appropriately trained to ensure successful design, construction and maintenance of WSUD. To ensure integration within teams, create a senior leadership 'WSUD' working group that reviews WSUD implementation opportunities and shares learnings and successes between internal teams.
- Standard WSUD drawings for use in Council infrastructure works (e.g. roads, renewals) as well as by the development industry to ensure consistent standards and requirements are met (noted currently under development in Council).
- Improved education and enforcement of Erosion & Sediment Control (E&SC) practices, particularly at the lot scale. Consider proactive enforcement of erosion and sediment control practices, potentially through a third party (e.g. State Government). A literature review by Taylor and Wong (2002) indicated that education alone is not sufficient to ensure compliance and that enforcement is essential for the successful implementation of erosion and sediment control programs. The literature review suggests that E&SC programs with strong educational and enforcement elements may represent the best performing non-structural BMP for managing stormwater pollutants. With the large amount of future development planned in the catchment, it is essential to ensure best practice erosion and sediment control practices are implemented and enforced. Healthy Land & Water have recently developed a toolkit for house builders that may be used as a basis to improve E&SC practices at the lot scale: https://hlw.org.au/download/erosion-and-sedimentcontrol-toolkit-for-house-builders/

Planning

- Adopt a maintain or improve conditions (from existing 2020 conditions) target for all future development until sustainable loads are determined. Note this is already referred to as a goal in various documents (some Development Control Plan chapters, Estuary Management Plan). However, it is unlikely that current performance targets (i.e. 80% reduction of total suspended solids, 45% reduction of total nitrogen and 45% reduction of total phosphorus from post development loads) will result in unchanged or improved conditions. Neutral or beneficial (NorBE) water quality targets are currently required for development in water supply catchments (Regional Plan 2036).
- Adopted water quality treatment targets should be included in the new Local Environmental Plan to give Council greater powers to enforce.
- Introduce planning controls for single dwelling developments to achieve water quality treatment. Examples can be sourced from other local Councils, such as MidCoast Council (Figures 5-18 and 5-19). A case study for Moonee Valley Council can be found here:

https://watersensitivecities.org.au/solutions/case-studies/moonee-valley-planning-scheme/

- Stormwater management / Integrated Water Management plan for Porters Creek. A number of investigations have been undertaken / are currently underway. A plan should be adopted to ensure development doesn't adversely impact Porters Creek wetlands through changes to flow regimes and increased pollutant loads. The costs and benefits of alternate options should be considered to determine the best triple bottom line outcome. A monitoring program will likely be required to establish and understand baseline conditions in Porters Creek Wetland to then assess future performance against.
- WaterPlan 2050 should be revised to develop an Integrated Water Resource Plan. Options should be considered in the context of the CMP and impacts on lake water quality and ecological health.
- Improved and consistent Development Assessment/Development Control Plan requirements during construction and establishment to ensure handover of good water quality treatment assets. Refer to Construction and Establishment Guidelines (WBD, 2010) and checklists.
- Developer bonds be secured by Council to better reflect cost of rectification in the event of water quality asset failure. Consider third party enforcement of this requirement (e.g. state government).
- Existing modelling framework would likely need significant investment to be able to determine sustainable catchment loads for the lakes. This should be undertaken as a priority, including collecting data to better calibrate and refine models.
- Current models should be used in the interim to set targets for maintaining / improving catchment loads, and assess the impact of development on future catchment loads. For example, while existing MUSIC and Source catchment models are not calibrated, they would still be able to estimate in relative terms the future increase in pollutant loads and identify the management measures needed to ensure 2020 conditions are maintained or improved upon.
- The current catchment models could also be used as a basis for investigating the treatment performance and cost effectiveness of:
    - existing treatment measures
    - future treatment options, including rural best management practices.

This could help prioritise works in the catchments more effectively. Key sources of sediment generation, where known e.g. unsealed roads, should also be included.

- Review creek rehabilitation plans and prioritisations due to the extent of works completed and changed river conditions since studies undertaken (10+ years). Consider learnings from current program in this review.
- Current impact to flows and water quality in Tuggerah Lakes caused by water supply offtake should be further investigated as part of Council's Integrated Water Resource Planning (i.e. updated Water Plan 2050).

Community education and capacity building

The significant work that Council has been undertaking in collaboration with Local Land Services to help educate the community is recognised, and it is recommended that these efforts be continued. The following suggestions are provided to strengthen the current program and help foster ownership and improved understanding of Water Sensitive Urban Design (WSUD) in the catchment.

- Use citizen science and the current Waterwatch program to help identify pollution hot spots in the catchment and suitable locations for treatment initiatives such as raingardens / passively irrigated street trees. Consider using a community selected site as a demonstration project to educate others in the local community (similar to Council's Saltmarsh Swale project).
- Similarly, use citizen science to help monitor the effectiveness of new types of assets in the area such as saltmarsh swale and raingardens, as well as existing devices. This can help to foster ownership and improved understanding of WSUD.
- Melbourne Water's 10,000 Raingardens Program provides a good example of how Council could work with the community to raise awareness about the need to manage stormwater, drive behavioural change and improve water quality through implementation of measures on private lots. Such a program would also help measure the performance of educational campaigns (Milenkovic et al., 2012). Resources from this program can be found online https://www.melbournewater.com.au/water-data-and-education/environmental-issues/why-weneed-save-water/tips-saving-water/raingardens.
- Consider including a raingarden building workshop in the waterways related events program.

Opportunities

- The current Coastal Management Planning framework only requires an estuary wide approach, limiting funding of treatment options to within the estuary. The review of key pressures to receiving water quality in this chapter has clearly shown that a catchment wide approach is needed to improve water quality in Tuggerah Lakes. It is therefore recommended that a catchment wide approach be adopted for the Tuggerah Lakes' Coastal Management Program.
- Look for opportunities to integrate WSUD into Council renewal works (e.g. Lake Haven centre and through the northern growth corridor). All landscaping should consider WSUD e.g. flush kerbs, pervious pavements, raingardens, swales, self-watering street trees. It will be most cost effective to integrate WSUD retrofits through urban renewal or growth projects, so this should be a priority to consider for all infrastructure works. Standard WSUD drawings would also assist to more easily integrate these works.
- In high priority existing urban catchments, work with the community to integrate streetscape systems such as raingardens and passively irrigated street trees upstream of conventional

drainage inlets, to treat stormwater prior to entering the stormwater system. Consider including passively irrigated street trees in all new developments rather than conventional street trees. They provide multiple benefits including water quality treatment benefits and can be designed to include a range of storage options to help mitigate flows (such as wicking beds and underground storages).

- Review the uptake and effectiveness of rural Best Management Practices through continued partnership with Local Land Services. As the rural lands make up a large proportion of the catchment, this will be important to reduce overall catchment loads.
- In partnership with Local Land Services and NSW Department of Primary Industries, Council to investigate the applicability of bioreactors in the catchment for treating agricultural runoff. Recent studies in Queensland have shown them to be highly effective form of removing nitrate through dentification (Manca et al., 2020). They are a simple to construct, low cost, passive technology with an expected design life of approximately 10+ years. These treatments are best suited to areas with shallow groundwater tables and lateral inflows to waterways, with high concentrations of nitrate.
- Expand the Lakes Festival to celebrate successes. For example, 'waterway warrior' awards to recognise significant community group achievements for improving catchment and receiving water quality in Tuggerah Lakes. It could also be used to announce social media competition winners for programs promoting community action for improving waterway health, such as best (as voted) home raingarden or highest social media postings of '# Take 3' (picking up rubbish near waterways).
- Use community education centre space (e.g. Marine Discovery Centre) to showcase water sensitive urban design, including a raingarden. This could be used to demonstrate how a raingarden works and what it looks like (e.g. Figure 5-20). It could also provide toolkits for teaching the community how to build their own raingarden, and have plant giveaway days or even workshops to encourage people to build their own.

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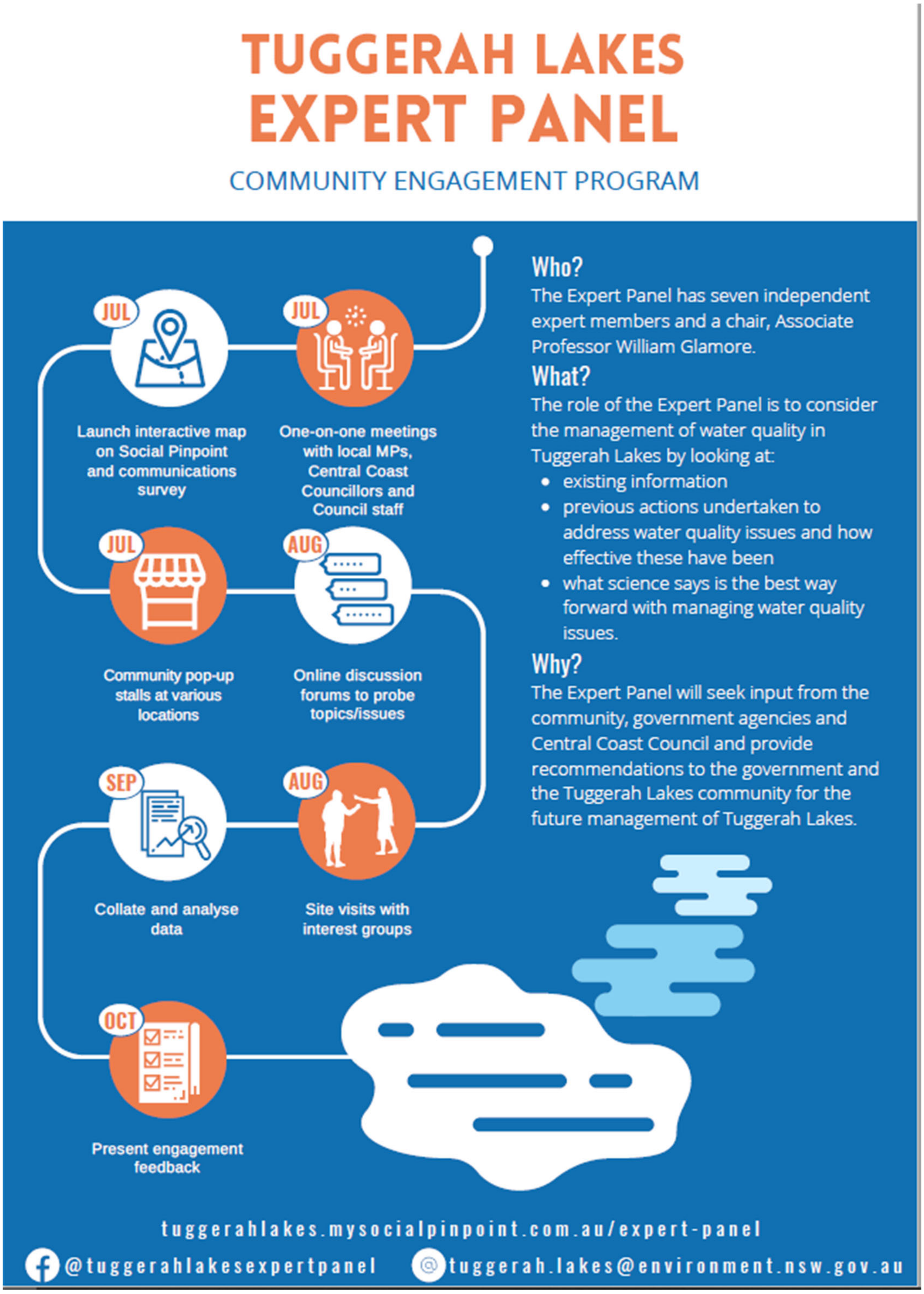
Appendix A TLEP Consultation Information

Engagement Infographic



TUGGERAH LAKES EXPERT PANEL

Have your say about Tuggerah Lakes

The Expert Panel is an independent advisory panel committed to consulting with the community and other stakeholders to identify and understand issues relating to Tuggerah Lakes, its estuary health and water quality.

We want to hear from the community about:

- the places, activities and experiences you value on or around the lakes
- your ideas and suggestions
- your concerns and issues
- your views on barriers and challenges to change.

Head to the Expert Panel's website or find us on Facebook to find out how you can get involved.

tuggerahlakes.mysocialpinpoint.com.au/expert-panel

Scan me with your phone

The Expert Panel has seven independent expert members and a chair, Associate Professor William Glamore. The role of the Expert Panel is to consider the management of water quality in Tuggerah Lakes by looking at:

- existing information
- previous actions undertaken to address water quality issues and how effective these have been
- what science says is the best way forward with managing water quality issues.

The Expert Panel will seek input from the community, government agencies and Central Coast Council and provide recommendations to the government and the Tuggerah Lakes community for the future management of Tuggerah Lakes.

TUGGERAH LAKES
EXPERT PANEL

MEDIA RELEASE

17 September 2020

LAST CHANCE FOR COMMUNITY TO HAVE THEIR SAY ABOUT TUGGERAH LAKES

The Tuggerah Lakes Expert Panel is urging the community to have their say about Tuggerah Lakes before consultation closes at the end of this month.

Since launching consultation in July, the Panel has heard from more than 1,800 people across the catchment area who have shared more than 2,000 comments, reactions, survey responses, written and oral submissions about water quality and the future management of the lakes system.

With only two weeks left until the Panel start preparing their reports, the community is invited to have one last say by participating in an online discussion forum about what a healthy lakes system means to them.

Panel chair Will Glamore said understanding what the community expects the lakes to look, smell and sound like when “fixed” can help the Panel understand what successful management looks like.

“So far we have asked the community about key issues and concerns regarding Tuggerah Lakes and what ideas they have for improvements,” he said.

“The community has also told us about the places and aspects that they value and we appreciate all of their potential solutions, 'fixes' and actions.

“Now, we want to understand how the community will perceive that water quality has improved and we are encouraging people to think beyond specific ideas or actions - such as a breakwall or gross pollutant traps.

“Instead, we would like to know more about the things you would expect to see with improved water quality in the lakes system. Are the beaches clean? Are you fishing? Can you see the lake bottom? What does success look and feel like to you?”

To join the conversation, head to the Expert Panel’s website https://tuggerahlakes.mysocialpinpoint.com.au/expert-panel and add your comments to the discussion forum before 30 September.

The information collected from the community will be used by the Panel to make recommendations that will be considered as part of implementing the NSW coastal management framework. The Panel is expected to pass on its recommendations by the end of the year.

ENDS

Media contact

Associate Professor Will Glamore

Tuggerah Lakes Expert Panel Chair

0404 822 080

Background

The independent Tuggerah Lakes Expert Panel is funded by the NSW Government to determine best practice management for improved water quality in Tuggerah Lakes. The Expert Panel is an independent advisory panel with seven independent expert members and a chair.

For more information about the Expert Panel and its Terms of Reference see https://www.environment.nsw.gov.au/topics/water/estuaries/protecting-and-managing-estuaries/tuggerah-lakes-expert-panel

TUGGERAH LAKES
EXPERT PANEL

MEDIA RELEASE

19 August 2020

ONLINE MEETINGS PROVIDE OPPORTUNITY FOR EXPERT PANEL TO LEARN MORE FROM THE COMMUNITY

The Tuggerah Lakes Expert Panel will host a series of online meetings starting next week to learn more from the community about key issues with Tuggerah Lakes.

Following the successful conclusion of phase one of the engagement strategy on Monday, the Panel will be taking a closer look at some of the common themes that emerged from its interactive map and online survey.

These include water quality, wrack and ooze, understanding The Entrance and ideas for its management and effects on the lakes, and how the catchment surrounding the lakes affects water quality.

The first meetings will take place on Tuesday 25 August from 6.30pm and will focus on water quality issues including wrack and ooze.

Each community group or individual that registers will be allocated a 20-minute timeslot with the Panel, between 6.30pm and 8.30pm.

Stakeholders can register their interest in a meeting through the Panel's website https://tuggerahlakes.mysocialpinpoint.com.au/expert-panel. The meetings will be hosted using the video meeting platform Zoom.

Panel chair Will Glamore said the online meetings were being held in lieu of the planned site visits due to the evolving Covid-19 situation.

"It had always been our intention to meet on site with various stakeholder and interest groups so they could talk through and show the Panel the issues under discussion," he said.

"With the ongoing uncertainty that COVID-19 has forced on us all we had to find a virtual option that allows us to talk with the community.

"We hope people will take this opportunity to share their knowledge and experience with us directly. At this stage in our work the Panel are interested to hear about any detailed submissions or from anyone that hasn't had the opportunity to speak with us directly. We appreciate local knowledge, local experiences and local history from those that live with the lakes year-round."

The remaining online meeting sessions will be on:

- 9 September from 6.30pm - Understanding the Entrance: ideas for its management and effects on the lakes
- 17 September from 6.30pm – Understanding the Catchment: stormwater quality, pollution sources and ideas for management

Since launching its consultation program on 20 July, the Panel has received more than 6,750 visits to its website from almost 1,700 stakeholders. There were 445 comments left on the interactive map and 719 reactions as people shared their issues, ideas and concerns about estuary health and water quality. There were also 389 responses to the online survey about how stakeholders receive and trust communication and information about Tuggerah Lakes.

The information collected from the community will be used by the Panel to make recommendations that will be considered as part of implementing the NSW coastal management framework. The Panel is expected to pass on its recommendations by the end of the year.

ENDS

Media contact

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Tuggerah Lakes Expert Panel Chair

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TUGGERAH LAKES
EXPERT PANEL

MEDIA RELEASE

7 August 2020

REMINDER FOR COMMUNITY TO HAVE THEIR SAY ABOUT TUGGERAH LAKES

Phase one of consultation for the Tuggerah Lakes Expert Panel is closing soon and the community is being reminded to have their say about this important issue.

Since launching an online interactive map and survey on 20 July, Tuggerah Lakes Expert Panel has received more than 4,400 visits to its website (https://tuggerahlakes.mysocialpinpoint.com.au/expert-panel) and almost 700 responses, comments and reactions as people share their issues, ideas and concerns about estuary health and water quality.

Due to Covid-19, and in the interest of providing a safe environment for Panel members and the community, the community pop-up stalls scheduled for late July and early August were regrettably cancelled. However, Panel Chair Will Glamore said the Panel was still committed to hearing from as many people as possible.

“We understand there is a lot of community interest in the health of Tuggerah, Budgewoi and Munmorah lakes,” he said.

“We've been speaking to and listening to stakeholders from state government, Central Coast Council, business owners and the community to find out what they perceive as the issues with the lakes as well as looking at previous studies, surveys and what science tells us about best practice lake management.

“We understand there has been lots of consultation about this issue and some people are frustrated with what they see as yet another process.

“But as an independent panel, it is important to us that we are hearing directly from the community so that we can validate and add to our existing understanding or community issues. We strongly encourage people to participate in this conversation.”

Mr Glamore said the Panel is finalising dates for a series of online discussion forums and virtual meetings to be held in August to take a closer look at some of the key themes coming through from the consultation to date.

“We want to thank those who have participated so far and let people know there is still time to have your say and help inform our discussions,” he said.

To have your say on the interactive map and complete the survey, head to https://tuggerahlakes.mysocialpinpoint.com.au/expert-panel before 17 August. You can also email the Panel at tuggerah.lakes@environment.nsw.gov.au

The information collected from the community will be used by the Panel to make recommendations that will be considered as part of implementing the NSW coastal management framework. The Panel is expected to pass on its recommendations by the end of the year.

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TUGGERAH LAKES
EXPERT PANEL

MEDIA RELEASE

20 July 2020

TUGGERAH LAKES EXPERT PANEL COMMENCES COMMUNITY CONSULTATION

The Tuggerah Lakes Expert Panel has today launched a three-month community engagement program to find out what the community and other stakeholders think about Tuggerah Lakes.

The focus of the consultation approach will be on understanding how stakeholders value Tuggerah, Budgewoi and Munmorah lakes, the issues and concerns they have, as well as their ideas or suggestions to improve estuary health and water quality.

Stakeholders will have opportunities to provide input using online and offline methods. These include interactive maps, surveys, pop-up stalls in community locations, online discussion forums, site visits and meetings.

Discussions between Panel chair Associate Professor William Glamore and key stakeholders, including local MPs, Central Coast Councillors and Council staff, are already under way while site visits with interest groups are scheduled to commence in August.

Today, the Panel launched an interactive map and survey using the online engagement platform Social Pinpoint tuggerahlakes.mysocialpinpoint.com.au/expert-panel

Stakeholders can drag themed markers onto the interactive map and leave a comment and/or photo about a particular location, in or around the lakes or the surrounding catchment area.

Once a user has finished leaving their comments, they will be asked to complete a short survey.

The interactive map and survey will be open until 17 August.

The online map and survey will be supported by a series of pop-up stalls where the community is welcome to speak to members of the project team, provide input on maps, and complete the survey.

In late August, stakeholders will have another opportunity to have their say through a series of online discussion forums. The questions or topics for the forums will help the Panel drill down into specific issues, values and comments provided by stakeholders on the map, at the pop-up stalls and in the survey.

The information collected from the community will be used by the Panel to make recommendations that will be considered as part of implementing the NSW coastal management framework. The Panel is expected to pass on its recommendations by the end of the year.

For more details about the community engagement program and activities of the Expert Panel, head to https://tuggerahlakes.mysocialpinpoint.com.au/expert-panel or send an enquiry to tuggerah.lakes@environment.nsw.gov.au

ENDS

Media contact

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Tuggerah Lakes Expert Panel Chair

0404 822 080

Background

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For more information about the Expert Panel and its Terms of Reference see https://www.environment.nsw.gov.au/topics/water/estuaries/protecting-and-managing-estuaries/tuggerah-lakes-expert-panel

Tuggerah Lakes Expert Panel communication and information survey

Thank you for taking the time to complete this survey for the Tuggerah Lakes Expert Panel. Your responses will help us understand how you trust and receive information about Tuggerah Lakes to help inform future education and information campaigns.

It should take 5-7 minutes to complete.

Which statement/s best describe you (select all that apply)

- ☐ I live in the Tuggerah Lakes catchment area
- ☐ I work in the Tuggerah Lakes catchment area
- ☐ I own a business in the Tuggerah Lakes catchment area
- ☐ I am a visitor to Tuggerah Lakes

Tuggerah Lakes Expert Panel communication and information survey

How long have you been a resident in the Tuggerah Lakes catchment area?

- ○ Less than 1 year
- ○ 1-2 years
- ○ 2-5 years
- ○ 5-10 years
- ○ 10-15 years
- ○ 15-20 years
- ○ More than 20 years

Tuggerah Lakes Expert Panel communication and information survey

How do you currently receive most of your news or information about Tuggerah Lakes?

- ◯ Radio
- ◯ TV
- ◯ Social media managed by Central Coast Council
- ◯ Social media - other
- ◯ Signs around the lakes
- ◯ Email newsletters/flyers
- ◯ Other (please specify)
- ◯ Newsletter/flyers in my letterbox
- ◯ Central Coast Council website
- ◯ Family/friends
- ◯ Newspaper
- ◯ Personal experience

How would you prefer to receive most of your news or information about Tuggerah Lakes?

- ◯ Radio
- ◯ TV
- ◯ Social media managed by Central Coast Council
- ◯ Social media - other
- ◯ Signs around the lakes
- ◯ Email newsletters/flyers
- ◯ Other (please specify)
- ◯ Newsletter/flyers in my letterbox
- ◯ Central Coast Council website
- ◯ Family/friends
- ◯ Newspaper
- ◯ Personal experience

Who do you trust for your news and information about Tuggerah Lakes, where 1 is most trustworthy and 11 is least trustworthy?

Media - newspapers

Media - radio

Media - television

NSW government departments

Central Coast Council - staff

Central Coast Council - elected Councillors

Local members of parliament (MPs)

Social media

Family/friends

Personal experience

Consultants/experts

Which best describes your impression of any written communications you have received about Tuggerah Lakes?

Keeps me fully informed	Keeps me fairly well informed	Keeps me adequately informed	Gives me only a limited amount of information	Doesn't tell me much at all about what's going on	I have not received any written communication about Tuggerah Lakes

Tuggerah Lakes Expert Panel communication and information survey

How do you feel about the information you receive or hear about Tuggerah Lakes?

I can almost always believe it	I can usually believe it.	I can believe it about half the time.	I usually can't believe it.	I can almost never believe it.	I have not received or heard anything about Tuggerah Lakes before today
○	○	○	○	○	○

Tuggerah Lakes Expert Panel communication and information survey

Can you tell us why you feel that way?

Tuggerah Lakes Expert Panel communication and information survey

Have you participated in consultation about Tuggerah Lakes before today? (eg surveys, workshops, focus groups, meetings, pop-up stalls, forums, online)

- ○ Yes
- ○ No
- ○ Not sure

Tuggerah Lakes Expert Panel communication and information survey

To what extent did you feel listened to by the people undertaking the consultation?

I felt listened to all the time	I felt listened to most of the time	I felt listened to about half the time	I felt listened to only sometimes	I felt listened to rarely or never
○	○	○	○	○

Tuggerah Lakes Expert Panel communication and information survey

Can you tell us why you felt that way?

Tuggerah Lakes Expert Panel communication and information survey

Before this survey, had you heard about the Tuggerah Lakes Expert Panel?

- Yes
- No
- Not sure

Tuggerah Lakes Expert Panel communication and information survey

To what extent do you think the Expert Panel will make a positive contribution to the future management of Tuggerah Lakes?

Highly likely	Likely	I'm not sure	Unlikely	Highly unlikely
○	○	○	○	○

Tuggerah Lakes Expert Panel communication and information survey

Can you tell us why you feel that way?

Tuggerah Lakes Expert Panel communication and information survey

What kind of information about Tuggerah Lakes are you most interested in? Select all that apply.

- ☐ Seaweed/wrack management
- ☐ Dredging
- ☐ Community events and activities at, near or on the lakes
- ☐ Boating
- ☐ Swimming
- ☐ Water quality
- ☐ Cycling/walking tracks around the lakes
- ☐ Other (please specify)
- ☐ Stormwater management
- ☐ Fishing
- ☐ Seagrasses/saltmarshes
- ☐ Tourism/visitor information
- ☐ Things I can do to improve estuary health
- ☐ I am not interested in information about Tuggerah Lakes

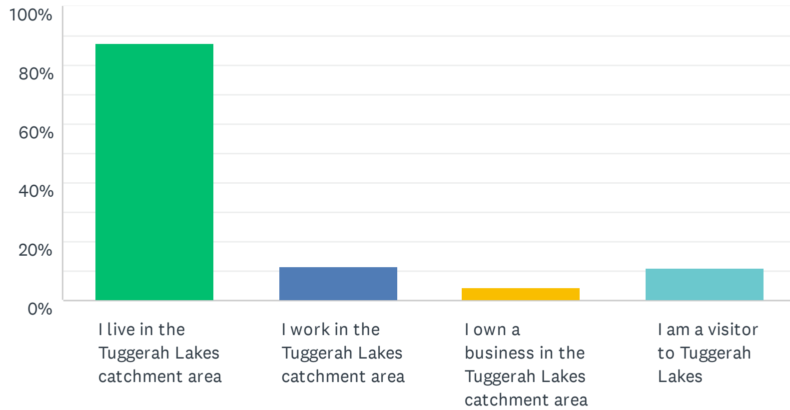
Is there anything else about communication, information or consultation about Tuggerah Lakes that you would like to say?

What is your age bracket?

- ○ 17 and under
- ○ 18-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65-74
- ○ 75+
- ○ I'd prefer not to say

Q1 Which statement/s best describe you (select all that apply)

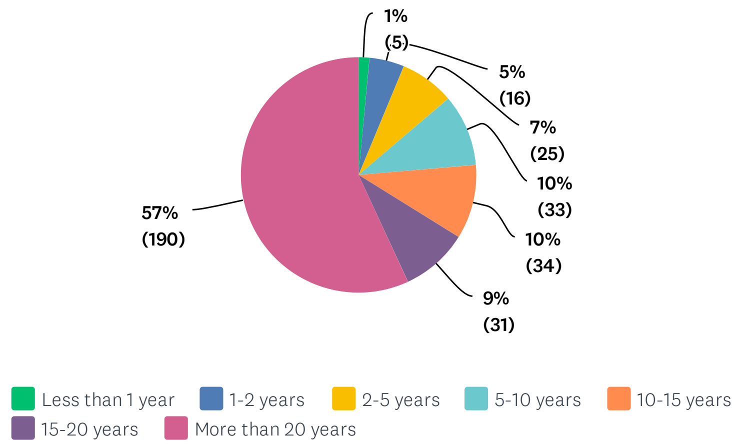
Answered: 389 Skipped: 0



ANSWER CHOICES	RESPONSES	
I live in the Tuggerah Lakes catchment area	87.40%	340
I work in the Tuggerah Lakes catchment area	11.57%	45
I own a business in the Tuggerah Lakes catchment area	4.37%	17
I am a visitor to Tuggerah Lakes	11.05%	43
Total Respondents: 389		

Q2 How long have you been a resident in the Tuggerah Lakes catchment area?

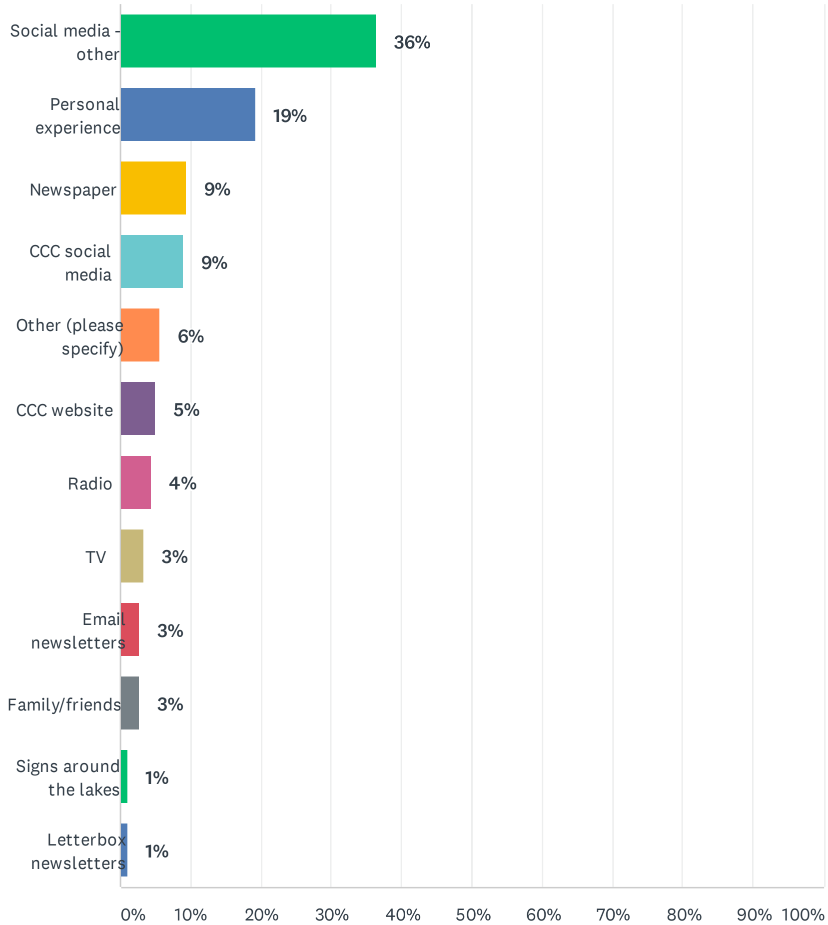
Answered: 334 Skipped: 55



ANSWER CHOICES	RESPONSES	
Less than 1 year	1%	5
1-2 years	5%	16
2-5 years	7%	25
5-10 years	10%	33
10-15 years	10%	34
15-20 years	9%	31
More than 20 years	57%	190
TOTAL		334

Q3 How do you currently receive most of your news or information about Tuggerah Lakes?

Answered: 297   Skipped: 92



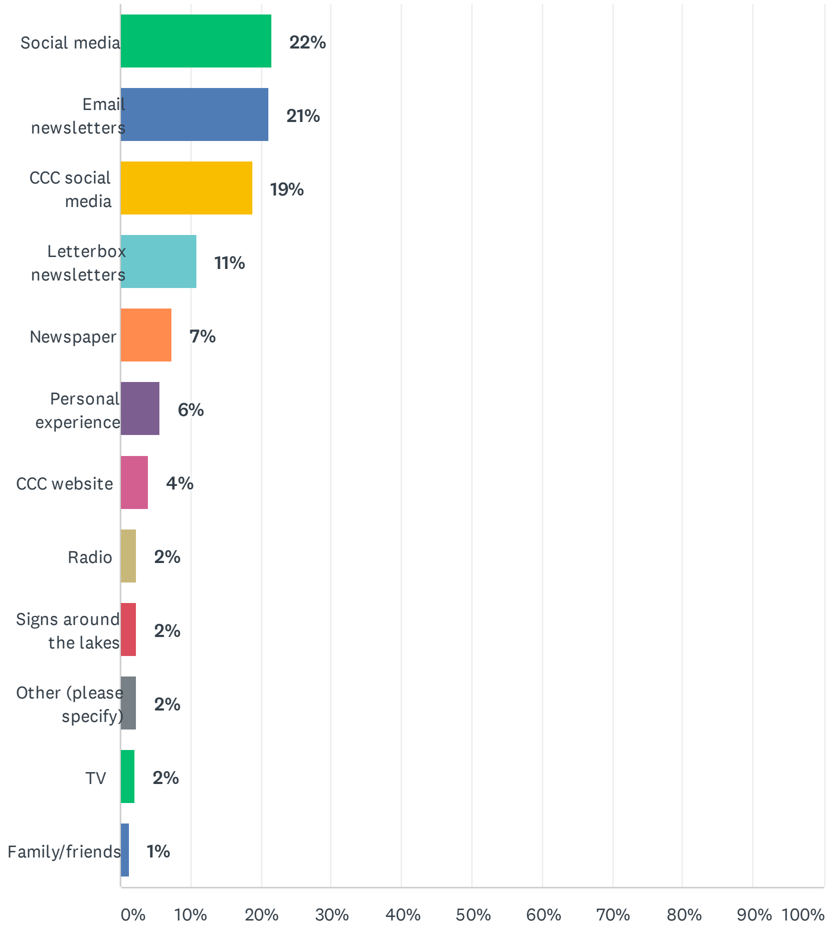
ANSWER CHOICES	RESPONSES	
Social media - other (4)	36%	108
Personal experience (11)	19%	57
Newspaper (10)	9%	28
CCC social media	9%	27
Other (please specify) (12)	6%	17
CCC website	5%	15
Radio (1)	4%	13
TV (2)	3%	10
Email newsletters	3%	8
Family/friends (9)	3%	8
Signs around the lakes (5)	1%	3
Letterbox newsletters	1%	3
TOTAL		297

BASIC STATISTICS				
Minimum	Maximum	Median	Mean	Standard Deviation
1.00	12.00	4.00	6.51	3.53

#	OTHER (PLEASE SPECIFY)	DATE
1	xx	8/19/2020 4:17 PM
2	xx	8/19/2020 4:10 PM
3	xxx	8/19/2020 3:30 PM
4	xx	8/19/2020 3:20 PM
5	xx	8/19/2020 2:47 PM
6	x	8/19/2020 2:17 PM
7	x	8/19/2020 2:15 PM
8	I was one of 2 community reps. on the original Tuggerah Lakes resoration programme, some 25 years ago!	8/17/2020 2:14 PM
9	Do not receive any	8/11/2020 8:45 PM
10	David Harris and facebook	8/11/2020 8:11 PM
11	all of the above	8/10/2020 4:40 PM
12	Historical research, including reports, historical documents. photographs and anecdotal evidence from old locals. and	8/10/2020 3:33 PM
13	Don't hear anything constructive	8/9/2020 12:12 PM
14	A combination of social media, tv news and CCC information	8/8/2020 10:28 PM
15	Mostly Facebook	8/7/2020 6:52 PM
16	http://www.friendsoftuggerahlakes-cen.org.au	8/5/2020 10:36 PM
17	Don't see any information about the lake	8/5/2020 1:15 PM

Q4 How would you prefer to receive most of your news or information about Tuggerah Lakes?

Answered: 297 Skipped: 92

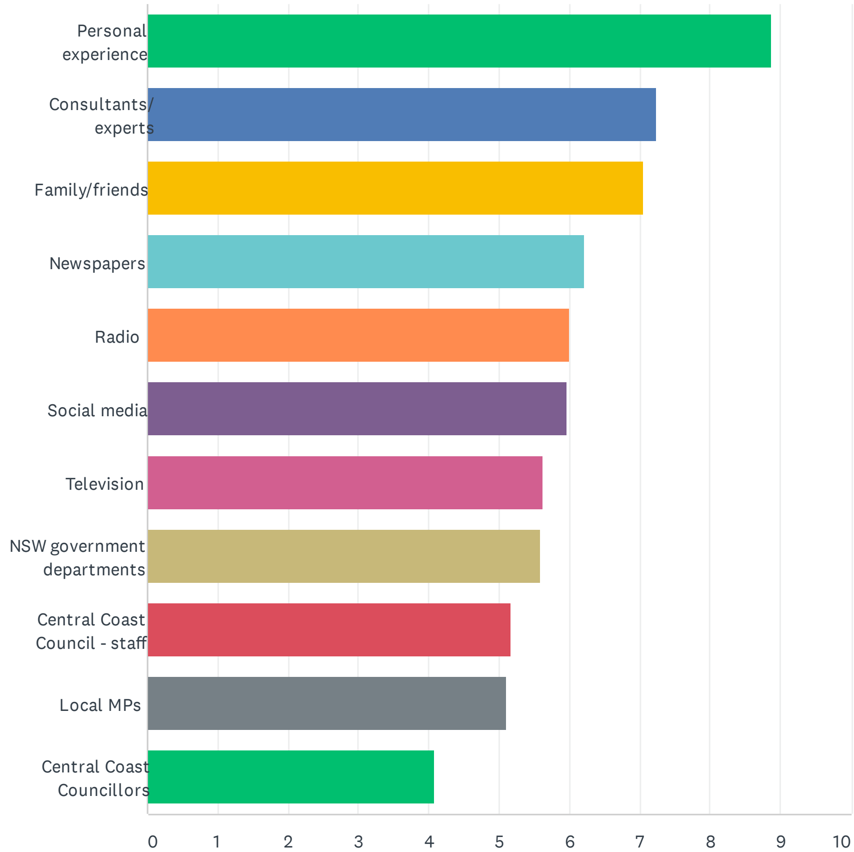


ANSWER CHOICES	RESPONSES	
Social media	22%	64
Email newsletters	21%	63
CCC social media	19%	56
Letterbox newsletters	11%	32
Newspaper	7%	22
Personal experience	6%	17
CCC website	4%	12
Radio	2%	7
Signs around the lakes	2%	7
Other (please specify)	2%	7
TV	2%	6
Family/friends	1%	4
TOTAL		297

#	OTHER (PLEASE SPECIFY)	DATE
1	By years of Study and experience	8/19/2020 4:13 PM
2	I like multiple sources. Friends of Tuggerah lakes has a web site of most of the studies done. The CSIRO study is excellent.	8/19/2020 3:20 PM
3	A combination of all of these options, TVC, Social Media, Radio, Signs for visitors, the lake is our greatest asset.	8/17/2020 2:41 PM
4	Newsletter from council	8/15/2020 8:13 PM
5	A variety: ABC Local radio, email, newsletters, on Council's website.	8/11/2020 3:27 AM
6	Talking with long time residents about their lives times of personal observation and experiences.	8/8/2020 10:15 AM
7	All of the above	8/6/2020 7:54 PM

Q5 Who do you trust for your news and information about Tuggerah Lakes, where 1 is most trustworthy and 11 is least trustworthy?

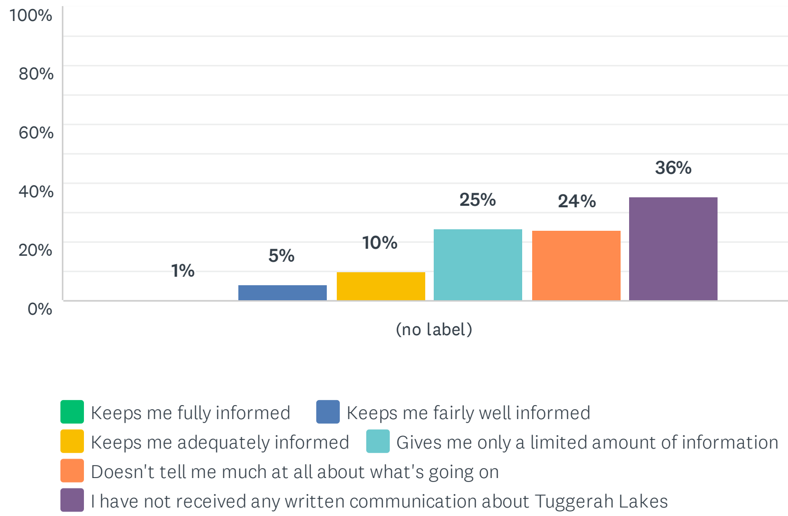
Answered: 297 Skipped: 92



	1	2	3	4	5	6	7	8	9	10	11	TOT
Personal experience	47.22% 136	13.54% 39	8.68% 25	6.94% 20	4.17% 12	4.17% 12	2.08% 6	3.82% 11	3.13% 9	3.47% 10	2.78% 8	
Consultants/ experts	18.01% 49	15.07% 41	13.60% 37	7.35% 20	7.35% 20	5.51% 15	7.72% 21	5.88% 16	10.29% 28	5.88% 16	3.31% 9	
Family/friends	5.95% 16	22.30% 60	15.99% 43	5.95% 16	11.15% 30	9.67% 26	4.83% 13	8.18% 22	5.58% 15	5.95% 16	4.46% 12	
Newspapers	4.43% 12	6.64% 18	8.49% 23	15.50% 42	13.65% 37	13.65% 37	9.96% 27	12.55% 34	4.80% 13	4.43% 12	5.90% 16	
Radio	2.87% 8	6.09% 17	8.24% 23	14.70% 41	15.05% 42	12.54% 35	9.32% 26	11.83% 33	8.24% 23	5.38% 15	5.73% 16	
Social media	5.51% 15	7.35% 20	13.24% 36	11.03% 30	10.66% 29	8.82% 24	10.29% 28	6.25% 17	8.82% 24	6.25% 17	11.76% 32	
Television	4.83% 13	5.58% 15	5.20% 14	9.29% 25	10.04% 27	13.01% 35	15.99% 43	11.90% 32	11.90% 32	8.55% 23	3.72% 10	
NSW government departments	3.69% 10	10.33% 28	9.23% 25	9.23% 25	5.54% 15	9.59% 26	9.96% 27	12.55% 34	11.44% 31	8.86% 24	9.59% 26	
Central Coast Council - staff	6.30% 17	7.78% 21	7.41% 20	8.15% 22	6.30% 17	6.67% 18	7.78% 21	8.15% 22	9.63% 26	20.37% 55	11.48% 31	
Local MPs	5.22% 14	6.34% 17	6.72% 18	6.34% 17	8.58% 23	6.72% 18	11.94% 32	10.07% 27	12.31% 33	15.30% 41	10.45% 28	
Central Coast Councillors	2.63% 7	3.01% 8	5.64% 15	6.39% 17	6.39% 17	7.52% 20	7.89% 21	6.39% 17	11.65% 31	13.53% 36	28.95% 77	

Q6 Which best describes your impression of any written communications you have received about Tuggerah Lakes?

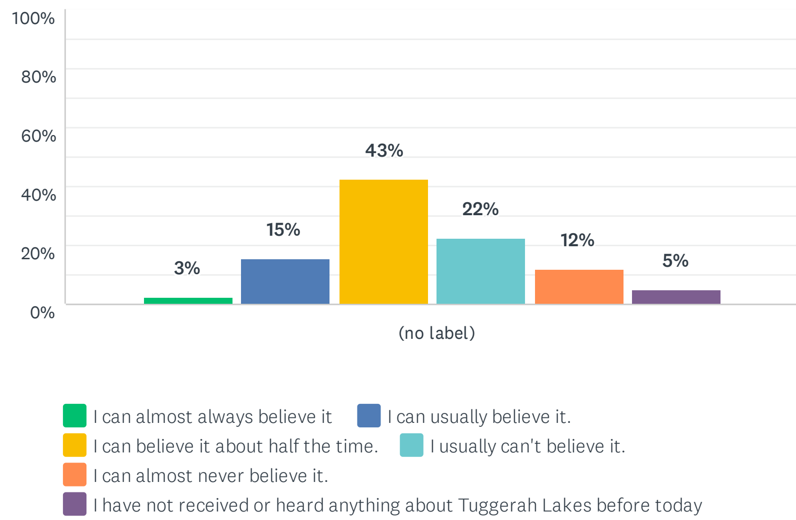
Answered: 297 Skipped: 92



	KEEPS ME FULLY INFORMED	KEEPS ME FAIRLY WELL INFORMED	KEEPS ME ADEQUATELY INFORMED	GIVES ME ONLY A LIMITED AMOUNT OF INFORMATION	DOESN'T TELL ME MUCH AT ALL ABOUT WHAT'S GOING ON	I HAVE NOT RECEIVED ANY WRITTEN COMMUNICATION ABOUT TUGGERAH LAKES	TOTAL	WEIGHTED AVERAGE
(no label)	1% 2	5% 16	10% 29	25% 73	24% 71	36% 106	297	4.73

Q7 How do you feel about the information you receive or hear about Tuggerah Lakes?

Answered: 188 Skipped: 201



	I CAN ALMOST ALWAYS BELIEVE IT	I CAN USUALLY BELIEVE IT.	I CAN BELIEVE IT ABOUT HALF THE TIME.	I USUALLY CAN'T BELIEVE IT.	I CAN ALMOST NEVER BELIEVE IT.	I HAVE NOT RECEIVED OR HEARD ANYTHING ABOUT TUGGERAH LAKES BEFORE TODAY	TOTAL	WEIGHTED AVERAGE
(no label)	3% 5	15% 29	43% 80	22% 42	12% 23	5% 9	188	3.40

Q8 Can you tell us why you feel that way?

Answered: 55 Skipped: 334

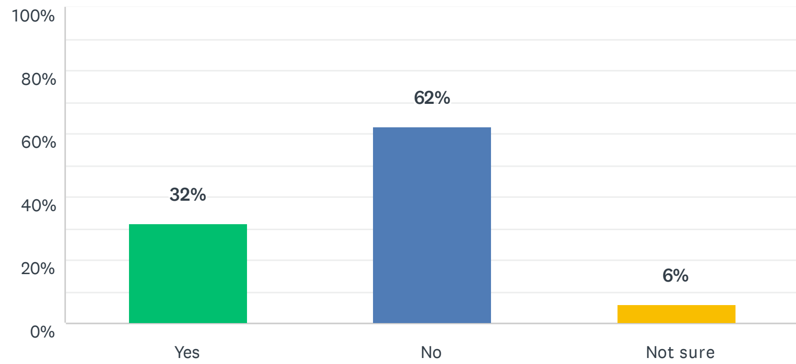
#	RESPONSES	DATE
1	There is a lot of misunderstanding	8/19/2020 4:13 PM
2	Council only does something when there back is up against the wall. They donâ€™t get credible information.	8/19/2020 3:43 PM
3	Too many opinions on the lakes are expressed from a position of little science but a lot of greed.	8/19/2020 3:41 PM
4	Any information about action is generally non existent or will not happen anyway.	8/19/2020 3:39 PM
5	Comments are usually informed uneducated.	8/19/2020 3:22 PM
6	They only look at recent events, time before Taylor Ferries back to the 1880's should be given more weight in the care for our system. Also many "expert" take old studies as gospel, when they are flawed..	8/19/2020 3:20 PM
7	The Council always say that they are going to do something about the channel and nothing has been done hence the last flood	8/19/2020 3:03 PM
8	Have spoken to several council on several occasions and they are so not informative.	8/19/2020 2:57 PM
9	Most of it has no science background and is spread by misinformation on social media	8/19/2020 2:54 PM
10	The information release by Council staff (i.e. YouTube Video) is excellent and presents facts. It appears elsewhere opinion overrides most other forms of communication. Evidence and expert opinion should be promoted and taken on board. However, the NSW Government themselves implement measures that are contrary to best practice i.e. training wall (and dangerous to estuary processes). Councillors, MPs, locals are uninformed. The dangers of entrance modification need to be communicated (see Lake Illawarra) and have been inadequately highlightd. Messaging from councillors is unhelpful and dangerous.	8/19/2020 2:47 PM
11	Councillors, MPs and the media lie. Council wants to cover themselves. The community IQ is low so I distrust anything they say. Not a lot of good information sources.	8/19/2020 2:35 PM
12	The only information I hear is the blame game and all the reasons why we can't do anything.	8/19/2020 2:11 PM
13	I live on the lake front, it smells, it is complete and utter sludge and weed out at least five metres. In the short time we have lived on the lake edge it has increasingly become shallower as more sludge settles. It is criminal, an embarrassment a true disgrace. A long term solution needs to be arrived out before the lake is dead! We mustn’t go down in history as the Council that allowed the destruction of the lake ...	8/17/2020 5:42 PM
14	Information received from official sources ie CCCouncil always appears to be in contradiction to of our personal observations	8/16/2020 8:09 PM
15	Central Coast Council and the Expert Panel are doing NOTHING to improve the quality of the lake system. The wrack is a complete disgrace and spending $1.5m per year on an ineffective and inefficient paddle boat and tank rake is a complete waste of money. We need to solve the problems and not just waste money on removing the wrack every 10 weeks. Time for change!!!	8/16/2020 12:14 PM
16	Unfortunately most of the previous so called experts are fresh out of university with no practical experience	8/15/2020 8:29 PM
17	I see false statements all the time on social media when you talk to the fishos down the lake you get the real info.	8/14/2020 9:15 PM
18	POLITICS GET IN THE WAY OF PROGRESS	8/12/2020 7:00 PM
19	We have lived on the Lake for 38 years, it has been declining rapidly, especially over the last 10 years.	8/12/2020 2:51 PM
20	since the amalgamation of councils there seems to be a large proportion of funds spent in liberal state gov areas	8/11/2020 4:40 PM
21	Nick Greiner ruined the lake with his $11 million dollar works over a decade ago useless ignorant experts	8/11/2020 1:38 PM
22	dealt with and attended Council meeting and feel totally pissed with the green , labor controlled Council. We want the Lake to be clean and no filthy, smelling lake, No browny/ green coloured flood proned lake. [which did happen].Opened The Entrance up and the water got recycled and the water colour changed with the fish jumping again , the birds came back and the boats started to return, It's a no brainer keep The Entrance opened . A petition was presented to the State member for Council to told what to do to keep our lake GREAT	8/11/2020 6:34 AM
23	I live in an area frequently affected by the councils failures to manage the local environment	8/10/2020 10:39 PM
24	They have done nothing in 40 years to fix a problem that can be fixed but now it needs extensive work and under ground pumps in the upper end of the lake to save the ecosystem trust me I’m no Greeny but something need to be done and now not later that’s yyyy we are at this point look at the floods in the area the housing boom rain water off the roofs has quadrupled plus some it’s time to act and for won’t of better word make a name for your self that you saved the lake I know the entrance to the lake cannot be Enlarged because of the rock underneath but pumps in the upper end of the lake will save the lake as it would open up up there when it need to in year gone buy check the library regards Brett	8/10/2020 8:44 PM

25	Council do not act in the interest of the LGA. They act on personal interests and the NSW Governments priorities	8/10/2020 5:56 PM
26	I think the way that council has handled the whole issue of Tuggerah Lakes has been abysmal even when the State Government offered money they hummed and harred. Ask any person who recreationally fishes Tuggerah Lakes they will tell you how bad it is. The question of the main channel at the Entrance is just ignored quick fix to them is dredge rather than looking at a more permanent solution to the problem.	8/10/2020 5:21 PM
27	The lake was first destroyed when wrong counsel gave a dredge contract out they were one who started the downfall of lake changing way that natural water been flowing for 56years of my life and stupid weed cutter is over stupid enviomentally stuff up removing all weed has removed millions of shrimp and prawn habbitate from lake	8/9/2020 4:57 PM
28	I have lived here over 60 years and so much money had been wasted on consultants reports with no action. I have no faith in local council after a personal experience 30 years ago	8/9/2020 4:01 PM
29	Money and corruption talks and the poor old Tuggerah lakes is a victim of both	8/8/2020 9:59 PM
30	Nothings been done for years	8/8/2020 7:59 PM
31	Council and council staff do not care about the maintenance and remediation of the lake. When we attend consultations they tell us a rehearsed speech about what they think we want to hear. Councillors making decisions and action about the lakes us appalling. The flooding in February was evidence of their apathy. The councillors are negligent about maimtsing the lakes and weee responsible for the flooding to homes due to their inaction. The community had to take matters into their own hands to get action all be it far too late.	8/8/2020 7:06 PM
32	Lies	8/8/2020 6:23 PM
33	often contradicts prior information	8/8/2020 3:45 PM
34	My life experience of living on or near the lake usually tells me otherwise.	8/8/2020 3:18 AM
35	Seems haphazard attempts to start and then complete improvements, or even close before improvements can be seen. Insufficient funds, seemingly lack of want to really improve the lakes and a constant deferral of improvements until existing funds are insufficient to finish the job properly. Sorry for being somewhat critical, and I appreciate some of the improvements that get completed, but the constant building in the catchment only makes matters more expensive and difficult to keep up with the problems affecting the Lakes.	8/7/2020 7:48 PM
36	The Mayors Facebook rant and saying the Channel was open.	8/7/2020 6:50 PM
37	I have lived here for 56 years, Most of the so called expert panel haven’t lived here long enough to reflect on how clean our lake system was...They have absolutely no idea!	8/7/2020 11:15 AM
38	That many plans that many millions have been spent the result is the lakes are a shambles even with development	8/7/2020 8:10 AM
39	we want sand islands throughout the lakes to make it deeper so it will never flood and open the heads so boats can come in and spend money	8/7/2020 8:06 AM
40	Because my personal experience, living alongside the creek, belies anything the Council says, especially when it comes to flood mitigation	8/7/2020 2:10 AM
41	STINKS	8/6/2020 11:40 PM
42	Too many self interested people involved. Council is simply not plausible	8/6/2020 10:35 PM
43	Tuggerah lakes is severely neglected, it is an environmental disaster and the people responsible for looking after it (council) couldn’t care less.	8/6/2020 10:23 PM
44	Anything I heat from Council is never followed up on. All they do is write reports, no action taken	8/6/2020 9:22 PM
45	The info that is put out to the public is usually misinformed. Written by a So called panel of experts who really don’t know/understand the Tuggerah lakes system	8/6/2020 9:15 PM
46	There isn’t enough detail and transparency about what is happening with the management of the estuary system.	8/6/2020 9:01 PM
47	I have personal experience with the lake for over 50years and have spoken to elderly people who lived at budgewoi when the lake was open yet council keeps telling us it wasn't open. I have lived on spring creek for 30years and when the lake was closed the flood water just say there and didn't move. The day council opened tuggerah lake to the ocean the flood water went down about 200mm.withon 24hrs the flood water went down over 600mm. The last rain we had the water came up about 7foot but went back down overnight because the lake is open. I was told by an old councilmen that the weed causing problems in the lake was an introduced species to stop the smell of sewage from killarney vale creek back in the late fifties, early sixties. With the southerly wind it has pushed it all the way to lake munmorah .council is to political. Politics should be removed from council completely. The joining of the two councils has been a tragedy for riggers lakes and the wyong shire in general. Council has built a million dollar boat ramp at Sanremo in a place where nobody in there right mind would leave their car yet they can't clean up the smelly dead weed and open the lake to the ocean which is what the rate payers want. The so called experts said the lake was over a metre above sea level and that it would drain out of opened. Guess what it hasn't drained out and is working perfectly. Council paid to remove weed build up from the beach in terrigal yet it won't remove the dead	8/6/2020 8:18 PM

	weed from tuggerah lakes. Council is building a boardwalk at terrigal costing millions of dollars that most people in terminal don't want because they get exercise walking up over the hilland it will be an eyesore. The so called experts called tuggerah lakes a lagoon. When the northern end of the lake was open to the ocean the southern entry to the ocean was always open. Council closed the northern end of the lake to pit a road in and now the lake has major problems. You seriously need to take a good look at your so called experts. More like guess sperts. Wamberal beach and nth entrance residents need a rock wall to protect their multi million dollar homes that they built on sand dunes. Rather than building the boardwalk at terrigal that nobody wants why not build a rock wall on wamberal beach and nth entrance with a bike path/walking path on top of it. The public could then enjoy a walk or exercise along the beach and the he's of the well to do folks get saved from the ocean for a few years.	
48	Nothing you hear makes sense	8/6/2020 8:05 PM
49	Too many conflicting opinions	8/6/2020 7:55 PM
50	Most information is biased or not from a reputable source.	8/6/2020 7:40 PM
51	Because council lies about the lake. They are only worried about spending money on Gosford waterfront	8/6/2020 7:35 PM
52	Distrust of council	8/6/2020 7:33 PM
53	I lived here for 40 years and all they do is talk and promise.And nothing gets done	8/6/2020 6:55 PM
54	I know what it was like 60 years ago	8/6/2020 1:30 PM
55	?	8/5/2020 3:05 PM

Q9 Have you participated in consultation about Tuggerah Lakes before today? (eg surveys, workshops, focus groups, meetings, pop-up stalls, forums, online)

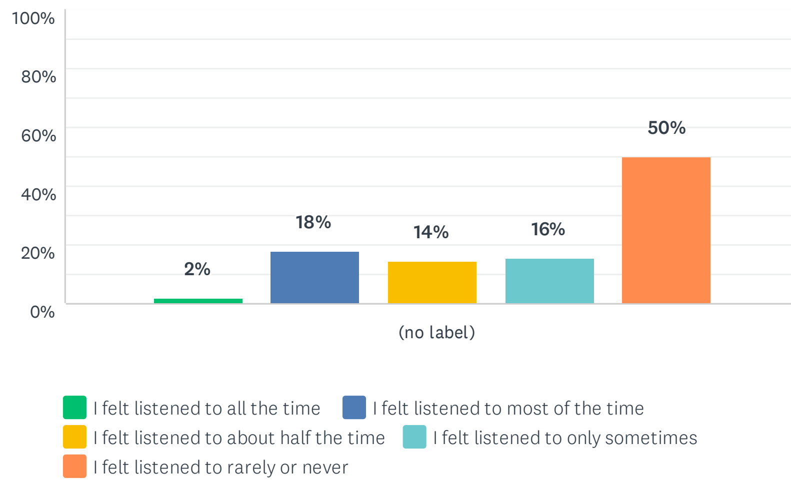
Answered: 292 Skipped: 97



ANSWER CHOICES	RESPONSES	
Yes	32%	93
No	62%	182
Not sure	6%	17
TOTAL		292

Q10 To what extent did you feel listened to by the people undertaking the consultation?

Answered: 90 Skipped: 299



	I FELT LISTENED TO ALL THE TIME	I FELT LISTENED TO MOST OF THE TIME	I FELT LISTENED TO ABOUT HALF THE TIME	I FELT LISTENED TO ONLY SOMETIMES	I FELT LISTENED TO RARELY OR NEVER	TOTAL	WEIGHTED AVERAGE
(no label)	2% 2	18% 16	14% 13	16% 14	50% 45	90	3.93

Q11 Can you tell us why you felt that way?

Answered: 64 Skipped: 325

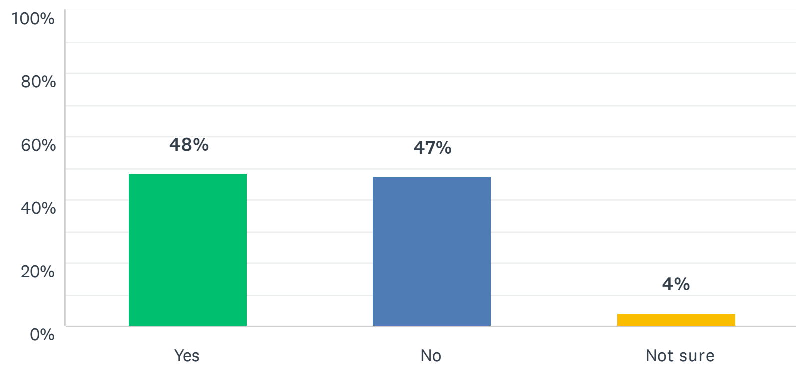
#	RESPONSES	DATE
1	Based on the comments I received from the consultors, they had already formed their opinion and believed themselves to be the experts	8/19/2020 4:20 PM
2	Over twenty submissions submittes in 2019-2020 on an array of development issues without a thank you	8/19/2020 4:17 PM
3	People think they know before they learn	8/19/2020 4:13 PM
4	Numerous correspondence as a member of the TL Catchment Advisory Committee have been submitted and ignored.	8/19/2020 4:10 PM
5	I have had many discussions with council staff and it turns into a too hard or buck passing exercise.	8/19/2020 3:54 PM
6	Because the real need for the community was pushed away by one group and the environmental survey has not been released	8/19/2020 3:24 PM
7	Council has been negligent about itâ€™s responsibly and passes the buck!	8/19/2020 3:15 PM
8	The council never follow through with what they say.	8/19/2020 3:03 PM
9	On several occasions I have spoken at council meeting with warnings about the flooding that would occur if flood mitigation was not taken seriously by council and the usual happened. NOTHING, which caused 5700 homes and businesses to be inundated by flood waters which saw many homes to have sewage floating through them	8/19/2020 2:58 PM
10	Ive done a lot of research but most people prefer to get information off people that spread misinformation to serve their own agenda	8/19/2020 2:54 PM
11	I think what they say is all talk. No action	8/18/2020 7:03 PM
12	I have not been contacted by any of the panel or council.	8/18/2020 2:53 PM
13	There is so much mis-information about the lakes .. council has to spend time debunking many of the myths and dealing with lobby groups pushing their own (often impractical) 'solutions'	8/17/2020 8:02 PM
14	What’s happened?	8/17/2020 5:44 PM
15	Ignoring flood risks	8/17/2020 10:59 AM
16	Council staff keep telling us the lake system is getting better when clearly it isn't.	8/16/2020 8:27 PM
17	Have had a number of discussions with Council who seem to be in total denial of any problems regarding the poor condition of the lakes	8/16/2020 8:14 PM
18	Central Coast Council waste time and money defending the expensive, ineffective and inefficient $1.5m wrack removal paddle boat and rake tank. Here is the most recent response to questions about long term sustainability and improving the lake system health and quality: Thanks Chris, this is your chance to have your say to the relevant experts and they are keen to hear directly from residents. I am not responsible for passing on your comments to them. Please also note that this is not my personal lake management plan. I am carrying out assigned duties in accordance with the current Estuary Management Plan and relevant permits obtained from authorised State Gov agencies . This requires me to work within the budget and resource allocation available. I would also kindly request that in the future you raise a customer service request for any wrack removal works rather than messaging me directly. Regards Matt	8/16/2020 12:19 PM
19	Previous Wyong Shire Council staff that have rolled over to Central Coast Council handle the truth very badly and are very unhelpful at trying to find solutions to fix the lakes.	8/16/2020 4:29 AM
20	Attended meeting after meeting. Consultants had not even gone out into the lake to understand what they could not see from the bank. If it wasn't in a text book they were not interested. The shared pathway is exactly the same	8/15/2020 8:32 PM
21	Central coast council do NOT listen to the people, they do as they wish	8/15/2020 5:24 PM
22	Because our council pretend the lake is cleaner then it is	8/12/2020 5:56 PM
23	I felt like we are fighting a losing battle	8/12/2020 2:52 PM
24	These problems with the Tuggerah lakes system are endemic now. We know the solutions bsed on the science but we get caught up in the populist politics and are always playing catch up with the public. We give credence to false solutions and the Central Coast Council does not have the money required to fix these problems. It requires a large capital injection of funds, property buy backs, revegetation and sloping of land, removal of sea walls and grass along the water's edge etc. Some of the work would be unpopular initially and this makes it politically unpalatable as remedies are always used as a wedge for re-election. We don't effectively educate the public about the lagoon system, they expect it to function like Lake Macquarie, won't accept its natural weather system and want to turn back the clock before the State Government and Council allowed all of the development around the shoreline, removing vegetation and salt marsh and habitats. People don't want to face up the harsh truth of the situation and actually do what is right for the ecosystem and the public purse in the long run. Short term solutions that can be sold to the public always win out - until the next crisis, and	8/12/2020 1:32 PM

	there will b e one again soon. Climate change is exacerbating and accelerating these problems.	
25	When flood issues were current local members listened until it blew over then no feedback!	8/11/2020 8:37 PM
26	Lived in the area for 40 years. Deteriorated greatly due to many studies payed for by the taxpayer yet no action taken.	8/11/2020 6:19 PM
27	At the Lakes worst I was told by staff that the quality was at its best in 5 years, WRONG. Was also told by an employee of Council , "I'm just telling you what they are instructing me to say". Come on ,nobody agrees. Attended the Council meeting where The Boatshed owner had 3 mins then 2 mins they back to 3 mins to explain her situation and a lot of the Councillors talked or got up and walked away, RUDEST thing I have ever seen. Oh yea the WRACK machine can't do our area so I asked him to send it up our way to appease me , he did	8/11/2020 6:44 AM
28	Because nothing has changed in 30 years	8/10/2020 10:40 PM
29	decisions are made with winning votes in mind	8/10/2020 4:41 PM
30	Survey on breakwalls - no conclusion waste of time and money. Weed harvester no longer used consequently rotting weed built up in floods. Large tree branches fallen on property and reserve council refused to remove.	8/10/2020 12:17 PM
31	Because my comment never appeared on council site	8/10/2020 6:45 AM
32	Nothing discussed was enacted, or it was done differently to what was discussed.	8/9/2020 8:10 PM
33	I have only recently heard of them through social media	8/9/2020 8:17 AM
34	As I mentioned earlier	8/8/2020 10:01 PM
35	They act like they listen and then do not action maintenance and remediation if the lake. I have attended numerous consultations wth both councillors and staff. Nothing changes, nothing gets done. They continue to employ a contractor to collect weed that has ancient machinery that is inefficient and breaks down continually. Weeding work is a disgrace but we continue to lay the contractor. They cause damage to the lake edge and are totally ineffective. Go out to areas in the north of the city sat Canton beach, Peace Park foreshore toukley, long jetty and have a look at the disgusting rotting weed on the foreshores.	8/8/2020 7:15 PM
36	So called experts spoke over anything we had to say	8/8/2020 5:22 PM
37	My view may have been repetitious, or echoing others views however the receiver seemed disinterested and was not informative or committed to having a conversation regarding concerns.	8/8/2020 4:52 PM
38	they have their own personal experience & because my personal experience is very different because I live in an area that floods regularly they find it hard to relate to my real & regular experiences with flooding	8/8/2020 1:27 PM
39	Government does not deviate from its plans even if they are useless	8/8/2020 9:17 AM
40	Because the situation and conditions ave steadily worsened over the last twenty years and particularly this last year	8/7/2020 7:54 PM
41	Go for a walk through the sludge, then listen to Mayor telling people water quality is fine.	8/7/2020 6:52 PM
42	Because nothing ever gets done the lake will close up again if sand is not removed	8/7/2020 5:42 PM
43	Because any issues to do with the opening of the channel, inadequate drainage, ridiculous bike tracks planned to impact wildlife (aquatic and land based) never get addressed properly or have any positive outcome.	8/7/2020 2:18 PM
44	Up to this, not much opportunity to contribute the enormous experience of lake users	8/7/2020 1:54 PM
45	I am a young local whom has lived 9n the coast my whole life, I have seen the lake deteriorate from where we used to swim and fish and enjoy to what it now. I see all the hype in social media but dont rely on that as evidence, i have had numerous converstation with my grandfather who lives on the lake whom is from a well know family whom parlty founded the local area. My main concern was when in attendance of a council meeting to which I left work early to attend. Our mayor could only sit and roll her eyes and other members were also rolling their eyes at comment being made. I could personally act in a more mature manner and take critism and infomation on a unbiased perspective. They act like children and do not consider the local implications and well-being of the inaction. I understand funding and policies and what red tape is required to perform action. But action in general will produce benefits in years to come. Why not look at local help and put out to tender upgrade of local drainage and out of the normal innovative ideas to provide solutions. They might not pay off, but studys show how putting it out to people with different background produce different concepts which come in under budget and more rewarding	8/7/2020 9:28 AM
46	Nothing is ever achieved	8/7/2020 8:11 AM
47	For example the march east coast low residents had to lead the way to open the entrance	8/7/2020 5:15 AM
48	We have flooded twice this year and Sunday 26/7/20 the river rose 50cms higher than it's previous highest peak in February 2020. 50cms above our pool and blocked my neighbours front entrance, wrecked her washing machine. Surveys, studies, BS. We need action not more talk!	8/7/2020 2:14 AM

49	They Turkey's in power have NO idea absolutely none.	8/6/2020 9:31 PM
50	The council has lied alot about the lake , and refuses to acknowledge that its a man made disaster. Primarily to do with the power station and the man made sand dunes at lakes beach. It desperately needs a 2nd opening, the opening at the Entrance needs to be kept open across the entire bay and not a 5 metre wide trickle of water. The fish are disappearing!	8/6/2020 9:30 PM
51	The people running it had their own agenda so the voice of the locals didn’t get a chance.	8/6/2020 9:16 PM
52	Many studies over the years no results	8/6/2020 8:57 PM
53	Too many biased opinions	8/6/2020 8:36 PM
54	Mayor at the time had 2 people stand on platform of Save Tuggerah Lakes. I campaigned for them & they were duly elected. Told after election nomination fees were paid by Best & Eaton. These other guys were yes men for the 2 stooges. Crooked as horses hind legs.	8/6/2020 8:24 PM
55	As a resident of the Tuggerah Lakes Catchment for 36 I believe council have never listen to any concerns of residents.	8/6/2020 8:04 PM
56	“Experts” are fixed in their knowledge	8/6/2020 8:03 PM
57	Nothing gets done	8/6/2020 7:55 PM
58	Most people don't understand the ecology, history, issues, etc. Most people expect TL to be something it never was.	8/6/2020 7:42 PM
59	Council has there own agenda what ever you say just falls on deaf ears .if u rake the weed they threaten to fine you	8/6/2020 7:26 PM
60	They appeared just to need to tick the 'I have consulted' box. Although they listened, i felt it was just lip service and no attempt was being made to understand or consider another point of view that might have differed from their own.	8/6/2020 7:11 PM
61	No	8/6/2020 6:56 PM
62	I responded by commenting on Facebook. Noted other public comments.	8/6/2020 3:20 PM
63	Not much hope of people taking notice of what I said or listening to what was said ,the people living on the lakes should have more say as we use it the most every day ,and pay big rates ,council don't LISTEN to people who live here for 40years or more or the community as well	8/6/2020 4:49 AM
64	?	8/5/2020 3:05 PM

Q12 Before this survey, had you heard about the Tuggerah Lakes Expert Panel?

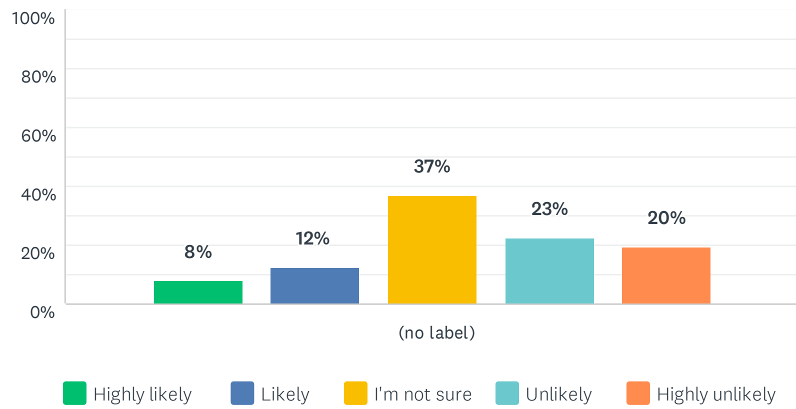
Answered: 289 Skipped: 100



ANSWER CHOICES	RESPONSES	
Yes	48%	140
No	47%	137
Not sure	4%	12
TOTAL		289

Q13 To what extent do you think the Expert Panel will make a positive contribution to the future management of Tuggerah Lakes?

Answered: 137 Skipped: 252



	HIGHLY LIKELY	LIKELY	I'M NOT SURE	UNLIKELY	HIGHLY UNLIKELY	TOTAL	WEIGHTED AVERAGE
(no label)	8% 11	12% 17	37% 51	23% 31	20% 27	137	3.34

Q14 Can you tell us why you feel that way?

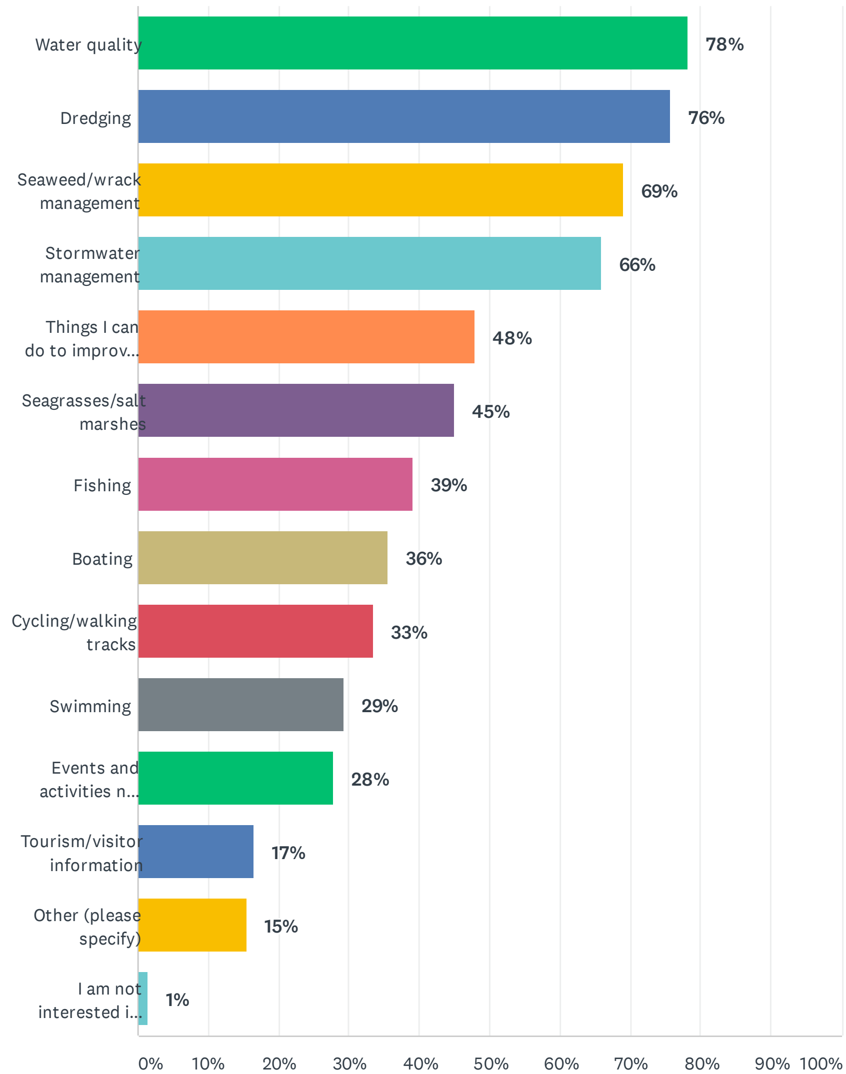
Answered: 53 Skipped: 336

#	RESPONSES	DATE
1	Because there has been alot of consultation over many years, but most action has been window dressing without meaningful outcomes such as a breakwall	8/19/2020 4:20 PM
2	No funding to back outcomes. Initiatives chosen to progress will be at the mercy of external funding priorities and/or political whims.	8/19/2020 3:57 PM
3	The recommendations will be left will council to enact on. Nothing will happen except for a little dredging. Council are not interested in fixing the lakes they only go through processes such as this as an appeasement.a	8/19/2020 3:54 PM
4	Council have zero intention of spending any real money or effort to fix the lake system , they would prefer to pretend it isnâ€™t there .	8/19/2020 3:50 PM
5	Really need to see some action, I'm unsatisfied with more reports and studies	8/19/2020 3:46 PM
6	Council needs to actually act on the findings!! Not just fob it off !!	8/19/2020 3:16 PM
7	Nothing has changed in 20 years. Most people who live around the lake may not know best management practices for the area. Lots of mixed messages.	8/19/2020 3:03 PM
8	The expertise and knowledge of the panel	8/19/2020 2:49 PM
9	As usual a report will be done and no action will be taken everyone is feed up with the non action	8/19/2020 2:38 PM
10	Nothing but lip service manny of us locals feel we only get and funds being wasted with no permanent solution	8/19/2020 2:32 PM
11	We have had panel after panel, consultation after consultation, recommendations, plans and nothing has happened, I have been a resident for 42 years. Not a local, but long enough to realise nothing will happen. On the weekend, we struggled to get our not very big boat under the entrance bridge. Just don't think anything will change.	8/17/2020 9:12 PM
12	I have listened to meetings where constructive suggestions have been made and they have been shut down in the blink of an eye !	8/17/2020 5:45 PM
13	There has been numerous studies and surveys in the past which has not resulted in any positive action bring taken	8/16/2020 8:16 PM
14	Years of neglect, corruption and wasted funding has done nothing. The lake system continues to deteriorate and all of the agencies have done nothing to reverse the cycle. It is disgraceful!	8/16/2020 12:20 PM
15	Once you hand your recommendations over to Central Coast Council it will be filed in the room that contains the other 10,000 reports and recommendations that have been sourced over the past 50 years and never acted on.	8/16/2020 4:32 AM
16	They have no capacity to ensure any action starts let alone is completed. Expert - x= an unknown quantity, spurt= a drip under pressure.	8/13/2020 7:21 AM
17	My understanding is that there is already a wealth of information and advice available on better management practice for the lakes, yet little or nothing has been done to improve them to date.	8/12/2020 10:07 PM
18	All the councils ‘experts’ have always had a negative effect they don’t listen to the people who live near the waterway	8/12/2020 3:09 PM
19	Because it's all talk an no action	8/11/2020 10:08 PM
20	Money continuously spent on numerous studies by expert panels nothing changes...waste of money etc	8/11/2020 8:30 PM
21	Cause nothing constructive had been completed by council to daye	8/11/2020 8:12 PM
22	the lakes are a disaster and should be filled in and make canals for housing	8/11/2020 4:42 PM
23	Incompetence	8/11/2020 8:38 AM
24	*Local & State governments change. *Large corporations are affected by any decissions. And possibly involved in the discussion/decission-making processes concerning Tuggerah Lakes. *Mother Nature is the final decision maker in our, so-called, "unprecidented" natural events.	8/11/2020 3:41 AM
25	Again, Nothing has changed in terms on environmental management	8/10/2020 10:41 PM
26	Tuggerah lakes is deliberately being managed by council to achieve an objective rather than what the wider community wants, council dictates results with terms of reference and amendments relating to environmental excuses	8/10/2020 6:56 PM
27	We've had many experts study our waterway and write comprehensive reports that provide strategies to improve water quality. Those reports get shelved because it's too big a task for local government and David Harris seems to be the only State MP keen to improve water quality; and he can't do that because Liberals keep getting elected due to the population density of Sydney voters and their need for a new motorway. The Tuggerah Lakes system is in two state electoral areas, which makes it tricky for anything to get done.	8/10/2020 3:47 PM
28	Been here before. Millions supposedly spent on lakes and nothing seen.	8/10/2020 8:11 AM
29	As said before many consultants and council over my 60 plus years have spent many $100’s	8/9/2020 4:03 PM

	of thousands of dollars and done very little	
30	Council do not take positive action even after engaging so many experts to do studies year after year. They have spent so much money on reports with recommendations that have never been actioned. Council us totally inefficient when it comes to the remediation of the lakes.	8/8/2020 7:19 PM
31	They have been talking and talking about doing things for more than 30 years	8/8/2020 5:23 PM
32	Suspicious of input by unqualified committees and the like.	8/8/2020 10:18 AM
33	I have yet to see anything done by experts actually improve fishing conditions	8/7/2020 7:57 PM
34	Previous surveys, panels, consultations, committees etc appear to have little influence over a Council obsessed with Green principles opposing remedial infrastructure. I refer to the lake system in general, not specifically the Entrance.	8/7/2020 10:55 AM
35	in action and red tape, ideas will be put forward but there will be inaction	8/7/2020 9:29 AM
36	Every three or four years there is anew “expert” panel and further millions for no result	8/7/2020 8:13 AM
37	prior excuses not to do things and always been proven wrong	8/7/2020 8:07 AM
38	Going on to long.	8/6/2020 11:42 PM
39	Because council doesn’t care about the north end of the central coast, it has been neglected for as long as I can remember. We use to swim in the lake as kids but there is no way I would ever let my kids swim in there, it’s so dirty	8/6/2020 10:26 PM
40	The so called expert panel should be asking the people who live in the area what can they do to improve the environment around Tuggerah Lakes	8/6/2020 10:02 PM
41	What they want to spend ridiculous amounts of money on so called experts who have no idea	8/6/2020 9:33 PM
42	Because all that ever happens is , millions will be spent dredging at the Entrance. I feel the this expert panel will just be another waste of money.	8/6/2020 9:33 PM
43	Due to the past events, where reports and studies are made about the area and no action is taken. Time for action is now. No more reports or studies because it’s all just a waste of time and money.	8/6/2020 9:20 PM
44	Usually people that don’t really know anything about the lake	8/6/2020 8:26 PM
45	State government doesn't care as seats are held by parties in opposition.	8/6/2020 8:26 PM
46	From past experiences	8/6/2020 8:00 PM
47	I don't believe the members are experts.	8/6/2020 7:43 PM
48	Nothing has been done since this council was put in place	8/6/2020 7:28 PM
49	Like I said nothing ever gets done	8/6/2020 6:57 PM
50	Because it will be directed by councillors with their own agendas and not what is best for the lake and community	8/6/2020 6:02 PM
51	Environmental action by council and governments too slow if at all. Always in the too hard basket, too expensive, always excuses for non action. Etc	8/6/2020 3:23 PM
52	as a fishermen i have lived around The Entrance since 1981 and seen the Lake go down hill since then to the point it is at a shocking state today.	8/6/2020 4:51 AM
53	Because nothing ever gets done , even dredging is being done no where near as much as it should , a resident had to excavate the channel when the lake was flooding while the council sat on its hands and watched people's homes flood , the debate on a breakwall has been going on for my whole 50 years of life when it is common sense it needs to happen for the health of the lakes , just like almost every other inlet up the east coast of Australia .	8/5/2020 6:41 PM

Q15 What kind of information about Tuggerah Lakes are you most interested in? Select all that apply.

Answered: 284 Skipped: 105



ANSWER CHOICES	RESPONSES	
Water quality	78%	222
Dredging	76%	215
Seaweed/wrack management	69%	196
Stormwater management	66%	187
Things I can do to improve estuary health	48%	136
Seagrasses/saltmarshes	45%	128
Fishing	39%	111
Boating	36%	101
Cycling/walking tracks	33%	95
Swimming	29%	83
Events and activities near or on the lakes	28%	79
Tourism/visitor information	17%	47
Other (please specify)	15%	44
I am not interested in information about Tuggerah Lakes	1%	4
Total Respondents: 284		

#	OTHER (PLEASE SPECIFY)	DATE
1	breakwall Build a breakwall	8/19/2020 4:20 PM
2	Work being done on the system and especially The channel,The Gap, And Colongra and work done by GPM on the old powerstation site at the moment and much more	8/19/2020 4:14 PM
3	Would like the lakes health to return to levels, where Black Swans can once again breed more around our lakes in reeds.	8/19/2020 3:21 PM
4	flooding All of above points, and primarily flood risk mitigation plans. Extensive research I have undertaken to date and personal experiences reflect what is in place at present is completely ineffective. The event of Feb 9th 2020 is a clear example. Had the channel been managed effeciently and effectively opened when a resident tried to do so, the impact/cost to some 5000 building surrounding the lake system would have been greatly minimised.	8/19/2020 2:45 PM
5	Everything. That the council will not fix. Rubbish near water ways trolleys in water dirty used drug stuff near lake	8/19/2020 2:30 PM
6	xxx	8/19/2020 2:18 PM
7	maintenance Shoreline maintenance. E.g. rubbish removal	8/17/2020 7:44 PM
8	maintenance As a start it would be good to see the foreshores maintained with rotting weed removed and a greater exchange of water on the lake	8/16/2020 8:22 PM
9	permanent opening Establishment of a permanent opening at The Entrance.	8/16/2020 4:43 AM
10	flooding Flood mitigation	8/11/2020 8:38 PM
11	All of the above	8/11/2020 8:13 PM
12	breakwall Breakwall	8/11/2020 7:30 PM
13	fix 3 PROBLEMS and the rest will all fall in to place. NO BRAINER	8/11/2020 6:48 AM
14	development The long & short term effects of residential and industrial development in and around the Tuggerah Lakes & catchment areas.	8/11/2020 3:55 AM
15	breakwall Break wall	8/10/2020 8:17 PM
16	breakwall permanent opening Development of channel with the use of sea walls and break walls	8/10/2020 6:59 PM
17	maintenance interested in the preservation of the lake and its foreshore areas. not destroying whats left	8/10/2020 4:43 PM
18	maintenance Managing the removal of the sludge / black ooze and getting our white sandy beaches back on the foreshore.	8/10/2020 3:52 PM
19	All information	8/9/2020 8:11 PM
20	development Remove houses from the catchment	8/9/2020 7:23 PM
21	permanent opening The entrance channel ! Please wake up	8/8/2020 10:15 PM
22	What is being done to protect the lake. I would like access to the bushland around Wallarah creek restricted to stop car dumping. They get in around Charmhaven on the Highway. I have reported dumped cars to council who wouldn't return my calls until I notified the local paper. The cars are still there. Rubbish is still being dumped. So really let me know when the trails are blocked off. I kyak in the lake and its tributaries and care greatly for it. Please protect it.	8/8/2020 9:04 PM
23	breakwall flooding permanent opening rock wall from the sea into the lakes & a second spillway at the north end of the lakes for circulation & to stop flooding, more water depth for boating, rock walls control sand entering at the entrance much the same as what the rock wall has done on the entrance beach it could do the same for north entrance beach. to limit flooding would make the lower entrance & north entrance would have a more quality standing value	8/8/2020 3:16 PM
24	breakwall Twin break walls and dredged to a depth of 5.5m to Pelican Island	8/8/2020 11:30 AM
25	Creating an effective tidal interchange in the three lakes	8/8/2020 10:24 AM
26	Biodiversity Biodiversity and health of our wildlife	8/8/2020 9:41 AM
27	Biodiversity ecology and bird watching	8/8/2020 8:02 AM
28	breakwall permanent opening Break wall options or permanently open Channel	8/8/2020 3:21 AM
29	Navigation. Ocean access	8/7/2020 6:54 PM
30	flooding Flood mitigation work	8/7/2020 6:53 PM
31	Steps taken to improve things	8/7/2020 1:59 PM
32	maintenance Mitigation of lake bank erosion caused by wind/wave action	8/7/2020 11:10 AM
33	permanent opening A second opening.	8/7/2020 9:30 AM
34	permanent opening Keeping mouth open and do something to help water movement in the lake	8/7/2020 9:05 AM

35	Fix it	8/7/2020 8:15 AM
36	If the lakes are looked after, fishing, boating etc will follow	8/6/2020 9:24 PM
37	breakwall A breakwall at the entrance. An opening on the northern end of the lake to compliment the breakwall at the entrance	8/6/2020 8:28 PM
38	Biodiversity Commercial fishing operations - how is it being managed (and by whom?) What consideration is there for the health of fish stocks in the Lake - a natural breeding ground for fish? What monitoring processes are in place, for both recreational and commercial fishing?	8/6/2020 7:27 PM
39	permanent opening Channel opening	8/6/2020 6:58 PM
40	What can you do to improve the water and foreshore quality. I wouldn't swim in these waters. They appear to be stagnant at times, toxic signs displayed at waters edge. What is the chance of opening both lakes, North tuggerah and budgewoi?	8/6/2020 3:30 PM
41	breakwall Break wall	8/6/2020 4:54 AM
42	Old fashioned ooze removal.	8/5/2020 10:48 PM
43	breakwall building a break wall	8/5/2020 6:45 PM
44	permanent opening Opening the mouth of the lake	8/5/2020 1:17 PM

Q16 Is there anything else about communication, information or consultation about Tuggerah Lakes that you would like to say?

Answered: 178 Skipped: 211

#	RESPONSES	DATE
1	There have been many consultation activities and expert reports over several decades. Whilst your intention is commendable, I don't believe you have the support of government and the necessary financial support for meaningful outcomes. If you can make one or more political parties commit to funding works, you may actually make a difference.	8/19/2020 4:20 PM
2	Regular workshops or seminars to work with the community instead of seeing them as the opposition. We like most of you chose the region as our home and we need it managed correctly.	8/19/2020 4:18 PM
3	As a resident on Lake Budgewoi, it would be great to see it flourish once again. Being able to swim in the lake while enjoying the natural wildlife would be amazing.	8/19/2020 4:16 PM
4	Yes Face book is good, See the page Bring Back the Gap and Save Tuggerah Lakes	8/19/2020 4:14 PM
5	The Feb 2020 Flood affected 5,500 properties. The flood warnings had been communicated to Council but ignored. The management of The Entrance berm has been ignored. The recommendations from the 2014 TL Floodplain Risk Management Plan have been ignored. There has been very little professional and quality consultation with Council. The Council is devoid of practical strategies to manage the catchment.	8/19/2020 4:11 PM
6	It can be biologically diverse, with care and planning.	8/19/2020 4:02 PM
7	Tuggerah Lakes needs its own authority. One person in charge, who would be responsible and accountable for the management of the lakes. Council has "dropped the ball" badly in managing the health of the lakes. There seems to be an culture of no accountability on how the lake is mismanaged. Millions of dollars have been spent on trying to remedy the situation of the lakes, but the money has not been spent in a cost effective and efficent way to get best value. Council has done some good work in the catchment areas of the Lakes, to improve the health of the lakes, but their wrack management stategy and The Entrance channel management have been a total and dismal failure.	8/19/2020 4:01 PM
8	The council managed the February floods very badly and then lied to cover up their incompetence. Council can not be trusted. I would not trust anyone or any information they provide regarding Tuggerah Lakes.	8/19/2020 3:55 PM
9	I would hope that apart from environmental experts there would be representation from real local residents that want to see this community move forward and utilize the lakes as a draw card for our economy itâ€™s currently not even considered .	8/19/2020 3:50 PM
10	I would as a lake front house love to receive more information on what is being done to help the situation of lake health and flood warning systems I feel as if I and my neighbours were failed as we were under water for a whole week all because the lake entrance was blocked.	8/19/2020 3:47 PM
11	I would like an opportunity to have a say in the process of warning residents in regards to flooding.	8/19/2020 3:45 PM
12	The primary goal for caring for the lake is ensuring the ecological health of the system from the headwaters of the feeder streams to the lake and the sea. This must be determined by science not opinion. Opinions from real estate agents and developers, tourism operators, political interests, business owners and most others are generally overly simplistic and/or self serving.	8/19/2020 3:42 PM
13	I would just like to see improved quality of our lake system.	8/19/2020 3:40 PM
14	It would be good to get information on what is going to be done to improve the quality of Tuggerah lakes. The lake is extremely shallow, its water quality is poor and dirty, it's weed ridden, it stinks and its lacking fish species. It needs to be opened up properly at the entrance and at another point near Budgewoi Beach. I have heard that it used to be open at Budgewoi, these needs to happen again.	8/19/2020 3:38 PM
15	The impact of entrance management on broader coastal processes (eg at North Entrance Beach) needs to be considered.	8/19/2020 3:32 PM
16	Why is there no Indigenous representation on this panel?	8/19/2020 3:30 PM
17	Make it more known that itâ€™s happening and people will comment not just the people living on the lake front	8/19/2020 3:24 PM
18	I am against a breakwall. There is a rockshelf at The Entrance bay area that protects the area and Tuggerah lakes from damaging swells. This needs better mapping. An open Entrance combined with strong southerly winds, draws fresh sea water into our system, improving water quality greatly, including causing the reduction of ooze around the shoreline. When The Entrance is fully open, AHD is around 200mm and we have spring tides, we do have small 50mm tidal movements measured by MHL in Budgewoi lakes. MHL has recently upgraded their measuring equipment. Much more sensitive now. The movement is usually the nightly high tide which is the largest of the two high tide. Most computer modelling should be redone after the winds of 22-24 May pushed over 550mm raise in Budgewoi lakes at a time of only light showers. This may have also entered Munmorah lakes, but we have no measuring equipment there.	8/19/2020 3:21 PM
19	In the past Iâ€™ve cleaned up areas of debris, rubbish etc only to be told council cannot pick it up. I was left distributing rubbish into bins for weeks. Residents should be able to do clean ups and have council pick up our collections. We all need to work together.	8/19/2020 3:14 PM
20	Myself and 2 other residents had a meeting with Council staff regarding the state of the	8/19/2020 3:04 PM

	reserve as a result of the recent flood and were assured staff would return but this did not happen. Only tell you what you want to hear with no intention of carrying out works. Please inform us of a way we can all contribute and maybe get the best possible outcome for our area.	
21	I am only interested in some action. Not reports….. We need to see a change or The Entrance and the surrounding areas will be sunk. Donâ€™t know how many times this has to be said	8/19/2020 2:58 PM
22	I would like to see a plan for the waterway, That once and for all ends the speculation and incorrect rhetoric about the lakes water quality, its opening and the best way to go about keeping it in its best state	8/19/2020 2:54 PM
23	The information is avaiable on multiple platforms and to community groups working towards education/community awareness about the lake system.	8/19/2020 2:50 PM
24	Let's promote the facts. More than $35M has been invested in improving the health of the estuary and there have been many great acheivements and improvements. Council should bring the community on a journey through the Coastal Management Program development process… and ensure accurate information on water quality, entrance management etc. Community need to stop pointing fingers and look at their individual/cumulative impacts on stormwater and the estuary itself.	8/19/2020 2:48 PM
25	I would welcome the opportunity of personally meeting to review the scope of your project, and targeted outcomes. To also share my views in a rationale and constructive manner. I own the last 2 properties on Geoffrey Road, Chittaway Point which are essentially in centre of Tuggerah Lake, and as such am in an ideal position to provide valued input.	8/19/2020 2:45 PM
26	Not enough hard facts hitting the streets. Lack of good quality information and complete lack of communication lead to lots of gossip and lies.	8/19/2020 2:36 PM
27	Manny of us resident's are hoping this is not anther fast and waste of funds with no permanent solution reached	8/19/2020 2:32 PM
28	Need to fix it. I canâ€™t Evan use my boat in the water it is so bad. Or go for a swim at the entrance. Or fish you guys should be ashamed of your self for letting it get this bad	8/19/2020 2:30 PM
29	Inform residents residing by the lakes to cease mowing down to the waters edge and not to use fertilisers containing phosphates on their lawns.	8/19/2020 2:28 PM
30	The entrance channel needs to be sorted ASAP for businesses & tourism alike	8/19/2020 2:25 PM
31	We need a balanced perspective and an education strategy targeting different sectors of the community based on their beliefs. It's not one size fits all and audience research is vital in developing an educational communication campaign.	8/19/2020 2:18 PM
32	Speak to lots of locals in particular the residents who have lived there for most of their lives. Geoffrey Rd Chittaway Point would be a great place to start.	8/19/2020 2:12 PM
33	CC Council has been approving developments at unsuitable locations in the catchment such as DA 171/2019 at 292 Palmdale Rd, Palmdale. Despite over 100 objections pointing out the environmental damage it will cause to the cathment, Council staff ignored objectors and expert consultants, provided false and contradictory information to elected Councillors who approved it. Consultation only works when the facts and the legislation are taken into account. And some legislation ties the hands of organisations tasked with protecting catchments such as NRAR. Dwellings are exempt from water management legislation designed to protect catchments like Tuggerah Lakes.	8/19/2020 1:59 PM
34	No	8/18/2020 7:05 PM
35	start doing it!	8/18/2020 2:54 PM
36	No. Just need it fixed.	8/17/2020 9:13 PM
37	Recommendations from the expert panel will only be useful if the State government commits $$ to implementation. It's been 30 years since the NSW government has committed substantial funding to lakes restoration	8/17/2020 8:05 PM
38	The lake needs a plan that is actually executable and actionable. It needs to include economic redevelopment of public areas. There is no reason that the Entrance and surronding areas can be like Terrigal or Lake Macquarie, Newcastel Foreshore. This council continues to play party politics instead of uniting and focusing on the needs of the local residents like we pay them to do. Party politics should have no place in local government. The LAC should be independent	8/17/2020 2:44 PM
39	Stop spending money on endless reports. With all the money spent over the years a break wall could have been built where as all we have for all that time and rate payers money is more reports and expert groups.	8/17/2020 2:32 PM
40	No	8/17/2020 11:00 AM
41	no	8/17/2020 9:16 AM
42	My fathers family holidayed at Budgewoi from the mid 1920's. The family built a holiday home in the 1950/1. In 1956 we moved to Budgewoi to live. I was 12 years old, and at 76 still here. It is heart breaking to see how the Tuggerah Lakes have changed in my lifetime…….	8/16/2020 10:54 PM
43	I would like the expert panel to read the reports written by Anthony Scott CSIRO commissioned by the Wyong Council in 1995.	8/16/2020 8:30 PM

44	No	8/16/2020 8:22 PM
45	Why on earth dont you dredge the foreshore and build a small island for bird life. The foreshore around wallarah bay is disgusting. There are no paths, it hardly ever gets mowed let alone dredged and the stench is unbareable.	8/16/2020 12:33 PM
46	Clean the lake, come up with a plan that addresses the problem and STOP wasting money on expensive, ineffective and inefficient wrack removal. It’s disgraceful!	8/16/2020 12:22 PM
47	Keep the lakes dredged to avoid flooding!	8/16/2020 9:32 AM
48	We should be using our beautiful waterways to encourage people to enjoy the views and use the water make it something to see	8/16/2020 8:00 AM
49	After the recommendations are handed over to Central Coast Council will there be any follow ups from the Expert Panel to see whether any of the recommendations are acted on and if so will the results be monitored and recorded. Similar to Lake Illawarra an authority needs to be formed to keep a close watch on improvements and detractions.	8/16/2020 4:43 AM
50	No	8/15/2020 9:57 PM
51	We need a Council that listens to the people, not feather their own nest, Tuggerah Lakes is a disgrace, the floods in February were very stressful, all because the Entrance Chanel was neglected. Listen to the people that pay their rates on time every quarter & Jeep us informed on progression.	8/15/2020 5:29 PM
52	When I first moved to the coast I could take my boat out through the channel. Has been a long time since I did that.	8/14/2020 9:18 PM
53	Can I get on a committee	8/14/2020 4:46 PM
54	Its not currently managed at all. It stinks, the water quality is horrid and its not open to the ocean in the right spot. Look at the history of the water way. It used to have morrings and a ferry. Its silted up so badly its not usable.	8/14/2020 2:22 PM
55	No	8/13/2020 7:22 AM
56	I would hope that any findings or recommendations will be made public with clear reasoning and research supplied.	8/12/2020 10:09 PM
57	the lake is filth	8/12/2020 5:57 PM
58	Fix the lakes	8/12/2020 4:32 PM
59	No	8/12/2020 3:09 PM
60	Perhaps contacting waterfront residents more often. Either by email or mail. Thank you	8/12/2020 2:53 PM
61	Found this difficult to find any information about to be able to respond to you. Not sure how you are advertising but I usually receive information from Central Coast council or th eCouncillors in our ward telling me that various issues are up for discussion but not this time. that is very disappointing as i don't know how many responses and from which groups in the community you will receive comments which may affect your findings and bias them.	8/12/2020 1:35 PM
62	An update on the walking track	8/11/2020 10:41 PM
63	No	8/11/2020 8:46 PM
64	No	8/11/2020 8:38 PM
65	Everything relies on the chanel remaining open so exchange of waters can flush & refresh lakes	8/11/2020 8:30 PM
66	No	8/11/2020 8:19 PM
67	More public involvement	8/11/2020 8:13 PM
68	sick of councils inaction in dredging the channel and steps to prevent it. Build the break wall	8/11/2020 7:30 PM
69	Nothing I say will make any difference, vested interests will reign over it all.	8/11/2020 6:16 PM
70	no	8/11/2020 4:43 PM
71	What about the brake wall	8/11/2020 11:41 AM
72	too much talk over the last 25years,NO IMPROVEMENTS. SHAME!!!!!!	8/11/2020 8:41 AM
73	Like to see some action, even trialling a few systems	8/11/2020 7:45 AM
74	Dredge the Entrance channel to prevent flooding and clean lake	8/11/2020 7:38 AM
75	get the people who live here involved as we are not the paper experts BUT we live here and we are the experts from experience	8/11/2020 6:48 AM
76	I hope the aims of the Panel are to ensure the long-term viability of the Tuggerah Lakes and catchment areas. To ensure the effects residential, recreational & corporate activities ARE controlled and planned for. And, prioritise the healthy existence of native flora & fauna, in Tuggeragah Lakes areas	8/11/2020 3:55 AM
77	you dont hear anything until election time because they want your vote.	8/10/2020 9:24 PM

78	No thanks regards Brett	8/10/2020 8:47 PM
79	We need the lakes cleaned of seaweed and a break wall	8/10/2020 8:17 PM
80	No	8/10/2020 8:02 PM
81	No	8/10/2020 7:44 PM
82	Stop putting the brakes on development of the lake, channel and area generally	8/10/2020 6:59 PM
83	When will dredging of the Entrance Channel begin again as no-one seems to be willing to make a decision on a breakwater.	8/10/2020 6:07 PM
84	can ylu please be open and honest regardless of cost to council	8/10/2020 5:57 PM
85	Keep David Harris MP in the loop.	8/10/2020 3:52 PM
86	Improve water flow into the lake and don't allow the lake entrance to close.	8/10/2020 12:59 PM
87	No	8/10/2020 9:27 AM
88	Need more of it	8/9/2020 8:11 PM
89	Would like to hear that there is adequate consultation via meetings etc before any final decisions are enacted!	8/9/2020 5:08 PM
90	When the government started removing weed they removed a lot of winter fishing tourist who bought money into the township of entrance since they started weed removal the Limerick influx every year last 5years would be at lowest ever seen it if no feed in lack fish not come into lake to spawn they not come in lake for last 5years not need be a professor to know answer why	8/9/2020 5:03 PM
91	No	8/9/2020 4:04 PM
92	Dumping of waste along storm water drains. You inform the council and they do nothing to either clean or enforce action	8/9/2020 12:15 PM
93	When will the council finally do something to help restore the lake	8/9/2020 9:16 AM
94	Information on bird life	8/9/2020 8:18 AM
95	I would like the truth from Council's employees. I feel the correspondence is faulty.	8/8/2020 10:32 PM
96	Now that munmorah power station has been decommissioned and the title follow is not a issue please open up the entrance channel	8/8/2020 10:15 PM
97	Why aren't you asking what problems I am seeing?	8/8/2020 9:04 PM
98	The lakes desperately need HELP. They are such a wonderful part of. Our local area and should be treated that way. So many people want to use the lakes for swimming,picnics, kyacking, water sports such as water skiing etc. these sports bring people to our local area and provide good tourist dollars to local businesses and community.	8/8/2020 7:23 PM
99	No	8/8/2020 7:20 PM
100	Need to promote Kayaking and boating on the lake ststem	8/8/2020 5:25 PM
101	Not currently, I may as the processes and advancements of the expert panel move forward.	8/8/2020 4:54 PM
102	would love to hear if any of the things i have mentioned will ever happen because it is what the people have hoped & voted for over the years to only be let down again. we should be carefull because if we dont keep on improving the lakes then they could become a second rate back water which would devalue every thing around it . the lakes should only be improved not let go into disrepair. 7 voted for over the years	8/8/2020 3:16 PM
103	Website with current info would be great	8/8/2020 3:03 PM
104	no	8/8/2020 1:28 PM
105	Yeah. Instead of surveying us, tell us what you're doing day by day to improve the lake. You've got a Facebook page; tell us what you're doing.	8/8/2020 1:18 PM
106	Water quality and tourism would be greatly improved with the installation of twin break walls and dredged to a depth of 5.5m to Pelican Island. Small marina could be on southern wall. I would love to have a chat about my thoughts if that helps, 0412 882 016 Simon	8/8/2020 11:30 AM
107	Bring it on	8/8/2020 10:24 AM
108	We need to clarify if we are treating TL as recreational lakes or an estuary. People need clarity so they dont have false expectations of what the lakes should or should not be	8/8/2020 10:02 AM
109	What habitat restoration projects have been implemented and or planned	8/8/2020 9:41 AM
110	I get some info on social media which advocates the reopening of the king tide to budgie lake and an ocean inlet into munmorah but don't know if this is the group.. such logical solutions will never be embraced by govrrnment	8/8/2020 9:20 AM
111	It's time to put money where the research is and listen to the locals with long histories around the lake and fix the problems we have.	8/8/2020 3:21 AM

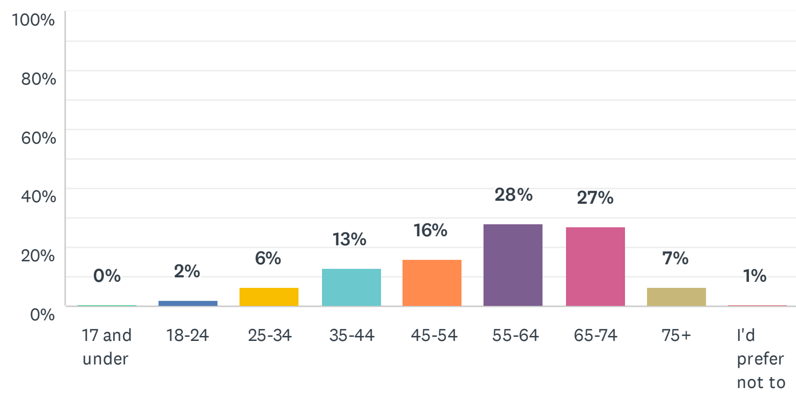
112	no	8/8/2020 1:07 AM
113	Water quality of Tuggerah Lakes is the most important issue.	8/7/2020 10:23 PM
114	No	8/7/2020 8:15 PM
115	No	8/7/2020 8:08 PM
116	NO	8/7/2020 7:58 PM
117	More funds are needed on the coast in general funded by the NSW Government to ensure meaning full progress for the future. The Central Coast total area is now to large to be funded by local funding given the extensive and variety of the topography.	8/7/2020 7:55 PM
118	Bring back the gap	8/7/2020 7:12 PM
119	Breakwall options ?	8/7/2020 6:54 PM
120	We dont hear much about anything	8/7/2020 6:53 PM
121	30+ years of mismanagement and endless studies, none of which seem to be acted upon, and the politicization of the lakes has left many residents wary of any bodies claiming to actually achieve any long lasting improvements to the lake	8/7/2020 6:08 PM
122	No	8/7/2020 5:44 PM
123	No	8/7/2020 5:39 PM
124	Please address the issues with the channel, dredging, weed etc as soon as possible so we all don't get inundated with water again, improve the health of the lake and help increase water quality.	8/7/2020 2:21 PM
125	Hopefully this attempt to improve things will result in some action based on Science - not such another talkfest!!	8/7/2020 1:59 PM
126	No	8/7/2020 1:37 PM
127	Living on a lake reserve we get no vommunication or help after flooding or heavy rain. The sediment pond in front of us is a stinking disgrace, usually full of mozzie wrigglers	8/7/2020 12:43 PM
128	Include local residents who have lived here for most of their lives!	8/7/2020 11:19 AM
129	Yet another effort by Council to placate (read hoodwink) the Community.	8/7/2020 11:10 AM
130	No comment	8/7/2020 9:35 AM
131	Maybe another proposal to put in second opening at top end of lake system	8/7/2020 8:15 AM
132	put in a break wall and islands	8/7/2020 8:09 AM
133	Our garden backs onto the lake. This elevates our shared interest. Without knowledge, better water flow, a bigger or a second entrance appears to be a good solution. Now the power station has gone, we can set up for nature, not cooling...	8/7/2020 6:02 AM
134	The definition of Expert = X is an unknown quantity and spert is a drip under pressure. In the last 40 years I've heard nothing but talk and broken promises, from Council X Spurts, I don't expect any action will eventuate after this survey either.	8/7/2020 2:20 AM
135	No	8/6/2020 11:43 PM
136	How to clean all the rubbish up and to reduce the stench. I'd like something fine about ash dams cleaned up at the northern end of the system.	8/6/2020 10:38 PM
137	Yes please investigate council and why they feel they can justify destroying the environment, why they are ok with peoples houses flooding and being washed away and why it is ok for sewerage to be constantly dumped into lake, why won't they open the lake back up to the sea as it was originally	8/6/2020 10:28 PM
138	No	8/6/2020 10:27 PM
139	Clean it up....build a stone jetty at The Entrance	8/6/2020 10:03 PM
140	no	8/6/2020 10:03 PM
141	Just fix the lake, the water is too stagnate and would be more natural if a 2nd opening near toukley golf course and lakes beach. Yes it would cost alot building a bridge ect. But it would be cheaper in the long run, plus clean lake means house/land values goes up, rates go up, tourism and buisnessess get built . All this would mean happy residents , more money for the central coast and the council	8/6/2020 9:41 PM
142	NA	8/6/2020 9:36 PM
143	Sack the useless council and get some people in who are not CORRUPT	8/6/2020 9:35 PM
144	While I have only lived here for a short time I have spent a lot of time visiting regularly in the 20 years before the relocation. The part I love about Tuggerah Lakes is the apparent lack of sharks. You can jump off and swim just about anyway without a care. We also need more clean beach area along the lakes edges for skiers and tubers to beach their boats. Dredging of the channel an under the bridge needs to be done desperately, it's quite sad to see how little room there is for error and fishing in The Entrance. I'm also disappointed that nothing was done	8/6/2020 9:26 PM

	to save the island that the old bridge used go across. What history we do have in the area we shouldn't be letting go so easily.	
145	Council need to stop reading and writing reports and act.. beyond ridiculous	8/6/2020 9:24 PM
146	Listen to what the locals have to say about the issues we are facing with our local waterway.	8/6/2020 9:21 PM
147	More communication is best. Educating the public is the start of them having a better connection and understanding of the natural environment. Especially with ongoing flooding events occurring in the estuary system the residents in the flood zone impacted areas must acknowledge that by choosing to live in these areas flooding is going to happen.	8/6/2020 9:12 PM
148	I've lived here just shy of 50 years and it's no where near the quality it was when I was a child. The entrance channel needs to bi permanently open.	8/6/2020 9:04 PM
149	at this point in time i think that central coast council does a reasonable job	8/6/2020 8:55 PM
150	Info on permanent solutions. Ie breakwalls	8/6/2020 8:39 PM
151	No	8/6/2020 8:36 PM
152	We now have the opportunity to put a wall of sand bags to form a brealwall to test which is the best way to move forward with opening up the lake to the ocean. The so called experts are really only guess sperts. Putting environmental sand bags in place now and seeing how it goes for a couple of years. Moving them around if necessary to find the best permanent solution to this on going problem of flooding and water turn over in the lake. The council that does it will go down in history as a Council that did the best for their Raye payers and tourism.	8/6/2020 8:28 PM
153	More transparency & less secret squirrel shit.	8/6/2020 8:27 PM
154	Yeah bloody clean it up	8/6/2020 8:19 PM
155	Yes ......tell people that opening the channel will NOT stop low lying areas (eg Chittaway Point) from flooding. AND tell them why !!!	8/6/2020 8:06 PM
156	Lakes should be opened at two place	8/6/2020 8:02 PM
157	Sick of all the reports, committees etc and nothing happening. The council needs to work with state and federal gov to obtain funds. Party politics shouldnt come into it.	8/6/2020 7:58 PM
158	Need to ignore the uneducated viewpoints. Ecological management is not about public opinion or popularity, lets stick to the science and facts.	8/6/2020 7:47 PM
159	It should be on messenger or email	8/6/2020 7:36 PM
160	Please look after the health of the lake and it's flora and fauna	8/6/2020 7:34 PM
161	If council keeps the entrance channel open my house won't flood . If the muppets at council let it close up my house will flood again	8/6/2020 7:32 PM
162	Would love to be kept up to date with management practices and procedures involving the Lake, particularly regarding any expectations of us as residents, or how we might be able to be involved - particularly regarding environmental issues, what can we do (or not do!) To help.	8/6/2020 7:27 PM
163	No	8/6/2020 7:24 PM
164	No	8/6/2020 7:20 PM
165	No	8/6/2020 6:58 PM
166	More paddling canoes skis tmrather than. Motor boats	8/6/2020 6:19 PM
167	Appalled how such a scenic part of the central coast has been mismanaged by council.	8/6/2020 6:04 PM
168	No	8/6/2020 5:37 PM
169	Open the entrance and let the lake breath	8/6/2020 1:32 PM
170	Sea wall	8/6/2020 8:59 AM
171	Need to stop all FLOODING of lakes ,keep the entrance open for water to get out and keep it tidal,I am still dealing with trouble from FLOODING property ,because of council neglect,so are many others , shocking	8/6/2020 5:00 AM
172	it stinks and dying thanks to council	8/6/2020 4:54 AM
173	Many reports and computer modelling is wrong due to historical error in height of rockledge, not considering ocean flush in strong winds reports have a fear of action.	8/5/2020 10:48 PM
174	Clean it up to what it was like 50yrs ago	8/5/2020 9:57 PM
175	NEED A DEDICATED WEBPAGE	8/5/2020 8:37 PM
176	the lake is in a disgusting condition , when I was a young kid these lakes were beautiful and clean with sandy bottom that you could swim in at any spot in the lakes teaming with fish (commercial fishing needs to end in these lakes) , these lakes need to be restored to their former glory .	8/5/2020 6:45 PM
177	Seaweed harvesting is a joke, the machine hardly ever operates and please don't say it does	8/5/2020 3:08 PM

178	No	8/5/2020 1:17 PM

Q17 What is your age bracket?

Answered: 284 Skipped: 105



ANSWER CHOICES	RESPONSES	
17 and under	0%	1
18-24	2%	5
25-34	6%	18
35-44	13%	37
45-54	16%	46
55-64	28%	79
65-74	27%	77
75+	7%	19
I'd prefer not to say	1%	2
TOTAL		284