



Final Report

Tuggerah Lakes Estuary CMP Stage 2 – Risks, Vulnerabilities and Opportunities Report

Central Coast Council

23 July 2026



Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
V01	Draft Report	Neil Dufty	Neil Dufty	24.10.2025
V02	Draft Report	Neil Dufty	Neil Dufty	27.02.2026
V03	Final Report	Neil Dufty	Neil Dufty	23.07.2026

Project Details

Project Name	Tuggerah Lakes Estuary CMP Stage 2 – Risks, Vulnerabilities and Opportunities Report
Client	Central Coast Council
Client Project Manager	Nicole McGaharan
Water Technology Project Manager	Neil Dufty
Water Technology Project Director	Chris Beadle
Authors	Eliza Middleton; Chris Beadle; Courtney Smith
Document Number	225050178_R01_V03_Tuggerah Lakes Estuary CMP Stage 2



COPYRIGHT

Water Technology Pty Ltd has produced this document in accordance with instructions from Central Coast Council for their use only. The concepts and information contained in this document are the copyright of Water Technology Pty Ltd. Use or copying of this document in whole or in part without written permission of Water Technology Pty Ltd constitutes an infringement of copyright.

Water Technology Pty Ltd does not warrant this document is definitive nor free from error and does not accept liability for any loss caused, or arising from, reliance upon the information provided herein.

Suite 3, Level 1, 20 Wentworth Street
 Parramatta NSW 2150
 Telephone (02) 9354 0300
 ACN 093 377 283
 ABN 60 093 377 283





ACKNOWLEDGEMENT OF COUNTRY

The Board and employees of Water Technology acknowledge and respect the Aboriginal and Torres Strait Islander Peoples as the Traditional Custodians of Country throughout Australia. We specifically acknowledge the Traditional Custodians of the land on which our offices reside and where we undertake our work.

We respect the knowledge, skills and lived experiences of Aboriginal and Torres Strait Islander Peoples, who we continue to learn from and collaborate with. We also extend our respect to all First Nations Peoples, their cultures and to their Elders, past and present.



Artwork by Maurice Goolagong 2023. This piece was commissioned by Water Technology and visualises the important connections we have to water, and the cultural significance of journeys taken by traditional custodians of our land to meeting places, where communities connect with each other around waterways.

The symbolism in the artwork includes:

- Seven circles representing each of the States and Territories in Australia where we do our work
- Blue dots between each circle representing the waterways that connect us
- The animals that rely on healthy waterways for their home
- Black and white dots representing all the different communities that we visit in our work
- Hands that are for the people we help on our journey



EXECUTIVE SUMMARY

This report has been prepared for Stage 2 of the Tuggerah Lakes Estuary Coastal Management Program (CMP) which spans the estuarine systems of Tuggerah Lake, Budgewoi Lake, and Lake Munmorah.

The purpose of this report is to fulfil the requirements of Stage 2 as set out in the NSW Coastal Management Manual (OEH, 2018c), and in doing so, to identify and evaluate the various risks and threats affecting the environmental, social, and economic assets and values of the estuary.

The report includes a detailed risk assessment that builds on the first-pass risk assessment (FPRA) undertaken in the Stage 1 Scoping Study (Central Coast Council, 2021). To maintain efficiency and avoid duplicating information already covered in Stage 1, this report focuses primarily on the **high-risk threats** identified in the Stage 1 First Pass Risk Assessment. A select number of **moderate-risk threats** have also been included where additional analysis is considered beneficial for future decision making in Stage 3 of the CMP process.

A total of 22 stressors has been assessed through the application of a systemic risk-based framework, as per the requirements of the NSW Coastal Management Manual (OEH, 2018c) and the *Coastal Management Act 2016*. Using this method, the level of risk associated with each stressor has been assessed through scales of 'likelihood' and 'consequence'.

Whilst the CMP will largely focus on implementing management actions over the coming 10-year management horizon, it is also important to consider the evolution of the various threats and stressors facing the study area over longer timeframes. Therefore, the risk assessment has considered not just the present-day risk, but potential future risk over 20 year (~2045), 50 year (~2075), and 100 year (~2125) planning horizons.

It is also important to acknowledge that not all of the threats and stressors are uniformly distributed across the Tuggerah Lakes estuary and catchment. Therefore, where required to inform site specific management actions in Stage 3, the risk assessment has been conducted at sub-catchment and foreshore zone level.

Governance, Engagement and Communication

Effective management of Tuggerah Lakes depends on strong governance, sustained community engagement, and clear communication between all partners. The Stage 2 assessment found that current arrangements are complex and fragmented, with overlapping responsibilities between agencies and inconsistent coordination across catchment, estuary, and planning programs. Decision-making remains largely project-driven and funding-dependent, resulting in duplication, short-term focus, and limited accountability. Both the Scoping Study (Central Coast Council, 2021) and Expert Panel Review (Glamore, et al., 2020) highlight the need for a coherent governance framework that defines roles, establishes clear pathways for coordination and reporting, and promotes transparency in delivery and performance tracking.

Community engagement was also identified as a key area for improvement. Although many of the local residents and Indigenous peoples share a strong connection to the lakes, engagement has often been reactive, inconsistent, and constrained by limited communication resources. Technical information has historically not always been accessible, feedback mechanisms are limited, and regulatory processes are often perceived as complex or inconsistently applied. Building trust will require long-term, values-based engagement supported by open communication, consistent messaging, and co-designed initiatives.

Furthermore, effective delivery of the CMP will depend on stable and reliable resourcing. The current reliance on ad-hoc, contestable funding has limited continuity and internal capacity, underscoring the need for more predictable investment, improved coordination between Council teams, and ongoing staff development to sustain outcomes over the long term.



Catchment pressures

The Tuggerah Lakes catchment has undergone significant transformation over recent decades, with urban expansion, land use intensification, and aging infrastructure contributing to widespread ecological stress. The catchment spans 790 km² and includes high-risk sub-catchments identified by the NSW Estuary Health Risk Dataset (DPIE, 2019b), particularly in the southern, northeastern and central regions.

Urban stormwater runoff is a persistent and damaging source of pollution, carrying nutrients, sediments, hydrocarbons, and heavy metals into the lakes. Infrastructure is often under-maintained or poorly located, and newer developments frequently fail to meet best-practice design standards. The estuary's limited flushing capacity exacerbates these impacts, leading to prolonged residence times and degraded water quality.

Sewage-related pollution remains a concern, with overflow events during heavy rainfall and legacy septic systems contributing to nutrient and microbial contamination. The Central Coast region has a disproportionate number of overflow events compared to other LGAs, with designated swimming areas such as Canton Beach and Lake Munmorah particularly vulnerable.

Recommended actions include retrofitting stormwater controls, upgrading sewage infrastructure, implementing WSUD principles, and establishing a Catchment Coordinator Taskforce to oversee strategic planning and stakeholder coordination.

Entrance management

Tuggerah Lakes is a wave dominated Intermittently Closed and Open Lakes and Lagoons (ICOLL) that has been modified for more than a century to address flooding, navigation and amenity. Since 1993, modern operations have relied on periodic cutter-suction dredging of tidal shoals at The Entrance, with sand reused primarily on North Entrance Beach.

Current practice is guided by the 2022 Interim Entrance Management Procedure (MHL, 2022), which uses real-time monitoring and flood intelligence to trigger works such as berm scraping, pilot channels and maintenance dredging. Dredging has also been considered as a stand-alone stressor. Evidence indicates that both the Interim Entrance Management Procedure and dredging activities mostly redistribute sediment within the local sand-sharing system, support initial flood drawdown, and maintain local amenity, while producing only modest and short-lived geomorphic adjustments. Water quality effects are minor and localised during works, and ecological impacts are limited to small, temporary disturbances inside the dredge footprint with scheduling to avoid sensitive periods. It should be noted that the impacts of dredging would increase as more sand volume is removed.

Risk assessments for the current regime are low to moderate at present, increasing over longer planning horizons as sea levels rise and hydrodynamics shift. Higher mean sea level is expected to increase tidal exchange, shorten closure durations, and gradually change channel stability and nearshore habitat, introducing uncertainty for long-term management. Social and cultural values remain positive where navigation and beach amenity are maintained, noting short-term access and safety constraints during campaigns.

The groyne at South Entrance Beach is outside the Tuggerah Lakes CMP extent; nonetheless, it has a significant impact on sand distribution and entrance behaviour. This has been rated as high risk, with significant impacts on entrance morphology and social and cultural values.

A range of alternative options has been considered in previous studies, from larger structural training works to programmatic, event-based approaches. Two of the most frequently raised alternative options, a second entrance at Budgewoi and training of the current entrance, have been assessed in this report, and are a very high risk particularly in the longer term. Stage 3 of the CMP process will provide further analysis, and test alternatives with updated modelling and socio-ecological analysis and will involve comprehensive community



and stakeholder engagement to weigh trade-offs among flood mitigation, estuary health, recreation and cultural values.

Ecology and Water Quality

The Tuggerah Lakes estuary supports extensive seagrass meadows, saltmarsh communities, and coastal wetlands, but these habitats are under increasing pressure from pollution, vegetation loss, and climate change. The estuary's morphology and limited tidal exchange make it particularly sensitive to nutrient inputs and sedimentation.

Seagrass beds are declining due to reduced light penetration, wrack accumulation and disrupted natural wrack and algae processes, and sediment instability. Saltmarsh areas are at risk of permanent inundation due to sea level rise, with limited capacity for inland migration due to foreshore development. Predictive habitat mapping indicates that many wetland pockets will be lost under a +0.5 m SLR scenario.

Point and diffuse source pollution from urban, industrial, and agricultural activities contributes to eutrophication, algal blooms, and oxygen depletion. Monitoring data shows elevated concentrations of nitrogen and phosphorus in key tributaries, with persistent water quality decline across the estuary.

Freshwater wetlands and riparian corridors are also degrading due to urban encroachment, invasive species, and altered hydrology. Many areas lack formal protection or management plans, and restoration efforts are hindered by fragmented governance and limited resources.

Recommended actions include habitat restoration, sediment management, nutrient reduction strategies, and integration of ecological corridors into planning instruments. These actions are critical to maintaining biodiversity, ecosystem services, and cultural values.

Foreshore and Nearshore Management

Foreshore and nearshore areas across the Tuggerah Lakes estuary are under pressure from disrupted wrack processes, organic sediment build-up, historic land reclamation, and poorly coordinated management practices. These issues affect both ecological health and community amenity and are expected to intensify with climate change and urban growth.

Seagrass wrack accumulation is a natural process but has become problematic due to shoreline modification and estuary water levels remaining more static than under natural ICOLL conditions. Accumulated wrack contributes to eutrophication and poor water quality, impacting biodiversity, tourism, and recreational use. Without intervention, wrack may become a chronic feature of the lakes.

Organic enrichment of sediments leads to black ooze formation, driven by nutrient-rich runoff and anaerobic decomposition. This process produces sulfidic compounds, reduces benthic habitat quality, and generates odour complaints. Historical management efforts, such as the Tuggerah Lakes Restoration Project, have delivered short-lived benefits, highlighting the need for more strategic approaches that address causes rather than symptoms.

Foreshore development has led to vegetation clearing, shoreline hardening, and habitat fragmentation. Public/private ownership conflicts and unmanaged access contribute to ecological disturbance and user conflict. Groundwater pollution from reclaimed lands and legacy infrastructure is an emerging threat, with limited monitoring and understanding of subsurface nutrient pathways.

Recommended actions include the establishment of wrack reserves, shoreline rehabilitation, sediment management, groundwater monitoring, and community education. These actions will support ecological resilience and improve public amenity across the foreshore zones.



Coastal Hazards and Climate Change

The Tuggerah Lakes estuary is highly sensitive to coastal hazards because of its shallow basins, narrow wave-dominated entrance, and persistently super-elevated mean water levels relative to the ocean. Hazard expression is interconnected: tidal inundation, storm-driven coastal water levels, and catchment inflows can coincide, while entrance behaviour modulates drainage and recovery.

The NSW Estuary Tidal Inundation Exposure Assessment (OEH, 2018g) identifies Tuggerah Lakes as one of the most exposed estuarine systems in NSW. Even under present-day conditions, 364 properties are impacted by inundation during high astronomical tides. This exposure increases significantly under future sea level rise scenarios, with 1,590 properties affected at +0.5m SLR and over 5,000 properties at +1.5m SLR. Local “hot spots” of future tidal inundation risk include The Entrance–Long Jetty foreshore, Killarney Vale/Tumbi Umbi, Chittaway Bay/Berkeley Vale, sections of Gorokan–Budgewoi, and selected Lake Munmorah foreshore precincts. Priority near-term actions include local-scale inundation modelling, integration of exposure mapping into planning and asset management, targeted foreshore adaptation pathways, drainage upgrades, and ongoing monitoring.

Flooding arises from the interaction of catchment runoff with elevated ocean levels. A large catchment area relative to lake surface means substantial rainfall can rapidly raise lake levels. An open but hydraulically constrained entrance can delay recession when storm surges and wave setup coincide with peak inflows. Historic peaks up to ~+2.1 m AHD and design levels to +2.7 m AHD (PMF) frame current risk, while SLR is expected to increase frequency, duration, and extent of flooding.

Entrance instability remains moderate at present but can escalate during major events, especially for the unarmoured northern spit, as well as the Dunleith Tourist Park frontage which has limited erosion protection; SLR is likely to heighten erosion pressure and alter sediment pathways.

Bank erosion - both along tributaries (notably Wyong River and Ourimbah Creek) and lake foreshores (e.g., Long Jetty, Chittaway Bay, Berkeley Vale, Tuggerawong, Gorokan) - is an ongoing driver of fine sediment loads and habitat loss, with risk increasing under SLR and more frequent high-water events. Recommended directions include coordinated nature-based shoreline stabilisation, updated condition assessments, strengthened planning controls for low-lying land, and sustained community engagement on adaptation to progressively rising baseline water levels.

Risk summary

A summary of the present-day risks is provided in Table EX-1. It shows that there are numerous threats and stressors facing the Tuggerah Lakes estuary. The evolution of these risks over the coming decades is described in further detail in the main body of this report.


Table EX-1 Summary of Stage 2 Risk Assessment Outcomes

Threat	Stressor	Present Day Risk Rating (2025)	20 Year Risk Rating (2045)	50 Year Risk Rating (2075)	100 year Risk Rating (2125)	Key Locations
Governance, Engagement & Communication	Unclear governance and shared responsibilities	High	High	High	High	Entire study area / Tuggerah Lakes estuary and catchment area
	Insufficient or ineffective community engagement	Moderate	High	High	High	
	Inadequate, inefficient, over and under regulation	High	High	Very High	Very High	
	Reliable funding sources and resourcing	High	High	Very High	Very High	
Catchment Pressures & Development	Catchment development	High	High	Very High	Very High	Warnervale Wadalba Land Release Area, Tuggerah – Wyong Growth Corridor, Northern Growth Corridor, Lake Munmorah, Spring Creek
	Urban stormwater runoff and discharges	High	High	Very High	Very High	Current nearshore catchments and heavily urbanised areas, Proposed Growth Corridors and Land Release Areas, Developments further afield (e.g. Warnervale)
	Sewage effluent and septic overflows	High	High	Very High	Very High	Central Coast region has disproportionate number of overflows when compared with other local regions (EPA pers. comm., 2020). Designated swimming areas incl Canton Beach (high priority) and Lake Munmorah (moderate to low priority).
Entrance Management	Dredging	Moderate	Moderate	Moderate	Moderate	The Entrance & The Entrance North (during works)
	Interim Entrance Management Procedure	Low	Low	Low	Low	The wider estuary (more broadly)
	Rock Groyne	High	Very High	Very High	Very High	



Threat	Stressor	Present Day Risk Rating (2025)	20 Year Risk Rating (2045)	50 Year Risk Rating (2075)	100 year Risk Rating (2125)	Key Locations
Ecology & Water Quality	Second Entrance	Very High	Very High	Very High	Very High	
	Entrance Training	High	Very High	Very High	Very High	
	Changes in estuarine vegetation (seagrass, saltmarsh, estuarine vegetation)	High	Very High	Very High	Very High	Tuggerah Lake basin, Foreshores, All areas
	Point and diffuse source water pollution	High	Very High	Very High	Very High	Urban fringes, in particular southern and northern aspects of each water body
	Degradation/ clearing of freshwater wetland, riparian and catchment vegetation	High	High	High	High	Toukley Wetland, Tumbi Wetland, Blue Haven wetlands
Foreshore/Nearshore & Wrack Management	Impacts on social and recreational amenity from seagrass wrack accumulation	Moderate	High	High	High	All foreshore areas. In Spring – Long Jetty, Canton Beach, Toukley, Budgewoi, Gorokan (north), in Summer – Killarney Vale, Berkeley Vale, Chittaway Bay (south), in Autumn – Tuggerawong, Gorokan (south), San Remo, Budgewoi, Munmorah (north)
	Organic enrichment of sediment and black ooze formation	Moderate	High	Very High	Very High	All foreshore areas, primarily found in areas where seagrass wrack accumulation occurs in combination with muddy shores, limited wave energy and nutrient inputs
	Foreshore development and management	High	Very High	Very High	Very High	Public foreshores, private foreshores, Natural areas (although limited)
	Ground water pollution	Moderate	High	Very High	Very High	Berkeley Vale (known), multiple other potential locations



Threat	Stressor	Present Day Risk Rating (2025)	20 Year Risk Rating (2045)	50 Year Risk Rating (2075)	100 year Risk Rating (2125)	Key Locations
Coastal Hazards	Tidal Inundation (Including Future Sea Level Rise)**	Low	Moderate	High	Very High	Tuggerah Lake: The Entrance, Long Jetty, Tumby Umbi, Killarney Vale, Chittaway Bay, Berkley Vale, Tuggerawong, Wyongah
	Combined Coastal and Catchment Flooding (including Future Sea-Level Rise)**	High	High	Very High	Very High	Budgewoi Lake: Gorokan, Lake Haven, Charmhaven, San Remo, Budgewoi, Toukley Lake Munmorah: Budgewoi, North-eastern foreshore, Budgewoi Beach
	Estuary Entrance Instability	Moderate	Moderate	Moderate	High	Entrance spit, Northern foreshore (including holiday park)
	Bank Erosion	Moderate	High	Very High	Very High	Streambank erosion: Wyong River, Ourimbah Creek Lake foreshore erosion: Long Jetty, Chittaway Bay, Berkeley Vale, Tumby Creek, and Tuggerawong

** the risks ratings provided here are a generalisation for the estuary as a whole. Section 8 provides a more detailed, locality based risk assessment



Opportunities

The development of the Tuggerah Lakes Estuary CMP represents a significant opportunity to address the complex and long-standing threats facing the estuary. The CMP – developed in line with the NSW Government Coastal Management Framework – will provide a strategic and integrated long-term management plan for the estuary. The “systems” approach of a CMP provides an opportunity to more effectively address catchment-based issues, threats and risks, and approach estuary issues in a broader strategic context.

The Tuggerah Lakes estuary is at a critical turning point. Despite decades of remediation efforts, ecological condition continues to decline, and community expectations for improved water quality, amenity, and resilience remain unmet (Glamore, et al., 2020). The CMP provides a formal mechanism to respond to these challenges through coordinated planning, evidence-based action, and collaborative governance.

The CMP therefore represents an opportunity to:

- Establish a collaborative and coordinated management framework. The current governance system of the Tuggerah Lakes estuary and its catchment is fragmented, with overlapping responsibilities across local, state, and federal agencies. The CMP can provide a platform to align stakeholder roles, clarify jurisdictional boundaries, and foster new partnerships. This includes:
 - Formalising inter-agency coordination mechanisms
 - Embedding estuary and catchment management into Council's operational and strategic planning
 - Supporting cross-departmental collaboration within Council (e.g. planning, infrastructure, environment).
- Consolidate and build upon existing research and programs. A significant body of work has been undertaken across the Tuggerah Lakes estuary and catchment, including technical studies, monitoring programs, and community-led initiatives. The CMP offers a framework to consolidate these efforts, identify gaps, and ensure strategic alignment of estuary health goals. This includes:
 - Integrating findings from the Expert Panel Review (Glamore, et al., 2020), Wetland Refugia Study (Waddington, Glamore, & Heimhuber, 2023), Recreational Use Study (Middle & Middle, 2023) and the Coastal Processes and Socio-Economic Assessment (Bluecoast Consulting Engineers and Rhelm, 2026).
 - Coordinating data collection and monitoring across agencies
 - Supporting knowledge-sharing between researchers, practitioners, and community groups.
- Unlock funding for implementation. The CMP provides access to multiple funding streams for the implementation of management actions, including:
 - NSW Coast and Estuary Grants Program
 - Clean Coastal Catchments Program
 - Federal resilience and infrastructure grants
 - Potential co-investment from private industry and philanthropic sources.

By aligning proposed actions with CMP priorities and demonstrating strategic value, Council can maximise funding opportunities and deliver cost-effective outcomes.

- Develop Adaptive Management Strategies. The CMP enables the development of adaptive strategies that respond to changing conditions, including climate change, urban growth, and ecological feedback. This includes:
 - Scenario-based planning for sea level rise and flooding



- Trigger-based actions for wrack management and sediment enrichment
- Monitoring frameworks to track ecological condition and inform future updates.

Adaptive management will ensure that actions remain relevant, effective, and responsive over the CMP's 10-year horizon and beyond.

- Enhance community engagement and stewardship. The CMP provides a platform to rebuild trust, improve transparency, and empower the community to participate in estuary management. This includes:
 - Co-designing actions with local stakeholders
 - Supporting citizen science and community monitoring
 - Delivering education and outreach programs to build awareness and stewardship.

By embedding community values and knowledge into the CMP, Council can foster long-term support and shared responsibility for the health of the estuary.

- Improve resilience of environmental, social and economic values. The Tuggerah Lakes estuary delivers a wide range of benefits, including biodiversity, recreation, tourism, and cultural heritage. The CMP provides a pathway to protect and enhance these values through targeted actions, planning controls, and infrastructure investment. This includes:
 - Restoring saltmarsh and seagrass habitats
 - Improving water quality and amenity in recreational zones
 - Safeguarding cultural heritage and supporting Indigenous peoples' involvement.

This systems-based approach will ensure that the environmental, social and economic values of the Tuggerah Lakes estuary and its catchment are enhanced and maintained.



CONTENTS

1	INTRODUCTION	15
1.1	Background	15
1.2	The Study Area	15
1.3	Objectives and Structure of this Report	21
1.4	Associated Studies and Supporting Documentation	21
1.5	Industry Standards and Guidelines used in this Assessment	22
2	METHODOLOGY	24
2.1	Application of a Risk Based Framework	24
2.2	Spatial and Temporal Scale of the Assessment	26
2.3	Limitations	27
3	GOVERNANCE, ENGAGEMENT AND COMMUNICATION	28
3.1	Introduction	28
3.2	Unclear governance and shared responsibilities	28
3.3	Insufficient or ineffective community engagement	30
3.4	Inadequate, inefficient, over and under regulation	31
3.5	Reliable funding sources and resourcing	32
4	CATCHMENT PRESSURES AND DEVELOPMENT	35
4.1	Introduction	35
4.2	Catchment Development	39
4.3	Urban and rural stormwater runoff and discharges	40
4.4	Sewage effluent and septic overflows	43
5	ENTRANCE MANAGEMENT	45
5.1	Overview	45
5.2	Dredging	48
5.3	Interim Entrance Management Procedure	53
5.4	Rock Groyne	57
5.5	Potential Alternative Entrance Management	60
6	ECOLOGY AND WATER QUALITY	66
6.1	Introduction	66
6.2	Changes in estuarine vegetation (seagrass, saltmarsh, estuarine vegetation)	66
6.3	Point and diffuse source water pollution	68
6.4	Degradation/clearing of freshwater wetland, riparian and catchment vegetation	69
7	FORESHORE/NEARSHORE AND WRACK MANAGEMENT	72
7.1	Introduction	72
7.2	Impacts on social and recreational amenity from seagrass wrack accumulation	72
7.3	Organic enrichment of sediment and black ooze formation	74
7.4	Foreshore development and management	76
7.5	Groundwater pollution	78



8	COASTAL HAZARDS	80
8.1	Introduction	80
8.2	Tidal Inundation (Including Future Sea Level Rise)	80
8.3	Combined Coastal and Catchment Flooding (including Future Sea-Level Rise)	84
8.4	Estuary Entrance Instability	87
8.5	Bank Erosion	89
9	HERITAGE AND CULTURE	92
10	RESOURCE CONFLICTS AND ACCESSIBILITY	93
11	OPPORTUNITIES	95
12	CONCLUSIONS AND NEXT STEPS	98
12.1	Summary	98
12.2	Next Steps	98
13	REFERENCES	100

LIST OF FIGURES

Figure 1-1	The CMP process	15
Figure 1-2	CMP Study Area and R&H SEPP Coastal Use Area & Coastal Environment Area	19
Figure 1-3	CMP Study Area and R&H SEPP Coastal Wetlands & Littoral Rainforest	20
Figure 4-1	Land use disturbance (left) and predominant land use type (right) for Tuggerah Lakes (State of NSW and Department of Planning, Industry and Environment, 2021)	36
Figure 4-2	NSW Estuary Health Risk scores for each sub-catchment in Tuggerah Lakes, 16 indicates the greatest risk of negative impacts on the ecological health of the estuary, 1 indicates the lowest risk (DPIE, 2019b)	38
Figure 4-3	Changes in vegetation and impervious surfaces in Warnervale from 2007 to 2025 (<i>Google Earth</i>)	39
Figure 4-4	Annual total load per sub-catchment (top) and average export of total nutrient load from 1 hectare per sub-catchment (bottom) (State Government of NSW and NSW Department of Climate Change, Energy, the Environment and Water, 2019)	43
Figure 6-1	Projected distribution of estuarine saltmarsh under +0.5m sea level rise only (State of NSW Department of Primary Industries and Regional Development, 2023)	67
Figure 8-1	Long Jetty - Tidal Probability of Exceedance Plot	81
Figure 8-2	Long Jetty - Annual Days of Exceedance Plot	81
Figure 8-3	Total numbers of properties exposed to inundation (HHWSS) for the 10 most exposed NSW estuaries, including proportion-of-lot, under 0, 0.5, 1.0 and 1.5 m SLR	83
Figure 8-4	Flooding in the Tuggerah Lakes entrance in 2022	86
Figure 12-1	Stage 3 of the CMP (adapted from the CM Manual)	99



LIST OF TABLES

Table EX-1	Summary of Stage 2 Risk Assessment Outcomes	7
Table 1-1	Snapshot of Key Physical Parameters	16
Table 2-1	Consequence Definitions, Adapted from TARA (BMT WBM, 2017)	25
Table 2-2	Likelihood Definitions, Adapted and Modified from TARA (BMT WBM, 2017)	25
Table 2-3	Risk Assessment Matrix, Adapted from TARA (BMT WBM, 2017)	25
Table 3-1	Risk Rating: Unclear governance and shared responsibilities	30
Table 3-2	Risk Rating: Insufficient or ineffective community engagement	31
Table 3-3	Risk Rating: Inadequate, inefficient, over and under regulation	32
Table 3-4	Risk Rating: Reliable funding sources and resourcing	34
Table 4-1	Risk Rating: Catchment development	40
Table 4-2	Risk Rating: Urban and rural stormwater runoff and discharges	42
Table 4-3	Risk Rating: Sewage effluent and septic overflows	44
Table 5-1	Risk Rating: Dredging	53
Table 5-2	Risk Rating: Interim Entrance Management Procedure	57
Table 5-3	Risk Rating: Groyne	60
Table 5-4	Risk Rating: Second Entrance	64
Table 5-5	Risk Rating: Training Walls	64
Table 6-1	Risk Rating: Changes in estuarine vegetation	68
Table 6-2	Risk Rating: Point and diffuse source water pollution	69
Table 6-3	Risk Rating: Degradation/clearing of freshwater wetland, riparian and catchment vegetation	71
Table 7-1	Risk Rating: Impacts on social and recreational amenity from seagrass wrack accumulation	74
Table 7-2	Risk Rating: Organic enrichment of sediment and black ooze formation	76
Table 7-3	Risk Rating: Foreshore development and management	77
Table 7-4	Risk Rating: Ground water pollution	79
Table 8-1	NSW Tidal Inundation Exposure Assessment – Results for the Tuggerah Lake Estuary	82
Table 8-2	Snapshot of tidal inundation risk distribution and rating	84
Table 8-3	Historic and Design peak flood levels within Tuggerah Lakes (MHL, 2025)	85
Table 8-4	Risk Rating: Combined Coast and Catchment Flooding	87
Table 8-5	Risk Rating: Estuary Entrance Instability	89
Table 8-6	Risk Rating: Bank Erosion	91



1 INTRODUCTION

1.1 Background

Central Coast Council (Council) is currently preparing the Tuggerah Lakes Estuary Coastal Management Program (CMP), which will establish an integrated, 10-year framework for the coordinated management of the Tuggerah Lakes estuary. The CMP aims to address key coastal issues while preserving and enhancing the area's social, cultural, economic, and environmental values.

The CMP is being developed in line with the NSW Coastal Management Framework, including the statutory requirements of the *Coastal Management Act 2016* (CM Act) and the mandatory provisions outlined in the NSW Coastal Management Manual (OEH, 2018a), hereafter referred to as the CM Manual. The program is supported by funding and technical assistance from the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW).

The CMP will be prepared through a five-stage risk management process set out in the CM Manual and depicted in Figure 1-1.

Stage 1 of the CMP was completed in 2021, with the adoption of the Stage 1 Scoping Study Report (Central Coast Council, 2021) which included a review of relevant background information, a first pass risk assessment, a data gap analysis, and the development of a forward program for the CMP.

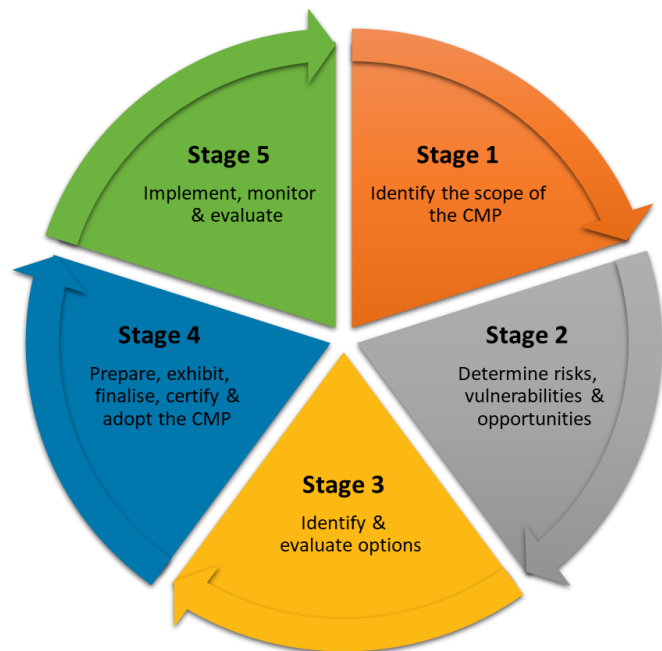


Figure 1-1 The CMP process

This Stage 2 report has been prepared on behalf of Council to meet the requirements of Stage 2 of the CMP process, building on the Stage 1 Scoping Study (Central Coast Council, 2021). Its purpose is to identify and assess the key risks, vulnerabilities, and opportunities across the study area.

The risk assessment presented in this report will support Council in understanding the complex challenges facing the estuary and inform the identification of management options and actions in Stages 3 and 4 of the CMP process.

1.2 The Study Area

1.2.1 Overview of the Estuary

The Tuggerah Lakes estuary, located on the Central Coast of New South Wales (NSW), consists of Tuggerah Lake, Budgewoi Lake, and Lake Munmorah – see Figure 1-2 and Figure 1-3. These 3 interconnected water bodies are linked by a series of shallow, narrow channels and are collectively referred to as “the Tuggerah Lakes estuary” or “Tuggerah Lakes”.

The estuary is classified as a wave-dominated estuary and falls within the category of intermittently closed or open lakes or lagoons (ICOLLs) (Roy, et al., 2001). In 2020, the Tuggerah Lakes Independent Expert Panel Review highlighted ongoing confusion surrounding the naming and classification of these water bodies, particularly in distinguishing between lakes and lagoons (Glamore, et al., 2020). To maintain consistency with the CMP Scoping Study (Central Coast Council, 2021), this report will use the following specific terminology:



- **“The estuary”** refers to the estuarine areas, including brackish rivers and creeks, saltmarshes, low-lying foreshores, water bodies, and the entrance channel.
- **“The catchment”** encompasses the surrounding landscape, including freshwater rivers and creeks, coastal wetlands, floodplains, valleys, and the adjacent plateau.

The Tuggerah Lakes estuary has an average surface water area of approximately 81 km², while its catchment spans about 790 km² (Office of Environment and Heritage (OEH), 2013). The estuary connects to the ocean via a single, narrow entrance at Tuggerah Beach embayment (The Entrance), which is kept open through mechanical intervention and periodic dredging. Key physical parameters for the estuary are provided below in Table 1-1.

Table 1-1 Snapshot of Key Physical Parameters

Category and Data Source	Parameter	Value
Classification (Roy, et al., 2001)	Estuary Group	Wave dominated
	Estuary Type	Barrier estuary
	Evolution Stage	Intermediate
Waterbody Parameters (Roper, et al., 2011; DPIE, 2020)	Waterbody Area (km ²)	81
	Estuary Volume (ML)	190,000
	Average Depth (m)	2.4
	Foreshore Perimeter (km)	138
Water levels (Long Jetty Gauge – 211418)	Average Water Level	0.27 m AHD
	Water level range	0.09-0.50 m AHD (90% of the time)
	Tidal range	1-3 cm
	Maximum tidal range	15 cm (2007 flood)
Flood Levels (MHL, 2025)	Highest recorded level (1949 flood)	2.10 m AHD
	2022 flood level	1.76 m AHD
	1% AEP (1 in 100 chance per year flood)	2.24 m AHD
Catchment Area (MHL, 2022)	Catchment Area (km ²)	790
Catchment Land Usage (Roper, et al., 2011)	Undisturbed Forest (%)	65%
	Urban (%)	14%
	Agricultural (%)	19%
	Other (%)	2%
Catchment Hydrology (Roper, et al., 2011)	Annual Rainfall (mm/yr)	1,032
	Annual Surface Flow (ML/yr)	93,110
	Annual Base Flow (ML/yr)	31,420
	Total Annual Flow (ML/yr)	124,530
	Licensed Water Extraction (ML/yr)	29,960



Category and Data Source	Parameter	Value
Estuarine Ecology (DPIRD, 2025b)	Seagrass (ha)	1,840
	Mangrove (ha)	< 1
	Saltmarsh (ha)	12
	Total Coast Wetlands (ha)	1,850
Recreational Infrastructure (TfNSW, 2022; Middle & Middle, 2023)	Public Boat Ramps	20
	Public Wharfs / Jetties	11
	Marinas	0

The Tuggerah Lakes estuary delivers a wide range of environmental, social, and economic benefits. These include clean water and air, fertile soils, carbon storage, and habitat for diverse aquatic vegetation, including State Significant Coastal Wetlands. The estuary also provides recreational opportunities and holds deep cultural and intrinsic value for the local community, in particular Indigenous peoples.

However, the estuary has experienced increasing pressure over recent decades due to population growth, land use intensification, and associated increases in stormwater runoff and pollutant loads. Since the 1960s, residential, commercial, and industrial development has significantly altered the natural functioning of the catchment and estuary. These pressures are expected to intensify with ongoing urban growth and the impacts of climate change. As an ICOLL with a large catchment relative to its estuarine area, the Tuggerah Lakes estuary is particularly vulnerable to catchment-derived impacts. The estuary's limited tidal exchange - less than 1% of the estuary's volume exchanges with the ocean during a tidal cycle - exacerbates these impacts, leading to prolonged water residence times and degraded water quality.

The health of the estuary has long been a concern for the Central Coast community and has attracted considerable political and media attention over the years. Despite extensive catchment remediation efforts over the past 10 to 15 years across public reserves, wetlands, streambanks, rural properties, and foreshore areas, and Council's monitoring programs showing that the ecological condition of the estuary is generally stable despite continued development, the health of the estuary is not improving at a pace that meets community expectations or safeguards against long-term decline.

In response to these concerns, the NSW Government established the Tuggerah Lakes Expert Panel (TLEP) in 2020 to assess water quality issues and advise on management. The Panel reviewed existing information, scientific research, and past actions, and submitted its final report in December 2020. Key areas of focus included the role of the entrance in influencing water quality, the internal characteristics of the estuary, and the impacts of catchment-based pressures. The report concluded that the Tuggerah Lakes estuary is at a critical turning point, and that effective management requires a whole-of-catchment approach supported by strong stakeholder and community collaboration. The TLEP made 52 recommendations covering planning, communication, engagement, and practical on-ground actions, many of which inform the approach taken in this CMP.

1.2.2 Legally Defined Study Area for the CMP

In accordance with the CM Act, this CMP gives effect to the management objectives for the 4 coastal management areas (CMAs) that define the coastal zone of the study area. Each CMA has different characteristics and objectives, and the areas may overlap. The CM Act provides the definition and objectives for each of the management areas. The State Environmental Planning Policy (Resilience and Hazards) 2021 (R&H SEPP) provides development controls for each of the management areas, and state-wide mapping of 3 of the 4 areas. The 4 coastal management areas as defined by the CM Act are:



- **Coastal environment area (CEA):** Land containing coastal features such as the coastal waters of the state, estuaries, coastal lakes, coastal lagoons, and land adjoining those features including headlands and rock platforms. Beaches, dunes, and foreshores are included in this area.
- **Coastal use area (CUA):** Land adjacent to coastal waters, estuaries, coastal lakes and lagoons where development is or may be carried out (at present or in the future) and impacts of development on the scenic and cultural values and use and enjoyment of the beaches, foreshores, dunes, headlands, rock platforms, estuaries, lakes and the ocean need to be considered.
- **Coastal wetlands and littoral rainforests area (CWLR):** Land which displays the hydrological and floristic characteristics of coastal wetlands or littoral rainforests, as well as a surrounding proximity area to manage impacts of adjacent development.
- **Coastal vulnerability area (CVA):** Land which is subject to any of the coastal hazards listed in the CM Act, including beach erosion, shoreline recession, coastal lake or watercourse entrance instability, coastal inundation, tidal inundation, coastal cliff and slope instability. Mapping for the coastal vulnerability area has not been provided from the R&H SEPP, and no such coastal vulnerability area (CVA) map yet exists for the study area. Nonetheless, it is recognised that the estuary is subject to coastal hazards and that the scope of this CMP also covers managing coastal vulnerability.

The study area for the CMP therefore comprises the envelope extent of these CMAs within the bounds of the estuary catchment. A map of the CMP study area is provided in Figure 1-2 and Figure 1-3, along with mapping of the CMAs discussed above.

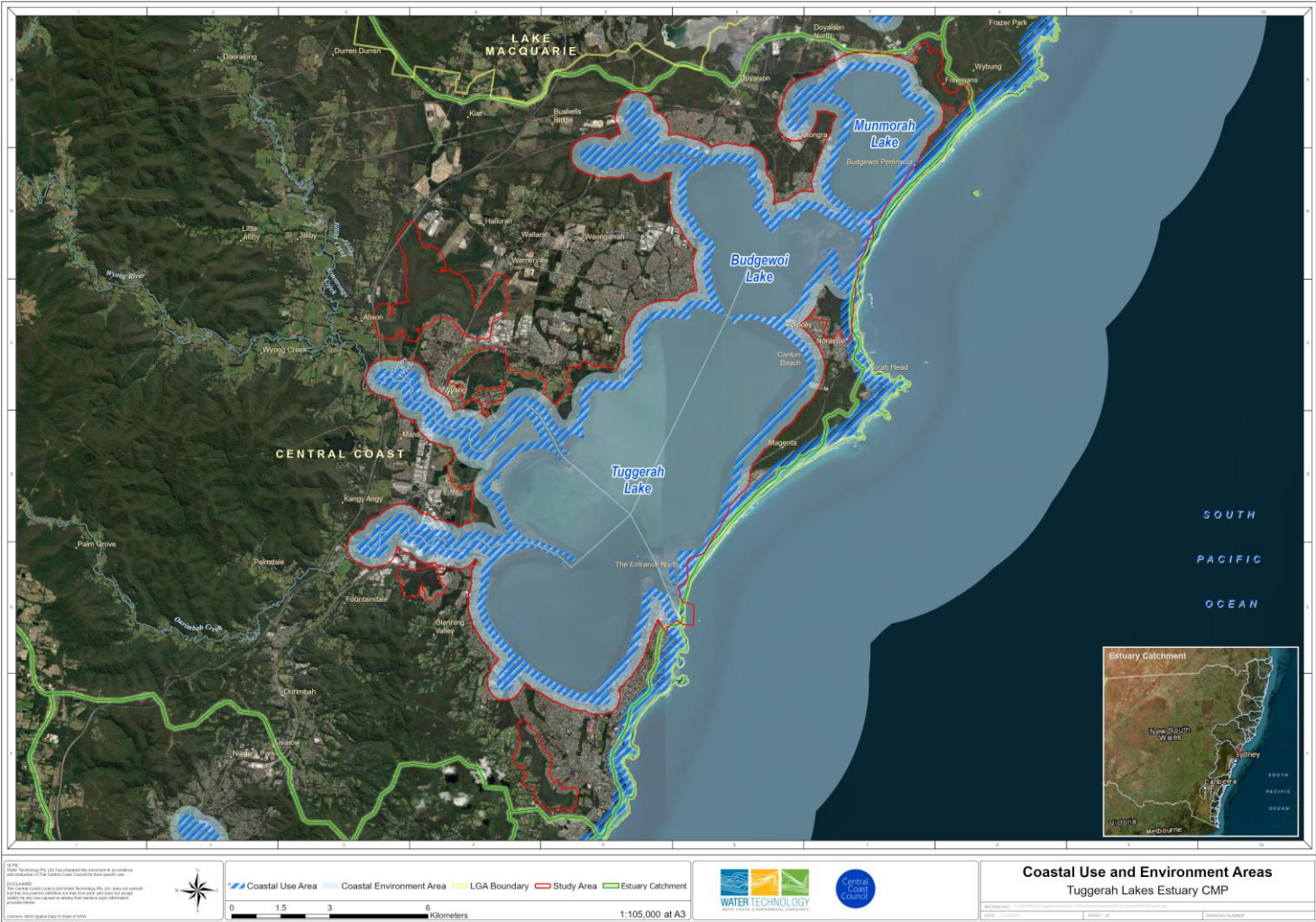


Figure 1-2 CMP Study Area and R&H SEPP Coastal Use Area & Coastal Environment Area

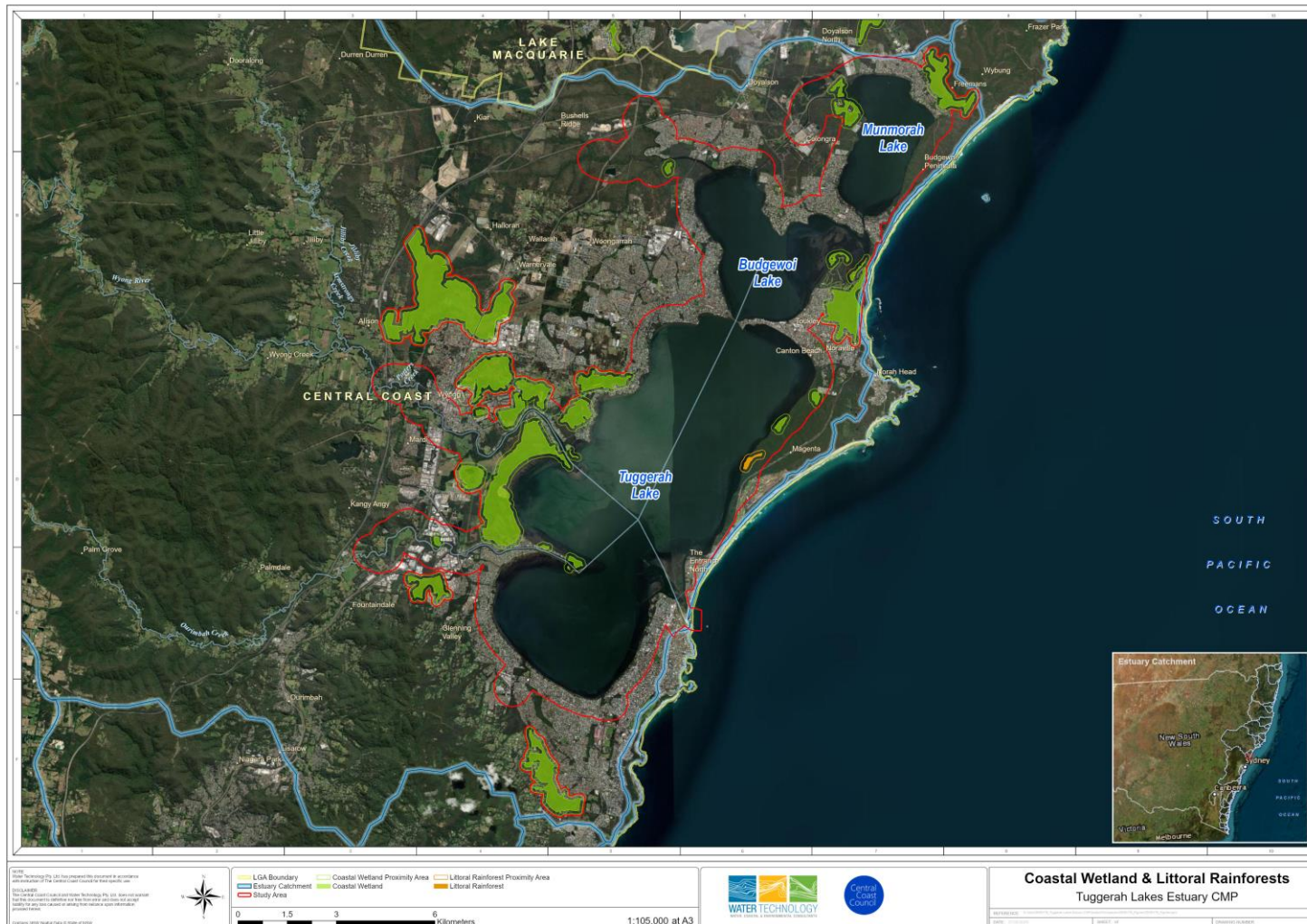


Figure 1-3 CMP Study Area and R&H SEPP Coastal Wetlands & Littoral Rainforest



1.3 Objectives and Structure of this Report

This report meets the requirements of Stage 2 as set out in the NSW Coastal Management Manual (Part B) (OEH, 2018c). It provides a focused analysis of the key threats and risks across the study area, along with a detailed and updated risk assessment.

Building on the background and first-pass risk assessment (FPRA) from the Stage 1 Scoping Study (Central Coast Council, 2021), this Stage 2 assessment offers deeper analysis of the priority threats previously identified as high risk over current and future management timeframes. These threats have been reassessed using a more detailed and robust methodology, with greater emphasis on long-term planning considerations.

While the Stage 1 FPRA remains a strong foundation, this report adds value by refining and expanding the assessment to better support the development and evaluation of management options in Stage 3. The updated risk assessment will assist Council in understanding the complexity of the issues and risks affecting the environmental, social and economic assets and values across the study area.

In particular, the following threat groups, identified in the Stage 1 Scoping Study, have been prioritised for further analysis:

- Governance, engagement and communication
- Catchment pressures and development
- Ecology and water quality
- Entrance management
- Foreshore/nearshore and wrack management
- Coastal hazards and climate risks
- Heritage and culture
- Resource conflicts and accessibility.

Each of these Issue Themes is summarised in a specific chapter of this report. To maintain efficiency and avoid duplicating information already covered in Stage 1, this report focuses primarily on the **high-risk threats** identified in the earlier FRPA. A select number of **moderate-risk threats** have also been included where additional analysis is considered beneficial. A full overview of all identified risks and threats is found in the Stage 1 Scoping Study.

1.4 Associated Studies and Supporting Documentation

1.4.1 Associated Stage 2 CMP Studies

This Stage 2 Risk Assessment Report provides a high-level synthesis of the key threats and risks affecting the Tuggerah Lakes estuary. It should be read alongside several companion technical studies prepared under Stage 2 of the CMP, each of which explores specific issues in greater detail. Together, these documents form an integrated evidence base that supports the development of management options in subsequent CMP stages.

The 4 principal companion studies are:

- *Tuggerah Lakes Entrance Management Study* (MHL, 2022) - providing updated hydrodynamic analysis and management recommendations for the lake entrance, building on previous investigations.
- *Entrance Channel Coastal Processes and Socio-economic Assessment* (Bluecoast Consulting Engineers and Rhelm, 2026) - examining the physical behaviour of the entrance channel, associated sediment dynamics, and the social and economic implications of different entrance management options.



- *Recreational Use Study* (Middle & Middle, 2023) - investigating current recreational patterns and pressures within the lakes and foreshore environments, with attention to access, amenity, and conflicts between different user groups.
- *Wetland Refugia Study* (Waddington, Glamore, & Heimhuber, 2023) - identifying key wetland areas that function as ecological refugia during periods of disturbance and assessing threats to their ongoing viability.

Each of these studies contributes critical technical insights that underpin the risk evaluation presented in this report, particularly in relation to coastal processes, ecological resilience, and human use pressures across the estuary.

1.4.2 Relevant Technical Assessments

In addition to the Stage 2 CMP studies, a number of external investigations and technical assessments have recently been completed for the Tuggerah Lakes estuary and catchment. Their findings and recommendations have been considered in preparing this report, as they provide valuable background and continuity across regional management initiatives. Key documents include:

- *Tuggerah Lakes Water Quality Independent Expert Panel Review* (Glamore, et al., 2020) – a comprehensive scientific review that examined long-term water-quality trends and identified priority actions to improve ecosystem health.
- *The Tuggerah Lakes Improvement Project* (DRAFT) (JBP, 2025) – outlining a suite of proposed restoration, infrastructure, and community engagement initiatives intended to enhance the estuary and catchment's environmental performance and recreational value, undertaken with support from an Australian Government grant.

In addition to these site-specific assessments, the risk evaluation also draws upon several regional and state-based frameworks that provide context and comparative datasets for assessing estuarine condition, exposure, and vulnerability:

- *The NSW Marine Estate Threat and Risk Assessment* (MEMA TARA) (BMT WBM, 2017).
- *The NSW Estuary Health Risk Dataset* (DPIE, 2019b)
- *The NSW Estuary Tidal Inundation Exposure Assessment* (OEH, 2018g).

These broader assessments assist in benchmarking local risks against regional patterns and contribute to the development of consistent risk and exposure indicators across NSW coastal systems.

1.5 Industry Standards and Guidelines used in this Assessment

The risk assessment framework also draws upon a range of national and international standards and guidelines that establish best practice approaches for risk identification, evaluation, and adaptation planning. These include:

- *The NSW Risk-based Framework for Considering Waterway Health Outcomes in Strategic Land-use Planning Decisions* (OEH, 2017)
- *ISO 31000:2018 Risk management – Principles and guidelines, provides principles, framework, and a process for managing risk* (International Standards Organisation, 2018)
- *AS 5334:2013 Climate change adaptation for settlements and infrastructure – a risk-based approach* (Standards Australia, 2013)
- *The NCCARF Local government framework for coastal risk assessment in Australia* (Wainwright & Verdon-Kidd, 2016).
- *The Intergovernmental Panel on Climate Change 6th Assessment Report* (IPCC, 2023).



Together, these documents establish a robust technical foundation for the CMP and align this Stage 2 Risk Assessment with best practice risk management and adaptation planning standards applied across Australia and internationally. The methodology presented in Section 2 builds upon these frameworks, outlining how they have been applied to identify, analyse, and evaluate coastal risks across the Tuggerah Lakes estuary.



2 METHODOLOGY

2.1 Application of a Risk Based Framework

Section 21 (3) (b) of the CM Act requires the application of a risk management process when preparing CMPs and identifying where management actions are required (OEH, 2018c). In line with this legislative requirement, this assessment applies a structured and transparent approach consistent with the industry standards and guidelines summarised in Section 1.5.

Risk management provides a logical and systematic process for establishing context, identifying, analysing, evaluating, treating, monitoring, and communicating the risks associated with natural processes, anthropogenic pressures, and management interventions (International Standards Organisation, 2018). When applied effectively, this process supports informed decision-making, prioritises resource allocation, and helps to minimise losses while maximising opportunities to enhance the environmental, social, and economic values of the coastal zone.

A FPRA was undertaken during the Stage 1 Scoping Study (Central Coast Council, 2021), and this assessment identified a range of existing and future emerging issues likely to affect the study area over future planning horizons of 20, 50 and 100 years.

Building upon the FPRA, this Stage 2 assessment applies a refined and expanded risk-based framework. The approach remains conceptually similar to that of the FPRA but has been broadened to:

- Incorporate a more detailed assessment of likelihood and consequence using criteria aligned with MEMA TARA (BMT WBM, 2017) definitions.
- Improve consistency and comparability across estuaries and coastal systems statewide.
- Better integrate social, economic, and cultural dimensions of risk alongside environmental considerations.
- Facilitate clearer translation of identified risks into management actions in subsequent CMP stages.

This expanded framework enables the identification and ranking of risks in a manner that supports an adaptive management approach, allowing future updates to respond to emerging threats, monitoring outcomes, and changes in system behaviour.

The likelihood and consequence scales used in this assessment are presented in Table 2-1 and Table 2-2 respectively. These definitions are adapted from the MEMA TARA (BMT WBM, 2017) to suit the context of the Tuggerah Lakes estuary and its associated catchment. Consequence ratings range from negligible (minimal or no discernible impact) to catastrophic (irreversible or permanent damage to key values). Likelihood ratings describe the expected frequency with which a threat may occur, from rare (less than once in a century) to almost certain (frequent or ongoing impacts).

Based on these scales, an overall risk rating has been assigned to each identified issue using the risk definition matrix presented in Table 2-3. The combination of likelihood and consequence provides a qualitative indication of the level of risk, categorised as *Low*, *Moderate*, *High*, or *Very High*. This methodical and repeatable process allows risks to be compared across themes and management domains, providing a defensible foundation for prioritising management actions.


Table 2-1 Consequence Definitions, Adapted from TARA (BMT WBM, 2017)

Consequence	Definition
Negligible	No or barely discernible negative impacts on the environmental, social or economic values
Minor	Discernible and/or temporary negative impacts on the environmental, social or economic values
Moderate	Measurable and on-going negative impacts on the environmental, social or economic values
Major	Substantial measurable and ongoing negative impacts on the environmental, social or economic values
Catastrophic	Significant on-going and/or permanent negative impacts on the environmental, social or economic values, and where these values are endangered either permanently or irreversibly

Table 2-2 Likelihood Definitions, Adapted and Modified from TARA (BMT WBM, 2017)

Likelihood	Definition
Rare	This threat is extremely unlikely to be realised at a level that would impact on the environmental, social or economic values within a 100-year period.
Unlikely	This threat is extremely unlikely to be realised at a level that would impact on the environmental, social or economic values within a 20-year period.
Possible	This threat is not expected to be realised at a level that would impact on the environmental, social or economic values every year, but could be expected in a 10-year period.
Likely	This threat is not expected to be continuous, but could be expected to be realised at a level that would impact on the environmental, social or economic values every year
Almost Certain	This threat is expected to be realised at a level that would impact on the environmental, social or economic values frequently throughout a year or more-or-less continuously.

Table 2-3 Risk Assessment Matrix, Adapted from TARA (BMT WBM, 2017)

Consequence →	Negligible	Minor	Moderate	Major	Catastrophic
Likelihood ↓					
Almost Certain	Low	Moderate	High	Very High	Very High
Likely	Low	Moderate	Moderate	High	Very High
Possible	Low	Moderate	Moderate	High	High
Unlikely	Low	Low	Moderate	Moderate	High
Rare	Low	Low	Low	Moderate	Moderate

In order to inform the derivation of management actions in Stage 3 of the CMP, outputs of the assessment should be considered using a 'risk tolerance' approach. In this context, assignment of a 'High' (and in certain cases a 'Moderate') risk level is a trigger for further examination of the threat, and consideration of management controls or activities to reduce this risk.

It should be noted that in some cases, it will not be feasible, practical or possible to manage all threats to low or minimal risk levels. This will then need to be considered in the context of the tolerance of the risk, both now and over the 10-year CMP planning horizon. Likewise, rating as a 'Minimal' or 'Low' risk level indicates the



threat is currently acceptable but still needs to be considered and tracked over time, particularly where there is poor information or evidence related to the threat or stressors and its effect is not well known (BMT WBM, 2017).

2.2 Spatial and Temporal Scale of the Assessment

Spatial Scale

The spatial scale of the risk assessment has been tailored to match the nature of each stressor and the scale at which management decisions are most relevant. The Tuggerah Lakes estuary is extensive and spatially diverse, comprising interconnected lagoons, tidal channels, wetlands, foreshores, and a developed urban fringe. Some threats - such as declining water quality, altered entrance dynamics, or loss of aquatic habitat - operate at the estuary-wide scale, meaning their impacts and management responses are broadly consistent across the estuary.

Other pressures are site-specific or locally expressed, such as shoreline erosion, infrastructure vulnerability, or recreational access conflicts. These vary according to local land use, exposure, and environmental setting. By assessing risks at the most appropriate geographic resolution, the analysis avoids unnecessary complexity while still capturing meaningful spatial variation that can influence management actions.

This approach provides several practical advantages for Stage 3:

- It identifies where interventions can be applied strategically - for example, water-quality improvements that benefit the entire estuary versus localised works such as bank stabilisation or habitat restoration.
- It highlights management units or zones (e.g. entrance channel, foreshores, backswamps) that can be used to organise actions and assign responsibilities.
- It supports the development of scalable responses, enabling Council to prioritise investments in locations where risk is highest or where management leverage is greatest.

Overall, the spatial framing has been intentionally designed to generate outputs that are actionable, map-based, and directly usable in subsequent stages, particularly for identifying feasible management options, preparing concept designs, and aligning future works with Council's asset management systems and grant programs.

Temporal Scale

Whilst the CMP will largely focus on implementing management actions over the coming 10-year management horizon, it is important to consider the evolution of the various threats and stressors facing the study area over longer timeframes. For this reason, the NSW Coastal Management Manual requires that risk should be assessed over a range of future management horizons (OEH, 2018c). This requires consideration of:

- Potential climate change impacts such as sea-level rise, altered rainfall patterns, and temperature-driven ecosystem change.
- Population growth and urban intensification, influencing stormwater loads, foreshore access, and recreational demand.
- Ongoing development and land-use change within the coastal zone and contributing catchments.

When considering future scenarios for critical infrastructure or long-term land use planning decisions, it is appropriate to gain an understanding of the full range of risks over longer timeframes and high range projections (OEH, 2018c). Therefore, the risk assessment has considered not just the present-day risk, but potential future risk over the following standard planning horizons:

- Present Day (~2025) – representing current estuary and catchment condition and management context.



- 20 Years (~2045) – aligning with near-term urban growth and infrastructure planning cycles.
- 50 Years (~2075) – capturing mid-century climate projections and generational shifts in land use and policy.
- 100 Years (~2125) – representing a high-range, long-term scenario used primarily for stress-testing strategic planning and infrastructure resilience.

This temporal framing is intended to guide practical decision-making rather than predict precise future states. It helps identify where immediate actions can meaningfully reduce current risks, and where longer-term adaptation pathways may be required. For example:

- If a risk remains low across all horizons, short-term operational responses may suffice.
- If a risk escalates markedly by 2075 or 2125, the focus can shift toward progressive adaptation measures, planning controls, or monitoring triggers to inform future CMP updates.

By explicitly linking timeframes to the scale and reversibility of each issue, the assessment provides a clear and pragmatic basis for prioritising management responses in Stage 3, balancing what is actionable now against what requires staged planning, ongoing observation, or policy adjustment in future cycles.

2.3 Limitations

While this risk assessment provides a structured and transparent evaluation of threats and stressors affecting the Tuggerah Lakes estuary and catchment, several limitations should be acknowledged when interpreting the results and applying them to Stage 3 decision-making. These limitations do not reduce the overall validity of the assessment but are important context for understanding how the outputs should be used.

While this risk assessment provides a robust framework for evaluating threats, risks, and opportunities across the CMP Study Area, a number of limitations and uncertainties should be acknowledged:

- Data availability and accuracy - The assessment draws upon the best available data at the time of preparation, including hydrodynamic modelling, ecological monitoring, and recent technical studies completed under Stage 2. However, data coverage and spatial resolution vary across the study area. In some cases, surrogate datasets or expert judgement were used where monitoring records were limited. The results therefore represent the most reliable current understanding rather than definitive estuary and catchment conditions.
- Qualitative Nature of Risk Ratings - Risk ratings are qualitative and relative, intended to identify and compare management priorities rather than quantify absolute probabilities or impacts. They should be viewed as a screening and prioritisation tool to guide decision making in Stage 3 and beyond.
- Uncertainty in Future Projections - The inclusion of long-term horizons (20, 50, and 100 years) introduces uncertainty associated with climate change projections (IPCC, 2021), land-use assumptions, and policy settings. These scenarios reflect the best available guidance at the time of assessment but will require review at the end of the CMP's 10 year life cycle, as new data and modelling become available.
- Scale and Scope of Assessment - The analysis has been scoped to remain proportionate to management needs, focusing on risks and scales most relevant to practical decision-making. It does not attempt to model every process or quantify all stressors in detail, as this would provide limited additional value for management planning. Site-specific development proposals may require more detailed geotechnical or coastal engineering investigations.
- Interpretation and Application - The outputs of this assessment should be used as a strategic decision-support tool to inform the prioritisation and design of management actions in Stage 3. The results identify relative risks, highlight where targeted investigations or monitoring are justified, and provide an evidence-based foundation for adaptive management and resource allocation.



3 GOVERNANCE, ENGAGEMENT AND COMMUNICATION

3.1 Introduction

Effective governance, transparent communication, and meaningful community engagement are essential to the success of long-term coastal and estuary management. The Scoping Study (Central Coast Council, 2021) and the Expert Panel Review (Glamore, et al., 2020) identified significant institutional, procedural, and communication challenges that continue to limit coordinated planning, implementation, and community confidence.

The governance structure for the Tuggerah Lakes estuary involves multiple agencies and overlapping responsibilities across state and local government, with additional contributions from community groups, industry, and research organisations. This complexity has created uncertainty over leadership, accountability, and funding responsibilities for key management actions.

Similarly, while the community has a long history of engagement in lake management programs, consultation efforts have often been fragmented, reactive, and short-term. Engagement is commonly driven by specific events or projects, rather than by a consistent, ongoing program of dialogue that builds understanding and trust.

Both the Scoping Study and community submissions noted frustration with regulation and policy frameworks that are seen as either inconsistent or excessive, with conflicting requirements across planning, environmental protection, and coastal management instruments. This has led to delays, duplication, and at times a lack of confidence in the decision-making process.

The Scoping Study (Central Coast Council, 2021) FPRA identified 4 key stressors related to governance, engagement, and communication that were found to be High Risk (over present day and/or future planning horizons) that have been addressed in more detail in this Stage 2 risk assessment:

- Unclear governance and shared responsibilities – see Section 3.2
- Insufficient or ineffective community engagement – see Section 3.3
- Inadequate, inefficient, over and under regulation – see Section 3.4
- Reliable funding sources and resourcing – see Section 3.5

3.2 Unclear governance and shared responsibilities

The management of Tuggerah Lakes involves a broad network of entities, each with legitimate but often overlapping interests. Council carries principal responsibility for on-ground works, foreshore planning, and implementation of the CMP. However, strategic and statutory roles are distributed among numerous NSW Government agencies - such as DCCEEW, NPWS, Transport for NSW, and Crown Lands - alongside regional catchment, water, and biodiversity authorities.

The Scoping Study (Central Coast Council, 2021) found that this distributed model leads to fragmented planning, duplication of effort, and difficulty sustaining collective accountability for outcomes. Decision-making is frequently project-specific and funding-driven rather than guided by a unified, long-term framework. Key risks include:

- Diffuse accountability – No single body is responsible for tracking system-wide outcomes or maintaining strategic oversight once projects conclude.
- Variable capacity and resourcing – Funding and expertise fluctuate between agencies, leaving some programs under-resourced or dependent on short-term grants.



- Lack of integration between catchment and coastal planning – Different planning cycles and statutory frameworks create misalignment between land-based and marine processes.
- Inconsistent monitoring and data sharing – Monitoring programs have been initiated by multiple entities using differing methods, leading to data fragmentation and duplication.

Without a clear governance framework, many strategic actions remain aspirational rather than operational. The Expert Panel Review emphasised that improved governance is not solely an administrative issue, it directly affects how science is translated into management and how confidence is built among the community (Glamore, et al., 2020).

Future stages of the CMP provide an opportunity to address this through development of a Tuggerah Lakes Governance Framework that clearly defines responsibilities, coordination mechanisms, and accountability pathways. This could include:

- A standing multi-agency Steering Committee or Lake Management Partnership to coordinate delivery, reporting, and funding.
- Formalisation of role delineation between Council divisions and state agencies, clarifying who leads, supports, and funds each category of action.
- Memoranda of Understanding or implementation agreements to support continuity across political and budget cycles.
- A transparent monitoring and reporting system, accessible to both agencies and the public, to track performance indicators and outcomes over time.

Clarifying governance arrangements will strengthen alignment between coastal, catchment, and planning programs, and provide the institutional stability required for effective delivery of Stage 3 actions.

It should be noted that the Expert Panel Report recommended 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 CMP. 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 the Tuggerah Lakes estuary 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.

Risk Rating

In considering the risk rating for unclear governance and shared responsibilities, the following factors were considered:

- Present day – Overlapping agency roles, inconsistent communication, and fragmented delivery responsibilities between Council, State agencies, and stakeholders, however, with actions underway to improve governance.
- 20 years – Increasing policy complexity, competing statutory obligations, and administrative duplication as new frameworks emerge.
- 50 years – Institutional fatigue, lack of accountability, and loss of institutional knowledge as staff turnover and structural changes accumulate.
- 100 years – Increasing governance failure leading to uncoordinated management, duplication of effort, and loss of public trust.


Table 3-1 Risk Rating: Unclear governance and shared responsibilities

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	Entire study area / Tuggerah Lakes estuary and catchment area
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Likely	Major	High	
100 years (~2125)	Likely	Major	High	

3.3 Insufficient or ineffective community engagement

Community connection to the Tuggerah Lakes estuary is deep and enduring. Residents, recreational users, Indigenous peoples, and local groups all express strong attachment to the estuary and a vested interest in its management. Yet, the Scoping Study (Central Coast Council, 2021) and Expert Panel Review (Glamore, et al., 2020) both observed that engagement to date has been inconsistent, with periods of high participation followed by long gaps in communication.

Past initiatives such as the Tuggerah Lakes Expert Panel and local Landcare projects demonstrated that communities are willing to participate when information is clear and outcomes are visible. However, without a long-term communication strategy, engagement often reverts to one-off consultations focused on contentious issues like entrance dredging, wrack removal, or foreshore access. This episodic approach erodes public confidence and limits opportunities for shared ownership of management outcomes.

Several challenges have been identified:

- Complex technical language – Scientific findings are not always translated into accessible formats, limiting understanding of why certain actions are prioritised.
- Perceived lack of responsiveness – Community feedback is not consistently incorporated into decisions, leading to frustration and disengagement.
- Limited visibility of progress – The community rarely sees how management actions are tracked or evaluated, contributing to perceptions of inaction.
- Fragmented messaging – Different agencies and programs sometimes deliver inconsistent information about objectives, priorities, or progress.

Improving engagement for the Tuggerah Lakes estuary requires a sustained and coordinated approach that treats communication as a core management function rather than an ancillary task. Priorities include:

- Developing a long-term Communication and Engagement Plan linked directly to CMP implementation, outlining clear principles, channels, and responsibilities.
- Establishing a public information portal and interactive dashboards to provide regular updates on projects, monitoring results, and funding status.
- Adopting plain-language materials and visual summaries to make scientific and technical information accessible to a general audience.
- Building local stewardship networks through schools, community groups, and volunteer programs to support on-ground monitoring and habitat restoration.
- Integrating First Nations engagement to recognise cultural values and traditional knowledge in ongoing management.



- Hosting regular community forums and open days to maintain dialogue, rather than limiting participation to formal exhibition periods.

A more transparent and inclusive engagement framework will improve public understanding, reduce conflict, and support collaborative decision-making under Stage 3. In doing so, it will also build the long-term social licence needed to support adaptation measures such as land-use change, foreshore realignment, or new regulatory controls.

Risk Rating

In considering the risk rating for community engagement, the following factors were considered:

- Present day – Limited community awareness, inconsistent communication channels, and consultation fatigue.
- 20 years – Growing population diversity and digital communication gaps increase barriers to participation.
- 50 years – Reduced social cohesion, declining volunteerism, and disconnection from place.
- 100 years – Potential Loss of community stewardship and erosion of support for environmental management.

Table 3-2 Risk Rating: Insufficient or ineffective community engagement

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Moderate	Moderate	■ Entire study area / Tuggerah Lakes estuary and catchment area
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Likely	Major	High	
100 years (~2125)	Likely	Major	High	

3.4 Inadequate, inefficient, over and under regulation

The regulatory landscape for Tuggerah Lakes is complex and is impacted by a wide range of legislation, and a suite of state environmental planning policies and local development controls. The Scoping Study (Central Coast Council, 2021) concluded that this framework has become both overly burdensome in some respects and insufficiently protective in others.

At one end of the spectrum, small-scale, environmentally beneficial works - such as foreshore revegetation, wrack removal, or minor dredging to restore conveyance - can require multiple permits and lengthy environmental assessments. At the other, activities such as private foreshore modification, illegal infilling, or unapproved vegetation clearing often proceed with limited oversight due to jurisdictional ambiguity or resource constraints. The result is a patchwork of enforcement that undermines public confidence.

Key regulatory challenges include:

- Duplication of approvals across state and local processes, often requiring parallel applications to multiple agencies.
- Inconsistent interpretation of policy, with different authorities applying varying thresholds for assessment.
- Insufficient clarity for landholders regarding permissible works and environmental obligations.
- Limited capacity for compliance and monitoring, leaving breaches unresolved or detected too late to remedy environmental harm.



This regulatory imbalance constrains adaptive management and slows delivery of legitimate works. It also perpetuates community perceptions that regulation is unfairly applied or ineffective.

Improving regulatory efficiency and transparency for the Tuggerah Lakes estuary will require coordinated reform rather than isolated procedural changes. Potential directions include:

- Developing a Regulatory Alignment Plan as part of Stage 3 to identify overlaps, streamline approval pathways, and clarify responsibilities.
- Creating standing exemptions or fast-track pathways for low-impact maintenance and restoration works consistent with CMP objectives.
- Reviewing local planning controls to explicitly integrate CMP hazard mapping, setback provisions, and habitat protection measures.
- Preparing clear guidelines for foreshore landowners, outlining permissible activities, design standards, and approval requirements.
- Strengthening enforcement mechanisms for illegal filling, reclamation, and vegetation clearance through coordinated compliance programs.
- Improving communication between agencies, including shared databases of permits and enforcement actions.

Regulatory improvement should not aim solely at simplification, but at achieving balance where environmental safeguards are strong, approval processes are proportionate, and compliance is transparent. By addressing these issues, Stage 3 of the CMP can help create a policy environment that supports timely, effective, and adaptive management across the Tuggerah Lakes estuary and catchment.

Risk Rating

In considering the risk rating for regulatory inefficiency, the following factors were considered:

- Present day – Complex and overlapping policy instruments with limited enforcement and monitoring.
- 20 years – Growth in competing development pressures and inconsistent application of planning controls.
- 50 years – Regulatory fatigue and widening gaps between statutory intent and on-ground outcomes.
- 100 years – Complete regulatory misalignment resulting in unmanaged development and system decline.

Table 3-3 Risk Rating: Inadequate, inefficient, over and under regulation

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	■ Entire study area / Tuggerah Lakes estuary and catchment area
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	

3.5 Reliable funding sources and resourcing

Long-term improvement of the Tuggerah Lakes estuary and catchment depends not only on sound governance and planning but also on stable and sufficient resourcing. The Scoping Study (Central Coast Council, 2021) and internal Council reviews have highlighted that inconsistent funding, limited staff capacity, and fragmented processes remain key barriers to implementing priority actions.



Ad Hoc and Constrained Funding

Council's capacity to deliver coastal and estuarine management actions is limited by its overall financial position and heavy reliance on external grants. While state and federal funding has supported works such as dredging, stormwater upgrades, and, wetland, saltmarsh and riparian rehabilitation, these programs are typically competitive and short-term. Expenditure rules often restrict how funds can be applied, with outcomes defined by project-specific milestones rather than CMP priorities. This results in fragmented investment, high administrative effort, and limited continuity once grants conclude.

Many of the most important ongoing needs - such as monitoring, adaptive management, and community engagement - do not align neatly with available funding streams. The outcome is a cycle of visible but temporary works, rather than long-term improvement in estuary and catchment condition.

Internal Capacity and Collaboration

Within Council, resource constraints and workload pressures affect the ability to integrate and sustain coastal management across programs. Staff responsible for environmental, engineering, and planning functions often operate within separate systems and budgets, limiting collaboration on complex, cross-disciplinary projects. Internal silos, time-poor teams, and competing priorities make it difficult to embed CMP actions into day-to-day operations such as road upgrades, drainage renewal, or land-use planning.

A further challenge lies in capability. Some staff lack the technical background or support to identify opportunities for improved coastal outcomes or to prepare competitive funding submissions. Without a dedicated coordination role or delivery group, the integration of CMP priorities across Council remains inconsistent.

Improving Funding and Resourcing

To move from opportunistic project delivery to strategic, long-term management, Stage 3 of the CMP should include development of a Business Plan that:

- Identifies priority, costed actions suitable for inclusion in Council's Delivery Program and Operational Plan.
- Establishes ongoing internal budgets for coordination, monitoring, and maintenance.
- Explores co-funding and partnership models with State agencies, research institutions, and local stakeholders.
- Builds internal capability in funding strategy, project scoping, and benefit–cost analysis.
- Improves internal communication and tracking of grant opportunities through a shared register or funding database.

Reliable funding and skilled, well-connected staff are fundamental to the effective delivery of the Tuggerah Lakes Estuary CMP. Building this capacity will help shift the program from reactive, grant-driven works to a stable and adaptive management framework capable of sustaining long-term outcomes for the estuary.

Risk Rating

In considering the risk rating for funding and resourcing, the following factors were considered:

- Present day – Heavy reliance on short-term external grants and limited internal coordination capacity.
- 20 years – Ongoing financial constraints, increased competition for grants, and staff resource limitations.
- 50 years – Structural under-funding of environmental programs and growing maintenance backlogs.
- 100 years – Chronic funding shortfall resulting in systemic decline of estuarine condition and service delivery.


Table 3-4 Risk Rating: Reliable funding sources and resourcing

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	Entire study area / Tuggerah Lakes estuary and catchment area
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	



4 CATCHMENT PRESSURES AND DEVELOPMENT

4.1 Introduction

Ongoing and future catchment development poses a significant threat to the Tuggerah Lakes estuary, with urbanisation, stormwater runoff, sewage overflows, and agricultural activities contributing to water pollution and ecological decline. Despite some planning controls and remediation efforts, management remains inadequate to address the scale of current and projected impacts, particularly given the region's rapid population growth, ageing infrastructure, and resource constraints.

Land use across the Central Coast LGA is mixed, as set out in Table 1-1 (Roper, et al., 2011). The largest form of land use is conservation and natural environments, covering approximately 65% of the area. Other significant land uses include urban (14%) and agricultural (19%), while the surface waterbody also comprises a large proportion of the catchment (9%), reflecting the abundance of lakes, lagoons, rivers, and creeks throughout the region (State of NSW and Department of Planning, Industry and Environment, 2021). A map of the prevailing land usage across the catchment is provided in Figure 4-1.

Within the catchment, moderate disturbance land use is the most widespread (42.7%), largely due to forestry in the upper catchment and grazing in the mid-to-lower lying areas. This is closely followed by low disturbance land use (42.5%), comprising conservation areas, mostly in the upper catchment, though some are being encroached upon by grazing and urban development. High disturbance areas make up 14.8% of the catchment, a slightly higher proportion than in the broader Central Coast LGA, mainly due to urban development around Tuggerah Lake and intensive agriculture in the lower floodplains and western boundary areas. Population density is highest in the lower catchment, particularly in urban zones near Tuggerah Lakes, Wyong River, and Ourimbah Creek, while rural residential development is more common in the mid and lower catchment, often mixed with grazing and agricultural land (Figure 4-1).

The Scoping Study (Central Coast Council, 2021) FPRA identified 3 key stressors related to catchment pressures that were found to be high risk (over present day and/or future planning horizons) that have been addressed in more detail in this Stage 2 risk assessment:

- Catchment development – see Section 4.2
- Urban stormwater runoff and discharges – see Section 4.3
- Sewage effluent and septic overflows – see Section 4.4

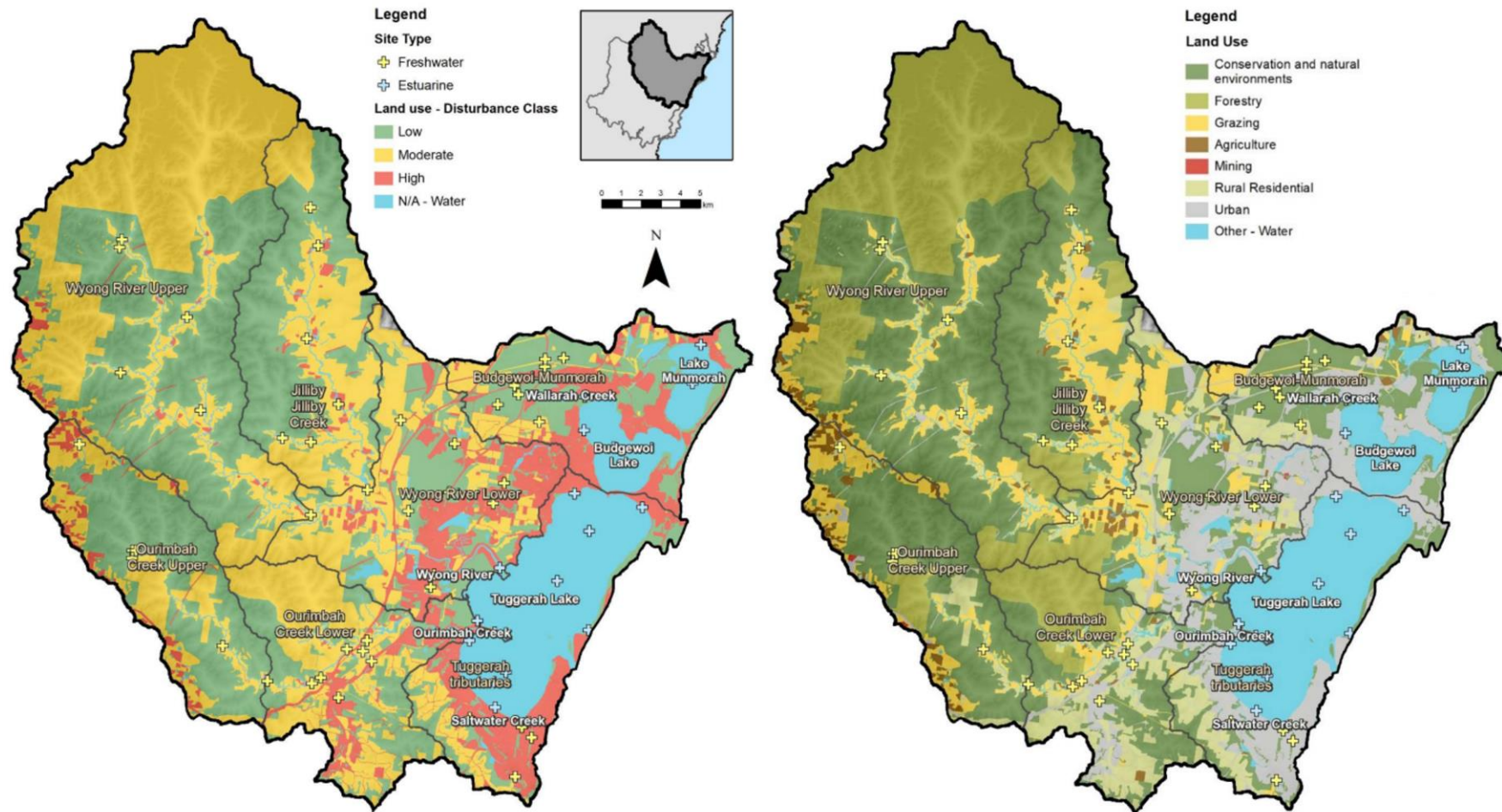


Figure 4-1 Land use disturbance (left) and predominant land use type (right) for Tuggerah Lakes (State of NSW and Department of Planning, Industry and Environment, 2021)



The NSW Estuary Health Risk Dataset (EHRD) from NSW DPIE indicates that the Tuggerah Lakes estuary is under significant and uneven pressure from its surrounding sub-catchments (DPIE, 2019b). The EHRD uses a risk matrix approach, and each sub-catchment is assessed based on the likelihood and magnitude of its runoff impacting the estuary's health. Risk scores range from 1 to 16, with higher scores indicating greater potential harm (Figure 4-2).

High-Risk Areas (scores 12-16; orange to red)

High-risk sub-catchments are widespread across the Tuggerah Lakes catchment, with notable concentrations in the south, southeast, northeast, and central regions. These areas pose the greatest threat to the estuary's ecological health due to the combined effect of a high likelihood of runoff and a high magnitude of impacts (further explored in Section 4.3). Their proximity to the estuary's shoreline suggests that key inflows may be delivering substantial loads of pollutants or significantly altered water flow directly into the estuary. As a result, these high-risk sub-catchments are likely contributing disproportionately to declining water quality, habitat degradation, and increased ecological stress within the estuary.

Moderate-Risk Areas (scores 6-9; yellow to light orange)

Moderate-risk sub-catchments are distributed across the interior and the border (predominantly north-west) zones of the catchment. These areas may be experiencing moderate levels of land-use pressure or runoff, and while they currently pose less threat than the highest-risk zones, they remain important to monitor. With appropriate management, these areas could either improve in condition or, if left unchecked, deteriorate further and contribute to additional impacts on estuarine health. As such, they represent a critical focus for preventative and adaptive management strategies.

Low-Risk Areas (scores 1-4; green to blue)

In contrast, several sub-catchments, mostly located in the northwestern and a few scattered interior areas, have been classified as low risk (scores of 1 to 4). These sub-catchments are likely characterised by intact vegetation, low-intensity land use, or effective natural buffering of runoff. While these areas currently contribute minimal impact to the estuary, maintaining their condition is vital. They may serve as ecological refuges or play a role in supporting the overall resilience of the estuary and catchment.

The Tuggerah Lakes estuary is currently facing widespread ecological pressure, particularly from numerous high-risk sub-catchments. Without targeted management, restoration, or mitigation, the estuary's ecological condition is likely to decline further. Immediate intervention is needed in the most critical sub-catchments (score 16) to protect and possibly restore ecological health. A catchment-wide integrated management approach is essential for sustainable estuarine health.

Recommended actions regarding broad estuary health include:

Prioritise High-Risk Sub-Catchments (Scores 12–16)

- Implement targeted pollution control measures, such as riparian buffer restoration, sediment traps, and nutrient management.
- Reduce land-use pressures through improved regulation of agricultural, industrial, or urban development activities contributing to runoff.
- Establish or strengthen local stormwater management infrastructure, including detention basins and green infrastructure (e.g., rain gardens, swales).
- Promote land use change or conservation easements where feasible, especially in areas of steep slopes or poor soil stability.
- Enhance community engagement and compliance with land and water management guidelines.



Stabilise Moderate-Risk Sub-Catchments (Scores 6–9)

- Increase monitoring and data collection to detect early signs of ecological degradation.
- Encourage best management practices in agriculture, such as controlled fertiliser use, cover cropping, and managed grazing.
- Support landholder incentives and stewardship programs to adopt soil and water conservation techniques.
- Control invasive species and manage fire regimes to protect vegetation cover and reduce erosion.

Protect and Maintain Low-Risk Sub-Catchments (Scores 1–4)

- Preserve existing natural vegetation and wetland areas that provide filtering and buffering functions.
- Prevent land use intensification or infrastructure development in these areas.
- Designate conservation zones or ecological corridors to maintain connectivity and biodiversity.

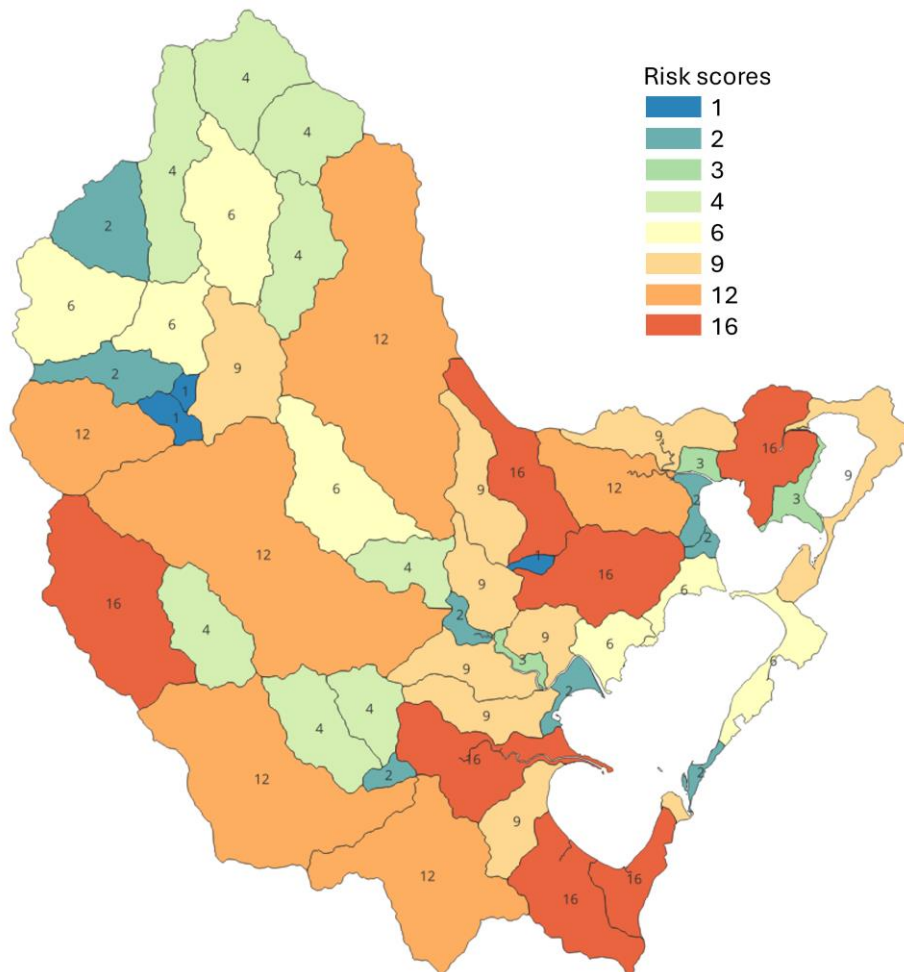


Figure 4-2 NSW Estuary Health Risk scores for each sub-catchment in Tuggerah Lakes, 16 indicates the greatest risk of negative impacts on the ecological health of the estuary, 1 indicates the lowest risk (DPIE, 2019b)



4.2 Catchment Development

The Tuggerah Lakes catchment has experienced profound changes over the past several decades. Historically, the region was characterised by extensive wetlands, forested areas, and low-density rural land uses that naturally filtered water and supported ecological resilience. These landscapes played a critical role in maintaining the health of the estuary by regulating nutrient inputs, slowing runoff, and supporting biodiversity.

Since the 1980s, however, urbanisation has accelerated, particularly in growth corridors such as Warnervale – Wadalba, and Tuggerah – Wyong (Figure 4-3). This expansion has led to a dramatic increase in impervious surfaces, such as roads, rooftops, and paved areas, which disrupt natural hydrological cycles which have effects on downstream ecological features such as Porters Creek Wetland. Rainfall that once infiltrated into the ground now flows rapidly into stormwater systems, carrying with it sediments, nutrients (especially nitrogen and phosphorus), and pollutants. These changes have intensified nutrient loading into the estuary and its surrounding wetlands, contributing to eutrophication, fuelling algal blooms, depleting oxygen levels, and threatening aquatic life.



Figure 4-3 Changes in vegetation and impervious surfaces in Warnervale from 2007 to 2025 (Google Earth)

The Tuggerah Lakes Water Quality Independent Expert Panel Review warns that without strategic planning and intervention, future development could return the estuary to the degraded conditions of the late 20th century, when fish kills, algal blooms, and poor water quality were common (Glamore, et al., 2020). These impacts are not unique to Tuggerah Lakes, similar patterns have been observed in other NSW estuaries, such as Lake Illawarra, where rapid urbanisation led to severe ecological decline (BMT Commercial Australia Pty Ltd, 2020). In that case, restoration efforts, including catchment reforestation, stormwater retrofitting, and community engagement, were necessary to reverse decades of damage.

In the Tuggerah Lakes estuary, the risk is compounded by the estuary's shallow depth and limited tidal exchange, which make it particularly sensitive to nutrient inputs. The lakes' morphology as an ICOLL means that pollutants tend to accumulate rather than flush out, increasing the likelihood of long-term ecological degradation if development pressures are not carefully managed.



Recommended actions for catchment development include:

- Integrate sustainable catchment development principles into the CMP, ensuring that future growth aligns with ecological capacity.
- Develop and apply planning controls that mandate Water Sensitive Urban Design (WSUD) in all new developments, including rain gardens, permeable pavements, and vegetated swales, with prescriptive requirements that must be met.
- Establish a Catchment Coordinator Taskforce to oversee strategic planning, stakeholder coordination, and implementation of catchment-wide water quality initiatives.

Risk Rating

In considering the risk rating for catchment development, the following factors were considered:

- Present day – Ongoing urban expansion, legacy infrastructure, limited WSUD uptake.
- 20 years - Continued population growth, loss of wetland buffers, increased impervious surfaces
- 50 years – Intensified land use, climate-driven hydrological changes, reduced estuary resilience
- 100 years – Near-total urbanisation, chronic nutrient enrichment, irreversible habitat loss

The consequences of those factors were identified and rated for potential impact:

- Present day – Localised degradation and land clearing, increased nutrient loading, requiring targeted interventions
- 20 years – Major impacts including elevated runoff, sedimentation, and stress on aquatic ecosystems, requiring coordinated planning and investment
- 50 years – Major and widespread eutrophication, frequent algal blooms, and biodiversity decline
- 100 years – Catastrophic estuary-wide ecological failure, collapse of ecosystem services and cultural values

Both the factors and consequences were then taken together to determine a final risk rating for catchment development over the next 100 years, as outlined in Table 4-1.

Table 4-1 Risk Rating: Catchment development

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	■ Warnervale Wadalba Land Release Area ■ Tuggerah – Wyong Growth Corridor ■ Northern Growth Corridor ■ Lake Munmorah ■ Spring Creek
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	

4.3 Urban and rural stormwater runoff and discharges

Stormwater runoff is one of the most persistent and damaging sources of pollution in the Tuggerah Lakes estuary. As urban areas expand, rainfall increasingly flows over hard surfaces, collecting nutrients, sediments, hydrocarbons, heavy metals, and litter before entering the lakes. This runoff contributes to nutrient enrichment, sedimentation, and algal blooms, which degrade water quality and aquatic habitats.



Historically, stormwater infrastructure in the region has been reactive and fragmented. While gross pollutant traps and constructed wetlands exist, they are often under-maintained or poorly located. The Tuggerah Lakes Estuary Process Study (hereafter referred to as the Estuary Process Study) highlights that many older suburbs lack effective stormwater treatment, and newer developments sometimes fail to meet best-practice design standards (Wyong Shire Council, 2000). Comparatively, the Georges River catchment in Sydney has implemented successful stormwater retrofitting programs, demonstrating the value of sustained investment and community education (Georges Riverkeeper, 2025).

Pollutants enter the Tuggerah Lakes freshwater and estuarine extents from both rural and urban sub-catchments, but in different ways and with different impacts (Figure 4-4). The majority of total pollutant loads come from rural areas during large rainfall or flood events. These areas, mainly used for agriculture and grazing, are extensive, and during heavy rains, water runs over the land, picking up sediments, nutrients (like nitrogen and phosphorus), and animal waste, which are then washed into the lakes. While these events usually only occur several times a year, they contribute a significant amount of pollution all at once. Managing this type of runoff involves strategies that reduce erosion and nutrient loss, such as maintaining vegetation buffers along waterways, improving land and grazing practices, and constructing wetlands or sediment traps to slow and treat runoff during floods.

In contrast, urban sub-catchments generate more reactive pollutants per unit area and have a greater impact on the estuary's nearshore zones throughout the year. Urban environments, with their large areas of impervious surfaces like roads, rooftops, and pavements, prevent water from soaking into the ground. As a result, even small rain events quickly create runoff that carries pollutants such as oils, heavy metals, garden fertilisers, litter, and pet waste directly into storm drains and then into the estuary. These consistent, year-round inputs affect areas closest to the shore, where recreational and ecological values are highest. Managing urban runoff requires a different approach, focusing on water sensitive urban design and source control measures like rain gardens, permeable surfaces, stormwater treatment systems, and public education. Together, these strategies can help reduce the intensity and frequency of urban pollution entering the estuary.

Recommended actions for urban and rural stormwater runoff and discharges:

- Retrofit stormwater controls in existing urban areas to improve pollutant capture in high priority sub-catchments first.
- Enhance maintenance and performance of stormwater treatment devices.
- Introduce a stormwater levy to fund infrastructure upgrades and regular audits.
- Maintain vegetation buffers along waterways.
- Improve land and grazing practices.
- Construct wetlands or sediment traps to slow and treat runoff during floods.
- Educate landholders and the broader community on pollution prevention and stormwater quality management.

Risk Rating

In considering the risk rating for urban and rural stormwater runoff and discharges, the following factors were considered:

- Present day - Stormwater runoff from existing developments; under-maintained stormwater infrastructure; localised pollution events, high rainfall events in the catchment.
- 20 years - Increased impervious surfaces; insufficient retrofitting of stormwater controls; higher pollutant loads, changed landuses in catchment.



- 50 years – Cumulative effects of urbanisation; climate-driven rainfall intensity; overwhelmed stormwater systems
- 100 years – Chronic pollutant accumulation; infrastructure failure; no natural buffers remaining

The consequences of those factors were identified and rated for potential impact:

- Present day – Measurable impacts on water quality and aquatic habitats; occasional recreational water use restrictions
- 20 years – Substantial degradation of water quality; frequent algal blooms; reduced ecosystem health
- 50 years – Persistent water quality decline; loss of sensitive habitats; long-term ecological stress
- 100 years – Estuary-wide ecological collapse; irreversible damage to estuarine values and recreational use

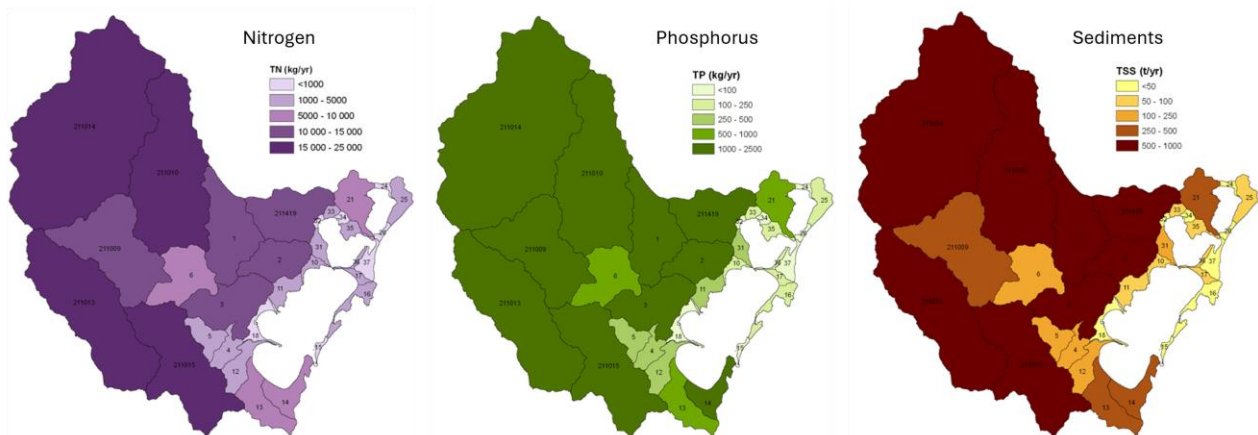
Both the factors and consequences were then taken together to determine a final risk rating for urban stormwater runoff and discharges over the next 100 years, as outlined in Table 4-2.

Table 4-2 Risk Rating: Urban and rural stormwater runoff and discharges

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	▪ Current nearshore catchments and heavily urbanised areas ▪ Proposed Growth Corridors and Land Release Areas Developments further afield (e.g. Warnervale) ▪ Rural areas of the catchment including turf farms and other intensive agriculture
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	



Annual total load per subcatchment (kg/yr)



Average export of total nutrient load from 1 hectare per subcatchment (kg/ha/yr)

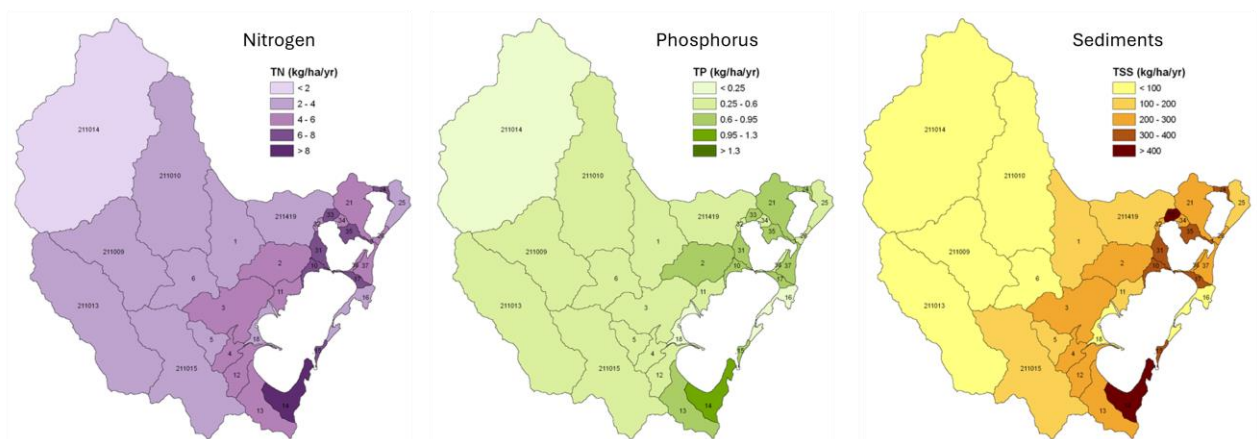


Figure 4-4 Annual total load per sub-catchment (top) and average export of total nutrient load from 1 hectare per sub-catchment (bottom) (State Government of NSW and NSW Department of Climate Change, Energy, the Environment and Water, 2019)

4.4 Sewage effluent and septic overflows

Sewage-related pollution has long been a concern in the Tuggerah Lakes catchment. Before the rollout of regional sewerage schemes, many households relied on septic systems, which often leaked nutrients and pathogens into groundwater and surface waters. While most urban areas are now connected to sewerage infrastructure, overflow events during heavy rainfall still occur, particularly in low-lying or flood-prone zones.

The Estuary Process Study and Expert Panel Review both note that legacy septic systems and ageing sewer infrastructure continue to pose risks (Glamore, et al., 2020; Wyong Shire Council, 2000). Faecal contamination has been detected in several lake zones, prompting temporary closures and public health advisories. Similar challenges have been faced in the Brisbane River catchment, where targeted upgrades and monitoring programs have helped reduce sewage-related impacts (Brisbane City Council, 2025).

Recommended actions for sewage effluent and septic overflows include:

- Continue upgrading and monitoring sewage infrastructure to prevent overflow events.
- Investigate sources of faecal contamination and implement targeted mitigation measures.



- Promote sustainable water use to reduce pressure on freshwater systems and maintain environmental flows to the estuary.

Risk Rating

In considering the risk rating for sewage effluent and septic overflows, the following factors were considered:

- Present day - Overflow events during heavy rainfall; legacy septic systems in older developments; moderate ecological and public health risks
- 20 years - Increased urban density; aging sewer infrastructure; higher frequency of overflow events; limited capacity for stormwater infiltration.
- 50 years – Cumulative infrastructure failure; climate-driven rainfall intensity; widespread contamination from legacy systems
- 100 years – Chronic pollution from outdated systems; irreversible damage to aquatic ecosystems and public health infrastructure

The consequences of those factors were identified and rated for potential impact:

- Present day – Measurable impacts on water quality and recreational use; manageable with monitoring and infrastructure upgrades
- 20 years – Substantial degradation of water quality; increased faecal contamination; frequent recreational closures and ecological stress
- 50 years – Persistent water quality decline; long-term ecological degradation; reduced resilience of estuarine habitats
- 100 years – Estuary-wide ecological collapse; permanent loss of recreational and cultural values; high public health risk

Both the factors and consequences were then taken together to determine a final risk rating for sewage effluent and septic overflows over the next 100 years, as outlined in Table 4-3.

Table 4-3 Risk Rating: Sewage effluent and septic overflows

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	■ Central Coast region has disproportionate number of overflows when compared with other local regions (EPA pers. comm., 2020). ■ Designated swimming areas incl Canton Beach (high priority) and Lake Munmorah (moderate to low priority).
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	



5 ENTRANCE MANAGEMENT



5.1 Overview

Tuggerah Lakes is a large, wave-dominated ICOLL which alternates between natural closure and periods of open tidal exchange. Prior to European settlement, the entrance would have often remained closed for many months – sometimes more than a year – reopening only when major rainfall or coastal storms raised lake levels high enough to breach the berm (CSIRO, 1999; MHL, 2022).

Human modification began early in the twentieth century, driven by the dual pressures of flooding and navigation. Local residents and fishers occasionally dug pilot channels to drain flooded lowlands or restore tidal access. Council records and newspaper reports describe formal entrance openings as early as 1915 and dredging of navigation shoals from 1912 (MHL, 2022). Documented government programs include works by Erina Shire Council (1939) and Wyong Shire Council (1957 – 1968; 1986) to relieve flooding (CSIRO, 1999; Umwelt, 2011). These early efforts straightened the channel, reclaimed intertidal flats near Memorial Park, created small islands, and removed several minor channels. Despite repeated intervention, the entrance was recorded as closing at least 13 times during the 20th century (Umwelt, 2011).

Physical Works

Between the 1960s and 1990s, extensive revetment works stabilised both the northern and southern foreshores of the lower estuary, constraining local shoreline movement but exerting little influence on the natural berm position at Dunleith Point (Bluecoast Consulting Engineers and Rhelm, 2026).

A significant structural intervention adjacent to the entrance occurred in 2017, when the NSW Government constructed a 100 m long rock groyne on The Entrance Beach, about 150 m south of the typical channel. The groyne was intended to retain sand for beach amenity in front of South Entrance beach and surf club (Cardno, 2015). Ongoing monitoring and evaluation of the performance and impact of the groyne indicate that it is



serving its intended function of retaining sand on South Entrance beach for longer durations. However, there has been a loss of beach width to the north of (downdrift) of the groyne. Although the groyne was not intended to function as an entrance management measure, its longer-term impacts on entrance dynamics has not yet been fully established (Salients, 2024). In recent times, there has been more frequent channel openings adjacent to this groyne, and coastal erosion occurring just to the north of the groyne, exposing a buried seawall in poor condition. The channel outflow between the rock shelf and groyne was not previously common. It has impacts to access, amenity, public safety, Surf Life Saving and emergency response access.

Modern Entrance Management

A consistent dredging program began in 1993, marking the start of modern, structured entrance management. Wyong Shire Council (later Central Coast Council) purchased and operated a small cutter-suction dredge (CSD) under an Environmental Protection Licence. Dredging targeted tidal shoals within the entrance to maintain limited tidal exchange, improve amenity, and modestly reduce flood levels.

Dredging campaigns typically progressed upstream to downstream, removing sand from the inner channel near Terilbah Island through to the outer delta, then pumping it to North Entrance Beach for nourishment. Occasional placements also occurred at The Entrance Beach. The outer channel – seaward of the bridge – was dredged most frequently, while upper reaches such as Terilbah Channel and flood-tide shoals were addressed as required (Umwelt, 2011).

Dredging was previously trigger based and now is undertaken on an as-needed basis rather than on a fixed annual schedule, to maintain hydraulic connectivity (MHL, 2022). Dredging volumes vary with storm frequency, infilling rates, and sediment availability. Between 1993 and 2018, cumulative extraction is estimated at 0.6 – 1.4 million m³ (WorleyParsons, 2009; GHD, 2019), range between 30,000 – 80,000 m³ per dredging campaign.

Spoil has traditionally been placed south of Hargraves Street, near the longshore “null point” within the compartment, allowing sand to recirculate toward the entrance. Placement followed Review of Environmental Factors (REF) requirements (WorleyParsons, 2009): dune crest matching, stable 1 V: 5 H foredune gradients, and berm slopes of 1 V: 20 – 30. Additional nourishment of The Entrance Beach occurred in 1994, 1999, 2004, and 2018.

Operations were suspended in 2018 after an EPA stop-work order concerning spoil handling. Council’s ageing dredge was decommissioned after reaching the end of its budgeted serviceable life, and subsequent works have been delivered by external contractors with improved methodologies under the 2020 REF which accounted for changes to the dredge program, legislation and licensing. The 2020 campaign removed ~25,000 m³ from reaches upstream and downstream of The Entrance Bridge (RoyalHaskoningDHV, 2020), pumping material to Karagi Park for dewatering and trucking it to North Entrance Beach. This workflow remains the approved operational model for future campaigns of similar scale, including planned 2026 works.

Current Management

To modernise operations, Council developed the Interim Entrance Management Procedure (EMP) through the Tuggerah Lakes Entrance Management Study (MHL, 2022). The EMP is supported by the MHL Flood Intelligence Tool (MHLFIT), which combines rainfall forecasts from the Bureau of Meteorology with lake-level and tidal data to predict estuary levels up to 4 days ahead, which allows proactive and informed management.

Entrance condition is classified into 5 states, each prescribing different predefined responses commensurate with the degree of constriction:

- Berm scraping to lower the crest height,
- Pilot channel excavation to initiate a secondary opening, or
- Reactive mechanical opening under rare full-closure scenarios.



Monitoring uses real-time tracking of the M_2 tidal constituent as a quantitative proxy for entrance constriction within the channel compartment. This is supported by observations of throat width using satellite imagery and drone surveys. Modelled outcomes indicate that entrance management provides flood-level reductions of <0.2m – modest but beneficial for local damage mitigation (MHL, 2022).

The procedure formalises a proactive, risk-based operational framework, recognising that flooding in the Tuggerah Lakes estuary cannot be eliminated but can be partially mitigated through timely, evidence-based intervention.

Strategic Context, Evolving CMP Management Framework and future of the entrance

The Tuggerah Lakes CMP Scoping Study (Central Coast Council, 2021) identifies the entrance management as a key management priority, recognising that entrance behaviour is a contributor to estuarine health.

The Scoping Study recommended the following sequential actions:

- A detailed Stage 2 Coastal Processes and Socio-economic Study (Bluecoast Consulting Engineers and Rhelm, 2026) – to consolidate and clarify information on the physical processes shaping the entrance and to assess how past, current, and proposed management interventions influence entrance condition, tidal exchange, flushing, water quality, and related socio-economic values.
- A Stage 3 Entrance Management Strategy – to build upon Stage 2 findings and previous investigations, incorporating stakeholder and community input to balance multiple objectives including flood mitigation, recreation, amenity, and ecological sustainability. This will be a formal Entrance Management Strategy, superseding interim arrangements. This work will be undertaken as part of the next stage (Stage 3) of the CMP.

Additionally, there remains considerable uncertainty regarding how the entrance will evolve over coming decades. Climate change introduces multiple interacting pressures, including sea level rise, altered storm intensity, and changes in rainfall patterns. These drivers will influence both ocean and estuarine processes, potentially modifying sediment transport pathways, entrance stability, and shoreline configuration.

The Open Coast CMP coastal erosion hazard mapping indicates that, under the 2100 1% AEP erosion extent, shoreline recession could extend landward through the Karagi Point car park (Bluecoast Consulting Engineers, 2024). Such recession would fundamentally alter the configuration of the entrance compartment compared to its present-day form. This may result in a re-alignment or widening of the entrance channel, changes to the stability of the tombolo and adjacent beaches, and modified wave and tidal energy penetration into the entrance compartment.

These projected changes highlight that the entrance is not a static landform but a highly dynamic coastal feature subject to both coastal and catchment influences. Accordingly, long-term entrance management must consider not only current behaviour but also the potential for climate-driven reshaping of the entrance morphology. Adaptive management approaches that retain flexibility may be better suited to this uncertainty than permanent structural interventions, which could constrain the system's natural capacity to adjust to future conditions.

The following sections provide the risk assessment for dredging, the Interim Entrance Management Strategy, the groyne, and potential alternative entrance management options.



5.2 Dredging

5.2.1 Impacts on Natural Hydraulic and Morphological Processes

Context

The entrance to the Tuggerah Lakes estuary is a dynamic and inherently unstable coastal feature that responds rapidly to changes in hydrodynamic forcing and sediment supply. Natural processes of long-shore sand transport, wave action, and flood-driven outflow continuously reshape the entrance bar and ebb delta, maintaining a delicate balance between fluvial and marine influences (MHL, 2022; Cardno, 2013).

Over the past century, these processes have been progressively modified by dredging, spoil placement, and shoreline stabilisation.

The CMP Scoping Study (Central Coast Council, 2021) and Entrance Management Study (MHL, 2022) both conclude that the entrance is now in a semi-managed equilibrium: still dominated by natural processes but influenced by the frequency, timing, and configuration of dredging (and entrance opening) operations.

Modification of Sediment Transport Processes

Each dredging campaign produces an immediate, short-term adjustment to sediment transport and entrance morphology. Excavation of the entrance throat and ebb delta temporarily modifies flow patterns and redistributes sand between the inner channel, flood-tide shoals, and nearshore bar. Despite these short-term disturbances, successive REFs have consistently found that these impacts are modest, and manageable through adaptive monitoring and environmental controls (RoyalHaskoningDHV, 2020; WorleyParsons, 2009).

A key finding across several studies is that dredged material remains within the active sand-sharing system of The Entrance. Dredged material is required to be placed within the same sediment compartment. Therefore, sand removed from the channel nourishes eroded locations and improves access and amenity. The sand is placed on adjacent beaches – most commonly North Entrance Beach – where it continues to contribute to the local littoral sediment budget (MHL, 2022). This circulation pattern means dredging primarily redistributes sediment rather than removing it from the system.

Monitoring and aerial imagery confirm that long-shore processes gradually rework the placed sand, with much of it migrating back toward the entrance throat during subsequent seasons or storm events. When managed correctly, this cycle effectively recycles sediment within the natural coastal compartment, minimising net change to the overall sediment budget (Central Coast Council, 2021; MHL, 2022).

The dredge footprint has also been refined to limit erosion risks to adjacent foreshores within the channel. Although community concern has been raised regarding the angle of the main channel alignment, observed erosion along the southern edge of Dunleith Tourist Park and the Karagi Foreshore Park is largely attributed to ebb-tide flow concentration and natural current patterns, rather than to dredging activity (RoyalHaskoningDHV, 2020; Cardno, 2013).

Sand placed on North Entrance Beach, within the same sediment compartment, provides short-term nourishment and amenity gains but is highly mobile. Storms and seasonal drift can cause some of this material to return to the channel, driving periodic infilling and reinforcing the need for continued maintenance dredging (MHL 2022). In addition, the magnitude and frequency of rainfall events influence catchment inflows, and is a key driver of entrance infilling. REFs have consistently concluded that dredging does not significantly alter the estuary's hydrodynamics or sediment-transport behaviour beyond the natural range of variability observed at The Entrance (RoyalHaskoningDHV, 2020; WorleyParsons, 2009).



Modification of Hydrodynamics / Flooding

Entrance dredging is intended to maintain flow connection between the main lake to the entrance throat. Connectivity is primarily driven by catchment rainfall but supported to a lesser extent by maintenance dredging.

Under the Interim Entrance Management Procedure (MHL, 2022), these works are designed to replicate natural morphology and maintain average water levels within the lakes.

Modelling and empirical studies indicate that maintaining an open entrance improves flood-water discharge during the initial stages of flood events. When compared to pre-flood conditions – where the entrance may be partly or completely closed – a dredged channel provides a more effective pathway for flood outflow and initial scour (Central Coast Council, 2021; MHL, 2022; Cardno, 2013). However, this benefit diminishes for major events where lake outflows exceed entrance conveyance capacity.

Consistent with previous assessments, dredging is not expected to significantly reduce peak flood levels across the wider estuary (MHL, 2022; Cardno, 2013). Instead, it primarily assists with the timing and efficiency of flood recession by facilitating faster initial drawdown of high water levels once rainfall ceases.

Overall, the hydrodynamic effects of entrance dredging are considered localised and temporary. By maintaining channels in an open condition consistent with natural morphology, dredging improves hydraulic responsiveness without materially changing long-term tidal behaviour or sediment-transport trends.

Climate Change and Entrance Management

Looking ahead, climate change and rising sea levels are expected to gradually alter entrance dynamics and estuarine hydraulics. Higher mean sea levels will increase the frequency and duration of tidal exchange, reduce the duration of entrance closures, and enhance the potential for oceanic inundation. Under these conditions, the geomorphic and hydraulic consequences of dredging - currently minor and short-term - may become progressively more pronounced, requiring ongoing review of management triggers and adaptation of the current entrance management framework (MHL, 2022).

However, as highlighted by the Expert Panel (Glamore, et al., 2020), there is significant uncertainty regarding how the entrance will evolve as ocean levels continue to rise. It is anticipated that sand within the entrance shoals will gradually be reactivated, with more sand washing in from the ocean to raise sand levels within the entrance. This process is likely to be accompanied by a landward recession of the coastal barrier, potentially stabilising the entrance against future closure. At the same time, higher ocean water levels will diminish the protective function currently provided by Karagi Point, increasing exposure of low-lying areas to marine inundation. The balance between these two competing processes - enhanced stability versus reduced protection - is not yet well understood and represents a key source of uncertainty for long-term entrance management under climate change (Glamore, et al., 2020).

5.2.2 Impacts on Water Quality

Context

Water quality within the Tuggerah Lakes estuary is primarily governed by catchment inputs, wind resuspension, and nutrient cycling, rather than by entrance management or tidal exchange (Roberts, 2001; OEH, 2013). Investigations undertaken for the Tuggerah Lakes Estuary Process Study (Roberts, 2001) and the Waterway Monitoring, Evaluation and Reporting Program (2011–2020) found that nutrient concentrations are typically lower in the entrance channels than in the open lake basins, reflecting the dominance of marine sand and stronger flushing at The Entrance.

The most recent REF for dredging activities (RoyalHaskoningDHV, 2020) confirmed that dredging activities have limited influence on overall lake water quality, as the clean, sandy sediments in the entrance contain little fine material or organic matter. Turbidity across the Tuggerah Lakes estuary is instead driven largely by



resuspension of fine silts and clays in the shallow basins (average depth ~1.7 m), whereas the entrance channels remain comparatively clear due to their coarser substrate and higher settling velocities (Glamore, et al., 2020).

Six functional zones were identified in the Tuggerah Lakes estuary (Glamore, et al., 2020):

- 1. Open lake basins** - As noted above, the open lake basins are relatively shallow (up to 3.5m deep). These basins generally have fine-grained organic-rich sediments due to infilling sediment from creeks. The basins are slowly filling due to incoming catchment sediment.
- 2. Soft-sediment nearshore zones** - The predominate lake nearshore zone (defined as from the shoreline to approximately 100 - 250m offshore) consists of shallow (<1.5m deep) sandy and silty sediments, subject to sorting and transport due to wind waves. This zone has also been subject to the formation of 'ooze' on the surface layer, due to excessive growth and subsequent decomposition of macroalgae.
- 3. Rocky nearshore zones** - The lake nearshore zone also has some areas of foreshore with rocky shores and sub-tidal reefs. This zone is similar to the soft-sediment nearshore zone, however the hard shoreline impacts physical and ecological processes differently.
- 4. Entrance compartment** - This marine delta zone is consists of Dunleith Point (entrance berm) and the entrance channel and shoals to west of The Entrance bridge. The eastern portion of this compartment is highly dynamic in terms of depth and channel location (if any) with marine sands susceptible to prevailing ocean and fluvial conditions, and mechanical intervention.
- 5. Estuarine river channels** – This zone includes Wyong River, Ourimbah Creek, Tumby Creek and Wallarah Creek. These waterways are consistently deep (>3m), with steep banks.
- 6. Fringing wetlands** – These wetlands sit around the typical lake and creek extents and are irregularly inundated during high water levels so subject to wetting and drying phases. This zone has an important ecological function.

In the lake basins (functional zone 1), water quality appears to be largely controlled by the quality of incoming water rather than by variations in entrance width. Although only two significant flood events occurred during the monitoring period—making it difficult to fully assess flooding impacts—available evidence indicates that even major entrance widening during floods does not result in long-term changes to water quality in these basins (Bluecoast Consulting Engineers and Rhelm, 2026).

In the nearshore zones (functional zones 2 and 3), water quality similarly reflects the characteristics of inflowing water. These areas show greater variability and are more prone to fluctuations, which could increase the risk of algal blooms and other water quality issues.

No direct water quality measurements are available for the entrance compartment (functional zone 4). However, observations from the community and tidal monitoring data (MHL, 1993) suggest that water quality in this zone is likely influenced by the width of the entrance. While the precise extent of this effect into the flood tide delta is unknown, aerial imagery indicates that the entrance compartment—extending at least to The Entrance Bridge—is generally well flushed by tidal flows (Bluecoast Consulting Engineers and Rhelm, 2026)

Potential Impacts from Dredging Activities

During dredging campaigns, short-term increases in turbidity can occur around the dredge footprint and spoil placement areas. These plumes are typically localised and temporary, settling rapidly once pumping ceases. Where dredged material is pumped to shore for dewatering, sediment-control measures such as silt curtains or sand bunds are applied where feasible to contain suspended material and protect adjacent waterways (RoyalHaskoningDHV, 2020).



Sediment testing has confirmed that entrance sands possess adequate acid-neutralising capacity, meaning there is no expected change to pH or risk of acid sulfate activation. Similarly, no significant changes to dissolved oxygen, salinity, or nutrient levels are anticipated, and all predicted impacts remain within the thresholds of the project's Environmental Protection Licence (EPL).

Any short-term reduction in water clarity is confined to the immediate works area and typically dissipates within hours to days. The REF determined that these effects are minor, localised, and temporary, representing a low risk to overall estuarine water quality.

For water quality, the consensus from available studies (MHL, 2022; Glamore, et al., 2020); is that climate change and SLR are not expected to significantly alter water quality outcomes related to entrance management.

Over future planning horizons, the ecological impacts of dredging are expected to remain minor but may change in nature as sea levels rise. Higher ocean water levels will alter the hydrodynamic regime of the entrance, potentially increasing the frequency and duration of tidal exchange and modifying salinity gradients in the lower estuary. These shifts could influence seagrass composition and distribution. Dredging campaigns may become less necessary for maintaining entrance stability as higher sea levels promote a more persistently open channel, though the ecological footprint of dredging may extend slightly landward as intertidal habitats migrate. Overall, while dredging will continue to have low water quality risk, its interactions with evolving coastal conditions will warrant ongoing monitoring and adaptive management.

5.2.3 Impacts on Ecological Pressures

The entrance channel and adjacent nearshore environments support a range of estuarine and coastal habitats, including seagrass, saltmarsh, intertidal sandflats, and dune vegetation. These habitats provide feeding and breeding grounds for diverse aquatic fauna, including fish, invertebrates, and migratory shorebirds. The area is classified as Class 1 – Major Key Fish Habitat under the *NSW Fisheries Management Act 1994* and supports both Type 1 (Highly Sensitive) and Type 2 (Moderately Sensitive) fish habitats due to the presence of *Zostera capricorni* seagrass and macroalgae beds (NSW DPI-Fisheries, 2013; RoyalHaskoningDHV, 2020).

The Terilbah Island and North Entrance foreshores also support coastal vegetation communities, including Spinifex grasslands, coastal wattle, and casuarina stands, as well as breeding habitat for the Little Tern (*Sterna albigula*), listed as endangered under the *Biodiversity Conservation Act 2016*.

Dredging has a localised, short-term effect on ecological processes, primarily within and adjacent to the dredge footprint (RoyalHaskoningDHV, 2020). Potential impacts include:

- Temporary disturbance or removal of small seagrass patches within the entrance channel, conservatively estimated at < 300 m² (WorleyParsons, 2009). This represents a negligible proportion of the ~ 17.7 km² of seagrass meadows across the Tuggerah Lakes estuary.
- Localised turbidity plumes during dredging, which may temporarily reduce light penetration and affect photosynthesis in nearby seagrass beds. Given the coarse, sandy nature of sediments, these effects are minor and short-lived, with seagrass typically recolonising disturbed areas once stability returns.
- Disturbance to benthic fauna in shallow sands, which is expected to be temporary given the high natural variability and mobile nature of the substrate.
- Minimal effects on macroalgae, saltmarsh, and terrestrial vegetation, as these communities are largely outside the dredging and placement zones.
- Potential disturbance to shorebirds, particularly the Little Tern, during nesting periods. Dredging campaigns are scheduled to avoid the key breeding season and may cease temporarily if nesting activity occurs nearby.



Overall, these effects are short-term, reversible, and spatially confined, with no significant impacts expected on key ecological communities, threatened species, or overall ecosystem function. No further assessment under the *EPBC Act 1999* or *BC Act 2016* has been deemed necessary (Royal HaskoningDHV 2020).

5.2.4 Impacts on Social and Cultural Values

The entrance and adjacent foreshores hold high social and cultural value for both local residents and visitors, supporting recreation, tourism and community identity. Community surveys indicate that the most valued aspects of the area are its natural beauty, marine life and water clarity, with boating, swimming and fishing being dominant recreational uses (Bluecoast Consulting Engineers and Rhelm, 2026). Maintaining a visually appealing and accessible entrance channel is closely tied to perceptions of environmental health and amenity, contributing to the local tourism economy and the sense of place for nearby communities (Glamore, et al., 2020).

Recreational Access and Safety

Periodic dredging and consequent sand nourishment provide direct social benefits through the maintenance of safe boating access, navigable depths for small watercraft, and aesthetically improved beaches. Another benefit is the improvement of access, e.g. sand nourishing near Karagi carpark, which is otherwise eroded by ebb scour, as well as the beach access. Dredged material placed along North Entrance Beach and The Entrance Beach has improved local recreational quality and supported the coastal tourism economy. However, during dredging campaigns, temporary disruptions can occur. These include restricted public access to foreshore areas, reduced visibility, construction noise, and safety restrictions for boaters, swimmers, and beach users.

The REF (RoyalHaskoningDHV, 2020) identifies that navigation during dredging is limited by the presence of the dredge and floating pipelines, requiring temporary closures or rerouting for larger vessels. Public safety risks are mitigated through site management measures such as fencing, exclusion zones, high-visibility markers, and Notices to Mariners. Works are typically scheduled outside of peak tourism and fishing seasons, including the summer prawn season and the Little Tern breeding period, to minimise user conflict and ecological disturbance.

In the longer term, dredging improves safety by reducing navigation hazards within the channel, and stabilising eroded foredunes with beach nourishment. Beach nourishment can lead to improved beach access and the maintenance of key vehicle beach access points – for example, for the Entrance Surf Club, and to reach the berm for implementation of the entrance management procedure prior to a flood event. These benefits contribute to a more predictable and safer environment for both waterway users and foreshore visitors.

Cultural and Heritage Values

The Tuggerah Lakes region contains numerous Aboriginal heritage sites associated with fishing, foraging and ceremonial activity, with several sites within the vicinity of the lake entrance (Central Coast Council, 2021). While the entrance area has been repeatedly disturbed by historical dredging, the potential remains for unrecorded heritage items. In accordance with standard management practice, any suspected finds during dredging would trigger a stop-work procedure and notification to the relevant authorities under the NPW Act 1974.

Amenity and Community Perception

The entrance channel is a highly visible and symbolic element of the Tuggerah Lakes landscape. Maintenance of a clean, open channel with clear water and sandy beaches has been closely linked to community satisfaction and public perception of estuary health (MHL, 2022; Glamore, et al., 2020). Prolonged closure of the entrance or the accumulation of stagnant water and algal growth are typically associated with negative public concern.



Conversely, well-timed dredging campaigns and visible improvement in beach conditions are generally regarded positively by both residents and visitors.

Future Risks under Sea Level Rise

Over future planning horizons, the social and amenity risks associated with entrance management are expected to remain low but will evolve with rising sea levels and changes in coastal use. Higher water levels may increase tidal exchange and alter shoreline access patterns, particularly at Karagi Park and North Entrance Beach. Entrance management works may become less critical for maintaining tidal flow, yet the footprint of works may shift landward as the barrier recedes. Continued engagement with the community and Indigenous peoples will be essential to balance navigation, recreation, heritage and environmental objectives under changing coastal conditions.

Risk Rating

In considering the risk rating for dredging, the following factors were considered:

- Present day - the hydraulic and morphological impacts of entrance dredging are considered localised and temporary. Social benefits including access.
- 20 years - Increased urban density; Impacts of sea level rise, changed hydrological regimes as a result of climate change
- 50 years – Entrance management works may become less critical for maintaining tidal flow, yet the footprint of works may shift landward as the barrier recedes.
- 100 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change

The consequences of those factors were identified and rated for potential impact:

- Present day – Impacts on lake water quality are minimal. Ecological effects are short-term, reversible, and spatially confined, with no significant adverse impacts anticipated on key ecological communities, threatened species, or overall ecosystem function.
- 20 years – Dredging may become problematic due to changes in rainfall patterns, sea level rise and community expectations.
- 50 years – Higher water levels may increase tidal exchange and alter shoreline access patterns
- 100 years – Higher water levels may increase tidal exchange and alter shoreline access patterns

Table 5-1 Risk Rating: Dredging

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Possible	Moderate	Moderate	■ The estuary entrance
20 years (~2045)	Possible	Moderate	Moderate	
50 years (~2075)	Possible	Moderate	Moderate	
100 years (~2125)	Possible	Moderate	Moderate	

5.3 Interim Entrance Management Procedure

The estuary entrance is currently managed through the Interim Entrance Management Procedure (EMP) (MHL, 2022). Management options include periodic, event-based berm-scraping, pilot channel excavation, and the beneficial reuse of spoil, and limited mechanical intervention.



The entrance condition is classified into 5 states, each prescribing different predefined responses commensurate with the degree of constriction:

- Berm scraping to lower the crest height,
- Pilot channel excavation to initiate a secondary opening, or
- Reactive mechanical opening under rare full-closure scenarios.

5.3.1 Impacts on Natural Hydraulic and Morphological Processes

The EMP was developed to allow natural morphological processes to continue, with targeted intervention only when risk levels justify management action. It seeks to allow natural entrance processes to operate with minimal disturbances in accordance with the NSW Government's Policy and Guidelines for Fish Habitat Conservation and Management (DPI, 2013).

Berm scraping and pilot channel excavation are undertaken to promote opening at a preferred alignment (e.g. avoiding excessive northern or southern migration), thereby reducing the likelihood of adverse hydraulic behaviour such as inefficient discharge, elevated upstream water levels, or unintended erosion adjacent to assets.

The primary objective of the EMP is to reduce risks to life, public assets, and private property associated with flooding (MHL, 2022). Modelled flood level reductions are relatively small (generally less than 0.2 m); however, within low-gradient estuarine systems, even minor reductions in peak water level may materially reduce the probability of property inundation.

Importantly, the interim procedure does not seek to maintain a permanently open entrance. Instead, it recognises the dynamic nature of the system, whereby the entrance naturally constricts during drier periods with limited catchment inflows and scours during wetter periods with increased rainfall and discharge. Maintaining a permanently open condition would introduce greater and more continuous disturbance to sediment transport processes and may increase long-term geomorphic and ecological risk. The adopted approach of berm scraping and pilot channel excavation if required therefore represents a risk-balanced strategy between flood mitigation and environmental impact. Any spoil from the berm maintenance and pilot channel excavation is used to nourish North Entrance Beach, which is in the same sediment compartment as the entrance, and thus has minimal long-term impacts.

The EMP seeks to support natural entrance processes; continuous or routine berm works to maintain a permanently "flood-ready" condition were not considered feasible due to the highly dynamic nature of the entrance and its susceptibility to rapid berm rebuilding and channel infilling. Such an approach would likely increase operational costs, ecological disturbance, and morphological instability, without proportionate risk reduction benefits.

While the EMP does introduce some alteration to natural hydraulic processes, interventions are generally implemented in anticipation of significant coastal or flood events, when hydraulic and community risk is elevated. Works are minor, localised, and short-term in nature, with impacts comparable to small-scale dredging. The impacts were assessed in the Tuggerah Lakes Entrance Management Study, and hydraulic and morphological risks were considered low and transient (MHL, 2022).

The Expert Panel (Glamore, et al., 2020) emphasised that effective entrance management requires maintaining a delicate equilibrium between reducing catchment flood impacts and avoiding excessive tidal intrusion or ecological disturbance. The panel observed that while periodic dredging provides short-term hydraulic and social benefits, it also alters sediment dynamics, influencing delta morphology, channel alignment, and long-term shoreline stability. The EMP recognises this delicate equilibrium and follows Government Policy to support minimal interference with estuary entrances, allowing natural processes to operate to the greatest extent possible.



5.3.2 Impacts on Water Quality

Scraping activities are typically limited in scale, shallow in depth, and undertaken within sandy berm material that is regularly reworked by natural coastal processes. As such, sediment disturbance is minor and spatially confined to the entrance zone. Short-term increases in turbidity may occur during excavation; however, these are expected to be localised and transient, comparable to turbidity levels generated during natural entrance scour or elevated wave conditions. Given the high-energy setting of the entrance, suspended sediments are typically rapidly dispersed and redistributed.

The exposure of buried organic-rich sediments during scraping is considered unlikely, as the berm is predominantly composed of recently deposited marine sand. In the event that minor organic material is encountered, any short-term oxygen demand or nutrient release would be expected to be limited in magnitude and duration, and similar to processes that occur naturally during flood-driven channel scour (MHL, 2022). The risk of sustained hypoxia, acid sulfate soil mobilisation, or significant nutrient enrichment is therefore considered low.

These risks are assessed as low in consequence and short in duration, particularly when compared with the magnitude of natural disturbance during storm or flood-driven entrance scour (MHL, 2022). Works are undertaken on an event-based basis rather than continuously, further limiting cumulative effects.

Water quality in the lake basins (functional zone 1) appears primarily influenced by inflowing water rather than entrance width. Although only two major floods occurred during the monitoring period, evidence suggests that temporary entrance widening during floods does not have a lasting effect on water quality (Bluecoast Consulting Engineers and Rhelm, 2026).

Nearshore zones (functional zones 2 and 3) show a similar pattern but with greater variability, making them more susceptible to fluctuations and potential algal blooms.

No water quality data exist for the entrance compartment (functional zone 4); however, community observations and tidal monitoring (MHL, 1993) indicate that water quality is likely affected by entrance width. Aerial imagery suggests that tidal flushing effectively circulates water through this zone, at least as far west as The Entrance Bridge (Bluecoast Consulting Engineers and Rhelm, 2026).

5.3.3 Impacts on Ecological Pressures

The Interim Entrance Management Procedure seeks to support natural entrance behaviour while minimising ecological disturbance, consistent with the NSW Policy and Guidelines for Fish Habitat Conservation and Management (DPI, 2013). Ecological risks associated with berm scraping and pilot channel excavation are considered low due to the limited spatial extent, short duration, and event-based nature of works.

Aquatic and wetland ecological impacts are minimal - works are not located within mapped seagrass beds and are therefore unlikely to directly impact seagrass habitat. As the EMP does not aim to maintain a permanently open entrance, dry-weather water level variability supporting fringing habitats is not expected to be materially altered due to the EMP. Assisted entrance opening prior to flood events may improve flushing and reduce stagnation during high inflow conditions (MHL, 2022). Overall, residual ecological risk to aquatic and wetland systems is low and comparable to natural flood-driven entrance processes.

Dune and berm ecological impacts include minor vegetation disturbance and localised sand surface destabilisation from machinery access. However, works are confined to the highly dynamic southern berm near the typical throat channel location and are to remain within the range of natural scour associated with flood events. Disturbance is therefore comparable to natural geomorphic variability.

The primary ecological risk relates to potential disturbance of nesting shorebirds, including *Sternula albifrons* (Little Tern), listed as endangered under the Biodiversity Conservation Act 2016, and *Charadrius ruficapillus* (Red-capped Plover). Breeding typically occurs on the northern berm between mid-October and mid-February.



To manage this risk, the EMP requires:

- Pre-work inspections for nesting activity in consultation with relevant agencies;
- Confined works within the designated southern berm area and outside agreed buffers;
- Defined access routes and operational controls to avoid nesting areas;
- Avoidance of peak breeding periods where practicable; and
- Consideration of beneficial reuse of sand to enhance nesting habitat, subject to approval.

With these controls, residual risk to threatened and migratory shorebirds is considered low and manageable.

Overall, ecological impacts are localised, temporary, and consistent with natural entrance processes. With appropriate inspections, spatial controls, and regulatory, residual ecological risk is considered low and acceptable in the context of reducing flood risk to life and property (MHL, 2022).

5.3.4 Impacts on Social and Cultural Values

The Interim Entrance Management Procedure provides social benefits primarily through modest reductions in flood severity and associated damages during flood events that are not compounded by extreme coastal anomalies. Even minor reductions in peak water levels may translate to reduced property inundation, lower recovery costs, and improved community confidence in flood preparedness.

However, the benefits of interim entrance management are context dependent. Effectiveness diminishes where flooding coincides with extreme coastal water levels (e.g. storm surge or elevated ocean conditions), under projected sea level rise over the next 50–100 years, or where the entrance is already in a naturally scoured, post-storm condition requiring no intervention. Importantly, none of the interim management options (nor a wide, naturally scoured entrance) eliminate flood risk. Flood impacts to the community will continue to occur under larger or compound events.

From a social perspective, short-term disruptions may occur during works, including temporary closure of the Hutton Road carpark, restricted access to the entrance berm, and the presence of machinery on the beach. These disruptions are localised and temporary but may affect recreational users, beach access, and community amenity during operational periods.

Overall, social impacts associated with the EMP are considered short-term and manageable, while the primary social benefit relates to incremental flood risk reduction. Residual flood risk remains and will require complementary long-term adaptation and resilience planning.

Risk Rating

In considering the risk rating for the EMP, the following factors were considered:

- Present day - Works are minor, localised, and short-term in nature. Interventions are generally implemented in anticipation of significant coastal or flood events, when hydraulic and community risk is elevated
- 20 years - Increased urban density; impacts of sea level rise, changed hydrological regimes as a result of climate change
- 50 years – Entrance management works may become less critical for maintaining tidal flow, yet the footprint of works may shift landward as the barrier recedes.
- 100 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change

The consequences of those factors were identified and rated for potential impact:



- Present day – Ecological impacts are generally localised and temporary, aligning with natural entrance processes. Social impacts are also short-term and manageable, with the primary benefit being incremental reduction in flood risk. Residual flood risk remains, highlighting the need for complementary long-term adaptation and resilience measures.
- 20 years – Entrance management may change due to changes in rainfall patterns, sea level rise and community expectations.
- 50 years – Higher water levels may increase tidal exchange and alter shoreline access patterns
- 100 years – Higher water levels may increase tidal exchange and alter shoreline access patterns

Table 5-2 Risk Rating: Interim Entrance Management Procedure

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Possible	Negligible	Low	■ The estuary entrance
20 years (~2045)	Possible	Negligible	Low	
50 years (~2075)	Possible	Negligible	Low	
100 years (~2125)	Possible	Negligible	Low	

5.4 Rock Groyne

The rock groyne at South Entrance Beach, constructed in 2017, was designed to increase beach width and enhance recreational amenity. By retaining sand along the beach, the groyne was intended to reduce erosion and improve resilience to shoreline recession associated with sea level rise (NSW DPI, 2016).

While the groyne is addressed under the Open Coast CMP, its position immediately south of the Tuggerah Lakes entrance means it also affects sediment dynamics within the entrance region, and it has therefore been included in this risk assessment.

5.4.1 Impacts on Natural Hydraulic and Morphological Processes

As per its intended purpose, the groyne interrupts the natural northward littoral drift of sand from The Entrance Beach toward the entrance throat. By reducing the northerly sediment transport, the structure has reduced sand accumulation across the supratidal rock platform north of the groyne (Salients, 2025). Review of aerial imagery since construction in 2017 indicates that the rock platform to the north has remained comparatively free of sand, and the former tombolo between the headland and the rock platform has transitioned to an open tidal channel (Salients, 2021). Additionally, the open tidal channel alongside the rock groyne has led to increased erosion around Karagi Point, resulting in forced landwards relocation of the lifeguard tower, and exposure of a previously buried seawall.

The groyne represents a permanent intervention in a highly dynamic sediment system and therefore alters natural sediment transport pathways. By reducing sand supply toward the entrance throat, the structure may influence the rate and pattern of entrance infilling and closure, including the location of entrance opening.

The groyne does not prevent natural closure processes, which remain primarily governed by catchment inflows, coastal storm events, and broader sediment dynamics. Overall, the groyne has achieved its primary objective of widening South Entrance Beach and improving recreational amenity (Salients, 2021); however, it introduces an ongoing modification and structural control within a naturally dynamic sediment system and has resulted in erosion north of the groyne (Bluecoast Consulting Engineers and Rhelm, 2026).



Analysis of aerial imagery, survey data, and mean annual shoreline positions indicates that the groyne has reduced sand supply to the beach north of the structure, including the tombolo that normally covers the rock shelf (Bluecoast Consulting Engineers and Rhelm, 2026). This reduction has contributed to localised recession along this section of the beach (Salients, 2025).

5.4.2 Impacts on Water Quality

The construction of the groyne has reduced sand accumulation immediately north of the structure (Salients, 2021), increasing the likelihood of tidal exchange occurring across the rock platform, and between the rock platform and the groyne when the entrance is open. This may marginally enhance tidal flushing and promote the ingress of marine water into the estuary under open entrance conditions.

Increased tidal exchange can influence salinity distribution and stratification patterns within the lower estuary. In some circumstances, enhanced flushing may provide short-term water quality benefits through improved dilution and export of nutrients and urban runoff. Conversely, greater marine intrusion may alter salinity regimes in the lower reaches, with potential implications for estuarine ecological communities that are adapted to variable brackish conditions.

Notwithstanding these localised effects, entrance behaviour remains highly variable and primarily governed by catchment inflows, storm events, coastal water levels, and broader sediment dynamics. Accordingly, while the structure may influence tidal exchange patterns immediately adjacent to its footprint, its overall impact on estuarine water quality is considered minor relative to natural variability.

5.4.3 Impacts on Ecological Pressures

The direct impact from the groyne footprint has minimal ecological impact. As a fixed coastal structure located on the rock platform south of the entrance, it does not directly encroach upon mapped seagrass beds, fringing wetlands, or known critical aquatic habitats.

However, the groyne has altered sediment transport, as it was designed to do, which impacts berm and channel processes, to at least some extent. Threatened shorebirds, such as the Little Tern, directly rely on the sand berm during the nesting season and The Entrance is one of the most important nesting sites.

The primary ecological consideration relates to its influence on sediment transport processes. By reducing northward littoral drift, the groyne reduces sediment supply immediately north of the structure and toward the entrance area. Over time, changes in sediment distribution may influence the configuration of the entrance berm and adjacent sandy habitats. However, there is currently sufficient sediment stored within the ebb tide delta and broader sediment compartment to maintain berm formation and natural entrance cycling. As such, any ecological effects associated with altered sediment supply are expected to be minor and spatially limited.

Indirect ecological effects may arise from localised changes in shoreline morphology or salinity patterns near the entrance under open conditions. The groyne is impacting behaviour of the channel which in turn impacts on the duration of flooding within the estuary, if that continues there could be flow on changes. More understanding of ecological impacts will become available through a NSW Government investigation into the impacts of the groyne.

Overall, ecological risks associated with the groyne are considered low in the current day, with impacts largely confined to localised sediment redistribution rather than substantive habitat loss or degradation. However, impacts to entrance channel behaviour caused by the groyne over a longer period could have flow on impacts to the estuary's ecology that will take longer time periods to become obvious.



5.4.4 Impacts on Social and Cultural Values

Community engagement undertaken as part of the Stage 2 Coastal Processes and Socio-economic Assessment found that the Tuggerah Lakes entrance is a key focal point for recreation, with 57 percent of respondents visiting the area at least six times per year (Bluecoast Consulting Engineers and Rhelm, 2026). This high level of use highlights the social and cultural significance of the entrance for local residents and visitors.

The groyne, however, introduces long-term changes to sediment transport and shoreline morphology, which carry several secondary social implications. Reduced sand supply north of the groyne has altered beach stability and progressively modified the configuration of the entrance berm. These changes can affect navigation and small boat access, limiting safe recreational use in areas adjacent to the entrance.

Specific impacts observed include accelerated erosion of the headland at Karagi Point, causing the lifeguard tower to move landward, restricting access to the tombolo. The tombolo has been eroded away, so beach continuity has been altered.

These changes pose direct safety risks, including delayed lifeguard response times and reduced emergency access. The altered beach configuration may also reduce recreation opportunities, such as walking, fishing, and beach access, and could affect the visual amenity valued by the community.

Additionally, the long-term nature of groyne-induced sediment changes creates ongoing management challenges. Localised erosion north of the structure may necessitate periodic intervention, such as sand nourishment or erosion mitigation works, which can temporarily disrupt access and recreational activities. These interventions carry their own social impacts, including construction noise, restricted foreshore access, and potential conflicts between recreational users and maintenance works.

Overall, while the groyne provides benefits in terms of sand retention and protection for the southern beach, the cumulative social and cultural risks north of the structure, including reduced access, safety concerns, and changes to the recreational experience, are notable and require ongoing monitoring and management.

Risk Rating

In considering the risk rating for the groyne, the following factors were considered:

- Present day - the groyne has decreased the volume of sand reaching the beach immediately north of the structure, including the tombolo that typically overlies the rock shelf
- 20 years – Longer term changes to the beach and entrance as a result of the groyne.
- 50 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change
- 100 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change

The consequences of those factors were identified and rated for potential impact:

- Present day – groyne has decreased the volume of sand reaching the beach immediately north of the structure, including the tombolo that typically overlies the rock shelf. Impacts on beach width, safety, access and amenity.
- 20 years – consequences may increase over time if sediment deficits persist, particularly in the context of sea-level rise and ongoing entrance variability. Water quality impacts are considered possible, primarily due to minor and localised alterations to tidal exchange patterns in the immediate vicinity of the structure.
- 50 years – consequences may increase over time if sediment deficits persist, particularly in the context of sea-level rise and ongoing entrance variability



- 100 years – consequences may increase over time if sediment deficits persist, particularly in the context of sea-level rise and ongoing entrance variability

Table 5-3 Risk Rating: Groyne

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Almost Certain	Moderate	High	▪ The estuary entrance
20 years (~2045)	Almost Certain	Major	Very High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Major	Very High	

5.5 Potential Alternative Entrance Management

A range of alternative entrance management approaches for the Tuggerah Lakes estuary have been proposed and investigated over several decades. These include various combinations of dredging programs, structural modifications (such as groynes, revetments and training walls), secondary openings, and mechanical or event-based opening interventions. Collectively, these alternatives aim to address long-standing community aspirations relating to flooding, water quality, navigation and amenity.

Previous studies, including those by Patterson Britton & Partners (1994), Cardno (2013; 2015) and MHL (2022), have modelled or conceptually assessed these interventions. Options examined have included larger-scale dredging campaigns (to –2.5 m AHD or deeper), northern or twin training walls, short groynes, and combinations of structural works with sand nourishment.

Further detailed evaluation of entrance management options will occur in Stage 3 of the CMP. However, the most recurring suggestions of alternatives (those being a second entrance at Budgewoi, and training of the current entrance) have been included in this Stage 2 risk assessment due to their high and enduring risks to the long-term form, function and resilience of the estuary.

5.5.1 Impacts on Natural Hydraulic and Morphological Processes

The Tuggerah Lakes estuary is classified as an ICOLL (Intermittently Closed and Open Lake or Lagoon), a common estuarine type along the NSW coast. ICOLLs are inherently dynamic systems, characterised by episodic entrance opening and closure, variable water levels, and strong dependence on catchment inflows and ocean conditions. This variability is central to their natural hydraulic and geomorphic functioning.

The proposal for a second entrance at Budgewoi has been raised periodically. However, the Expert Panel's review of historical records found no clear evidence of a sustained or well-defined secondary entrance since European settlement (Glamore, et al., 2020). In addition, the three lake basins are perched above mean sea level, meaning that tidal exchange plays a limited role in governing broader lake hydrodynamics or water quality. The existing entrance does not materially alter circulation or water quality across the lake system. Consequently, there is little evidence to suggest that constructing a secondary opening would produce meaningful or lasting water quality improvements.

Construction of training walls at the entrance would also fundamentally alter the hydraulic regime. Training walls function by stabilising and deepening the entrance channel, pushing the offshore bar seaward and reducing littoral drift into the entrance. While this can maintain a permanently open channel, it also significantly disrupts natural sediment transport processes. A deeper, stabilised entrance would likely increase tidal range and tidal prism, concentrate flows, and elevate current velocities, with potential to trigger progressive or “runaway” scour within the entrance and adjoining channels (Glamore, et al., 2020).



Experience at other trained coastal lagoons, including Lake Macquarie and Lake Illawarra, demonstrates that entrance training works can initiate ongoing erosion of adjacent foreshores, often necessitating extensive and costly bank protection works within the broader entrance compartment (Bluecoast Consulting Engineers and Rhelm, 2026). Such interventions reduce the natural adaptability of the system, increase long-term maintenance burdens, and permanently alter estuarine morphology. Maintenance dredging may also be required to manage sand bypassing and channel stability under a trained configuration.

Flooding is another critical consideration in evaluating potential entrance modification options. In 2013, Cardno assessed whether constructing training walls could improve lake water quality and modify flood behaviour (Cardno, 2013). Modelling of both single and dual training wall configurations, with entrance widths of 150 m and 200 m, indicated no meaningful reduction in peak flood levels across the estuary. The analysis also suggested that, under these scenarios, elevated water levels could persist for several additional days compared to other management approaches, with more than 1,300 properties around the lakes projected to experience above-floor inundation. A narrower 100 m opening was subsequently discounted due to performance and risk considerations. Overall, the findings indicated that maintaining a permanently open entrance through the construction training walls would not materially enhance flushing of the estuary or provide flood reduction benefits (Cardno, 2013).

Consistent with these findings, the Stage 2 Coastal Processes and Socio-Economic Assessment determined that entrance training walls would involve substantial capital and ongoing costs, pose risks to estuarine habitats and ecological processes, and carry a high likelihood of initiating unstable estuarine responses (Bluecoast Consulting Engineers and Rhelm, 2026).

Accordingly, large-scale structural modifications, such as training walls or a secondary entrance, present an extremely high risk of fundamentally altering the natural hydraulic and morphological behaviour of Tuggerah Lakes. While technically achievable, they would effectively convert a naturally dynamic ICOLL into a heavily engineered system, with significant and enduring geomorphic, ecological and management consequences.

5.5.2 Impacts on Water Quality

Water quality and ecological condition within Tuggerah Lakes are closely linked to the system's geomorphology, climatic variability, urbanisation and catchment-derived pressures (Glamore, et al., 2020; Bluecoast Consulting Engineers and Rhelm, 2025). These drivers create distinct "functional zones" with differing hydrodynamic behaviour and water quality responses, such as the lake basins, nearshore zones, and the entrance.

Training walls or a secondary entrance would alter tidal exchange processes significantly, increasing the tidal range and water exchange volume (Glamore, et al., 2020). However, available real-world evidence suggests that such modifications are unlikely to deliver system-wide water quality improvements. Experience at Lake Illawarra, another ICOLL that has been permanently trained, shows that entrance training did not eliminate algal growth in areas further from the entrance, nor did it improve overall water quality to the extent initially anticipated (Glamore, et al., 2020). This reflects the reality that catchment inputs, nutrient loads and internal cycling processes are the dominant controls on water quality in perched lagoon systems such as the Tuggerah Lakes estuary.

At present, tidal exchange through the existing entrance is estimated to replace, on average, approximately 1% of the lake volume per day when open (Glamore, et al., 2020). This exchange contributes to gradual salinity increases during extended dry periods. However, ocean water intrusion is largely confined to the entrance channels during flood tides, with wind-driven mixing processes rapidly dispersing and diluting marine inflows before they substantially influence the broader lake basins.

Monitoring indicates that water quality in the lake basins (functional zone 1) is primarily governed by catchment inflows rather than entrance width (Bluecoast Consulting Engineers and Rhelm, 2026). Although only two major floods occurred during the regular monitoring period, available data suggest that even significant flood-



driven entrance widening does not result in persistent changes to basin-scale water quality (Bluecoast Consulting Engineers and Rhelm, 2026). A similar pattern is observed in the nearshore zones (functional zones 2 and 3), where water quality also appears strongly linked to catchment inputs. These zones exhibit greater variability and are more prone to short-term fluctuations, increasing their susceptibility to algal blooms and episodic water quality issues (Bluecoast Consulting Engineers and Rhelm, 2026).

On this basis, while training walls or a secondary entrance would likely increase tidal exchange, their influence on water quality improvements in the lake basins and nearshore zones is expected to be limited. The primary risk associated with such structural modifications is therefore not a failure to improve water quality per se, but the introduction of substantial hydraulic and morphological change without commensurate water quality benefit. Catchment management remains the more effective long-term mechanism for addressing nutrient loads and algal bloom risk within the system (Glamore, et al., 2020).

The Expert Panel concluded that a permanently open entrance is not justified on water quality grounds, noting that catchment-related pressures such as land use and development are the primary drivers of water quality issues in the estuary. In fact, improvements in water quality over time have been observed without permanent structural modification of the entrance (Glamore, et al., 2020).

5.5.3 Impacts on Ecological Pressures

Training walls or the creation of a secondary entrance would be expected to have profound ecological implications for the Tuggerah Lakes estuary due to the fundamental changes they would impose on the system's hydrodynamics and sediment regime. These interventions would increase tidal exchange, modify salinity gradients, expand the tidal prism, concentrate flow velocities and potentially initiate channel deepening and erosion. In a perched ICOLL system, such changes would alter the balance between freshwater inflows and marine intrusion, reshaping the physical and chemical environment that underpins ecological processes.

Altered circulation and salinity patterns could significantly affect seagrass meadows, which are sensitive to changes in light availability, turbidity, current velocity and salinity stability. Increased tidal currents and scour may destabilise shallow sandy substrates that support seagrass, while deeper or more saline conditions could shift species composition. Similarly, fringing habitats such as saltmarsh, wetlands and mudflats, currently adapted to the existing hydrological regime, would experience altered inundation frequency and duration. Even small changes in water level range can transform wetland zonation, alter habitat extent, and affect the ecological function of these transitional areas.

Fisheries resources would also be vulnerable to hydrodynamic modification. Many estuarine fish and invertebrate species rely on the sheltered, low-energy conditions typical of ICOLL environments for spawning, recruitment and juvenile development. Increased tidal prism and stronger currents may reduce nursery habitat suitability, alter connectivity between habitats, and change species distribution patterns over time.

Experience at Lake Illawarra provides a relevant comparison. Lake Illawarra, an ICOLL south of Wollongong with similarities in morphology and entrance setting to Tuggerah Lakes, was initially modified through construction of a southern breakwater adjacent to a tombolo, followed by full training with twin breakwaters. Despite these works, reported outcomes indicate that permanent entrance training did not eliminate algal growth in areas remote from the entrance, nor did it deliver the level of water quality improvement originally anticipated (Glamore et al., 2020). This case demonstrates that large-scale structural modification may significantly alter hydraulic and ecological processes without resolving the underlying drivers of water quality and ecological stress, which are predominantly catchment-based (Glamore, et al., 2020).

Accordingly, training walls or a secondary entrance to the Tuggerah Lakes estuary would carry a very high ecological risk, not only through direct habitat disturbance during construction but through long-term alteration of circulation patterns, sediment transport and salinity regimes that define the character and functioning of the estuarine ecosystem.



5.5.4 Impacts on Social and Cultural Values

The construction of training walls or the establishment of a secondary entrance into Budgewoi Lake would have substantial implications for the social and cultural values associated with the Tuggerah Lakes estuary and its coastal setting.

Community amenity and beach usability would likely be reduced. As identified in the socio-cultural assessment, the entrance area is of high recreational value (Bluecoast Consulting Engineers and Rhelm, 2026). Training walls are large, engineered rock structures that extend into the marine environment, permanently altering the visual and physical character of the entrance. Their presence can fragment beach space, interrupt longshore walking routes, and create areas of deeper water and stronger currents adjacent to the structure. These changes may reduce safe swimming areas and limit informal recreational uses such as beach fishing and family-based activities.

A secondary entrance would introduce similar constraints. New channels or stabilised openings would completely alter the Budgewoi area, potentially requiring revetments, dredging works, significant investment relocating assets (power, water, etc), construction of bridge/alterd road or disconnection of a vital transport corridor and ongoing maintenance. This would industrialise portions of what is currently a largely natural coastal landscape, diminishing the undeveloped character valued by residents and visitors.

In addition to functional impacts, there are aesthetic and landscape considerations. GHD (2019) concluded that entrance training would adversely affect the visual quality of the region. The Tuggerah Lakes entrance is widely valued for its natural appearance, dynamic sand shoals, and open coastal vistas. The introduction of substantial rock armouring and engineered structures would create a more hardened, artificial landscape character. This may diminish the scenic appeal of the entrance area, which contributes to local identity, tourism appeal, and community attachment to place.

There are also broader cultural and sense-of-place implications. The Tuggerah Lakes estuary holds strong social value as a location for recreation, family gatherings, and community events. Its intermittently open and closed nature forms part of the system's identity and historical narrative. Altering the entrance regime through permanent structural works could fundamentally change the character of the lakes from a dynamic ICOLL system to a more permanently tidal estuary, potentially affecting how the community relates to and values the waterbody.

Where Aboriginal cultural heritage values are present, changes to hydrology, shoreline position and sediment processes may also affect culturally significant sites and landscapes, particularly along foreshore margins and low-lying areas.

Accordingly, training walls or a secondary entrance would not only generate physical and ecological changes but would also carry meaningful and long-term impacts on community amenity, landscape character, recreational use, and the cultural identity of the Tuggerah Lakes region.

Risk Rating

In considering the risk rating for the Second Entrance, the following factors were considered:

- Present day - Little evidence to suggest that constructing a secondary opening would produce meaningful or lasting water quality improvements
- 20 years – Longer term changes to estuary as a result of the second entrance
- 50 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change
- 100 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change

The consequences of those factors were identified and rated for potential impact:



- Present day – New channels or stabilised openings would completely alter the Budgewoi area, potentially requiring revetments, dredging works, significant investment relocating assets (power, water, etc), construction of bridge/alter road or disconnection of a vital transport corridor and ongoing maintenance
- 20 years – Extremely high risk of fundamentally altering the natural hydraulic and morphological behaviour of Tuggerah Lakes.
- 50 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change
- 100 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change

In considering the risk rating for training walls, the following factors were considered:

- Present day - Permanent structural works would fundamentally modify the behaviour of this ICOLL system, potentially initiating channel deepening, altered scour patterns, shoreline recession or accretion in new locations, and increased tidal penetration into the lakes.
- 20 years – Longer term changes to the beach and entrance as a result of the training walls.
- 50 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change
- 100 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change

The consequences of those factors were identified and rated for potential impact:

- Present day – While structural modification may increase tidal exchange locally, available evidence from comparable systems suggests that entrance training does not necessarily translate to meaningful improvements in broader estuarine water quality
- 20 years – Structural entrance works would alter landscape character, beach amenity, recreational use patterns, and the community's connection to the natural, dynamic character of the lakes. Changes to salinity regime, inundation frequency, current velocity, and sediment stability may affect seagrass meadows, saltmarsh, wetlands, mudflats, and fisheries habitat.
- 50 years – consequences may increase over time if sediment deficits persist, particularly in the context of sea-level rise and ongoing entrance variability
- 100 years – Impacts of sea level rise, changed hydrological regimes as a result of climate change.

Table 5-4 Risk Rating: Second Entrance

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Catastrophic	Very High	■ Budgewoi Lake
20 years (~2045)	Likely	Catastrophic	Very High	
50 years (~2075)	Likely	Catastrophic	Very High	
100 years (~2125)	Likely	Catastrophic	Very High	

Table 5-5 Risk Rating: Training Walls

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Possible	Catastrophic	High	■ The estuary entrance
20 years (~2045)	Likely	Catastrophic	Very High	



Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
50 years (~2075)	Likely	Catastrophic	Very High	
100 years (~2125)	Likely	Catastrophic	Very High	



6 ECOLOGY AND WATER QUALITY

6.1 Introduction

The Tuggerah Lakes estuary supports one of the largest and most diverse estuarine wetland complexes on the NSW Central Coast. However, it faces significant and cumulative ecological pressures arising from urban development, altered catchment hydrology, degraded water quality, invasive species, and foreshore disturbance, all of which threaten the integrity of estuarine vegetation and aquatic habitats (Central Coast Council, 2021). While past restoration efforts have delivered measurable improvements, management remains inadequate to address ongoing and future risks, particularly in the face of climate change and increasing urbanisation, and some key data gaps still hinder effective, integrated planning (Glamore, et al., 2020).

The Tuggerah Lakes CMP Scoping Study (Central Coast Council, 2021) recognised ecology and water quality as a cornerstone management issue for the broader catchment and estuary. The study identified the need for coordinated management across sub-catchments and a stronger focus on maintaining ecological function and resilience. It highlighted that existing management responses are fragmented and that critical data gaps persist in relation to sediment–nutrient interactions, groundwater inputs, and the thresholds that control seagrass and saltmarsh health.

The Tuggerah Lakes Expert Panel Review (Glamore, et al., 2020) reinforced this view, noting that ecosystem health is primarily constrained by high nutrient and sediment loads from the catchment rather than by entrance dynamics or tidal exchange. The panel emphasised that long-term ecological improvement would depend on addressing the sources of pollution and protecting key habitats from incremental degradation.

The Scoping Study (Central Coast Council, 2021) FPRA identified 3 key stressors related to ecology and water quality that were found to be High Risk (over present day and/or future planning horizons) that are addressed in more detail in this Stage 2 risk assessment:

- Changes in estuarine vegetation (seagrass, saltmarsh, estuarine vegetation) – see Section 6.2
- Point and diffuse source water pollution – see Section 6.3
- Degradation/clearing of freshwater wetland, riparian and catchment vegetation – See Section 6.4

6.2 Changes in estuarine vegetation (seagrass, saltmarsh, estuarine vegetation)

The estuarine vegetation of Tuggerah Lakes, including seagrass meadows, saltmarsh communities, and other foreshore vegetation, has undergone significant degradation over the past several decades. Historical studies such as the Estuary Process Study (Wyang Shire Council, 2000) and the Tuggerah Lakes Estuary Management Plan (Bio-Analysis Pty Ltd, 2006) documented extensive loss of saltmarsh, estimating that up to 85% of this critical habitat had been lost due to foreshore development, illegal infilling, and altered hydrological regimes. These changes were largely driven by urban expansion and infrastructure encroachment into low-lying coastal zones.

Seagrass beds, which play a vital role in stabilising sediments, supporting fish nurseries, and maintaining water quality, have also been impacted. The accumulation of wrack (see Section 7.2), often exacerbated by nutrient enrichment and disconnection of the shallow nearshore zones and deeper lake basins, has led to smothering of seagrass beds and reduced light penetration. The Expert Panel Review emphasised that catchment-derived sediment and nutrient loads are the primary drivers of seagrass decline, rather than entrance dynamics alone (Glamore, et al., 2020). This finding challenges earlier assumptions that dredging or modifying the entrance would significantly improve ecological conditions.

The 2023 Coastal Wetland Refugia Study added a climate change perspective, showing that many saltmarsh areas are at risk of being permanently inundated due to sea level rise (Waddington, Glamore, & Heimhuber, 2023). These habitats lack sufficient elevation to migrate inland, and urban development along the foreshore



restricts their ability to retreat naturally. Without intervention, these ecosystems face functional collapse. Predictive habitat distribution mapping from the NSW DPIRD Estuarine Habitat Dashboard (State of NSW Department of Primary Industries and Regional Development, 2023) further indicates that with a +0.5 m rise in sea level, many of the small wetland pockets around the lakes will be lost (Figure 6-1). What remains is expected to be highly fragmented and vulnerable to ongoing impacts.



Figure 6-1 Projected distribution of estuarine saltmarsh under +0.5m sea level rise only (State of NSW Department of Primary Industries and Regional Development, 2023)

These challenges have been experienced in other locations, such as Lake Illawarra, where entrance modification and catchment controls led to partial seagrass recovery, and Botany Bay wetlands, where saltmarsh restoration succeeded through fencing and community involvement (Dragonfly Environmental, 2014).

Recommended actions for changes in estuarine vegetation include:

- Restoration of saltmarsh and seagrass beds, including replanting and sediment management.
- Protection of existing vegetation through fencing, signage, and access control.
- Planning for wetland migration using elevation modelling and land use controls.
- Community education and stewardship to build awareness of ecological roles and threats.

Risk Rating

In considering the risk rating for changes in estuarine vegetation, the following factors were considered:

- Present day - Persistent nutrient and sediment inputs, wrack buildup, and early climate stress begin to affect low-lying vegetation and estuarine habitats
- 20 years - Urban expansion, loss of wetland buffers, and intensifying climate impacts reduce space for saltmarsh migration and increase cumulative catchment pressures.



- 50 years – Intensified land use, chronic nutrient enrichment, and sea level rise overwhelm estuarine systems and block inland habitat migration.
- 100 years – Near-total urbanisation and irreversible sea level rise result in long-term pollution, sedimentation, and estuarine change

The consequences of those factors were identified and rated for potential impact:

- Present day – Seagrass and saltmarsh degradation is measurable but still potentially reversible with targeted intervention
- 20 years – Estuarine vegetation declines, connectivity weakens, and restoration becomes more complex and costly.
- 50 years – Saltmarsh ecosystems experience functional collapse, with frequent algal blooms and major loss of ecosystem services
- 100 years – Estuary-wide ecological failure occurs, with permanent loss of saltmarsh and seagrass and collapse of biodiversity and cultural values.

Both the factors and consequences were then taken together to determine a final risk rating for changes in estuarine vegetation over the next 100 years, as outlined in Table 6-1.

Table 6-1 Risk Rating: Changes in estuarine vegetation

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	Tuggerah Lake basin Foreshores All areas
20 years (~2045)	Almost Certain	Major	Very High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	

6.3 Point and diffuse source water pollution

Water quality degradation in the Tuggerah Lakes estuary is driven by a combination of point source and diffuse source pollution. Point sources include sewage treatment plants, septic systems, and industrial discharges, while diffuse sources encompass urban stormwater runoff, agricultural activities, and erosion from cleared land. The Tuggerah Lakes Riverine and Catchment Health Monitoring Program provides robust data showing elevated concentrations of nitrogen (NO_x, ammonia, total nitrogen) and phosphorus (phosphate, total phosphorus) in tributaries such as Saltwater Creek, Tumby Umbi Creek, and Ourimbah Creek (Figure 4-4) (State of NSW and Department of Planning, Industry and Environment, 2021). These pollutants contribute to eutrophication, algal blooms, and oxygen depletion, which in turn affect aquatic life and recreational amenity.

The Expert Panel Review concluded that entrance management (e.g., dredging) has limited effect on improving water quality. Instead, the focus must shift to catchment-wide nutrient reduction strategies (Glamore, et al., 2020). The CMP Scoping Study and the Prioritisation Report reinforce this approach, recommending targeted investment in stormwater treatment infrastructure, wetland restoration, and land use planning reforms to reduce pollutant loads (Central Coast Council, 2021; JBP, 2025).

Agricultural runoff, particularly from grazing and turf farming in the upper catchments (e.g., Jilliby Creek, Wyong River), contributes significantly to nutrient loads. These areas often lack adequate riparian buffers, allowing sediment and nutrients to enter waterways unchecked. Septic system leakage and sewer overflows are also a concern, especially in older urban areas where infrastructure is ageing or poorly maintained (see Section 4.4).



Issues with point and diffuse source water pollution are not unique to the Tuggerah Lakes estuary and are managed in a variety of ways at other locations. For example, Terrigal Lagoon undertook catchment audits that led to targeted remediation, improving water quality (Central Coast Council & State of NSW Department of Planning, Industry and Environment, 2020; State of NSW Department of Planning, Industry and Environment, 2020).

Recommended actions for point and diffuse source water pollution include:

- Upgrading stormwater infrastructure, including gross pollutant traps (GPTs), biofiltration systems, and constructed wetlands.
- Implementing nutrient reduction targets for catchment runoff.
- Auditing and repairing septic systems and sewer networks.
- Revising planning controls to require water-sensitive urban design (WSUD) in new developments.

Risk Rating

In considering the risk rating for changes in point and diffuse source water pollution, the following factors were considered:

- Present day - Ongoing nutrient and sediment inputs, aging infrastructure, and limited WSUD uptake cause episodic algal blooms.
- 20 years - Urban growth and inadequate stormwater systems increase pollution and pressure on waterways.
- 50 years – Pollution buildup and climate-driven runoff changes overwhelm natural filtration
- 100 years – Irreversible hydrological change and infrastructure failure eliminate natural treatment capacity.

The consequences of those factors were identified and rated for potential impact:

- Present day – Water quality declines, but recovery is still possible with coordinated action
- 20 years – Frequent eutrophication and biodiversity loss make restoration harder and more expensive.
- 50 years – Persistent blooms and species collapse reduce water quality and ecosystem services
- 100 years – Estuary-wide water quality collapse impacts ecology, health, and cultural use.

Both the factors and consequences were then taken together to determine a final risk rating for point and diffuse source water pollution over the next 100 years, as outlined in Table 6-2.

Table 6-2 Risk Rating: Point and diffuse source water pollution

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	Urban fringes, in particular southern and northern aspects of each water body
20 years (~2045)	Almost Certain	Major	Very High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	

6.4 Degradation/clearing of freshwater wetland, riparian and catchment vegetation

Freshwater wetlands, riparian corridors, and catchment vegetation are essential components of the Tuggerah Lakes ecosystem, providing habitat, filtering pollutants, and stabilising hydrology. However, these areas have



been increasingly degraded due to urban expansion, agricultural clearing, and infrastructure development. The Tuggerah Lakes Riverine and Catchment Health Monitoring Program shows poor riparian condition scores in many sub-catchments, particularly in the lower reaches of Wyong River and Tuggerah Lake tributaries (State of NSW and Department of Planning, Industry and Environment, 2021). Common issues include invasive species, rubbish dumping, erosion, and lack of native vegetation.

The CMP Scoping Study identifies riparian degradation as a high-priority risk, noting that many areas lack formal protection or management plans (Central Coast Council, 2021). The Wetland Refugia Study highlights the vulnerability of low-lying freshwater wetlands to climate change, especially in areas where urban development prevents inland migration (see Section 4.2) (Waddington, Glamore, & Heimhuber, 2023). The Estuary Management Plan (Bio-Analysis Pty Ltd, 2006) and the Prioritisation Report (JBP, 2025) both call for stronger protection and restoration of these zones, emphasising their role in maintaining water quality and ecological resilience.

Jilliby State Conservation Area stands out as a positive example, with intact vegetation and high ecological scores. In contrast, urban creeks such as Porters Creek and Chittaway Creek show signs of severe degradation, with sedimentation, bank erosion, and poor habitat quality. Elsewhere, South Creek in Western Sydney offers a comparative case where riparian restoration improved water quality and biodiversity, demonstrating the value of coordinated action and long-term investment (State of NSW Department of Environment and Conservation, 2005; Duxbury, 2019).

Recommended actions include:

- Riparian restoration through native plantings, weed control, and fencing.
- Enforcing buffer zones and vegetation standards in planning instruments.
- Supporting community stewardship programs such as Landcare and Bushcare.
- Integrating riparian corridors into biodiversity and water quality strategies.

Risk Rating

In considering the risk rating for degradation/clearing of freshwater wetland, riparian and catchment vegetation the following factors were considered:

- Present day - Urban development, clearing, and poor riparian protection degrade wetland corridors and hydrology, however, existing freshwater wetlands are protected under the Coastal Management SEPP.
- 20 years - Land use intensification and habitat fragmentation reduce ecological connectivity and resilience, however, existing freshwater wetlands are presumed to be protected.
- 50 years – Long-term clearing, erosion, and climate stress weaken wetlands and block migration, however, existing freshwater wetlands are presumed to be protected.
- 100 years – Irreversible hydrological change and planning failure drive long-term landscape degradation, however, existing freshwater wetlands are presumed to be protected.

The consequences of those factors were identified and rated for potential impact:

- Present day – Vegetation loss and runoff impacts are measurable but still reversible with targeted action.
- 20 years – Vegetation loss and declining filtration and flood mitigation make restoration more difficult.
- 50 years – Wetland collapse, water quality decline, and ecosystem service loss become widespread
- 100 years – Freshwater wetlands and riparian habitats collapse, with severe biodiversity and cultural losses.



Both the factors and consequences were then taken together to determine a final risk rating for degradation/clearing of freshwater wetland, riparian and catchment vegetation over the next 100 years, as outlined in Table 6-3.

Table 6-3 Risk Rating: Degradation/clearing of freshwater wetland, riparian and catchment vegetation

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	- Toukley Wetland - Tumbi Wetland - Blue Haven wetlands
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Likely	Major	High	
100 years (~2125)	Likely	Major	High	



7 FORESHORE/NEARSHORE AND WRACK MANAGEMENT

7.1 Introduction

The foreshore and nearshore environments of the Tuggerah Lakes estuary form a critical ecological and social interface, supporting biodiversity, recreation, and cultural values. Foreshore and nearshore areas across Tuggerah Lakes are under pressure from natural wrack accumulation, organic sediment build-up, historic land reclamation, and poorly coordinated management practices. While wrack and ooze issues are well studied and partially managed through existing programs, ongoing community expectations, groundwater pollution risks, and ad-hoc foreshore development highlight a need for more strategic, collaborative, and better-resourced approaches moving forward (Central Coast Council, 2021).

The Tuggerah Lakes CMP Scoping Study (Central Coast Council, 2021) identified foreshore and nearshore management as a key challenge for the CMP, noting that the estuary's shallow morphology and limited tidal exchange make it highly sensitive to both natural and anthropogenic change. The study emphasised the cumulative impact of nutrient inputs, shoreline modification, and urban development in driving wrack accumulation, sediment enrichment, and foreshore instability. It also noted that management responses to date have often been reactive, site-specific, and under-resourced, lacking the integration needed to address underlying causes across the catchment–estuary continuum.

The Tuggerah Lakes Expert Panel Review (Glamore, et al., 2020) reinforced these findings, concluding that wrack accumulation and black ooze formation are not isolated issues but visible symptoms of broader ecological stress. The panel observed that nutrient and sediment loads from the catchment, combined with the limited flushing capacity of the estuary, have created conditions that allow organic matter to accumulate and decompose, leading to odour, water quality decline, and habitat loss. The panel also highlighted the importance of managing wrack within an ecological framework - acknowledging its natural role in shoreline stability and nutrient cycling - while developing targeted interventions to address problem hotspots and maintain community amenity.

The Scoping Study (Central Coast Council, 2021) FPRA identified 4 key stressors related to foreshore management that were found to be High Risk (over present day and/or future planning horizons) that have been addressed in more detail in this Stage 2 risk assessment:

- Seagrass wrack accumulation – see Section 7.2
- Organic enrichment of sediment and black ooze formation – see Section 7.3
- Foreshore development and management – See Section 7.4
- Ground water pollution – see Section 7.5

7.2 Impacts on social and recreational amenity from seagrass wrack accumulation

Wrack accumulation is a natural process that supports ecological functions, providing habitat for invertebrates, birds, and juvenile fish, contributing to nutrient cycling and shoreline stabilisation, and acting as a natural buffer reducing coastal erosion (Dee, et al., 2024). In the Tuggerah Lakes estuary, wrack accumulation has become problematic due to shoreline modification and altered water levels (Alluvium and EcoFutures, 2023; Heerhartz, Dethier, Toft, Cordell, & Ogston, 2014). Accumulated wrack, especially when trapped in nearshore barriers which impact water movement between shallow nearshore zones and deeper parts of the estuary, contributes to eutrophication and poor water quality, impacting biodiversity, tourism, local fisheries, and recreational water use (Central Coast Waterways, 2025), at times resulting in negative social and recreational amenity impacts. Historically, wrack harvesting has been reactive and inconsistent, failing to meet community expectations.

The Expert Panel Review emphasised that wrack accumulation is a symptom of broader catchment issues, particularly excessive nutrient inputs from urban stormwater, agriculture, and sewage systems (Glamore, et



al., 2020). The shallow, perched nature of the estuary limits tidal exchange, allowing organic material to settle and accumulate. Without intervention, wrack may become a chronic feature of the lakes, further degrading ecological health and recreational value.

A notable case study from Port Geographe in Western Australia illustrates both the challenges and potential solutions to wrack management (Fifield, Maslin, Clarke, & Todd, 2019). Prior to 2013, the original entrance structures at Port Geographe acted as a barrier to littoral transport, resulting in the accumulation of up to 150,000 m³ of seagrass wrack each winter. This led to severe odour issues, reduced beach amenity, and costly annual dredging and bypassing operations. Following the transfer of management responsibilities to the Department of Transport (DoT), the entrance structures were reconfigured in 2014 to improve natural bypassing of sand and wrack. This “working with nature” approach aimed to reduce wrack accumulation, mitigate erosion, and lower maintenance costs. Post-reconfiguration monitoring showed improved outcomes, although wrack accumulation remains a seasonal challenge requiring ongoing adaptive management.

In contrast, other regions such as Botany Bay and parts of Moreton Bay have struggled with wrack management due to extensive shoreline armouring and lack of ecological buffers (BMT WBM and Moreton Bay Regional Council). Mechanical removal in these areas has often been reactive, costly, and ecologically disruptive, failing to address the underlying causes of wrack accumulation. These examples underscore the importance of integrating ecological restoration, hydrodynamic understanding, and strategic planning into wrack management efforts. The Tuggerah Lakes estuary can draw on these lessons to develop a more sustainable and effective approach that balances ecological health with community expectations.

Recommended actions from the Expert Panel Review and the Wrack Management Strategy include:

- Establish designed wrack reserves to allow natural decomposition for ecological benefit.
- Improve nearshore flushing through infrastructure upgrades and shoreline design that enables wave energy to disperse wrack.
- Reduce nutrient inputs from stormwater and groundwater to limit organic buildup.
- Conduct active wrack removal using machinery to skim floating wrack and transfer it to drying pads or waste facilities.
- Strategically place wrack pads to support aerobic decomposition and minimise ecological harm.
- Monitor and adapt management practices to ensure wrack removal does not damage seagrass beds or aquatic habitats.
- Engage the community in regulated wrack collection and stewardship activities.

Risk Rating

In considering the risk rating for seagrass wrack accumulation, the following factors were considered:

- Present day - Local weather, ocean currents and human activities
- 20 years - Sea level risk, warming oceans, changing storm patterns
- 50 years – Increased algal blooms, climate-induced changes
- 100 years – Major climate and ecosystem shifts

The consequences of those factors were identified and rated for potential impact:

- Present day – Local nuisance, manageable
- 20 years – Seasonal beach closures, ecosystem stress
- 50 years – Frequent disruption, coastal degradation



- 100 years – Widespread ecological and socio-economic impacts

Both the factors and consequences were then taken together to determine a final risk rating for the accumulation of seagrass wrack over the next 100 years, as outlined in Table 7-1.

Table 7-1 Risk Rating: Impacts on social and recreational amenity from seagrass wrack accumulation

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Possible	Moderate	Moderate	Locations identified in the Wrack Management Strategy
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Likely	Major	High	
100 years (~2125)	Likely	Major	High	

7.3 Organic enrichment of sediment and black ooze formation

Organic enrichment and black ooze formation in the Tuggerah Lakes estuary is a progressive environmental threat. Black ooze forms when nutrient-rich organic matter accumulates in sediments and decomposes anaerobically, producing sulfidic compounds (Alluvium and EcoFutures, 2023). This process is driven by stormwater and groundwater nutrient inputs, macroalgal blooms, and limited mixing between nearshore and basin waters. Seagrass wrack plays a minor role but can trap more labile organic matter, accelerating the enrichment process in stagnant zones.

The issue is compounded by the loss of natural buffers such as seagrass beds and saltmarsh, which normally help regulate nutrient cycling and sediment stability. Their decline, often due to foreshore development and urban encroachment, leads to increased wrack accumulation and sediment enrichment. The Expert Panel Review notes that wrack accumulation and black ooze are not only ecological problems but also social ones, affecting public perception, access, and enjoyment of the lakes (Glamore, et al., 2020). Without intervention, these conditions may become chronic and increasingly difficult to manage.

Currently, the likelihood of localised black ooze formation is moderate. Nearshore areas with poor circulation are already experiencing reduced recreational amenity due to odour and aesthetic degradation. The Wrack Management Strategy identifies these zones as priority areas for targeted wrack removal and infrastructure upgrades to improve water circulation and reduce stagnation (Alluvium and EcoFutures, 2023).

By 2045, the risk escalates to 'high'. Without intervention, ooze zones will expand, leading to the loss of seagrass beds and increased ecological degradation. The Expert Panel Review emphasises that entrance management, such as opening the estuary to the ocean, will not resolve these issues (Glamore, et al., 2020). Instead, the focus must shift to reducing nutrient inputs, restoring natural water level variation, and enhancing nearshore flushing. Sediment management strategies are also recommended to reduce nutrient loading and organic buildup.

By 2075, the risk becomes very high. Widespread sediment toxicity is expected, resulting in the collapse of nearshore ecosystems and significant biodiversity loss. Long-term monitoring of sediment chemistry and biological impacts will be essential to track changes and guide adaptive management. Without sustained action, the estuary's ecological resilience will be severely compromised.

By 2125, the risk is certain. Persistent anaerobic conditions and irreversible habitat loss will likely lead to estuary-wide ecological failure. The consequences will extend beyond environmental degradation to include long-term social and cultural impacts, particularly for communities with strong connections to the estuary.



This trajectory underscores the urgency of implementing a coordinated management response.

Elsewhere, management of organic sediment enrichment has seen mixed results. Lake Illawarra in NSW benefited from entrance opening and catchment controls, which improved flushing and reduced black ooze formation (Wollongong City Council, 2024). However, success was contingent on simultaneous ecological restoration. In the case of the Tuggerah Lakes estuary, the Expert Panel Review emphasises that entrance management, such as opening the lakes to the ocean, will not resolve these issues (Glamore, et al., 2020). Instead, the focus must shift to reducing nutrient inputs, restoring natural water level variation, and enhancing nearshore flushing. Sediment management strategies are also recommended to reduce nutrient loading and organic buildup.

In contrast, Botany Bay wetlands experienced long-term sediment disturbance due to dredging and hard infrastructure, without addressing upstream nutrient sources, leading to persistent black ooze and habitat degradation (Sydney Metropolitan Catchment Management Authority, 2011; URS and Sydney Ports, 2003). Moreton Bay in Queensland also faced widespread black ooze formation due to seagrass loss and urban runoff, with delayed recovery attributed to fragmented governance and insufficient catchment planning (Smart, et al., 2025; Lyons, Phinn, & Roelfsema, 2019). These examples underscore the importance of integrated, catchment-to-coast strategies that address both sources and symptoms of organic enrichment.

Previous attempts to manage black ooze during the Tuggerah Lakes Restoration Project completed in the early 1990s were also unsuccessful. The project involved nearshore weed and ooze removal, foreshore reclamation, installation of stormwater treatment zones, and channel dredging to enhance tidal exchange. Despite the considerable investment of time, effort, and funding, the ecological benefits were short-lived, lasting only one to two years before macrophytes and ooze re-established. This outcome highlighted a key limitation of the project, as while it effectively addressed the symptoms of ecological decline, it did not sufficiently target the underlying causes, such as nutrient-rich runoff and organic matter inputs from the catchment.

Recommended actions from the Expert Panel Review and the Wrack Management Strategy include:

- Reducing nutrient inputs from stormwater and groundwater sources.
- Restoring shoreline and saltmarsh habitats to support natural decomposition processes.
- Upgrading infrastructure to improve water circulation and reduce stagnation.
- Conducting targeted wrack removal in high-risk zones.
- Implementing sediment management strategies to limit organic buildup.
- Establishing long-term monitoring programs to assess sediment chemistry and ecological health.

Risk Rating

In considering the risk rating for organic enrichment of sediment and black ooze formation, the following factors were considered:

- Present day – Stormwater runoff (urban and agricultural), legacy nutrient loading, minimal tidal exchange
- 20 years – Increased development leading to higher nutrient inflows, warmer water temperatures, increasing wrack accumulation events
- 50 years – Sea level rise, climate-induced changes, continued nutrient inflows without interventions
- 100 years – Major climate shifts and land-use intensification leading to further nutrient inflow, failed mitigation systems

The consequences of those factors were identified and rated for potential impact:



- Present day – Hydrogen sulfide release, odour complaints, loss of benthic fauna
- 20 years – Expansion of anoxic zones, ecosystem degradation
- 50 years – Persistent black ooze, ecosystem stress
- 100 years – Estuary-wide eutrophication, ecological collapse

Both the factors and consequences were then taken together to determine a final risk rating for organic enrichment of sediment and black ooze formation over the next 100 years, as outlined in Table 7-2.

Table 7-2 Risk Rating: Organic enrichment of sediment and black ooze formation

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Possible	Moderate	Moderate	All foreshore areas Primarily found in areas where seagrass wrack accumulation occurs in combination with muddy shores, limited wave energy and nutrient inputs
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	

7.4 Foreshore development and management

The foreshore is a critical interface between land and water, supporting ecological functions, recreational use, aesthetic and cultural values. However, increasing development pressure, fragmented governance, and inconsistent management practices have led to a range of ecological and social disturbances.

Vegetation clearing and mowing, often for aesthetic or recreational purposes, have significantly reduced the extent and quality of native foreshore vegetation, including saltmarsh and riparian buffers. These areas are essential for stabilising shorelines, filtering pollutants, and providing habitat. Their removal exposes the foreshore to erosion, reduces ecological resilience, and limits the capacity for natural regeneration. In many cases, mowing extends into sensitive zones, further degrading habitat and disconnecting ecological corridors.

The issue of public versus private ownership also complicates foreshore management. Many properties back directly onto the estuary, and informal or unauthorised use of public land for private purposes, such as lawns, jetties, and landscaping, has created a sense of privatisation. This undermines public access, contributes to habitat loss, and creates tension between residents and broader community interests. The lack of clearly defined management zones exacerbates this problem, with overlapping responsibilities between council, state agencies, and private landholders leading to inconsistent enforcement and maintenance.

Uncontrolled access, including informal tracks, vehicle use, and unmanaged recreational activity, contributes to physical disturbance of the foreshore. These activities compact soil, damage vegetation, and increase erosion, particularly in high-use areas like The Entrance, Canton Beach, and Long Jetty. Physical disturbance is often accompanied by ecological disturbance, including the spread of invasive species, loss of native flora, and disruption of wildlife corridors.

User conflict is also emerging as a significant issue. As population and tourism grow, competition for space between different recreational users, such as walkers, cyclists, anglers, and boaters, is increasing. Without coordinated planning and infrastructure investment, these conflicts may intensify, reducing the quality of the visitor experience and placing further strain on the foreshore environment.

Elsewhere, foreshore management has seen varied success. In Lake Macquarie, coordinated planning and community engagement have helped balance ecological protection with recreational access, including the use of foreshore management plans and vegetation guidelines. In contrast, parts of Moreton Bay and Botany Bay have experienced persistent degradation due to unmanaged access, vegetation loss, and privatisation of public land, with limited success in reversing these trends. These examples highlight the importance of



integrated, place-based management that recognises the foreshore as both a public asset and an ecological system requiring protection.

Recommended actions for foreshore development and management:

- Restore natural foreshore vegetation (e.g. saltmarsh) to support wrack decomposition and habitat health.
- Implement planning controls to limit further hardening of shorelines and infilling.
- Define and enforce foreshore management zones with clear responsibilities across agencies and landholders.
- Design foreshore infrastructure to accommodate wrack movement and drying.
- Integrate water-sensitive urban design (WSUD) into planning controls, including for single-dwelling developments.
- Undertake foreshore rehabilitation, including saltmarsh restoration for nutrient filtering and odourless wrack breakdown.
- Educate the community on sustainable foreshore practices and the ecological role of wrack and vegetation.

Risk Rating

In considering the risk rating for foreshore development and management, the following factors were considered:

- Present day – Ongoing residential growth, public land encroachment, weak planning enforcement, vegetation loss, early habitat fragmentation.
- 20 years – Intensified development, loss of buffers, increased hard structures, limited vegetation, minimal rehabilitation.
- 50 years – Accumulated hardening, rising seas, no retreat space, entrenched private use.
- 100 years – Permanent natural shoreline loss, severe habitat fragmentation, chronic erosion, failing infrastructure.

The consequences of those factors were identified and rated for potential impact:

- Present day – Noticeable ecological decline, reduced access and stability, but still reversible with action.
- 20 years – Widespread natural character loss, habitat disconnection, rising erosion, and declining public use.
- 50 years – Ecosystem collapse, water quality decline, loss of recreation and visual appeal; restoration is difficult.
- 100 years – Irreversible ecological and social collapse, with permanent loss of access, biodiversity, and heritage.

Both the factors and consequences were then taken together to determine a final risk rating for foreshore development and management over the next 100 years, as outlined in Table 7-3.

Table 7-3 Risk Rating: Foreshore development and management

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Major	High	
20 years (~2045)	Almost Certain	Major	Very High	



Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
50 years (~2075)	Almost Certain	Major	Very High	Public foreshores Private foreshores
100 years (~2125)	Almost Certain	Catastrophic	Very High	Natural areas (although limited)

7.5 Groundwater pollution

Groundwater is a significant but poorly understood source of nutrients to the estuary, especially following rainfall events that increase hydraulic gradients. Potential sources of contamination include reclaimed shoreline areas, aging sewer infrastructure, and unlined ash dams (Glamore, et al., 2020; Alluvium and EcoFutures, 2023). While surface water pollution has long been the focus of estuary management, groundwater is increasingly recognised as a hidden but significant pathway for nutrient and contaminant transport into the estuary. Elevated concentrations of nitrogen and other pollutants have been detected in groundwater near urban areas such as Berkeley Vale, suggesting that subsurface flows may be contributing to eutrophication and ecological degradation.

Land reclamation and urban development in low-lying areas have altered natural hydrology reducing infiltration zones and increasing impervious surfaces. These changes disrupt groundwater recharge and redirect flows through disturbed or contaminated sediments. In reclaimed or infilled areas, groundwater may pass through layers of polluted soil, picking up nutrients, heavy metals, and other contaminants before discharging into the estuary or its tributaries. This process is largely invisible and difficult to monitor, making it a persistent and under-addressed threat.

Groundwater infiltration through polluted sediments is particularly problematic in areas with legacy industrial activity, ageing septic systems (see Section 4.4), and poorly managed stormwater infrastructure (see Section 4.3). These sources contribute to nutrient loading in the subsurface, which can seep into nearshore zones and exacerbate algal blooms, wrack accumulation, and sediment enrichment. Unlike surface runoff, groundwater pollution is slow-moving and difficult to remediate once contamination occurs, requiring long-term monitoring and proactive land use planning.

Water pollution from nutrients, especially nitrogen and phosphorus, is a key driver of groundwater contamination. These nutrients originate from fertilisers, wastewater, and urban runoff, and can leach into groundwater through permeable soils or compromised infrastructure. Once in the groundwater system, they may persist for decades, slowly discharging into the estuary and undermining water quality improvement efforts.

Elsewhere, groundwater pollution has been managed with varying success. In the Lower Hunter region, targeted monitoring and infrastructure upgrades have helped identify and mitigate groundwater nutrient hotspots (State of NSW Water, 2024; State of NSW Department of Planning and Environment, 2022). In contrast, parts of Moreton Bay and Botany Bay have experienced persistent groundwater contamination due to historical land reclamation and limited subsurface monitoring, with long-term impacts on estuarine health (Orica, 2025; Stening, 2018; Saeck, et al., 2019; State of QLD Department of the Environment, Tourism, Science and Innovation, 2025). These examples underscore the need for proactive, science-based management of groundwater systems, particularly in shallow, perched estuaries like the Tuggerah Lakes estuary.

Recommended actions for ground water pollution include:

- Map and monitor groundwater pathways and pollutant concentrations, especially in urban and reclaimed areas.



- Restrict land reclamation and infilling in sensitive zones; prioritise permeable surfaces and natural infiltration.
- Remediate polluted sediments in known discharge zones and legacy industrial sites.
- Upgrade septic systems and stormwater infrastructure to reduce nutrient leaching.
- Integrate groundwater protection into planning controls and development assessments.
- Support collaborative research to better understand groundwater–surface water interactions.

Risk Rating

In considering the risk rating for ground water pollution, the following factors were considered:

- Present day – Limited groundwater data, early nutrient hotspots, aging septic systems, weak monitoring, low public awareness.
- 20 years – Urban growth, rising nutrient inputs, limited cleanup, growing groundwater use
- 50 years – Long-term contamination, climate impacts on recharge, aging infrastructure, reduced natural filtration.
- 100 years – Persistent pollution, aquifer damage, filtration system failure, failing infrastructure, climate-driven shifts

The consequences of those factors were identified and rated for potential impact:

- Present day – Moderate water quality issues nearshore; manageable with better monitoring and upgrades.
- 20 years – Significant nutrient buildup, triggering eutrophication and algal blooms; management grows harder.
- 50 years – Widespread groundwater decline, affecting estuaries and freshwater; restoration is costly and complex.
- 100 years – Irreversible groundwater collapse, ecosystem loss, and severe health and economic impacts.

Both the factors and consequences were then taken together to determine a final risk rating for ground water pollution over the next 100 years, as outlined in Table 7-4.

Table 7-4 Risk Rating: Ground water pollution

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Possible	Moderate	Moderate	■ Berkeley Vale (known) ■ Multiple other potential locations
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	



8 COASTAL HAZARDS

8.1 Introduction

The Tuggerah Lakes estuary is highly sensitive to coastal hazards due to its shallow basins and narrow, wave-dominated entrance. Inside the estuary, tidal range is small and mean water levels sit persistently above offshore mean sea level, which increases exposure of low-lying foreshores. Hazard expression is shaped by this hydraulic setting, local wind-wave climate, and the extent of urban development around the shoreline.

Coastal hazards in this chapter are treated as interacting processes. Tidal inundation, coastal water-level setup, and catchment inflows often overlap during storms, while entrance behaviour controls how quickly the estuary can drain after high water. Bank stability depends on water levels, wind-waves, and the condition of riparian and foreshore vegetation. Over time, sea level rise will lift the baseline for all hazards and shift active shoreline zones landward.

This chapter provides short, decision-focused summaries of the priority hazards, their present exposure, and likely change over common planning horizons.

The Scoping Study (Central Coast Council, 2021) FPRA identified two key stressors related to coastal hazards that were found to be High Risk (over present day and/or future planning horizons) that have been addressed in more detail in this Stage 2 risk assessment:

- Tidal inundation (including future sea level rise) – see Section 8.2
- Combined coastal and catchment flooding – see Section 8.3

It should be noted that although outside the study area of this CMP, predicted coastal recession and the potential for significant changes to channel location/processes (Section 5) may impact coastal hazards related to this CMP.

For completeness, an assessment has also been made with regards to other relevant coastal hazards listed in the CM Act, including the following:

- Estuary entrance instability – see Section 8.4
- Bank erosion – See Section 8.5

It should be noted that CM Act lists other coastal hazards (such as coastal erosion, long term shoreline recession, and cliff and slope instability) These hazards are related more to the open coastline and as such have been addressed in the Central Coast Open Coast CMP.

8.2 Tidal Inundation (Including Future Sea Level Rise)

Tidal inundation (often referred to as “sunny-day flooding”) describes the periodic flooding of low-lying estuarine foreshores under normal tidal conditions. This natural process plays a vital role in sustaining wetland function, influencing soil salinity, vegetation zonation, and habitat productivity.

The tidal regime within the Tuggerah Lakes estuary differs markedly from that of the adjacent ocean. Continuous water level monitoring at the Long Jetty gauge (211418) since September 1991 shows that the average lake level over the 34-year record is approximately +0.27 m AHD (MHL, 2022). This indicates that mean lake water levels are consistently super-elevated above mean sea level offshore. The degree of this elevation varies through the spring–neap cycle and in response to oceanographic fluctuations, such as coastal-trapped waves and barometric effects.

This persistent super-elevation results from asymmetry in tidal flows through the entrance channel, where flood tides enter more efficiently than ebb tides due to wave-driven setup over the entrance bar and frictional



resistance to outflow (Cardno, 2013). This process, known as tidal pumping, produces a net residual inflow that elevates the mean water level within the estuary. Such behaviour is typical of wave-dominated estuaries with narrow and shallow entrances, where wave energy and restricted conveyance combine to maintain higher mean lake levels relative to offshore conditions (MHL, 2022).

The tidal range inside the estuary is highly constrained, with a semi-diurnal range typically between 1–3 cm, increasing to around 15 cm following major rainfall or entrance-scouring events when channel conveyance temporarily increases (MHL, 2022).

A probability of exceedance analysis based on 34 years of water level records at Long Jetty is depicted in Figure 8-1 and Figure 8-2. It shows that around 90% of observed water levels lie between 0.0 m AHD and +0.5 m AHD, and levels exceed +0.5 m AHD less than 20 days per year. This highlights the relatively stable but elevated hydraulic regime of the estuary, which has direct implications for present and future tidal inundation, particularly under projected sea level rise scenarios.

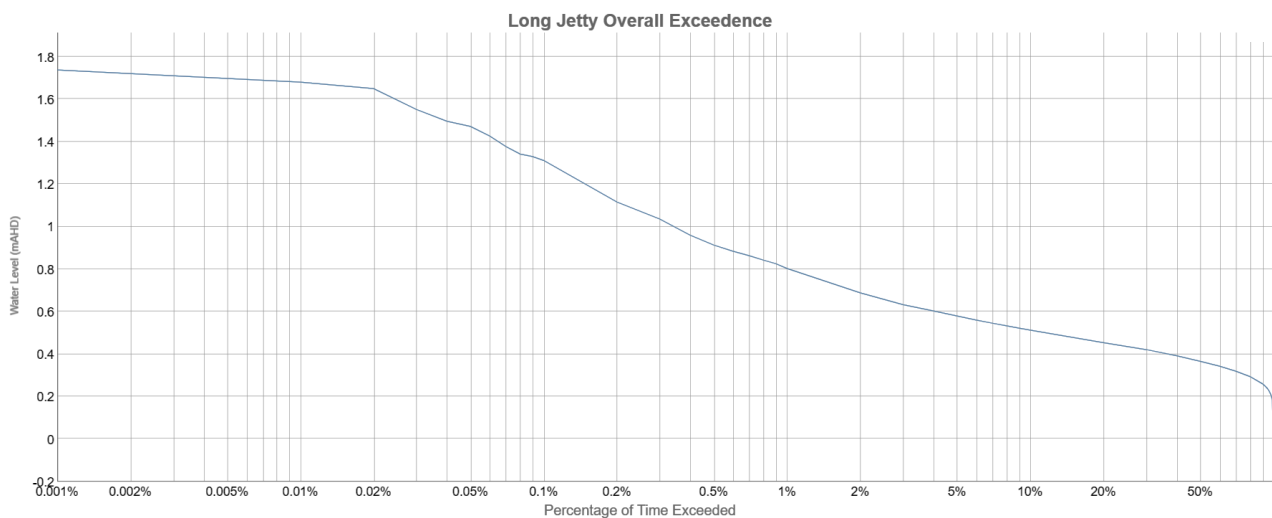
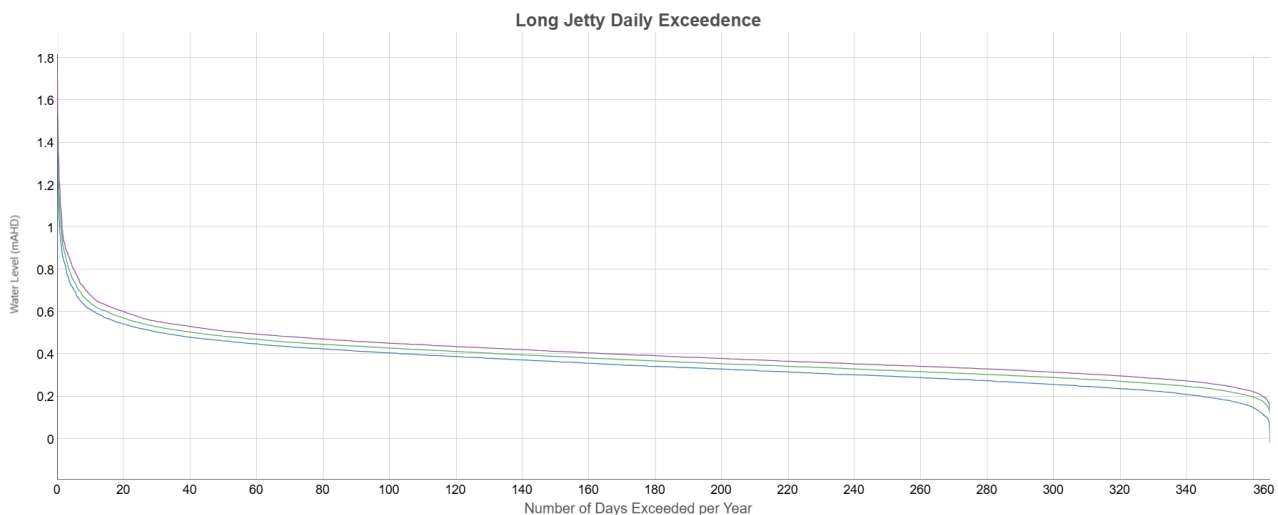


Figure 8-1 Long Jetty - Tidal Probability of Exceedance Plot



Legend: ☒ Daily Minimum ☒ Daily Mean ☒ Daily Maximum

Figure 8-2 Long Jetty - Annual Days of Exceedance Plot



The NSW Estuary Tidal Inundation Exposure Assessment (OEH, 2018g) provides a state-wide overview of tidal inundation exposure across NSW estuaries and forms an important baseline for understanding estuary-scale inundation risk. While no site-specific tidal inundation modelling has been undertaken for Tuggerah Lakes, the state dataset provides a robust broadscale assessment suitable for identifying regional patterns of tidal exposure and sensitivity.

The study mapped inundation extents corresponding to the High High Water Solstice Springs (HHWSS) tidal plane, which represents the higher astronomical tides (king tides) typically experienced along the NSW coast. It also evaluated a series of future sea level rise (SLR) increments of +0.5 m, +1.0 m, and +1.5 m, representing a plausible range of design and planning scenarios. These levels are not tied to specific planning horizons but are intended to illustrate the progressive expansion of tidal inundation under projected sea level conditions. Importantly, they should not be viewed as an upper bound, as longer-term SLR beyond +1.5 m may need to be considered for strategic land-use and infrastructure planning. Using these tidal surfaces, a vulnerability assessment was undertaken to estimate the number of potentially affected properties and the length of inundated road network based on the Geocoded Urban and Rural Addressing System (GURAS) database. The summary results for the Tuggerah Lakes estuary are presented in Table 8-1.

Table 8-1 NSW Tidal Inundation Exposure Assessment – Results for the Tuggerah Lake Estuary

Parameters	SLR=0m	SLR=0.5m	SLR=1.0m	SLR=1.50m
Properties Impacted (#)	364	1,590	3,249	5,266
Length of Road Impacted (km)	0.8	19.6	56.2	97.4

The results of the NSW Estuary Tidal Inundation Exposure Assessment indicate that the Tuggerah Lakes estuary is among the most vulnerable estuaries in New South Wales to tidal inundation and future sea level rise. Even under present-day conditions (SLR = 0 m), an estimated 364 properties and 0.8 km of road are subject to inundation during high astronomical tides. Under a +0.5 m sea level rise scenario, this exposure increases substantially to 1,590 properties and nearly 20 km of road, highlighting the sensitivity of low-lying foreshore areas. At the higher-end scenarios of +1.0 m and +1.5 m SLR, the potential impacts escalate sharply, with more than 5,000 properties and almost 100 km of road network affected.

In broad terms, this analysis places the Tuggerah Lakes estuary as the fourth most impacted estuary in NSW in terms of potential property exposure to tidal inundation (Figure 8-3). This reflects the estuary's extensive low-lying topography, limited tidal exchange capacity, and large perimeter of developed foreshore land. These characteristics make the Tuggerah Lakes estuary particularly sensitive to small increases in mean water level, underscoring the importance of forward planning for adaptation, foreshore management, and infrastructure resilience in future stages of the CMP.

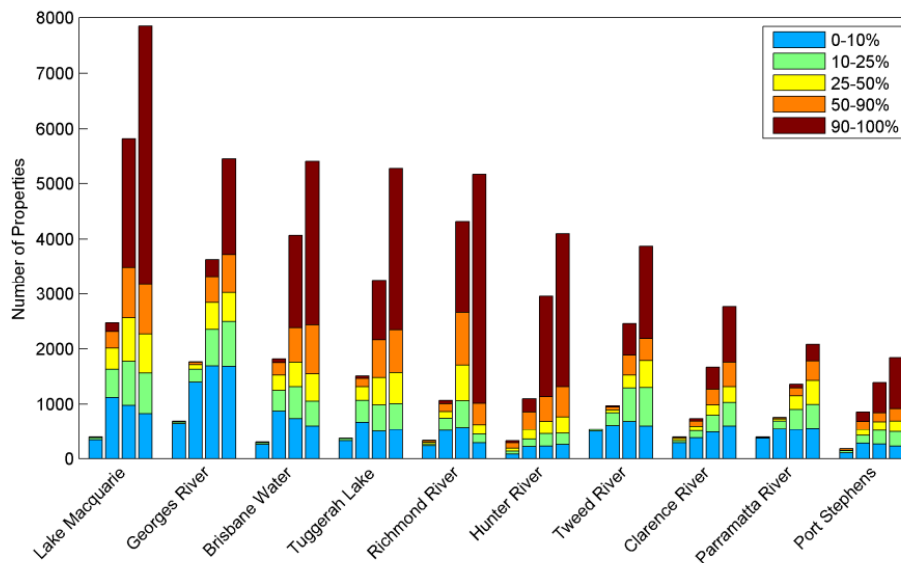


Figure 8-3 Total numbers of properties exposed to inundation (HHWSS) for the 10 most exposed NSW estuaries, including proportion-of-lot, under 0, 0.5, 1.0 and 1.5 m SLR

Potential management actions for assessing and managing tidal inundation risk include:

- Undertake detailed local-scale inundation modelling to refine understanding of exposure and better quantify risks identified in the state-wide assessment. This could include integration of stormwater networks to provide a robust detailed picture of tidal inundation risk around the estuary. Additionally, this could include assessment of the potential response of the entrance berm to rising sea levels, including how its position, height, and stability may shift over time and influence future tidal inundation risk.
- Integrate inundation mapping into Council's land-use planning and development controls, ensuring new development and redevelopment in low-lying areas account for future sea level rise.
- Develop foreshore adaptation strategies for identified hot spots, including options such as controlled retreat, raised infrastructure, or low-impact shoreline protection.
- Review and upgrade stormwater and drainage infrastructure to reduce backwater flooding and improve flow conveyance during elevated water levels in the estuary.
- Incorporate tidal inundation considerations into asset management planning, prioritising at-risk public infrastructure for resilience upgrades or redesign.
- Support community awareness and preparedness initiatives, including communication tools, signage, and property-level adaptation guidance.
- Monitor and evaluate changes in lake level dynamics and entrance behaviour to inform adaptive management and future CMP updates.

Risk Rating

Analysis of the state-based inundation mapping highlights several key foreshore "hot spots" within the Tuggerah Lakes estuary that are most susceptible to present and future tidal inundation. These areas share common physical characteristics - low-lying elevation, proximity to the estuary margin, and limited local drainage or topographic relief - making them particularly sensitive to even small increases in mean water level. Notable hot spots include those listed in Table 8-2 below.


Table 8-2 Snapshot of tidal inundation risk distribution and rating

Hot Spot Description	SLR=0m	SLR=0.5m	SLR=1.0m	SLR=1.50m
Tuggerah Lake				
The Entrance and Long Jetty: Foreshore reserve along Tuggerah Parade	Moderate	High	Very High	Very High
Long Jetty: Properties along Tuggerah Parade and adjoining streets – in between Archibold St and Minto Ave	Low	Low	High	Very High
Tumbi Umbi and Killarney Vale: Low lying properties along Lucinda Ave, and around the entrance to Tumbi Umbi Creek	Low	Moderate	Very High	Very High
Chittaway Bay and Berkeley Vale: Low lying properties along Lake Edge Ave and Aloha Drive	Low	Moderate	High	Very High
Tuggerawong and Wyongah: East of Tuggerawong Road	Low	Low	Moderate	High
North Entrance: Holiday Park	Low	Low	High	Very High
Budgewoi Lake				
Gorokan and Lake Haven: Foreshore properties east of The Corso and Malvina Parade	Low	Low	Moderate	High
Charmhaven: Properties East of Panorama Ave	Low	Low	Moderate	Moderate
San Remo: Foreshore Reserve	Low	Moderate	High	Very High
Budgewoi: Foreshore properties along Scenic Drive and Diamond Head Drive	Low	Moderate	Very High	Very High
Toukley: Foreshore reserve and properties west of Leonard Ave, and properties north of Main Road	Low	Moderate	High	Very High
Toukley: Golf Course	Moderate	Very High	Very High	Very High
Lake Munmorah				
Budgewoi: Foreshore properties and foreshore reserve along Natuna and Sunrise Ave	Low	High	Very High	Very High
North-eastern foreshore: Low lying properties along Green Acre Ave	Low	Low	Moderate	High
Budgewoi Beach: Holiday Park	Low	High	Very High	Very High

8.3 Combined Coastal and Catchment Flooding (including Future Sea-Level Rise)

Flooding in the Tuggerah Lakes estuary results from the combined influence of catchment runoff and elevated ocean water levels (MHL, 2025). These two drivers often interact during major storm events, when strong onshore winds, large waves, and low atmospheric pressure generate temporary rises in coastal water levels. The main components of these elevated levels include wind setup, wave setup, and inverse barometric setup, all of which act to increase ocean and entrance water levels above normal tides. These elevated levels typically rise rapidly to a peak and recede over a period of several days, superimposed on the normal tidal cycle.



The extent of lake flooding depends on whether these elevated ocean levels coincide with peak inflows from the catchment (MHL, 2022; Lawson and Treloar, 1994; MHL, 2025). When both occur simultaneously, the water level in the estuary can rise sharply, as floodwaters are temporarily trapped by restricted outflow through the narrow entrance channel. However, this overlap does not always occur, since catchment and ocean responses can differ in timing and intensity depending on storm duration, rainfall distribution, and entrance conditions (MHL, 2022).

The Tuggerah Lakes catchment covers roughly 790 square kilometres, draining into an estuarine water body of only about 80 square kilometres. This large ratio means that substantial rainfall events can quickly translate to widespread flooding across low-lying foreshore and floodplain areas. No feasible engineering intervention can fully eliminate flooding in these zones (MHL, 2022); periodic inundation is an inherent characteristic of the estuary. Importantly, these natural water level fluctuations are ecologically beneficial, redistributing organic matter, watering saltmarsh vegetation, and maintaining the health of wetland habitats.

Under typical conditions, lake levels fluctuate between about +0.2 m and +0.4 m AHD. Rainfall of around 200 mm across the catchment can raise lake levels to approximately +1.3 m AHD (minor flood), while 350 mm or more may produce levels near +1.6 m AHD (major flood). The minor flood level is defined at +0.9 m AHD, at which some local roads become inundated, and there is roughly a 50% probability of reaching this level in any given year. Historical records indicate that lake levels have reached as high as +2.1 m AHD (June 1949), with at least six major flood events exceeding +1.7 m AHD, including the July 2022 event (see Figure 8-4), which peaked at +1.72 m AHD (MHL, 2025) – see Table 8-3.

The 2025 Tuggerah Lakes Flood Study Review (Draft) (MHL, 2025) modelling indicates that the Probable Maximum Flood (PMF) could reach approximately +3.04 m AHD. The previous PMF of +2.7 m AHD has been used for several decades as the minimum floor level for habitable structures surrounding the estuary to safeguard property from extreme flood events. Flood hazard and risk information is publicly available through Council's regional online flood mapping tool, which presents a range of flood layers and probabilities consistent with state and national floodplain management guidance.

Table 8-3 Historic and Design peak flood levels within Tuggerah Lakes (MHL, 2025)

Event	Peak WL (mAHD)
June 1949	2.1
July 2022	1.72
February 2020	1.68
June 2007	1.65
PMF (Probable Maximum Flood)	3.04
1% AEP (1 in 100 chance per year flood)	2.24
5% AEP (1 in 20 chance per year flood)	1.73
20% AEP (1 in 5 chance per year flood)	1.22



Figure 8-4 Flooding in the Tuggerah Lakes entrance in 2022

Unlike smaller coastal lagoons, the Tuggerah Lakes estuary remains predominantly open, with the entrance rarely closing for extended periods (the last full closure occurred in 1987). During forecast flood events, Council implements entrance management procedures designed to facilitate natural scouring and improve outflow capacity, helping to moderate flood peaks.

Looking ahead, SLR will exacerbate flooding impacts across the Tuggerah Lakes floodplain. Even modest long-term increases in baseline lake level will reduce the available storage capacity of the estuary, increase the frequency and duration of flood events, and extend the reach of inundation into currently unaffected low-lying areas. Consequently, the cumulative influence of climate change must be considered in long-term flood risk planning.

Flood management for the Tuggerah Lakes estuary is primarily delivered through the NSW Flood Risk Management Program (FRMP) rather than the CMP process. The FRMP provides the framework for catchment-scale hydrologic and hydraulic modelling, floodplain risk studies, and the implementation of physical and planning measures to reduce risk to life and property. The CMP process complements this by focusing on coastal and estuarine ecosystem resilience, land-use interface issues, and adaptation planning, ensuring that the two programs operate in alignment.

Recommended actions for combined coastal and catchment flooding management:

- Apply updated coincident flood and coastal hazard data to guide development and redevelopment along the foreshore.
- Maintain and periodically review current floor level controls (+2.7 m AHD) in light of new flood and sea level rise information.
- Limit new development or land-use intensification in low-lying flood-prone areas through planning instruments such as the DCP.
- Incorporate natural buffers and adaptive design measures - such as setbacks, vegetated edges, and raised structures - to improve resilience



- Continue monitoring lake levels, shoreline condition, and entrance dynamics to support adaptive management.

Risk Rating

In considering the risk rating for combined coastal and catchment flooding, the following factors were considered:

- Present day – Localised tidal inundation and minor flooding already affect low-lying foreshore areas, particularly during king tides and heavy rainfall. Risks are *high* but largely manageable through existing planning controls and asset maintenance. It should be noted that the current day risk has been increased from the “low” in the CMP Scoping study as this report has combined catchment flooding into this risk, and catchment flooding is where the greater risk currently is due to the estuary being protected from tidal inundation currently by its relatively small entrance.
- 20 years – Increasing frequency of minor inundation events and more frequent exceedance of current floor levels due to gradual sea level rise. Risk continues as *high* in vulnerable precincts if adaptive planning measures are not implemented.
- 50 years – Sustained sea level rise and more frequent flood events likely to cause widespread nuisance flooding and reduced effectiveness of existing drainage infrastructure. Risk becomes *high to very high*, particularly for older residential areas and low-lying public assets.
- 100 years – Significant sea level rise results in permanent inundation of some low-lying land and loss of usable foreshore areas. Long-term risk is *very high*, requiring strategic adaptation such as planned retreat, elevation of assets, or reconfiguration of land use

Both the factors and consequences were then taken together to determine a final risk rating for foreshore development and management over the next 100 years, as outlined in Table 3-14.

Table 8-4 Risk Rating: Combined Coast and Catchment Flooding

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Possible	Major	High	■ See Section 8.1 (Tidal Inundation) for inundation hot spot areas
20 years (~2045)	Possible	Major	High	
50 years (~2075)	Likely	Catastrophic	Very High	
100 years (~2125)	Almost Certain	Catastrophic	Very High	

8.4 Estuary Entrance Instability

The Tuggerah Lakes entrance is a dynamic, wave-dominated coastal feature that has historically shown periods of instability, particularly following large flood events when the entrance channel can shift, scour, or widen dramatically. While the southern foreshore of the entrance channel is now heavily reinforced with seawalls, revetments, and developed urban land, the northern side - including the Holiday Park and the sandy spit that forms the northern entrance arm - remains largely unprotected and morphologically active.

During high-flow events, the combination of flood discharge from the estuary and strong wave-driven currents at the mouth can trigger entrance breakout events, where large volumes of water scour through the entrance channel and across the northern spit. An example of this process from the 2022 flood event is provided in Figure 8-4.

These events can result in rapid erosion, channel migration, and, in extreme cases, the complete breaching or washing away of the northern spit and foreshore areas. Following such events, sediment is gradually re-



deposited through wave and tidal action, and the entrance tends to re-stabilise over weeks or months as littoral processes rebuild the sand barrier (Cardno, 2013; MHL, 2022).

Although the Tuggerah Lakes estuary has remained predominantly open since the late 1980s, the entrance continues to fluctuate in width, depth, and alignment depending on storm intensity, catchment inflows, and prevailing wave climate. Whilst the formal foreshore protection structures along the southern foreshore provide a degree of protection from a meandering entrance channel, the northern foreshore is relatively unprotected. The northern foreshore can experience significant localised erosion, and channel reformation can occur during major floods.

Future SLR is also expected to exacerbate entrance instability by increasing the frequency and depth of elevated ocean water levels, intensifying wave energy at the entrance bar, and promoting more sustained periods of tidal exchange. This may increase erosion risk to the northern spit and adjoining foreshore assets, while also influencing sediment transport patterns and the overall hydraulic efficiency of the entrance channel.

Management of entrance behaviour and flood breakout risk is primarily addressed through the Tuggerah Lakes FRMP and Council's Interim Entrance Management Procedure, which guide operational dredging, monitoring, and emergency response procedures. Within the CMP context, entrance instability is addressed from an ecosystem health and foreshore resilience perspective, focusing on the impacts of geomorphic change on habitat condition, recreation, and public safety.

Recommended actions for managing entrance instability include:

- Continue regular bathymetric and topographic monitoring of the entrance channel and northern spit to detect early signs of erosion or channel migration.
- Maintain and periodically review Council's Interim Entrance Management Procedure to ensure clear procedures for flood response and sand management are in place. Note that this Interim Procedure will be replaced with the Entrance Management Strategy to be developed during the CMP process.
- Coordinate entrance management works with broader FRMP actions and NSW Government agencies to balance flood mitigation, recreational access, and ecological values.
- Model expected berm / channel processes response to sea level rise.
- Model potential future entrance breakout scenarios under sea level rise to assess impacts on infrastructure, access, and sediment pathways.

Risk Rating

In considering the risk rating for estuary entrance instability, the following factors were assessed:

- Present day – The entrance is generally stable but remains prone to localised erosion and channel widening during major floods. Risk is *moderate*, primarily affecting the northern spit and Holiday Park area.
- 20 years (~2045) – Increased storm activity and gradual sea level rise likely to heighten erosion pressure on unarmoured foreshores. However, the risk generally remains *moderate*.
- 50 years (~2075) – More frequent high-water events and sustained wave energy likely to drive recurring instability, periodic spit breaches, and potential sediment redistribution. Risk is *moderate to high*.
- 100 years (~2125) – Projected sea level rise and intensified coastal processes may cause major geomorphic change during severe events, including full loss of the northern spit and major erosion of the northern entrance channel foreshore. Long-term risk is *high*.


Table 8-5 Risk Rating: Estuary Entrance Instability

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Possible	Minor	Moderate	- Entrance spit - Northern foreshore (including holiday park)
20 years (~2045)	Possible	Moderate	Moderate	
50 years (~2075)	Likely	Moderate	Moderate	
100 years (~2125)	Almost Certain	Moderate	High	

8.5 Bank Erosion

Bank erosion within the Tuggerah Lakes catchment and estuarine foreshores remains one of the most significant ongoing geomorphic and water quality management issues. The problem extends from the estuary margins to the major tributaries - particularly Wyong River, Ourimbah Creek, Wallarah/Spring Creek, Tumbi Umpi Creek, and Saltwater Creek - all of which contribute fine sediment and nutrients to the estuary.

Tributary Bank Erosion

The historical Estuary Management Plan (Bio-Analysis Pty Ltd, 2006) identified streambank rehabilitation as a priority management action, aimed at reducing erosion, improving riparian vegetation, and limiting the export of nutrient-rich sediments during flood events. These sediments often accumulate within the estuary due to its low hydraulic gradient and the influence of denser saline water, leading to delta formation and infilling of lake margins (Glamore, et al., 2020).

Detailed streambank condition assessments and rehabilitation plans were subsequently completed for the major catchments, including:

- Ourimbah Creek Streambank Management Plan (Cardno Lawson Treloar, 2008a)
- Wyong River Streambank Management Plan (Cardno Lawson Treloar, 2008b)
- Tumbi Umpi Creek Streambank Rehabilitation Plan (Storm Consulting, 2007a)
- Saltwater Creek Streambank Rehabilitation Plan (Storm Consulting, 2007b)
- Spring and Wallarah Creeks Streambank Condition and Conservation Report (Storm Consulting, 2008)

Although numerous streambank rehabilitation works have since been implemented, no comprehensive reassessment has been undertaken in over a decade, and many earlier recommendations now require review or renewal.

- Wyong River and Ourimbah Creek together drain over 70% of the catchment and contribute the greatest sediment load to the estuary. Both waterways exhibit bank undercutting, loss of riparian cover, and localised collapse of sandy banks. Boat wash, and wind waves worsen instability in lower tidal reaches.
- Wallarah and Spring Creeks are mostly stable but have localised erosion near Blue Haven and San Remo associated with public access and degraded vegetation.
- Tumbi Umpi Creek and Saltwater Creek show mostly stable or engineered channels, though local scouring occurs near stormwater outlets and channelised sections. However, an area of erosion persists on Tumbi Umpi Creek between Molsten Ave and Blue Crane Cl despite previous rehabilitation efforts.

Studies by NSW OEH (2011) found that streambank erosion can contribute sediment loads equal to or greater than those generated by surface runoff, particularly in the Wyong and Ourimbah catchments. This highlights the importance of continued riparian rehabilitation and erosion control.



Foreshore Erosion around Tuggerah Lakes

Along the estuary margins, wind-wave action during elevated water levels drives ongoing erosion, especially in exposed areas such as Long Jetty, Chittaway Bay, Berkeley Vale, and Tuggerawong. Removal of fringing vegetation and the installation of scattered hard structures (e.g. private seawalls and boat ramps) have disrupted natural sediment transport, causing flanking erosion and foreshore retreat. The combination of shallow lakebed slopes, sandy soils, and frequent wave exposure leaves many public reserves vulnerable (Central Coast Council, 2021).

Sea level rise will increase the frequency of shoreline inundation and shift the active erosion zone landward, particularly along low-lying reserves and areas where natural foreshore vegetation has been removed. Without intervention, this may lead to progressive loss of public open space, tree fall, and damage to recreational infrastructure.

Management of bank erosion within the Tuggerah Lakes estuary and catchment are primarily addressed through local foreshore improvement works, land-use planning controls, and asset management programs. Within the CMP context, the focus is on identifying erosion-prone areas, supporting the use of nature-based solutions (such as re-vegetation, coir logs, and living shorelines), and integrating erosion risk into broader adaptation and recreational planning.

Recommended actions for managing bank erosion include:

- Update and expand streambank and foreshore condition assessments across the entire Tuggerah Lakes estuary, including a prioritisation process.
- Develop foreshore management plans for the priority precincts identified in the bank and foreshore condition assessment (e.g. Chittaway Bay, Killarney Vale, Tuggerawong) identifying preferred stabilisation approaches.
- Implement a foreshore erosion monitoring program using aerial imagery and fixed photo points to track changes over time.
- Implement nature-based stabilisation measures such as revegetation, coir logs, and foreshore buffers rather than hard structures where feasible.
- Review and, where necessary, upgrade existing hard structures to reduce reflection and improve integration with natural shoreline processes.
- Coordinate with Council's Asset Management and Parks teams to align foreshore maintenance and revegetation works with erosion-prone zones.

Risk Rating

In considering the risk rating for this risk, the following factors were assessed:

- Present day – Localised erosion along tributaries and estuary margins; *moderate to high risk* where banks are along low-lying reserves and areas where natural foreshore vegetation has been removed.
- 20 years (~2045) – Ongoing shoreline retreat and continued sediment input from unstable reaches; *high risk* in exposed precincts.
- 50 years (~2075) – Sea level rise and increased storm intensity likely to cause widespread foreshore and bank erosion; *very high risk*.
- 100 years (~2125) – Persistent wave exposure and reduced sediment supply result in permanent shoreline retreat and habitat loss; *very high long-term risk*.


Table 8-6 Risk Rating: Bank Erosion

Timeframe	Likelihood	Consequence	Risk Rating	Key Locations
Present day (2025)	Likely	Moderate	Moderate	- Streambank erosion: Wyong River, Ourimbah Creek - Estuary foreshore erosion: Long Jetty, Chittaway Bay, Berkeley Vale, and Tuggerawong
20 years (~2045)	Likely	Major	High	
50 years (~2075)	Almost Certain	Major	Very High	
100 years (~2125)	Almost Certain	Major	Very High	



9 HERITAGE AND CULTURE

While no high-risk threats were identified in the Scoping Study (Central Coast Council, 2021) for the current or future scenarios for Heritage and Culture under existing legislative frameworks, the assessment reveals a significant strategic gap in the integration of Indigenous cultural values and knowledge into estuary management. The Tuggerah Lakes estuary and catchment is a landscape of deep cultural significance to the Indigenous peoples, with known sites such as the Tuggerah Lakes Resting Place and numerous heritage-listed locations. However, many culturally significant places remain undocumented or unprotected under current systems, and the absence of formal mechanisms for engagement with Indigenous peoples limits the cultural depth and inclusivity of planning processes.

The Expert Panel Review and CMP Scoping Study both highlight that Indigenous knowledge, particularly ecological insights grounded in long-standing relationships with Country, is not yet adequately incorporated into the management of the lakes (Glamore, et al., 2020; Central Coast Council, 2021). This omission represents a missed opportunity to enrich estuary planning with holistic perspectives that connect ecological health, cultural continuity, and community wellbeing. It also risks perpetuating a management model that is technically sound but culturally incomplete.

In addition to the lack of formal engagement pathways, there is limited recognition of cultural landscapes as dynamic systems that include both tangible heritage (e.g. middens, burial sites, ceremonial grounds) and intangible values (e.g. stories, seasonal knowledge, spiritual connections). These values are often embedded in places that may not meet conventional heritage listing criteria but are nonetheless vital to Indigenous peoples' identity and stewardship.

To address these gaps, the Expert Panel recommends that future planning and engagement efforts actively involve Indigenous communities, not only in identifying heritage values but also in shaping the vision and priorities for the estuary. This includes supporting co-designed management strategies, embedding cultural protocols in decision-making, and ensuring that cultural heritage is protected alongside ecological and recreational goals. The CMP Scoping Study further proposes the development of a Land and Sea Country Plan, led by the Darkinjung Local Aboriginal Land Council, to guide culturally informed management and foster long-term partnerships.

Examples from other regions, such as the co-management of the Gippsland Lakes in Victoria (Victorian Marine & Coastal Council and Gunaikurnai Land and Waters Aboriginal Corporation, 2020; Commissioner for Environmental Sustainability Victoria, 2021) and the inclusion of Ngarrindjeri Nation in the Lower Murray-Darling Basin planning (Wallis, 2007; State of SA Department of Environment, Water and Natural Resources, 2013), demonstrate the benefits of integrating Indigenous leadership into estuary governance. These models have improved ecological outcomes, strengthened cultural resilience, and built trust between communities and agencies.

In summary, while current legislative protections for known heritage sites are generally adequate, the broader cultural landscape of the Tuggerah Lakes estuary remains underrepresented in planning and management. Addressing this requires a shift from consultation to collaboration, and from protection to empowerment.



10 RESOURCE CONFLICTS AND ACCESSIBILITY

While no high-risk threats were identified in the Scoping Study (Central Coast Council, 2021) with regards to resource conflicts and accessibility (in the current or future scenarios), it is noted that the Tuggerah Lakes estuary faces increasing pressure on recreational infrastructure, public access, and shared-use spaces. These pressures are driven by ageing assets, constrained budgets, and a growing population and tourism footprint. High-use areas such as The Entrance, Canton Beach, and the Lakes Cycleway are particularly vulnerable to infrastructure fatigue and overcrowding. Although current management frameworks and capital works programs are generally adequate, future risks will escalate without sustained investment and strategic coordination.

The degradation of ecological buffers, particularly saltmarsh and seagrass, is compounding these pressures. These natural systems play a critical role in regulating nutrient loads, stabilising shorelines, and supporting biodiversity. Their decline, as noted in the Expert Panel Review and Tuggerah Lakes Riverine and Catchment Health Monitoring Program, contributes to wrack accumulation, algal blooms, and odour issues, which in turn diminish the recreational and aesthetic value of foreshore areas (Glamore, et al., 2020) (State of NSW and Department of Planning, Industry and Environment, 2021). This creates a feedback loop where ecological degradation undermines public amenity, leading to increased demand for artificial infrastructure and maintenance.

Urban development is a major driver of future risk. With over 41,000 new dwellings projected by 2036 under the Central Coast Regional Plan 2041, stormwater runoff and pollutant loads are expected to rise significantly (State of NSW Department of Planning and Environment, 2022). Current planning controls and infrastructure programs are not equipped to manage this scale of growth. Without reform, the estuary will face mounting pressure from poorly managed stormwater systems, increased erosion, and loss of public access to natural foreshore areas. The CMP Scoping Study and the Tuggerah Lakes Improvement Project Prioritisation Report both highlight the need for integrated catchment planning and proactive infrastructure upgrades (Central Coast Council, 2021; JBP, 2025).

To address these risks, the Expert Panel Review recommends establishing a Catchment Coordinator Taskforce (Glamore, et al., 2020). This body would oversee strategic planning, stakeholder coordination, and implementation of water-sensitive urban design (WSUD) audits. It would also help align state and local government efforts, reduce duplication, and ensure accountability across agencies. The CMP Scoping Study supports this recommendation, noting that fragmented governance is a barrier to effective estuary management (Central Coast Council, 2021).

Funding remains a critical barrier. The Expert Panel Review calls for the introduction of environmental and stormwater levies to provide a stable financial base for infrastructure upgrades, ecological restoration, and long-term maintenance (Glamore, et al., 2020). These levies would reduce reliance on ad hoc grants and enable forward planning for recreational and ecological resilience. The CMP Scoping Study further notes that other councils in NSW have successfully implemented similar levies, resulting in improved waterway health and community satisfaction (Central Coast Council, 2021).

Community engagement is also central to the recommended approach. The Expert Panel Review and Recreational Use Study advocate for collaborative decision-making, citizen science initiatives, and transparent communication of water quality data (Glamore, et al., 2020; Middle & Middle, 2023). By involving residents in shaping the future of the lakes, management strategies can better reflect shared values and priorities. Examples from other regions, such as Lake Macquarie (Lake Macquarie City Council, 2023; Lake Macquarie City, 2019) and the Georges River (Georges River Council, n.d.), demonstrate that inclusive planning and sustained investment in recreational infrastructure can enhance both ecological outcomes and community wellbeing.



In summary, while current infrastructure and planning systems are holding, they are not future-proofed. Without reform, investment, and inclusive governance, the Tuggerah Lakes estuary will face escalating resource conflicts and reduced accessibility, undermining its ecological, recreational, and cultural value.



11 OPPORTUNITIES

While this assessment highlights significant and interrelated risks, it also reveals clear opportunities for measurable improvement across governance, ecology, water quality, and community engagement. Decades of research, monitoring, and policy reform have created a strong evidence base that can now be operationalised. Both the Tuggerah Lakes Scoping Study (Central Coast Council, 2021) and the Expert Panel Report (Glamore, et al., 2020) emphasise that effective management is not limited by knowledge gaps but by coordination, continuity, and shared purpose. With a well-structured Stage 3 process, the CMP can translate existing understanding into targeted, evidence-based action that delivers ecological, social, and cultural benefits.

Building an Integrated Governance and Knowledge Framework

The current governance structure remains fragmented, but this can be reshaped into a model of cooperative estuary management. The CMP provides a statutory mechanism to align state, regional, and local roles within a single, outcomes-focused framework. Establishing a dedicated multi-agency coordination group - similar to the Catchment Coordinator Taskforce proposed by the Expert Panel - would strengthen accountability, streamline approvals, and support whole-of-catchment planning

Integrating existing datasets and research programs is another major opportunity. The Scoping Study recommends that Stage 3 consolidate long-term monitoring, modelling, and management records to build a shared information system for adaptive management. Aligning these datasets across agencies will allow for spatial and temporal trend analysis, reducing duplication and improving the reliability of decision-making.

Enhancing Catchment-to-Coast Management

Catchment pressures remain the dominant driver of water quality decline, but they also represent the greatest opportunity for improvement. The Expert Panel's catchment management recommendations highlight that targeted stormwater retrofits, erosion-and-sediment-control enforcement, and widespread WSUD adoption can deliver substantial reductions in nutrient and sediment loads over time

Stage 3 of the CMP can extend this by embedding an urban water design principles local policy and local planning instruments, reinforcing a no-net-loss principle for water quality and habitat. Improved upstream land-use management - particularly in the Wyong River and Ourimbah Creek catchments - offers a practical means to reduce downstream eutrophication. These interventions can be complemented by stormwater network optimisation, vegetated detention systems, and riparian restoration throughout the broader catchment.

The forthcoming CMP will include a Catchment Implementation Plan that is designed to integrate these upstream measures directly with estuarine management objectives. This approach draws from the model developed for the Hawkesbury–Nepean River System CMP, where a dedicated companion document defined catchment-scale water quality and flow management actions under a consistent governance and reporting framework. A similar model for the Tuggerah Lakes estuary would provide a clear mechanism to coordinate Council, state agencies, and catchment stakeholders; establish shared performance indicators for load reduction and habitat condition; and maintain alignment between floodplain, stormwater, and estuary programs over time.

Sustaining Ecological and Cultural Resilience

Ecological degradation within the Tuggerah Lakes estuary and catchment is reversible if restoration focuses on re-establishing system-wide processes rather than isolated habitat patches. Saltmarsh and seagrass restoration, foreshore revegetation, and reconnection of wetland corridors have all proven effective in comparable NSW estuaries. The Wetland Refugia Study (Waddington, Glamore, & Heimhuber, 2023) and Scoping Study (Central Coast Council, 2021) both identify an opportunity to plan proactively for wetland migration under sea-level rise, using elevation modelling and land-use controls to protect high-value areas



In parallel, there are clear opportunities to strengthen collaboration with the Darkinjung Local Aboriginal Land Council (LALC) and other Traditional Custodian groups to support culturally led stewardship of the Tuggerah Lakes estuary and catchment. Engaging early and meaningfully with Indigenous peoples in identifying values, setting priorities, and shaping management actions will embed cultural knowledge into decision-making processes. Integrating these perspectives not only aligns with the intent of the CM Act 2016 but also promotes long-term partnerships, shared understanding, and stronger community support for future estuary management initiatives.

Reliable Funding and Capacity Building

Both the Scoping Study and Expert Panel identified that reliance on short-term, contestable grant funding has limited continuity, constrained strategic delivery, and often diverted effort toward one-off projects rather than long-term outcomes. Strengthening the financial base for estuary management is therefore essential to achieve durable, system-wide improvements.

There are opportunities to explore a mix of existing and emerging funding pathways to support long-term implementation. This may include aligning with established state and federal programs, developing partnerships with government agencies and research institutions, and identifying collaborative models that pool resources across multiple stakeholders. Alternative funding structures - such as ongoing maintenance budgets for stormwater and coastal assets, or incentive-based partnerships that link investment to measurable environmental outcomes - could also be considered to build financial stability over time.

A transparent, costed implementation framework supported by clear investment logic would help strengthen Council's position in future funding rounds and build confidence among community and partner organisations. This framework should be accompanied by consistent performance monitoring, allowing progress to be demonstrated and resources to be directed where they have the greatest impact.

Capacity building within Council represents another high-return opportunity. Strengthening internal expertise in WSUD design, sediment-control enforcement, and adaptive management will improve integration across departments and enhance delivery of on-ground works. Supporting staff development and inter-team collaboration will also foster a more resilient and capable organisation - one that can continue to advance estuary management objectives regardless of external funding variability.

Communication, Engagement, and Co-Design

Renewed engagement under Stage 3 provides an opportunity to rebuild trust through transparent, evidence-based communication. A "values and opportunities" synthesis, as proposed in the Scoping Study, can act as a bridge between technical outcomes and public priorities.

This phase should focus on learning together rather than simply "fixing the problem," creating space for community members to explore how the estuary functions and why management challenges are complex. Collaborative forums, workshops, and school or citizen-science initiatives could help build shared understanding and foster a sense of ownership. Regular, plain-language updates on monitoring and progress will improve transparency and strengthen confidence in Council's stewardship.

Continued partnerships with local groups, volunteers, and Indigenous peoples offer opportunities to co-design practical actions that align with cultural values and community aspirations. By maintaining an open dialogue and inviting joint problem-solving, Stage 3 can rebuild relationships, enhance local stewardship, and position collaboration at the heart of future estuary management.

Pathway to Stage 3

Collectively, these opportunities position Stage 3 as a pivotal transition from diagnosis to delivery. The next phase should:



- Integrate risk reduction and opportunity realisation into a unified options evaluation framework.
- Prioritise actions that deliver co-benefits across environmental, social, and cultural domains.
- Establish transparent performance measures and adaptive triggers for implementation.

By drawing on the strong scientific foundation established in Stage 2, and the collaborative spirit recommended by both the Expert Panel and the Scoping Study, the Tuggerah Lakes Estuary CMP can shift from a reactive to a regenerative management model - one that restores ecological function, supports community wellbeing, and builds long-term resilience for the estuary and catchment.



12 CONCLUSIONS AND NEXT STEPS

12.1 Summary

Stage 2 of the Tuggerah Lakes Estuary CMP has identified a complex and interconnected set of risks affecting the environmental, social, and economic values of the Tuggerah Lakes estuary and catchment. These risks span multiple domains, including coastal hazards, catchment development, ecological degradation, foreshore management, entrance dynamics, and governance.

This risk assessment undertaken builds upon the first-pass analysis from Stage 1 and applies a refined, consequence-likelihood framework across short-, medium- and long-term planning horizons. This approach has enabled the identification of priority threats, the spatial distribution of risk, and the escalation of impacts under future climate and development scenarios.

Key findings include:

- Coastal hazards, including tidal inundation and combined catchment flooding, pose a significant and escalating threat to low-lying foreshore communities and infrastructure, with over 5,000 properties exposed under high-end sea level rise scenarios.
- Catchment pressures, particularly urban stormwater runoff and sewage overflows, are contributing to persistent water quality decline, with high-risk sub-catchments delivering disproportionate pollutant loads.
- Ecological degradation, including the loss of seagrass, saltmarsh, and freshwater wetlands, is occurring at a rate that exceeds community expectations and threatens long-term ecosystem resilience.
- Foreshore and nearshore management challenges, such as wrack accumulation and black ooze formation, are symptomatic of broader catchment issues and require integrated, strategic responses.
- Entrance management remains a politically sensitive and technically complex issue, with community expectations often misaligned with ecological realities.
- Governance and engagement are currently fragmented, under-resourced, and lacking coordination, contributing to high residual risk across all management domains.

The CMP Stage 2 process has provided a robust evidence base to support the development of targeted, cost-effective, and achievable management actions in Stage 3. It has also established a transparent foundation for stakeholder engagement, prioritisation of investment, and long-term adaptation planning.

The findings in this report confirm that the Tuggerah Lakes estuary and catchment is at a critical juncture. Without coordinated intervention, the estuary's ecological condition is likely to decline further, undermining its recreational, cultural, and environmental values. The CMP now provides a pathway to reverse this trajectory and deliver enduring benefits for the Central Coast community.

12.2 Next Steps

The Stage 2 outputs provide the technical spine for Stage 3. The risk ratings, and issues profiles define where risk is concentrated, which values are most exposed, and what timeframes matter. These findings will directly inform the selection and sequencing of adaptation options, the testing of design performance across scenarios, and the development of practical triggers for action. Stage 2 also establishes a transparent basis for conversations with community and stakeholders about acceptable levels of residual risk, trade-offs, and co-benefits.

Stage 3 will translate risk into an implementable pathway of actions that protect people, place, and assets while sustaining coastal values. The outcome of this stage will be a succinct set of management actions that can be enacted through an achievable and cost-effective implementation schedule. Therefore, Stage 3 of the



CMP represents a critical component of the overall process. To achieve Council's objectives, Stage 3 will employ a robust, comprehensive, and transparent decision-making framework. The steps for Stage 3, as provided in the NSW Coastal Management Manual, are outlined in Figure 12-1.

These next steps convert the Stage 2 evidence base into a practical, staged program that helps Council and other stakeholders reduce risk, protect cultural and environmental values, and sustain amenity over the next 50 to 100 years.



Figure 12-1 Stage 3 of the CMP (adapted from the CM Manual)



13 REFERENCES

- Alluvium and EcoFutures. (2023). *Wrack Management Strategy for Tuggerah*.
- Bio-Analysis Pty Ltd. (2006). *Tuggerah Lakes Estuary Management Plan*.
- Bluecoast Consulting Engineers. (2024). *Open Coast & Coastal Lagoons Coastal Hazard Assessment*.
- Bluecoast Consulting Engineers and Rhelm. (2026). *Coastal Processes and Socio-Economic Assessment*.
- BMT Commercial Australia Pty Ltd. (2020). *Lake Illawarra Coastal Management Program (2020-2030)*.
- BMT WBM. (2017). *New South Wales Marine Estate Threat and Risk Assessment Report*. Prepared for the Marine Estate Management Authority.
- BMT WBM and Moreton Bay Regional Council. (n.d.). *Northern Moreton Bay Shoreline Erosion Management Plan - Summary Report*. Retrieved from <https://www.moretonbay.qld.gov.au/files/assets/public/v/1/services/publications/northern-moreton-bay-semp-summary-report.pdf>
- Brisbane City Council. (2025). *Waterway Projects*. Retrieved from <https://www.brisbane.qld.gov.au/environment-and-water/creeks-and-waterways/waterway-projects>
- Cardno. (2013). *Tuggerah Lakes – The Entrance Morphodynamic Modelling*. Prepared for the NSW and Office of Environment and Heritage.
- Cardno. (2015). *The Entrance Morphodynamic Modelling - Entrance Beach Management Investigations*.
- Cardno Lawson Treloar. (2008a). *Ourimbah Creek Streambank Management Plan*. . Prepared for Wyong Shire Council. .
- Cardno Lawson Treloar. (2008b). *Wyong River Streambank Management Plan*. . Prepared for Wyong Shire Council. .
- Central Coast Council & State of NSW Department of Planning, Industry and Environment. (2020). *Terrigal and Coastal Lagoon Audit: Terrigal Catchment Audit*.
- Central Coast Council. (2021). *Tuggerah Lakes Estuary Coastal Management Program Scoping Study*.
- Central Coast Waterways. (2025). *Wrack Management*. Retrieved from <https://loveourwaterways.centralcoast.nsw.gov.au/wrack>
- Commissioner for Environmental Sustainability Victoria. (2021). *Case Study: Gunaikurnai Joint Management program protecting coastal lagoons and wetlands on-Country*. Retrieved from <https://www.ces.vic.gov.au/state-of-reports/state-marine-and-coastal-environment-2021-report/stories/gunaikurnai-joint>
- CSIRO. (1999). *Ecological History of the Tuggerah Lakes*. CSIRO Land and Water, Canberra. .
- Dee, S., Beltran, L., Billingham, J., Lavery, P. S., Gras, O. S., Whale, J. W., & Hyndes, G. (2024). *Wrack N' Roll: The Ecological Role of Beach Wrack*. doi:doi:10.3389/frym.2024.1369401
- DPIE. (2019b). *NSW Estuary Health Risk Dataset: A first-pass risk assessment to help with the prioritisation of catchment management actions*.
- DPIE. (2020). *Estuaries of NSW*. Retrieved from <https://www.environment.nsw.gov.au/topics/water/estuaries/estuaries-of-nsw>
- DPIRD. (2025b). *Estuarine Habitat Dashboard*. Retrieved from https://nsw-dpi.shinyapps.io/NSW_Estuarine_Habitat/
- Dragonfly Environmental. (2014). *Port Botany-Penrhyn Estuary*. Retrieved from <https://www.dragonflyenv.com.au/projects/wetlands-and-waterways/penrhyn-estuary/>
- Duxbury, E. (2019). *A novel course for South Creek Catchment*. Macquarie University. doi:https://doi.org/10.25949/19431635.v1
- Fifield, J. T., Maslin, M., Clarke, L., & Todd, J. (2019). Management of sand and seagrass wrack at the reconfigured entrance of Port Geographe - A Case Study. *Australasian Coasts & Ports 2019 Conference*.
- Georges River Council. (n.d.). *Council Plans and Strategies*. Retrieved from <https://www.georgesriver.nsw.gov.au/Council/About-Your-Council/Council-Plans-and-Strategies>
- Georges Riverkeeper. (2025). *Stormwater & Sewage Program*. Retrieved from <https://georgesriver.org.au/about-us/stormwater-sewage-program>
- GHD. (2019). *The Entrance Channel Dredging Operations Feasibility Review*. .
- Glamore, W. C., Waters, S., Wainwright, D., Ferguson, A., Dafforn, K., Maher, D., . . . Fawcett, S. (2020). *Tuggerah Lakes Water Quality Independent Expert Panel Review*.
- Heerhartz, S. M., Dethier, M. N., Toft, J. D., Cordell, J. R., & Ogston, A. S. (2014). Effects of Shoreline Armoring on Beach Wrack Subsidies to the Nearshore Ecotone in an Estuarine Fjord. *Estuaries and Coasts*, 37, 1256-1268. doi:https://doi.org/10.1007/s12237-013-9754-5



- International Standards Organisation. (2018). *Risk Management: ISO 31000: 2018 - International Organization for Standardization*.
- IPCC. (2021). *Summary for Policymakers: In Climate Change 2021 The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.
- IPCC. (2023). *Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC.
- JBP. (2025). *Tuggerah Lakes Improvement Project Draft Technical Project Report*.
- Lake Macquarie City. (2019). *Lake Macquarie Community Participation Plan*.
- Lake Macquarie City Council. (2023). *Lake Macquarie Coastal Management Program*. Retrieved from https://cooksriver.org.au/wp-content/uploads/2025/07/Lake-Macquarie-Coastal-Management-Program_WEB-1.pdf
- Lawson and Treloar. (1994). *Tuggerah Lakes Flood Study*.
- Lyons, M., Phinn, S., & Roelfsema, C. (2019). Moreton Bay and catchment urban expansion and vegetation change. In I. R. Tibbetts, P. C. Rothlisberg, D. T. Neil, T. A. Homburg, D. T. Brewer, & A. H. Arthington, *Moreton Bay Quandamooka & Catchment: Past, present, and future*. Retrieved from <https://moretonbayfoundation.org/articles/land-cover-and-land-use-change/>
- MHL. (2022). *Tuggerah Lakes Entrance Management Study*.
- MHL. (2025). *Tuggerah Lakes Flood Study Review - Draft Report*.
- Middle, G., & Middle, I. (2023). *Central Coast Recreational Use Study - Stage 2: The Tuggerah Lakes. A report for the Department of Central Coast Council, NSW*.
- NSW DPI-Fisheries. (2013). *Fisheries NSW Policy and Guidelines for Fish Habitat Conservation and Management*. NSW Department of Primary Industries, a part of the Department of Trade and Investment, Regional.
- OEH. (2011). *Tuggerah Lakes Ecological Response Project Stage 1.2 Final Report*. Prepared for Wyong Shire Council. .
- OEH. (2012). *OEH NSW Tidal Plane Analysis 1990-2010. Report MHL2053, October 2012*.
- OEH. (2013). *Restoration of Tuggerah Lakes through Improved Water Quality Management - Overview Report*.
- OEH. (2017). *Risk-based Framework for Considering Waterway Health Outcomes in Strategic Land-use Planning Decisions*. .
- OEH. (2018a). *NSW Coastal Management Manual Part A: Introduction and mandatory requirements for a coastal management program*. Sydney: Office of Environment and Heritage.
- OEH. (2018c). *NSW Coastal Management Manual Part B: Stage 2 – Determine risks, vulnerabilities and opportunities*.
- OEH. (2018d). *NSW Coastal Management Manual Part B: Stage 3 – Identify and evaluate options*.
- OEH. (2018g). *NSW Estuary Tidal Inundation Exposure Assessment*. doi:ISBN 978-1-76039-958-0. OEH 2017/0635. July 2018
- Office of Environment and Heritage (OEH). (2013). *Restoration of Tuggerah Lakes through Improved Water*.
- Orica. (2025). *Groundwater Cleanup*. Retrieved from <https://www.orica.com/Locations/Asia-Pacific/Australia/Botany/Botany-Transformation-Projects/Groundwater-Cleanup>
- Patterson Britton and Partners. (1994). *Tuggerah Lakes, Entrance Training Walls: Technical Discussion*.
- Roberts, D. E. (2001). *Tuggerah Lakes Estuary Process Study*.
- Roper, T., Creese, B., Scanes, P., Stephens, K., Williams, R., Dela-Cruz, J., . . . Fraser, M. (2011). *Assessing the conditions of estuaries and coastal lake ecosystems in NSW*.
- Roy, P., Williams, R., Jones, A., Yassini, I., Gibb, P., Coates, B., . . . Nichol, P. (2001). Structure and Function of South-east Australian Estuaries. *Estuarine, Coastal and Shelf Science*, 53, 351-384.
- RoyalHaskoningDHV. (2020). *The Entrance Dredging Program Review of Environmental Factors*.
- Saeck, E., Udy, J., Maxwell, P., Grinham, A., Moffatt, D., Senthikumar, S., . . . Weber, T. (2019). Water quality in Moreton Bay and its major estuaries: Change over two decades. In I. R. Tibbetts, P. C. Rothlisberg, D. T. Neil, T. A. Homburg, D. T. Brewer, & A. H. Arthington, *Moreton Bay Quandamooka & Catchment: Past, present, and future*. doi:10.6084/m9.figshare.8072597
- Salients. (2021). *Impact Assessment Study of The Entrance Rock Groyne*.
- Salients. (2024). *The Entrance Groyne Impact Assessment: Addendum 2*.
- Salients. (2025). *The Entrance Groyne Impact Assessment: Addendum 3*.



- Smart, J. N., Hammerman, N. M., Golding, K. M., Markey, K., Kovacs, E., & Roelfsema, C. (2025). Decadal monitoring shows seagrass decline and community shifts following environmental disturbance in Moreton Bay, south-eastern Queensland, Australia. *Marine & Freshwater Research*. doi:<https://doi.org/10.1071/MF25049>
- Standards Australia. (2013). AS 5334—2013. *Climate change adaptation for settlements and infrastructure – A risk-based approach*. Standards Australia.
- State Government of NSW and NSW Department of Climate Change, Energy, the Environment and Water. (2019). *NSW estuary health risk dataset, accessed from The Sharing and Enabling Environmental Data Portal* [<https://datasets.seed.nsw.gov.au/dataset/3cbb800a-0ac2-4eed-8bce-15601e4a665f>].
- State of NSW and Department of Planning, Industry and Environment. (2021). *Tuggerah Lakes Riverine and Catchment Health Monitoring Program*.
- State of NSW Department of Environment and Conservation. (2005). *South Creek demonstration site, Western Sydney riparian corridors, Erskine Park : recovering and managing riparian bushland on an intermediate scale; works to retain, enhance and expand a corridor of riparian bushland along South Creek*.
- State of NSW Department of Planning and Environment. (2022). *Central Coast Regional Plan 2041*. Retrieved from <https://www.planning.nsw.gov.au/sites/default/files/2023-03/central-coast-regional-plan-2041.pdf>
- State of NSW Department of Planning and Environment. (2022). *Lower Hunter Water Security Plan*. Retrieved from <https://www.hunterwater.com.au/documents/assets/src/uploads/documents/lower-hunter-water-security-plan.pdf>
- State of NSW Department of Planning, Industry and Environment. (2020). *Towards safer swimming - Terrigal region*.
- State of NSW Department of Primary Industries and Regional Development. (2023). *Estuarine Habitat Dashboard*. Retrieved from https://nsw-dpi.shinyapps.io/NSW_Estuarine_Habitat/
- State of NSW Water. (2024). *Monitoring, evaluation and reporting on the Lower Hunter Water Security Plan*. Retrieved from <https://water.dpie.nsw.gov.au/our-work/plans-and-strategies/metropolitan-water-plans/lower-hunter-water-security-plan/monitoring-evaluation-and-review-of-the-plan>
- State of QLD Department of the Environment, Tourism, Science and Innovation. (2025). *Ecosystem Health Monitoring Program - Estuarine and Marine*. Retrieved from <https://wetlandinfo.des.qld.gov.au/wetlands/assessment/monitoring/current-and-future-monitoring/ecosystem-health-monitoring-estuarine-marine.html>
- State of SA Department of Environment, Water and Natural Resources. (2013). *Ngarrindjeri partnerships*. Retrieved from <https://cdn.environment.sa.gov.au/environment/docs/climm-ngarrindjeri-partnerships-fact.pdf>
- Stening, J. (2018). Botany Groundwater Cleanup Project: Arguably the Largest and Most Complex in Australia. *Chlorinated Conference Proceedings*. Retrieved from <https://www.battelle.org/docs/default-source/conferences/chlorinated-conference/proceedings/2018-chlorinated-conference-proceedings/i3-botany-mega-site-cleanup-project/417.pdf>
- Storm Consulting. (2007a). *Tumbi Umbi Creek Streambank Rehabilitation Plan*. . Prepared for Wyong Shire Council.
- Storm Consulting. (2007b). *Saltwater Creek Streambank Rehabilitation Plan*. Prepared for Wyong Shire Council. .
- Storm Consulting. (2008). *Spring and Wallarah Creeks Streambank Condition and Conservation Report*. Prepared for Wyong Shire Council. .
- Sydney Metropolitan Catchment Management Authority. (2011). *Botany Bay & Catchment Water Quality Improvement Plan*. Retrieved from <https://www.sydneycoastalcouncils.com.au/wp-content/uploads/2018/11/BOTANY-BAY-WATER-QUALITY-IMPROVEMENT-PLAN-2011-2.pdf>
- TfNSW. (2022). *NSW Boat Ramps*. Retrieved from <https://roads-waterways.transport.nsw.gov.au/maritime/using-waterways/boat-ramps-map/boat-ramps/index.html#/boatramp/1104>
- Umwelt. (2011). *Entrance Dynamics and Beach Condition at The Entrance and North Entrance Beaches*.
- URS and Sydney Ports. (2003). *Port Botany Expansion Environmental Impact Statement: Chapter 15 Hydrodynamic and Coastal Processes + Chapter 16 Hydrology and Water Quality*.
- Victorian Marine & Coastal Council and Gunaikurnai Land and Waters Aboriginal Corporation. (2020). *Protecting Traditional Owner Country of the Gippsland Lakes*. Retrieved from



<https://www.marineandcoastalcouncil.vic.gov.au/news-and-events/previous-events/2020/protecting-traditional-owner-country-of-the-gippsland-lakes>

Waddington, K., Glamore, W., & Heimhuber, V. (2023). *Coastal Wetland Refugia Study: Central Coast, NSW*.

Wainwright, D., & Verdon-Kidd, D. (2016). *A local government framework for coastal risk assessment in Australia*. National Climate Change Adaptation Research Facility, Gold Coast.

Wallis, L. (2007). Caring for Ngarrindjeri Country: Collaborative Research, Community Development and Social Justice. *Indigenous Law*.

Water Technology. (2020). *Woolgoolga Region Estuaries Coastal Management Program: Stage 1 Scoping Study*.

Water Technology. (2021). *Central Coffs Estuaries Coastal Management Program: Stage 1 Scoping Study*.

Wollongong City Council. (2024). *Options for the Lake Illawarra Entrance*. Retrieved from <https://our.wollongong.nsw.gov.au/lake-illawarra-entrance-options-study>

WorleyParsons. (2009). *The Entrance Dredging Project Review of Environmental Factors*.

Wyong Shire Council. (2000). *Tuggerah Lakes Estuary Process Study*.

Melbourne

15 Business Park Drive
Notting Hill VIC 3168

Brisbane

Level 5, 43 Peel Street
South Brisbane QLD 4101

Perth

Level 1, 21 Adelaide Street
Fremantle WA 6160

Wangaratta

First Floor, 40 Rowan Street
Wangaratta VIC 3677

Wimmera

597 Joel South Road
Stawell VIC 3380

Darwin

Unit 40/29 Woods Street
Darwin City NT 0800

Sydney

Suite 3, Level 1, 20 Wentworth Street
Parramatta NSW 2150

Adelaide

1/198 Greenhill Road
Eastwood SA 5063

New Zealand

7/3 Empire Street
Cambridge New Zealand 3434

Geelong

51 Little Fyans Street
Geelong VIC 3220

Gold Coast

Suite 37, Level 4, 194 Varsity Parade
Varsity Lakes QLD 4227

Sunshine Coast

Office #4 of the Regatta 1 Business Centre
2 Innovation Parkway
Birtinya QLD 4575

1300 198 413



watertech.com.au

