FINAL REPORT:

Lake Illawarra Bank Management Strategy

November 2022

Developed as a part of:

Lake Illawarra Coastal Management Program

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EXECUTIVE SUMMARY

This report was prepared for Wollongong City Council (WCC) and Shellharbour City Council (SCC) to address part of action FB1 in the Lake Illawarra Coastal Management Program (LICMP) with the aim of improving the understanding of current and likely future bank erosion throughout the estuary, and to prioritise and present options for the management of eroding sites.

Located approximately 80 km south of Sydney, Lake Illawarra is situated between the coastal barrier system of Windang Peninsula in the east, which extends from Windang to Port Kembla (Perkins Beach); and the steep western backdrop of the Illawarra Escarpment. The lake and its catchment straddle the WCC and SCC Local Government Areas (LGAs). It is a highly modified wave-dominated barrier estuary that has a surface area of approximately 35 km^2 and receives runoff from a 240 km^2 catchment. The estuary is naturally infilling as sediment is transported from the catchment, with the estuary classified geologically as being in an intermediate evolutionary stage. In 2007, the Lake was permanently opened to the sea via the construction of entrance breakwaters, with the entrance channel positioned between Windang Island and Windang Beach. These works have resulted in major geomorphic, hydrodynamic and ecological changes to the Lake.

The study area includes the majority of Lake Illawarra shoreline, excluding the entrance, and all major tributaries up to the tidal limit, totalling approximately 40 km of lake shoreline and 12 km of stream bank. The entrance channel is subject to its own detailed study, as a part of action EC1 in the LICMP.

Bank erosion within Lake Illawarra and its tributaries is a result of several interconnected mechanisms that are by both natural and human influenced processes. The primary factors that are likely contributing to shoreline erosion in the study area include degraded bank and riparian vegetation, inappropriate or poorly maintained foreshore protection structures, boat waves, wind waves, tidal processes and fluvial geomorphology. While some of these causes of erosion arise from human activity, estuary systems are naturally dynamic and erosive processes should be expected to occur at times in response to naturally variable environmental conditions.

The study involved two key phases. In the first phase, sites were assessed via a desktop study which investigated the geomorphic form, riparian vegetation extent, and change over time for the entire study area shoreline. The desktop assessment was then followed by a field investigation during which the entire study area shoreline was surveyed for active erosion. In addition to recording the sites where active erosion was occurring, further data were collected on site, including photos and data relating to bank typology and condition, any visible evidence of the likely causes and trajectory of erosion, and any observed social, cultural, environmental or infrastructure related values associated with the site. The product of the first stage of the project was a set of maps, each showing areas where:

- Erosion observed
- Engineered bank protection works are present
- The shoreline is characterised by exposed bedrock.

In the second phase, the outcomes of the desktop and field assessments were used to categorise the erosion risk level for each site. The risk rating was then used to inform the identification and prioritisation of options for shoreline stabilisation. This was partially done through the use of the NSW DPI Fisheries Decision Support Tool (DST). During the options identification and prioritisation process, sites were grouped by considering risk, erosive drivers, the nature of design constraints and the potential outcomes of erosion mitigation.

The prioritisation resulted in a total of 19 Low, 20 Medium and 5 High and 1 Very high priority sites. The report proposes bank stabilisation options for each of the Medium and High-risk sites. Several of the sites had similar characteristics and the same proposed option so they were put into 10 groups for ease of presentation.

This report presents a strategy for managing eroding banks within the Lake Illawarra Estuary. The key next step in implementing this strategy is the development of a delivery plan that acknowledges varying roles and responsibilities for erosion sites that integrates with WCC, SCC's and other asset owners asset management framework . Once funding is obtained for bank management works, sites should be progressed to design and construction in the order of the site prioritisation.

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1 Introduction

Alluvium Consulting Australia Pty Ltd (Alluvium) was engaged by Wollongong City Council (WCC) and Shellharbour City Council (SCC), as the responsible councils for implementing the Lake Illawarra Coastal Management Program (LICMP), to develop a Lake Illawarra Bank Management Strategy. The Lake Illawarra Coastal Management Program identified that foreshore and bank erosion are a threat to the ecological condition of Lake Illawarra, its community uses and values, cultural heritage values and assets located near the shoreline. To address the threat, the CMP included action FB1 to "*undertake a bank condition assessment and determine and implement erosion control measures*" (BMT, 2020). Alluvium has been engaged for the first stage of this action which is to identify and map current sites of erosion within the lake and the tidal reaches of its major tributaries, and then consider and propose bank management strategies. The information from this study will be used to prioritise and initiate projects to address shoreline erosion issues.

This project draws from the Decision Support Tool (DST) for bank erosion management, developed by DPI Fisheries in 2020, as input to a bespoke Bank Management Strategy (BMS) built on new and existing data on foreshore and bank erosion in Lake Illawarra. The application of the DST and development of a BMS will provide WCC and SCC with an updated and enhanced knowledge of the risk and exposure of bank erosion in Lake Illawarra which can be used in future management decisions and community engagement.

Importantly, this work represents a tangible step by WCC and SCC in implementing their CMP and its recommended management actions. Providing an accurate understanding of the system-wide processes at play regarding bank erosion and condition in Lake Illawarra is crucial in supporting local governments in management and investment decisions. This is a fundamental step in ensuring that Lake Illawarra remains a healthy coastal ecosystem into the future and can continue to respond to the needs of the wider community.

Figure 1. *The Lake Illawarra Shoreline adjacent to Holborn Park (photo taken on 5 April 2022)*

1.1 Study overview and objectives

The overarching objective of this project is the development of a BMS for Lake Illawarra and its major tributaries and smaller creeks. The objective of the BMS is "*to assess the current bank condition of the foreshore and identify and map effective, efficient, and consistent best management practice to treat foreshore erosion at an estuary scale*". Delivering this objective will enable land managers to better manage shoreline erosion with evidence-based defendable decision-making.

The core scope of works involved:

- Undertaking a desktop assessment and field work (via boat, kayak and foot) to determine the current bank condition of the study area.
- Develop a BMS that identifies areas actively eroding and outlines appropriate erosion control measures. The BMS was to draw from the NSW DPI DST where practical.
- Prepare a series of maps (with accompanying GIS layers) of the bank erosion risk across the study area.
- Develop options for the management of the eroding shoreline, with a prioritisation ranking for their implementation.

1.2 Report structure

This report is presented in the following structure:

Section 1 – Introduction: Provides an overview of the study and report structure.

Section 2 – Background: Provides a description of the study area and relevant geomorphic processes, riparian and foreshore conditions and key values, and provides an overview of previous relevant studies.

Section 3 – Method: Outlines the methods used in the study.

Section 4 – Erosion assessment results: Presents an overview of the erosion assessment results.

Section 5 – Site prioritisation: Discussed how sites should be prioritised for works.

Section 6 – Options assessment: Presents the results of the options assessment.

Section 7 – Summary and next steps: Presents a summary of the study to date and our proposed next steps.

Section 8 – Roles and responsibilities – Acknowledges varying roles and responsibilities for delivery of the strategy.

Section 8 – References

Appendix A – Site data collection explanatory notes

Appendix B – First pass assessment maps

Appendix C – Photobank for priority sites

Appendix D – Description of stabilisation options

Appendix E – Public facing study summary

2 Background

2.1 Study area

Located approximately 80 km south of Sydney, Lake Illawarra is a highly modified wave-dominated barrier estuary that has a surface area of approximately 35 km^2 and receives runoff from a 240 km^2 catchment. The lake and its catchment straddle the WCC and SCC Local Government Areas (LGAs). The study area for this project covers the entire Lake Illawarra foreshore area including tributaries up to their tidal limit (or the extent mapped in the project brief) but excluding the entrance channel. The major tributaries of Lake Illawarra include Macquarie Rivulet, Mullet Creek, Brooks Creek, Duck Creek, and Horsley Creek. In addition to these larger tributaries, several smaller creeks and gullies feed into the lake, including:

- Kully Bay Creek
- Small unnamed creek near Kully Bay Creek
- Hospital Creek
- Minnegang Creek
- Budjong Creek
- Hooka Creek
- Mullet Creek Tank Trap
- Albion Creek
- Oaky Gully.

A map of the study area showing the shoreline that was assessed in this project is shown in Figure 2.

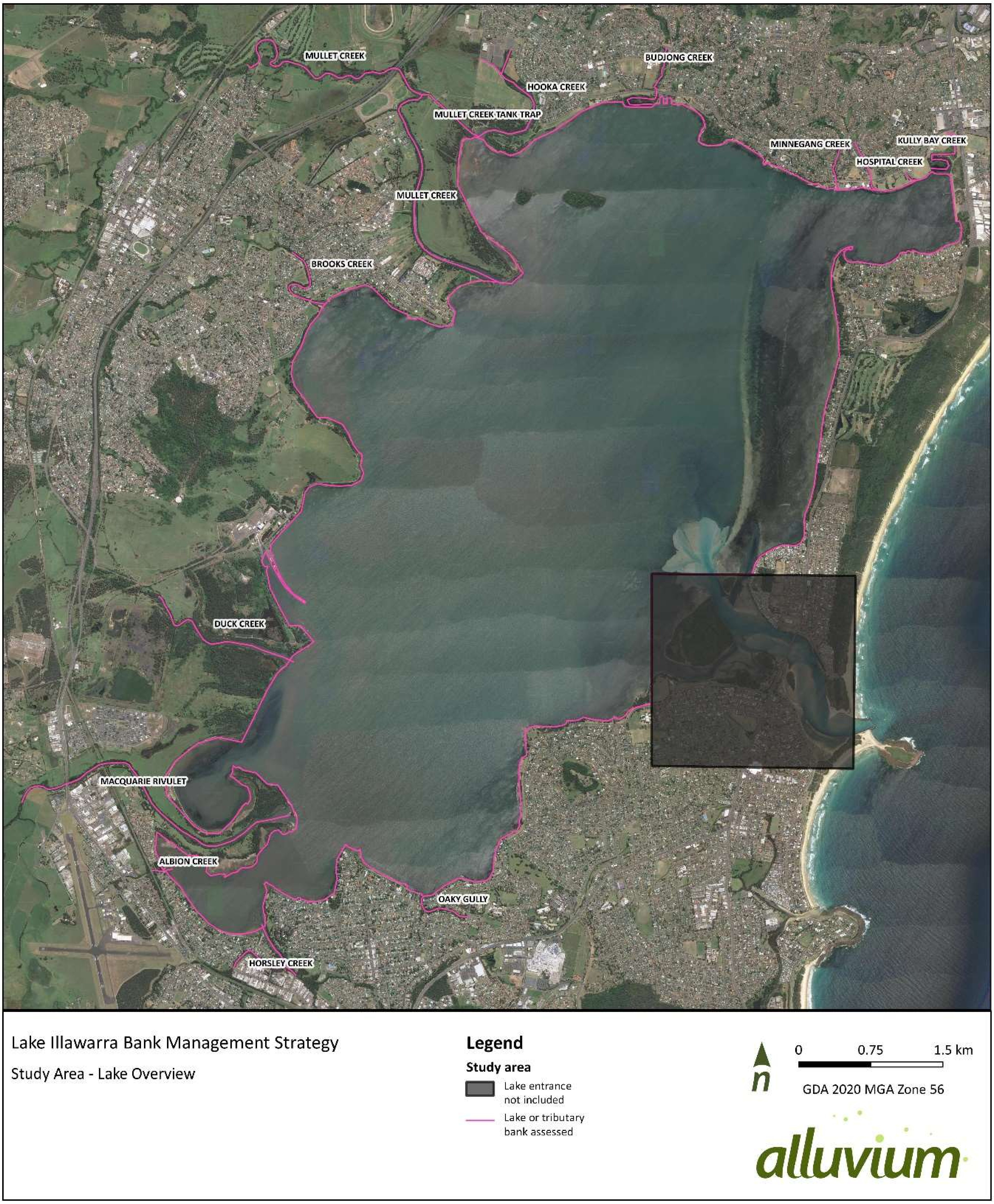

Figure 2. *Shows the project study area, which encompasses the entire Lake Illawarra foreshore area including tributaries up to their tidal limit but excludes the entrance channel.*

2.2 Values

Lake Illawarra is one of the most environmentally and socially important estuaries on the NSW coast, highly valued by residents of the Illawarra region and beyond. It is viewed as a recreational and environmental asset by the community and residents of the growing metropolitan areas of Wollongong and Shellharbour and is an integral part of the identity of the local area (Figure 3). The Lake is frequently used for a variety of recreational pursuits, including fishing, boating, swimming and canoeing/kayaking, supporting diverse estuarine habitats including mangroves, saltmarshes and seagrasses which are home to many species of fish and birds (BMT, 2020). Lake Illawarra is also highly valued for its natural scenic amenity, along with its cultural and historical significance. Local people have strong historical and cultural ties to Lake Illawarra through the connection of the Traditional Owners, the Tharawal people to the land and water, and through historical artifacts of early colonial Australia around the lake.

Figure 3. *Lake Illawarra is one of the most environmentally and socially important estuaries on the NSW coast and is highly valued by residents of the Illawarra region as shown in these images.*

2.3 Geomorphic processes and condition

Lake Illawarra is a large, shallow coastal lake, characterised as a wave-dominated barrier estuary system. It is situated between the wide, long coastal barrier system of Windang Peninsular in the east, and the steep western backdrop of the Illawarra escarpment in the west (BMT, 2020).

The main waterbody of the Lake is elongated in a general southwest-northeast direction. It has a surface area of around 35 km^2 and an average and maximum water depth of 2.1 and 3.2 m respectively (OEH, 2012; Sloss, 2005) however, hydrographic surveys have identified some areas of much greater depth within the entrance channel (MHL, 2017). The Lake is fringed by low-lying land, particularly along its eastern margin adjacent to Windang Peninsular, and where Macquarie Rivulet and Mullet Creek flow into the estuary along its western margin (BMT, 2020).

2.3.1 Sediments and sedimentation

Typical soils of the Illawarra region are described as structured red and brown loams and clay loams with some areas of mellow texture and contrast soils. On beach and dune areas, the soils comprise siliceous sands, with podsol profiles in older dunes. Peaty sands and organic silts occur in swamps and around the estuaries (NSW NPWS, 2003). In the fluvial inlets and surrounding lowland floodplain areas, the sediments comprise a mix of fluvial sand, gravel, silt and clay in addition to organic mud and peat. Landward of the fluvial deltas, the watercourse in-channel sediments and adjoining terraces comprise various fluvial sediments, including sands, silts, clays and gravels (Geological Survey of NSW, 2015).Where muddy organic sediments occur, such as in the Lake's basin and near fluvial inlet areas, there is a higher risk of potential acid sulfate soils materials (OEH, 2014).

Lake Illawarra's tributaries contribute both flows and sediment to the Lake, with the volume, extent of sedimentation, and flow rates dependent on their upstream catchments, amount of rainfall, the quality of their banks, and land use activities. Since the early 1800's when European occupation began within the catchment, human actions have disturbed the natural sedimentary system and resulted in increased rates of sediment transport into the Lake. High rates of sedimentation in the Lake resultant from creek flows are evident by the formation of deltas at the stream mouths and the broadening of mudflats around the foreshore (LIA, 2013). Similarly, the installation of weirs and tank traps on the Lake's two main watercourses has also impacted natural creek flows, sediment migration and deposition, and delta evolution (BMT, 2020).

Macquarie Rivulet and Mullet Creek comprise the two major fluvial inputs into the Lake. This process is apparent at the Macquarie Rivulet fluvial delta, located in the southwest corner of the Lake, which has an elongated 'bird's foot' form. This feature is formed primarily of fluvial sands and muds which have been accreting in response to human activity in the catchment. The Mullet Creek fluvial delta located on the western shores of the Lake has a lobate form and is also formed primarily of fluvial sands and muds.

2.3.2 Entrance management works

Before entrance management works were completed in 2007, Lake Illawarra was an ICOLL (Intermittently Closed and Open Lake or Lagoon) with the entrance heavily shoaled and/or closed around 80% of the time (WBM Oceanics Australia, 2003). The Lake is now permanently open to the sea due to entrance breakwaters which have trained the entrance channel to be positioned between Windang Island and Windang Beach. These works have resulted in major geomorphic, hydrodynamic and ecological changes to the Lake (BMT, 2020). Key changes to the Lake that impact on the study area include:

- Lake water levels now continually fluctuate diurnally due to ocean tidal water levels that penetrate the Lake through a permanently open entrance. Prior to entrance training, the Lake levels fluctuated in response to the prevailing entrance condition (shoaled or scoured), which in turn were driven by flood and drought cycles.
- Impacts on estuarine vegetation composition and distribution, which are continuing to adjust to a shift from ICOLL to permanently tidal conditions. Mangroves have begun to flourish in some areas with an associated shift in species that utilise the Lake with a reduction in prawn numbers and an increase in blue swimmer crabs (Baxter & Daly, 2010).

2.3.3 Wind and waves

The orientation of the elongate waterbody of the Lake provides a northeast-southwest fetch of over 8 km and a northwest-southeast fetch of around 4 km. This geometry allows for the local generation of wind waves and associated currents that are strong enough to rework sediments and erode or accrete foreshore sections at times (BMT, 2020).

Moderate winds from the southern sector are experienced all year round. Strong westerly winds are typically experienced during winter, while lower energy northeast winds prevail over the summer. The form and orientation of sedimentary features occurring along the Lake foreshore are consistent with the wind-generated wave and current patterns expected from the prevailing winds across the fetch distances described (BMT, 2020). The geomorphology of sedimentary features indicates that wind-generated waves and currents capable of eroding and transporting sediment occur along those shorelines exposed to the prevailing winds. Conversely, foreshore areas sheltered from prevailing winds undergo less reworking by waves (BMT, 2020).

2.4 Estuarine, riparian and foreshore vegetation condition

Lake Illawarra contains a diverse range of habitats including open water, seagrass systems, rocky intertidal reefs, fringing reefs, mangroves, terrestrial vegetation, saltmarsh communities and sand shoals. Increased tidal exchange due to entrance training has resulted in significant ecological changes throughout the Lake including redistribution of seagrass and saltmarsh. Areas of mangroves and saltmarsh are reported to have been increasing, however, there are also signs that some of the newly established saltmarsh areas could be outcompeted by mangroves (Baxter & Daly, 2010), as documented for other NSW estuaries (BMT, 2020).

Riparian vegetation and coastal wetlands have important ecological habitat values, providing a link between the terrestrial environments and estuarine vegetation such as mangroves and saltmarsh. They also provide numerous other benefits to the Lake by filtering and decelerating runoff from the land into creeks and the Lake itself, reducing sediment and nutrient loads to the Lake. Importantly, riparian vegetation and wetlands also stabilise riverbanks and lake foreshores, reducing the likelihood of erosion (BMT, 2020).

Macquarie Rivulet has riparian vegetation communities (Riparian River Oak Forest) unique to the south-western portions of the catchment (OEH, 2002). Tall River Oak and eucalypt species line the banks of these creeks before transitioning to *Casuarina glauca* (Coastal Swamp Oak Forest) and *Melaleuca spp.* with increasing proximity to Lake Illawarra as the tidal waters influence the riparian vegetation communities. Deltas located at the stream entrances to the Lake and around the foreshore are alluvial forests comprised of Endangered Ecological Communities (EECs), as defined in the *Biodiversity Conservation Act 2016*. Two dominant EECs are present including Coastal Swamp Oak Forest and Coastal Saltmarsh (OEH, 2002). These EECs are surrounded by shallow waters and tidal mudflats supporting seagrasses and macroalgae communities (BMT, 2020).

Macquarie Rivulet delta is bordered by two shallow, low energy embayments (Koona and Haywards Bay). The delta and adjoining embayments provide important estuarine habitat, with large extents of coastal saltmarsh inhabiting the low-lying foreshore and seagrass meadows occurring throughout the surrounding shallow waters (BMT, 2020). Surrounding Mullet Creek, saltmarsh fringe the low-lying foreshore and seagrasses occur across the shallow subtidal slopes. Hooka Creek inlet occurs immediately north of Mullet Creek delta, at the head of Kong Burry Bay. Seagrass meadows also occur across the wide shallow sandy-mud flats within Kong Burry Bay (BMT, 2020).

Weed species have emerged in some riparian foreshores resultant of past clearing and grazing activities including *Lantana camara* and Privet (*Ligustrum spp.*) and exotic trees such as Camphor laurel (*Cinnamomum camphora*) and Coral tree (*Erythrina X sykesii*) (OEH, 2002).

Bank erosion has occurred and is likely to occur at locations where the riparian vegetation has been removed, where introduced weed and grass species extend to the water's edge preventing native vegetation growth, where areas have become damaged by illegal use or prohibited access, and where the surrounding land use has resulted in the degradation of creek banks, such as grazing (LIA, 2013).

The Lake Illawarra CMP (Action EV1) identifies areas where revegetation to rehabilitate banks is to occur. Locations include:

- Picnic Island, Beragereee Island, Pelican View Reserve, Bevans Island, Cudgeree Island, Hooker Park, Boonerah Point Reserve, Whyjuck Bay
- Karoo Bay, Moureendah Bay, Oaky Creek,
- Burroo and Koona Bay, northern bank of Horsley Inlet upstream of Slaters Bridge, Macquarie Rivulet
- Duck Creek, Nijong Bay
- Yallah Bay, Tallawarra Point, Boomberry Point
- Mullet Creek, and Purrah Bay, Kanahooka foreshore including Brooks Creek
- Fred Finch Park (Hooka Creek, Hooka Point Park and Hooka Creek wetland
- Berkeley Boat Harbour, Tuggerah Bay
- Wollamai Point, Lake Heights foreshore, Minnegang Creek, Creek adjacent to Kully Bay Oval
- Kully Bay wetland, Griffins Bay
- Korrungulla Wetland
- Foreshore from Purry Burry Point to Cudgeree Bay, Windang Peninsula
- Lake Projects West, North and East

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

A portion of the Lake is lined by hard structures designed to limit bank erosion. This impacts the Lake's ecology as these structures provide minimal habitat benefits, which in turn affects the fish and other species dependent upon fringing habitats. Such structures also impound estuarine habitats by creating a barrier that limits the landward extent of bank and riparian vegetation (e.g. saltmarsh, which is then unable to migrate and may be drowned or outcompeted by mangroves). Protection structures with certain design, such as sloping rock revetment, or other eco-friendly elements can provide some habitat benefit (OEH, 2009). The main areas with armoured foreshore include sections of Griffins Bay, Cudgeree Bay, the northern foreshore of Koonawarra Bay, and the foreshore of the caravan parks on the eastern side of the Lake (BMT, 2020).

2.5 Factors contributing to erosion

Foreshore erosion within the study area is a result of several interconnected mechanisms that are influenced by several factors, both natural and human made. These include factors such as foreshore slope, presence, density and type of vegetation, soil type, fetch of prevailing winds, wave size, adjacent and upstream land use practices such as grazing or mowing, or extensive upstream clearing of vegetation for development. Foreshore areas with extensive land clearing, particularly of the riparian vegetation, are much more susceptible to erosion as the exposed banks are susceptible to erosive forces such as waves and flowing water.

In addition to bank erosion around the Lake, erosion of the Lake's tributaries has been noted in response to the clearing of riparian vegetation, grazing practices and urbanisation (BMT, 2020). The greater proportion of impervious surfaces and consequential runoff has also resulted in increased peak flows in the tributaries. Increased peak flows can cause bank erosion and substantial geomorphic changes (WBM Oceanics Australia, 2003), however, the impacts of increased streamflow rates are expected to be more pronounced in the reaches of the tributaries upstream of the tidal limit, as below the tidal limit stream force increases are attenuated by the tidal prism.

The primary factors that are likely contributing to shoreline erosion in the study area are:

- Degraded bank and riparian vegetation due to grazing, clearing and the proliferation of exotic species
- Waves generated by boat wash
- Tidal processes, which contribute to erosion both through sediment transport via tidal currents and by changing water levels causing wave-related forces to approach the shore at varying heights. Sea level rise will exacerbate this process in the future.
- Wind waves, which are largely dependent on fetch. Although the wind climate has not likely changed, the removal of riparian vegetation may have impacted the local wind conditions, and the opening of the entrance may have changed the lake bathymetry, both factors potentially exposing some banks to increased wind-generated waves.
- Saturated bank soils immediately following a flood event can subsequently dislodge bank material through seepage processes where there is poor root reinforcement, such as where the banks have been cleared of riparian vegetation.

The factors described above result in various mechanisms of erosion or bank failure, including:

- Surface scour of bank material by fluvial and tidal processes and wave action resulting in bank retreat and over-steepening of the bank profile
- Excessive pore water pressure, which causes slumping of the shoreline
- Mass failure of over-steepened bank profiles

Several other factors contribute to bank erosion in the study area including:

- Increased amplitude of repetitive wake-generating activities, e.g. wake boarding and wake surfing
- Adjacent land uses including rural residential and recreational leading to public and private water and foreshore access
- Inappropriate or poorly maintained foreshore protection structures or structures not designed to cater for sea level rise
- End effects caused by foreshore protection structures or other assets
- Dredging
- Climate change, including increased storm activity and sea level rise

2.6 Previous studies

The most recent assessment of bank condition was undertaken by the Lake Illawarra Authority (LIA) and DPIE - Coasts & Estuaries in 2013. This report describes the perimeter of the Lake as being covered with approximately 44 hectares of rocky shoreline, particularly along the western and northern shorelines and the Lake's entrance (LIA, 2013). Areas around the Lake considered having potential issues with foreshore/bank erosion and posing risks to the Lake at this time include:

- the foreshore areas of Pelican View Reserve near Picnic Island,
- Mt Warrigal,
- Lake Heights and Illawarra Yacht Club,
- Windang Foreshore Park,
- Cudgeree Bay, and

- the creek banks along Macquarie Rivulet (LIA, 2013).

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

Since the completion of the LIA study, the Lake itself has continued to respond to the changing tidal regime and erosion continues to increase within the study area. There was also a large east coast low event in June 2016 which resulted in significant erosion in several locations including Windang, Boonerah Point, Deakin Reserve, Skiway Park and Reddall Reserve. In this case, the foreshore condition and bank erosion mapping provided in the LI CMP may not have captured all recent erosion events.

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

2.7 Data gaps

The project team was able to source the majority of data required for the project, however, the analysis could be further refined with the following additional data:

- Multi temporal Lake bathymetry data
- Additional LiDAR data of the study area shoreline that could be used to calculate shoreline change over time
- Further data regarding Aboriginal Heritage sites within the study area.

3 Method

The study involved a five-step process as described in the following sections.

3.1 Desktop assessment

A desktop analysis of the study area was undertaken using spatial analysis. This was a preliminary assessment used to:

- Identify areas of shoreline where erosion may threaten various infrastructure or assets.
- Make a preliminary assessment of the geomorphology and riparian condition.

The key components of the preliminary desktop assessment of the geomorphology and riparian condition are described below.

3.1.1 Geomorphic form

An assessment of terrain, channel form and bank morphology was undertaken using the most recent available LiDAR data (see Figure 4) sourced from the NSW Spatial Services Database—ELVIS (https://elevation.fsdf.org.au/). A terrain assessment provided an understanding of the types of geomorphic units throughout the study area, including the likely presence of bedrock along the shoreline and for the tributaries, and the degree of valley confinement, which helps inform where bank instabilities/adjustments are more likely to occur. Within the study area, the lateral adjustment of parts of the shoreline and tributary channels can be limited by bedrock. In many areas, alluvial and estuarine plains are formed in the foreshore area as a result of vertical accretion associated with Holocene sea level rises. These geomorphic units are more vulnerable to bank erosion processes.

3.1.2 Riparian vegetation extent

A high-level assessment of riparian vegetation type and extent was performed. The most recently available high-resolution imagery was assessed at each site to determine the longitudinal connectivity and width of the woody riparian vegetation. Estuarine habitat mapping sourced from the NSW DPI Fisheries Estuarine Habitat Dashboard (NSW Estuarine Mapping (shinyapps.io)) was also mapped to help identify the extents of mangrove, saltmarsh and seagrass habitats surrounding the study sites. An example of habitat mapping is provided in Figure 5. The latest date of available habitat mapping was 2019 for the Lake Illawarra estuary.

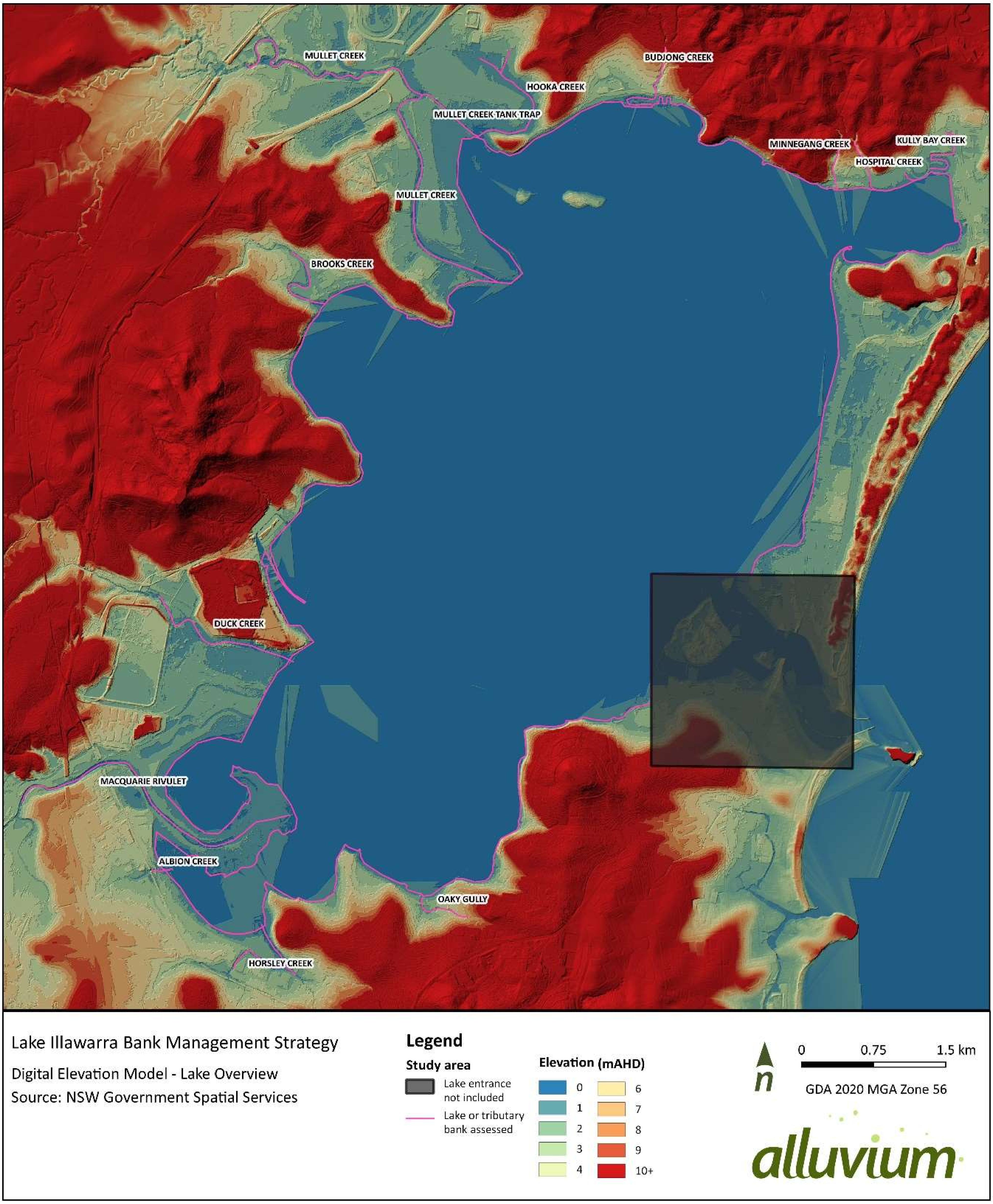

Figure 4. *A map showing a digital elevation model of the study area*

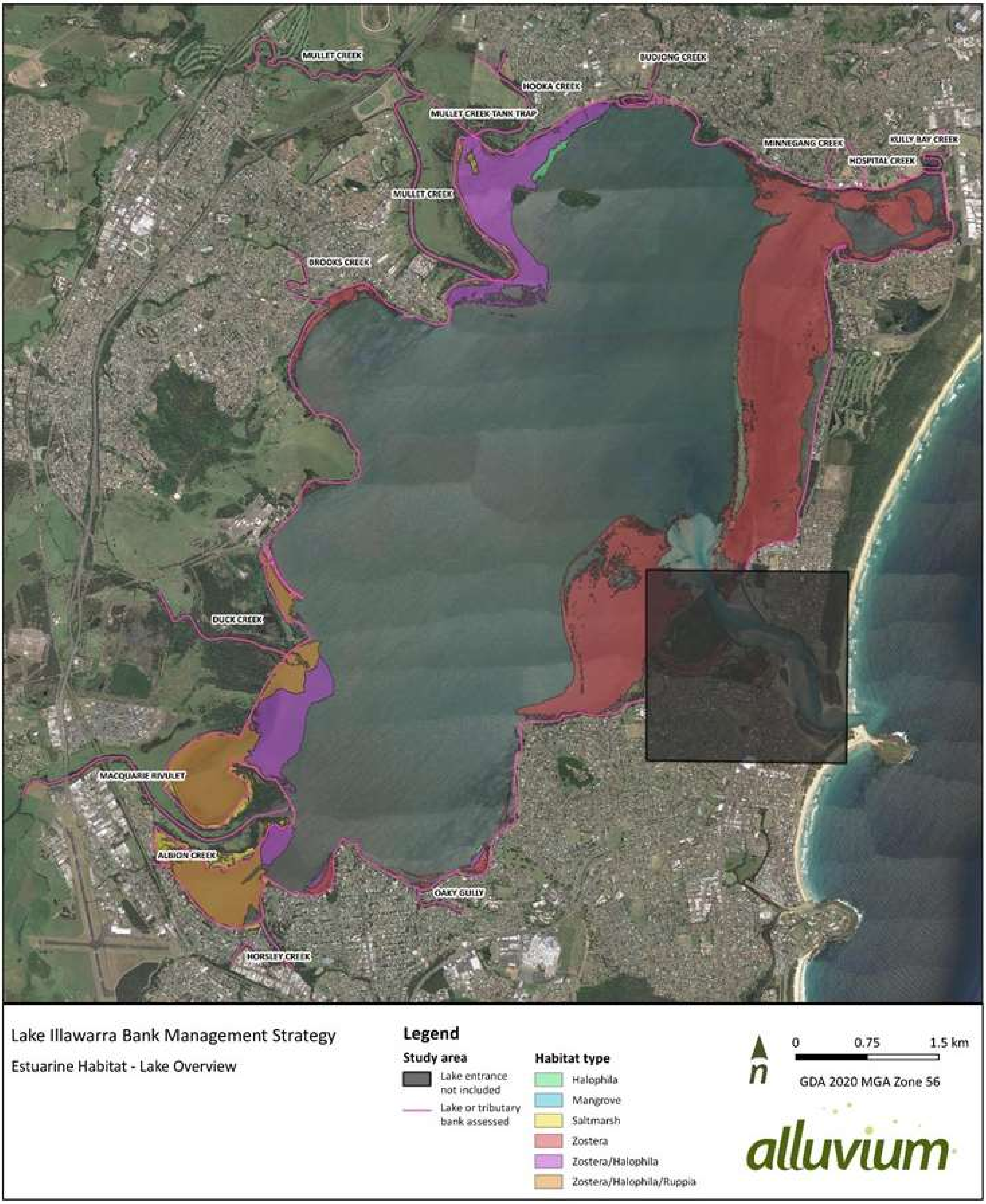

Figure 5. *A map showing estuarine habitat within the study area*

3.2 Field assessment

A field assessment approach was developed to provide a repeatable assessment of shoreline condition. The approach was largely based on the *NSW DPI: Fisheries Development and Validation of a Decision Support Tool for Bank Erosion Management in NSW Estuaries, Part A: Desktop and Field Erosion Risk Assessment Methodology* (Hydrosphere, 2020).

The project team conducted a field assessment of the entire study area shoreline. The assessment was conducted over three visits:

- 5-6 April 2022
- 3-4 May 2022
- 18 May 2022

The shoreline was assessed through a combination of inspection from shore and by boat during which we captured georeferenced photos of the shoreline and took notes of observation. Where flying regulations allowed, high-resolution Unmanned Aerial Vehicle (UAV) imagery of the shoreline was also captured.

The term 'site' has been used to describe a length of shoreline with similar characteristics. The shoreline was delineated into sites during the field assessment based on observations from the desktop and field assessments. A total of 167 sites were delineated.

The team collected photography and data notes for each site, noting:

- Evidence of any erosion
- The presence, type and condition of any engineered bank protection works
- Any visible infrastructure
- The type and extent of vegetation on the banks and behind the shoreline.

Where erosion was observed, further information was recorded regarding:

- The nature of the erosion
- The likely cause and trajectory of the erosion
- Any observed implications of if the erosion were to progress.

Only sites where evidence of bank erosion was observed were carried forward into the detailed risk assessment, site prioritisation, and options assessment. For these sites, additional data were collected to aid in the management options development, including bank height, bank slope, the width of intertidal bench, presence of mangroves as well as notes on surrounding instream habitat features and/or constructability constraints. The data collected was aimed at collecting as much data as possible to fill out the DST data collection form, which is shown in Table 1.

Table 1. Field data collection form. Field and options explanatory notes are provided in Appendix A.

Substrate	Bedrock	Cohesive	Non-cohesive	Bedrock / cohesive	Bedrock / non-cohesive	Cohesive / non-cohesive	All					
Bank shape	Concave	Convex	Planar	Steeped	Wide lower bench	Undercut						
Bank height	<1	1-3	3-6	6-10	>10							
Bank slope	Gentle (<3:1)	Low (3:1 - 2:1)	Moderate (2:1 - 1:1)	Steep (>1:1)	Vertical							
Intertidal / subtidal bench	<2	2-5	>5	none								
Current Erosion severity	Negligible	Low	Moderate	High	Extreme							
Estimated future trajectory	Not occurring, not likely	Not occurring, but likely	Occurring and continuing	Occurring and accelerating	Occurred but ongoing unlikely							
Existing protection present	None	Rock revetment	Geobags	Timber walling	Timber revetment	Large woody debris	Revegetation	Groynes	Cobble beach	Seawall Concrete	Other - acceptable	Other - unacceptable
Condition of existing protection	No existing control	Completely	Partially-condition	Partially-design	Ineffective							
Immediate landward constraint	>10	5-10	3-5	<3	unconstrained							
Mangroves	Present	Nearby	None	Cleared								
Riparian vegetation type	Natural riparian vegetation	Mixed veg fringing altered land use	Low - common land / foreshore	Insignificant - weed infested								
Riparian vegetation value	High - conservation value	Moderate - native veg in good condition	Low - common land / foreshore									
Riparian vegetation continuity	None	Low	Moderate	High								
Riparian vegetation width (m)	<2m	<5m	<10m	<20m	>20m							
Landuse	Road reserve	Grazing	Other agricultural	Commercial	Residential	Urban	Parkland / recreational					
Erodible width	Confined	<3	3-10	>10								
Contributing causes of erosion	Wind waves	Ocean waves	Vessel waves	River / tidal flow	Sediment extraction	Stock access	Public access	Overland flow	Bank saturation			
High value asset at immediate risk	Yes	No										
Environmental impact	Negligible	Low	Moderate	High								
Infrastructure / commercial Impact	Negligible	Low	Moderate	High								
Amenity / safety impact	Negligible	Low	Moderate	High								
Public access required	Yes	No										

3.3 Mapping

The data collected and developed during the desktop and field assessments were input into a GIS database. A polyline shapefile of the shoreline was developed with the shoreline delineated into 'sites' with similar characteristics.

The shapefile was assigned attribute data fields for each of the following characteristics:

- Was erosion observed (y/n)
- Are engineered bank protection works present (y/n)
- Was bedrock observed at the shoreline (y/n)

At the sites where erosion was observed, as many of the attributes defined by the DST field data collection (Table 1) form as possible was recorded.

A suite of maps was produced using the data which are presented in Appendix B. The maps present the first pass assessment of the shoreline, showing key factors that would later be used to:

- Summarise future erosion risk along the shoreline
- Review the areas requiring bank management strategy.

3.4 Risk assessment

A method for assessing and categorising erosion risk throughout the study area was devised. The risk assessment approach included an assessment of:

The **consequence** of ongoing erosion in terms of:

- Environmental impact
- Safety/amenity impact
- Infrastructure impact (public, commercial and private)
- Cultural heritage impact.

The **likelihood** of ongoing erosion based on:

- Recent historic erosion rate
- Distance to the asset from the shoreline.

The following section describes the development of consequence and likelihood metrics.

3.4.1 Consequence calculations

For each of the sites where erosion was evident, a consequence of continued erosion was determined in terms of environmental, infrastructure, safety/amenity, and cultural heritage impact, as per the metrics outlined below in

Table 2 to Table 5. Definitions for these impact categories have been adapted from the DPI Fisheries Decision Support Tool.

Therefore, each site was assigned four separate consequence ratings, one for each category. This approach was used so that risk ratings at each site for each impact category could be determined.

Table 2. Environmental impact (definitions adapted from DPI Fisheries DST)

Insignificant	No features of biodiversity of conservation value likely to be under threat, no impacts of erosion likely to affect downstream environments. And/or the area is a class 5 acid sulfate soil area: acid sulfate soils are not likely to be found or there are no known occurrences.
Minor	No features of biodiversity or conservation under significant threat. Potential for localised impacts such as loss of low value vegetation or localised water quality impacts. Impacts are small scale and threats to biodiversity and conservation values are considered minimal. And/or the area is a class 3 to 4 acid sulfate soil area: acid sulfate soils are likely to be found 1-3 metres below the natural ground surface.
Moderate	Features of biodiversity or conservation value affected. Scale of impact is significantly greater than natural. Impacts on instream values through siltation or turbidity likely to extend beyond the length of the bank segment. And/or the area is a class 2 acid sulfate soil area: acid sulfate soils area likely to be found <1m below the natural ground surface.
Major	Features of listed biodiversity or conservation value are directly threatened. Significant direct impacts to features of biodiversity or conservation value. Potential for downstream impacts due to turbidity or extensive siltation. And/or the area is a class 1 acid sulfate soil area: acid sulfate soils are likely to be found on and below the natural ground surface.

Table 3. Infrastructure impact (definitions adapted from DPI Fisheries DST)

Insignificant	No built assets under threat.
Minor	Minor assets of low value potentially under threat. May require relocation or minor works typically able to be accommodated without significant labour or cost implications. Loss of land is relatively minor and likely to be of low concern to landholder.
Moderate	Assets of intermediate value threatened. Relocation or repairs necessary with costs up to $100,000. Examples include boat ramps, footpaths, park benches, minor access stairs, etc. Loss of land is likely to be of concern to landholder.
Major	High value or otherwise important assets under threat. Likely significant follow-on impacts. Examples include loss of public utilities such as power lines, water and sewer infrastructure, houses, other buildings, roads, carparks. Loss of land likely to be of significant concern to landholder with some evidence of protection works evident. Likely costs > $100,000.

Table 4. Safety / amenity impact (definitions adapted from DPI Fisheries DST)

Insignificant	No impact on visual amenity, foreshores not used by public, very low risk of injury attributable to erosion.
Minor	Some impact on visual amenity, foreshores used less frequently by public, low risk of serious injury.
Moderate	Significant visual impact. Public access to foreshore impeded. Potential for increased risk of injury to members of the public due to greater usage and/or hazard.
Major	Amenity for a large number of users is affected. Foreshore access significantly impeded. Specific public safety risks in popular areas.

Table 5. Cultural heritage impact*

Insignificant	No known (recorded or declared) Aboriginal sites or objects are affected.
Minor	Potential Aboriginal sites or objects are affected Or a known (recorded or declared) Aboriginal site or object is minorly affected.
Moderate	A known (recorded or declared) Aboriginal site or object is affected.
Major	Multiple known (recorded or declared) Aboriginal sites or objects are affected Or a significant and/or unique Aboriginal Place is affected.

*The cultural heritage impact assessment was undertaken with publicly available data from the NSW Aboriginal Heritage Information Management System (AHIMS). Further information on impacts to Aboriginal Heritage will be collected before any options are implemented.

3.4.2 Likelihood calculations

Likelihood ratings were determined for each site by considering the rate of recent erosion (m/year) and the distance to assets. The rate of recent erosion is a strong indicator of future erosion potential. This was determined using multi-temporal analysis of high-resolution aerial imagery.

Understanding historical rates of change can assist in predicting the future trajectory of the system. A multi-temporal imagery analysis was used to identify shoreline changes and measure the recent rates of shoreline adjustment. High-resolution aerial imagery was obtained from NearMap (https://apps.nearmap.com/maps) at two capture dates, spanning the last 10-12 years, to calculate the recent historic rate of shoreline movements.

For each site, the following process was undertaken:

1. Two aerial images were sourced – one recent and one from approximately 10-12 years ago.
2. The bank/shoreline position was delineated on each image
3. The eroded or accreted distance (in metres) was calculated by measuring the difference in bank position between the two images. For each site, the largest change in bank position along the reach was taken for a more conservative estimate of shoreline movement rate.
4. The recent erosion rate (in metres/year) was calculated by dividing the change in bank position over the time elapsed between each image. Sites that were seen to be accreting were given a zero recent erosion rate (i.e. negative values were not used).

It was not always possible to assess the change in bank position due to vegetation cover, hence three sites do not have an erosion rate attributed to them.

To determine the likelihood of erosion impacting infrastructure, the distance to the nearest asset was divided by the rate of erosion to estimate the number of years until the asset is exposed to erosion at the current rate. A conservative approach was taken to when measuring the distance to the nearest asset, that is, the shortest distance from the shoreline to an asset along the length of the site was used.

The likelihood rating for infrastructure risk was then determined by the number of years until an asset would be exposed, based on the observed past rate of erosion. The likelihood scale increments were selected with consideration for the effective time span of the current CMP, and the design life of the most common assets that could be impacted (i.e., footpaths, powerlines, houses, carparks). The metrics for this likelihood rating are described in Table 6.

Table 6. Likelihood metrics based on years until the nearest infrastructure asset is exposed to erosion based on the recent erosion rate and distance from the shoreline.

Very unlikely	Greater than 30 years until exposure
Unlikely	Greater than 15 years and less than 30 years until exposure
Possible	Greater than 10 years and less than 15 years until exposure
Likely	Less than 10 years until exposure

A different approach to determining the likelihood of erosion impacts to environmental, amenity, and cultural heritage assets/values has been applied. The values considered in these impact categories are not always linked to a specific asset or location, but sometimes rather the ability of the area to support the values. A faster erosion rate indicates a higher likelihood that this ability will be compromised, and these values will be impacted. Therefore, the past erosion rate was used as an indicator of the likelihood of future erosion impacts on environmental, safety/amenity and cultural heritage values. The scale used for these likelihood categories is described below in Table 7.

Table 7. Likelihood scale based on recent historical erosion rate used for environmental, safety/amenity, and cultural heritage risk assessment.

Very unlikely	Less than 0.1 m/year
Unlikely	Greater than 0.1 m/year and less than 0.25 m/year
Possible	Greater than 0.25 m/year and less than 0.5 m/year
Likely	Greater than 0.5 m/year

3.4.3 Risk calculation

A risk rating for each impact category was calculated using the consequence and likelihood ratings as described above (i.e. Risk = Consequence x Likelihood). Therefore, each site was assigned four separate risk scores. Table 8 explains which consequence and likelihood ratings were used to calculate the risk score for each category.

Table 8. Consequence and likelihood ratings used to calculate risk for each category.

Category	Consequence	Likelihood
Environmental	Environmental impact (Table 2)	Rate of recent erosion (Table 7)
Infrastructure	Infrastructure impact (Table 3)	Years until exposure of asset (Table 7)
Safety/amenity	Safety/amenity impact (Table 4)	Rate of recent erosion (Table 7)
Cultural heritage	Cultural heritage impact (Table 5)	Rate of recent erosion (Table 7)

A risk assessment matrix was developed based on the DPI Fisheries Decision Support Tool (see Table 9). For example, for a bank segment with a likelihood = 'Possible and a consequence rating of 'Minor' the risk assigned would = 'Low'.

Table 9. Risk matrix

		Consequence			
		Insignificant	**Minor**	**Moderate**	**Major**
Likelihood	**Likely**	Very low	Medium	High	Very high
	Possible	Very low	Low	Medium	High
	Unlikely	Very low	Low	Low	Medium
	Very unlikely	Very low	Very low	Very low	Low

Using the risk matrix, a risk rating was determined for each site in terms of environmental risk, infrastructure risk, safety/amenity risk and cultural heritage risk. Following this, an overall risk rating for each site was calculated by taking the highest risk rating from any one category as the overall risk. This method is consistent with that outlined in the DST. We performed a sensitivity test of using the sum of the risks from each category to determine the overall risk rating, rather than the highest risk category. The test showed that the risk ratings were reordered slightly, though with no major changes to any particular rating. Following discussions within the project team we stuck to assigning overall risk based on the highest risk rating as it ensured a high or very high risk for one category is not 'watered down' by low risks from other categories, and a key risk element missed.

3.4.4 Additional considerations

The likelihood for increased localised erosion impacts as a result of climate change and urbanisation trends was considered during the development of the risk assessment. The potential for these trends to impact future erosion could result from the following factors:

- Sea level rise (SLR)
- Changing rainfall patterns and hydrology within the catchment

Locally generated wind waves in the Lake are both fetch limited (distance available for wind generated waves to traverse open water) and depth limited (shallow bathymetry dissipating wave energy as it approaches the foreshore). The length of fetch within the Lake will not significantly increase, therefore the height of waves generated within the Lake is unlikely to increase significantly. However, with SLR, water depth is likely to increase, potentially reducing the areas where shallow bathymetry is currently depth-limiting waves. Under present day sea level, these shallow areas cause waves to dissipate their energy before they reach the foreshore. With SLR, waves might move towards shore without being influenced by the shallow bathymetry, arriving at the foreshore with greater energy and erosion potential. Therefore the areas that are most likely to be affected by SLR are wide shallow areas that are fetch aligned with predominant wind conditions. Wind roses for the lake are presented in Figure 6.

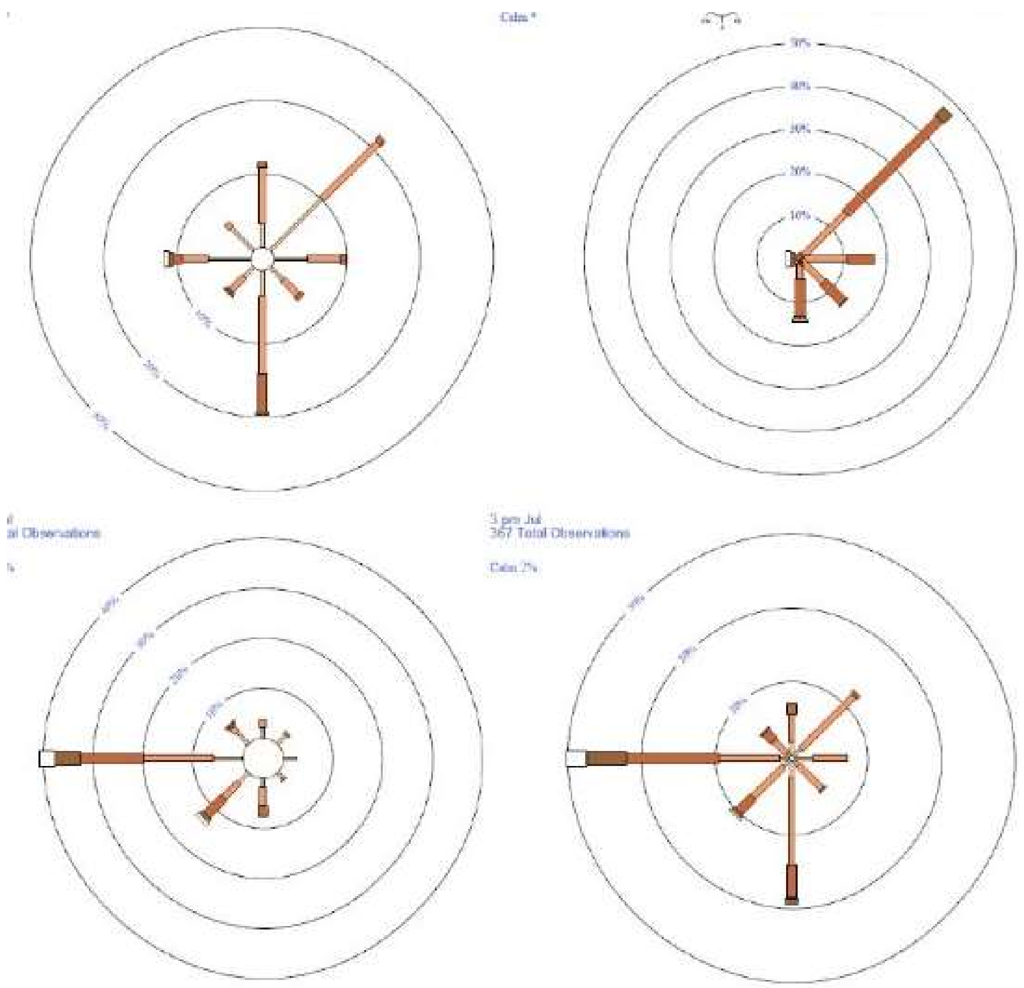

Figure 6. *Wind roses for Illawarra Regional Airport, showing average 9am (left) and 3pm (right) conditions for January (top) and July (bottom) (Adapted from* BMT, 2020*) (source: BoM)*

Figure 7 shows the bathymetry of Lake Illawarra and highlights areas of the lake with a depth of less than 1 m. The map indicates that the area of the lake most likely to be impacted by the changing wave processes is the eastern side of the lake. This area is currently protected from wave forces by a large area of shallow water, though is also exposed to the relatively wide westerly fetch from which winter winds frequently blow (see wind roses in Figure 6). Therefore, this foreshore is the most at risk from changes to wave climate as a result of SLR. However, it is worth noting that the land adjacent to these areas is low lying, and inundation due to SLR is likely to be a greater concern compared to erosion in the future. Other shallow areas that could be of concern are more sheltered or around the fluvial deltas of the major tributaries on the west side of the lake where complex sediment dynamics hinder the ability to make good assumptions about the impact of sea level rise. This is because there is the potential that sediment deposition in these areas will be similar to the rate of sea level rise and hence negate any impact on depth limiting of waves.

As mentioned briefly above, the potential for impacts to wave heights as a result of sea level rise was based on the assumption that the sedimentation rate in these areas of the lake will be outpaced by SLR. This may not be the case if healthy sea grass habitats continue to thrive, producing and trapping sediment over time. Secondly, this assumes that predominant wind patterns will remain constant in a climate change future, although it's deemed to be a low probability that wind patterns will change remarkably.

Due to the uncertainty regarding these potential impacts of sea level rise, they have not been incorporated in the risk assessment. Instead, when discussion the proposed management option at each we have provided an additional recommendation to manage the banks in these areas adaptively, monitoring them for impact of climate change and adjusting management approaches accordingly.

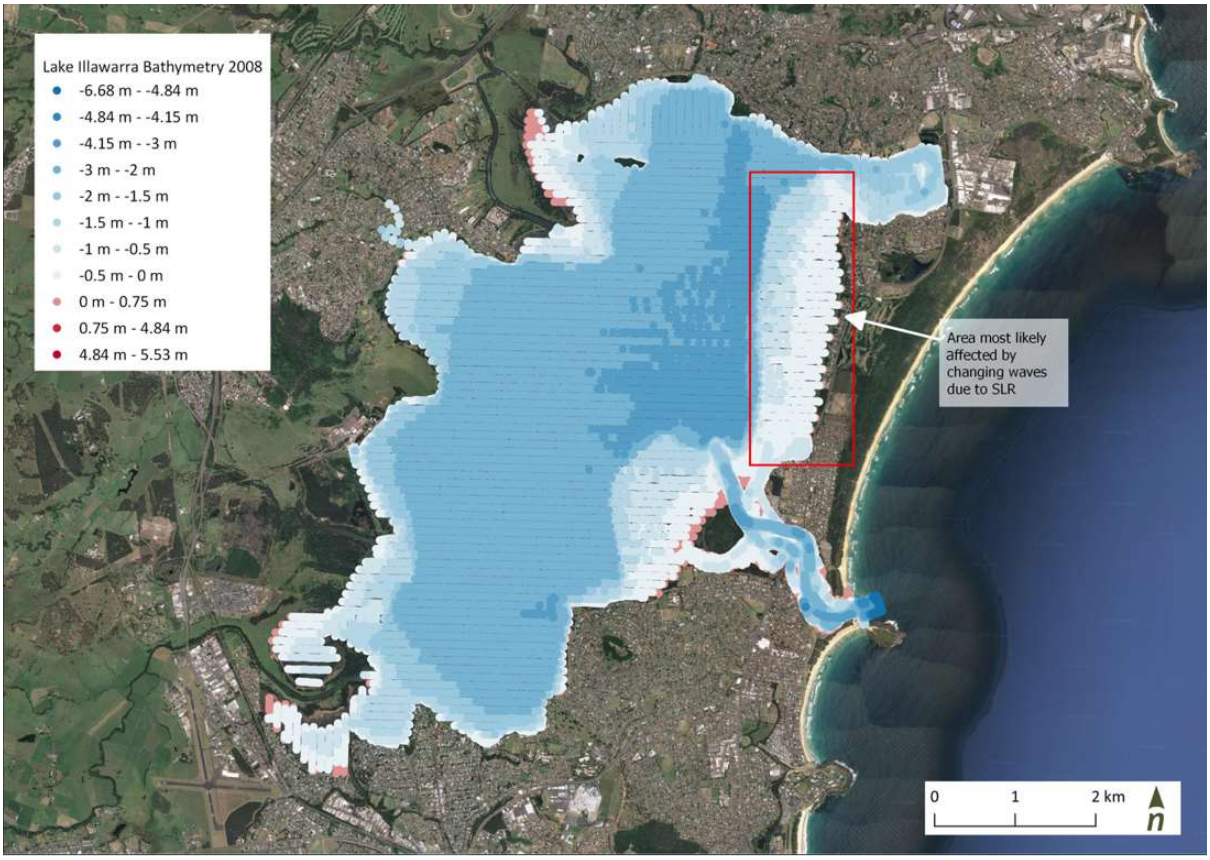

Figure 7. *A map showing a the bathymetry of Lake Illawarra which helped inform a high level assessment of where sea level rise may impact foreshore erosion the most.*

Changing hydrology and rainfall patterns within the catchment will be driven by both increasing urbanisation within the catchment and climate change. Significant planned urban growth in the catchment will lead to increased imperviousness of surfaces accompanied by changes to stormwater runoff volumes and velocities. This may be exacerbated by climate change which is projected to increase the likelihood of more intense rainfall events in the region. Therefore, erosion risk within the streams and tributaries, driven by shear stress from increased streamflow rates will potentially increase. This will be attenuated in the reaches closer to the tidal influence from the Lake.

A qualitative understanding of this process has been considered in the risk assessment, however hydrodynamic modelling beyond the scope of this study is needed to quantify and compare this risk across multiple sites and scenarios.

3.5 Prioritisation

A prioritisation method is used to determine which sites will benefit most from bank management works. A priority ranking was assigned to each site based on the risk ratings derived from the risk assessment. The priority classification of each site was determined by the highest risk rating across all four categories. Additional consideration was given to whether the site was in a tributary, and thus posed an additional threat to sedimentation of downstream habitats. The tenure of assets behind the shoreline was also accounted for with public shorelines considered a higher priority, due to Council and other public authorities having limited means to implement bank erosion works on private property.

All of the sites were classified as either very low, low, medium, high or very high priority. The implications of each priority classification are described in Table 10.

Table 10. Descriptions of each prioritisation classification.

Very low	The site is at very low risk in all categories. Bank management works are not recommended, a monitoring approach is most appropriate.
Low	The site is at low risk in at least one category. Bank management works are not recommended, a monitoring approach is most appropriate.
Medium	The site is at medium risk in at least one category. Bank management works should be considered, however monitoring, vegetation management, and access control is likely appropriate and stabilising works are not urgent.
High	The site is at high risk in at least one category. Bank management works should be considered, and vegetation management and access control are likely appropriate. Stabilising works should be considered.
Very high	The site is at very high risk in at least one category. Bank management works should be implemented urgently.

3.6 Options assessment

Bank management options were developed for each of the medium, high and very high priority sites. For the very low and low-risk sites, a monitoring program that aligns the type and frequency of monitoring with the risk/vulnerability of the sites has been recommended and is detailed further in Section 6. The options were developed through the following process:

1. Input the site information into the DPI Fisheries DST which generated a primary recommended option and a shortlist of secondary recommended options.

2. Review and modify the options based on:
    a. Knowledge of the site dimensions, and geotechnical and hydraulic conditions.
    b. The nature and magnitude of erosion risk.
    c. Erosion trajectory as a result of climate change
    d. Strategies that would not require an excessive amount of material to construct, in particular, hard engineering materials such as rock
    e. Incorporate fish habitat features including large woody debris, mangrove fillets and structural habitat units (e.g., reef balls). In some locations fish habitats can be incorporated into the bank stabilisation works however in other cases they will need to be modular/add-on (i.e., reef balls). All habitat options developed will consider factors such as constructability, durability, safety and cost.
    f. Enhance the condition and extent of riparian vegetation including within the intertidal zone.
    g. Incorporate environmentally sustainable materials where possible, utilising natural materials, and recycled or reused products where practical and economical.
    h. The adaptability of the option will be to changing bank condition (i.e., ongoing bank erosion).
    i. Construction techniques and impacts on adjacent land uses and public access.

The proposed options are presented in Section 6.

4 Erosion assessment results

4.1 First pass assessment

Following completion of the desktop and field assessment, the results were processed and a suite of maps of the study area showing where:

- Erosion observed
- Engineered bank protection works are present. In these maps, 'mixed' indicates interspersed protection works along a length of foreshore.
- The extent of bedrock-controlled shoreline.

Maps illustrating the results of the first pass assessment are provided in Appendix B.

4.2 Detailed erosion risk assessment

At the 46 sites where erosion was observed, a 'full risk assessment' was undertaken using the method described in Section 3.4. Table 11 presents the results of the detailed risk assessment process. Maps displaying the sites classified by overall risk, which is defined as the highest risk category for each site, are provided in Figure 8 to Figure 11.

Table 11. Detailed erosion risk assessment results

Sites		Consequence				Likelihood					Risk				
Bank segment ID	Description	Environmental	Safety/amenity	Infrastructure	Cultural heritage	Erosion rate (m/year)	Infrastructure setback distance (m)	Years to infrastructure asset	Infrastructure Likelihood	Env / amenity / cultural Likelihood	Environmental	Safety/amenity	Infrastructure	Cultural heritage	Overall risk
L2	Beach east of Marina	Minor	Moderate	Moderate	Insignificant	0.14	32	230	Very unlikely	Unlikely	Low	Low	Very low	Very low	**Low**
L3	Gabions finish and transition to just a low level walking track on natural shoreline	Minor	Major	Major	Minor	0.13	4	30	Unlikely	Unlikely	Low	Medium	Medium	Low	**Medium**
L4	Per reach G	Minor	Major	Major	Minor	0.11	4	38	Very unlikely	Unlikely	Low	Medium	Low	Low	**Medium**
L5	Bedrock and grass edge	Minor	Major	Moderate	Insignificant	0.13	2	15	Possible	Unlikely	Low	Medium	Medium	Very low	**Medium**
L6	Natural section between timber wall and Small Unnamed creek	Moderate	Major	Moderate	Insignificant	0.22	2	10	Likely	Unlikely	Low	Medium	High	Very low	**High**
L7	Natural section between Small Unnamed Creek and next timber walling	Moderate	Major	Moderate	Insignificant	0.29	6	21	Unlikely	Possible	Medium	High	Low	Very low	**High**
L19	South of minor stream at the end of 'Z'	Major	Moderate	Moderate	Major	0.50	7	14	Possible	Likely	Very high	High	Medium	Very high	**Very high**
L18	Between steel groyne and sandstone blocks	Moderate	Moderate	Major	Major	0.00	8	Inf	Very unlikely	Very unlikely	Very low	Very low	Low	Low	**Low**
L17	Between Duck Creek and Energy Australia outlet channel	Major	Minor	Minor	Moderate	0.18	10	56	Very unlikely	Unlikely	Medium	Low	Very low	Low	**Medium**
L16	The stretch 200m from the mouth of the Macquarie Rivulet towards Hayward Bay (South portion of Gerongar Pt)	Moderate	Minor	Insignificant	Insignificant	0.58	1000	1723	Very unlikely	Likely	High	Medium	Very low	Very low	**High**
L13	Oaky Gully to Karoo Point	Minor	Major	Moderate	Insignificant	0.24	4	16	Unlikely	Unlikely	Low	Medium	Low	Very low	**Medium**
L12	93 The Esplanade to Jetty at Davies Bay	Minor	Moderate	Moderate	Insignificant	0.04	2	58	Very unlikely	Very unlikely	Very low	Very low	Very low	Very low	**Very low**
L11	100m north of Madigan Blvd to toilet block in Boonerah Point	Minor	Moderate	Moderate	Major	0.12	12	101	Very unlikely	Unlikely	Low	Low	Very low	Medium	**Medium**
L10	Rock protection to end of bedrock near 243 Rendall Pde	Moderate	Minor	Moderate	Moderate	0.30	5	17	Unlikely	Possible	Medium	Low	Low	Medium	**Medium**
L8	North of Lakeside Cabins to golf course	Major	Minor	Major	Major	N/A	25	N/A	Unlikely	Unlikely	Medium	Low	Medium	Medium	**Medium**
L9	Jetties Caravan Park	Moderate	Minor	Major	Insignificant	0.07	5	67	Very unlikely	Very unlikely	Very low	Very low	Low	Very low	**Low**
DU1	Duck Creek upstream left bank	Moderate	Minor	Minor	Insignificant	0.03	44	1434	Very unlikely	Very unlikely	Very low	Very low	Very low	Very low	**Very low**
MR1	Macquarie Rivulet (downstream of rail crossing) - left bank	Major	Insignificant	Moderate	Minor	0.10	14	145	Very unlikely	Very unlikely	Low	Very low	Very low	Very low	**Low**
MR2	Macquarie Rivulet (downstream of rail crossing) - right bank	Major	Moderate	Moderate	Moderate	0.00	5	Inf	Very unlikely	Very unlikely	Low	Very low	Very low	Very low	**Low**
L20	near Koonawarra Bay Viewing platform. Stretch east of jetty until rock revetment	Minor	Moderate	Moderate	Insignificant	0.24	2	6	Likely	Unlikely	Low	Low	High	Very low	**High**
L21	Stretch immediately south west of mullet ck entrance	Moderate	Moderate	Moderate	Minor	0.28	5	16	Unlikely	Possible	Medium	Medium	Low	Low	**Medium**
MU7	Stretch just south of 16	Moderate	Moderate	Major	Insignificant	0.07	2	30	Unlikely	Very unlikely	Very low	Very low	Medium	Very low	**Medium**
HL1	hospital creek where bank meets lake	Moderate	Major	Major	Insignificant	0.22	5	21	Unlikely	Unlikely	Low	Medium	Medium	Very low	**Medium**
HK2, HK3	Hooka creek between two ped bridges	Major	Moderate	Major	Insignificant	0.05	4	80	Very unlikely	Very unlikely	Low	Very low	Low	Very low	**Low**
HK4	upstream end of Hooka creek (west arm) coming down from the culverts	Moderate	Moderate	Moderate	Insignificant	0.09	7	74	Very unlikely	Very unlikely	Very low	Very low	Very low	Very low	**Very low**
HK1	Bit of bank erosion	Moderate	Major	Major	Insignificant	0.08	2	24	Unlikely	Very unlikely	Very low	Low	Medium	Very low	**Medium**
MU1	Upstream of mullet creek tank trap	Moderate	Insignificant	Major	Insignificant	0.00	8	Inf	Very unlikely	Very unlikely	Very low	Very low	Low	Very low	**Low**
L15	Small stretch of houses with no riparian corridor in front	Minor	Insignificant	Major	Moderate	0.10	33	331	Very unlikely	Very unlikely	Very low	Very low	Low	Very low	**Low**
L14	Stretch just south of Kurrura point	Minor	Moderate	Major	Insignificant	0.08	37	444	Very unlikely	Very unlikely	Very low	Very low	Low	Very low	**Low**

Sites		Consequence				Likelihood					Risk				
Bank segment ID	**Description**	**Environmental**	**Safety/amenity**	**Infrastructure**	**Cultural heritage**	**Erosion rate (m/year)**	**Infrastructure setback distance (m)**	**Years to infrastructure asset**	**Infrastructure Likelihood**	**Env / amenity / cultural Likelihood**	**Environmental**	**Safety/amenity**	**Infrastructure**	**Cultural heritage**	**Overall risk**
OK2	Oaky gully a bit further downstream	Moderate	Insignificant	Major	Insignificant	N/A	7	N/A	Very unlikely	Very unlikely	Very low	Very low	Low	Very low	**Low**
OK1	Oaky gully downstream end from road crossing to lake	Minor	Major	Moderate	Insignificant	N/A	7	N/A	Very unlikely	Very unlikely	Very low	Low	Very low	Very low	**Low**
MR4	Macquarie rivulet midstream, right bank	Moderate	Major	Moderate	Moderate	0.02	2	115	Very unlikely	Very unlikely	Very low	Low	Very low	Very low	**Low**
MR3	Macquarie rivulet midstream, left bank	Moderate	Minor	Minor	Moderate	0.00	4	Inf	Very unlikely	Very unlikely	Very low	Very low	Very low	Very low	**Very low**
MR6	Macquarie rivulet upstream, right bank	Moderate	Moderate	Major	Major	0.06	6	101	Very unlikely	Very unlikely	Very low	Very low	Low	Low	**Low**
MR5	Macquarie rivulet upstream, left bank	Minor	Insignificant	Minor	Moderate	0.03	75	2991	Very unlikely	Very unlikely	Very low	Very low	Very low	Very low	**Very low**
BR1	Houses with mixed protection along left bank of brooks creek looking downstream	Moderate	Minor	Major	Insignificant	0.05	1	19	Unlikely	Very unlikely	Very low	Very low	Medium	Very low	**Medium**
MU2	Mullet creek erosion	Major	Minor	Major	Insignificant	0.13	15	113	Very unlikely	Unlikely	Medium	Low	Low	Very low	**Medium**
MU3	Erosion	Moderate	Minor	Moderate	Insignificant	0.08	95	1226	Very unlikely	Very unlikely	Very low	Very low	Very low	Very low	**Very low**
MU5	Erosion on bank just south/east of 84	Minor	Moderate	Major	Insignificant	0.39	6	15	Possible	Possible	Low	Medium	High	Very low	**High**
MU6	Erosion just south of carpark at mullet creek	Minor	Moderate	Moderate	Insignificant	0.07	22	336	Very unlikely	Very unlikely	Very low	Very low	Very low	Very low	**Very low**
MU4	Bit of bank erosion where RSP (stretch 87) ends	Minor	Minor	Insignificant	Insignificant	N/A	16	N/A	Unlikely	Unlikely	Low	Low	Very low	Very low	**Low**
L1	Stretch directly east of Hooka Ck mouth	Minor	Major	Major	Moderate	0.35	8	23	Unlikely	Possible	Low	High	Medium	Medium	**High**
MT1	Mullet tank trap	Major	Insignificant	Moderate	Insignificant	0.09	6	60	Very unlikely	Very unlikely	Low	Very low	Very low	Very low	**Low**
HL2	Hospital creek right bank downstream of bridge	Moderate	Major	Major	Insignificant	0.00	7	Inf	Very unlikely	Very unlikely	Very low	Low	Low	Very low	**Low**
DU2	Duck Creek upstream right bank	Major	Minor	Insignificant	Insignificant	0.00	46	Inf	Very unlikely	Very unlikely	Low	Very low	Very low	Very low	**Low**

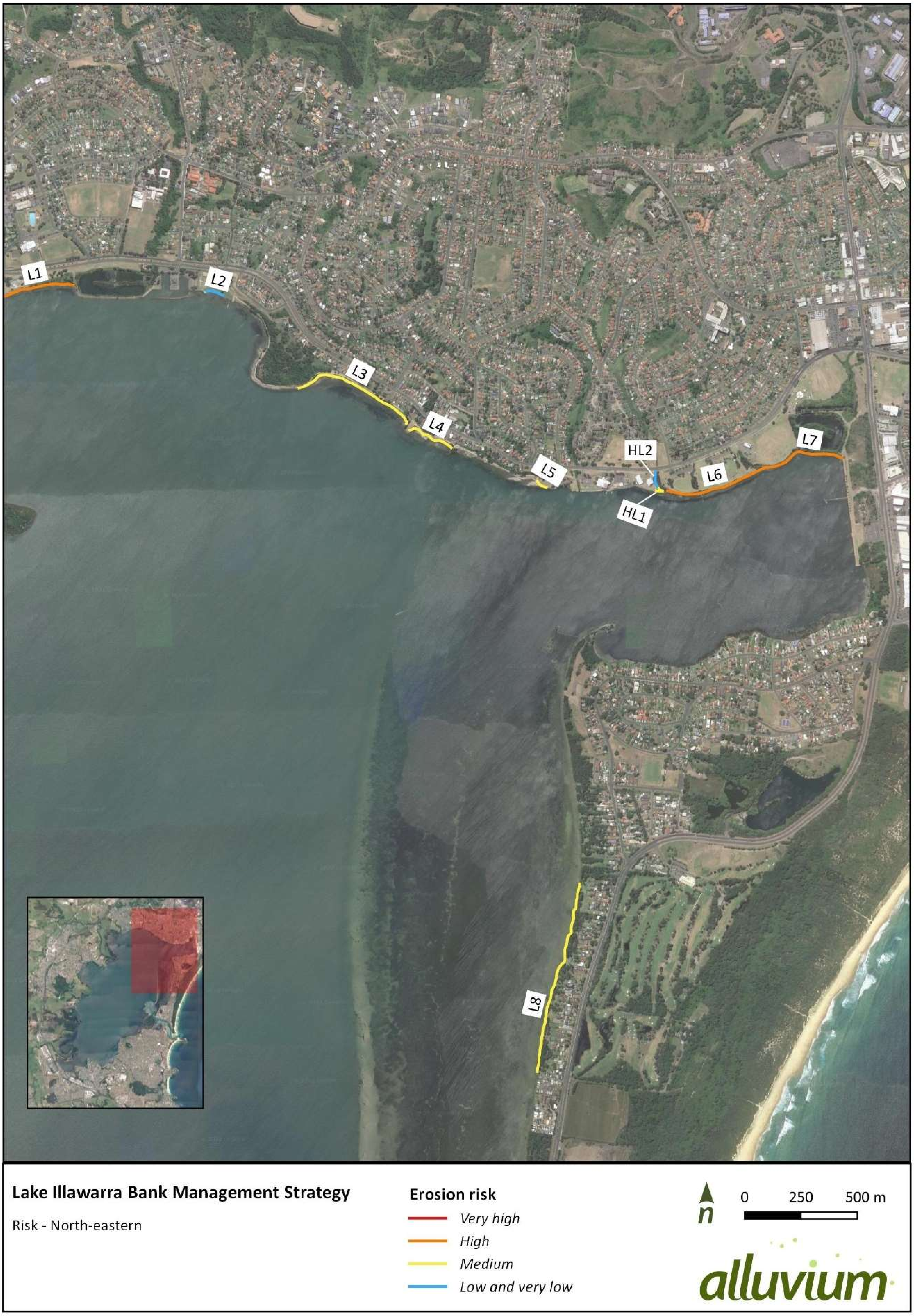

Figure 8. *A map showing the results of the erosion risk assessment in the North-eastern quadrant*

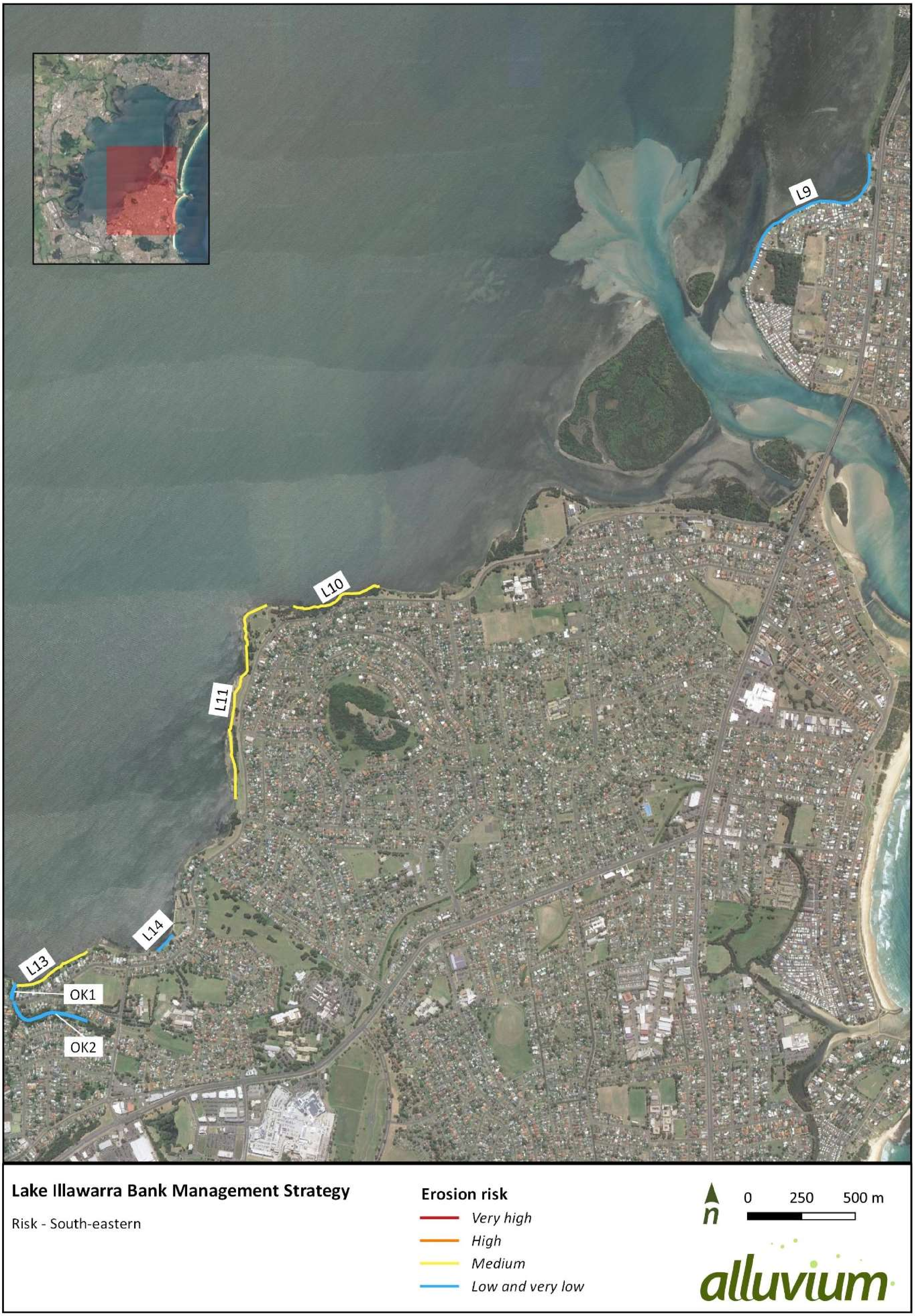

Figure 9. *A map showing the results of the erosion risk assessment in the South-eastern quadrant*

Figure 10. *A map showing the results of the erosion risk assessment in the South-western quadrant*

Figure 11. *A map showing the results of the erosion risk assessment in the North-western quadrant*

5 Prioritisation

A priority rating was given to each site based on the method described in Section 3.5. Table 12 presents the results of the prioritisation process with sites listed in priority order. Maps displaying the sites classified by priority are provided in Figure 12 to Figure 15. Appendix C provides a photobank of each of the priority sites.

Table 12. List of prioritised sites

Bank segment ID	Site description	Overall risk	Tributary sediment deposition*	Asset/Land Manager[†]	Priority rating
L19	South of minor stream at the end of 'Z'	Very high	No	Crown Lands	Very high[o]
L6	Natural section between timber wall and Small Unnamed creek	High	No	Property NSW	High[o]
L7	Natural section between Small Unnamed Creek and next timber walling	High	No	Property NSW	High[o]
L16	The stretch 200m from the mouth of the Macquarie Rivulet towards Hayward Bay (South portion of Gerongar Pt)	High	No	Council	High
MU5	Erosion on bank just south/east of 84	High	Yes	Council	High
L1	Stretch directly east of Hooka Ck mouth	High	No	Council	High
L3	Gabions finish and transition to just a low level walking track on natural shoreline	Medium	No	Council	Medium
L4	Per reach G	Medium	No	Council	Medium
L5	Bedrock and grass edge	Medium	No	Private	Medium[o]
L17	Between Duck Creek and Energy Australia outlet channel	Medium	No	Private	Medium[o]
L13	Oaky Gully to Karoo Point	Medium	No	Council	Medium
L10	Rock protection to end of bedrock near 243 Rendall Pde	Medium	No	Council	Medium
MR2	Macquarie Rivulet (downstream of rail crossing) - right bank	Low	Yes	Council	Medium
L20	near Koonawarra Bay Viewing platform. Stretch east of jetty until rock revetment	High	No	Council	Medium[‡]
L21	Stretch immediately south west of mullet ck entrance	Medium	No	Council	Medium
MU7	Stretch just south of 16	Medium	Yes	Council	Medium
HL1	Hospital creek where bank meets lake	Medium	Yes	Property NSW	Medium[o]
HK2, HK3	Hooka creek between two ped bridges	Low	Yes	Council	Medium
HK1	Bit of bank erosion	Medium	Yes	Council	Medium
MU1	Upstream of mullet creek tank trap	Low	Yes	Private	Medium[o]
MR4	Macquarie rivulet midstream, right bank	Low	Yes	Council	Medium
MR6	Macquarie rivulet upstream, right bank	Low	Yes	Council	Medium
MU2	Mullet creek erosion	Medium	Yes	Private	Medium[o]
MT1	Mullet tank trap	Low	Yes	Private	Medium[o]
L8	North of Lakeside Cabins to golf course	Low	No	Private	Medium[o]

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Bank segment ID	Site description	Overall risk	Tributary sediment deposition*	Asset/Land Manager†	Priority rating
MR1	Macquarie Rivulet (downstream of rail crossing) - left bank	Low	Yes	Private	Medium°
L2	Beach east of Marina	Low	No	Crown Lands	Low°
L18	Between steel groyne and sandstone blocks	Low	No	Crown Lands	Low°
L11	100 m north of Madigan Blvd to toilet block in Boonerah Point	Medium	No	Council	Low•
L9	Jetties Caravan Park	Low	No	Crown Lands, northernmost section is private	Low°
DU1	Duck Creek upstream left bank	Very low	Yes	Private	Low°
HK4	Upstream end of Hooka creek (west arm) coming down from the culverts	Very low	Yes	Council	Low
L15	Small stretch of houses with no riparian corridor in front	Low	No	Private	Low°
L14	Stretch just south of Kurrura point	Low	No	Private	Low°
OK2	Oaky gully a bit further downstream	Low	Yes	Private	Low°
OK1	Oaky gully downstream end from road crossing to lake	Low	Yes	Council	Low
MR3	Macquarie rivulet midstream, left bank	Very low	Yes	Council	Low
MR5	Macquarie rivulet upstream, left bank	Very low	Yes	RMS	Low°
BR1	Houses with mixed protection along left bank of brooks creek looking downstream	Medium	Yes	Private	Low°
MU3	Erosion	Very low	Yes	Private	Low°
MU6	Erosion just south of carpark at mullet creek	Very low	Yes	Council	Low
MU4	Bit of bank erosion where RSP (stretch 87) ends	Low	Yes	Private	Low°
HL2	Hospital creek right bank downstream of bridge	Low	Yes	Property NSW	Low°
DU2	Duck Creek upstream right bank	Low	Yes	Private	Low°
L12	93 The Esplanade to Jetty at Davies Bay	Very low	No	Council	Very low

* This column relates to whether or not the bank segment has potential to contribute new eroded sediment from the tributaries to the lake, as these sites were given a higher priority given the additional risk this poses to estuarine values.

† This column relates to the infrastructure that would be at risk, rather than the owner of the shoreline.

‡ L20 was lowered to medium priority status due to the minor severity of erosion observed.

• L11 was lowered to low priority status as it is bedrock controlled and so future erosion risk is very little.

° denotes sites that are not managed by Council, hence have a different pathway to action under the CMP

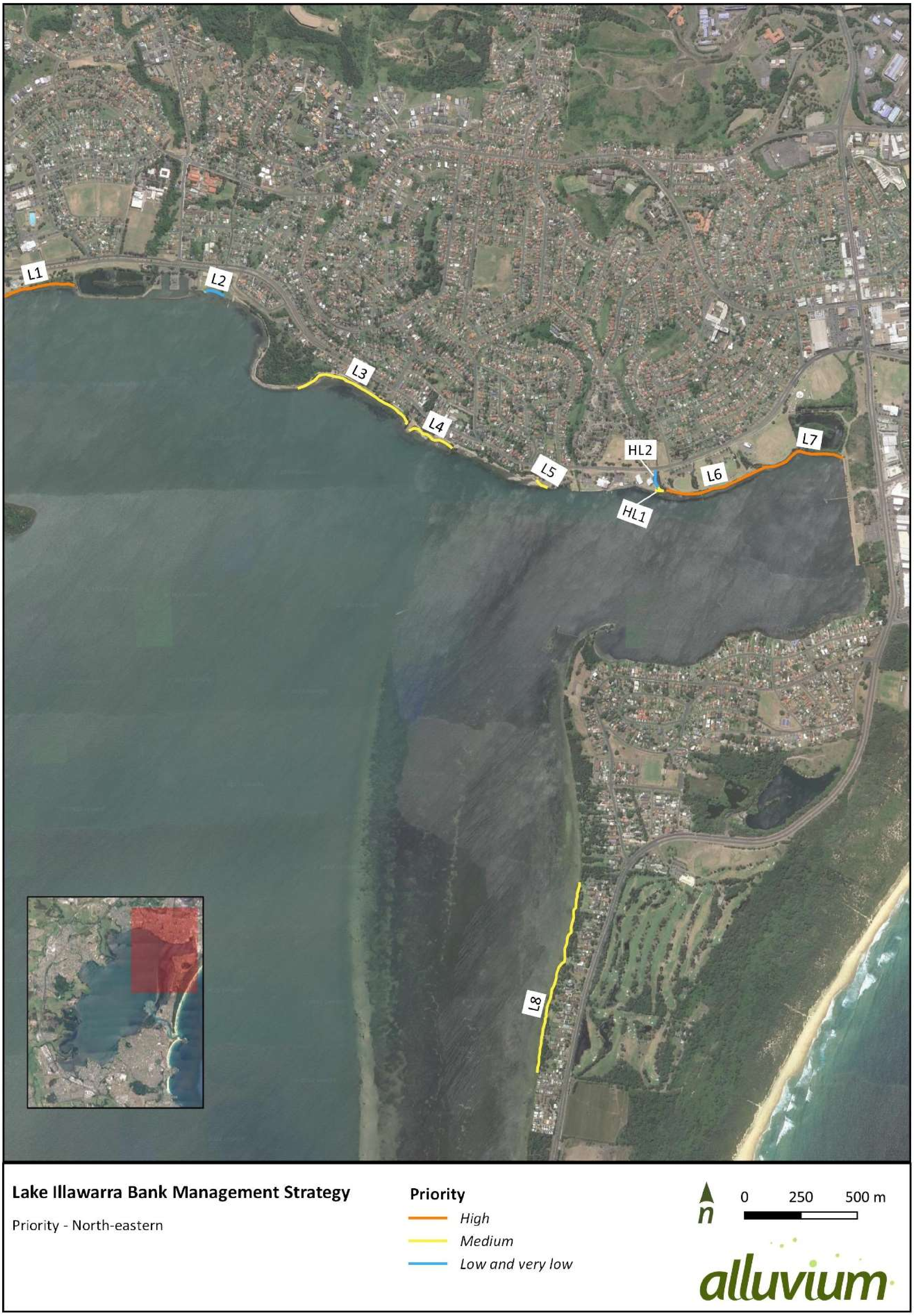


Figure 12. *A map showing the priority ranking of sites in the North-eastern quadrant*

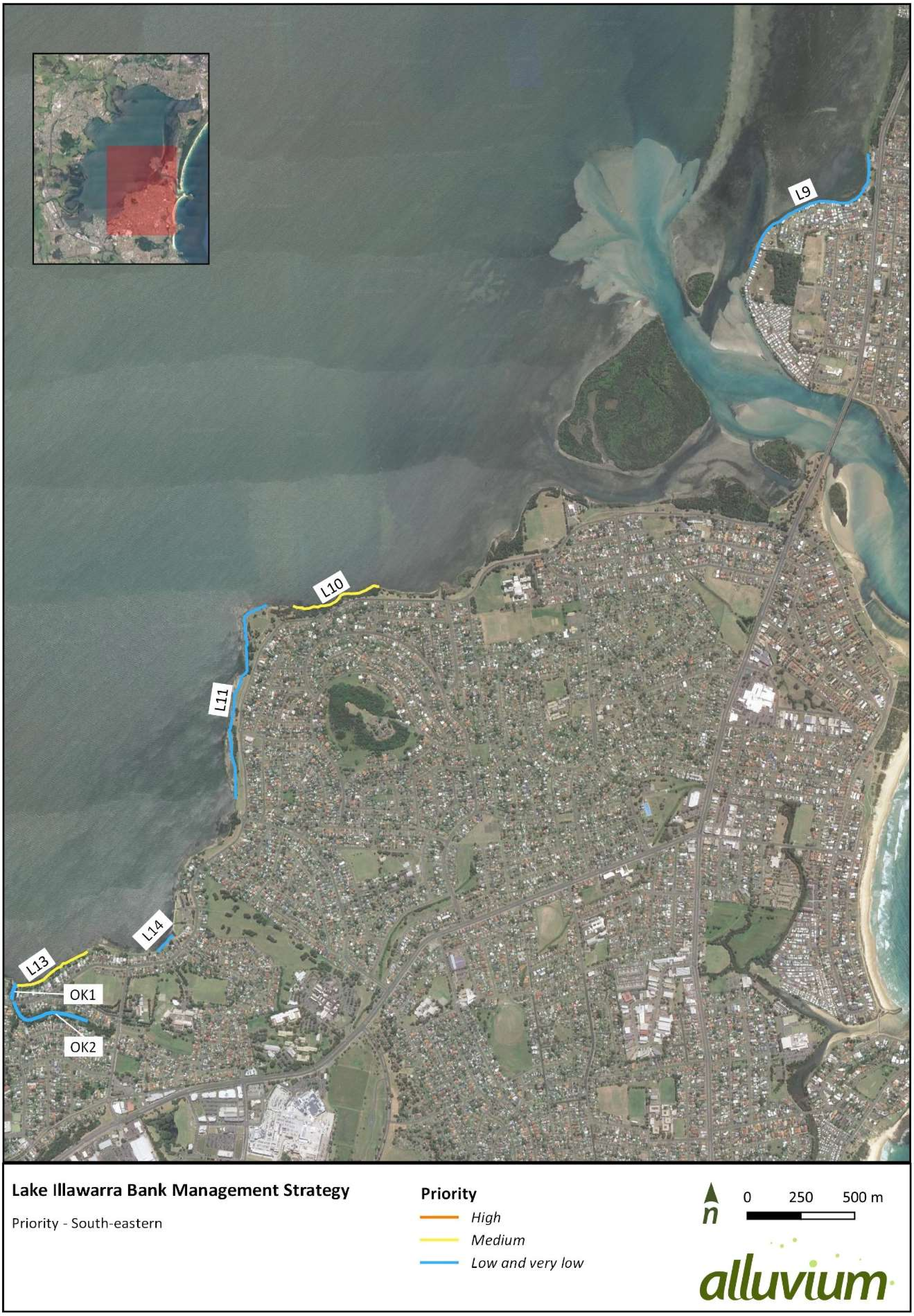


Figure 13. *A map showing the priority ranking of sites in the South-eastern quadrant*

Figure 14. *A map showing the priority ranking of sites in the South-western quadrant*

Figure 15. *A map showing the priority ranking of sites in the North-western quadrant*

6 Options assessment

Bank stabilisation options have been developed for the 26 priority sites (Medium risk and above) listed in Section 5 and are presented in Table 13. Where possible, sites with similar characteristics have been grouped and management options have been developed for each group of sites. These groupings are presented below in Table 14 along with the key characteristics of each of the groups and their recommended management options.

For each group of sites, 2 to 3 bank stabilisation/management options were developed which aim to increase bank stability, and enhance fish habitat, riparian and amenity values. As a first pass, options were developed using the DST. When reviewing the options proposed by the DST, we modified them where necessary based on the criteria listed in Section 3.6. The outcome of the options assessment was two or three recommended management options for each of the 10 groups.

The options are listed in Table 13 and descriptions of the proposed strategies are provided in Appendix D. For some sites, monitoring has been included as an option. These are sites where the erosion risk is not an immediate risk requiring physical action. At these sites a monitoring program that will improve the understanding of erosion trends will give a better understanding of the processes at play, and either eventually inform future works or show that erosion slowed or halted without the need for any intervention. Appendix D includes an indication of the relative cost of each option with consideration for upfront costs of design and construction as well as whole of life consideration for maintenance and repairs. In general, nature based options require less cost due to the use of natural materials for installation and the tendency for the living vegetation to grow and become established without human intervention. Nature based protection will also recover naturally after sustaining damage, assuming it is healthy and well established, therefore reducing maintenance costs throughout the life of the asset.

Very low to low priority sites

A list of options was not proposed for sites that are classified as very low or low priority. These sites were included in the detailed risk assessment because there was visual evidence of erosion, however, due to low consequence, low likelihood of erosion, or a combination of those two factors, they do not require proactive bank management.

For these sites, the most appropriate action is to implement a fit-for-purpose monitoring program. The monitoring program could utilise available aerial imagery to periodically update the multi-temporal analysis to detect any acceleration of the rate of erosion. At the low and very low priority sites that are characterised by cleared or degraded foreshore vegetation, management should focus on revegetating the riparian zone, as this will provide additional environmental benefits such as ecological habitat and pollutant capture amongst in addition to long term bank protection.

Table 13. Bank management options

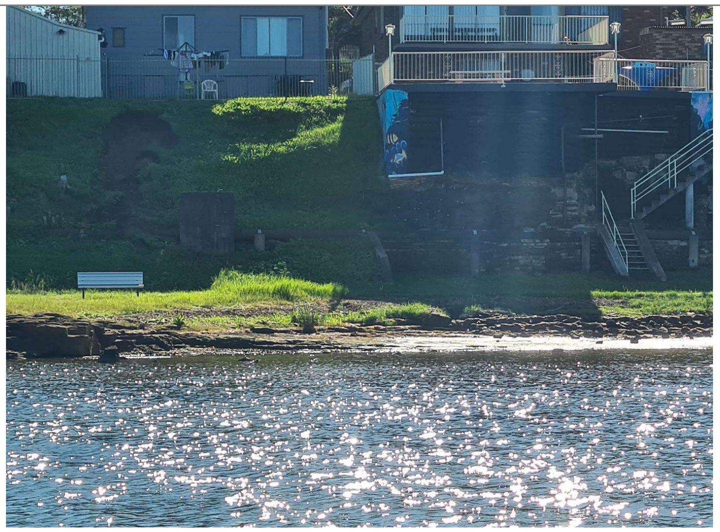
Bank segment ID	Priority rating	Option 1	Option 2	Option 3	DST primary recommended option
L19*	Very high	Toe or bank protection works (rock fillets or logs)	Rock fillet/oyster reef		Large woody debris
L6 (areas of good vegetation)	High	Monitor	Log or rock fillet protection at toe to encourage establishment of bank vegetation		Cobble beach
L6 (areas of poor vegetation)	High	Revegetation	Low key stabilisation with logs, or rock rubble, or geotextile sandbags		Cobble beach
L7	High	Monitor	Log or rock fillet protection at toe to encourage establishment of bank vegetation		Cobble beach
L16	High	Reposition fallen timber	Logs or rock fillet toe to protect vegetation	Oyster reef	Cobble beach
MU5	High	Revegetation and monitoring	Moderately designed stabilisation works (e.g., extend rock protection south)		Geotextile sand containers
L1	High	Revegetation	Low key stabilisation with logs, or rock rubble, or geotextile sandbags in areas close to footpath	Cobble beach around the jetty	Cobble beach
L3	Medium	Revegetation	Low key stabilisation with logs, or rock rubble, or geotextile sandbags		Cobble beach
L4	Medium	Monitor	Potential low key stabilisation works in active erosion areas (logs, rock rubble or geotextile sandbags		Cobble beach
L5	Medium	Revegetation	Potential low key stabilisation with logs, or rock rubble, or geotextile sandbags		Cobble beach

Bank segment ID	Priority rating	Option 1	Option 2	Option 3	DST primary recommended option
L8 (areas of good vegetation)	Medium	Monitor	Educate residents on the importance of not mowing riparian vegetation to help mitigate erosion		Cobble beach
L8 (areas of poor vegetation)	Medium	Revegetation	Educate residents on the importance of not mowing riparian vegetation to help mitigate erosion		Cobble beach
L17	Medium	Monitor	Logs or rock fillet toe to protect vegetation	Oyster reef	Rock fillets
L13	Medium	Revegetation	Low key stabilisation with logs, or rock rubble, or geotextile sandbags in areas close to footpath		Cobble beach
L10	Medium	Monitor	Log or rock fillet protection at toe to encourage establishment of bank vegetation		Cobble beach
MR2	Medium	Revegetation and stock exclusion fencing	Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas	Event-driven monitoring	Geotextile sand containers
L20	Medium	Revegetation	Low key stabilisation with logs, or rock rubble, or geotextile sandbags		Cobble beach
L21	Medium	Revegetation	Localised stabilisation works (logs, rock rubble, or geotextile sandbags) in areas close to footpath		Cobble beach
MU7	Medium	Revegetation and monitoring	Moderately designed stabilisation works (e.g., extend rock protection south)		Geotextile sand containers
HL1	Medium	Monitor	Pinned logs or rock fillet toe to protect vegetation	Oyster reef	Cobble beach
HK2, HK3	Medium	Monitor	Develop erosion progression trigger	Large woody debris to reduce fluvial energy and enhance	Large woody debris

Bank segment ID	Priority rating	Option 1	Option 2	Option 3	DST primary recommended option
				fish habitat in active erosion areas	
HK1	Medium	Monitor	Develop erosion progression trigger	Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas	Large woody debris
MU1	Medium	Revegetation and stock exclusion fencing	Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas		Large woody debris
MR4	Medium	Revegetation and stock exclusion fencing	Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas	Event-driven monitoring	Cobble
MR6	Medium	Revegetation and stock exclusion fencing	Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas	Event-driven monitoring	Geotextile sand containers
MU2	Medium	Revegetation and stock exclusion fencing	Bank reprofiling in active erosion areas	Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas	Large woody debris
MR1	Medium	Revegetation and stock exclusion fencing	Bank reprofiling in active erosion areas	Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas	Large woody debris
MT1	Medium	Revegetation and stock exclusion fencing	Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas		Cobble beach

**For sites with at risk cultural heritage assets, Indigenous community should be consulted on how they would like to protect the site.*

Table 14. Site grouping categories and management options

Site descriptor	Key characteristics	Example photo	Sites	Options
1. Lake shoreline with poor vegetation coverage	• Lakefront • Shallow water • Low angle shoreline • High amenity areas • Poor vegetation coverage • Wind wave dominated erosion	 *(photo taken on 5 April 2022)*	L1, L3, L5, L13, L20, L6*, L8*	• Revegetation • Low key stabilisation with logs, or rock rubble, or geotextile sandbags
2. Lake shoreline with inadequate existing protection	• Lakefront • Shallow water • Low angle shoreline • High amenity areas • Low erosion rate • Poor vegetation coverage • Wind wave dominated erosion	 *(photo taken on 3 May 2022)*	L4	• Monitor • Low key stabilisation works in active erosion areas (logs, rock rubble or geotextile sandbags)
3. Lake shoreline with good vegetation coverage	• Lakefront • Shallow water • Low angle shoreline • High amenity areas • Good vegetation coverage • Wind wave dominated erosion	 *(photo taken on 3 May 2022)*	L7, L10, L6*, L8*	• Monitor • Log or rock fillet protection at toe to encourage establishment of lower bank vegetation

4. Lake shoreline with cultural heritage values	• Lakefront • Shallow water • Low angle shoreline • Cultural heritage value • Good vegetation coverage • Wind wave dominated erosion • High recent erosion rate	 *(photo taken on 3 May 2022)*	L19	• Toe or bank protection works (rock fillets or logs) • Rock fillet/oyster reef • Consult with Indigenous community on how they would like to protect the site
5. Tributary channel with poor riparian vegetation corridor	• Within tributary channel • Vertical banks • Mixed amenity areas • Patchy, discontinuous, and narrow vegetation corridor • Erosion scarps in active areas of erosion • Exposed to fluvial and tidal currents • Bank saturation contributes to erosion	 *(photo taken on 5 April 2022)*	MU1, MU2, MT1, MR1, MR2, MR4, MR6	• Revegetation and stock exclusion fencing • Bank reprofiling in active erosion areas • Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas
6. Tributary channel with good riparian vegetation corridor	• Within tributary channel • Steep vegetated banks • Healthy, continuous, and wide vegetation corridor • Undercutting evident in active erosion areas • Exposed to fluvial and tidal currents • Bank saturation ameliorated by vegetation	 *(photo taken on 5 April 2022)*	HK1, HK2, HK3	• Monitor • Develop erosion progression trigger • Large woody debris to reduce fluvial energy and enhance fish habitat in active erosion areas

7. Tributary with meander development	• Within tributary channel • Low erosion scarp • Erosion at the edge of existing rock protection • Meander cut-off prevented by existing rock protection • Carpark within the meander peninsula • Discontinuous /poor vegetation • Exposed to fluvial and weak tidal currents	 *(photo taken on 5 April 2022)*	MU5, MU7	• Revegetation and monitoring • Toe or bank stabilisation works in active erosion areas (logs, piled rock or geotextile sandbags)
8. Tributary mouth	• Where tributaries flow into lake • Highly dynamic erosion and sedimentation areas • Low angle shoreline • Exposed to fluvial, tidal and wind wave-driven currents • Good native vegetation coverage with high biodiversity value	 *(photo taken on 5 April 2022)*	HL1, L17	• Monitor • Logs or rock fillet toe to reduce wave energy • Rock fillet/oyster reef
9. Tributary mouth with increased acid sulfate soil risk	• Where tributaries flow into lake • Highly dynamic erosion and sedimentation areas • Low angle shoreline • Exposed to fluvial, tidal and wind wave-driven currents • Good native vegetation coverage with high biodiversity value • Potential Class 2 acid sulfate soils with further bank retreat	 *(photo taken on 3 May 2022)*	L16	• Reposition fallen timber • Logs or rock fillet toe to protect vegetation • Rock fillet/oyster reef

10. Tributary mouth with bedrock influence	• Where tributaries flow into lake near bedrock features • Dynamic erosion and sedimentation controlled by stable southern headland • Exposed to fluvial, tidal and wind wave-driven currents • Varied vegetation coverage • Moderate amenity areas	 *(photo taken on 5 April 2022)*	L21	• Revegetation Localised stabilisation works (logs, rock rubble, or geotextile sandbags)

*This site has characteristics of more than one category and can be considered in both categories.

7 Roles and responsibilities

Delivery of this strategy will involve multiple stakeholders including state government, local government and private property owners. Much of the Lake's foreshore is in private ownership. The remainder is owned and managed by Department of Planning and Environment (DPE) - Crown Lands, Government Property NSW, SCC and WCC. The status of land ownership around the Lake remains complex due to the transition from the Lake Illawarra Authority (LIA) to the Councils. Prior to July 2014, the LIA jointly managed the Lake Illawarra foreshore public lands with WCC and SCC. Following the disbandment of the LIA, land and assets were to be transferred back to the State Government and local Councils. Transfer of lands has been finished and there are no more negotiations (BMT, 2020). A summary of land ownership from the Lake Illawarra Synthesis Report (BMT, 2020) is provided below.

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

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

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

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

Government Property responsibility includes:

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

DPIE – Crown Lands responsibility includes:

- Management of the Lake Illawarra Entrance Management Works;
- Berkeley Harbour and Kiosk, Yallah Bay open space, old squash court, jetties, paths, etc.;
- Shared path and boardwalk from Gilba Road to Yallah Bay;

- Judbooley Parade flats and foreshore strip to the west; and
- All jetties, wharves and boat ramps (except in Kully Bay).

A delivery plan should be developed to establish a clear pathway for the high priority sites to be stabilised, and for other management actions to be implemented.

Existing work has been undertaken by the partner Councils to identify and clarify the ownership of lake assets. Mitigating bank erosion on private property is the responsibility of the land owner however Council may support property owners by communicating information such as tips for foreshore maintenance via various available channels.

For the recommended structural options on Council managed land, it is important to align the delivery plan with the existing Council (WCC and SCC) asset management framework and asset management strategy. Collaboration with State government agencies should be sought where appropriate, (e.g., Local Land Service would be a key partner for the installation of stock fencing)

8 Summary and next steps

As a part of this study, over 40 km of lake shoreline and 12 km of stream bank have been assessed in order to characterise and map foreshore erosion. The results were used to inform and prioritise strategies intended to manage and mitigate risks of foreshore erosion and where possible, improve the local ecology and public amenity.

The study sites sit across a range of coastal and geomorphic settings, have varying degrees of erosion severity and causes. The consequences of erosion are also varied and largely depend on the riparian and intertidal condition and habitat values, the adjacent land use, as well as type and proximity of assets/infrastructure.

The erosional mechanism within the lake appears to be predominantly wind waves and tidal action, in many areas exacerbated by the loss of native vegetation. For the tributary sites, the common erosional mechanism of failure was bank slumping and mass failure. This was likely driven by a combination of bank saturation and scour of the toe of the bank driven by river/tidal flows, and again exacerbated by the loss of native vegetation.

The results of the erosion risk assessment show that the high erosion risk areas are distributed around the estuary. There are high-risk sites on the west and northwest extremes of the lake, as well as in Mullet Creek. A total of 10 management options have been recommended for groups of the 24 priority sites. The proposed options include:

- Revegetation/bank reprofiling
- Bank armouring
- Toe protection
- Fluvial energy reduction.

The next steps in this project include:

1. Develop delivery plan that acknowledges varying roles and responsibilities for sites with different tenure and integrates with WCC and SCC's asset management framework.
2. Seek funding for bank management works
3. Development of concept designs including community engagement with relevant stakeholders where appropriate.
4. Detailed design and construct.

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Appendix A – Site data collection explanatory notes

Field data collection explanatory notes (*Note: some fields have been adapted from or sourced from the DPI Fisheries Decision Support Tool*)

Substrate - The natural bank soil type determined visually or inferred from setting, types include:

- Rock/bedrock
- Cohesive - Clays, silts, loams
- Non-cohesive - Alluvium, sands, gravels etc.
- All

Bank shape - Typical shape of bank across the site or sub-site, types include:

- Concave
- Convex
- Planar
- Stepped
- Wide lower bench
- Undercut

Bank shape - Typical bank height range across the site or sub-site, ranges include:

- <1m
- 1-3m
- 3-6m
- 6-10m
- >10m

Bank slope - Typical bank slope range across the site or sub-site, ranges include:

- Gentle (<3V:1H)
- Low (3V:1H - 2V:1H)
- Moderate (2V:1h - 1V:1H)
- Steep (>1V:1H)
- Vertical

Intertidal/subtidal bench - The presence and typical width range of intertidal or subtidal bench:

- <2m
- 2-5m
- >5m
- None

Intertidal/subtidal bench notes - Any key notable features about the intertidal bench for example habitat features such as large woody debris or oyster colonisation.

Erosion severity - The degree of bank erosion occurring within a bank segment. Scores represent the initial overall rating of the bank segment. The assessment is made in the context of the environment at that location, waterway and bank uses/ activities and the likely degree of natural geomorphic activity.

- Negligible (currently aggrading or stable – no erosion).
- Low (e.g. some erosion occurring but considered within natural parameters).
- Moderate (e.g. rate or scale of erosion is considered more than natural).
- High (e.g. rate and scale of erosion is significant).

Erosion trajectory - The trajectory of existing erosion for erosion with a 10-year outlook. Note this is one of several fields used in consideration of likelihood of ongoing significant erosion including erosion severity and recent historic erosion rate. Categories include:

- Not occurring and not likely in foreseeable future.
- Not occurring now but likely in foreseeable future.
- Occurring and likely to continue at current rate.
- Occurring now and likely to accelerate
- Occurred but ongoing unlikely

Erosion protection - The type and effectiveness of bank protection and control works including:

- No existing controls
- Rock revetment
- Geobags
- Timber walling
- Timber revetment
- Large woody debris
- Revegetation
- Groynes
- Cobble beach
- Seawall Concrete
- Other - acceptable
- Other - unacceptable
- Seawall stone

The ***effectiveness*** of the bank protection works is also noted as one of the following categories:

- No existing control
- Completely
- Partially-condition
- Partially-design
- Ineffective
- Redundant

Landward constraints - Presence of and distance to landward constraint to help inform landward space for riparian revegetation or bank stabilisation works. Examples of landward constraints include roads, footpaths, buildings, fences. Ranges include:

- >10m
- 5-10m
- 3-5m
- <3m
- unconstrained

Constraint notes - Any key notes around constraints for example: power pole near top of bank at upstream end.

Mangroves - Presence of or proximity to mangroves at the site. This will help determine if site could be suitable for future mangrove growth as a part of stabilisation/protection works:

- Present
- Nearby
- None

Vegetation type - Broad grouping of riparian vegetation type across the site including:

- Natural riparian vegetation
- Mixed riparian vegetation fringing altered land use
- Cleared vegetation
- Absent

Vegetation value - Overall value of vegetation

- High importance/ conservation value
- Moderate importance/ native vegetation in moderate to good condition
- Low importance i.e. common land/foreshore
- Insignificant - weed infested

Riparian vegetation continuity - Refers to the general longitudinal vegetation coverage of riparian vegetation (including mangroves). Input options include:

- None- No vegetation or isolated individual trees/shrubs.
- Low- Woody vegetation is discontinuous with significant gaps. Gaps more dominant than vegetation.
- Moderate- Woody vegetation is almost continuous. Occasional small gaps but vegetation is dominant.
- High- Woody vegetation is continuous along bank segment. No significant gaps in vegetation, reflective of remnant vegetation

Riparian vegetation width - Refers to the general width of woody riparian vegetation coverage of riparian vegetation (including mangroves). Input options include:

- <2m
- <5m
- <10m
- <20m
- >20m

Land use - Refers to broad land use category immediately adjacent to site including:

- Road reserve
- Grazing
- Other agricultural
- Commercial
- Residential
- Urban
- Parkland/recreational
- Natural
- Carpark/track

Erodible width - Refers to the level of lateral confinement at the site and the ability and approximate width for lateral adjustment/bank retreat.

- Confined
- <3m
- 3-10m
- >10m

Contributing causes of erosion - The potential contributing cause(s) of erosion which are currently occurring, or may occur including:

- Wind waves
- Ocean waves - Ocean wave influence will be restricted to areas within close vicinity to estuary entrances.
- Vessel waves
- River/tidal flow – This includes daily river/tidal flows and intermittent flood flows.
- Sediment extraction – Historical sediment extraction may be difficult to discern.
- Stock access
- Public access - Consider that public access can cause erosion either directly or indirectly by compacting soil, channelising/concentrating overland flow, damaging vegetation, removing existing control measures etc. Look for signs of public access causing erosion such as pedestrian tracks, illegal vehicle use/boat launching, rope swings etc.
- Bank saturation
- Overland flow

High value asset at risk - Is there any high value assets such as roads, buildings etc currently at risk from erosion?

Public access required - Is public access to the shore and/or water required? Such areas may include, for example, popular public foreshore areas that are used for swimming, picnicking or fishing or other recreational day uses; areas adjacent to popular boat ramps/jetties/wharves; areas popular for launching of other vessels such as kayaks etc.

Environmental impact - Environmental impact if significant erosion was to occur at the site, inputs include:

- Negligible - No features of biodiversity of conservation value likely to be under threat, no impacts of erosion likely to affect downstream environments. No erosion or the erosion is considered within the natural envelope of change.
- Low - No features of biodiversity or conservation under significant threat. Potential for localised impacts such as loss of low value vegetation or localised water quality impacts. Impacts are small scale and threats to biodiversity and conservation values are considered minimal.
- Medium - Features of biodiversity or conservation value affected. Scale of impact is significantly greater than natural. Impacts on instream values through siltation or turbidity likely to extend beyond the length of the bank segment.
- High - Features of biodiversity or conservation value are directly threatened. Significant direct impacts to features of biodiversity or conservation value. Potential for downstream impacts due to turbidity or extensive siltation.

Infrastructure/commercial impact - Infrastructure/commercial impact if significant erosion was to occur at the site, inputs include:

- Negligible - No built or land assets under threat.
- Low - Minor assets of low value potentially under threat. May require relocation or minor works typically able to be accommodated without significant labour or cost implications. Loss of land is relatively minor and likely to be of low concern to landholder.
- Medium - Assets of intermediate value threatened. Relocation or repairs necessary with costs up to $100,000. Examples include boat ramps, footpaths, park benches, minor access stairs, etc. Loss of land is likely to be of concern to landholder.
- High - High value or otherwise important assets under threat. Likely significant follow-on impacts. Examples include loss of public utilities such as power lines, water and sewer infrastructure, houses, other buildings, roads, carparks. Loss of land likely to be of significant concern to landholder with some evidence of protection works evident. Likely costs > $100,000.

Amenity/safety impact - Amenity/safety impact if significant erosion was to occur at the site, inputs include:

- Negligible - No impact on visual amenity, foreshores not used by public, very low risk of injury attributable to erosion.
- Low - Some impact on a small number of people, low risk of serious injury.
- Medium - Significant visual impact. Public access to foreshore impeded. Potential for increased risk of injury to members of the public due to greater usage and/or hazard.
- High - Amenity for large number of users is affected. Foreshore access significantly impeded. Specific public safety risks in popular areas.

Multi-temporal bank retreat - Ranges of bank retreat evident from recent multi-temporal analysis, inputs include:

- <1m
- 1-3m
- 3-5m
- >5m
- None
- Can't tell

An overall likelihood and consequence of ongoing significant erosion has also been provided as part of the site summaries. The ***consequence*** has been derived from a combination of the three impact categories that have been described above, that is:

- Environmental impact
- Infrastructure/commercial impact
- Amenity/safety impact

The overall ***likelihood*** of ongoing significant erosion has been derived based on a semi-qualitative assessment of the of the site conditions including:

- Erosion severity
- Erosion trajectory
- Recent historic rates of erosion
- Existing erosion controls
- Riparian and intertidal vegetation condition/extent
- Causes of erosion

Appendix B – First pass assessment maps

Figure 16. *Observed erosion in the North-eastern quadrant*

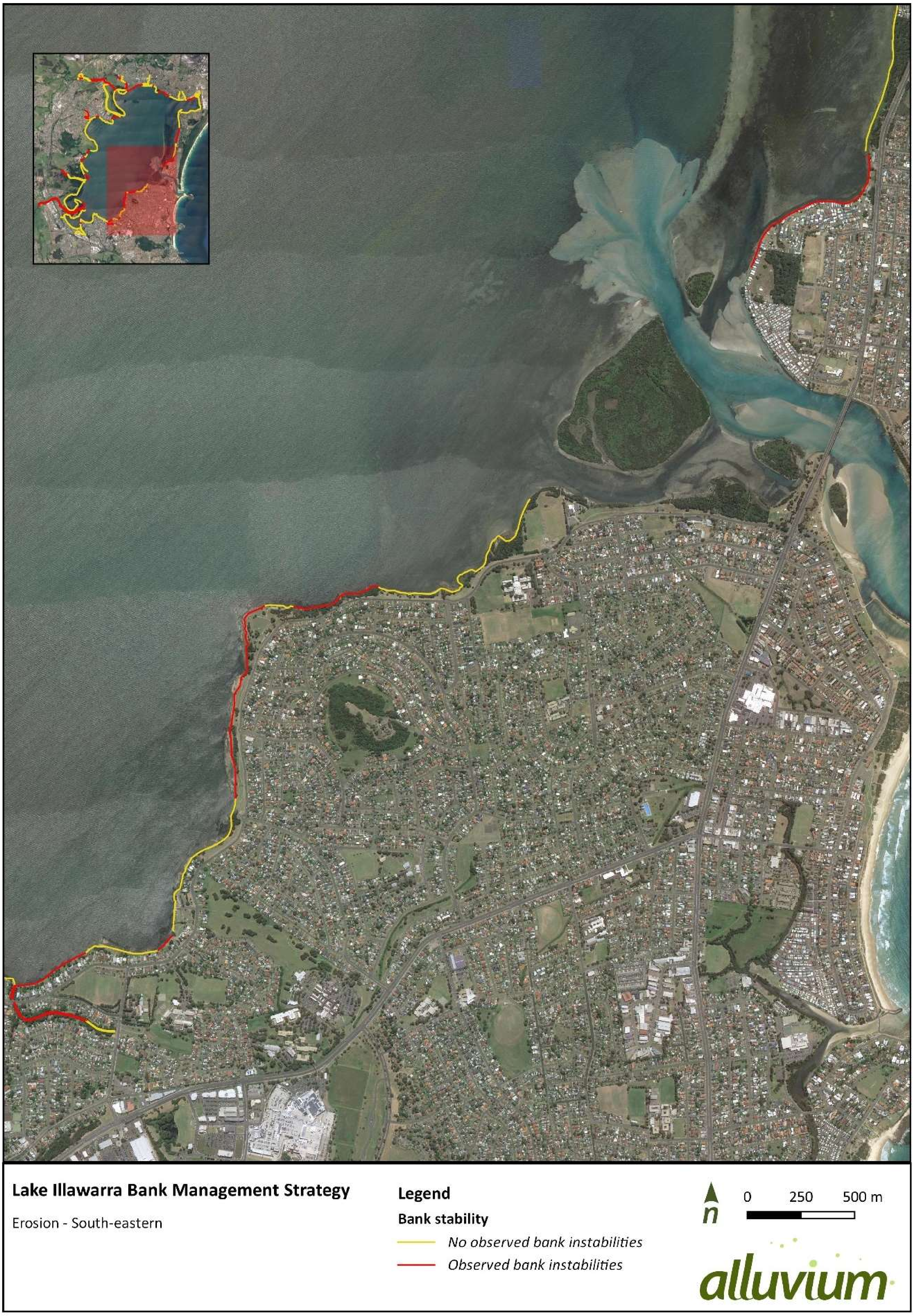


Figure 17. *Observed erosion in the South-eastern quadrant*

Figure 18. *Observed erosion in the South-western quadrant*

Figure 19. *Observed erosion in the North-western quadrant*

Figure 20. *Existing bank protection works in the North-eastern quadrant*

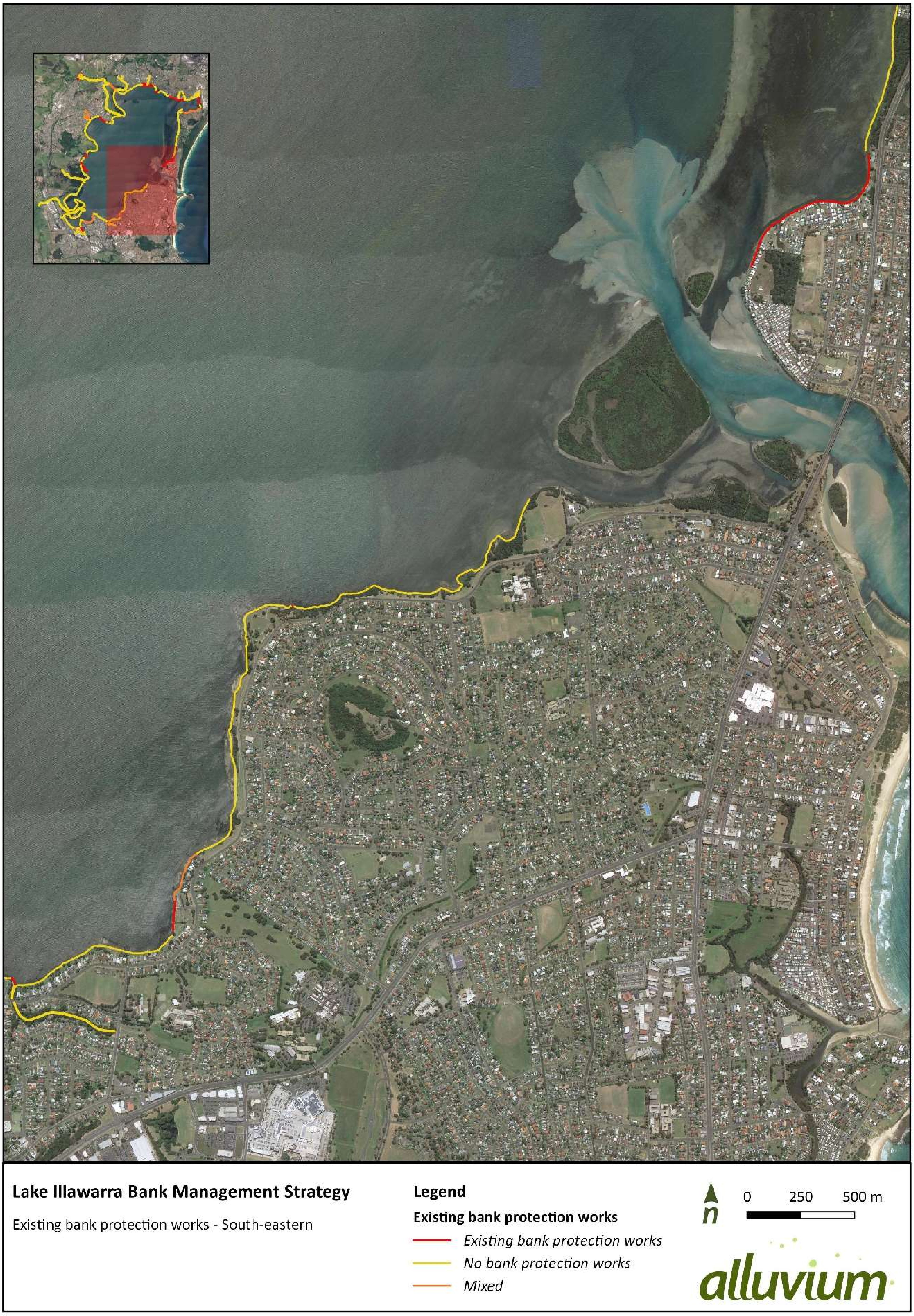


Figure 21. *Existing bank protection works in the South-eastern quadrant*

Lake Illawarra Bank Management Strategy

Existing bank protection works - South-western

Legend

Existing bank protection works

Existing bank protection works

No bank protection works

Mixed

n

0 250 500 m

alluvium

Figure 22. *Existing bank protection works in the South-western quadrant*

Figure 23. *Existing bank protection works in the North-western quadrant*

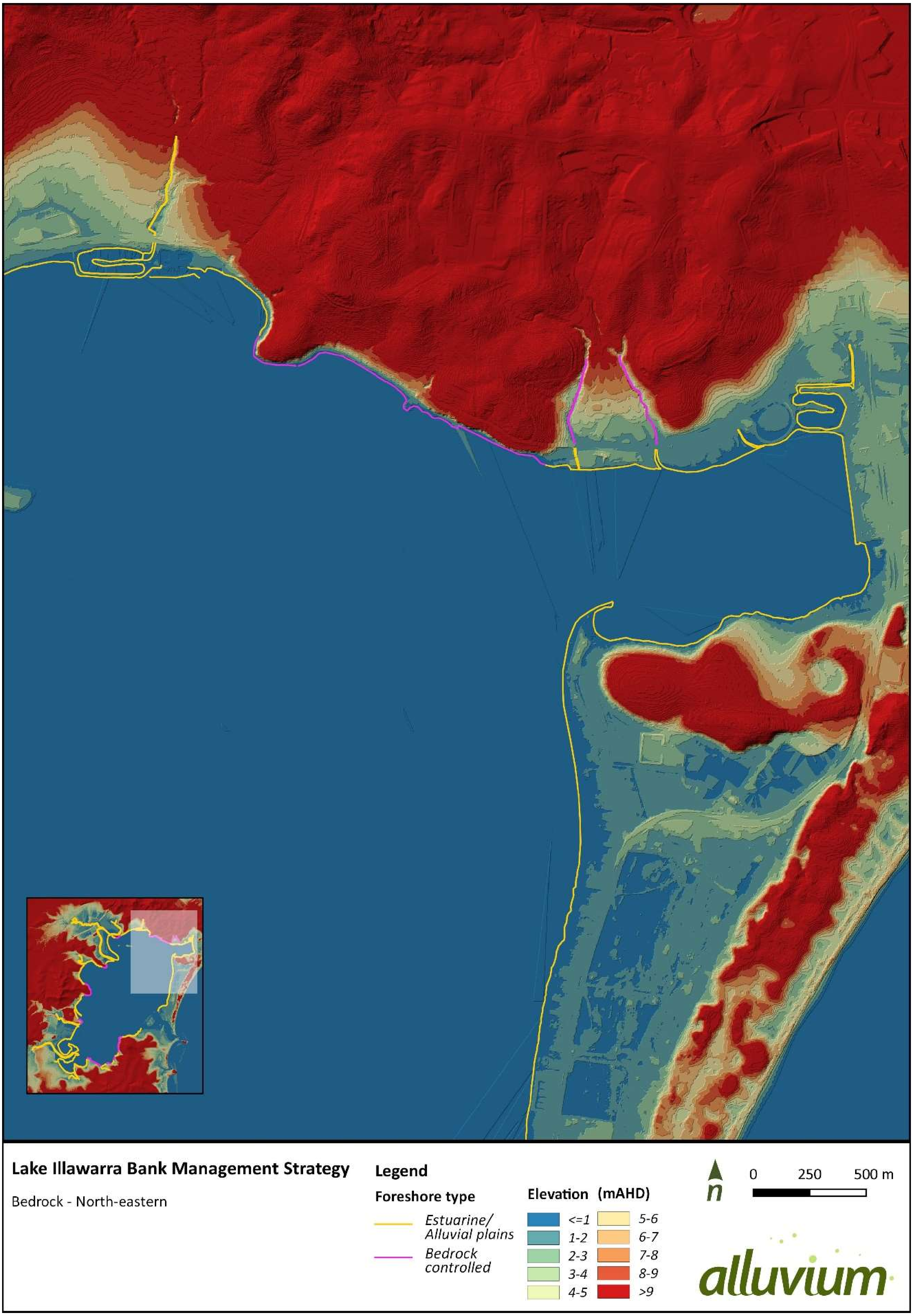


Figure 24. *Bedrock-controlled shorelines in the North-eastern quadrant*

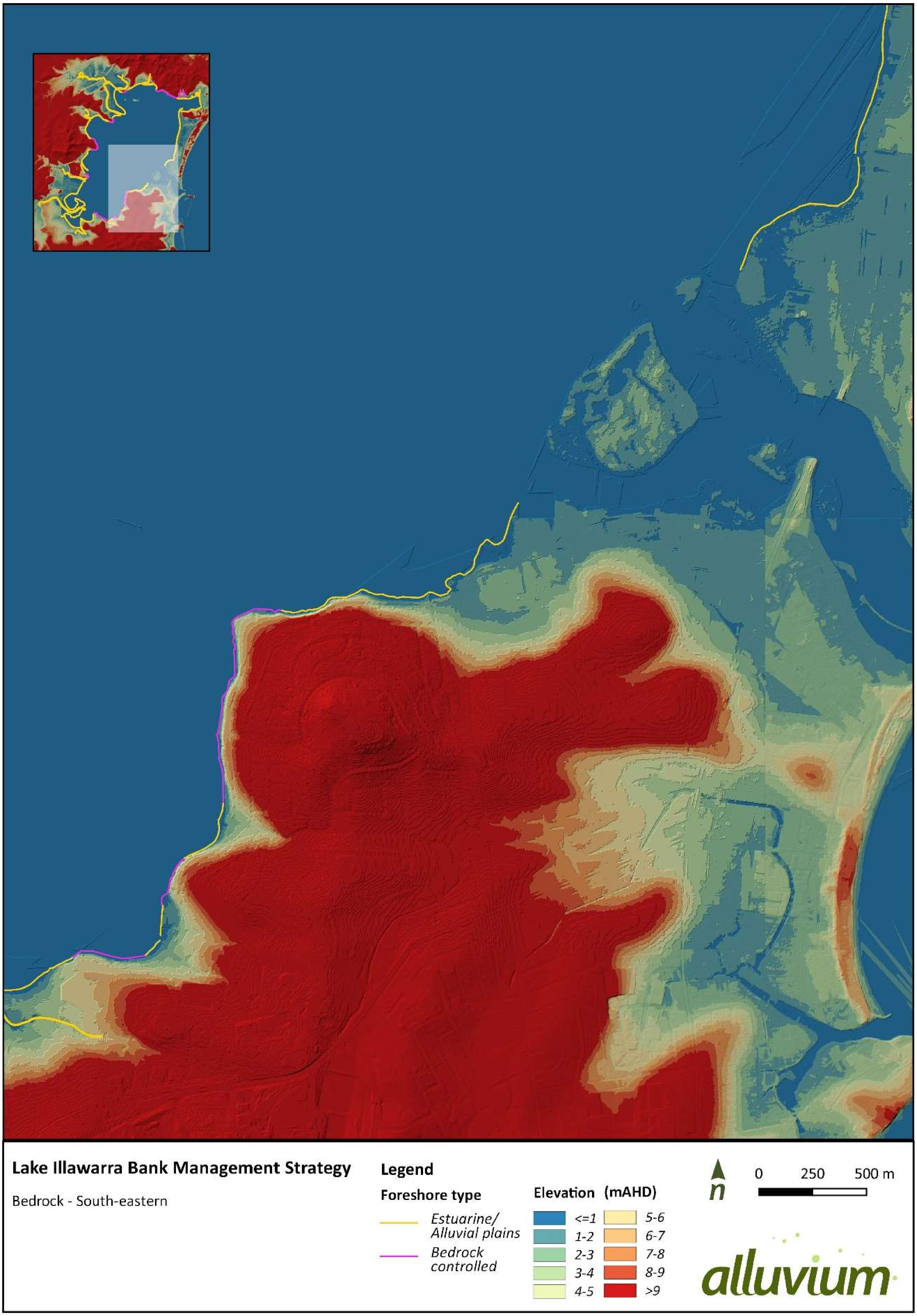


Figure 25. *Bedrock-controlled shorelines in the South-eastern quadrant*

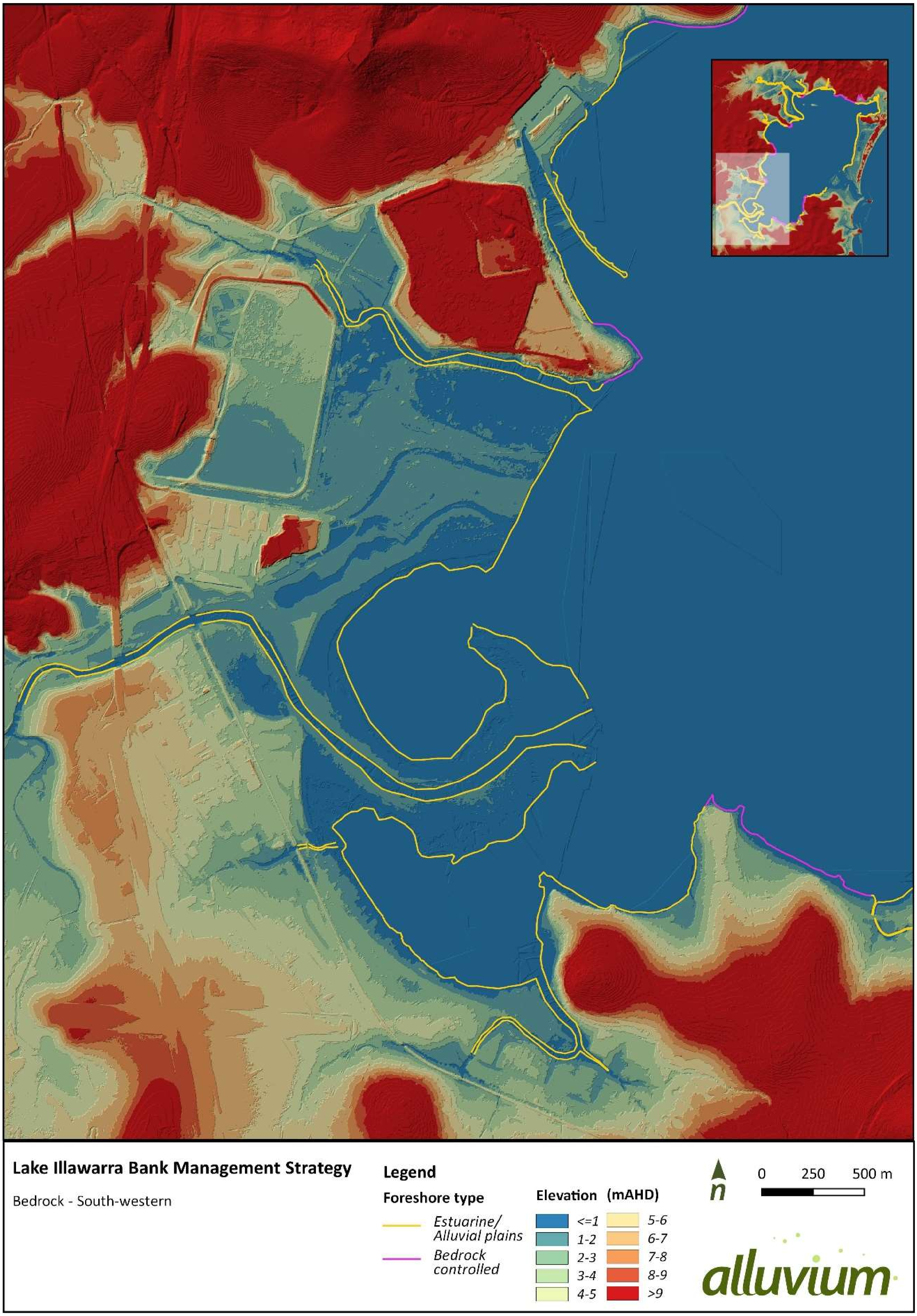


Figure 26. *Bedrock-controlled shorelines in the South-western quadrant*

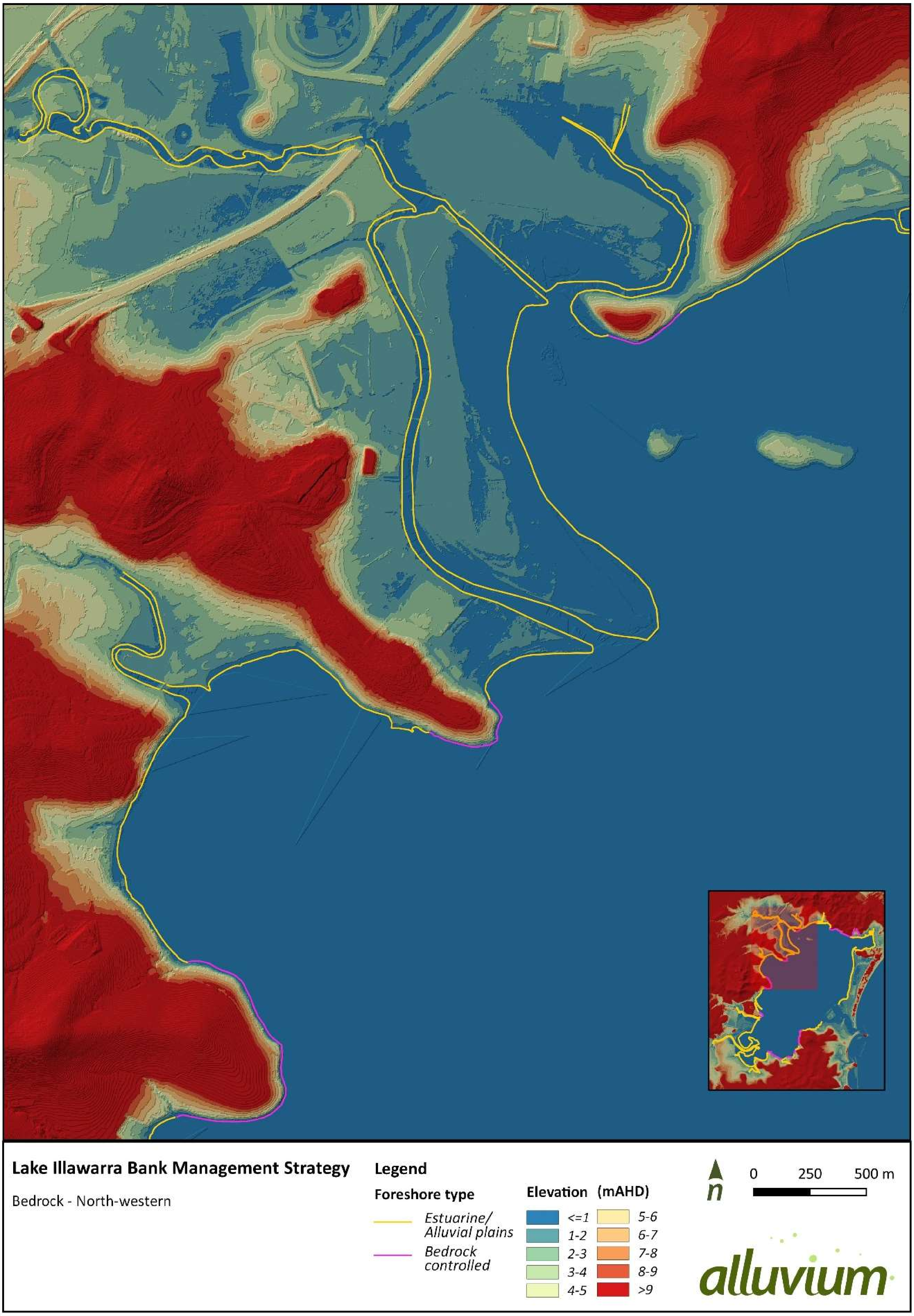
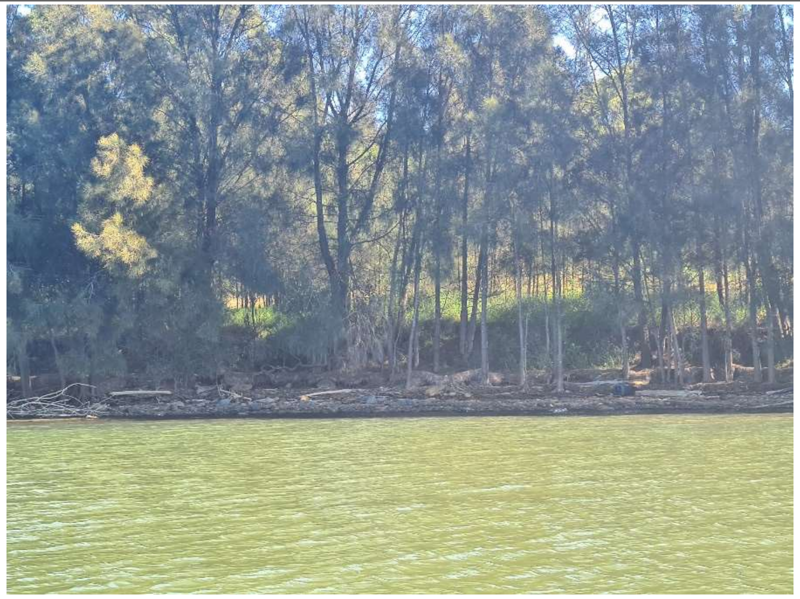
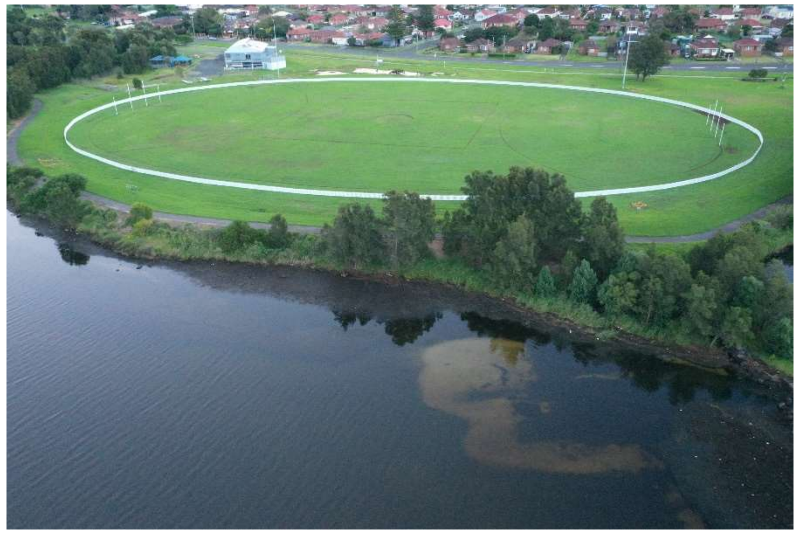
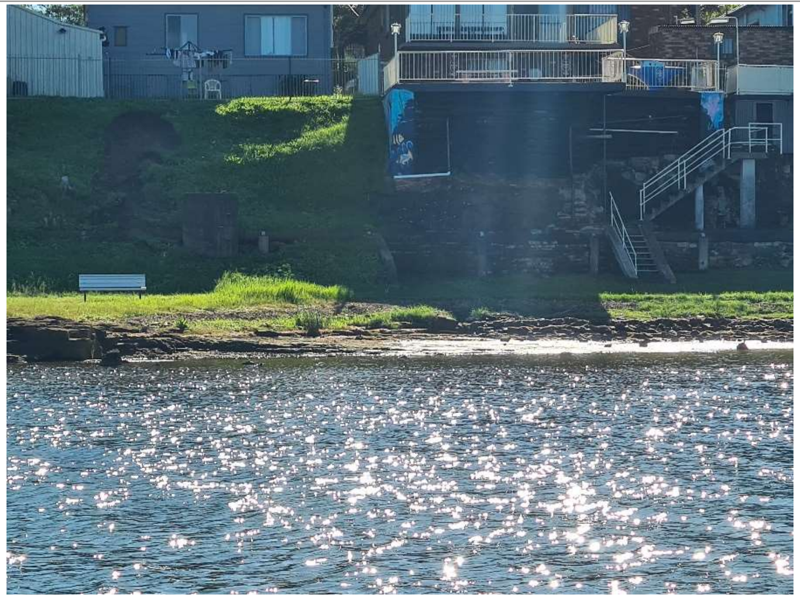
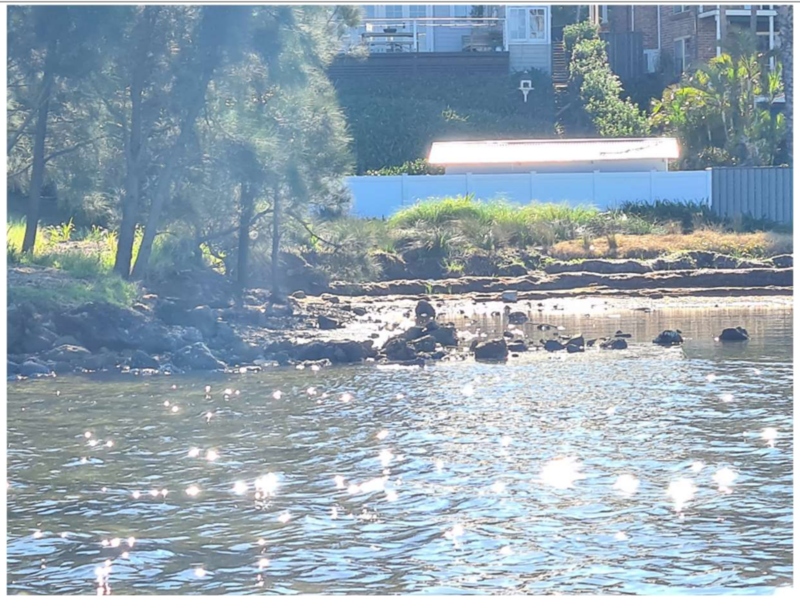


Figure 27. *Bedrock-controlled shorelines in the North-western quadrant*

Appendix C – Photobank of priority sites

Site ID	Photo 1	Photo 2	Photo 3
L19*	 20220503_121130	 20220503_120940	 20220503_121121
L6	 DJI_0424 (5 April 2022)	 IMG_9615 (5 April 2022)	 IMG_9616 (5 April 2022)
L7	 DJI_0404 (5 April 2022)	 DJI_0421 (5 April 2022)	 2022050_102414

L16	 20220503_140104	 20220503_140110	 20220503_140108
MU5	 IMG_4206 (5 April 2022)	 IMG_4208 (5 April 2022)	
L1	 DJI_0477 (5 April 2022)	 DJI_0511 (5 April 2022)	 DJI_0466 (5 April 2022)

L3	 IMG_9831 (3 May 2022)	 IMG_9838 (3 May 2022)	 20220503_093215
L4	 20220503_094135	 20220503_094109	 20220503_093912
L5	 20220503_095113	 20220503_095110	 20220503_095304

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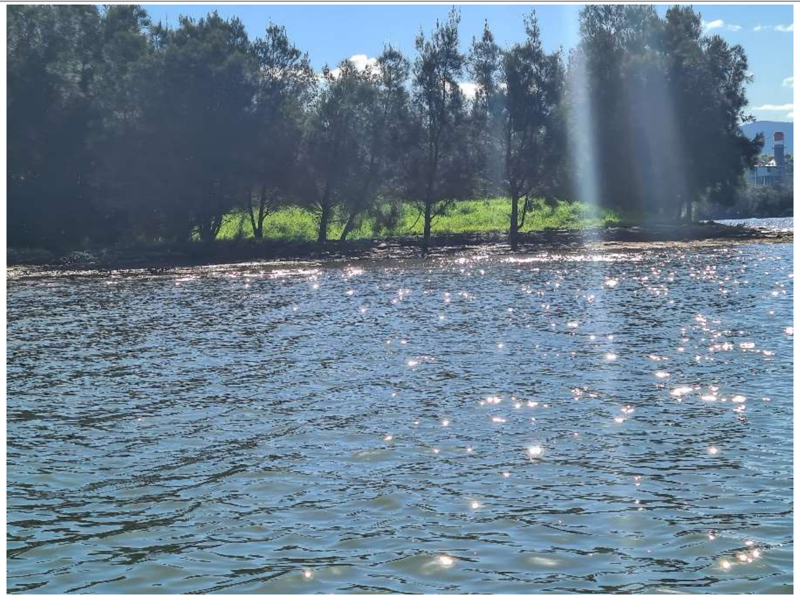
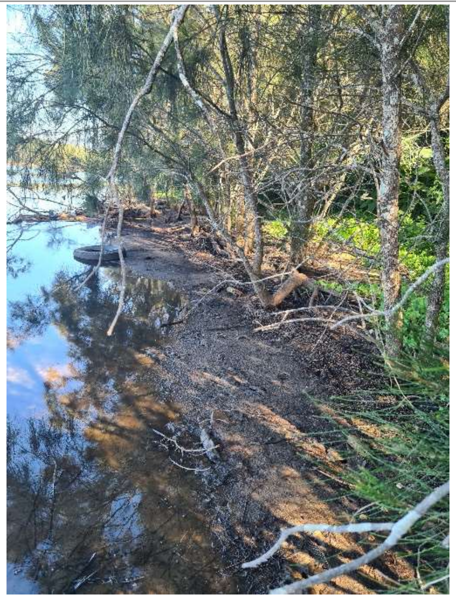
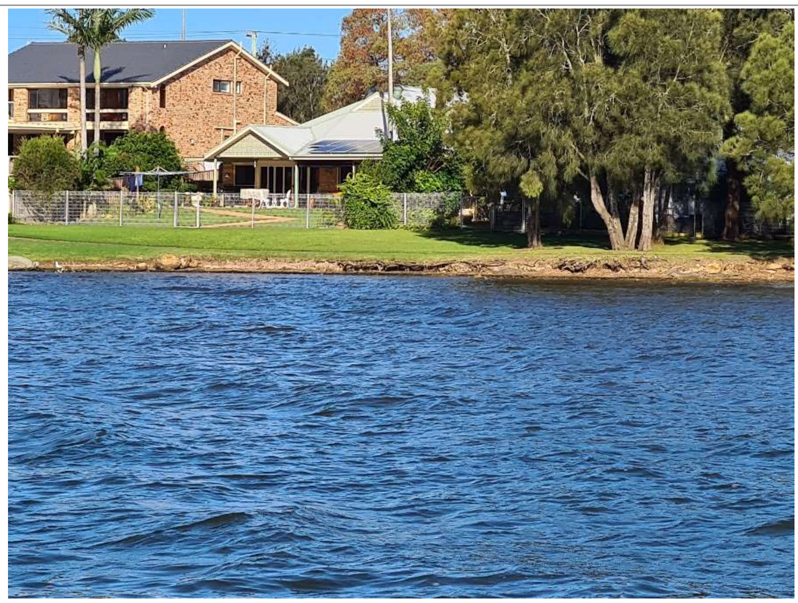
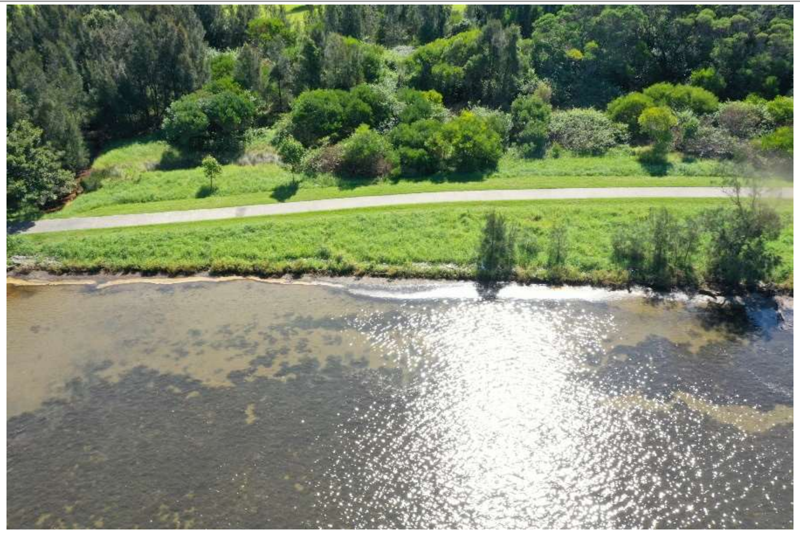
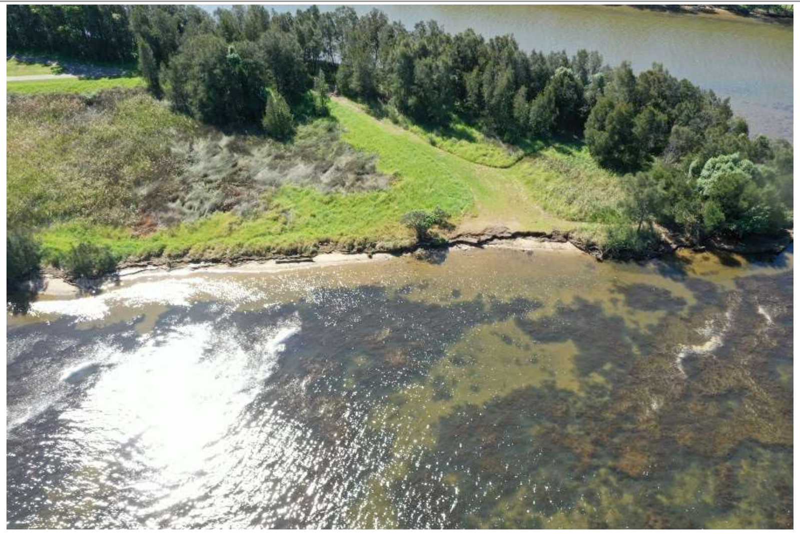
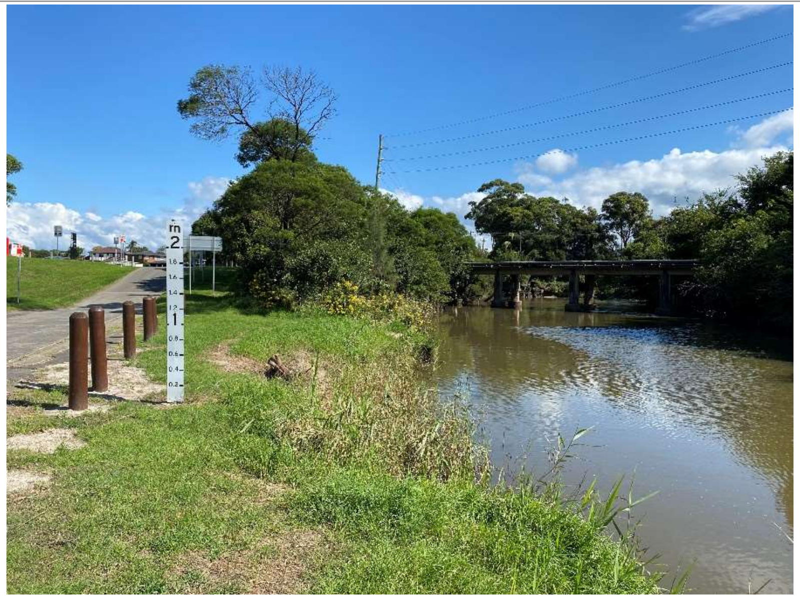
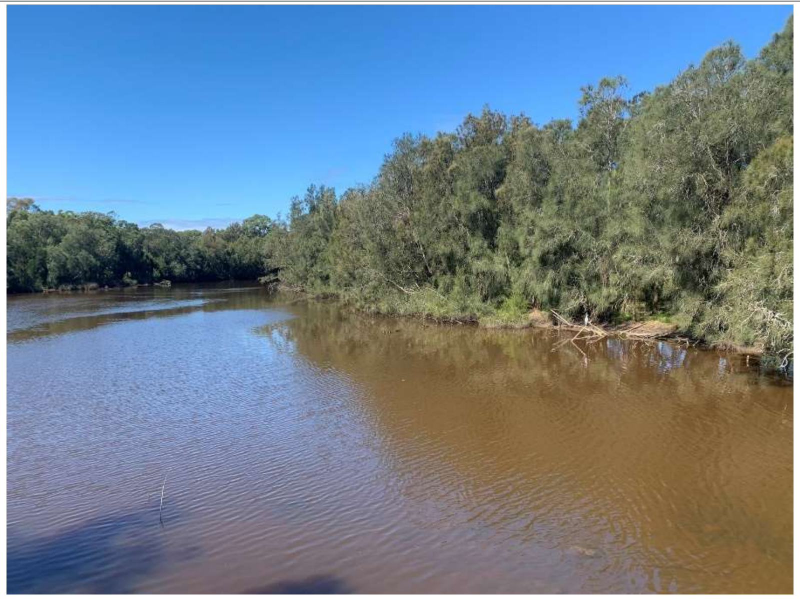
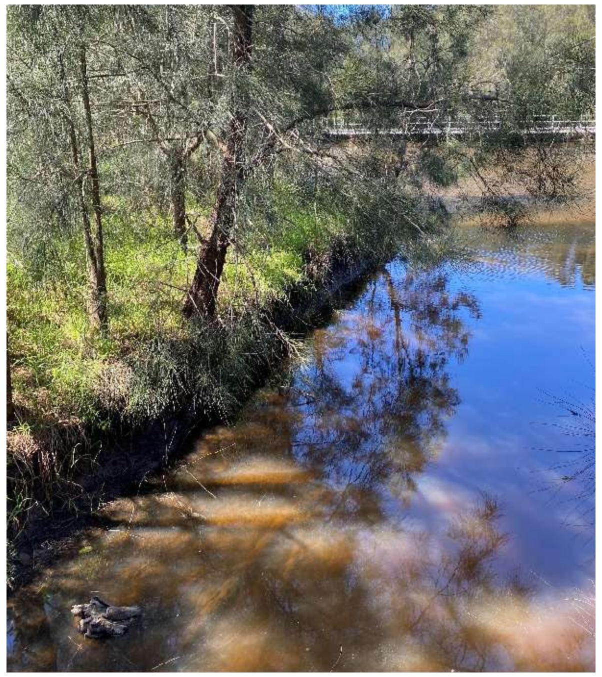
L8	 20220504_075213	 20220504_075323	 20220504_080736
L17	 20220503_132346	 20220504_105306	 20220504_105303
L13	 20220503_144625	 IMG_9699 (5 April 2022)	 IMG_9696 (5 April 2022)

L10	 20220503_151656	 20220503_151916	 20220503_151919
MR2	 20220518_143307	 20220518_143243	
L20	 IMG_4249 (5 April 2022)	 IMG_4247 (5 April 2022)	 IMG_4241 (5 April 2022)

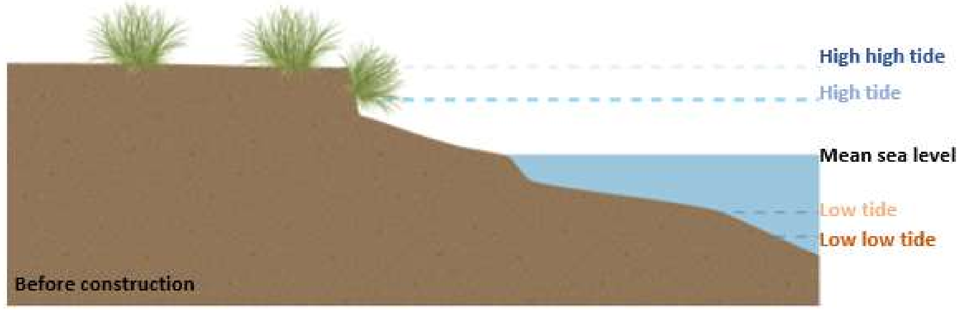
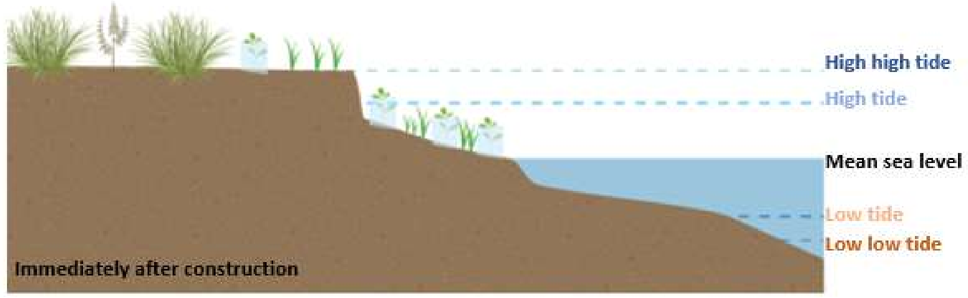
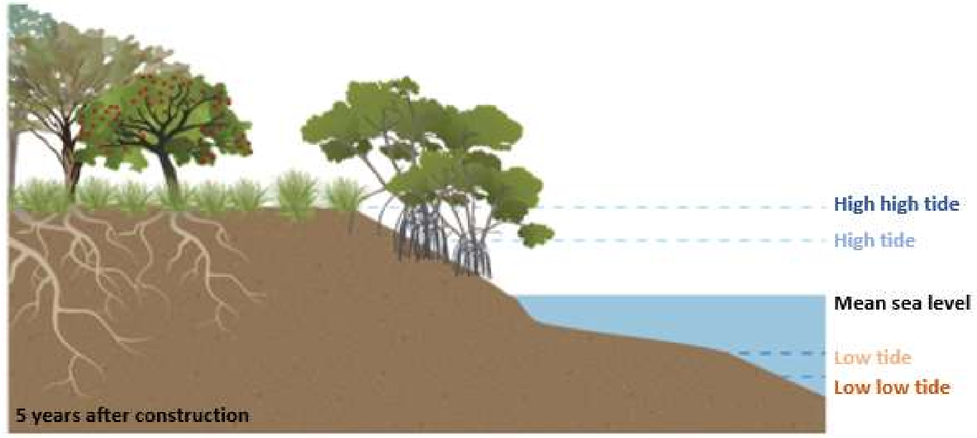
L21	 DJI_0544 (5 April 2022)	 DJI_0542 (5 April 2022)	 DJI_0552 (5 April 2022)
MU7	 IMG_4201 (5 April 2022)	 IMG_4204 (5 April 2022)	
HL1	 DJI_0439 (5 April 2022)	 IMG_9629 (5 April 2022)	 IMG_9628 (5 April 2022)

HK2, HK3	 IMG_9764 (5 April 2022)	 IMG_9766 (5 April 2022)	 IMG_9771 (5 April 2022)
HK1	 IMG_9492 (5 April 2022)	 IMG_9497 (5 April 2022)	
MU1	 DJI_0640 (5 April 2022)	 DJI_0641 (5 April 2022)	 DJI_0642 (5 April 2022)

MR4	 IMG_4176 (5 April 2022)	 IMG_9741 (5 April 2022)	 IMG_4179 (5 April 2022)
MR6	N/A	N/A	N/A
MU2	 DJI_0614 (5 April 2022)	 DJI_0617 (5 April 2022)	 DJI_0619 (5 April 2022)
MR1	 20220518_143556	 20220518_143307	 20220518_143313

MT1	 DJI_0628 (5 April 2022)	 DJI_0629 (5 April 2022)	 DJI_0630 (5 April 2022)

Appendix D – Description of stabilisation options

Option	Examples	Process	Strengths	Weaknesses	Relative cost	Example profile showing present day conditions, conditions after construction and conditions 5 years after construction
Native vegetation establishment / revegetation		**Root reinforcement** – The root networks of trees and shrubs provide root reinforcement to the bank substrate and provide tensile strength which reduces gravitational mass failure of the bank substrate. **Wave and scour protection** – The foliage of grasses and round covers armour the underlying sediments and protect them from fluvial and wave action. **Hydraulic roughness** – In the tributaries, the foliage of trees, shrubs and groundcovers provide frictional resistance which dissipates flow energy and reduces the near bank velocity and shear stress.	• Soft engineering • Enhances riparian habitat and connectivity • Requires no access by machinery	• Requires an establishment period during which the new vegetation is at risk • May not be possible on steep sites without regrading	Low	  

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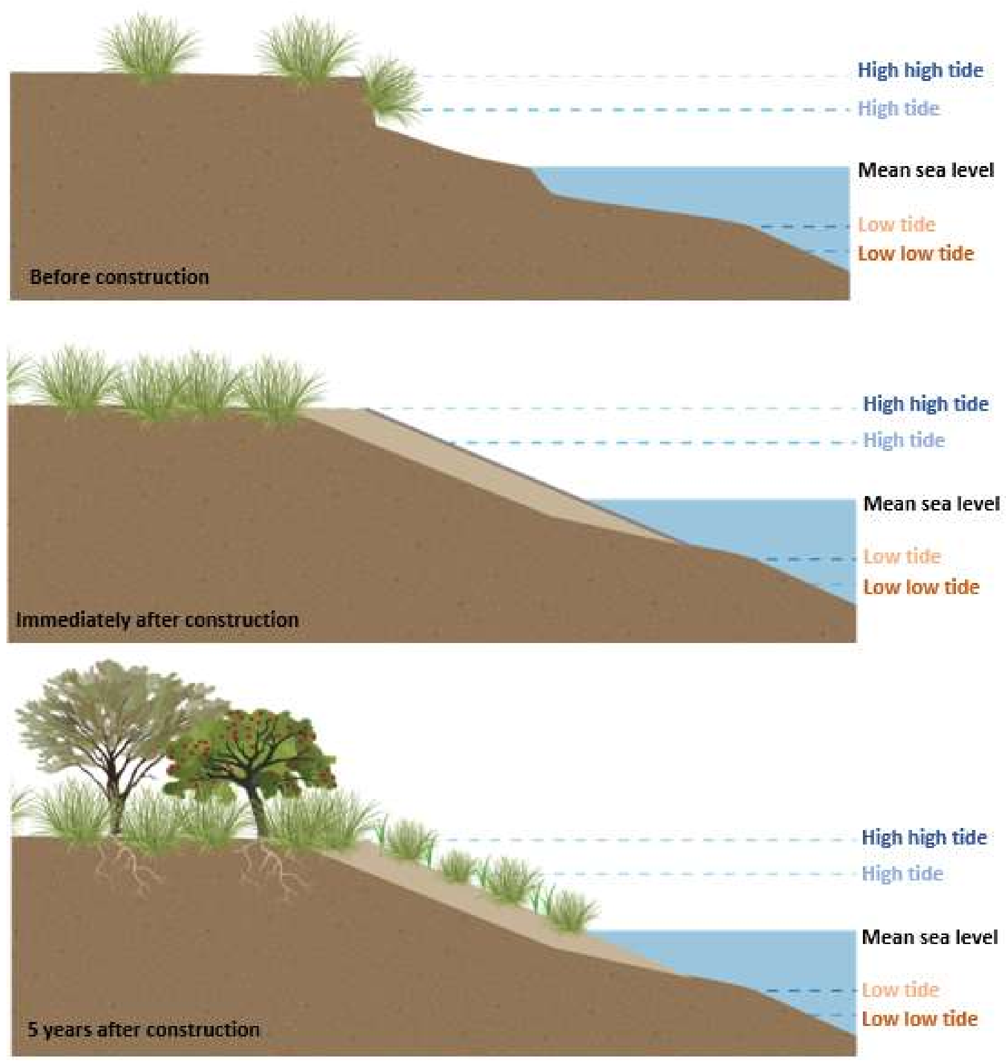
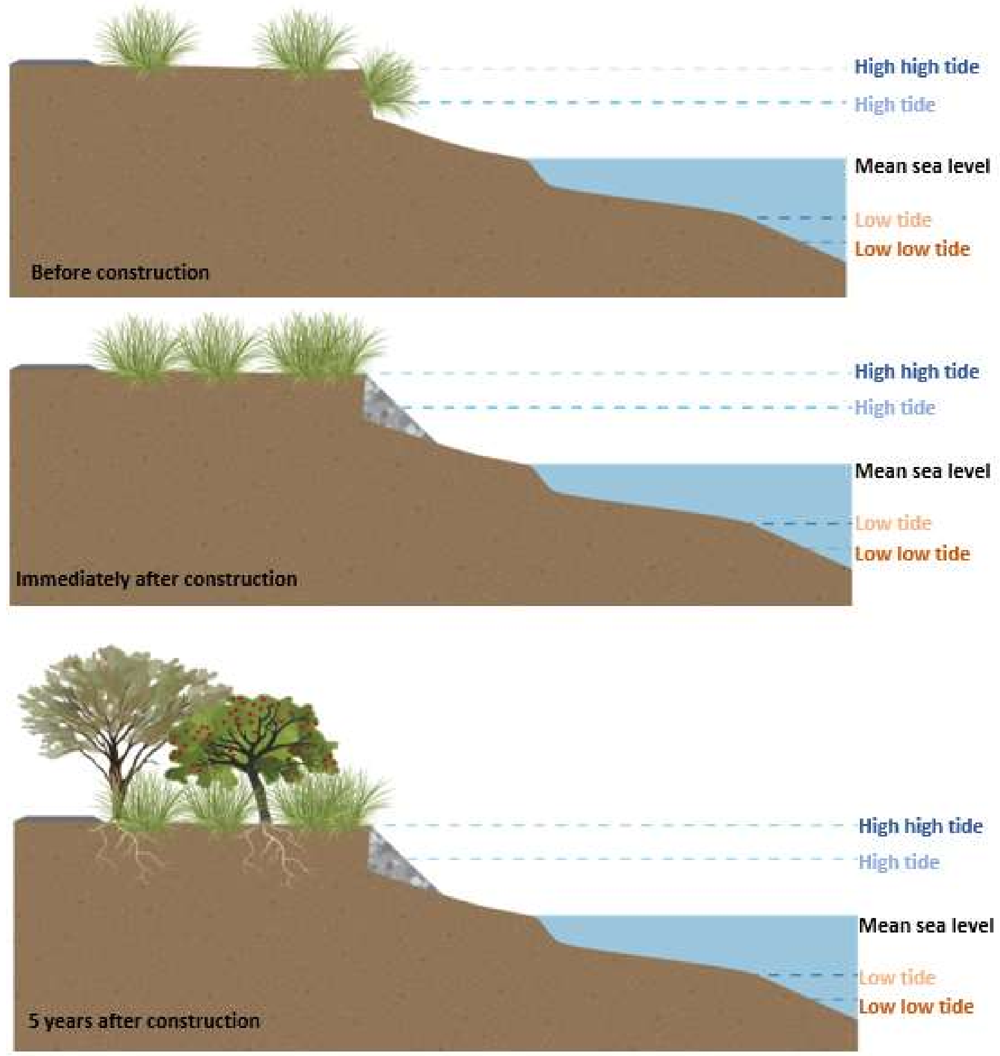
Option	Examples	Process	Strengths	Weaknesses	Relative cost	Example profile showing present day conditions, conditions after construction and conditions 5 years after construction
Reprofile bank		**Geotechnical stability** – Reducing the bank slope can increase the geotechnical slope stability. **Vegetation establishment** - Reducing the bank slope can provide more favourable conditions for vegetation establishment and long-term bank stability.	• Soft engineering • If done in combination with revegetation enhances riparian habitat and connectivity	• Requires an establishment period during which the new vegetation is at risk • Require the export and disposal of soil	Moderate	

Option	Examples	Process	Strengths	Weaknesses	Relative cost	Example profile showing present day conditions, conditions after construction and conditions 5 years after construction
Armour bank with: • Logs • Piled rock or rock rubble • Geotextile sandbags	 	**Wave and scour protection** – Structural bank protection (i.e., rock) armour the underlying sediments and protect them from fluvial and wave action. **Geotechnical stability** - Structural bank toe protection (i.e., rock) can increase the geotechnical slope stability.	• Can be incorporate materials that enhance aquatic habitat (i.e., large wood) • Provides an immediate stabilisation solution (no establishment period)	• Require the import of large quantities of material • Requires access by machinery • Modifies the aquatic/riparian ecosystem	High	

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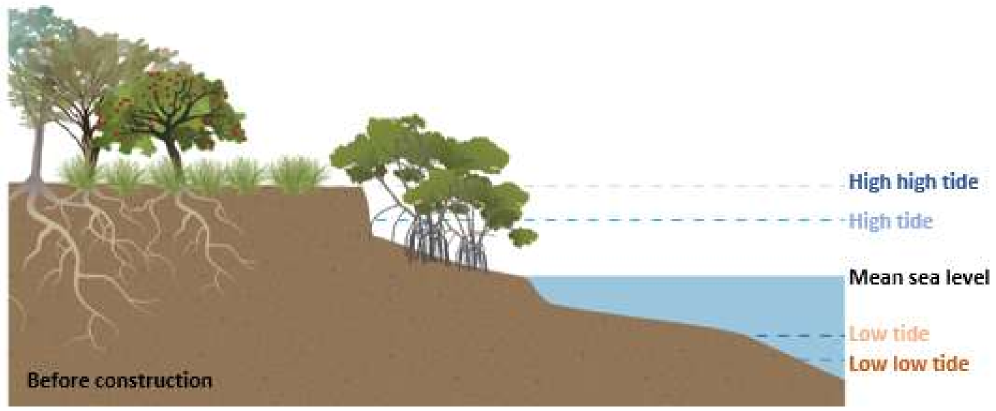
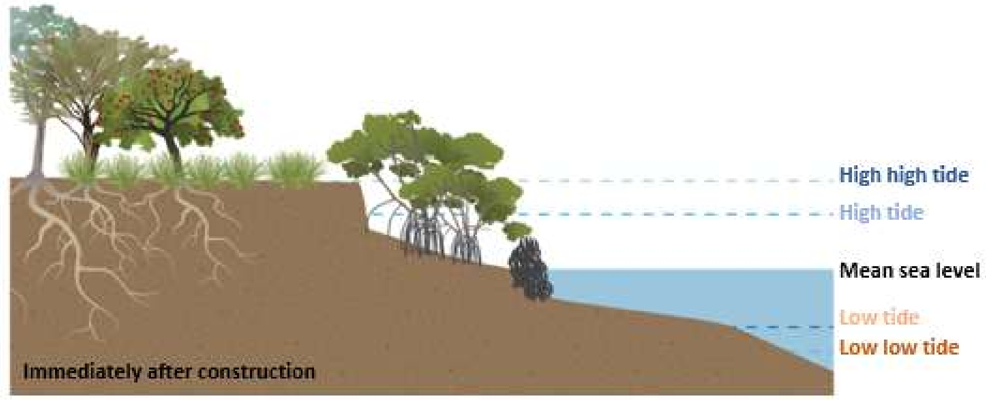
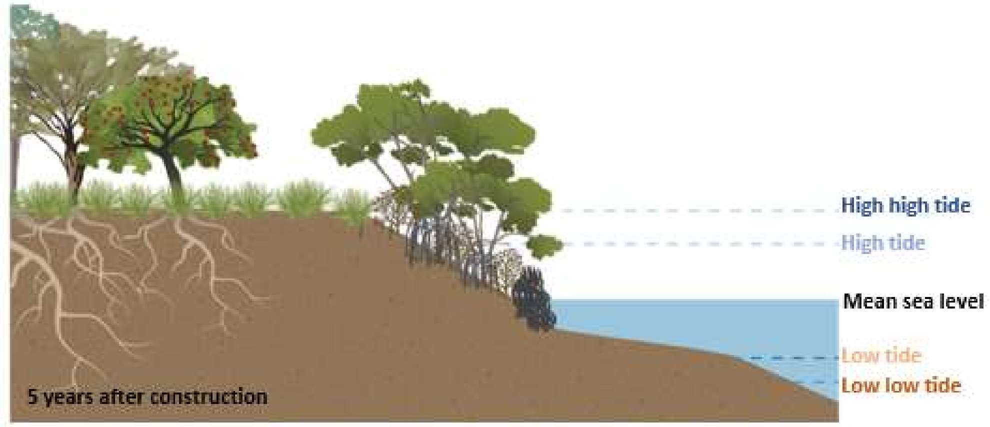
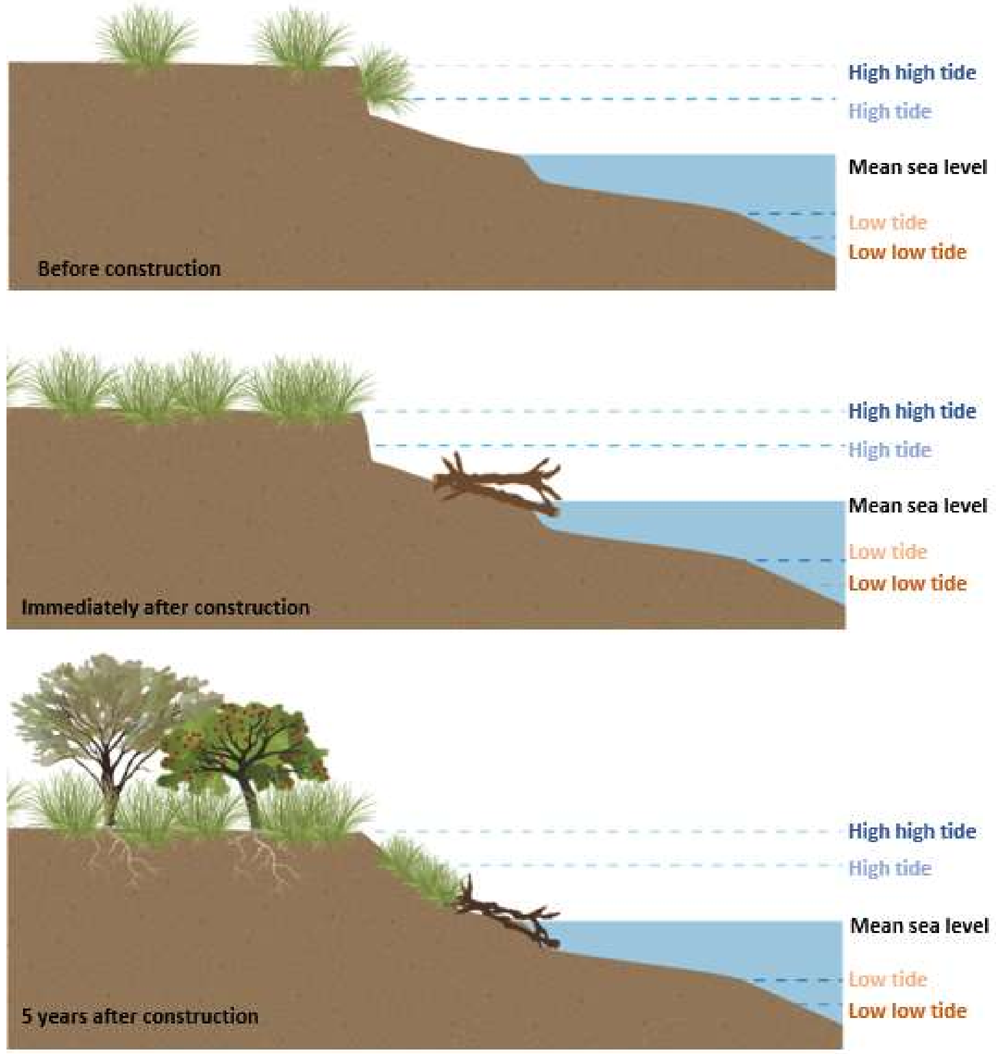
Option	Examples	Process	Strengths	Weaknesses	Relative cost	Example profile showing present day conditions, conditions after construction and conditions 5 years after construction
Toe protection to reduce wave action: • Oyster reef • Logs or rock fillet toe to protect vegetation • Reposition fallen timber	 	**Wave protection** - Structural works dissipate the wave energy and protect the bank from wave action.	• Can provide additional estuarine habitat • Do not impact riparian ecology	• Require the import of material • Requires access by machinery	Moderate	  

Option	Examples	Process	Strengths	Weaknesses	Relative cost	Example profile showing present day conditions, conditions after construction and conditions 5 years after construction
Reduce fluvial energy: • Large woody debris		**Hydraulic roughness –** Structural works provide frictional resistance which dissipates flow energy and reduces the near bank velocity and shear stress. Timber structures have a reduced design life and may not be appropriate for providing long-term protection to high value built assets.	• Can provide additional estuarine habitat • Do not impact riparian ecology	• Require the import of material • Requires access by machinery	Moderate	

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